Effects of prescribed fire on botanical composition, soil cover, and forage production in Caucasian bluestem-infested rangeland in the Kansas Smoky Hills

by

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Abstract

The spread of old-world bluestem species (*Bothriochloa* spp.) throughout the central and southern Great Plains poses a significant risk to native rangelands. The objective of this experiment was to evaluate the effectiveness of late-summer prescribed fire for reducing Caucasian bluestem (*Bothriochloa bladhii*) stands in native mixed-grass prairie and subsequent effects on soil cover, botanical composition, and forage biomass production. A mixed-grass prairie pasture with a heavy infestation of Caucasian bluestem was divided into 4,047-m^2 plots (n = 18) for this experiment. Plots were grouped into pairs and pairs assigned randomly to 1 of 2 treatments: no burn (n = 6), or burn (n = 12). Caucasian bluestem frequency, soil cover, and vegetative composition were measured along permanent 50-m transects in each plot, pre- and post-treatment. Forage biomass was estimated by clipping vegetation within three 50 × 50-cm frames per plot. Prescribed fire was applied on 14 August 2019. One and two years post-treatment, bare soil was greater (treatment × time; $P < 0.01$) in burned plots compared with non-burned plots. In contrast, litter cover was greater ($P < 0.01$) in non-burned plots compared with burned plots in years one and two post-treatment. Basal vegetation cover did not differ ($P > 0.19$) between burned and non-burned plots in either post-treatment year. Proportions of basal cover of native ($P = 0.54$) and introduced grasses ($P = 0.10$) were not different between treatments. the Conversely, proportion of basal cover attributable to all grasses decreased (treatment main effect; $P < 0.01$) in burned plots while remaining unchanged in non-burned plots. In years one and two post-treatment, basal cover of Caucasian bluestem was reduced ($P < 0.01$) by approximately 38% and 27%, respectively, compared with initial measurements. This trend was associated with less (treatment main effect; $P < 0.01$) forage biomass post-treatment in burned plots compared with non-burned plots. Proportions of total basal cover of all forbs and perennial forbs were greater (treatment main effect; $P < 0.01$) in burned plots than in non-burned plots; moreover, grass species richness was greater (treatment × time; $P < 0.01$) in burned plots compared with non-burned plots. Forb richness was greater ($P < 0.01$) in burned plots than in non-burned plots in year one post-treatment only. These data were interpreted to suggest that application of late-summer prescribed fire may be an effective means of reducing Caucasian bluestem frequency while increasing native plant richness.

Key words: Caucasian bluestem, plant diversity, prescribed fire

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Chapter 1 - Review of Literature

Old-World Bluestems (*Bothriochloa* spp.)

Introduction

North America's grasslands are classified as threatened, based on the fact that less than 2% or the original, pre-colonial area remains (Samson and Knopf, 1994; Noss et al., 1995). Conversion to agricultural land, increasing urbanization, and other human activities have contributed to this disappearance and degradation of native grasslands. One major barrier to maintenance and restoration of native grasslands has manifested in the form of invasive plants. Two of these invasive species include yellow bluestem (*Bothriochloa ischaemum*) and Caucasian bluestem (*Bothriochloa bladhii*). Both of these so-called old-world bluestems were purposefully introduced into the central and southern Great Plains in the early twentieth century for livestock forage and soil conservation. Unfortunately, the distribution of old-world bluestems across the Great Plains threatens numerous rangeland ecosystems, such as the Kansas Smoky Hills mixed grass prairie, the Flint Hills tallgrass prairie, and the Texas coastal prairies. In order to maintain native biodiversity and productive rangelands, effective control methods should be researched, commercialized, and implemented.

The popularity of old-world bluestems was supported by early reports of excellent forage production and elevated tolerance to fire and grazing (Coyne and Bradford, 1984; Eck and Sims, 1984; Sanderson et al., 1999). In addition to deliberate planting as a forage source, old-world bluestems have spread in the absence of purposeful intervention. A 36-year trial revealed that yellow and Caucasian bluestem dominated their respective grazed and non-grazed plots in addition to spreading into adjacent native-grass plots (Eck and Sims, 1984). Yellow and Caucasian bluestem have invaded countless grassland hectares under non-experimental conditions through accidental introductions by movement of people, livestock, hay, agricultural equipment, and road-maintenance equipment (Gabbard and Fowler, 2007; Smith, 2010).The spread of old-world bluestems beyond their original planting boundaries is compounded by allelopathic effects observed against native plants growing in close proximity to old-world bluestems (Schmidt et al., 2007; Greer et al., 2014). Yellow and Caucasian bluestem produce allelopathic biochemicals which inhibit the seed germination, growth, and survival of native grasses (Greer et al., 2014), imbuing these old-world bluestems with greater ability to spread within grassland ecosystems once they have gained a foothold.

Across the southern Great Plains, the spread of old-world bluestem species is connected with the degradation of native grasslands. Grasslands dominated by old-world bluestems are associated with decreased native plant diversity (Reed et. al., 2005; Gabbard and Fowler, 2007), avian diversity (Hickman et al., 2006), small mammal diversity (Sammon and Wilkins, 2005), and arthropod diversity (Johnson et al., 2008). Degraded grasslands may also result in the loss of production potential for cattle producers. In one Kansas study, steers grazing Caucasian bluestem gained less bodyweight than steers grazing native grasses (Launchbaugh, 1971). Caucasian bluestem reportedly matures more rapidly than native species, quickly becoming unpalatable and non-nutritious to grazing animals (Harmoney and Hickman, 2004). This rapid maturation results in greater herbivory on remaining native plants and, in turn, over-utilization of native vegetation.

The rapid spread of old-world bluestems warrants investigation into effective control measures to preserve and restore native rangelands. The most common control methods for invasive *Bothriochloa* spp. rely on herbicides. Glyphosate, imazapyr, and sulfometuron-methyl have been used successfully to reduce old-world bluestem frequency in native grasslands for short periods of time (Harmoney et al., 2007; Simmons et al., 2007; Gunter and Gillen, 2010;

Ruffner and Barnes, 2010). The problem with these herbicides is that, although they reduce old-world bluestem abundance in treated areas, the use of non-selective herbicides will reduce native plant diversity in treated areas, as reported by Harmoney et al. (2007) and Ruffner and Barnes (2012).

Mammals

Few reports have shown the effects of old-world bluestem invasion on mammal populations. Sammon and Wilkins (2005) sampled rodent populations in yellow-bluestem pastures and in three native grassland habitats in central Texas. Rodent diversity was found to be less in yellow bluestem habitat compared with native grassland habitats. Grasslands dominated by *Muhlenbergia* sp. (i.e., a native genus) supported the greatest rodent diversity (four species), whereas yellow-bluestem dominated grasslands supported the least rodent diversity (one species). Sites dominated by little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and Eastern gamagrass (*Tripsacum dactyloides*) were found to be intermediate between the two extremes. The hispid cotton rat (*Sigmodon hispidus*) was the only rodent found in all four habitats sampled.

Birds

Compared to intact native grasslands, rangelands dominated by old-world bluestems have been associated with decreased bird abundance and diversity (Hickman et al., 2006; George et al., 2013). George et al. (2013) examined the relationship between yellow bluestem monocultures and avian density and species richness. Grasshopper sparrows were found in greater densities within yellow bluestem-dominated grasslands when compared with native mixed-grass prairie; however, native prairie was associated with greater avian species richness than yellow bluestem-degraded prairie. In that experiment, vegetative structure was more important to avian species richness than plant composition, suggesting that yellow bluestem monocultures, when managed properly, may be capable of supporting viable populations of some breeding birds. These findings were mirrored in an earlier study by Chapman et al. (2004) where relatively low plant diversity in yellow bluestem-dominated plots was not associated with changes to bird species diversity or frequency when compared with intact native mixed-grass prairie. These researchers reported that differences in bird community composition were most associated with changes to vegetation structure. While George et al. (2013) and Chapman et al. (2004) suggested that yellow bluestem monocultures may be capable of supporting native bird populations, Hickman et al. (2006) reported lesser individual bird numbers and species richness in yellow bluestem-dominated pastures compared with native mixed-grass pasture, regardless of vegetation structure.

Arthropods

Previous studies have established that arthropods are an important food source for many grassland bird species (Wiens, 1963; Wiens, 1969; Martin, 1987). As a result, most arthropod studies involving old-world bluestem monocultures have been examined as a component of avian studies. Hickman et al. (2006) and George et al. (2013) evaluated arthropod biomass and composition at the order rank in native grasslands and old-world bluestem pastures. Hickman et al. (2006) reported 4 times greater arthropod biomass in native grasslands compared with old-world bluestem grasslands. In a later study, George et al. (2013) similarly reported 3.9 times more arthropod biomass in native grasslands compared with that of old-world bluestem grasslands. Both Hickman et al. (2006) and George et al. (2013) noted decreased forb abundance in old-world bluestem grasslands compared with native grasslands. These authors interpreted their results to suggest that decreased arthropod biomass may be associated with decreased forb abundance.

Arthropods may also play a role in the biological control of certain vegetation types. Han et al. (2008) compared damage to big bluestem (*Andropogon gerardii*) and Caucasian bluestem caused by insect herbivory, pathogens, and abiotic factors in Kansas tallgrass prairie. Paired individual ramets of big bluestem and Caucasian bluestem were randomly sampled within the same pastures for comparison. Big bluestem ramets had greater leaf damage and more missing leaf area than Caucasian bluestem. In addition to physical damage, rates of fungal infection were found to be thirty times greater in big bluestem than Caucasian bluestem. These findings were interpreted to suggest that avoidance of old-world bluestems by herbivorous insects and greater resistance to fungal infection compared with similar native plants may facilitate the spread of old-world bluestems.

Ecosystem Function

In addition to changing biotic communities, old-world bluestems have been identified as an agent of change in abiotic systems. Ruffner et al. (2012) investigated the relationships between old-world bluestem invasion and biotic and abiotic ecological systems. On sandy soils, old-world bluestem-dominated grasslands were associated with greater organic C, organic N, inorganic N, soil mineralization rates, and litter decomposition than on sandy soils in intact native grasslands. No differences in these abiotic factors were detected between old-world bluestem grasslands and native grasslands on clay-based soils. These researchers speculated that soil texture and other soil properties may influence the degree of change exerted by old-world bluestems on ecosystem function.

Competitive Abilities

Both yellow and Caucasian bluestem have been observed to inhibit growth of other grass plants. Schmidt et al. (2007) evaluated growth characteristics of little bluestem, big bluestem, and sideoats grama (*Bouteloua curtipendula*) when grown in co-culture with yellow or Caucasian bluestem. The authors reported both old-world bluestems inhibited grow of all native grasses under study. In addition, Caucasian bluestem was observed to exhibit significant intraspecific competition, a condition wherein individuals of the same species compete for the same pool of resources. In contrast, yellow bluestem displayed little or no intraspecific competition, resulting in greater biomass production when compared with Caucasian bluestem when both were grown in co-culture with little bluestem.

Significant intraspecific competition by Caucasian bluestem was documented by Wilson et al. (2012) when comparing biomass production of Caucasian bluestem grown in conjunction with little bluestem, big bluestem, and conspecifics. Caucasian bluestem biomass was greater when grown with either native grass, than when grown with conspecifics (i.e., closely-related species). The authors interpreted these data to indicate that inhibition of native grass growth by Caucasian bluestem resulted in decreased competition for resources for the remaining Caucasian bluestem plants; however, decreased competition did not occur when planted with closely-related species.

Whereas earlier work by Schmidt et al. (2007) suggested allelopathic compounds produced by old-world bluestems inhibited the growth of native grasses, Wilson et al. (2012) attributed the inhibition of native grasses by Caucasian bluestem to changes in mycorrhizal root colonization rates. These researchers recorded significant reductions in mycorrhizal root colonization of native grasses when planted with Caucasian bluestem. Rapid growth of

Caucasian bluestem compared to native grasses may have allowed establishment of arbuscular mycorrhizal relationships in favor of invasive species, to the detriment of native species.

Greer et al. (2014) expanded on work by Schmidt and coworkers (2007) to quantify the allelopathic capabilities of yellow bluestem. Leachate from yellow bluestem and big bluestem roots and litter were applied reciprocally and conspecifically; moreover, leachates from both species were applied to little bluestem. Leachate and litter from big bluestem had no effect on growth characteristics of yellow bluestem or little bluestem. Conversely, yellow bluestem leachate reduced germination, biomass, and survival of both big and little bluestem.

Botanical Composition

Early research on native grasslands following old-world bluestem invasion was interpreted to suggest that old-world bluestems were incapable of establishing themselves on undisturbed range sites. Fowler and Dunlap (1986) conducted a botanical survey of 35 grassland sites in the Edwards Plateau in central Texas, in which they documented low frequency of yellow bluestem. They recorded yellow bluestem in only ten of thirty-five sites, at an average basal cover of 5.6%. These authors opined that yellow bluestem posed little or no threat to intact native grasslands, based on its relatively small presence.

Despite early suggestions of low impact on native grasslands, more recent research indicated that yellow bluestem was capable of changing the botanical composition of invaded sites. Gabbard and Fowler (2007) continued the work by Fowler and Dunlap (1986) to determine the presence of and the effects of yellow bluestem on native plant communities. In this survey in the Edwards Plateau, the only ecological sites where yellow bluestem was not found were in areas with >75% woody canopy cover. Yellow bluestem reduced perennial herbaceous species cover by an average of 30% in plots where it was the dominant plant species. In a modification of the conclusions of Fowler and Dunlap (1986), Gabbard and Fowler (2007) suggested that when yellow bluestem frequency was minor, native plant diversity may be unchanged; however, this would be dependent on yellow bluestem not expanding its cover once a site has been invaded. In contrast, a subsequent study by Robertson and Hickman (2012) reported a negative relationship between old-world bluestem cover and native plant diversity and native plant cover.

A 36-year long experiment by Eck and Sims (1984) demonstrated the capability of yellow and Caucasian bluestem to dominate planted areas and spread to nearby plots. Yellow bluestem and Caucasian bluestem were planted in plots adjacent to 23 other native and introduced grass species. At the time of sampling (36 years post-planting), yellow bluestem comprised 94 and 72% cover and Caucasian bluestem comprised 80 and 72% cover in their respective non-grazed and grazed plots. Despite being planted to one non-grazed and one grazed plot each, both species had spread to areas planted to other grasses (Eck and Sims, 1984). The abilities of old-world bluestems to dominate planted areas and to spread with or without grazing pressure suggested that, without some level of control, these plants will spread to any suitable location.

Forage Quality

Under deliberate seeding, monocultures of old-world bluestems have become a reasonably important forage source in some regions of Texas and Oklahoma. These grasses have been touted as valuable because of their high yields, resistance to grazing, and perceived nutritive value (Coyne and Bradford, 1984; Eck and Sims, 1984; White and Dewald, 1996; Sanderson et al., 1999). Burns (2011) evaluated quality and dry matter intake of Caucasian bluestem hay in feeding trials with wethers and steers. This researcher reported that hay made from early-season growth and regrowth was readily consumed by both sheep and cattle;

however, forage quality and dry matter intake decreased with increasing plant maturity. Crude protein levels and dry matter digestibility have been recorded at levels equal to or greater than native warm season grasses (Basurto et al., 2000; Harmoney and Hickman, 2012). Despite nutritional levels comparable to native grasses, old-world bluestems have been reported to promote lesser animal productivity than native grasses. Launchbaugh (1971) evaluated growth performance of steers grazing plots of pure Caucasian bluestem, pure western wheatgrass (*Pascopyrun smithii*), pure switchgrass, and mixed native grasses in western Kansas. Caucasian bluestem and switchgrass had greater average herbage yields than other forages under study. During the early growing season, all forages had similar crude protein concentrations; however, Caucasian bluestem promoted lesser individual-animal bodyweight gains and lesser bodyweight gains per acre than the other forage types under comparison. Dabo et al. (1988) subsequently reported that crude protein concentrations in old-world bluestem declined to levels insufficient to meet the daily requirements of mature cattle late in the growing season.

Increased plant maturity has been associated with decreased forage palatability and nutrient concentrations (Nelson and Moser, 1995; Burns et al., 1997), as well as depressed voluntary intake by livestock (Vona et al., 1984). Harmoney and Hickman (2004) reported Caucasian bluestem matured 5 to 11× faster than big bluestem, little bluestem, and sideoats grama. Launchbaugh (1971) had previously reported similar results. Crude protein concentrations early in the growing season were similar to that of native grasses but protein concentrations deteriorated at a more rapid rate than native grasses. Rapid maturation rates and associated declines in nutritional value of Caucasian bluestem likely resulted in a forage source that was inferior to native grasses after the middle of the growing seasons.

Growth Biology

Caucasian bluestem is reported to mature more rapidly than native grasses. Research by Harmoney and Hickman (2004) indicated that when starting from similar growth stages Caucasian bluestem matured 5 to 11× more rapidly than native species. These findings were supported by Wilson et al. (2012) who reported Caucasian bluestem reached reproductive maturity 14 weeks post-planting, at which time little bluestem and big bluestem were still in the vegetative stage of growth. Differences in maturation rates may affect the response of Caucasian bluestem to timing of prescribed fire.

In the vegetative growth state, grasses tend to recover from defoliation due to the location of active meristems close to the soil surface and due to high rates of photosynthetic activity (Isopp, 2000; Sosebee and Wan, 2004). Grasses should be allowed to rest after the reproductive stage to allow for allocation of carbon to storage organs. Repeated defoliation in the reproductive or post-reproductive stages may result in decreased subsequent vigor and increased mortality (Sosebee and Wan, 2004). Villanueva-Avalos (2008) reported that Caucasian bluestem defoliated to an 85% extent in the reproductive stage had decreased regrowth compared to lesser defoliation rates. This author indicated that the number of vegetative tillers increased with maturity and that the negative response to high defoliation rates during the reproductive stage may be attributed to the removal of high numbers of vegetative tillers, along with removal of photosynthetic surface. These findings are in disagreement with Ruckman et al. (2008) who reported suppression of spring tiller density subsequent to prescriptive fire was greatest when yellow bluestem plants were burned with 50% of tillers at the pre-reproductive stage, compared with more mature plants.

Villanueva-Avalos (2008) also examined carbohydrate reserves, which were reported to decrease in plants following defoliation at all stages of growth. While carbohydrate reserves increased following defoliation in plants in the vegetative stage, carbohydrate reserves remained low in plants when defoliated in the reproductive and post-reproductive stages of growth. Earlier analysis of carbohydrate reserves in Caucasian bluestem by Coyne and Bradford (1987) indicated that reserves decreased following spring growth and remained low until the beginning of inflorescence growth later in the year. The removal of vegetation at maturity in old-world bluestems is likely to negatively impact carbohydrate reserves and, thus, subsequent regrowth.

Vegetative reproduction through stolons and rhizomes has been reported in old-world bluestems (Harlan et al., 1958; Schmidt and Hickman, 2006); however, reproductive vulnerability to fire has been suggested to occur through sexual reproduction. Ruckman et al. (2012) exposed seeds of yellow bluestem, little bluestem, Indiangrass (*Sorghastrum nutans*), silver beardgrass (*Bothriochloa laguroides*), sideoats grama and Texas bluebonnets (*Lupinus texensis*) to heat treatments of 125, 175, 225, and 250°C for durations of 30, 60, 120, and 240 seconds. Germination rates for yellow bluestem and sideoats grama were decreased by both duration and temperature, whereas germination rates for Indiangrass, little bluestem, and silver beardgrass were affected only by duration. These data were interpreted to suggest that high intensity, quick-burning fires may preferentially target yellow bluestem with minimal changes to native plant germination rates; however, prescribed fire should be carefully timed to avoid damage to native vegetation, as the majority of seed production for warm-season grasses occurs during late summer and early fall (Coyne and Bradford, 1984; Diggs et al., 1999).

Control Methods for Old-World Bluestems

Mowing

Early research reposted that yellow bluestem was intolerant of mowing (Szente et al., 1996). Despite this postulate, more recent evaluations of mowing have indicated ineffectiveness in reducing basal cover of yellow bluestem. Simmons et al. (2007) evaluated mowing as a potential control for yellow bluestem in central Texas. Single or double mowing treatments were applied in August or again in October for two sites with yellow bluestem monocultures. No subsequent changes in yellow bluestem basal cover were observed at either site.

Herbicides

The use of herbicides to control old-world bluestems is well documented. Harmoney et al. (2004) evaluated nine herbicides for yellow bluestem control in central Kansas. Herbicide treatments were applied in May of 2001 and again in June of 2002; response criteria were yellow bluestem aerial cover and herbage yield. Sethoxydim (0.28 kg ai/ha), glyphosate (3.36 kg ai/ha), and clethodim (0.21 kg ai/ha) applications did not reduce yellow bluestem covers following either year of the experiment. Conversely, imazapyr (0.11 kg ai/ha) and bromacil (7.84 kg ai/ha) were effective in reducing yellow bluestem covers in both years. In 2001, imazapyr- (1.40 kg ai/ha) and bromacil-treated (7.84 kg ai/ha) locations had yellow bluestem covers of 25 and 17% respectively. The following year, imazapyr (0.11 kg ai/ha; 0% cover) and bromacil (7.84 kg ai/ha; 77% cover) were the only treatments that differed from non-treated control plots, which had yellow bluestem covers that averaged 95%. Imazapic (0.16 kg ai/ha), glyphosate (3.36 kg ai/ha), sulfometuron (0.21 kg ai/ha), bromacil (7.84 kg ai/ha), and imazapyr (0.11 kg ai/ha) reduced end-of-season biomass to at least 50% that of the non-treated controls. These findings indicated that imazapyr and bromacil represented the most likely candidates for short-term reduction of yellow bluestem aerial cover, while imazapic, glyphosate, and sulfometuron may be used to suppress yellow bluestem growth to allow for tillering and seed germination of more desirable species.

Harmoney et al. (2007) expanded on the work by Harmoney et al. (2004) by examining the effects of glyphosate (1.14 kg ai/ha), imazapic (0.105 kg ai/ha), imazapyr (0.280kg ai/ha), imazethapyr (0.055 kg ai/ha), and sulfometuron methyl (0.157 kg ai/ha) on aerial frequency of Caucasian bluestem when each herbicide was applied twice during each growing season. Herbicides in this experiment were applied during the 4 to 5 leaf stage (i.e., vegetative growth) and again 8 weeks later in both 2003 and 2005. The greatest control of Caucasian bluestem was achieved by split applications of glyphosate. Plots sprayed with glyphosate reduced Caucasian bluestem cover by more than 90% in both years. Imazapyr and sulfometuron also produced significant reductions in Caucasian bluestem cover in 2004 (i.e., > 85%); however, reductions in cover were subdued in 2005 compared with 2004 (64 and 46%, respectively). In both years, imazapyr, sulfometuron, and glyphosate reduced end-of-season biomass compared to non-treated controls. Furthermore, end-of-season biomass in imazapyr- and glyphosate-treated plots was reduced to near zero in 2003.

Simmons et al. (2007) evaluated the effects of single and double applications of glyphosate on yellow bluestem monocultures at two locations in central Texas (i.e., Blackland Prairie and the Edwards Plateau). Herbicide was applied in June and again in September. Yellow bluestem aerial cover responded differently between the research locations one year following glyphosate application. At the Blackland Prairie site, yellow bluestem canopy cover was not reduced by a single application of glyphosate (0.9 kg ai/ha) compared with non-treated controls; however, cover decreased moderately (i.e., approximately 20%) after a double application. At the Edwards Plateau site, both single and double applications of glyphosate (3.40 kg ai/ha) were associated with reductions in yellow bluestem canopy covers when compared with non-treated controls (i.e., approximately 50%). Differences in responses to herbicide between sites in this experiment were likely attributable to the fact that glyphosate was applied at greater rates at the Edwards Plateau site (3.40 kg ai/ha) than at the Blackland Prairie site (0.9 kg ai/ha).

Additional research by Harmoney et al. (2010) evaluated Caucasian bluestem responses to three application rates of glyphosate (i.e., 1.12, 2.24, or 3.36 kg/ha) at either the 5-leaf stage of growth (i.e., early vegetative stage), 8 weeks after the 5-leaf stage of growth (i.e., late vegetative stage), or at both stages of growth. Treatments were applied in 2006 and 2008. The greatest reductions in Caucasian bluestem aerial frequencies occurred following double applications of glyphosate where at least one treatment was applied at 2.24 kg/ha or more. Applications of this type produced aerial frequencies of less than 30% each year compared with control plots where frequencies were greater than 94%. A strong negative relationship was identified between total glyphosate applied and Caucasian bluestem aerial frequency (R^2 = 0.91); however, there was an equally-strong positive relationship between Caucasian bluestem frequency and dry matter yield (R^2 = 0.98). Similar economically relevant decreases in herbage availability following herbicide applications that were sufficient to decrease old-world bluestem frequencies have been reported elsewhere (Harmoney et al., 2004; Harmoney et al., 2007; Simmons et al., 2007).

Ruffner and Barnes (2012) evaluated the efficacy of glyphosate, imazapyr, and a combination of glyphosate and imazapyr with or without additional disking to control yellow bluestem in Texas. Three treatment groups were tested: herbicide application only, herbicide application followed by disking, and disking followed by herbicide application. Herbicide was applied to appropriate treatments in late May, followed days later by disking. A second application of herbicide was applied to disking-plus-herbicide treatments in July of the same year, whereas a second disking treatment was applied to all herbicide-plus-disking treatments the subsequent October. One year following treatment, plots treated with imazapyr (1.43 kg ai/ha) followed by disking averaged 18% yellow bluestem cover; other treatments averaged greater than 40% yellow bluestem cover. Disking followed by either herbicide resulted in the least yellow bluestem cover one-year post treatment. Despite initial reduction of yellow bluestem cover, two years following treatment, yellow bluestem had recovered to original cover levels in all plots.

Robertson et al. (2013) evaluated the effects of eleven combinations of herbicide, burning, and mowing on aerial cover of yellow bluestem in western Oklahoma. Glyphosate application (2.125 kg $\cdot$ ai^{-1} $\cdot$ application^{-1}) alone or in combination with burning or mowing decreased yellow bluestem cover when compared with non-treated controls. In general, the addition of mowing and burning accentuated the negative effects of glyphosate on yellow bluestem. These findings supported earlier research that regrowth following mechanical treatments increased glyphosate absorption by surviving plants (Ruffner and Barnes, 2012). While all treatments evaluated in this experiment reduced total yellow bluestem cover to some degree, mowing or burning early (i.e., in May) in the season followed immediately by a single application of glyphosate resulted in yellow bluestem having a similar number of reproductive tillers compared with control plots. The authors suggested that plants that survived an early growing season combination of mechanical and herbicide treatments were able to take advantage of the reduction in competition from neighboring plants to increase growth and reproductive tiller output.

Prescribed Fire

Traditionally, prescribed fire is applied across the Great Plains in the spring to control woody-stemmed plants and other non-desirable plant species. Prescribed burning in February increased biomass of yellow bluestem (Pase, 1971), whereas fire in March and April decreased yellow bluestem biomass at the end of the growing season (Berg, 1993). Mid-to-late growing season prescribed fire has also shown potential for controlling old-world bluestems, while enhancing native botanical diversity. Simmons et al. (2007) reported that yellow bluestem responded negatively to prescribed fire in August while native species remained undisturbed. Similar results were reported following September prescribed burning by Reemts et al. (2019). These researchers reported up to 65% reduction in yellow bluestem frequency in some plots, while native forb and grass frequency increased. These effects were still detectable three years following the burn, suggesting growing season prescribed fire is an effective method for reducing old-world bluestems without negatively affecting native vegetation. Significant reduction of biomass in plots treated with herbicides (Harmoney et al., 2004; Harmoney et al., 2007; Harmoney et al., 2010; Robertson et al., 2013) likely indicated that, while old-world bluestem frequencies were generally reduced, native vegetation tended to be harmed as well. Properly-timed prescribed burning, in contrast, has reportedly reduced old-world bluestem vigor without negatively affecting native vegetation (Simmons et al., 2007; Reemts et al., 2018).

Old-world bluestem frequencies have been observed to increase when subject to dormant-season prescribed fires (Pase, 1971; Gabbard and Fowler, 2007). Conversely, recent research concluded that growing-season prescribed fire can harm old-world bluestems. Simmons et al. (2007) examined prescribed fire timing on yellow bluestem frequencies at two sites in central Texas, referred to as the Edwards Plateau site and the Blackland Prairie site. Two growing season timings were applied: early (August) or late (October or November). Both burn times were associated with reduced yellow bluestem frequency, but effects were somewhat inconsistent between research sites. August prescribed fire reduced yellow bluestem frequency at both sites, whereas September or October prescribed fire was associated with reduced frequency at both sites but with reduced efficacy at the Edwards Plateau location. Authors attributed these differences in response to late-season prescribed fire may have occurred because of more abundant rainfall at the Edwards Plateau location immediately before and after prescribed fire was applied compared with the Blackland Prairie location. Authors reported that most native plants had neutral responses to growing season fires; the exception was Canada goldenrod (*Solidago canadensis*), which increased in frequency in response to growing-season fire. These findings were interpreted to suggest that growing season fires may be useful, to varying degrees, for controlling yellow bluestem without damaging native plant species.

Twidwell et al. (2012) evaluated the effects of a high-intensity, growing-season burn on yellow bluestem in Texas coastal prairie. A mid-growing season (June) prescribed burn was applied to treatment plots at the end of a severe 5-month drought. Despite earlier studies reporting decreases in yellow bluestem frequencies following growing-season fires (Simmons et al. 2007), increased native forb richness was the only significant botanical composition change recorded, when compared with adjacent non-burned areas. In addition, burned areas were associated with reductions in total end-of-season biomass. These findings were in agreement with conclusions by Simmons et al. (2007) with respect to the observation that native species did not respond negatively to growing season fires. Havill et al. (2015) subsequently documented reduced yellow bluestem tiller counts following prescribed fires applied during droughts at any time between June and January. Prescribed burning reduced tiller count by 32 to 64%, with the greatest reduction occurring after a June burn.

Reemts et al. (2018) evaluated the use of September prescribed fire as a control for yellow bluestem at two sites in central Texas, Fort Hood and Onion Creek. Growing season prescribed fire significantly reduced yellow bluestem frequency at both sites: 65% reduction at Fort Hood and 42% reduction at Onion Creek. Not only had yellow bluestem frequencies decreased the year following fire treatment but they remained lesser than non-burned plots three years following treatment. Yellow bluestem frequency at Fort Hood remained 56% less that control plots, whereas yellow bluestem frequency at Onion Creek was 29% less than control plots three years after treatment. As in previous studies, native vegetation responded to growing-season fire in positive or neutral ways. At Fort Hood, native graminoids increased in burned plots when compared with non-burned plots. No change in native graminoid frequencies was documented at the Onion Creek site. At both sites, forb frequencies increased sharply immediately following fire and then decreased during subsequent growing seasons. The significant reduction of yellow bluestem frequency three years after fire treatment, coupled with neutral to positive changes in native vegetation, was interpreted to indicate that further research is needed to evaluate growing-season prescribed fire as a control method for old-world bluestems.

In contrast to the aforementioned reports of reduced old-world bluestem frequencies subsequent to growing-season prescribed fire, other researchers attempts have reported no significant reduction of old-world bluestems in similar experiments (Clark, 2014; Davis, 2011; St. Clair, 2012; Toomey, 2015).Factors such as variability in fuel loads, plot sizes, old-world bluestem species, and ecological sites between experiments likely contributed to these contrasting results.

Although the effects of growing season prescribed fire on native botanical composition and yellow bluestem frequency have been documented in several Texas locations, no comparisons appear to exist for other regions of the US. Similarly, there appear to be no evaluations of growing-prescribed fire as a means of Caucasian bluestem control.

Conclusions

The unchecked expansion of old-world bluestems in the central and southern Great Plains represents a major hurdle for effective conservation and restoration. Rapid maturation rates and allelopathic capabilities contribute to aggressive growth patterns, which lead to a degradation of native rangelands and decreases in native biodiversity. While herbicide has been demonstrated to reduce frequency of old-world bluestems, economically-relevant decreases in herbage yield following herbicide applications have been noted by many authors (Harmoney et al., 2004; Harmoney et al., 2007; Simmons et al., 2007). Additionally, the use of herbicides may harm non-target native species.

Prescribed fire has historically been applied in the spring throughout the Great Plains as a means to decrease woody plant abundance and to increase forage quality; however, the application of fire during the dormant season has been reported to increase old-world bluestem frequency (Pase, 1971; Gabbard and Fowler, 2007). Conversely, shifting the timing of fire application to the growing season may reduce old-world bluestem frequency without harming native vegetation (Simmons et al., 2007; Reemts et al., 2018). Due to the increased maturation of old-world bluestems compared to native grasses, late-summer prescribed fire may decrease old-world bluestem vigor while native grasses are in a vegetative state of growth. Therefore, the objective of our experiment was to document the effects of late-summer prescribed fire on soil cover, botanical composition, Caucasian bluestem frequency, and forage biomass production over a 3-year period.

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Chapter 2 - Effects of Late-Summer Prescribed Fire on Caucasian Bluestem Frequency in Mixed-Grass Prairie

Abstract

The control of Caucasian bluestem (*Bothriochloa bladhii*) presents a major hurdle for the conservation and restoration of native rangelands across the central and southern Great Plains. Although previous research has demonstrated the efficacy of herbicides for reducing the frequency of old-world bluestem species, land managers continue to search for a control strategy which is less detrimental to native vegetation. The objective of this experiment was to evaluate the effectiveness of a one-time application of late-summer prescribed fire for reducing Caucasian bluestem frequency in mixed-grass prairie. A section of private rangeland was divided into 4,047-m^2 plots (n = 18) which were each assigned randomly to 1 of 2 treatments: no burn (n = 6), or burn (n = 12). Prescribed fire was applied on 14 August 2019. Botanical composition was measured using a modified-step point technique. Before fire application, no differences (P = 0.88) in Caucasian bluestem basal cover were detected between treatments. One year after treatment application, total basal cover of Caucasian bluestem in burned plots was reduced (treatment × time; $P < 0.01$) by approximately 38%, while remaining unchanged in non-burned plots. Two years following fire application, Caucasian bluestem basal cover was reduced ($P <$ 0.01) in burned plots by 27% compared with initial measurements. These data were interpreted to indicate that late-summer prescribed fire was effective in reducing Caucasian bluestem basal cover over a two-year period. Further monitoring will be needed to evaluate the long-term efficacy of late-summer prescribed fire on reducing Caucasian bluestem basal cover.

Key words: Caucasian bluestem, plant diversity, prescribed fire

Introduction

Caucasian bluestem (*Bothriochloa bladhii*) is a perennial bunchgrass native to Africa, Asia, and Australia. In the early twentieth century, Caucasian bluestem was introduced to the southern Great Plains for livestock forage and soil conservation. Despite early research indicating a low threat to native grasslands (Fowler and Dunlap, 1986), Caucasian bluestem has spread beyond cultivation boundaries and has established itself across large portions of the southern and central Great Plains. Grasslands dominated by old-world bluestems are associated with decreased native plant diversity (Reed et. al., 2005; Gabbard and Fowler, 2007), avian diversity (Hickman et al., 2006), small mammal diversity (Sammon and Wilkins, 2005), and arthropod diversity (Johnson et al., 2008).

The uncontrolled spread of old-world bluestems warrants investigation into an effective control measure to preserve and restore native rangelands. The most common control methods for invasive *Bothriochloa* spp. rely on herbicides. Glyphosate, imazapyr, and sulfometuron-methyl have been used successfully to reduce old-world bluestem frequency in native grasslands for short periods of time (Harmoney et al., 2007; Simmons et al., 2007; Gunter and Gillen, 2010; Ruffner and Barnes, 2010). The problem with these herbicides is that although they temporarily reduce old-world bluestem abundance in treated areas, there is significant concern that the use of non-selective herbicides will further reduce native plant diversity in treated areas, as reported by Harmoney et. al (2007) and Ruffner and Barnes (2010).

While dormant season burns have been traditionally applied in the Great Plains to control non-native plant species, old-world bluestem frequencies have been observed to increase when subject to dormant-season prescribed fires (Pase, 1971; Gabbard and Fowler, 2007). Shifting the timing of fire application to the growing season, however, may reduce old-world bluestem frequency without harming native vegetation (Simmons et al., 2007; Reemts et al., 2019). Therefore, the object of this experiment was to evaluate the potential of late-summer burning to reduce Caucasian bluestem frequency.

Materials and Methods

Experimental Design and Location

Our experiment was conducted on a private ranch southwest of Kanopolis Lake in Ellsworth Co., KS. Soils were of the Harney-Wells complex with 3 to 7% slopes (73.3% of total area) and Crete silt loam with 0 to 1% slopes (26.7% of total area). This region is typical of the Central Kansas Sandstone Hills ecological site. A heavy infestation of Caucasian bluestem was present on the site at the outset of this experiment.

The experimental site was divided into 18 plots of 4,047 m^2 each, with 10 m wide fire breaks between each plot. Plots were grouped into adjacent pairs, and pairs were randomly assigned to one of two treatments: no burn (n = 6), or late-summer burn (n = 12). A permanent 50-m transect was established within each plot on a southwest-to-northeast gradient. Endpoints of each transect and plot-corner points were marked with orange survey stakes (Forestry Suppliers Inc., Jackson, MS) and GPS coordinates were recorded (Garmin, Olathe, KS).

Prescribed Fire Application

Fire was applied on 14 August 2019 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.

Botanical Composition

Soil cover and botanical composition were evaluated annually between June and July. Fifty points were selected randomly along each transect, using a modified-step point device as described by Owensby et al. (1973). The species of the closest plant within a 180° arc in front of the selected point was recorded for each point. These observations were used to determine Caucasian bluestem basal cover and vegetative basal cover according to the method described by Farney et al. (2017).

Statistical Analyses

Results were analyzed using a mixed statistical model that contained treatment, year, and treatment × year as fixed effects and plot within treatment as a random effect. When protected by a significant F-test ($P < 0.05$), least-squares means of treatment main effects or treatment × year effects were separated using the method of Least Significant Difference. Treatment × year means were reported.

Results and Discussion

Initial basal cover of Caucasian bluestem did not differ between treatments (treatment × time; $P = 0.88$), comprising 32% proportion of basal cover in non-burned plots and 33% in burned plots (Figure 2.1). In years one and two following fire application, proportion of basal cover of Caucasian bluestem in burned plots was reduced ($P < 0.05$) by approximately 38% and 27%, respectively, when compared with the pre-treatment measurement. On non-burned plots, basal cover of Caucasian bluestem increased ($P < 0.04$) approximately 22% from year one to year two post-treatment (Figure 2.1). Despite the trend toward increased Caucasian bluestem proportion of basal cover on non-burned plots, no difference ($P = 0.11$) in Caucasian bluestem basal cover was detected between our pre-treatment measurements and year two post treatment.

Once established, Caucasian bluestem requires routine control to prevent spread, as demonstrated by Eck and Sims (1984). In a 36-year study, both yellow and Caucasian bluestem came to dominate their respective grazed and non-grazed plots, as well as spreading to adjacent plots that were planted to native grasses. The efficacy of late-summer prescribed burning to reduce Caucasian bluestem demonstrated in our experiment is supported by data from Reemts et al., (2019). Reemts et al. (2019) reported yellow bluestem (*Bothriochloa ischaemum*) decreased 58 and 88% following a single application of prescribed fire three years prior to measurement. In our experiment, Caucasian bluestem decreased 38% and 27% from pre-treatment measurements to years one and two post-treatment, respectively. Differences in response can possibly be attributed to differences in precipitation. Havill et al. (2015) reported that yellow bluestem tiller count decreased by 50% to 74% when prescribed fire was applied during a drought, suggesting vulnerability during dry years. The year our burn treatment was applied (i.e., 2019), our research site received greater-than-average precipitation (approximately a 33% increase) throughout the summer (Figure 2.2). This increased rainfall may have diminished the impact of prescribed fire on Caucasian bluestem survival.

The negative response of old-world bluestems to growing-season prescribed fire may be a result of their tendencies toward relatively early maturation compared with native vegetation. While grasses tend to recover from defoliation while in the vegetative growth stage (Isopp, 2000; Sosebee and Wan., 2004), repeated defoliation in the reproductive or post-reproductive stages may result in decreased vigor and increased mortality (Sosebee and Wan., 2004). This effect has been demonstrated in Caucasian bluestem by Villanueva-Avalos (2008), where Caucasian bluestem defoliated by 85% in the reproductive stage resulted in decreased regrowth compared with lower defoliation rates. These authors attributed diminished regrowth to the removal of photosynthetic surface and associated decreases to carbohydrate reserves. Caucasian bluestem, maturing 5 to 11× more rapidly than native species (Harmoney and Hickman, 2004), may therefore be more susceptible to growing season fires that target the plant in its reproductive or post-reproductive stages.

Differences in total biomass and litter accumulation may play an additional role in the efficacy of prescribed fire for decreasing Caucasian bluestem basal cover. The decreases in Caucasian bluestem basal cover observed in our experiment are in keeping with the observations of others when pre-treatment biomass was less than 2500 kg/ha (Simmons et al., 2007; Ruckman et al., 2012b). At greater levels of biomass production, decreases in basal cover of greater than 50% have been documented (Havill et al., 2015; Reemts et al., 2019). Intense fires may damage the shallow bud banks (Havill et al., 2015) in yellow bluestem, and possibly in Caucasian bluestem as well. High-intensity fires produced as a result of elevated biomass production (> 2200 kg/ha) and abundant accumulation of litter (> 72% soil cover) in our experiment likely contributed to mortality of mature Caucasian bluestem crowns and subsequent basal cover reductions.

While vegetative reproduction has been reported in old-world bluestems (Harlan, 1958; Schmidt and Hickman, 2006), reproductive vulnerability to fire has been suggested to occur through sexual reproduction. Seeds of yellow bluestem are less tolerant of high heat than native grass seeds (Ruckman et al., 2012a), with the majority of seed production occurring during mid- and late summer (Coyne and Bradford, 1984; Diggs et al., 1999). Therefore, late-summer prescribed fire while Caucasian bluestem is in the reproductive stage may reduce seed viability.

Even though a positive ($r^2 = 0.58$) relationship between yellow bluestem percent cover and seed density has been reported by Robertson and Hickman (2012), a one time-application of prescribed fire is unlikely to significantly change seed bank composition. In the absence of repeated treatments, Caucasian bluestem basal cover is likely to increase over time to pre-treatment levels through seed bank growth and vegetative reproduction of surviving plants.

Implications

Control of Caucasian bluestem is critical to the conservation and restoration of native rangelands throughout the central and southern Great Plains. Application of late-summer prescribed fire resulted in significantly reduced basal cover composition of Caucasian bluestem in heavily infested plots one and two years following treatment. Careful timing of prescribed fire is recommended for targeting Caucasian bluestem when it is most vulnerable to defoliation.

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Figures

Figure 2.1 Effects of late-summer prescribed fire on Caucasian Bluestem (*Bothriochloa bladhii*) percent botanical composition in the Kansas Smoky Hills. Prescribed fire was applied on 14 August 2019. Initial measurements of Caucasian bluestem cover did not differ between treatments (P = 0.88). One- and two-years following prescribed fire, Caucasian bluestem cover in burned plots decreased approximately 38% and 27%, respectively, compared with pre-treatment measurements. Treatment means with unlike superscripts differ ($P \leq 0.05$; SEM = 7.91).

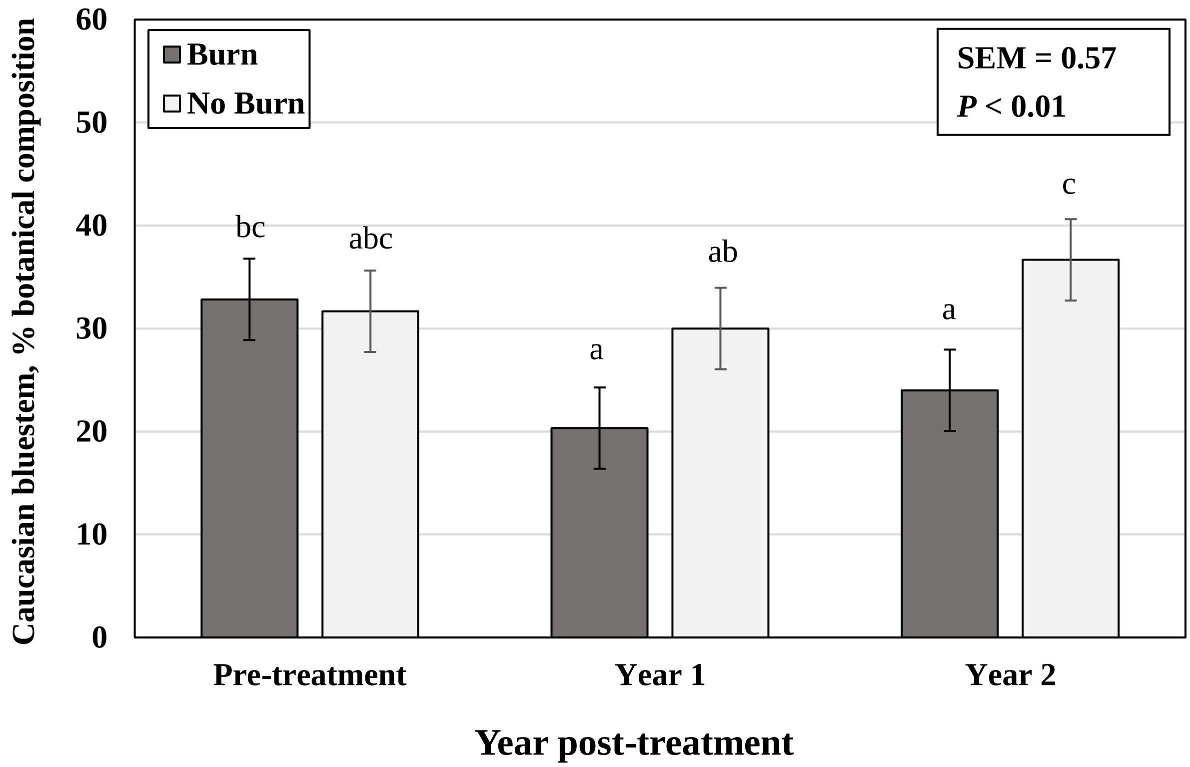
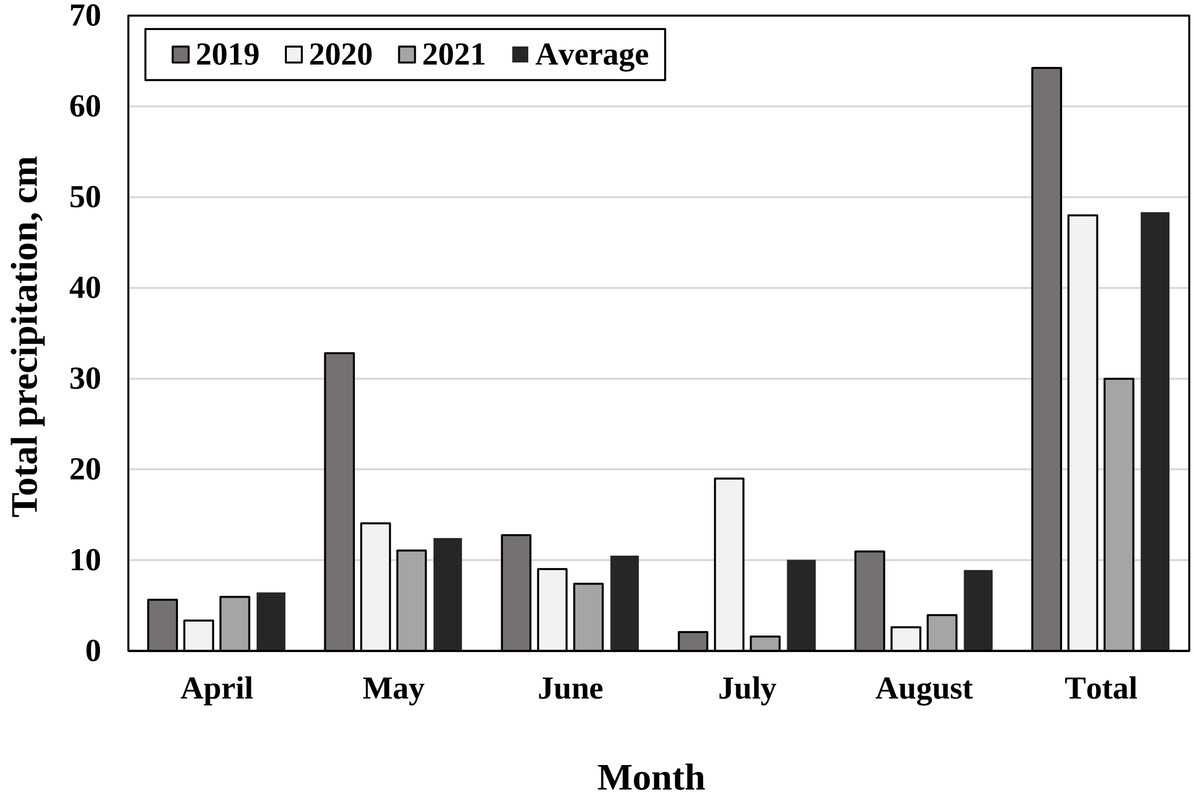


Figure 2.2 Total precipitation received during the late spring and summer of 2019, 2020, and 2021. Data were obtained from the National Oceanic and Atmospheric Administration station at Kanopolis Lake, KS. Total refers to the cumulative precipitation from April through August. Long-term historical average precipitation for the April-through-August period was 48.3 cm.



Chapter 3 - Effects of Late-Summer Prescribed Fire on Soil Cover, Vegetation Composition, and Forage Biomass Production in Mixed-Grass Prairie

Abstract

Since introduction in the early twentieth century, old-world bluestems have quickly spread beyond the intended scope of initial plantings. Old-world bluestems now dominate thousands of hectares of native rangeland through accidental introductions by movement of people, livestock, hay, agricultural equipment, and road-maintenance equipment (Gabbard and Fowler, 2007; Smith, 2010). Despite early indications that these invaders represented only a modest threat to native grasslands (Fowler and Dunlap, 1986), recent research has reported a negative relationship between old-world bluestem cover and native plant diversity (Robertson and Hickman, 2012). The most common control methods for old-world bluestems rely on the use of herbicides, primarily glyphosate and imazapyr; however, concerns about harm to non-target native species dictate a need for a novel treatment. The objective of this experiment was to evaluate the effectiveness of a one-time application of late-summer fire prescribed fire for reducing the proportion of basal cover of Caucasian bluestem in mixed grass prairie. A section of private rangeland was divided into 4,047-m^2 plots (n = 18) for this experiment, which were each assigned to 1 of 2 treatments: no burn (n = 6) or burn (n = 12). Prescribed fire was applied on 14 August 2019. Botanical composition and soil cover were measured using a modified-step point technique along permanent 50-m transects within each plot and biomass was estimated by clipping vegetation within three 0.25-m^2 clipping frames placed randomly within each plot. One and two years following treatment, bare soil was greater (treatment × time; $P < 0.01$) in burned plots compared with non-burned plots, whereas litter cover was greater (*P* < 0.01) in non-burned plots compared with burned plots in years one and two following treatment. Total basal plant cover differed (*P* < 0.01) between burned and non-burned plots in both years following treatment. While vegetative basal cover composition of native (*P* = 0.59) or introduced grasses (*P* = 0.21) were not different between treatments, total grass cover was less (treatment main effect; *P* < 0.01) in burned plots compared with non-burned plots. This trend was associated with less (treatment main effect; *P* < 0.01) forage biomass in burned plots compared with non-burned plots. Total basal cover of all forbs and perennial forbs was greater (treatment main effect; *P* ≤ 0.01) in burned plots than in non-burned plots; moreover, grass species richness was greater (treatment × time; *P* < 0.01) in burned plots compared with non-burned plots. Forb richness was greater (treatment × time; *P* < 0.01) in burned plots than in non-burned plots in year one post-treatment only. These data were interpreted to suggest that application of late-summer prescribed fire may increase native plant richness in Caucasian bluestem-invaded rangelands.

Key words: Caucasian bluestem, plant diversity, prescribed fire

Introduction

Rangelands of the central and southern Great Plains are threatened by numerous invasive plant species. Among the most pernicious of these invaders are two species of old-world bluestems: yellow bluestem (*Bothriochloa ischaemum*) and Caucasian bluestem (*Bothriochloa bladhii*). Initially planted for livestock forage and soil conservation, these old-world bluestems have quickly spread beyond the original-intended boundaries of cultivation. In their non-native habitat, old-world bluestem species have significantly degraded native rangelands. Grasslands dominated by old-world bluestems are associated with decreased native plant diversity (Reed et. al., 2005; Gabbard and Fowler, 2007), avian diversity (Hickman et al., 2006), small mammal diversity (Sammon and Wilkins, 2005), and arthropod diversity (Johnson et al., 2008).

Numerous methods have been evaluated as control methods for old-world bluestems but herbicide use remains the most prevalent. Broadcast applications of glyphosate, imazapyr, and sulfometuron-methyl have been used to reduce old-world bluestem frequency in native grasslands for short periods of time (Harmoney et al., 2007; Simmons et al., 2007; Gunter and Gillen, 2010; Ruffner and Barnes, 2010). Unfortunately, non-selective herbicide use carries with it the potential to harm native vegetation as well (Harmoney et al., 2007; Ruffner and Barnes, 2010).

Dormant season burns have historically been applied in the Great Plains to control non-native plant species; however, frequency of old-world bluestems have been observed to increase in response to dormant season prescribed fires (Pase, 1971; Gabbard and Fowler, 2007). Recent research has indicated that shifting the timing of fire application to the growing season may reduce old-world bluestem frequency without harming native vegetation (Simmons et al., 2007;

Reemts et al., 2019). Therefore, the objective of this experiment was to evaluate the efficacy of late-summer prescribed fire on soil cover, botanical composition, and forage biomass.

Materials and Methods

Experimental Design and Location

Our experiment was conducted on a private ranch southwest of Kanopolis Lake in Ellsworth Co., KS. Soils were of the Harney-Wells complex with 3 to 7% slopes (73.3% of total area) and Crete silt loam with 0 to 1% slopes (26.7% of total area). This region is typical of the Central Kansas Sandstone Hills ecological site description. A heavy infestation of Caucasian bluestem was present on the site at the outset of this experiment.

The study site was divided into 18 plots of 4,047 m^2 each, with 10-m wide fire breaks between each plot. Plots were grouped into pairs, and pairs were assigned randomly to one of two treatments: no burn (n = 6) or late-summer burn (n = 12). A permanent 50-m transect was established within each plot on a southwest-to-northeast gradient. Endpoints of each transect and plot-corner points were marked with orange survey stakes (Forestry Suppliers Inc., Jackson, MS) and GPS coordinates were recorded (Garmin, Olathe, KS).

Prescribed Fire Application

Fire was applied on 14 August 2019 under the following environmental conditions: average surface wind speed = 24 $km \cdot h^{-1}$; surface wind direction = east-northeast; mixing height ≥ 550 m; transport wind speed = 13 to 33 $km \cdot h^{-1}$; average relative humidity = 55%; average ambient temperature = 24°C; and Haines index ≤ 4.

Soil Cover, Botanical Composition and Forage Biomass

Soil cover and botanical composition were evaluated annually between June and July. Points were selected randomly along each transect (50 points/transect), at approximately 1-m intervals, using a modified-step point technique as described by Owensby et al. (1973). Soil cover (i.e., plant basal material, bare soil, or litter) and species of the closest plant within a 180° arc in front of the selected point, were recorded for each point. These observations were used to determine botanical basal composition and soil cover according to the method described by Farney et al. (2017).

Effects of late-summer prescribed fire on vegetation growth-form composition were evaluated as described by Hickman et al. (2004). Lists of graminoids, forbs, and shrubs encountered during sampling, along with their growth-form categories, are reported in Tables 3.1, 3.2, and 3.3, respectively. Common names, scientific names, and taxonomic authorities were taken from Haddock (2005).

Forage biomass was estimated by clipping vegetation within three 0.25-m^2 clipping frames placed randomly within each plot. Litter and standing dead material were removed from frames, and current-year's growth was clipped to a height of 1 cm above the soil surface. Clipped material was weighed, dried in a forced-air oven (50ºC; 96 h), and re-weighed to estimate standing forage biomass (kg DM ⋅ ha^{-1}).

Statistical Analyses

Results were analyzed using a mixed statistical model that contained treatment, year, and treatment × year as fixed effects and plot within treatment as a random effect. When protected by a significant *F*-test ($P < 0.05$), least-squares means of treatment main effects or treatment × year effects were separated using the method of Least Significant Difference. Treatment × year means were reported.

Results and Discussion

Soil Cover

Application of late-summer prescribed fire was associated with decreased (treatment × time; $P < 0.01$) litter cover in burned plots, while it remained extremely elevated in non-burned plots (Table 3.4). As a result of litter removal, the amount of bare ground was greater (treatment × time; $P < 0.01$) in burned plots compared with non-burned plots in both years following fire application.

Although the research site was grazed intermittently by beef cattle, prescribed fire had not been applied prior to the start of our experiment, leading to elevated (i.e., > 70%) litter cover and litter depth at the onset of our experiment. Excessive litter accumulation may have also been the result of temporal avoidance by cattle of Caucasian bluestem-infested areas in preference for native grasses. While immature Caucasian bluestem is readily consumed by cattle, it has been reported to mature 5 to 11× more rapidly than native warm-season grasses (Harmoney and Hickman, 2004). As increased plant maturity is associated with decreased palatability, nutrient concentrations, and voluntary intake (Nelson and Moser, 1995; Burns et al., 1997; Vona et al., 1984), cattle may preferentially graze Caucasian bluestem-free areas of the pasture after Caucasian bluestem becomes unpalatable. This grazing distribution in combination with the lack of regular prescribed fire may have resulted in extraordinary levels of litter we observed.

Yellow and Caucasian bluestems have been observed to exhibit allelopathic effects on native grass species (Greer et al., 2004; Schmidt et al., 2007). Greer et al. (2004) demonstrated that leachate from roots and litter of yellow bluestem inhibited germination, growth, and survival of big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*). Removal of Caucasian bluestem litter may result in decreased concentrations of allelopathic compounds, and subsequent increases in native plant seed germination, growth, and survival in Caucasian bluestem-infested rangelands.

Changes to water infiltration may occur following removal of litter, as reported by Hanks and Anderson (1957). Reductions in litter cover have been associated with reduced rates of water infiltration. Litter likely prevents loss of water through evaporation and run-off. Increased bare soil reported in our experiment was interpreted to suggest that reduced water infiltration and reduced soil moisture may have occurred in burned areas.

Forage Biomass

Burned plots were associated with lesser (treatment main effect; $P < 0.01$) standing forage biomass than non-burned plots (2,355 and 3,120 kg DM $\cdot$ ha^{-1}, respectively). In herbicide treated plots, Harmoney et al. (2010) reported a strong ($R^2 = 0.98$) positive relationship between dry matter yield and frequency of Caucasian bluestem. Our observations of decreased basal cover of Caucasian bluestem in burned plots (see Chapter 2 of this document) were interpreted to suggest that losses in forage biomass were related to reductions in Caucasian bluestem basal cover.

Measurements of forage biomass in old-world bluestem pastures following prescribed fire applications have been documented only in conjunction with dormant-season prescribed fires. Gunter and Gillen (2010) and Bodine et al. (2001) reported that dormant-season fires applied in April did not result in any changes to forage biomass at the end of the growing season. In contrast, dormant-season burning was documented to modestly reduce yellow bluestem yield by approximately 16% (Berg,1993). Differences in time of year in which prescribed fire was applied is likely the reason for dissimilarity between our results and those of Gunter and Gillen (2010) and Bodine et al. (2001). Towne and Craine (2014) attributed greater than 60% of variation in total biomass production to annual rainfall differences in tallgrass prairie. Although differences in precipitation were experienced between years during our experiment (Figure 3.3), lesser forage biomass in burned plots compared with non-burned plots was consistent in years subsequent to prescribed-fire treatment.

Botanical Composition

Total graminoid basal cover composition was less (treatment main effect; $P < 0.01$; Table 3.5) in burned plots compared with non-burned plots (85.6 and 91.0%, respectively). While our pre-treatment observations indicated no differences ($P = 0.62$) between plots in total C4 grass basal cover composition, application of fire resulted in decreased (treatment × time; $P < 0.01$) total C4 grass basal composition in burned plots, while remaining unchanged over time in non-burned plots. Additionally, basal cover composition of C4 mid-grasses cover tended to be less (treatment × time; $P = 0.06$) in burned plots compared with non-burned plots (21.1 and 28.4%, respectively). Basal cover of native grasses and introduced grasses was not different ($P \geq 0.10$) between treatments at any time point. Conversely, burned plots were associated with greater (treatment × time; $P < 0.01$) grass species richness one and two years following fire compared with non-burned plots (Figure 3.2). This increase in grass species richness was primarily attributed to the appearance of perennial C4 grasses, such as paspalum (*Paspalum setaceum*) and sand drop seed (*Sporobolus cryptandrus*) which were present only in burned plots in years one and two. Smooth brome (*Bromus inermis*) was the only C3 grass which was recorded solely in burned plots; however, smooth brome was only detected once in year 2. Each of these trends was associated with notable declines in Caucasian bluestem basal cover (see Chapter 2 of this document).

Total basal composition of C3 grasses (treatment × time; $P < 0.01$; Table 3.5) was not different ($P \geq 0.07$) between treatments at any measurement time; however, C3 grass basal composition increased ($P < 0.01$) in burned plots from the pre-treatment measurement to the first year following treatment. The C3 graminoids present at the site were primarily sedges (*Carex* sp.) and Scribner's panicum (*Dichanthelium oligosanthes*), two native perennial graminoids. Total basal C3 basal composition in the final year of observation did not differ (P = 0.95) between burned and non-burned plots.

Total basal cover composition of all forbs (8.5 and 14.2%, for non-burned and burned, respectively; Table 3.6) and perennial forbs only (8.3 and 13.3% for non-burned and burned, respectively) were greater (treatment main effect; $P \leq 0.01$) in burned plots compared with non-burned plots. Despite the significant differences in total basal cover composition of all forbs between treatments, these differences were detectable in the pre-treatment year as well, suggesting that differences in total basal cover composition of all forbs may not be attributed solely to application of prescribed fire. Additionally, basal cover of introduced, annual, and nectar-producing forbs increased (treatment × time; $P \leq 0.02$; Table 3.6) in burned plots from pre-treatment observations to year one post-treatment; by year two post-treatment, this effect had disappeared. These data are reflective of those of Simmons et al (2007); following growing-season fires, increased native forb richness was the only significant botanical composition change recorded when compared with adjacent non-burned areas. Hickman et al. (2006), Robertson and Hickman (2012), and George et al. (2013) noted decreased forb abundance in old-world bluestem grasslands compared with native grasslands, suggesting that consequences of reduced Caucasian bluestem cover may be observed in changes to forb community abundance and composition.

Increased forb frequency (Reemts et al., 2019) and cover (Ruffner and Barnes, 2012) in old world bluestem-dominated grasslands following disturbance has been documented in previous experiments. Following applications of herbicide and herbicide with disking, Ruffner and Barnes (2012) reported a flush of forbs (up to 50% basal cover) 52 weeks after treatment. Conversely, elevated forb cover decreased to pre-treatment levels 100 weeks after treatment. In contrast to these authors, the increase in forb cover we observed did not decrease to pre-treatment levels. Following the application of prescribed fire in September, Reemts et al. (2012) reported significant increases in total forb cover at two sites, which remained greater in burned plots than non-burned plots for two years following fire application. Burned plots in our experiment were associated with temporally greater (treatment × time; $P < 0.01$) forb richness one year following fire compared with non-burned plots (Figure 3.3). Conversely, forb species richness in our experiment was not different ($P = 0.67$) between treatments two years after fire. Our observations mirror the reports of Reemts et al. (2012). These data have been interpreted to suggest that late-summer prescribed fire in Caucasian bluestem-dominated rangelands may promote increased basal cover composition of certain categories of forbs for a prolonged (i.e., > 1 year) period.

Application of prescribed fire, as opposed to non-specific herbicide use, may have significant positive effects on forb cover in disturbed rangelands. Non-selective herbicides may harm non-target species and decrease native plant diversity, as reported by Harmoney et. al (2007) and Ruffner and Barnes (2012). Decreased cover of Caucasian bluestem along with neutral-to-positive responses of native graminoid and forb species basal composition we observed was interpreted to suggest that native vegetation may be more tolerant of growing-season fires than Caucasian bluestem.

Increased total basal composition of forbs following the reduction of Caucasian bluestem may also result in favorable changes for wildlife and livestock. Hickman et al. (2006) and George et al. (2013) suggested that decreased arthropod abundance in old-world bluestem dominated grasslands was a function of decreased forb abundance. Increasing total forb cover in old-world bluestem degraded grasslands may then promote the restoration of native arthropods, which are an important food source for many grassland bird species such as prairie chickens (Wiens, 1963; Wiens, 1969; Martin, 1987; Applegate and Riley, 1998). Additionally, increased forb cover provides favorable habitat for white-tail deer, which consume greater amounts of forbs than grasses (Kie et al., 1980).

The relationship between old-world bluestems and native plant diversity has been well documented. Both yellow and Caucasian bluestem have been reported to decrease native plant richness and diversity in North American rangelands (Gabbard and Fowler, 2006; Reed et al., 2005; Robertson and Hickman, 2012). Temporary increases in basal composition of introduced, annual, and nectar-producing forbs one-year post-fire in burned plots (Table 3.6) likely explained greater forb species richness in burned plots compared to non-burned plots during the same period. Despite the lack of differences in forb species richness two years post-fire, burned plots were associated with greater (treatment main effect; $P < 0.01$) basal composition of perennial forbs, such as blackeyed susan (*Rudbeckia hirta*), fringeleaf ruellia (*Ruellia humilis*), and tall goldenrod (*Solidago altissima*), which were observed only in burned plots. Increased forb heterogeneity has been equated with greater overall range health, reasserting the diagnostic value of forb species richness for evaluating environmental conditions (Biondini et al., 1989). Positive changes to species richness that we observed were interpreted to suggest that native vegetation may be more resilient to growing season prescribed fires than Caucasian bluestem and growing season prescribed fire may temporarily increase range health of Caucasian bluestem-dominated grasslands.

Implications

A single application of late-summer prescribed fire resulted in significant reductions in Caucasian bluestem basal composition in burned plots (see Chapter 2 of this document). This reduction in cover was associated with greater perennial forb basal composition, grass species richness, a temporary increase in forb species richness, and decreased forage biomass production. These data were interpreted to indicate that, while Caucasian bluestem is vulnerable to prescribed fire during the growing season, native vegetation exhibits greater resiliency to fire during the same period. Accordingly, utilization of late-summer prescribed fire in Caucasian bluestem-dominated grasslands should take into consideration a probable decrease in available forage biomass in subsequent years.

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Figures

Figure 3.1 Total precipitation received during the late spring and summer of 2019, 2020, and 2021. Data were obtained from the National Oceanic and Atmospheric Administration station at Kanopolis Lake, KS. Total refers to the cumulative precipitation from April through August. Long-term historical average precipitation for the April through August period was 48.3 cm.

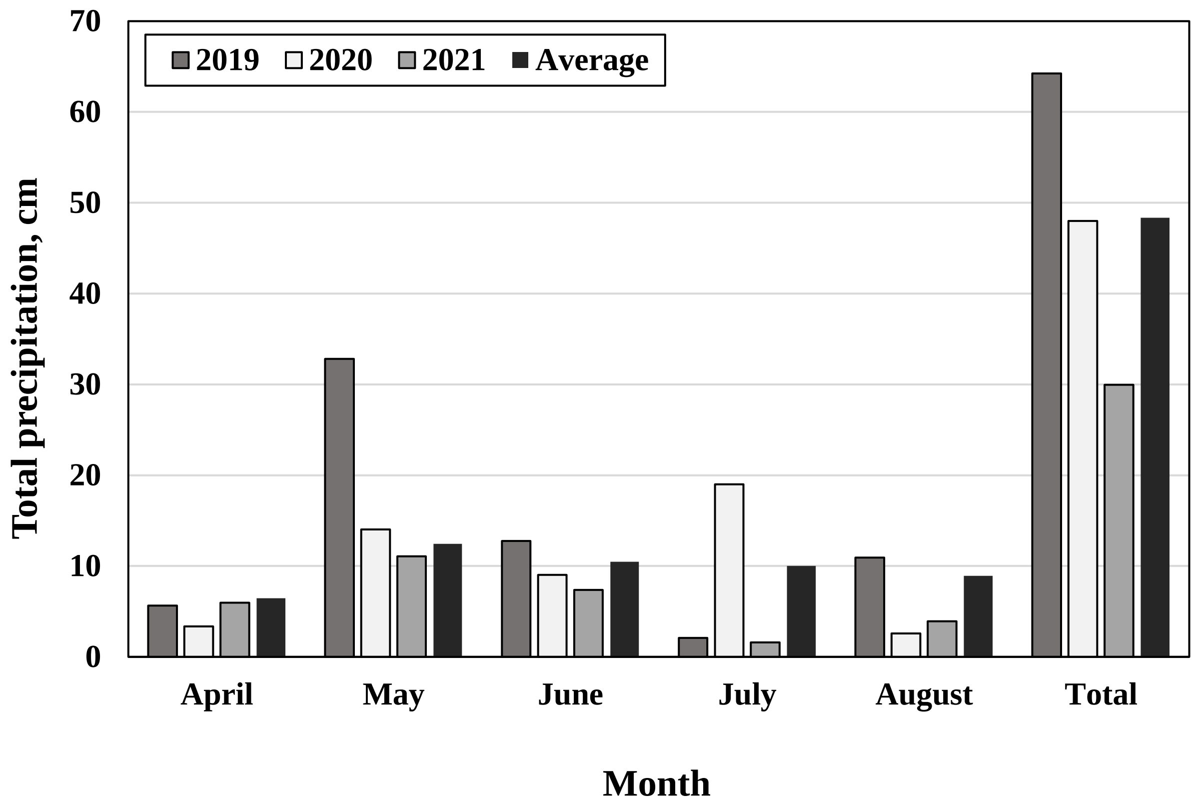


Figure 3.2 Effects of late-summer prescribed fire on forb species richness in the Kansas Smoky Hills. Prescribed fire was applied on 14 August 2019. Forb species richness (number of species) was greater (treatment × time $P < 0.01$) in burned plots compared to non-burned plots one-year following treatment. Two years following treatment, no differences ($P = 0.67$) were detected between burned and non-burned plots. Treatment means with unlike superscripts differ (treatment x time - $P < 0.01$).

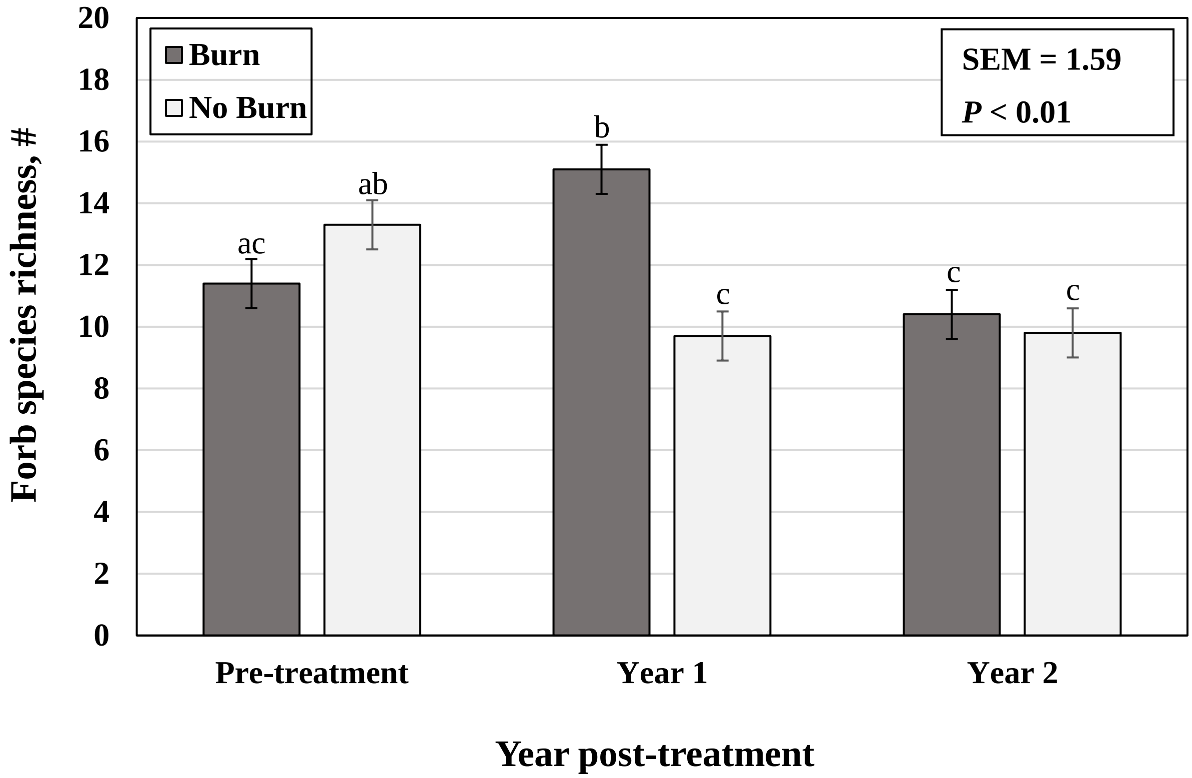
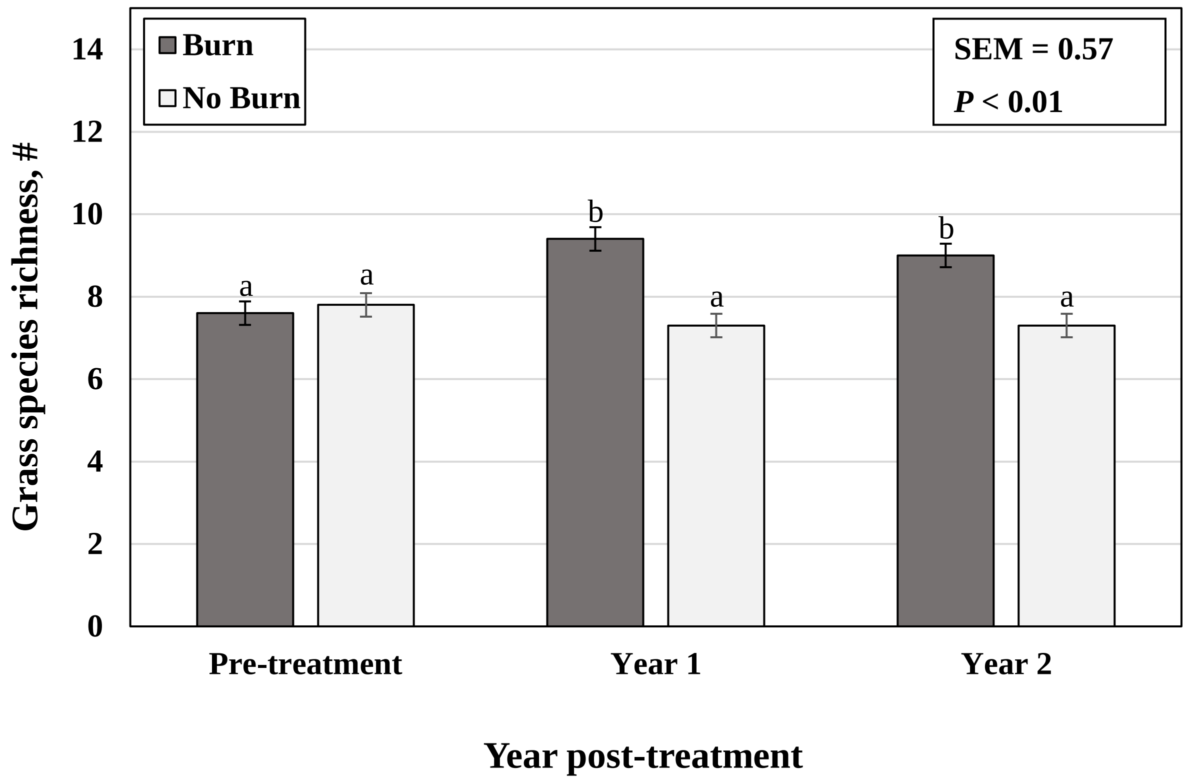


Figure 3.3 Effects of late-summer prescribed fire on grass species richness in the Kansas Smoky Hills. Prescribed fire was applied on 14 August 2019. No differences (P = 0.66) were detected between plots prior to treatment. Late-summer prescribed fire resulted in greater (treatment × year - P < 0.01) grass species richness (number of species present) in burned plots compared with non-burned plots. Treatment means with unlike superscripts differ (P < 0.01).



Tables

Table 3.1 Graminoid species encountered in Kansas Smoky Hills mixed-grass prairie during the 2019, 2020, and 2021 summer growing seasons.

Common name	Scientific name	Classification	Metabolism	Status	Growth form
Big bluestem	*Andropogon gerardii*	Perennial	C4	Native	Tall
Buffalograss	*Bouteloua dactyloides*	Perennial	C4	Native	Short
Canada wildrye	*Elymus canadensis*	Perennial	C3	Native	n.a.
Caucasian bluestem	*Bothriochloa bladhii*	Perennial	C4	Introduced	Mid
Fall witchgrass	*Digitaria cognata*	Perennial	C4	Native	n.a.
Indian grass	*Sorghastrum nutans*	Perennial	C4	Native	Tall
Kentucky bluegrass	*Poa pratensis*	Perennial	C3	Introduced	n.a.
Little bluestem	*Schizachyrium scoparium*	Perennial	C4	Native	Mid
Paspalum	*Paspalum setaceum*	Perennial	C4	Native	n.a.
Plains muhly	*Muhlenbergia cuspidata*	Perennial	C4	Native	Mid
Purple lovegrass	*Eragrostis spectabilis*	Perennial	C4	Native	n.a.
Purpletop	*Tridens flavus*	Perennial	C4	Native	Tall
Sand dropseed	*Sporobolus cryptandrus*	Perennial	C4	Native	Tall
Scribner panicum	*Dichanthelium oligosanthes*	Perennial	C3	Native	n.a.
Sedges	*Carex spp.*	Perennial	C3	Native	n.a.
Side-oats grama	*Bouteloua curtipendula*	Perennial	C4	Native	Mid
Smooth bromegrass	*Bromus inermis*	Perennial	C3	Introduced	n.a.
Switchgrass	*Panicum virgatum*	Perennial	C4	Native	Tall
Tall dropseed	*Sporobolus compositus*	Perennial	C4	Native	Mid
Western wheatgrass	*Pascopyrum smithii*	Perennial	C3	Native	n.a.
Witchgrass	*Panicum capillare*	Annual	C4	Native	n.a.

Table 3.2 Forb species encountered in Kansas Smoky Hills mixed-grass prairie during the 2019, 2020, and 2021 summer growing seasons.

Common Name	Scientific Name	Growth	Status
American burnweed	*Erechtites hieracifolius*	Annual	Native
American vetch	*Vicia americana*	Perennial	Native
Aromatic aster	*Symphyotrichum oblongifolium*	Perennial	Native
Baldwin's ironweed	*Vernonia baldwinii*	Perennial	Native
Blackeyed susan	*Rudbeckia hirta*	Perennial	Native
Black medic	*Medicago lupulina*	Annual	Introduced
Blue wildindigo	*Baptisia australis*	Perennial	Native
Buffalobur	*Solanum rostratum*	Annual	Native
Carolina cranesbill	*Geranium carolinianum*	Annual	Native
Common blue violet	*Viola sororia*	Perennial	Native
Common groundcherry	*Physalis longifolia*	Perennial	Native
Common ragweed	*Ambrosia artemisiifolia*	Annual	Native
Common St. Johnswort	*Hypericum perforatum*	Perennial	Introduced
Corn speedwell	*Veronica arvensis*	Annual	Introduced
Daisy fleabane	*Erigeron strigosus*	Annual	Native
Dotted gayfeather	*Liatris punctata*	Perennial	Native
False boneset	*Brickellia eupatorioides*	Perennial	Native
Field bindweed	*Convolvulus arvensis*	Perennial	Introduced
Field pussytoes	*Antennaria neglecta*	Perennial	Native
Fringed puccoon	*Lithospermum incisum*	Perennial	Native
Fringeleaf ruellia	*Ruellia humilis*	Perennial	Native
Giant ragweed	*Ambrosia trifida*	Annual	Native
Glandular croton	*Croton glandulosus*	Annual	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
Hairy aster	*Symphyotrichum pilosum*	Perennial	Native
Heath aster	*Symphyotrichum ericoides*	Perennial	Native
Illinois tickclover	*Desmodium illinoense*	Perennial	Native
Long-bearded hawkweed	*Hieracium longipilum*	Perennial	Native
Louisiana sagewort	*Artemisia ludoviciana*	Perennial	Native
Marestail	*Conyza canadensis*	Annual	Native
Missouri goldenrod	*Solidago missouriensis*	Perennial	Native
Narrowleaf milkweed	*Asclepias stenophylla*	Perennial	Native
Oneseed croton	*Croton monanthogynus*	Annual	Native
Pitcher sage	*Salvia azurea*	Perennial	Native
Plain-seeded plantain	*Plantago virginica*	Annual	Native
Prairie coneflower	*Ratibida columnifera*	Perennial	native
Prairie groundsel	*Senecio plattensis*	Perennial	Native
Prairie pepper-grass	*Lepidium densiflorum*	Annual	Native
Prairie trefoil	*Lotus unifoliolatus*	Annual	Introduced
Prickly lettuce	*Lactuca serriola*	Biennial	Introduced
Purple poppymallow	*Callirhoe involucrata*	Perennial	Native
Rough false pennyroyal	*Hedeoma hispida*	Annual	Native
Serrateleaf evening primrose	*Catylophus serrulatus*	Perennial	Native
Showy evening primrose	*Oenothera speciosa*	Perennial	Native
Slick-seed bean	*Strophostyles leiosperma*	Annual	Native
Snow-on-the-mountain	*Euphorbia marginata*	Annual	Native

Table 3.2 continued

Common Name	Scientific Name	Growth	Status
Spider milkweed	*Asclepias viridis*	Perennial	Native
Spotted spurge	*Chamaesyce maculata*	Annual	Native
Stiff goldenrod	*Solidago rigida*	Perennial	Native
Sulphur cinquefoil	*Potentilla recta*	Perennial	Introduced
Sweetclovers	*Melilotus spp.*	Perennial	Introduced
Tall goldenrod	*Solidago altissima*	Perennial	Native
Tall thistle	*Cirsium altissimum*	Annual	Native
Texas croton	*Croton texensis*	Annual	Native
Tube penstemon	*Penstemon tubaeflorus*	Perennial	Native
Velvety gaura	*Gaura parviflora*	Annual	Native
Violet lespedeza	*Lespedeza violacea*	Perennial	Native
Violet wood sorrel	*Oxalis violacea*	Perennial	Native
Virginia groundcherry	*Physalis virginiana*	Perennial	Native
Viscid euthamia	*Euthamia gymnospermoides*	Perennial	Native
Wavyleaf thistle	*Cirsium undulatum*	Perennial	Native
Western ragweed	*Ambrosia psilostachya*	Perennial	Native
Western yarrow	*Achillea millefolium*	Perennial	Native
Whorled milkweed	*Asclepias verticillata*	Perennial	Native
Whorled polygala	*Polygala verticillata*	Annual	Native
Wild alfalfa	*Psoralidium tenuiflorum*	Perennial	Native
Woolly verbena	*Verbena stricta*	Perennial	Native

Table 3.3 Shrub species encountered in Kansas Smoky Hills mixed-grass prairie during the 2019, 2020, and 2021 summer growing seasons.

Common Name	Scientific Name	Growth	Status
Buckbrush	*Symphoricarpos orbirculatus*	Perennial	Native
Chickasaw plum	*Prunus angustifolia*	Perennial	Native

Table 3.4 Effects of late-summer prescribed fire on mixed-grass prairie soil cover and biomass accumulations in the Kansas Smoky Hills

	Pre-treatment		Year post-treatment: Year 1		Year post-treatment: Year 2			
Item	No Burn	Burn	No Burn	Burn	No Burn	Burn	SEM	*P*-value
Bare soil, %	8.7[a]	5.7[a]	5.7[a]	65.8[b]	4.7[a]	63.0[b]	4.67	<0.01
Litter cover, %	80.0[a]	72.3[a]	81.0[a]	23.2[b]	87.7[c]	29.2[d]	4.58	<0.01
Basal vegetation cover, %	11.3[ab]	18.5[c]	13.3[b]	11.0[ab]	7.7[a]	7.8[a]	2.03	<0.01
Forage biomass, kg/ha*	2616	2229	3162	1978	3580	2859	417.7	0.30

[a,b,c] Within rows, means with unlike superscripts differ ($P < 0.01$).

*Treatment main effect - $P < 0.01$.

Table 3.5 Effects of late-summer burning on mixed-grass prairie graminoid composition in the Kansas Smoky Hills

	Pre-treatment		Year post-treatment: Year 1		Year post-treatment: Year 2			
Item, % of total	No Burn	Burn	No Burn	Burn	No Burn	Burn	SEM	P-value
Total graminoid*	92.0	91.2	89.0	81.5	92.0	85.2	1.81	0.14
Native	42.3	43.8	39.0	39.3	36.3	42.8	5.08	0.54
Introduced	49.7	46.3	50.0	42.2	55.7	42.3	6.25	0.10
Total C4 grasses	63.0[bc]	65.7[c]	63.7[bc]	46.8[a]	62.3[bc]	55.8[b]	5.29	<0.01
C4 tall grasses	17.7	18.3	16.0	16.5	8.0	14.7	2.94	0.24
C4 mid-grasses*	13.7	14.0	17.7	9.7	54.0	39.7	2.41	0.06
Total C3 graminoids	29.0[ab]	24.5[a]	25.3[ab]	34.7[b]	29.7[b]	29.3[b]	4.94	<0.01

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

*Treatment main effect - $P < 0.01$.

Table 3.6 Effects of late-summer prescribed fire on mixed-grass prairie forb composition in the Kansas Smoky Hills.

	Pre-treatment		Year post-treatment					
			Year 1		Year 2			
Item, % of total	No Burn	Burn	No Burn	Burn	No Burn	Burn	SEM	P-value
Total Forbs*	7.7	9.5	10.4	18.3	7.4	14.7	1.79	0.10
Native	7.6	9.4	10.3	16.8	7.4	14.5	1.78	0.14
Introduced	0.1[a]	0.2[a]	0.1[a]	1.6[b]	0.0[a]	0.2[a]	0.44	0.02
Perennial*	7.4	9.3	10.3	16.2	7.3	14.3	1.75	0.16
Annual	0.3[a]	0.3[a]	0.1[a]	2.1[b]	0.1[a]	0.4[a]	0.47	<0.01
Nectar-producing	3.5[a]	4.6[a]	5.0[a]	9.7[b]	0.7[c]	0.8[c]	1.12	<0.01
Legumes	0.5	0.7	0.8	0.9	0.0	0.1	0.18	0.72

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

*Treatment main effect - $P \leq 0.01$