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Timing and Intensity of Steer Use on Old World Bluestem (Bothriochloa Ischaemum) and Blue Grama (Bouteloua Gracilis) in Southern Mixed-Grass Prairie

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TIMING AND INTENSITY OF STEER USE ON OLD WORLD BLUESTEM (*BOTHRIOCHLOA ISCHAEMUM*) AND BLUE GRAMA (*BOUTELOUA GRACILIS*) IN SOUTHERN MIXED-GRASS PRAIRIE

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PREFACE

This thesis is written in the style required by Rangeland Ecology and Management, to which a portion will be submitted for publication.

ABSTRACT

Yellow bluestem (*Bothriochloa ischaemum*), an invasive species, was introduced as a forage species and as a roadside grass for erosion control. Yellow bluestem can negatively interact with native grasslands and reduce biodiversity. Livestock tend to avoid yellow bluestem after accumulation of standing lignified tissue, particularly at the end of the growing season. Mowing has been used in pasture situations to remove excess grass for hay and over coarse grass left from the previous season. It is essential to understand the role livestock play as either a catalyst for control or preventing further invasion of yellow bluestem. Quantification of the timing and intensity of yellow bluestem defoliation by livestock after mowing compared to native grass has not been previously documented. To evaluate this, I recorded steer utilization of yellow bluestem and blue grama (*Bouteloua gracilis*) in a southern mixed grass prairie following two mowing treatments during 2012-2013. I also recorded cover by litter. In 2012, mean utilization of blue grama (12%) was lower than mean utilization of yellow bluestem (22%), but in 2013, mean utilization of blue grama (20%) was higher than mean utilization of yellow bluestem (15%). Timing of utilization of yellow bluestem was different than was suggested previously, with utilization of yellow bluestem occurring late in the season. These data could be used to help assess the potential shifts in steer utilization of native rangelands where yellow bluestem is present and aid in making future grassland management decisions. However, the system that I worked with experienced a high degree of variation in temperature and precipitation between years, a longer-term experiment could distinguish between year to year utilization variation and an overall trend in yellow bluestem utilization.

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INTRODUCTION

Invasive species typically are non-native and adversely affect the habitats they invade economically, environmentally, or ecologically. Some impacts include raising costs of managing and producing livestock, interfering with grazing practices, and threatening native biodiversity. Roughly 50,000 invasive species, both plant and animal, have been recorded in the United States; the damages attributed to invasive species total around $2.1 billion dollars per year (Pimentel et al. 2004).

Many native grasslands have been lost to row crop agriculture and the invasion of non-native plants (Watkinson and Ormerod 2001). Invasive grasses are of particular concern when it comes to native grassland communities, because they increase fire frequency due to the increased amount of standing dead tissue, reduce available soil moisture for native species (Harris 1967; Melgoza et al. 1990; Aguirre and Johnson 1991), alter ecosystem structure through changes in nutrient cycling and soil organic matter composition (Knapp 1996), and change the chemical, physical, and biotic characteristics of soil (Wilson et al. 1987; Ehrenfeld et al. 2001; Ehrenfeld 2003; Haubensak et al. 2004; Sperry et al. 2006) as well as having a superior competitive ability where they eliminate native species through competitive exclusion (D'Antonio and Vitousek 1992). This might decrease the productivity of native grasses in the invaded ecosystem. However, invasive grasses might also increase the total productivity of the ecosystem, even as it decreases the native grass productivity. Although total productivity might be increased, the invasive species could inhibit growth of surrounding native species (Vilà and Weiner 2004; Schmidt 2008), invasive grasses could simply be more productive than the native grasses they replace (Smith and Knapp 1999). Old World Bluestems are one such group of exotic grasses that are threatening the grasslands of the Great Plains.

Old World Bluestems (OWB *Bothriochloa* spp.) were introduced into the United States from Asia and Europe in the 1920s (Celarier and Harlan 1955). OWB are warm season (C_4) grasses that were endorsed because of their superiority to native grasses with respect to quality, production, ability to respond to high fertility levels, persistence under grazing, and for production and rapid erosion control (Celarier and Harlan 1955; Coyne and Bradford 1985a). Some OWB outperform native species in yield, nitrogen recovery, and nitrogen use (Brejda et al. 1995). Coyne and Bradford (1985b) showed that when water was deficient, OWB have greater overall production of tillers than native grass species, increasing the total biomass of the species. OWB produce quality forage in spring and summer, but forage quality in late summer and winter can be very low (Dabo et al. 1987). Harmoney and Hickman (2004) noted that cattle appeared to avoid one OWB, Caucasian bluestem (*Bothriochloa bladhii*) when in mixed stands with native grasses. In pastures that contain OWB and native grasses, cattle will select the native grasses rather than the non-native OWB (Berg and Sims 1984). Selective grazing of native grasses over OWB by ungulates could promote the spread of OWB because they harness the changing availability of light and other resources (Burke and Grime 1996).

One notable species of OWB is yellow bluestem (*Bothriochloa ischaemum* (L.) Keng). Since it was introduced in the United States, yellow bluestem has invaded a diverse array of habitat types throughout the Great Plains (Turner et al. 2003; Gabbard and Fowler 2007). Yellow bluestem presence can interact negatively with plant, rodent, and avian species richness and diversity (Sammon and Wilkins 2005; Hickman et al. 2006; Gabbard and Fowler 2007). Many aspects of its competitiveness might come from growth earlier than its competitors. Seventy percent of the growth of yellow bluestem occurs in June, but its nutritive value decreases rapidly in July and throughout the rest of the growing season (White and Dewald 1996). It is a C_4 grass whose first sign of growth occurs by late spring, but most growth occurs in summer, one month earlier than native C_4 grasses (White and Dewald 1996). This earlier growth could allow for a competitive advantage through preemptive use of resources (Moore 1959; Daubenmire 1968). Yellow bluestem inhibits root growth of surrounding native grasses (Schmidt 2008). Its competitive and persistent nature, especially under grazing conditions, has been observed by researchers since its introduction (Harlan et al. 1958; Eck and Sims 1984).

Grazing has been used as a management tool and for many reasons and one of those reasons is to control or suppress an invasive plant species. This can be accomplished with selective grazing by manipulating when grazing takes place, usually when the invasive species is most vulnerable. Grazing at this time can hinder the invasive species and promote the spread and health of native plant species in the area (Frost and Launchbaugh 2003). Coyne and Bradford (1985a) stated cattle usually graze yellow bluestem from the time it starts to grow in late spring until the late vegetative stage. Yellow bluestem flowers before most of the native warm-season grasses that are usually associated with it (Coyne and Bradford 1985a). Livestock usually begin grazing yellow bluestem and cool-season grasses before they begin grazing native warm-season grasses

(Coyne and Bradford 1985a). It is unlikely, however, that with yellow bluestem's tolerance for intense grazing (Teague et al. 1996; Ackerman et al. 2001) that selective grazing would be a viable option for its control.

Livestock selectively graze grasses for green, leafy material, often restricting their foraging to localized patches surrounded by large, lightly grazed areas (Ring et al. 1985; Renken 1995). Livestock selectivity can be influenced by the amount of residual stems left on a plant; biting rates were reduced on plants that had more standing dead tissue (Ruyle et al. 1987). Therefore, accumulation of dead, standing tissue can discourage use by livestock and wildlife (White and Trudell 1980; Willms et al. 1981; Ruyle et al. 1987). For this reason, Willms and McLean (1978) concluded that cattle and deer selected bluebunch wheatgrass (*Psuedoroegneria spicata*) more often when it was clipped or burned than when not clipped or burned. Poor quality and accumulation of standing lignified tissue might influence livestock use of yellow bluestem, late in the season. Mowing has been used in pasture situations to remove excess grass for use as hay, or to remove overly coarse grass left after grazing the previous grazing season (Shoop et al. 1976). Encouraging young green tissue by mowing yellow bluestem might influence utilization patterns by livestock, by increasing livestock utilization.

Blue grama [*Bouteloua gracilis* (Willd. Ex Kunth) Lag. ex Griffiths] is a common native species in southern mixed grass prairies where yellow bluestem is invading. Blue grama is a perennial warm-season grass native to the short and mixed grass prairies with its range continuous from Canada to Mexico (Nicholson 1972). It is an important forage species that is palatable to livestock throughout the year and is very grazing tolerant because its growing points are near or at the soil surface (Great Plains Flora Association 1986). Hart et al. (1993) stated blue grama had less damage from severe defoliation than western wheatgrass (*Pascopyrum smithii*), and blue grama composition increases as stocking rate increases. Blue grama is highly selected by cattle, often second only to western wheatgrass (Samuel and Howard 1982; Kirby and Parman 1986).

Organic plant litter is important because it can influence many factors of plant growth and soil properties. Litter effects can be positive or negative to the micro-environment. One way that litter can affect the micro-environment chemically is by the amount and types of substances and nutrients released during decomposition, producing different formations of soil horizons (Prusienkiewiez and Bigos 1978). All the effects that litter has on organisms are due to the effects the litter has on the abiotic environment, whether that effect is a chemical or physical property of litter (Facelli and Pickett 1991). Litter can alter the physical micro-environment by altering the amount of rain and light to reach the top soil (Sydes and Grime 1981). One detrimental effect that litter can have on the micro-environment is prevention of germination in plants that respond positively to light (Grime 1979; Sydes and Grime 1981; Vazquez-Yanes et al. 1990; Vazquesz-Yanes and Orozco-Segovia 1992). Szentes et al. (2012) proposed that litter accumulation is an important mechanism by which yellow bluestem reduces beta-diversity in grasslands where it dominates. Herbivores can increase or decrease the production of litter, where grazing usually reduces the amount of standing dead tissue, by reducing the amount of litter that is produced (Facelli and Pickett 1991).

Quantification of the timing and intensity of yellow bluestem defoliation by cattle compared to native grass is essential to gain understanding of the potential of grazing to become a catalyst for further yellow bluestem invasion. Furthermore, these data will inform future researchers and managers on use patterns of yellow bluestem in invaded rangelands, which, to my knowledge, has not yet been quantified. The objectives of the study were to 1) determine whether both yellow bluestem and blue grama are being utilized by the steers, 2) determine time in the growing season each grass species is being utilized, 3) qualitatively examine the overall intensity of use of yellow bluestem and blue grama, 4) examine if removal of prior year standing residual dry matter influenced selectivity of yellow bluestem or blue grama, and 5) determine the defoliation rates of tillers in both mowed and un-mowed portions of yellow bluestem and blue grama.

Hypotheses

I hypothesized that 1) yellow bluestem and blue grama would be utilized by the steers, 2) yellow bluestem would be used earlier in the grazing season than blue grama, because yellow bluestem matures earlier in the season than blue grama, 3) the steers would utilize total percent of blue grama tillers with a greater intensity (higher rate) than yellow bluestem tillers, 4) the recently mowed areas would have greater defoliation rates of yellow bluestem than the un-mowed areas because standing dead tissue that would discourage steer use would be removed, 5) blue grama tillers would have a greater rate of defoliation than yellow bluestem tillers, and 6) yellow bluestems plots would have more litter accumulation than blue grama plots.

METHODS

Site Description

This experiment was conducted at the Kansas State University Agricultural Research Center, Hays, Kansas (38º 51'41" N, 99º 20'49" W) (Figure 1). The site has an average annual precipitation of 584 mm with an elevation of approximately 600 m. The study site occurred on a limy upland ecological site with Harney silt loam soil (fine, monotmorillonitic, mesic Typic Argiustoll), one of a series of deep, well drained, moderately sloping soils on flat ridgetops and sideslopes formed from loess (NRCS 2013).

The study site had formerly been dominated by native vegetation comprised of blue grama and buffalograss (*Buchloë dactyloides*), as described by Launchbaugh (1957). Pastures were stocked with 270 kg steers from May 1 to October 1 each year at a stocking rate of 1.5 hectares per steer. Precipitation was 365.5 mm in 2012 and 546.9 mm, in 2013 (Figure 2a and 2b).

Experimental Design

Three pastures with yellow bluestem invasion were selected. Yellow bluestem plots were measured by length and width and marked for the duration of this study with 91.5 cm fiberglass poles. A plot of native blue grama of the same size was marked 3 m from the yellow bluestem plot (Figure 3).

In April 2012, before steers were allowed to graze, permanent sample points were set with transects by using a grid system with 150 points in each of the three yellow bluestem plots and in the corresponding native blue grama grass plots. Size of the grid squares varied depending on the overall size of the plot, but were approximately 1 m^2 in the smallest yellow bluestem plot and 2.5 m^2 in the largest plot.

Half of each plot was mowed with a push mower to a height of 10 cm and bagged to remove biomass clipped by the mower (Figure 4). Seventy-five points were present in both mowed and un-mowed portions of each plot. Mowing took place prior to the first sampling period in both years. The purpose of mowing was to simulate recent defoliation and to remove the standing dead tissue that could discourage steer use.

Vegetation Data

Vegetation was sampled with the point-intercept method (Goodall 1952; Bonham 1989) at the 150 points described above. The point-intercept method is an index of the number of contacts between plants and a pin passed through the vegetation to the ground (Jonasson 1988). The following data were collected at each point along the transects: 1) visually estimated defoliation (percent removal) of the nearest blue grama or yellow bluestem by steers (hereafter referred to as estimated intensity), 2) basal cover by species, bare ground, litter, and 3) canopy cover by species and species composition calculated from these basal cover data. One sampling period took place in both April 2012 and May 2013 to establish baseline measurements before the steers were moved onto the pastures, and then further measurements were taken monthly May through October of 2012 and 2013.

Within the grid system, individual tillers of yellow bluestem or blue grama were marked with colored wire (Burboa-Cabrera et al. 2003). Ten tillers were marked in each of the mowed and the un-mowed sections of each of the plots for a total of twenty tillers per plot to quantify the rate of defoliation throughout the grazing season (Figure 5). During sampling periods, individual tillers and blades that were marked with the copper wires were measured using calipers (Absolute Digimatic Calipers; Mitutoyo Corporation, Kawasaki, Japan) to determine their lengths. Two exclusion cages were placed in each pasture, one for blue grama and one for yellow bluestem, for a total of six cages, to keep steers from grazing the vegetation (Albertson et al. 1957; Burboa-Cabrera et al. 2003). The exclusion cages were not placed in the plots to avoid influencing steer grazing; however, they were placed in the same pastures. Half of each cage was mowed to create a mowed and an un-mowed portion in each cage to emulate the plots. Six tillers were marked in the exclusion cages; three tillers in the mowed section and three tillers in the un-mowed section. Leaf tillers and blades in the exclusion cages were measured at each sampling period to determine the amount of growth. These measurements were compared to the blade lengths of the grazed plots. The rate and timing of defoliation can be determined by calculating percent utilization by steers between each of the sampling periods (hereafter referred to as quantified intensity). Defoliation rate was calculated by:

$$\% \, removal = \left\{ \frac{(H_{fp} - H_{ip}) + (H_{fc} - H_{ic})}{(H_{ip} + H_{fc} - H_{ic})} \right\} x \; 100 \qquad (1)$$

Where H_{fp}= final height of tillers in the plot, H_{ip}= initial height of tillers in the plot, H_{fc}=final height of tillers in the exclusion cage, and H_{ic}=initial height of tillers in the exclusion cage (Burboa-Cabrera et al. 2003).

In 2012, tiller height data were only collected for one month; the grasses were senescent early in the growing season due to drought. All other data were collected throughout the 2012 and 2013 growing seasons, regardless of drought conditions.

Statistical Analysis

All statistical analyses were performed by using the SPSS statistical package (version 12.0.0, SPSS Incorporated, Chicago, IL) and R statistical package (version 2.15.1, The R Foundation for Statistical Computing, Auckland, New Zealand). Normal distribution of data was assessed by using box plots and chi-square goodness of fit test. Parameters not normally distributed or with unequal variances were log, square, or square root transformed.

Treatment effect on quantified intensity and estimated intensity of steer removal of yellow bluestem and blue grama tillers was assessed by repeated measures analysis of variance (ANOVA). Repeated measures ANOVA also was used to determine if mowed and un-mowed treatments differed significantly between yellow bluestem and blue grama. Estimated intensity of mowed and un-mowed treatments over the entire grazing season was compared between blue grama and yellow bluestem by using a paired sample t-test. A paired sample t-test was also used to determine if litter cover differed between blue grama and yellow bluestem, and between the mowed and un-mowed treatments.

RESULTS

2012

Steers removed significantly more yellow bluestem over the 2012 grazing season compared to blue grama (paired sample t-test; Table 1 and Figure 6). Intensity of utilization by steers was not different between mowed tillers and un-mowed tillers of blue grama or yellow bluestem (Table 1 and Figure 6). Steers removed more yellow bluestem mowed tillers at 60% utilization compared to blue grama mowed tillers at 40% utilization ($P<0.001$; Table 1 and Figure 6); the same holds true for the un-mowed tillers with yellow bluestem tillers having greater intensity of use than blue grama un-mowed tillers (Table 1 and Figure 6). In 2012, regardless of treatment, yellow bluestem tillers had greater intensity of utilization compared to blue grama.

Steer removal of tillers differed over time (Repeated measures ANOVA; Table 2; Figure 7). Steers did not graze un-mowed and mowed tillers differently throughout the grazing season, and no time by treatment interaction was indicated ($P=0.675$; Table 2 and Figure 7). There was a time by species interaction ($P<0.001$; Table 2 and Figure 7); with yellow bluestem and blue grama being utilized at different rates over time, both species utilization increased over the grazing season, yellow bluestem was utilized used at a greater intensity than blue grama. Mean utilization of yellow bluestem was 57.5% and blue grama was 37.5%. Steer utilization was not influenced by mowing. Quantified intensity of grazing was not calculated from the twenty marked tillers in each plot due to early senescence of the tillers in 2012.

Cover by litter was significantly greater in blue grama plots than in yellow bluestem plots (paired t-test; P<0.001; Table 3). Cover by litter was significantly greater in mowed portions than in un-mowed portions across species (Table 3).

2013

Visually, blue grama tillers were utilized at higher rate compared to yellow bluestem tillers (paired sample t-test; Table 4 and Figure 8) over the 2013 grazing season. There was a higher rate of removal in the un-mowed treatment of blue grama compared to the mowed treatment (Table 4 and Figure 9). No difference was detected in the estimated intensity of steer removal of yellow bluestem tillers between un-mowed and mowed treatments (Table 4 and Figure 9). Steers removed un-mowed blue grama (mean utilization rate of 20%) which was greater in intensity than un-mowed yellow bluestem tillers (mean utilization rate of 16%) (P<0.001; Table 4 and Figure 9). The removal of blue grama and yellow bluestem mowed tillers were not different (P=0.759; Table 4 and Figure 9).

Estimated intensity of vegetation removal by steers indicated that time was a significant factor (Repeated measures ANOVA; Table 5; Figure 10); level of removal of tillers was different over the grazing season. No time by treatment interaction was found (P=0.889; Table 5 and Figure 10), signifying that mowing had no impact on the percent removal of tillers; the steers did not remove tillers of the mowed and un-mowed treatments differently. A time by species interaction was found (P<0.001; Table 5 and Figure 10) with blue grama and yellow bluestem being utilized differently over the grazing season. Blue grama was utilized at a greater intensity than yellow bluestem with mean utilization of blue grama at 18% and yellow bluestem at 15%. No time by treatment by species interaction was shown in this study (Table 5).

Quantified intensity of steer removal on tillers indicated that removal of vegetation differed over time (Repeated measures ANOVA; Table 6). A time by treatment interaction was not indicated (P=0.938; Table 6; Figure 11) with mowing having no effect on the level of tiller removal, the mowed and un-mowed tillers were not utilized differently. A time by species interaction was shown (P=0.005; Table 6; Figure 11); the two species were utilized at different intensities over the grazing season. Overall blue grama was utilization at a greater intensity than yellow bluestem with mean utilization of blue grama being 20% and yellow bluestem at 17%. These data agreed with the estimated intensity of vegetation removal (Tables 5 and 6).

Cover by litter was significantly greater in the blue grama plots compared to the yellow bluestem plots (paired sample t-test; P<0.001; Table 3). No difference was detected in the cover by litter between mowed and un-mowed treatments across species (P=0.732; Table 3). When 2012 and 2013 were compared there was no difference indicated between blue grama plots (Table 3), but a difference was found in yellow bluestem plots in 2012 when compared to yellow bluestem plots in 2013 (Table 3). Mowed and un-mowed portions in 2012 had significantly more litter than 2013 mowed and un-mowed portions (Table 3).

Discussion

It is important to understand ungulate utilization patterns of invading species to improve conservation and management practices. This study aimed to quantify timing and intensity of yellow bluestem defoliation by steers compared to native blue grama. This was achieved by mowing portions of yellow bluestem and blue grama plots to remove coarse standing dead tissue that can inhibit ungulate utilization (Shoop et al. 1976; White and Trudell 1980; Willms et al. 1981; Ruyle et al. 1987). Utilization and timing of use of yellow bluestem and blue grama were compared. Mowing treatments did not influence steer utilization on yellow bluestem.

Drought

Drought is the most prominent stress on rangelands, not grazing; as originally thought (Westoby 1980; Olson et al. 1985; Clarkson and Lee 1988; Milchunas et al. 1989; O'Connor 1991; Biondini and Manske 1996; Biondini et al. 1998). Drought can impose many stresses upon rangelands, including reduced vegetation cover and increased soil erosion, which in turn decreases the amount of soil water available for plants (Le Houérou 1996). Fuhlendorf et al. (2001) showed drought creates a decrease in plant density. Lagging responses can occur after drought at about two year intervals for tiller recruitment and turnover (Butler and Briske 1988; Briske and Hendrickson 1998). Prolonged drought reduces the basal cover of rangeland plants, reducing tiller and biomass production (Gibbens and Beck 1988; Busso et al. 1989; Busso and Richards 1995), leaving less new plant biomass for cattle to graze. Drought also can alter ecosystem composition and productivity in grasslands (Clark et al. 2002). During the course of my study, the pastures showed impacts of drought; however, there was a high degree of variation in temperature and precipitation between years.

Steer Utilization

In general, few trends were prevalent in this study because the two field seasons were so different from one another. The timing and amount of precipitation between years differed (Figure 2), and resulted in differences in vegetative responses, timing of senescence, and phenological status. The vegetation was stressed and senesced early in the 2012 season, which was hot with very little precipitation. Yellow bluestem and blue grama are adapted to drought, but by June green vegetation had disappeared, and all of the marked tillers were senescent. A rain event in late August caused some grass growth in September. Yellow bluestem appeared to respond to the precipitation event with more vigor than the surrounding native grasses. This provided what appeared to be the majority of green vegetation available for steer use at this time; therefore, defoliation rates of yellow bluestem increased rapidly during September (Figures 7b and 12). In 2013, more rain fell throughout the growing season compared to 2012, and vegetation responded with higher vegetation cover and more biomass production. There was no early senescence of marked grass tillers in 2013.

Both yellow bluestem and blue grama were grazed by the steers, supporting my hypothesis that both species would be utilized by steers. In the first month of data collection in both years, it appeared yellow bluestem had a greater level of utilization compared to blue grama (Figures 7d and 10d), however, the difference was very slight. This is not enough to support my hypothesis that yellow bluestem would be grazed by steers at a greater intensity than blue grama early in the grazing season. I originally developed the hypothesis based on yellow bluestem maturing one month earlier than native grasses and suggestions that grazing yellow bluestem earlier in the summer will yield the highest steer gains (Coyne and Bradford 1985b). Yellow bluestem is capable of supporting excellent livestock gains early in the summer grazing season with the gains decreasing in late summer (Coleman and Forbes 1998).

A difference was found in the intensity of utilization of yellow bluestem and blue grama (Tables 1, 2, 4, and 5; Figures 6, 7d, 8, 9, and 10d); however, which species had higher utilization depended on the year. Yellow bluestem had greater utilization in 2012 (Figure 6) and blue grama had greater utilization in 2013 (Figure 8). My hypothesis that blue grama tillers would have greater utilization than yellow bluestem tillers was neither supported nor rejected, with the two years varied results

In September 2012 yellow bluestem utilization increased after a substantial rainfall in late August (Figures 2, 7d, and 12). Basham (2013) showed yellow bluestem was more sensitive than native grasses to declining water availability in the soil (decreased photosynthetic and transpiration rates), but once a soil moisture pulse occurred, yellow bluestem could readily use the moisture, as could the natives. Ruckman et al. (2012) noted that even after persistent drought, yellow bluestem developed from senescent to flowering in less than four weeks after a very small rainfall event, showing that yellow bluestem is efficient at using resource pulses. Basham (2013) showed that yellow bluestem and native species all decreased in leaf investments in response to decreased water availability, but yellow bluestem decreases were significantly smaller than native species. This could help explain why yellow bluestem recovered sooner than blue grama, and was subsequently heavily utilized by steers late in the season in 2012 (Figure 12). Discrepancies in utilization across the two study years also could be explained by yellow bluestem exhibiting greater biomass production than natives during drought (Baruch et al. 1985; Baruch and Goldstein 1999; Nagel and Griffin 2001; Basham 2013).

In this study, there was no difference in the intensity of vegetation removal of yellow bluestem between mowed and un-mowed tillers. (Tables 1 and 4; Figures 6, 7, 9, 10, and 11). These data did not support my hypothesis that the mowed portions of yellow bluestem would have greater steer utilization compared to un-mowed portions. Mowing did not influence steer utilization; neither discouraging nor encouraging steers to utilize yellow bluestem. In 2012, no significant difference was detected in utilization between mowed and un-mowed tillers of blue grama (Table 1; Figures 6 and 7), which did not support my hypothesis that the mowed portions of blue grama would have significantly greater steer utilization than the un-mowed portions. In 2013, utilization of mowed and un-mowed portions of blue grama was different, with greater utilization in the un-mowed portions (Table 4; Figures 9, 10, and 11), which was opposite of my hypothesis. This result disagrees with Ruyle et al. (1987), who showed cattle grazing to be reduced in plants that had greater amounts of residual stems or standing dead tissue. Many studies have indicated increased utilization of plant material when removal of standing dead tissue has occurred (Shoop et al. 1976; Willms and McLean 1978; Willms et al. 1980;

Pfeiffer and Hartnett 1995). An explanation for my contrary result is not possible with the available data.

Comparison of Methods

I used two methods to determine utilization rate of tillers by steers: estimated intensity and quantified intensity. Estimated intensity is a visually estimated measure of steer use that allows for rapid measurements and more sampling units, and therefore, can be done at a larger scale. Quantified intensity was a measurement of leaf lengths to the nearest mm, making the measurements more precise than estimated intensity; however, marking the individual tillers takes more time and fewer sampling points can be measured in a timely manner in large scale projects. It is often better to quantify observable traits in question rather than to qualify traits, but it might not be practical or economical. Quantified intensity might be most useful for small scale experiments, such as greenhouse experiments. If I were to repeat this study, I would use the visually estimated method at more sample points in the plots because it did not require the purchase of special equipment to complete, and it was a faster method of obtaining data. The visually estimated method allowed me to record other data for each point, as well, including cover by litter.

Litter

Basham (2013) showed cumulative litter did not differ between yellow bluestem areas and native areas. This differed from my study in that percent litter cover was significantly greater in the blue grama plots compared to yellow bluestem plots for both years. My results in 2012 showed a significant difference between the mowed and un-mowed portions across species, with more litter in the un-mowed portions, which agrees with other studies that have shown reducing the amount of standing dead tissue reduces the amount of litter present at the sites (Facelli and Pickett 1991). No difference was found across species in mowed and un-mowed portions in 2013, which contradicts my results for 2012 as well as other studies. Consideration of the role that litter can play in species composition of a pasture could help to further conservation and management efforts for the suppression and control of invasive plant species.

Summary

The goal of this study was to quantify timing and intensity of yellow bluestem and native blue grama defoliation by steers. It is important to understand steer utilization patterns of invading species for the purpose of estimating their influence on ecosystem processes. To more fully understand the interactions of steer utilization on mixed stands of yellow bluestem and blue grama, another field study should be performed over a longer period to encompass drought and non-drought years. This, in concurrence with studies that are quantifying the rate and spread of yellow bluestem invasion in native grasslands, could be used to assess the potential shifts in steer utilization of native rangelands where yellow bluestem is also present.

The inconsistency between the two field seasons in this study supports the need for long-term data collection. Long-term studies can be used to separate trends from fluctuations (Bakker et al. 1996). Experimentation over a long period could help us to understand the complexity of biological invasions, increasing both the accuracy of invasion predictions and a scientist's ability to combat invasions (Willis and Birks 2006).

Long-term studies quantify the variability through time in ecological systems (Willis and Birks 2006) that can be incorporated into effective management practices. The system that I worked with experienced a high degree of variation in temperature and precipitation between years, but a long-term experiment could distinguish both between year to year variation and an overall trend in the data.

Conservation and management efforts can be challenging in ecosystems that are being invaded by plant species of similar functional groups. The greatest threat to native C_4 grasslands might come from exotic species also belonging to the C_4 functional group (Reed et al. 2005), such as yellow bluestem. Establishment of invasive species with similar competitive strategies as the dominant native grasses might not change the ecosystem at large, but rather change fundamental community traits (Reed et al. 2005). New management techniques are required for native C_4 grasslands to inhibit establishment of invasive species of the same functional group. Burning has been used in the past to promote native C_4 grasses (Smith and Knapp 1999), but this can promote exotics of the same functional group (Reed et al. 2005). In this situation the invasive species are difficult to target for control (Corbin and D'Antonio 2010), creating a challenging problem for conservation efforts. Therefore, knowledge of invasion patterns and the function of invaders in their introduced settings become all the more critical for prevention and management of invasive species.

Future Research

Future studies should include a more in-depth, long term experiment to better quantify intensity of livestock utilization on native grasslands with mixed stands of yellow bluestem in both drought and non-drought years. These studies could better elucidate vegetation responses to livestock utilization. Studies that are determining rate and spread of yellow bluestem in grazing systems could help to better understand the role livestock play as either a catalyst for control mechanism or preventing further invasion of yellow bluestem. Future studies should include physical and chemical properties of litter in soils containing invading grasses compared to soils consisting of only native grasses to determine the role that litter can play in effecting plant species community, also the role standing dead tissue can have facilitating or inhibiting plant production and ungulate grazing.

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Table 1. Paired sample t-test on estimated intensity of steer removal on tillers in blue grama and yellow bluestem plots in the mowed and un-mowed treatments of 2012.

Effect	t-value	Error df	p-value.
Blue grama * Yellow bluestem	-38.843	3599	<0.001
Blue grama mowed * Blue grama un-mowed	-2.833	1799	0.115
Yellow bluestem mowed * Yellow bluestem un-mowed	-0.334	1799	0.739
Blue grama mowed * Yellow bluestem mowed	-28.131	1799	<0.001
Blue grama un-mowed * Yellow bluestem un-mowed	-26.816	1799	<0.001

T**able 2.** Repeated measures analysis of variance (ANOVA) of estimated intensity of steer removal of yellow bluestem and blue grama tillers in mowed and un-mowed treatments of 2012.

Effect	F-value	Hypothesis df	Error df	p-value.
Time	162.567	4	1792	<0.001
Time * Treatment[a]	0.702	4	1792	0.675
Time * Species[b]	140.935	4	1792	<0.001
Time * Treatment * Species	0.601	4	1792	0.736

[a]Treatment is the mowed or un-mowed treatments

[b]Species is yellow bluestem and blue grama

Table 3. Paired sample t-test of litter occurrences in blue grama and yellow bluestem plots and mowed and un-mowed treatments.

Effect	t-value	Error df	p-value.
Blue grama * Yellow bluestem 2012	7.144	2726	<0.001
Mowed * Un-mowed 2012	-4.163	2726	<0.001
Blue grama * Yellow bluestem 2013	5.706	449	<0.001
Mowed * Un-mowed 2013	0.343	449	0.732
Blue grama 2012 * Blue grama 2013	-0.447	449	0.655
Yellow bluestem 2012 * Yellow bluestem 2013	4.994	449	<0.001
Mowed 2012 * Mowed 2013	4.325	449	<0.001
Un-mowed 2012 * Un-mowed 2013	4.570	449	<0.001

Table 4. Paired sample t-test on estimated intensity of steer removal on tillers in blue grama and yellow bluestem plots in the mowed and un-mowed treatments of 2013.

Effect	t-value	Error df	p-value
Blue grama * Yellow bluestem	7.079	3599	<0.001
Blue grama mowed * Blue grama un-mowed	-3.868	1799	<0.001
Yellow bluestem mowed * Yellow bluestem un-mowed	-0.198	1799	0.843
Blue grama mowed * Yellow bluestem mowed	-0.745	1799	0.759
Blue grama un-mowed * Yellow bluestem un-mowed	3.276	1799	<0.001

Table 5. Repeated measures analysis of variance (ANOVA) of estimated intensity of steer removal of yellow bluestem and blue grama tillers in mowed and un-mowed treatments of 2013.

Effect	F-value	Hypothesis df	Error df	p-value
Time	197.584	3	1792	<0.001
Time * Treatment[a]	0.210	3	1792	0.889
Time * Species[b]	26.536	3	1792	<0.001
Time * Treatment * Species	0.573	3	1792	0.633

[a]Treatment is the mowed or un-mowed treatments

[b]Species is yellow bluestem and blue grama

Table 6. Repeated measures analysis of variance (ANOVA) of quantified intensity of steer removal of yellow bluestem and blue grama tillers in mowed and un-mowed treatments of 2013.

Effect	F-value	Hypothesis df	Error df	p-value
Time	98.048	3	234	<0.001
Time * Treatment[a]	1.371	3	234	0.938
Time * Species[b]	4.614	3	234	0.005
Time * Treatment * Species	0.042	3	234	0.323

[a]Treatment is the mowed or un-mowed treatments

[b]Species is yellow bluestem and blue grama

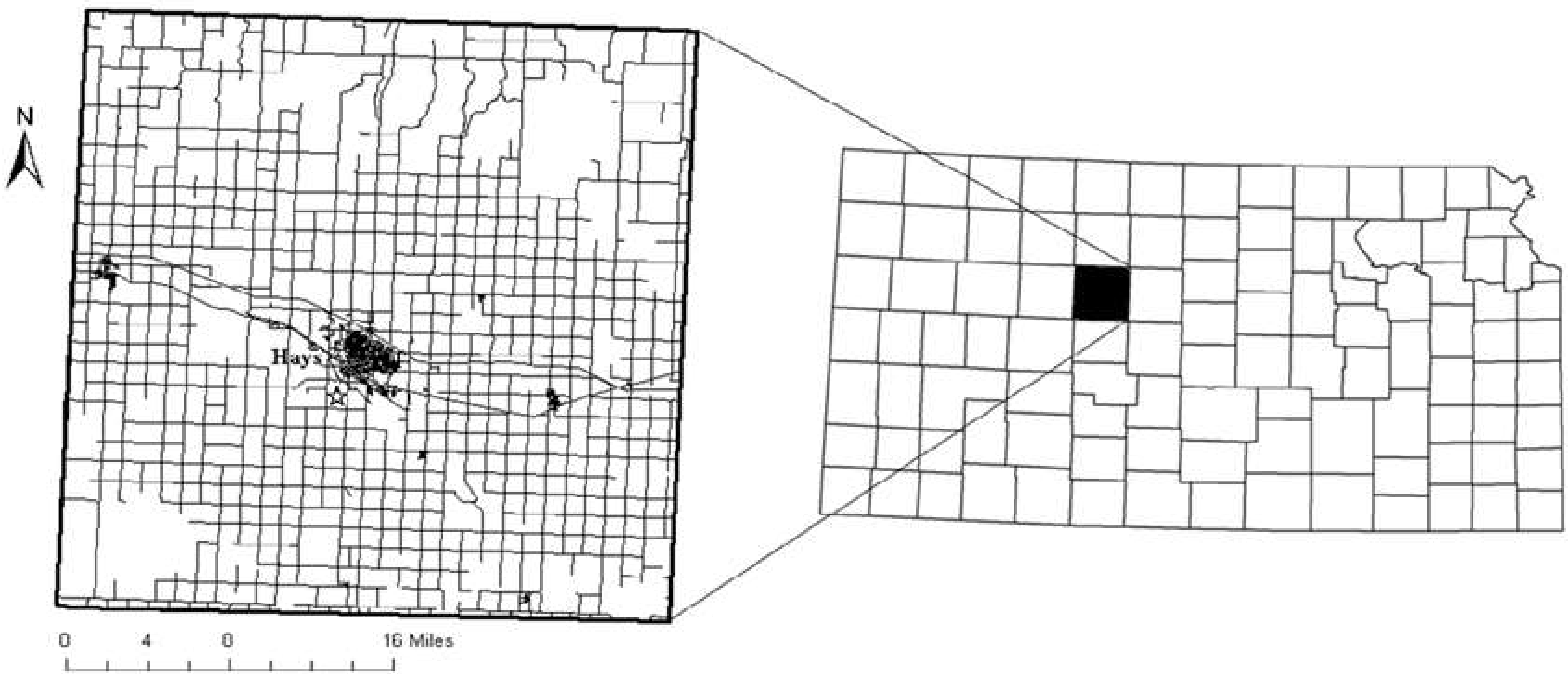
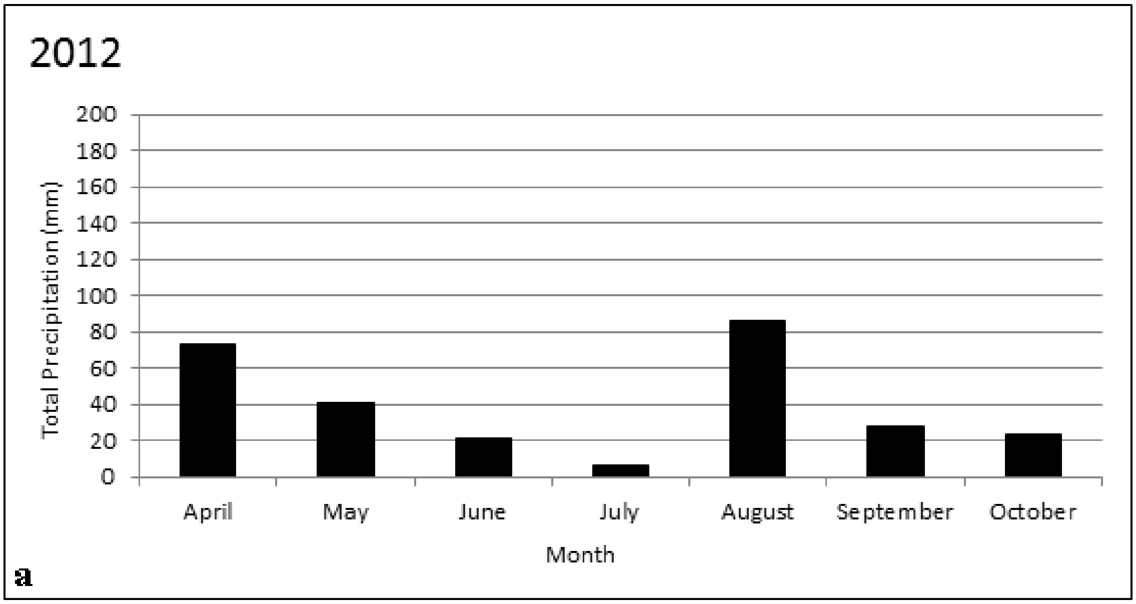


Figure 1. Location of yellow bluestem and blue grama plots in a southern mixed grass prairie of Ellis County, Kansas as depicted by the star.



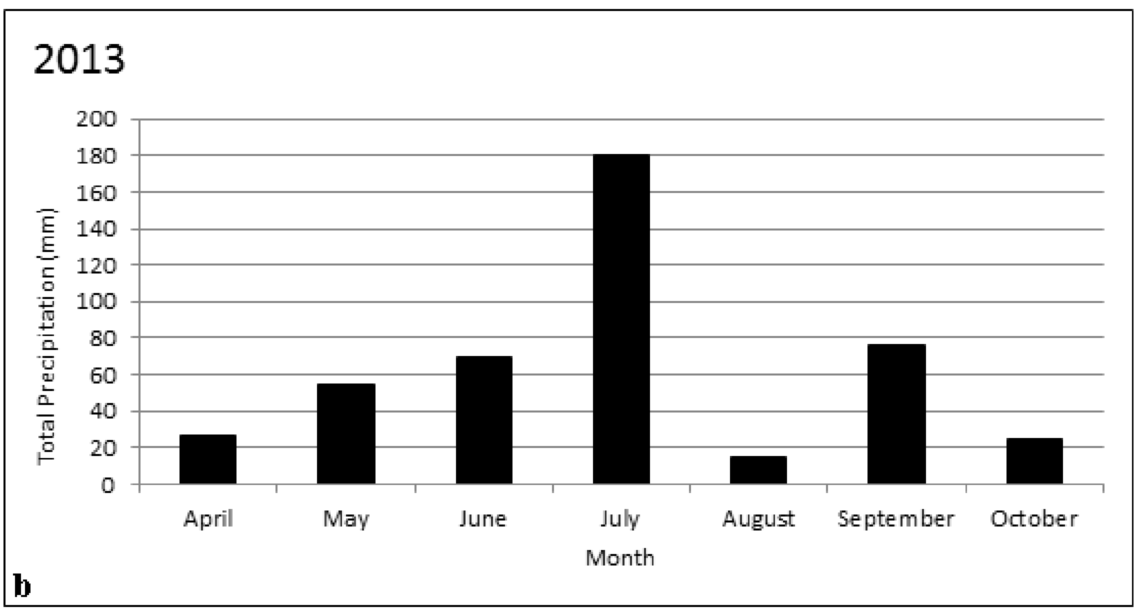


Figure 2. Total precipitation in mm for the growing season months during (a) 2012 and (b) 2013 at Kansas State University Agricultural Research Center in Hays, Kansas.

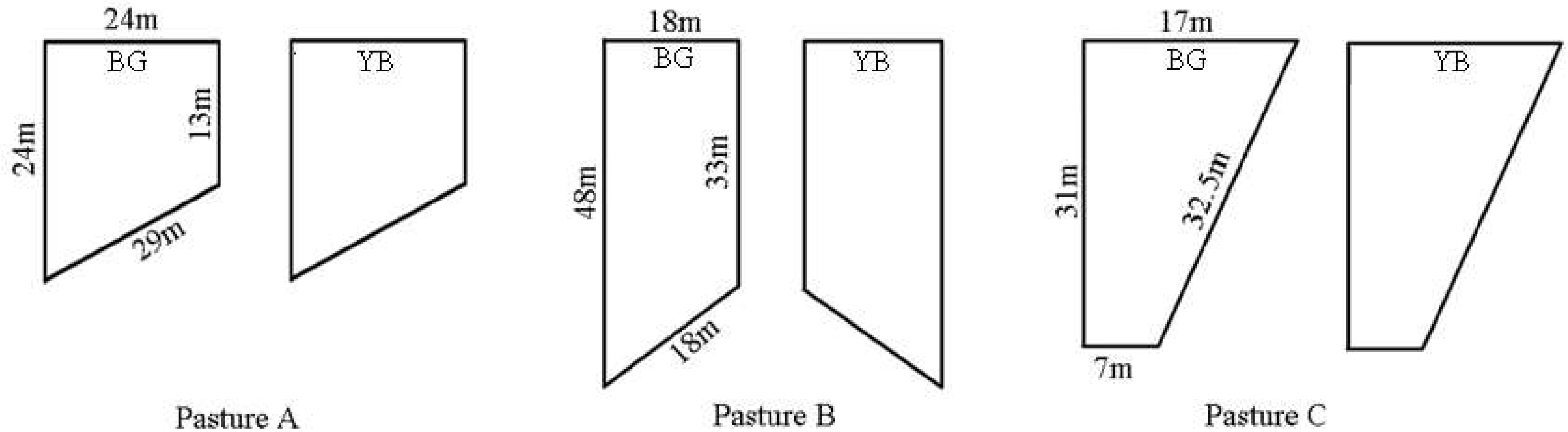


Figure 3. Plot layout for Pastures A, B, and C with blue grama (BG) plots and yellow bluestem (YB) plots. Plots were used to assess steer utilization on yellow bluestem and blue grama in 2012 and 2013. This demonstrates how the plots were the same size and shape for each pasture.

Figure 4. Mowed and un-mowed treatments are depicted in this blue grama plot with the recently mowed portion on the left and the un-mowed portion on the right in a pasture of the southern mixed-grass prairie.

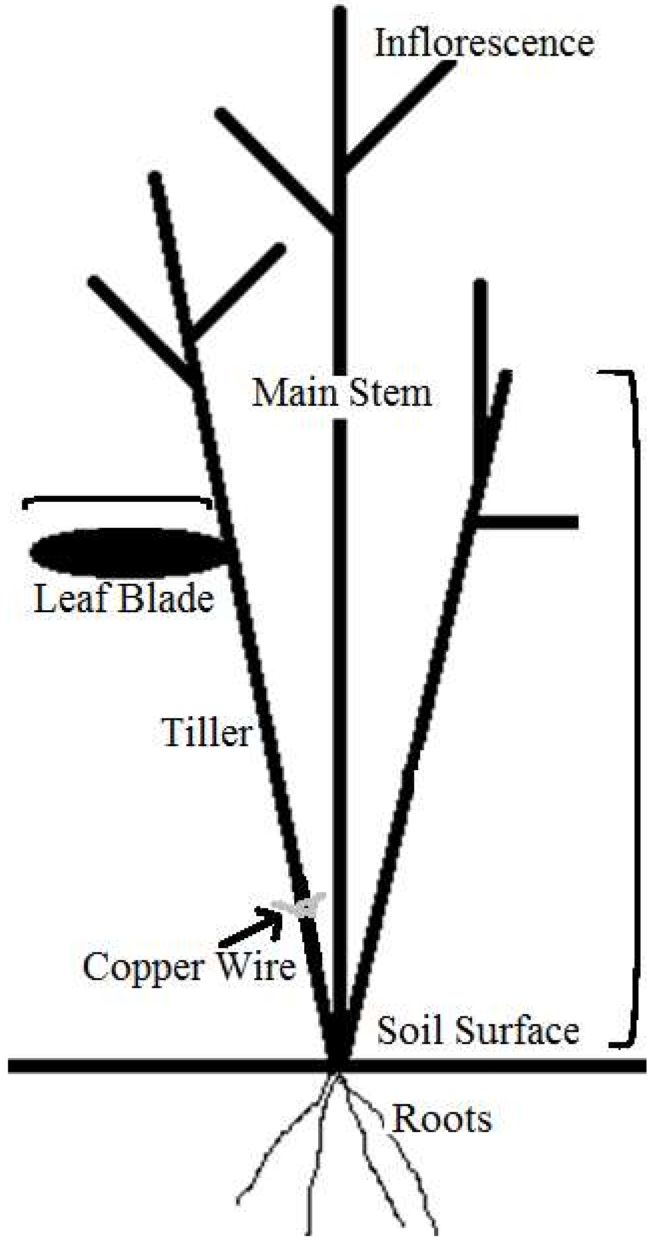


Figure 5. Diagram to illustrate placement of copper wire on tillers of yellow bluestem and blue grama as depicted by the arrow. Brackets indicate where calipers were placed to measure the tillers and the leaf blades.

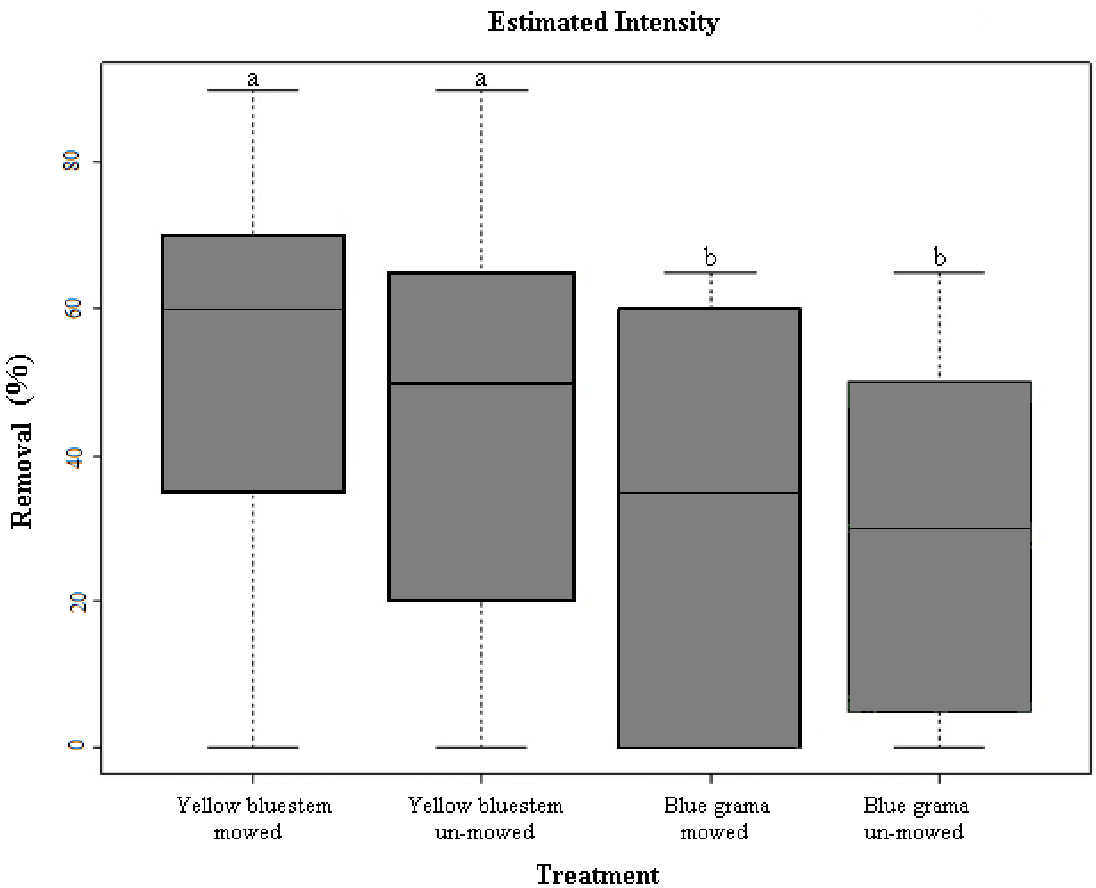


Figure 6. Estimated intensity of steer removal of yellow bluestem and blue grama tillers in 2012 between the un-mowed and mowed treatments in the southern mixed-grass prairie. The lines are the medians and the bars are standard error.

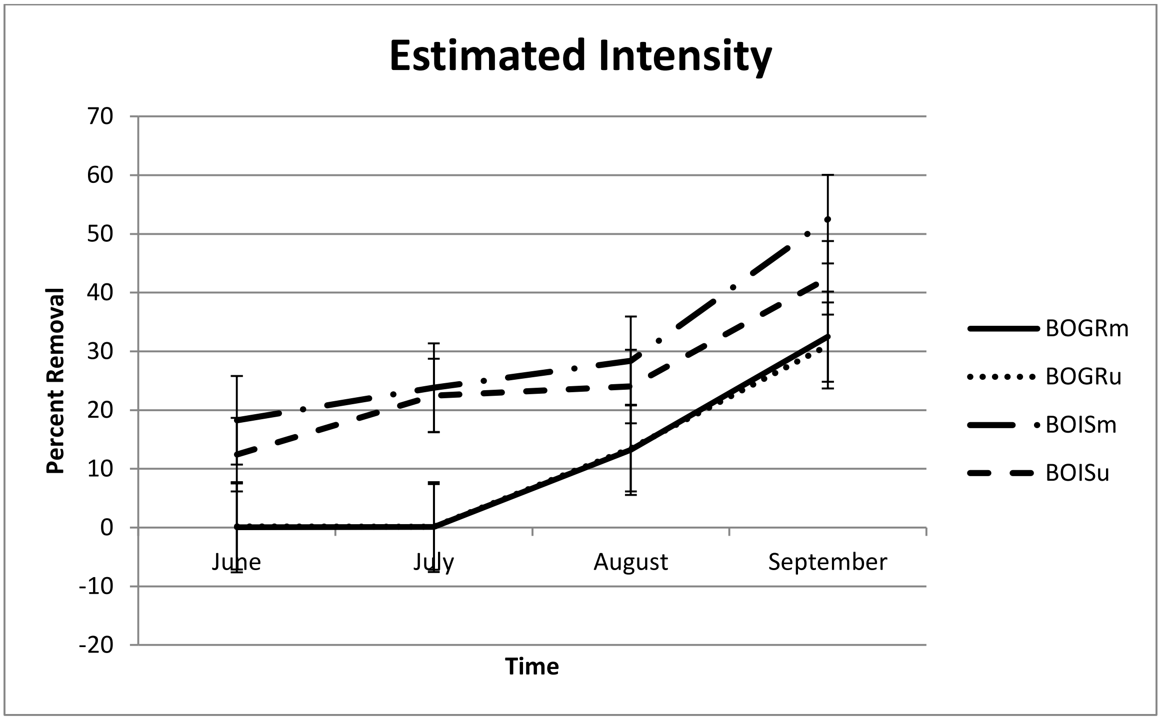


Figure 7. Estimated intensity of steer use of tillers in blue grama mowed treatments (BOGRm), blue grama un-mowed treatments (BOGRu), yellow bluestem mowed treatments (BOISm), and yellow bluestem un-mowed treatments (BOISu) over the grazing season in 2012. Error bars are standard error.

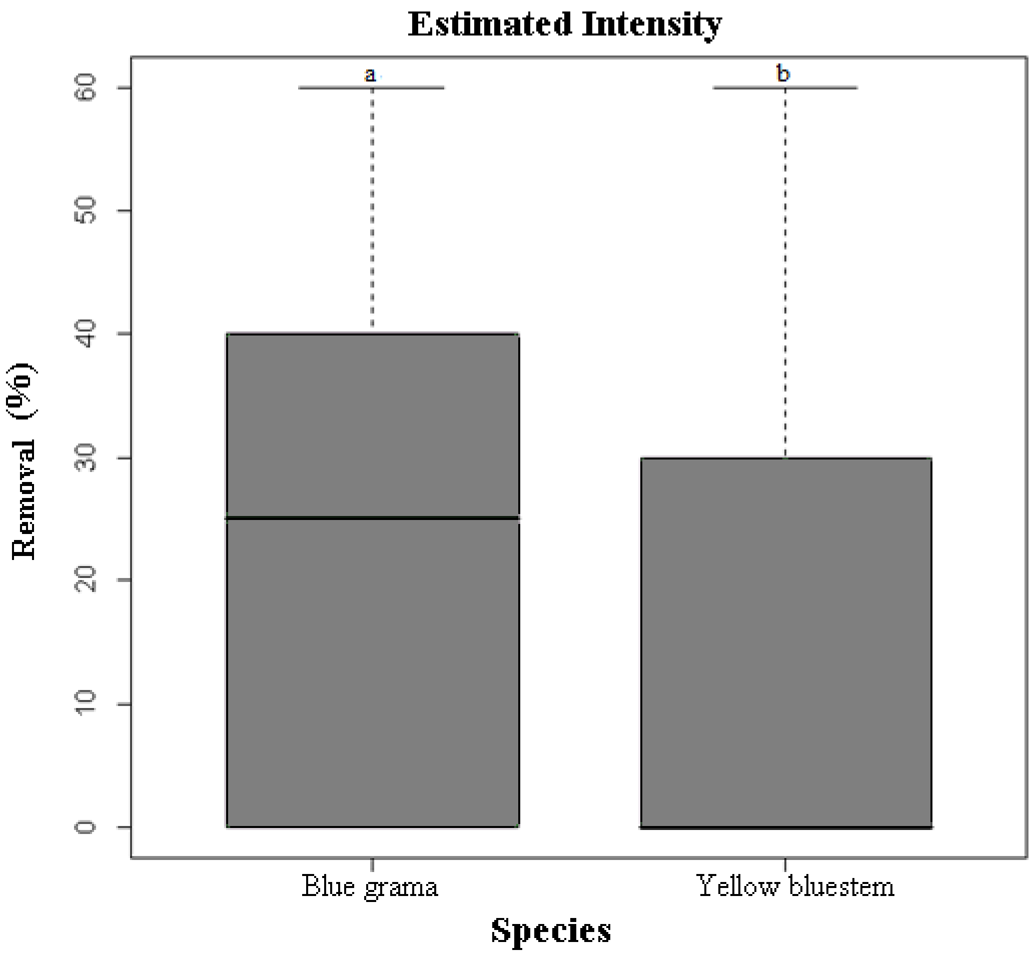


Figure 8. Estimated intensity of steer removal of tillers in 2013 between yellow bluestem and blue grama. The lines are the medians and the bars are standard error.

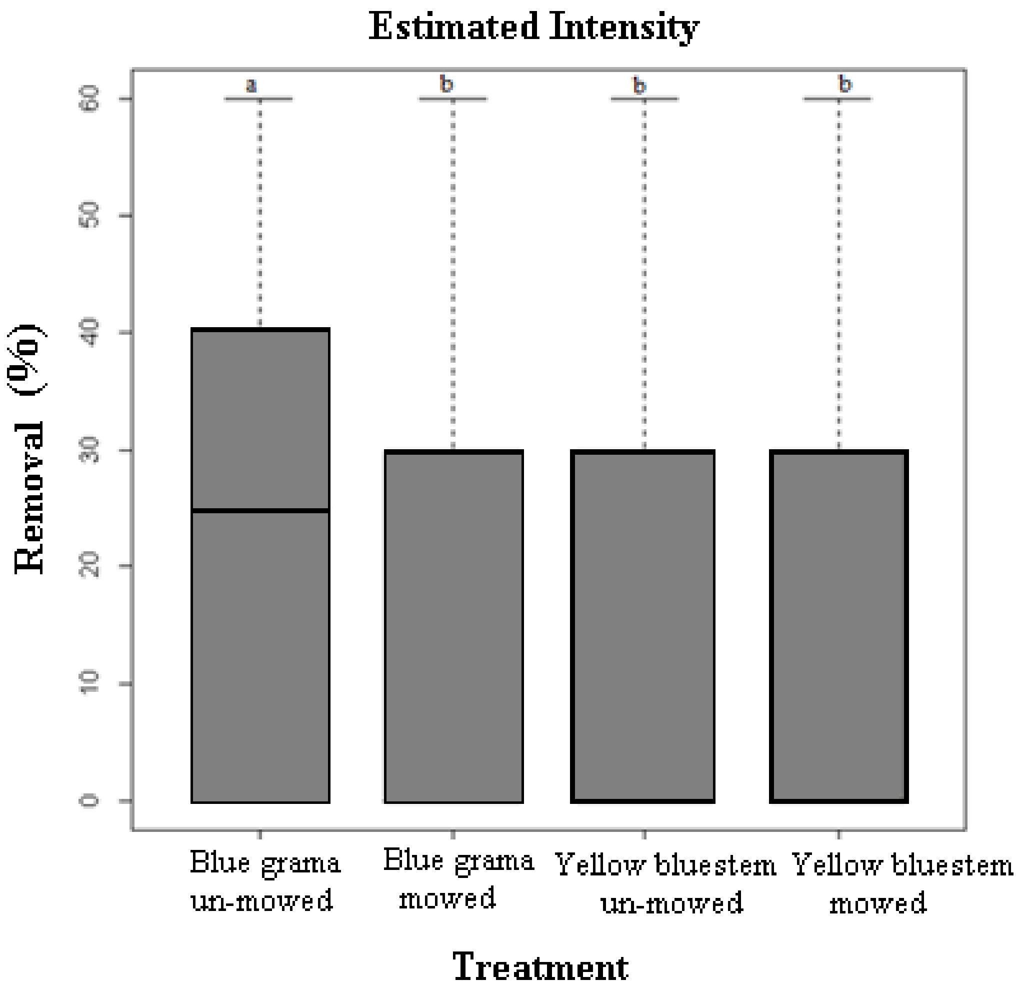


Figure 9. Estimated intensity of steer removal of tillers in 2013 between yellow bluestem and blue grama mowed and un-mowed treatments. The lines are the medians and the bars are standard error.

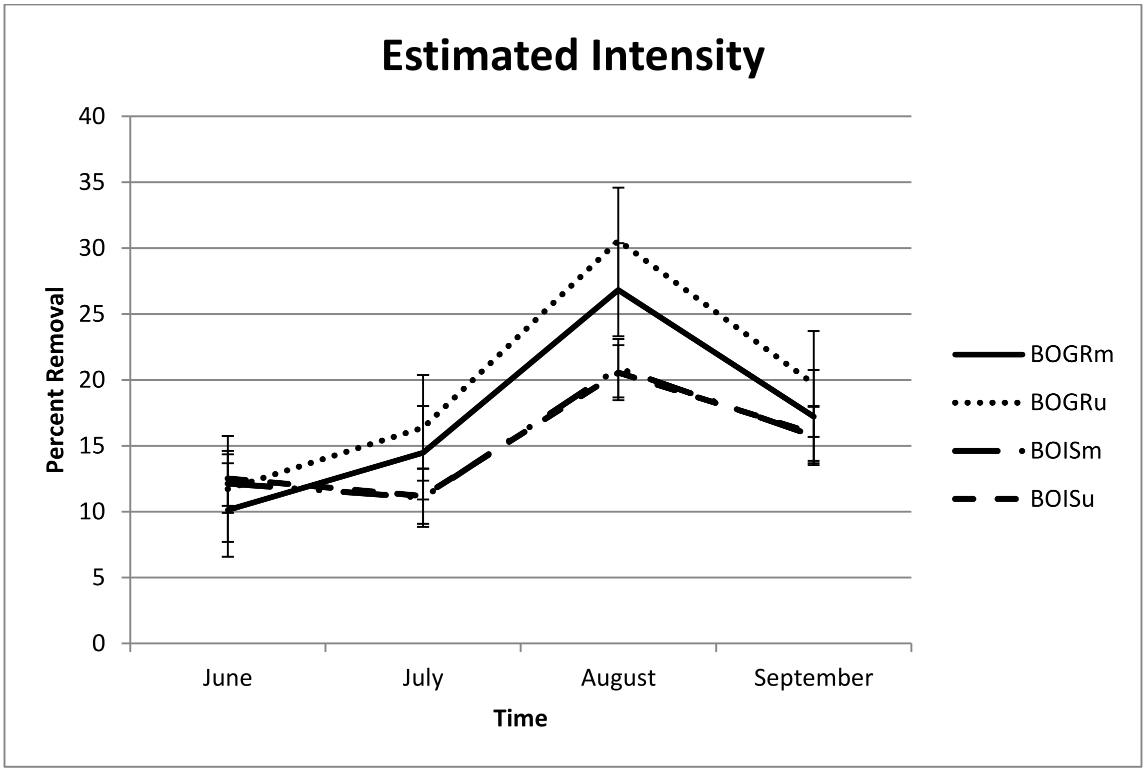


Figure 10. Estimated intensity of steer use of tillers in blue grama mowed treatments (BOGRm), blue grama un-mowed treatments (BOGRu), yellow bluestem mowed treatments (BOISm), and yellow bluestem un-mowed treatments (BOISu) over the grazing season in 2013. Error bars are standard error.

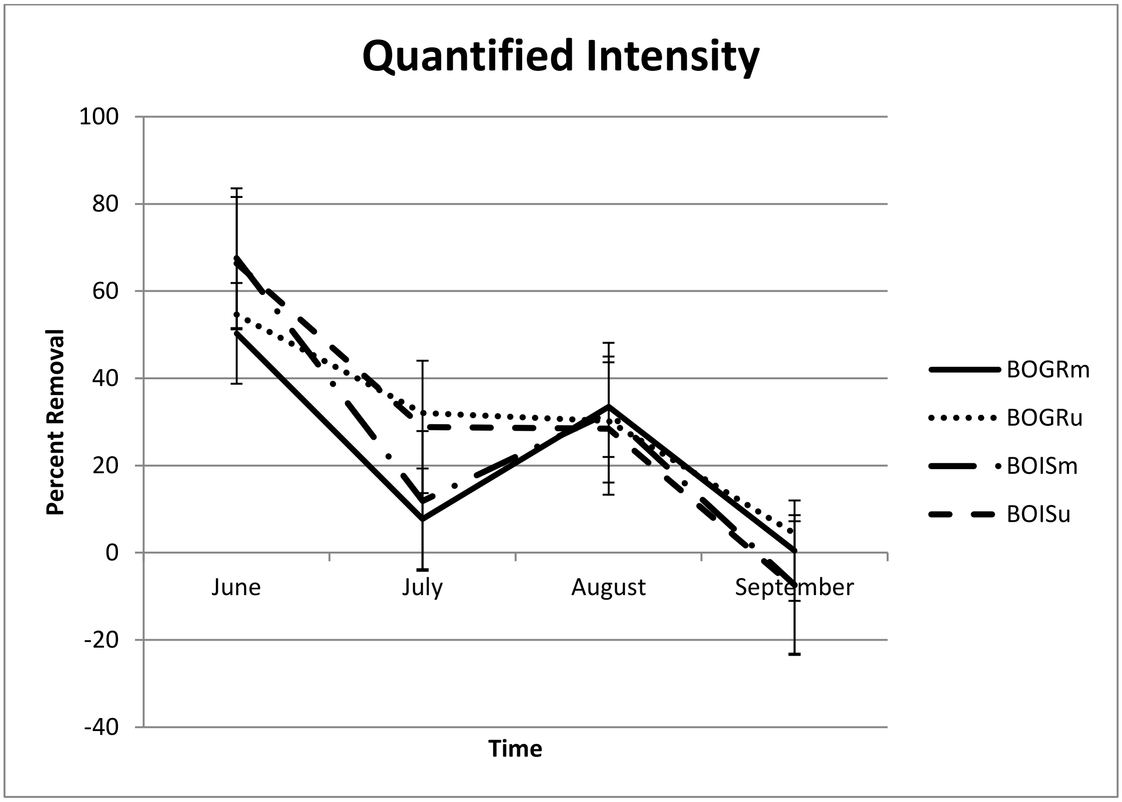


Figure 11. Quantified intensity of steer use of tillers in blue grama mowed treatments (BOGRm), blue grama un-mowed treatments (BOGRu), yellow bluestem mowed treatments (BOISm), and yellow bluestem un-mowed treatments (BOISu) over the grazing season in 2013. Error bars are standard error.

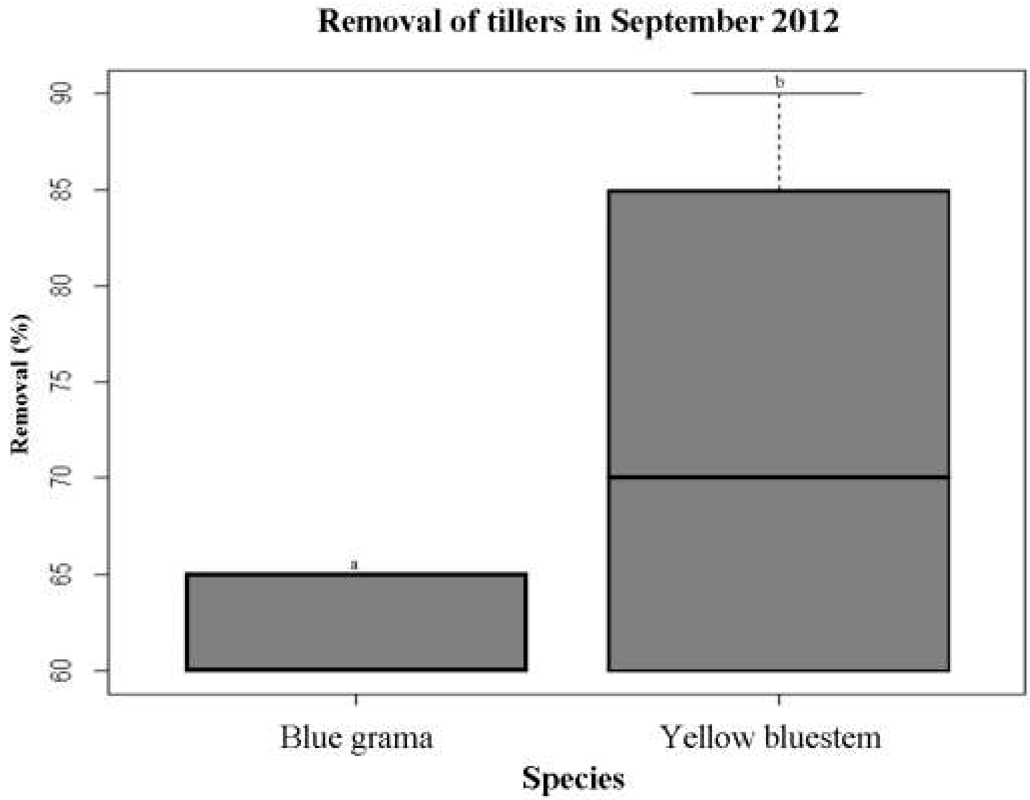


Figure 12. Estimated intensity of steer removal on tillers of blue grama and yellow bluestem in September of 2012. The lines are the medians and the bars are standard error.

APPENDICES

Appendix 1: Inorganic nutrient mobilization and volumetric soil moisture in invaded soils under yellow bluestem and the un-invaded soils under the native grass, blue grama

Introduction

Significant impacts of invasive grasses on soil nutrient cycling and hydrology have been documented by many studies in grassland ecosystems (Bais et al. 2003; Batten et al. 2008; Fink and Wilson 2011; Jordan et al. 2008; Mack et al. 2000; Pritekel et al. 2006). Yellow bluestem *(Bothriochloa ischaemum)* is an exotic grass introduced to the southern Great Plains for grazing of domestic livestock. It is highly competitive and invades ephemeral stream channels, roadsides, ditches, and grasslands to which it was not introduced (Gabbard and Fowler 2007; Matakis et al. 2011). Alterations in soil nutrient mineralization and soil moisture patterns have not been investigated following invasion of native grasslands by yellow bluestem. Due to its popularity as a seed mix component and the potential for further range expansion, data elucidating nutrient mineralization rates and soil moisture following invasion by yellow bluestem are essential. My objective was to quantify inorganic nutrient mobilization (particularly NO_3^-, NO_2^-, NH_4^+, and PO_4^{2-}) and volumetric soil moisture in invaded soils under yellow bluestem and the un-invaded soils under the native grass, blue grama *(Bouteloua gracilis).*

Methods

I measured volumetric water content of the soil by using a Field Scout TDR 300 Soil Moisture Meter with 7.6 cm probes. In 2013, I took five randomly selected measurements in each of two mowing treatments (mowed and un-mowed) sections of yellow bluestem and native plots at the end of each month during the growing season.

I quantified inorganic soil element availability by using in-situ ion-exchange membranes (Plant Root Simulator [PRS]^{TM} probes; Western Ag Innovations Inc, Saskatoon, Canada). Ions (nutrients) in the soil solution are adsorbed at the resin surface throughout the growing season, providing insight into nutrient availability rates over time (Johnson et al. 2005; Skogley and Dobermann 1996). In late April 2013, within each patch (both yellow bluestem and adjacent native) four points were selected randomly for PRS probe installation. At each point, the closest individual of the target grass species (yellow bluestem or blue grama in native) was located. Either directly beneath the canopy (2 replicates) or in the interspace adjacent to each individual (2 replicates), two 3 x 14 cm soil slices were created 23 cm apart. One cation and one anion exchange PRS probe were installed into corresponding slices randomly. Probes were recovered, cleaned and placed in labeled bags for analysis by Western Ag Innovations three more times during the growing season, 36 days apart (May 25, June 30, August 5, September 6, and October 11). The PRS probes assessed nutrient supply rates in the soil by absorbing charged ions; the probes mimic nutrient absorption by plant roots, which allows for a measure of the index of bioavailability. Adsorbed NO_3^- and NH_4^+ concentrations were determined colorimetrically and remaining analytes were determined using inductively-coupled plasma spectrometry by Western Ag Laboratories (Saskatoon, Canada).

Results

Table A. Volumetric soil moisture (%) under blue grama or yellow bluestem plants (n=15) following two mowing treatments during the 2013 growing season. Means followed by SE.

	Native				Yellow Bluestem			
Month	Mowed		Un-mowed		Mowed		Un-mowed	
May	11.2	(0.87)	11.8	(0.73)	12.9	(1.07)	14.6	(1.72)
June	30.9	(2.22)	36.3	(1.93)	26.1	(1.59)	20.1	(1.25)
July	12.0	(1.09)	12.6	(1.50)	13.6	(1.17)	12.9	(0.98)
August	12.4	(1.06)	12.7	(1.18)	15.9	(1.10)	12.5	(1.15)
September	8.9	(0.80)	8.6	(0.71)	10.2	(0.69)	9.7	(0.82)
October	8.3	(0.78)	8.7	(0.79)	9.2	(1.07)	10.5	(1.16)

Table B. Inorganic constituent supply rates (µg PRS probe-1 exchange period-1) under blue grama canopies following two mowing treatments during four 5-week exchange periods throughout the 2013 growing season. Exchange periods are as follows (May 25 -June 30, June 30 – August 5, August 5-September 6, and September 6- October 11). Means followed by SE.

		Exchange Period							
Treatment	Soil Nutrient (µg PRS probe^{-1} exchange period^{-1})	1		2		3		4	
Mowed	Total N	72.8	(27.60)	47.5	(39.64)	42.5	(33.55)	157.1	(76.08)
	NO3-N	64.7	(29.65)	43.7	(37.71)	38.7	(33.32)	125.6	(65.46)
	NH4-N	8.1	(2.81)	3.8	(1.95)	3.8	(0.34)	31.5	(14.42)
	Ca	1731.1	(379.91)	778.1	(727.20)	702.1	(374.80)	1702.8	(247.69)
	Mg	199.4	(22.90)	92.1	(79.98)	93.0	(52.92)	228.4	(38.10)
	K	151.8	(41.97)	66.0	(48.96)	42.1	(17.28)	386.0	(38.85)
	P	5.7	(1.58)	4.5	(3.91)	3.7	(3.04)	18.7	(2.31)
	Fe	3.8	(1.63)	2.1	(1.08)	2.1	(1.52)	4.1	(0.86)
	Mn	2.4	(1.14)	2.8	(2.79)	1.6	(1.44)	7.0	(3.54)

		Exchange Period							
Treatment	Soil Nutrient (µg PRS probe^{-1} exchange period^{-1})	1		2		3		4	
Mowed	Cu	0.3	(0.05)	0.2	(0.08)	0.2	(0.09)	0.4	(0.08)
	Zn	1.4	(0.51)	0.6	(0.31)	0.5	(0.33)	1.2	(0.05)
	B	0.2	(0.06)	0.6	(0.28)	0.6	(0.18)	0.2	(0.05)
	S	35.8	(2.24)	17.1	(13.77)	10.2	(6.07)	72.7	(8.93)
	Pb	1.0	(0.29)	1.4	(1.28)	0.6	(0.41)	1.2	(0.19)
	Al	18.1	(3.45)	14.3	(3.59)	16.3	(5.39)	16.2	(1.94)
	Cd	0.0	(0.01)	0.0	(0.01)	0.0	(0.00)	0.0	(0.03)
Un-mowed	Total N	65.7	(7.24)	81.9	(74.40)	108.1	(82.06)	114.0	(24.59)
	NO3-N	57.1	(6.99)	79.4	(73.67)	101.7	(79.34)	64.1	(27.16)
	NH4-N	8.7	(2.95)	2.5	(0.80)	6.4	(2.73)	50.0	(22.62)
	Ca	1915.4	(205.79)	830.6	(789.71	1157.5	(609.46)	1769.6	(438.78)

		Exchange Period							
Treatment	Soil Nutrient (μg PRS probe-1 exchange period-1)	1		2		3		4	
Un-mowed	Mg	22.7	(23.72)	88.5	(75.58)	129.6	(65.53)	232.0	(60.32)
	K	96.6	(26.18)	35.0	(19.18)	47.6	(19.25)	295.8	(106.96)
	P	5.4	(0.55)	2.9	(2.50)	4.3	(2.46)	20.4	(4.75)
	Fe	3.8	(1.88)	3.5	(3.06)	3.4	(1.76)	3.1	(0.71)
	Mn	2.7	(1.15)	2.3	(2.09)	2.1	(1.26)	3.9	(0.81)
	Cu	0.3	(0.09)	0.3	(0.18)	0.3	(0.15)	0.2	(0.04)
	Zn	0.4	(0.05)	0.5	(0.32)	0.6	(0.29)	0.7	(0.16)
	B	0.3	(0.07)	0.4	(0.23)	0.6	(0.18)	0.3	(0.12)
	S	49.4	(7.47)	15.6	(11.73)	20.7	(10.59)	55.2	(9.28)
	Pb	1.1	(0.33)	1.3	(1.07)	1.0	(0.69)	0.6	(0.37)
	Al	19.0	(1.37)	11.0	(0.71)	17.8	(2.45)	19.6	(2.68)
	Cd	0.0	(0.01)	0.0	(0.02)	0.0	(0.01)	0.2	(0.17)

Table C. Inorganic constituent supply rates (µg PRS probe^{-1} exchange period^{-1}) under yellow bluestem canopies following two mowing treatments during four 5-week exchange periods throughout the 2013 growing season. Exchange periods are as follows (May 25 -June 30, June 30 – August 5, August 5-September 6, and September 6- October 11). Means followed by SE.

		Exchange Period							
Treatment	Soil Nutrient (µg PRS probe^{-1} exchange period^{-1})	1		2		3		4	
Mowed	Total N	67.4	(8.51)	121.6	(59.36)	23.9	(15.61)	95.4	(53.02)
	NO3-N	54.4	(9.51)	117.1	(59.22)	13.9	(8.91)	44.6	(6.11)
	NH4-N	13.0	(1.73)	4.5	(1.14)	10.0	(6.80)	50.8	(47.40)
	Ca	1324.3	(251.66)	1244.3	(678.17)	481.0	(456.66)	2338.8	(281.26)
	Mg	168.4	(33.11)	138.7	(80.02)	91.0	(82.49)	279.0	(42.46)
	K	187.1	(46.19)	110.3	(60.12)	156.9	(141.99)	505.1	(379.63)
	P	9.9	(1.97)	7.3	(3.44)	2.0	(1.38)	13.8	(4.10)

		Exchange Period							
Treatment	Soil Nutrient (µg PRS probe^{-1} exchange period^{-1})	1		2		3		4	
Mowed	Fe	3.1	(0.47)	5.8	(3.33)	1.3	(0.32)	2.2	(0.13)
	Mn	2.9	(0.54)	3.4	(2.46)	1.0	(0.99)	2.9	(1.23)
	Cu	0.3	(0.02)	0.4	(0.15)	0.1	(0.03)	0.2	(0.03)
	Zn	0.9	(0.29)	0.8	(0.33)	0.3	(0.13)	0.5	(0.15)
	B	0.4	(0.08)	0.5	(0.20)	0.8	(0.15)	0.3	(0.06)
	S	35.0	(4.00)	34.1	(14.71)	6.9	(3.73)	55.7	(6.49)
	Pb	1.3	(0.27)	2.9	(1.77)	0.3	(0.16)	0.5	(0.09)
	Al	19.5	(3.39)	24.8	(7.51)	17.7	(3.65)	17.8	(4.55)
	Cd	0.1	(0.06)	0.0	(0.04)	0.0	(0.02)	0.1	(0.13)
Un-mowed	Total N	42.6	(5.72)	40.3	(17.76)	15.7	(8.57)	76.4	(24.56)

Treatment	Soil Nutrient (µg PRS probe^{-1} exchange period^{-1})	Exchange Period							
		1		2		3		4	
Un-mowed	NO3-N	33.5	(6.08)	37.1	(17.39)	11.0	(5.86)	65.2	(27.39)
	NH4-N	9.0	(1.97)	3.2	(0.38)	4.7	(2.76)	11.2	(5.19)
	Ca	1772.9	(73.29)	1095.4	(562.95)	338.7	(325.61)	2841.7	(412.69)
	Mg	224.1	(21.18)	123.4	(62.33)	53.2	(49.49)	306.6	(48.21)
	K	157.1	(26.65)	94.2	(53.17)	63.5	(47.83)	126.2	(13.51)
	P	6.0	(0.73)	8.4	(4.40)	3.0	(2.52)	16.6	(3.89)
	Fe	4.9	(1.70)	3.6	(2.17)	1.0	(0.24)	2.3	(0.42)
	Mn	2.9	(1.20)	5.6	(4.80)	0.5	(0.42)	2.4	(0.19)
	Cu	0.3	(0.04)	0.2	(0.11)	0.1	(0.03)	0.2	(0.07)
	Zn	0.5	(0.13)	1.0	(0.65)	0.3	(0.18)	0.6	(0.09)

		Exchange Period							
Treatment	Soil Nutrient (µg PRS probe^{-1} exchange period^{-1})	1		2		3		4	
Un-mowed	B	0.2	(0.03)	0.5	(0.16)	0.9	(0.23)	0.3	(0.03)
	S	45.3	(4.46)	29.5	(14.29)	15.6	(12.42)	61.6	(10.69)
	Pb	1.3	(0.42)	2.3	(2.06)	0.2	(0.15)	0.5	(0.08)
	Al	21.0	(2.23)	23.9	(5.81)	13.9	(1.45)	15.2	(3.81)
	Cd	0.0	(0.01)	0.0	(0.00)	0.0	(0.01)	0.0	(0.01)

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Appendix 3: Institutional Animal Care and Use Committee

KANSAS STATE UNIVERSITY | University Research Compliance Office

TO: John R. Jaeger
1232 240th Ave
Hays, KS 67601

Protocol Number: 3175

FROM: Sally Olson, Chair
Institutional Animal Care and Use Committee

DATE OF APPROVAL: 07/23/2012
DATE OF EXPIRATION: 07/23/2015

RE: Approval of Animal Care and Use Protocol Entitled, "Beef cattle investigations and improved efficiency of forage-based beef cattle production systems ."

The Institutional Animal Care and Use Committee (IACUC) for Kansas State University has reviewed the protocol identified above and has approved it for three years from the date of this memo. During the period of approval, the protocol will be subject to annual monitoring, which may include the examination of records connected with the project. Announced post-approval monitoring (PAM) will be performed during the course of this approval period by a member of the University Research Compliance Office staff. Changes in the protocol affecting the care or use of animals must be reviewed by the IACUC prior to implementation. Unanticipated problems related to the humane care or use of animals must be reported to the IACUC immediately.

It is important that your animal care and use project is consistent with submissions to funding/contract entities. It is your responsibility to initiate notification procedures to any funding/contract entity of any changes in your project that affects the use of animals.

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