EFFECTS OF PRESCRIBED BURNING ON UNDESIRABLE PLANT SPECIES AND SOIL PHYSICAL PROPERTIES ON TALLGRASS PRAIRIES

by

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Abstract

Prescribed burning has been a common conservation practice on native prairie dating back to the days of pioneer settlement. Advantages include increased forage quality, reduction of undesirable plants, improved wildlife habitat, removal of accumulated dead plant litter and relatively low costs. While spring is the commonly accepted time to burn, little research has been conducted on late-summer and fall burning for specific objectives that include targeting undesirable plant species and measuring potential effects on soil physical properties. The first part of this study was to evaluate the effect that prescribed burning has on population dynamics of sericea lespedeza (*Lespedeza cuneata* [Dumont] G. Don), rough-leaf dogwood (*Cornus drummondii* Meyer), and additional woody species. Stem counts and cover estimates were taken from 20, 0.25-m^2 frames prior to and post-burn. Change in botanical composition, plant density, frequency, and Daubenmire canopy cover estimates were calculated. Sericea lespedeza plant frequency across all clay upland burns decreased 2.27% and increased 4.76% across all loamy/limy upland burns the first growing season post-burn. Dogwood densities increased 3.12 stems m^{-2} on spring burns compared to a decrease of 0.30 stems m^{-2} on unburned plots the first growing season post-burn. Changes in frequency of other woody species the first growing season post-burn showed significant interactions between burn treatment and ecological site, and between ecological site and year. A significant interaction between burn treatment and ecological site was found on total woody species plant composition changes two growing seasons post-burn for the first year of burn treatments. The secondary part of this study was to evaluate the effect of prescribed burning on soil bulk density and wet-aggregate stability. Soil samples were collected along the same line-transects used for vegetation sampling. Significant differences among mean weight diameters (MWD), percent water-stable aggregates (WSA), and WSA size fractions occurred between burned and unburned soils following burning in the fall of 2011. Monitoring plant and soil response to prescribed burning in different seasons may lead to adjustments being made in management of rangelands where sericea lespedeza, dogwood, and additional woody species occur.

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Chapter 1 - Effects of Prescribed Burning on Vegetation

Abstract

Sericea lespedeza (*Lespedeza cuneata* [Dumont] G. Don) is considered to be one of the most troublesome noxious weeds in the eastern half of Kansas. It was originally introduced to Kansas as a conservation plant for soil erosion control and as wildlife forage. However, since introduction, it has become a serious weed in Kansas that inhibits the natural ecosystems of the tallgrass prairie, and results in a decrease of plant species diversity and productivity. Rough-leaf dogwood (*Cornus drummondii* Meyer) is a native shrub that is considered to be one of the most invasive woody species in tallgrass prairie. The reduction of prescribed burning and constant break up of large tracts of rangelands has allowed dogwood and other woody species to encroach upon the tallgrass prairie. Their presence on rangelands also leads to reduced production of desirable forages. The objective of this study was to evaluate the effect that spring and fall prescribed burning has on sericea lespedeza, rough-leaf dogwood and additional woody species density, frequency, and foliar cover. Ecological sites in Major Land Resource Area (MLRA) 76 on Fort Riley, Kansas were assessed in this study and included clay uplands, limy uplands and loamy uplands. Line transects, 100-m long, were established in MLRA 76 ecological sites on training areas where prescribed burning was to take place. A 0.25-m^2 frame was randomly placed at 20 recorded points along each transect to determine stem counts and estimate Daubenmire foliar cover for sericea lespedeza, dogwood and additional woody species. Sampling was done the growing season prior to burning and each growing season post-burn; two successive growing seasons for the first round of burns and the first growing season post-burn for the second year of burning. Statistical significance in changes was noted at the 0.10 level ($\alpha = 0.10$). Sericea lespedeza plant frequency across all clay uplands decreased 2.27% and increased 4.76% across all loamy/limy uplands the first growing season post-burn. Dogwood densities increased 3.12 stems m^{-2} on spring burns compared to a decrease of 0.30 stems m^{-2} on unburned plots the first growing season post-burn. Changes in density of other woody plant the first growing season post-burn decreased 0.61 stems m^{-2} on fall burned plots, in comparison to 0.98 stems m^{-2} increase on spring burned plots. An ecological site difference was found on changes in density of other woody species between the first growing season post-burn and the second growing season

post-burn for plots burned the first year and in successive springs. Frequency changes in other woody species the first growing season post-burn showed significant interactions between burn treatment and ecological site, and between ecological site and year. A significant interaction between burn treatment and ecological site was found on total woody species plant composition changes two growing seasons post-burn for the first year of burn treatments and plots burned in successive springs. Monitoring plant response to prescribed burning for different seasons may lead to adjustments being made in management of rangelands where sericea lespedeza, dogwood and additional woody species occur. However, further monitoring is warranted to assess long-term impacts on selected plant species and botanical composition.

Introduction

Sericea lespedeza (*Lespedeza cuneata* [Dumont] G. Don) is a warm-season, perennial legume native to Asia and eastern Australia. Stems, many-branched, grow erect up to a height of about 1 m. Stems become woody as the growing season progresses and senesce with exposure to freezing temperatures. Regrowth occurs from root crowns or deep tap roots the following spring. The leaves are alternate and trifoliate with leaflets arranged in pinnate fashion. The leaflets are long and narrow ranging up to 2.5 cm long and 0.5 cm wide in a cuneate shape. Flowering occurs from late July to October. Flowers emerge from the leaf axils and petals are white with tinged purple bases (Harrington and Durrell, 1957; McGregor et al., 1986).

Sericea lespedeza was first introduced in Kansas in the 1930's as a conservation plant for soil erosion control and as wildlife forage (Kilgore et al., 1998). However, since introduction it has become a serious weed in Kansas and its presence in tallgrass prairie results in decreased species diversity and productivity. Eddy and Moore (1998) did a study in the Chautauqua Hills of Kansas and found that, within 5 to 7 years of invasion, sericea lespedeza reduced the biomass of native forbs and grasses by 92% and native species richness from 27 to 8 species. Once established, sericea restricts the amount of light reaching other plants because it is tall with multiple branches and dense foliage. It requires more water to produce foliage than other warm season plants, creating a "drought" effect for competing vegetation (Kilgore et al., 1998). It also produces allelopathic chemicals that inhibit seed germination and growth of other plants. Laboratory and greenhouse studies by Kalburtji and Mosjidis (1992, 1993a, 1993b) found that sericea lespedeza residues and root exudates inhibit germination or growth of selected cool and warm-season grasses. In particular, tall fescue (*Festuca arundinacea* Schreb.) was not affected by sericea lespedeza root exudates, but did suffer reduced growth rates (Kalburtji and Mosjidis, 1993a). Sericea lespedeza stem and leaf residues were also found to reduce growth rates of bahiagrass (*Paspalum notatum* Flugge) and bermudagrass [*cynodon dactylon* (L.) Pers.] (Kalburtji and Mosjidis, 1992). While sericea lespedeza is a legume, it actually furnishes very little nitrogen to surrounding plants. Tall fescue and ryegrass (*Lolium multiflorum* Lam.) also suffered reduced growth rates and were found to have significantly lower nitrogen concentrations in their stems due to sericea lespedeza residues (Kalburtji and Mosjidis, 1993b). Research in these controlled environments focuses on individual factors of competition, while the combined negative effects on native plants in uncontrolled environments of native prairies and forests are probably much greater (Cummings et al., 2007).

Sericea lespedeza is found to have high levels of crude protein, but is considered to be a low-quality forage and undesirable due to its high concentrations of tannins (Dudley, 1998). Tannins bind protein, making it unavailable for digestion. As the growing season in Kansas progresses and air temperatures increase and rainfall decreases, sericea lespedeza accumulates higher levels of tannins rendering them less palatable and digestible for livestock. Excessive levels of tannin become quite bitter to livestock and decrease the rumen microbial population therefore lowering digestion rates (Fisher et al., 1995; Cheeke, 1991).

One stem of sericea lespedeza may produce up to 1500 seeds (Rossow, 2009). On a per plant basis, sericea lespedeza seed production was about five times that of the most fecund natives (Woods et al., 2008). Common methods of seed dispersal include animals and hay transport. Some studies state that sericea lespedeza seeds remained viable in the soil for 20 or more years (Czarapata, 2005), but no research was provided to support these assertions.

In 2000, sericea lespedeza was added as a statewide noxious weed in Kansas by the Kansas Department of Agriculture. Suggested methods of control include mowing and haying, grazing, burning, and herbicide treatments. However, numerous reports show that use of any one such application of control is not in itself beneficial (Cummings et al., 2007). Herbicide treatments can become costly and a land manager must be forced to weigh the benefits of herbicide application to overall forage quality. Seedling establishment can occur in densely-vegetated areas where there is substantial plant residue and ground cover, thus limiting the effect of herbicides. Therefore, land managers are forced to turn to management practices that are not costly or time consuming, such as burning.

Numerous studies have been conducted involving the burning of areas with sericea lespedeza and the benefits accompanying the practice. Researchers at The Nature Conservancy's Tallgrass Prairie Preserve in Oklahoma conducted a pilot study between 1996 and 1999 to determine effects of late-summer burns on sericea lespedeza. They found that late growing season burns significantly reduced adult stem count and seedling density compared with unburned plants (Hamilton, 2003). Others contest that fire may be an ineffectual control strategy because adult plants resprout following fire (Ohlenbusch et al., 2007). In one study, a spring burn once every 3 years failed to control sericea lespedeza after 6 years and resulted in large increases in sericea lespedeza cover compared to patch-burned treatments (Cumming et al., 2007). In addition, vulnerability to burns decreased as plants aged, but the effect was found to be weak relative to other factors (Wong, 2011). In addition to effects on immature plants, fire may alter germination rates. Anecdotal information suggests that fire may stimulate sericea germination (Ohlenbusch et al., 2007), therefore reducing overall seedbank. Bell and Koerner (2009) found that sericea lespedeza seed viability drops significantly at 225˚C and seeds were not viable at 250˚C. With prairie fires burning up to 411˚C (Engle et al., 1993), sericea lespedeza seed may be vulnerable to fire. In addition, fire may effectively kill young plants if applied before they have sufficient root reserves to resprout (Wong, 2011).

Rough-leaf dogwood (*Cornus drummondii* Meyer) is a major invading native shrub of the bluestem prairie. It can grow erect up to 6.1 meters, often forming clumps. Young twigs are rough, often reddish brown and as the plant matures the branches becomes a grayish brown. Dogwood roots are shallow and spreading. It has an opposite, simple leaf arrangement and leaves are broadly ovate to lanceolate-shaped, 6.4 to 11.4 cm long and 2.5 to 8.9 cm wide; they are ovate and smooth along their margins (Hilty, 2013). The upper surface of each leaf is green, rough-textured, and sparingly covered with fine appressed hairs with 3 to 5 pairs of lateral veins that curve toward the outer margins of the leaf. The lower surface of each leaf is whitish green and densely short-pubescent. At the base of each leaf, there is a slender petiole up to 2.5 cm long (Hilty, 2013). Cymes of white flowers develop from the axils of the leaves (Hilty, 2013). Each cyme is about 5.1 to 10.2 cm across and either gently rounded or flattened at the top (Hilty, 2013). Each white flower is about 0.6 cm across; it has 4 lanceolate petals, 4 stamens, and a pistil with a single style (Hilty, 2013). The blooming period occurs during the late spring or early summer for about 2 to 3 weeks. The flowers are replaced by white fleshy drupes, which ripen during the late summer or early fall. At that time, the peduncle and pedicels of the corymb become bright scarlet. Each drupe is about 0.6 cm across and globoid in shape and contains a single stone (Hilty, 2013).

Production and availability of desirable forage species may decrease as the cover of dogwood increases (Janicke and Fick, 1998). The root system normally consists of a woody branching taproot. However, if dogwood is subjected to disturbance, it may develop suckers or underground runners that send up vegetative shoots. These vegetative shoots can develop into a dense colony of multi-stemmed shrubs. This encroachment by the shrub results in reduced production and availability of desirable forage for livestock grazing (Janicke and Fick, 1998). Burning, as a method of defoliation and reducing carbohydrate reserves, is a common management practice on grasslands (Launchbaugh and Owensby, 1978). Janicke and Fick (1998) indicated reduced root TNC in burned dogwood compared to unburned plants.

Woody species may increase and reduce livestock carrying capacity when rangeland management practices such as prescribed burning and conservative grazing are absent (Dyksterhuis, 1958; Launchbaugh and Owensby, 1978). Smooth sumac (*Rhus glabra* L.) is a native, deciduous, large shrub to small tree, seldom over 3 to 4.5 meters tall (Stephens, 1969). The presence of fire encourages germination and resprouting (Stephens, 1969). Buckbrush (*Symphoricarpos orbiculatus* Moench) is a native shrub that grows to about 70 cm high (Stephens, 1969). It is commonly found in open pastures and woods and spreads rapidly by sending out runners above ground (Stephens, 1969). Wild plum (*Prunus americana* Marsh) sprouts from roots and forms dense thickets that can be 4 meters high and 10 meters or more across (Stephens, 1969). Wild plum is typically found in pastures, along roadsides, and at the margin of a woods (Stephens, 1969). Prairie rose (*Rosa suffulta* Greene) has a densely prickly main stem and grows between 38.1 to 117.8 cm high (Stephens, 1983). Black raspberry (*Rubus occidentalis* L.) is a deciduous shrub, 2 to 3 meters tall, with prickly shoots (Stephens, 1969). Elms (*Ulmus* spp.) are rapidly growing deciduous trees that commonly appear in native grasslands and can reach heights of 20 meters (Stephens, 1969). Honey locust (*Gleditsia triacanthos* L.) grows to a height of 15 meters and may be found in rich soil along streams or rocky hillsides (Stephens, 1969). It commonly has a thorny trunk and rapidly spreads (Stephens, 1969). Red mulberry (*Morus rubra* L.) trees occur along streams and rocky hillsides and grow usually to around 8 meters high, but have been found to reach heights of 20 meters (Stephens, 1969). Poison ivy [*Rhus radicans* (L.), var. *vulgaris* (Michx.) DC.] may be a simple shrub reaching 30 cm high with no branches, a thicket of shrubs 1 meter high with many branches, or may climb trees up to 20 meters high (Stephens, 1969). All woody species previously mentioned were grouped together for analysis discussed further in the chapter.

Since there is an increasing interest in the use of prescribed burning in the fall for various vegetation objectives, and because none of the previous studies featured the unique combination of factors present in northcentral Kansas, e.g., mesic perennial tallgrass-prairie ecosystem under, a humid continental climate; our objectives were to determine burn responses of the following plant species and changes in botanical composition due to burning:

I. Sericea lespedeza.

II. Rough-leaf dogwood.

III. Additional woody species.

Materials and Methods

Description of Study Sites and Soils

Research was conducted at Fort Riley Military Installation (Figure 1.1), a U.S. Army base in operation since 1853, located in Geary and Riley counties in the Flint Hills of northeastern Kansas (39˚15'N, 96˚50'W, 324 m above sea level) (Pride, 1997; McKale and Young, 2000). The installation, located in a mesic tallgrass-prairie ecosystem, uses 29,542 ha of its 40,434 ha for maneuver training (Althoff et al., 2010). The Flint Hills grasslands encompass greater than 1.6 million ha, covering much of eastern Kansas from near the Kansas-Nebraska border south into northeastern Oklahoma, and contains the largest remaining area of relict tallgrass prairie in North America (Knapp and Seastedt, 1998). The region has a humid continental climate, with hot summers and cold, dry winters. Mean monthly temperatures range from -7.8˚C in January to 33.9˚C in July. Annual precipitation averages 82.6 cm. Fort Riley lands host three major vegetation communities: grasslands (~32,200 ha), shrublands (~6000 ha), and woodlands (~1600 ha) (Althoff et al., 2010). All study plots on this project were not subjected to any grazing by domestic livestock.

An ecological site is defined as a distinctive kind of land with specific soil and physical characteristics that differ from other kinds of land in its ability to produce a distinctive kind and amount of vegetation and its ability to respond similarly to management actions and natural disturbances. Lands are classified by considering discrete physical and biotic factors. Physical factors include soils, climate, hydrology, geology, and physiographic features. Biotic factors include plant species occurrence, plant community compositions, annual biomass production, wildlife-vegetation interactions, and other factors. (USDA-ARS, 2013). From the National Cooperative Soil Survey, ecological sites were determined for all study sites based on soil series linkage (Figure 1.2). Test plots across the installation included three major ecological sites located in Major Land Resource Area (MLRA) 76; clay upland, limy upland, and loamy upland. Clay uplands are characterized by moderately deep to deep soils having a loam to silty clay surface (17.8 to 35.6 cm) over clayey subsoils. These soils vary from being somewhat poorly drained to well drained. Water permeability is slow to very slow. Although these soils can retain large amounts of water, it is tightly held, and therefore is not available in adequate amounts for the vegetation during stress periods. That reduces water availability and decreases potential forage production during dry years. On these soils with fine-textured surfaces, excessive removal of the vegetation prior to spring growth can permit heavy rains to seal the soil surface, reducing moisture intake. This condition not only reduces potential forage production, but can also create a sheet erosion hazard. Big bluestem (*Andropogon gerardii* Vitman), little bluestem [*Schizachyrium scoparium* (Michx.) Nash], Indiangrass (*Sorghastrum nutans* L. Nash), and switchgrass (*Panicum virgatum* L.) produce about 80 percent of the total vegetation with a dry vegetation production potential average of 2803 to 4484 kg per ha in a normal precipitation year (USDA-SCS, 1975). Limy uplands are characterized by moderately deep and shallow soils over calcareous shales. These soils are fine to medium textured. They are frequently calcareous to the surface and always strongly calcareous within 25.4 cm of the surface. These soils have a good infiltration rates and internal drainage. Total vegetative production in this rainfall belt is limited by low and moderate available water capacity and slope. Gullying and sheet erosion are severe hazards on these highly erosive soils. Livestock trailing and excessive removal of the vegetation prior to spring growth contributes to this hazard. Big bluestem, little bluestem, indiangrass, switchgrass, and side-oats grama [*Bouteloua curtipendula* (Michx.) Torr.] make up about 75 percent of the potential vegetation on this site with a dry herbage yield of 3363 to 4484 kg per ha in a normal precipitation year. (USDA-SCS, 1975). Loamy uplands are characterized by silty or loamy surface layers. The surface is usually well granulated and has good structure 35.6 cm or more in depth over loamy or clayey subsoils. The soils have a good water relationship to vegetation and high water-holding capacity. Some soils, or soil phases, may have stone, rock, or chert on the soil surface as well as in the soil profile. Excessive removal of the vegetation prior to spring growth allows early rains to cause sheet erosion (USDA-SCS, 1975). Big bluestem, little bluestem, indiangrass, switchgrass, and eastern gamagrass [*Tripsacum dactyloides* (L.) L.] produce about 85 percent of the total vegetation with a dry herbage yield of 3924 to 5605 kg per ha in a normal precipitation year (USDA-SCS 1975).

Specific management history was not available for study sites used on this project. However, many areas where study plots were established showed evidence of prior agricultural farming. This has resulted in secondary succession occurring on these sites and therefore species composition is directly affected.

Burn Regime and Treatment Design

Prescribed burning on the military installation has been a common management practice. The primary objective for burning is to set back woody species invasion on the grasslands. Another objective includes creating a habitat mosaic for wildlife. In the past, burning was determined on an individual training area basis, with considerations to duration since last burn conducted and priority based on woody species invasion. However, a new prescribed burn schedule has recently been designed that offers advantages over past practices. This design involves prescribed burn planning across entire north-south strips of training areas so that many areas may be burned in one day, assuming conditions are safe for burning. This new schedule also allows for the opportunity to burn training areas every two years on a more consistent basis. That differs from the old prescribed burn plans where some areas might go up to five years or more between burns.

A completely randomized design with 4 treatments was established in various training sites across the installation. The four treatments consisted of prescribed burning in the fall, prescribed burning in the spring, prescribed burning in the spring in successive years, and no burning. Date of each prescribed burn conducted was noted (Table 1.1).

Vegetation Sampling and Analysis

Botanical Composition

Botanical composition of each study site was determined using the line-point intercept method (Elzinga et al., 2001), with a modification allowing for closest broadleaf plant to be noted in the case that a grass was the closest plant to each 1-m interval point. This method involves the combination of a 100-m line transect with sampling at a predetermined interval of 1-m. Transects were randomly placed in conjunction with the prescribed burn plan to be conducted on the installation. Prior to burning, transects were permanently established. This was performed using a 100-m line transect that was marked at the beginning, middle and end by survey flags. Painted rocks approximately 25 cm by 25 cm were also placed at the beginning and end of each transect, and GPS coordinates were taken. At each 1-m interval it was noted if the point hit bare ground, litter, or a plant base. The closest plant to the point was then noted if a plant base was not hit. However, if the closest plant was a grass, then the closest forb or woody species was also noted. This allowed for a greater species richness of plants to be sampled along each transect.

Density and Frequency

Density and frequency were measured along the permanently established 100-m line transects. A frame with an area of 0.25 sq. m. was randomly placed at twenty recorded points along each transect. In each frame the numbers of tillers/stems were counted for sericea lespedeza, dogwood and any additional woody species.

Foliar Cover

The Daubenmire Canopy Cover Method (1959) was used in determining plant foliar cover for sericea lespedeza, dogwood and additional woody species. The Daubenmire method involves visually estimating the percentage of foliar cover within the frame and assigning a cover class based on the percentage of foliar cover estimated. An ocular estimate of foliar cover was completed for each frame used in plant density sampling for sericea lespedeza, rough-leaf dogwood, and any additional woody species.

Statistical Analysis

All data were analyzed using the PROC MIXED feature of SAS 9.2 (SAS Institute, 2008). Changes between pre-sampled data, one growing season post-burn data, and two growing seasons post-burn data were analyzed. Differences between least squares means were tested using 0.10 probability level (SAS Institute, 2008). A factorial analysis was performed for one growing season changes on the following variables: burn treatment, ecological site, and year. The statistical model was as follows:

$$Y_{ijk} = M + B_i + S_j + Y_k + BS_{ij} + BY_{ik} + SY_{jk} + Error_{ijk}$$

In order to observe interaction effects due to ecological site loamy uplands and limy uplands were considered as one ecological site in comparison to clay uplands. Limy uplands and loamy uplands were combined due to their similarities in plant composition and average annual forage production. A three-way interaction between burn treatment, ecological site, and year could not be performed because no data was taken for fall burned loamy/limy uplands in 2012 and unburned plots on loamy/limy uplands in 2011. For one growing season changes on plant components two years of data were used; prescribed fall burns in 2011 and 2012, and prescribed spring burns in 2012 and 2013.

Two growing season changes and changes between the first growing season post-burn and the second growing season post-burn were analyzed for burns performed in the fall of 2011, spring of 2012, and plots burned both in the spring of 2012 and 2013. The factorial analysis for two growing season changes was done only on the burn treatment and ecological site variables. The statistical model was as follows:

$$Y_{ij} = M + B_i + S_j + BS_{ij} + Error_{ij}$$

Statistical analyses for density changes were performed per individual frame. Statistical analyses for plant botanical composition, plant frequency, and plant foliar cover were performed per transect.

Results

Sericea Lespedeza

Plant Composition

Sericea lespedeza plant composition was measured at each study plot as part of the overall botanical plant composition. Sericea composition changes did not have any significant interactions or main effects due to burn treatment, ecological site or year burned the first growing season post-burn. Sericea composition changes two growing seasons post-burn for the first year of burn treatments and plots spring burned in 2012 and 2013 showed no significant impacts due burn treatments, ecological sites, or the interaction. Furthermore, the changes in sericea plant composition between the first growing season post-burn, 2012, and the second growing season post-burn, 2013, showed no significance due to burn treatment, ecological site, or the interaction.

Plant Density

Data used for statistical analysis of sericea lespedeza plant density includes both mature stems and seedlings. Sericea plant density response the first growing season post-burn showed no significant interactions or main effects of burn treatments, ecological sites, or year burned. Sericea lespedeza density changes two growing seasons post-burn showed no significance due to burn treatments, ecological sites, or the interaction. Sericea plant density changes between the first growing season post-burn, 2012, and the second growing season post-burn, 2013, were not significant due to burn treatment, ecological site, or the interaction.

Plant Frequency

Frequency of sericea lespedeza was analyzed based on the presence and absence of sericea plants within each frame. Sericea lespedeza frequency data were found to be normally distributed. The changes in sericea frequency the first growing season post-burn showed no significant interactions between burn treatments, ecological sites, and year burned (Table 1.2). A significant main effect due to ecological site was observed (Table 1.2). Plots on clay uplands showed a one growing season decrease of 2.27% and plots on loamy/limy uplands showed a 4.76% increase on sericea lespedeza frequency within the frames (Table 1.3). For the first year of burn treatments and successive spring burned plots, changes in sericea plant frequency two growing seasons post-burn were not significantly different due to burn treatment, ecological site, or the interaction of burn treatment by ecological site. An examination sericea frequency changes between the first growing season post-burn and the second growing season post-burn for the first year of burns and plots spring burned in 2012 and 2013 showed no significance due to the main effects of burn treatments or ecological site. There was not a significant interaction between burn treatment and ecological sites.

Foliar Cover

Foliar cover of sericea lespedeza was based on all sericea stems in the frames. There were no significant interactions or main effects due to burn treatment, ecological site, or year burned on changes of sericea foliar cover the first growing season post-burn. For the sites burned in the fall of 2011, spring of 2012, and successive springs, the two growing season changes in sericea foliar cover were not significantly impacted due to the interaction of burn treatment by ecological sites, or the main effects of each variable. Changes in sericea foliar cover between the first growing season post-burn and the second growing season post-burn for the first year of burn treatments and successive spring burned plots showed no significance due to burn treatments, ecological sites, or the interaction.

Rough-leaf Dogwood

Plant Density

Dogwood density changes the first growing season post-burn showed no significant interactions between burn treatments, ecological sites, and year burned (Table 1.4). There was a significant effect due to burn treatment on dogwood density changes with a difference between spring burned plots and unburned plots (Tables 1.4, 1.5). Dogwood densities increased 3.12 stems m^{-2} on spring burned plots in comparison to a decrease of 0.30 stems m^{-2} on unburned plots (Table 1.6). Two growing seasons responses of dogwood density on 2011 fall burns, 2012 spring burns, and successive spring burns showed no significant main effects of burn treatments, ecological sites, or the interaction. Changes in dogwood density between the first growing season post-burn and the second growing season post-burn for the first year of burn treatments and successive spring burns had no significant main effects due to burn treatments or ecological sites, and the interaction was not significant.

Plant Frequency

The changes in dogwood frequency the first growing season post-burn showed no significant interactions or main effects due to burn treatments, ecological sites, or year burned. Changes in dogwood frequency after two growing seasons for the first year of burn treatments and successive spring burned plots showed no significant interaction or main effects due to burn treatments or ecological sites. The changes in dogwood frequency between the first growing season post-burn and the second growing season post-burn for the first year of burn treatments and plots spring burned in 2012 and 2013 were not significantly impacted due to a burn treatment by ecological site interaction or the main effects.

Foliar Cover

Foliar cover changes of dogwood between the pre-burn figures and those sampled the first growing season post-burn showed no significant interactions or main effects due to burn treatments, ecological sites, or year burned. The two growing season changes in dogwood foliar cover on plots burned the first year of the study and plots burned in successive springs were not significantly impacted due to a burn treatment by ecological site interaction, or the main effects. Comparisons of changes in dogwood cover between the first growing season post-burn and the second growing season post-burn for the first year of burns and successive burned plots were not significant due to a burn treatment by ecological site interaction, or the main effects of each variable.

Additional Woody Species

Plant Density

All additional woody plants observed in transect frames were grouped together and analyzed for changes in density. There were no significant interactions between burn treatments, ecological sites, and year burned for changes in plant density of woody species the first growing season post-burn (Table 1.7). A main effect due to burn treatment was observed (Table 1.7). The plots fall burned showed a decrease in woody species density of 0.60 stems m^{-2} and spring burns increased 0.98 stems m^{-2} the first growing season post-burn (Table 1.8, 1.9). Two growing season responses of other woody species plant density on the plots burned the first year and successive spring burned plots had no significance due to burn treatment, ecological site, or the interaction.

The changes in other woody species density between the first growing season post-burn and the second growing season post-burn on plots fall burned in 2011, spring burned in 2012, and spring burned in both 2012 and 2013 did not have a significant interaction between burn treatments and ecological sites, or the main effect of burn treatment (Table 1.10). There was a significant difference between ecological sites on other woody plant density changes during this period of time (Table 1.10). Clay uplands across all burn treatments increased 0.28 plants m^{-2} in comparison to loamy/limy uplands that decreased 1.14 plants m^{-2} during this time (Table 1.11).

Plant Frequency

Additional woody species were grouped together for statistical examination in frequency changes as well. Significant interactions were found on additional woody species frequency changes the first growing season post-burn (Table 1.12). A burn treatment by ecological site interaction was found to be significant (Table 1.12). Fall burns on loamy uplands showed a 7.54% increase and spring burns on loamy uplands showed a 8.75% increase in other woody plant frequency and both these treatments were found to be significantly different from unburned loamy upland plots that showed a -14.42% decrease in other woody plant frequency (Tables 1.13, 1.14). Spring burns on clay uplands showed a 1.08% increase in other woody plant frequency and was found to be significantly different from plots spring burned on loamy uplands (Tables 1.13, 1.14). The ecological site by year interaction was also found to be significant (Table 1.12). Clay uplands the first round of burn treatments (Year 1) displayed an increase of 0.17% on other woody plant frequency and were significantly different from loamy uplands that decreased 11.28% on the first round of treatments (Tables 1.15, 1.16). The second round of burn treatments (Year 2) also showed a significant difference between clay uplands and loamy uplands, where there was an increase of 2.64% and 12.53% on other woody plant frequency, respectively (Tables 1.15, 1.16). Loamy uplands significantly differed between the two years of treatments (Table 1.15, 1.16). A significant interaction between burn treatment and ecological site was found for changes in other woody plant frequency two growing seasons post-burn (Table 1.17). The 2011 fall burned loamy/limy upland plots remained stable in other woody plant frequency and were significantly different than the 2012 spring burned loamy/limy uplands that decreased 20.00% (Tables 1.18, 1.19). The clay upland plots burned in the spring of 2012 remained stable in other woody plant frequency and were also significantly different than the 2012 spring burned loamy/limy upland plots (Table 1.18, 1.19). The changes in other woody plant frequency between the first growing season post-burn and the second growing season post-burn on plots burned the first year and plots spring burned in 2012 and 2013 were not significantly impacted due to burn treatment, ecological site, or the interaction.

Foliar Cover

Foliar cover of all additional woody species observed over frames was grouped together for statistical examination. First growing season post-burn changes on foliar cover of additional woody species yielded no significant interactions or main effects due to burn treatment, ecological site, or year burned. The changes in foliar cover of all other woody species on plots burned the first year and successive spring burned plots two growing seasons post-burn showed no significance due to burn treatments, ecological sites, or the interaction. There was no significance due to burn treatment, ecological site, or the interaction on foliar cover changes of all other woody species between the first growing season post-burn and the second growing post-burn for the first round of burn treatments and successive spring burns.

Botanical Composition

Warm-Season Grasses

The changes in warm-season grass composition the first growing season post-burn did not have any significant interactions or main effects due to burn treatment, ecological site, or year burned. Warm-season grass composition changes two growing seasons post-burn for burns in the fall of 2011, spring of 2012, and successive spring burns were not significantly impacted due to burn treatments, ecological sites, or the interaction. Comparisons of warm-season grass composition changes between the first growing season post-burn and the second growing season post-burn resulted in no significance due to burn treatment, ecological site, or the interaction.

Cool-Season Grasses

The changes in cool-season grass composition the first growing season post-burn did not display any significant interactions or main effects due to different burn treatments, ecological sites, or year burned. Cool-season grass composition was not significant due to burn treatment, ecological site, or the interaction when comparing the pre-burn compositions of the fall 2011, spring 2012, and successive spring burns to compositions the second growing season post-burn. The changes in cool-season grass composition from the first growing season post-burn to the second growing season post-burn for the first year of burn treatments and plots spring burned in 2012 and 2013 were not significantly impacted due to burn treatments, ecological sites, or the interaction.

Forbs

Observed changes in forb composition the first growing season post-burn did not show any significant interactions or main effects between burn treatment, ecological site, or year burned. Forb composition was not significantly affected by burn treatment, ecological site, or the interaction for the two growing season changes of plots burned in the fall of 2011, spring of 2012, and successively burned plots. The changes in forb composition between the first growing season post-burn and the second growing season post-burn were not significantly impacted due to burn treatments, ecological sites, or the interaction for the first year of burn treatments and plots spring burned in 2012 and 2013.

Total Woody Species

The changes in woody species plant composition one growing season post-burn showed no significant interactions between burn treatments, ecological sites, or year burned (Table 1.20). There was a significant main effect due to ecological site where woody species plant composition increased on clay uplands 0.19% compared to loamy/limy uplands that showed a decrease in woody species plant composition of 1.30% the first growing season post-treatment (Table 1.20, 1.21). Total woody species plant botanical composition changes two growing seasons post-burn for the first year of burn treatments and plots burned in successive springs showed a significant interaction between burn treatment and ecological site (Table 1.22). In particular, fall burns on loamy/limy uplands in 2011decreased in total woody composition 0.50% and was significantly different from loamy/limy uplands spring burned in 2012 that decreased in overall woody plant composition 7.00% (Tables 1.23, 1.24). Furthermore, clay uplands burned in the spring of 2012 decreased total woody composition 1.33% and was significantly different from clay uplands burned in the spring of 2012 and 2013 where woody species composition increased 1.25%, unburned clay uplands that showed an increase of 1.25%, and the previously mentioned loamy/limy uplands burned in the spring of 2012 (Tables 1.23, 1.24). Comparisons made between changes of total woody composition from the first growing season post-burn to the second growing season post-burn for the first year of burn treatments showed a significant interaction between burn treatment and ecological site (Table 1.25). Fall burns in 2011 on loamy/limy uplands showed an increase in total woody composition of 2.50% in comparison to spring burns in 2012 on loamy/limy uplands that decreased 7.00% (Tables 1.26, 1.27). In addition, spring burns in 2012 on clay uplands decreased in total woody composition 0.67% and was significantly different from clay uplands burned in the spring of 2012 and 2013 where total woody composition increased 1.50% (Tables 1.26, 1.27). Spring burns on clay uplands in 2012 also displayed different changes in woody species composition than spring burns in 2012 on loamy/limy uplands (Tables 1.26, 1.27).

Discussion and Conclusions

The only significance found on any sericea lespedeza plant component changes was an effect due to ecological site on sericea plant frequency changes the first growing season post-burn. All plots on clay uplands decreased 2.3% in sericea frequency after one growing season and all plots on loamy/limy uplands increased 4.7% after one growing season. The different responses can be attributed to the distinctly different soils and topography found on each ecological site. The responses in sericea frequency on clay uplands is a result of the soils' ability to tightly retain the water, limiting availability for plant uptake and vegetative production in years of drought, as was the case during the two year study. Ohlenbusch et al. (2007) states that fire may be an ineffectual control strategy because adult plants resprout following fire. Resulting high rates of sericea lespedeza plants to resprout following fire can be attributed to the perennating tissues within the caudex that occur about 2.5 to 8 cm below the soil surface, where heat from fires cannot reach (Emry, 2008). Our research concurs with this due to no significant differences being found on sericea density and foliar cover changes among burn treatment, ecological site, year, or the interactions.

Rough-leaf dogwood responses due to burning were similar to past studies. Prescribed burning achieved top-kill of dogwood plants. However, dogwood densities increased 3.1 stems m^{-2} on spring burned plots in comparison to a decrease of 0.3 stems m^{-2} on unburned plots. Prescribed burning, considered a disturbance to rough-leaf dogwood plants, triggered plants to develop additional lateral roots, suckers, that sent up vegetative shoots. The majority of burn dates for the spring prescribed burns were in early spring, which resulted in the stimulation of dogwood shoots. Changes in foliar cover of dogwood were not found to be significantly different due to burn treatments, ecological sites, year, or the interactions. Steinke (1969) stated that, when downward translocation was delayed by severe defoliation and adverse weather conditions, death of leaf and stem tissue caused a severe reduction in the size of the root system. However, reserves are sufficient enough to provide the necessary energy for the replacement of aboveground tissues. Long-term annual burning may not eliminate roughleaf dogwood, possibly because TNC levels are replenished during good growing seasons to levels similar to those in unburned plants (Janicke and Fick, 1998). While use of prescribed fire to kill dogwood has been proven, the timing of fires under the constraints of this study did not prove to have a detrimental effect on rough-leaf dogwood.

Effects due to burning on additional woody species displayed some significant differences. While additional woody plants were also top-killed by fire, resprouting occurred on a number of species. Changes in additional woody species plant density the first growing season after burning resulted in a decrease of 0.61 stems m^{-2} on fall burned plots and an increase of 0.98 stems m^{-2} on spring burned plots. Burning, as a method of defoliation and reduction of carbohydrate reserves, is a general management practice for control of undesirable plants on grasslands (Launchbaugh and Owensby, 1978). The timing of prescribed fires during these different seasons can result in its effectiveness being variable due to the level of carbohydrate reserves, bud location at the time of burns, and fire intensity. The significant interactions between burn treatment by ecological site and ecological site by year for changes in additional woody plant frequency the first growing season post-burn could be attributed to certain factors. The differences in the ecological sites by burn treatments interactions may be due to the differences in plant biomass, and therefore fuel loads and fire intensity, on different ecological sites. Differences in the ecological site by year interaction may be a result of weather and precipitation differences from year to year. The higher drought indexes that occurred between 2011 and 2012 could have resulted in additional harm to additional woody species following a burn the first year. Differences in ecological sites could also result in greater fire intensities on a loamy/limy upland where potential production is greater than that of clay uplands. In order to better understand effects of prescribed fire on additional woody species in the late summer/fall and spring, individual scientific experiments for select species are warranted.

Prescribed burning led to changes in composition of total woody species. An ecological site difference was found on changes of woody species plant composition the first growing season after burning where plant composition increased 0.19% on clay uplands and decreased 1.30% on loamy/limy uplands. The potential higher fuel loads and fire intensities on the loamy/limy uplands could result in woody plants being successfully killed more often than on clay uplands. Changes in total woody species plant composition after two growing seasons resulted in a significant burn treatment by ecological site interaction. In particular, plots burned once resulted in decreases of woody species composition and plots burned in successive springs and unburned plots showed a slight increase in woody species composition. Timing of prescribed fire can result in shifts of plant composition. However, the use of prescribed fire in this study was done in primarily during early spring and mid to late September, and did not result in significant shifts in composition. That is because plants are not actively growing during these times and therefore, prescribed fire is not having an effect on them. Overall plant botanical composition changes are an important factor to consider for a land manager considering the use and timing of a prescribed burn. The specific objectives a land manager is trying to accomplish should be of primary focus in deciding upon use of a prescribed burn.

Under the conditions of this study, results suggest that prescribed burning is generally ineffective in controlling sericea lespedeza, rough-leaf dogwood, and additional woody species as a short term measure. It is recommended that burning, in conjunction with patch-grazing and/or herbicide application, be used for control and spread prevention of these species. Long-term investigations of prescribed burning in the late-summer/fall, in comparison to traditional spring burning, are warranted in order to better determine if adjustments need to be made in management of native rangelands of the tallgrass prairie.

Figures and Tables

Figure 1.1 A) Location of Fort Riley Military Installation, KS. B) Location of all study sites on Fort Riley Military Installation.

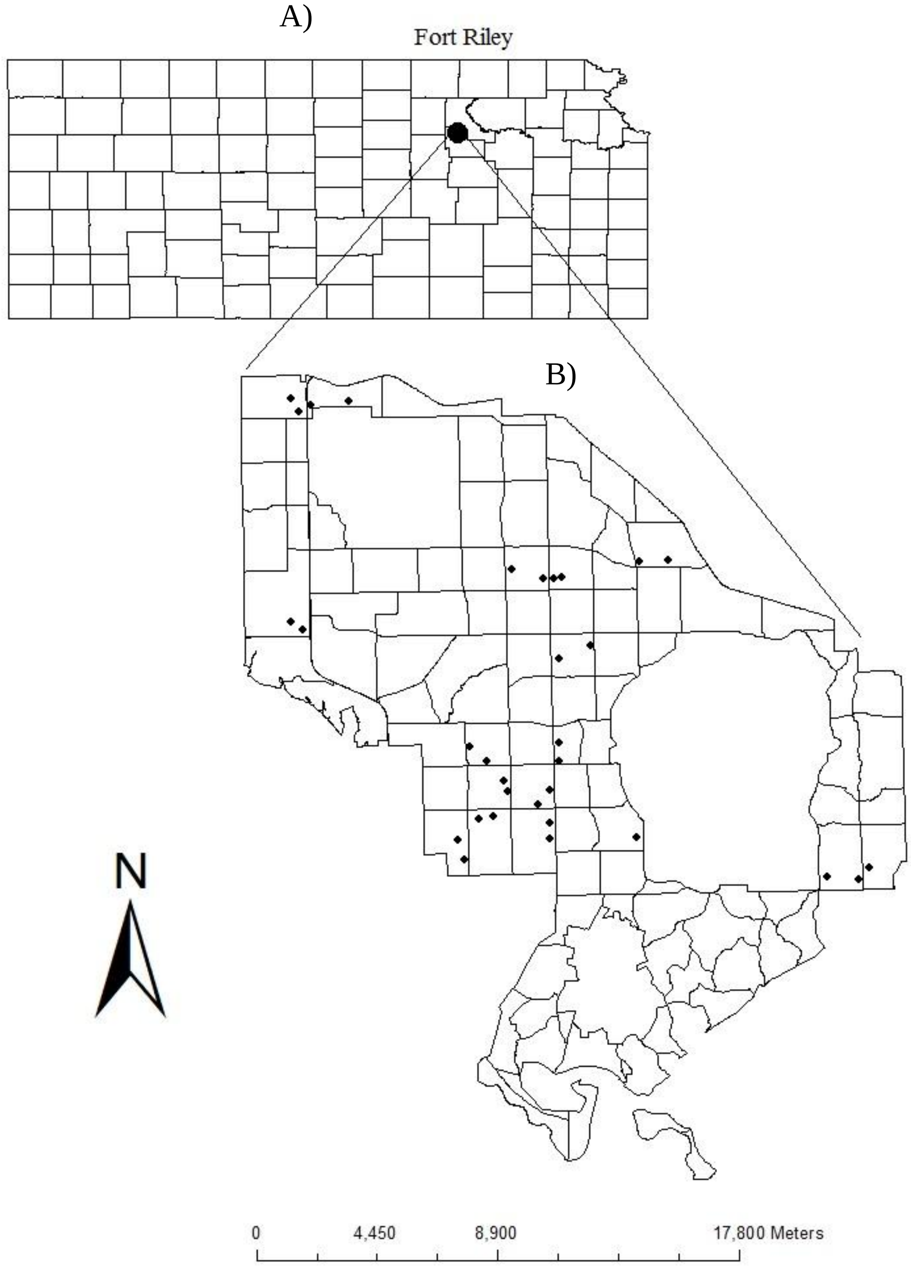

Figure 1.2 A) Training areas on Fort Riley Military Installation. B) Example of map for soil determination of each line transect.

A)

B)

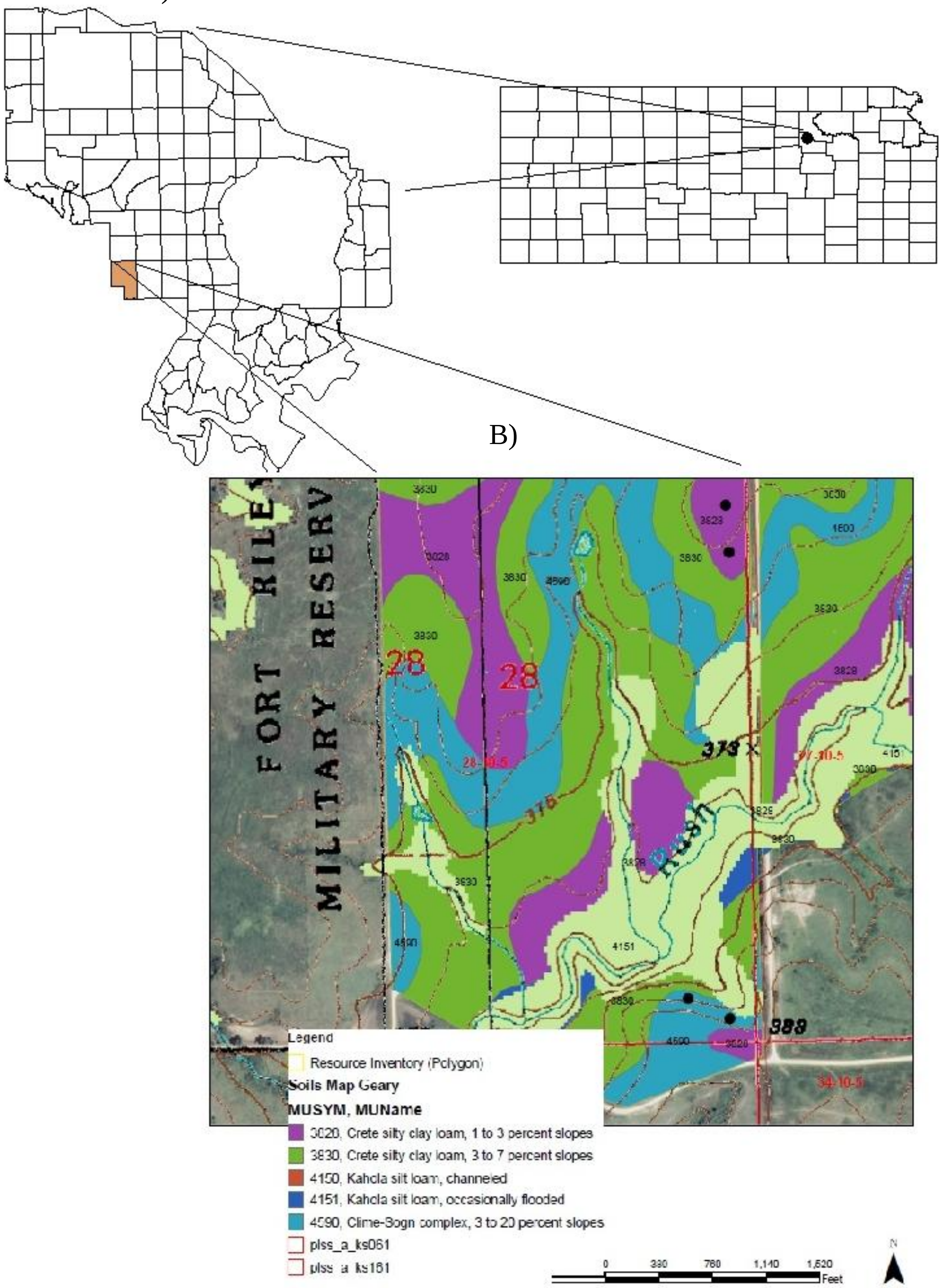

Table 1.1 Calendar date of each prescribed burn performed across line transects.

Area	Transect	Treatment	Burn 1	Burn 2
26A	1	Unburned	N/A	N/A
37A	1	Unburned	N/A	N/A
44B	2	Unburned	N/A	N/A
49A	1	Unburned	N/A	N/A
51A	1	Unburned	N/A	N/A
52A	1	Unburned	N/A	N/A
52B	2	Unburned	N/A	N/A
86B	2	Unburned	N/A	N/A
40A	1	Fall Burn	10/6/2012	N/A
40B	2	Fall Burn	10/6/2012	N/A
85A	1	Fall Burn	9/29/2012	N/A
85B	2	Fall Burn	9/29/2012	N/A
25A	1	Fall Burn	10/1/2011	N/A
25B	2	Fall Burn	10/1/2011	N/A
49B	2	Fall Burn	8/11/2011	N/A
51C	1	Spring Burn	12/3/2012	N/A
51B	2	Spring Burn	12/3/2012	N/A
52C	2	Spring Burn	12/3/2012	N/A
54A	1	Spring Burn	3/29/2013	N/A
54B	2	Spring Burn	3/29/2013	N/A
97A	1	Spring Burn	3/14/2013	N/A
97B	2	Spring Burn	3/14/2013	N/A
44A	1	Spring Burn	1/24/2012	N/A
47A	1	Spring Burn	4/9/2012	N/A
47B	2	Spring Burn	4/9/2012	N/A
65A	1	Spring Burn	3/4/2012	N/A
65B	2	Spring Burn	3/4/2012	N/A
86A	1	Spring Burn	4/16/2012	N/A
48A	1	Successive Spring Burns	4/9/2012	3/29/2013
48B	2	Successive Spring Burns	4/9/2012	3/29/2013
74A	1	Successive Spring Burns	4/1/2012	12/1/2012
74B	2	Successive Spring Burns	4/1/2012	12/1/2012
93A	1	Successive Spring Burns	4/1/2012	12/1/2012
93B	2	Successive Spring Burns	4/1/2012	12/1/2012

Table 1.2 ANOVA table of mean changes of sericea lespedeza plant frequency the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	2.22	0.13
Ecological Site	1	28	2.96	0.10
Year	1	28	0.18	0.67
Burn Treatment x Ecological Site	2	28	1.45	0.25
Burn Treatment x Year	2	28	0.22	0.81
Ecological Site x Year	1	28	0.01	0.93

Table 1.3 Table of mean changes of sericea lespedeza plant frequency on ecological sites the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Ecological Site	Change ---%---
Clay Upland	-2.27
Loamy/Limy Upland	4.76

Table 1.4 ANOVA table of mean changes of rough-leaf dogwood plant density the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	2.53	0.10
Ecological Site	1	28	2.14	0.15
Year	1	28	0.69	0.41
Burn Treatment x Ecological Site	2	28	1.08	0.35
Burn Treatment x Year	2	28	0.43	0.65
Ecological Site x Year	1	28	0.63	0.43

Table 1.5 Table of p-values comparing the main effect of burn treatment on dogwood density changes the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Burn Treatment	p-value	Burn Treatment
Fall	0.39	Spring
Fall	0.29	Unburned
Spring	0.05	Unburned

Table 1.6 Table of mean changes of dogwood plant density on burn treatments the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Burn Treatment	Change ---Stems m^{-2}---
Fall	1.96
Spring	3.12
Unburned	-0.30

Table 1.7 ANOVA table of mean changes of additional woody plant density the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	3.89	0.03
Ecological Site	1	28	0.00	0.97
Year	1	28	0.01	0.90
Burn Treatment x Ecological Site	2	28	1.17	0.33
Burn Treatment x Year	2	28	0.59	0.56
Ecological Site x Year	1	28	0.21	0.65

Table 1.8 Table of p-values comparing the main effect of burn treatment on additional woody plant density changes the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Burn Treatment	p-value	Burn Treatment
Fall	0.01	Spring
Fall	0.34	Unburned
Spring	0.40	Unburned

Table 1.9 Table of mean changes of additional woody plant density on burn treatments the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Burn Treatment	Change ---Stems m^{-2}---
Fall	-0.60
Spring	0.98
Unburned	0.34

Table 1.10 ANOVA table of mean changes of additional woody plant density for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	2.59	0.11
Ecological Site	1	11	4.70	0.05
Burn Treatment x Ecological Site	2	9	2.41	0.14

Table 1.11 Table of mean changes of additional woody plant density on ecological sites for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013).

Ecological Site	Change ---stems m^{-2}---
Clay Upland	0.28
Loamy/Limy Upland	-1.14

Table 1.12 ANOVA table of mean changes of additional woody plant frequency the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	2.93	0.07
Ecological Site	1	28	0.05	0.82
Year	1	28	9.25	0.01
Burn Treatment x Ecological Site	2	28	4.18	0.03
Burn Treatment x Year	2	28	1.19	0.32
Ecological Site x Year	1	28	7.80	0.01

Table 1.13 Table of p-values comparing the interaction effect of burn treatment by ecological site on additional woody plant frequency changes the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Burn x Site			Burn x Site	
Burn Treatment	Ecological Site	p-value	Burn Treatment	Ecological Site
Fall	Clay Upland	0.32	Fall	Loamy/Limy Upland
Fall	Clay Upland	0.63	Spring	Clay Upland
Fall	Clay Upland	0.06	Spring	Loamy/Limy Upland
Fall	Clay Upland	0.24	Unburned	Clay Upland
Fall	Clay Upland	0.09	Unburned	Loamy/Limy Upland
Fall	Loamy/Limy Upland	0.34	Spring	Clay Upland
Fall	Loamy/Limy Upland	0.86	Spring	Loamy/Limy Upland
Fall	Loamy/Limy Upland	0.58	Unburned	Clay Upland
Fall	Loamy/Limy Upland	0.06	Unburned	Loamy/Limy Upland
Spring	Clay Upland	0.05	Spring	Loamy/Limy Upland
Spring	Clay Upland	0.26	Unburned	Clay Upland
Spring	Clay Upland	0.04	Unburned	Loamy/Limy Upland
Spring	Loamy/Limy Upland	0.22	Unburned	Clay Upland
Spring	Loamy/Limy Upland	0.01	Unburned	Loamy/Limy Upland
Unburned	Clay Upland	0.02	Unburned	Loamy/Limy Upland

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Table 1.14 Table of mean changes of additional woody plant frequency on burn treatments by ecological sites interaction the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Burn x Site		Change
Burn Treatment	Ecological Site	---%---
Fall	Clay Upland	-0.63
Fall	Loamy/Limy Upland	7.54
Spring	Clay Upland	1.08
Spring	Loamy/Limy Upland	8.75
Unburned	Clay Upland	3.75
Unburned	Loamy/Limy Upland	-14.42

Table 1.15 Table of p-values comparing the interaction effect of ecological site by year on additional woody plant frequency changes the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Site x Year			Site x Year	
Ecological Site	Year	p-value	Ecological Site	Year
Clay Upland	1	0.36	Clay Upland	2
Clay Upland	1	0.02	Loamy/Limy Upland	1
Clay Upland	1	0.06	Loamy/Limy Upland	2
Clay Upland	2	0.01	Loamy/Limy Upland	1
Clay Upland	2	0.08	Loamy/Limy Upland	2
Loamy/Limy Upland	1	0.00	Loamy/Limy Upland	2

Table 1.16 Table of mean changes of additional woody plant frequency of ecological sites by year interaction the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Site x Year		Change
Ecological Site	Year	---%---
Clay Upland	1	0.17
Clay Upland	2	2.64
Loamy/Limy Upland	1	-11.28
Loamy/Limy Upland	2	12.53

Table 1.17 ANOVA table of mean changes of additional woody plant frequency for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	1.94	0.18
Ecological Site	1	11	3.92	0.07
Burn Treatment x Ecological Site	1	10	4.23	0.07

Table 1.18 Table of p-values comparing the interaction effect of burn treatment by ecological site on additional woody plant frequency changes for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013).

Burn x Site			Burn x Site	
Burn Treatment	Ecological Site	p-value	Burn Treatment	Ecological Site
Fall 2011	Clay Upland	1.00	Fall 2011	Loamy/Limy Upland
Fall 2011	Clay Upland	1.00	Spring 2012	Clay Upland
Fall 2011	Clay Upland	0.04	Spring 2012	Loamy/Limy Upland
Fall 2011	Clay Upland	0.85	Spring 2012 & 2013	Clay Upland
Fall 2011	Clay Upland	0.28	Unburned 2011	Clay Upland
Fall 2011	Loamy/Limy Upland	1.00	Spring 2012	Clay Upland
Fall 2011	Loamy/Limy Upland	0.02	Spring 2012	Loamy/Limy Upland
Fall 2011	Loamy/Limy Upland	0.81	Spring 2012 & 2013	Clay Upland
Fall 2011	Loamy/Limy Upland	0.17	Unburned 2011	Clay Upland
Spring 2012	Clay Upland	0.01	Spring 2012	Loamy/Limy Upland
Spring 2012	Clay Upland	0.77	Spring 2012 & 2013	Clay Upland
Spring 2012	Clay Upland	0.10	Unburned 2011	Clay Upland
Spring 2012	Loamy/Limy Upland	0.01	Spring 2012 & 2013	Clay Upland
Spring 2012	Loamy/Limy Upland	0.00	Unburned 2011	Clay Upland
Spring 2012 & 2013	Clay Upland	0.16	Unburned 2011	Clay Upland

Table 1.19 Table of mean changes of additional woody plant frequency of burn treatments by ecological sites interaction for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013).

Burn x Site		Change
Burn Treatment	Ecological Site	---%---
Fall 2011	Clay Upland	0.00
Fall 2011	Loamy/Limy Upland	0.00
Spring 2012	Clay Upland	0.00
Spring 2012	Loamy/Limy Upland	-20.00
Spring 2012 & 2013	Clay Upland	1.25
Unburned 2011	Clay Upland	7.50

Table 1.20 ANOVA table of mean changes of total woody species plant composition the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	1.74	0.19
Ecological Site	1	28	3.49	0.07
Year	1	28	0.00	0.98
Burn Treatment x Ecological Site	2	28	1.55	0.23
Burn Treatment x Year	2	28	0.17	0.84
Ecological Site x Year	1	28	0.95	0.34

Table 1.21 Table of mean changes of total woody species plant composition on ecological sites the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013.

Ecological Site	Change ---%---
Clay Upland	0.19
Loamy/Limy Upland	-1.30

Table 1.22 ANOVA table of mean changes of total woody species plant composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	5.90	0.01
Ecological Site	1	10	9.36	0.01
Burn Treatment x Ecological Site	1	9	3.76	0.08

Table 1.23 Table of p-values comparing the interaction effect of burn treatment by ecological site on total woody species plant composition changes for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013).

Burn x Site			Burn x Site	
Burn Treatment	Ecological Site	p-value	Burn Treatment	Ecological Site
Fall 2011	Clay Upland	0.36	Fall 2011	Loamy/Limy Upland
Fall 2011	Clay Upland	0.15	Spring 2012	Clay Upland
Fall 2011	Clay Upland	0.00	Spring 2012	Loamy/Limy Upland
Fall 2011	Clay Upland	0.86	Spring 2012 & 2013	Clay Upland
Fall 2011	Clay Upland	0.86	Unburned 2011	Clay Upland
Fall 2011	Loamy/Limy Upland	0.49	Spring 2012	Clay Upland
Fall 2011	Loamy/Limy Upland	0.00	Spring 2012	Loamy/Limy Upland
Fall 2011	Loamy/Limy Upland	0.15	Spring 2012 & 2013	Clay Upland
Fall 2011	Loamy/Limy Upland	0.15	Unburned 2011	Clay Upland
Spring 2012	Clay Upland	0.00	Spring 2012	Loamy/Limy Upland
Spring 2012	Clay Upland	0.03	Spring 2012 & 2013	Clay Upland
Spring 2012	Clay Upland	0.03	Unburned 2011	Clay Upland
Spring 2012	Loamy/Limy Upland	0.00	Spring 2012 & 2013	Clay Upland
Spring 2012	Loamy/Limy Upland	0.00	Unburned 2011	Clay Upland
Spring 2012 & 2013	Clay Upland	1.00	Unburned 2011	Clay Upland

Table 1.24 Table of mean changes of total woody species plant composition of burn treatments by ecological sites interaction for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013).

Burn x Site		Change
Burn Treatment	Ecological Site	---%---
Fall 2011	Clay Upland	1.00
Fall 2011	Loamy/Limy Upland	-0.50
Spring 2012	Clay Upland	-1.33
Spring 2012	Loamy/Limy Upland	-7.00
Spring 2012 & 2013	Clay Upland	1.25
Unburned 2011	Clay Upland	1.25

Table 1.25 ANOVA table of mean changes of total woody species plant composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	3.75	0.05
Ecological Site	1	10	2.37	0.15
Burn Treatment x Ecological Site	1	9	9.67	0.01

Table 1.26 Table of p-values comparing the interaction effect of burn treatment by ecological site on total woody species plant composition changes for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013).

Burn x Site			Burn x Site	
Burn Treatment	Ecological Site	p-value	Burn Treatment	Ecological Site
Fall 2011	Clay Upland	0.43	Fall 2011	Loamy/Limy Upland
Fall 2011	Clay Upland	0.36	Spring 2012	Clay Upland
Fall 2011	Clay Upland	0.00	Spring 2012	Loamy/Limy Upland
Fall 2011	Clay Upland	0.77	Spring 2012 & 2013	Clay Upland
Fall 2011	Clay Upland	1.00	Unburned 2011	Clay Upland
Fall 2011	Loamy/Limy Upland	0.05	Spring 2012	Clay Upland
Fall 2011	Loamy/Limy Upland	0.00	Spring 2012	Loamy/Limy Upland
Fall 2011	Loamy/Limy Upland	0.46	Spring 2012 & 2013	Clay Upland
Fall 2011	Loamy/Limy Upland	0.28	Unburned 2011	Clay Upland
Spring 2012	Clay Upland	0.01	Spring 2012	Loamy/Limy Upland
Spring 2012	Clay Upland	0.09	Spring 2012 & 2013	Clay Upland
Spring 2012	Clay Upland	0.18	Unburned 2011	Clay Upland
Spring 2012	Loamy/Limy Upland	0.00	Spring 2012 & 2013	Clay Upland
Spring 2012	Loamy/Limy Upland	0.00	Unburned 2011	Clay Upland
Spring 2012 & 2013	Clay Upland	0.65	Unburned 2011	Clay Upland

Table 1.27 Table of mean changes of total woody species plant composition of burn treatments by ecological sites interaction for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013).

Burn x Site		Change
Burn Treatment	Ecological Site	---%---
Fall 2011	Clay Upland	1.00
Fall 2011	Loamy/Limy Upland	2.50
Spring 2012	Clay Upland	-0.67
Spring 2012	Loamy/Limy Upland	-7.00
Spring 2012 & 2013	Clay Upland	1.50
Unburned 2011	Clay Upland	1.00

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Chapter 2 - Effects of Prescribed Burning on Soil Physical Properties on two Soils of the Tallgrass Prairie Region of KS

Abstract

While erosion on grassland soils following a prescribed burn is typically not of great concern, there are still questions that remain regarding the potential of late-summer and fall burning to increase erosion on native prairie soils. This can be attributed to the timing of these burns not allowing for regrowth of vegetation and leaving soils bare and exposed to the harsh fall and winter conditions of the Central Great Plains. This project assessed the effects of prescribed burning on physical soil properties of loess soils located on Fort Riley, KS. The soils were Wymore silt loam (fine, smectitic, mesic Aquertic Argiudolls) and Crete silt loam (fine, smectitic, mesic Pachic Udertic Argiustolls). Two burning treatments, assessed over two years, consisted of prescribed burning in the spring and fall to measure differences in bulk density, mean weight diameter (MWD) of soil aggregates, and water-stable aggregate (WSA) size by fraction in comparison to unburned soils. Statistical analysis was done for effective sampling on differences between burned and unburned plots per point-in-time of each sampling period. Significant effects were noted at the 0.10 level ($\alpha = 0.10$). There were no significant differences due to burning on soil bulk density. Significant effects due to burning were found on soil aggregate MWD and all WSA size fractions for the fall 2011 burns, except for the 1.00-2.00 mm fraction. The MWD of wet aggregates was greater on the burned sites in the fall of 2011 than the unburned sites. Total water-stable aggregates were higher on burned sites and microaggregates (<0.25 mm) were lower on burned sites in the fall of 2011. Results from the study suggest that burning does not adversely impact soil physical properties of these loess soils. However, further monitoring is warranted to objectively assess long term late-summer/fall and spring prescribed fire impacts on physical properties of soils in the tallgrass prairie region of Kansas.

Introduction

Loess-paleosol sequences of the Quaternary Period are present throughout much of the plains. Loess units widely recognized in the Central Plains include the Loveland (deposited approximately 500,000 to 100,000 yr BP), Gilman Canyon Formation (deposited approximately 41,000 to 20,000 yr BP), and Peoria Loess (deposited approximately 25,000 to 11,000 yr BP) (Presley et al., 2010). Welch and Hale (1987) used a combination of sources including geologic maps and county soil surveys to estimate that approximately 65% of Kansas was covered with Pleistocene loess.

Under normal circumstances, fires do not appear to affect grassland soils adversely (Lloyd, 1971) and generally appear to improve them (Hole and Watterston, 1972). Soil erosion is not a major concern in most grasslands unless adverse environmental conditions follow fire. Even then, the remaining basal crowns, fibrous and extensive root systems, ash, charcoal, and unconsumed plant litter usually protect the soils from severe and massive erosion. Most severe erosion in grasslands can be traced to causes other than fire, such as excessive rodent activities, heaving grazing, trampling, rooting, and disturbances and compaction by machinery (Vogl, 1974).

The annual burning of grassland will have multiple effects on the nutrient cycling and energy flow for the growing season immediately following that burn. The litter and standing dead is burned off and reduced, leaving nutrient rich ash in its place (DeBano et al., 1998). These nutrients are released from a previously immobilized state in the dead plants and litter to an inorganic state that is readily available. The resulting faster rates of nutrient turnover are essential for sustaining the high primary productivity typical of native tallgrass and mixed grass prairie (Brockway et al., 2002). That is because the newly available nutrients are quickly used up by growing plants and not given a chance for translocation deeper into the soil. The blackened state of the soil also absorbs more solar radiation. That increased energy penetrating the soil stimulates new growth of shoots. However, the fact that these soils are absorbing more solar radiation means they will warm up faster. That reduces soil moisture due to evaporation (McMurphy and Anderson, 1965) but can also stimulate earlier growth due to the faster rate that the soil warms up . Fire causes nitrogen and sulphur volatilization. That creates significant losses to the soil system (Caldwell et al., 2000). On the Konza Prairie, located in Kansas, annual burning resulted in a 25% increase in root growth compared to unburned watershed, as plants compensated for N limitation by increasing allocation to roots (Johnson and Matchett, 2001). That increased allocation to roots results in higher root and rhizome mass than that of unburned prairie. The increased root and rhizome mass can be attributed to an increased amount of fine roots and root hairs with a lower tissue N concentration, thus increasing N use efficiency. A burn has been reported to decrease soil-dwelling organisms living near the surface or in the litter (Pearse, 1943; Heyward and Tissot, 1936). That should be a concern since these organisms break down the litter making nutrients available, but since the fire breaks down the litter immediately, losing these organisms is not of concern. Soil-dwelling organisms generally increase in population following a fire. These include organisms such as springtails, mites, earthworms, beetles, centipedes and more. A resulting increase in these organisms helps to move soil around mixing the organic matter into the soils top 30 centimeters.

In agricultural systems, crop residue serves as a protective barrier from climatic conditions (e.g., high wind velocity, low precipitation, freeze-thaw cycles, and freeze-drying periods) that work to break down aggregates in the soil (Chepil and Woodruff, 1963; Bullock et al., 1988; Lehrsch et al., 1991; Staricka and Benoit, 1995; Larney et al., 2003). These climatic conditions can accelerate the breakdown of soil aggregates, leading to additional erosion and loss of soil sediment. Bullock et al. (1988) concluded that seasonal changes in stability of Utah silt loam textured soils were much larger than the difference between soils, or differences caused by residue. Decrease in stability was attributed to ice crystals expanding in the pores between particles, breaking particle-to-particle bonds, and effectively splitting larger aggregates into smaller aggregates (Bullock et al., 1988). Lehrsch et al. (1991) performed a study to determine the freezing effects on aggregate stability as affected by texture, mineralogy, and organic matter. They found that in greater than 85% of the cases, aggregate stability decreased as water content increased when subjected to freeze-thaw cycles. Freeze-drying can also be very detrimental to soil aggregates. Staricka and Benoit (1995) reported that thawing of moist soils results in more cohesion of aggregates to a degree; however, freeze-drying removes water from the soil by sublimation, thus avoiding any aggregation building cohesion between particles (Ihde, 2011).

Another measure of soil physical properties, bulk density, can be indicative of compaction and soil quality. Giovannini et al. (1998) determined that bulk density increases as a result of the collapse of organo-mineral aggregates. The sealing due to the clogging of soil pores by the ash or freed clay minerals can also attribute to increased bulk density (Durgin and Vogelsang, 1984). This implies a decrease in the water holding capacity of soil (Boyer and Miller, 1994; Boix, 1997) and a consequent accentuation of runoff and surface erosion (Martin and Moody, 2001).

O'Dea and Guertin (2003) concluded on a study done on a gravelly loam textured soil of a perennial grassland in Arizona that prescribed burning appears to affect the structure of surface soil layers. The removal of vegetative soil cover by fire is an important driver of surface runoff and erosion process, as it reduces the frequency and size of vegetated areas over the landscape (Baker, 1988; Simanton and Renard, 1981). Removal of vegetation exposes the soil surface to the energy of raindrop impact (Bennett, 1974; Hester et al., 1997), affecting soil surface aggregate stability (Armstrong and Stein, 1996; Gang et al., 1998; Warren, 1987) and the permeability of surface soil layers to water infiltration (Baker, 1988; Smith et al., 1990). Structure stability can be increased by low to moderate fires because of the formation of the hydrophobic film on the external surface of aggregates (Mataix-Solera and Doerr, 2004), whilst stability decreases dramatically when, at high temperatures, organic cements are disrupted (Badia and Marti, 2003). O'Dea and Guertin (2003) reported that increased bulk density was observed due to prescribed burning in the late-spring and also from a simulated rainfall with a return interval of 3.5 years.

Intensive cropping of native grassland soils generally decreases organic matter content and causes an associated degradation of soil physical properties (Dormaar, 1979; Hobbs and Brown, 1957; Olmstead, 1946; Skidmore et al., 1975). The physical deterioration often associated with a decline in organic matter content is manifested by a decline in wet aggregate stability, an increase in bulk and clod densities, an increase in modulus rupture, and a decline in large pore space (Skidmore et at., 1986). Harris et. al. (1966) stated that a soil's aggregate status usually deteriorates rapidly if the soil is repeatedly cropped with annuals that supply little organic matter to the soil, require extensive cultivation, and provide minimal vegetative cover. Dormaar et. al (1979) found that burning of crop residues led to reduced percentages of water-stable aggregates in the soil. Though burning may be used as a means of residue management on annually cropped fields, no comparisons can be made to that of untilled natural prairie grasslands due to the differences previously mentioned.

Since there is becoming an increasing interest in the use of prescribed burning in the fall for various vegetation objectives, and because none of the previous studies featured the unique combination of factors present in northcentral Kansas, e.g., mesic perennial tallgrass-prairie ecosystem under, a humid continental climate; and Pleistocene loess soils, our objectives were to determine impact of burning on the soil physical properties of:

I. Bulk density.

II. Mean weight diameter.

III. The size distribution of water stable aggregates.

Materials and Methods

Description of Study Sites and Soils

Research was conducted at the Fort Riley Military Installation (Figure 2.1), a U.S. Army base in operation since 1853, located in Geary and Riley counties in the Flint Hills of northeastern Kansas (39˚15'N, 96˚50'W, 324 m above sea level) (Pride, 1997; McKale and Young, 2000). The installation, located in a mesic tallgrass-prairie ecosystem, uses 29,542 ha of its 40,434 ha for maneuver training primarily for tanks and armored vehicles (Althoff et al., 2010). The Flint Hills grasslands encompass greater than 1.6 million ha, covering much of eastern Kansas from near the Kansas-Nebraska border south into northeastern Oklahoma, and contains the largest remaining relict of tallgrass prairie in North America (Knapp and Seastedt, 1998). The region has a humid continental climate, with hot summers and cold, dry winters. Mean monthly temperatures range from -7.8˚C in January to 33.9˚C in July. Annual precipitation averages 82.6 cm. Fort Riley contains three major vegetation communities: grasslands (~32,200 ha), shrublands (~6000 ha), and woodlands (~1600 ha) (Althoff et al., 2010). All study plots for the project were not subjected to any grazing by domestic livestock.

The slopes (Table 2.1), were determined using a laser level rod. Soil textures (Table 2.2) were determined by the Kansas State Soil Characterization Laboratory using a modified pipet method of Kilmer and Alexander (1949) as reported by Presley et al. (2011) from samples taken on study plots. Soil series was determined using mapped GPS coordinates (Figure 2.1). Two soils were primarily found and used for testing at the study plots. The Wymore series consists of very deep, moderately well drained, slowly or very slowly permeable soils that formed in loess (USDA-SCS, 1975). These soils are on uplands and have slopes ranging from 0 to 9 percent. Wymore soils are classified as fine, smectitic, mesic Aquertic Argiudolls. The Crete series consists of very deep, moderately well drained, slowly permeable soils that formed in loess (USDA-SCS, 1975). These soils are on interfluves and hillslopes on uplands and stream terraces on river valleys in Central Loess Plains and have slopes ranging from 0 to 11 percent. Crete soils are classified as fine, smectitic, mesic Pachic Udertic Argiustolls.

Specific management history was not available for study sites used on this project. However, many areas where study plots were established showed evidence of prior agricultural farming. This may have resulted in changes of soil physical properties.

Soil Sampling and Analysis

Purpose

The soil physical properties of bulk density and wet aggregate stability were measured because these two properties can be used to determine the potential for soil erosion due to water. Soil bulk density is an indirect measure of porosity. Wet aggregate stability suggests how well a soil can resist raindrop impact and water erosion (Nimmo, 2004). Observing differences in these soil physical properties on burned plots in comparison to unburned plots can lead to conclusions being made about water infiltration into the soil versus potential runoff.

Sampling Periods

Soil samples were collected prior to burning and post-burn for every season burned, except the fall of 2011 where only post-burn samples were taken. The date of each prescribed burn was documented (Table 2.3). Post-burn sampling dates are as follows: fall of 2011 (7 November 11), spring of 2012 (31 August 2012), fall of 2012 (13 November 2012), and spring of 2013 (28 May 2013).

Bulk Density

Intact soil cores of 4.8 cm diameter were collected at 0 to 5 cm depth from each treatment plot sampled prior to and after burning had commenced. Stainless steel sleeves (volume of 91.0 cm^3) were hammered into the soil 5.0 cm, so that the top of the sleeve was flush with the soil surface. The sleeves were excavated using a soil knife and the soil cores were placed into pre-labeled metal tins, weighed within the same day, and dried at 105°C for 48 h for gravimetric water content determination. Bulk density was determined by the core method (Blake and Hartge, 1986). Samples were collected randomly at five locations, three samples per location, along each 100 m transect sampled. Sampling was done by parting stems in order to reach the soil surface. The three samples were then averaged at each of the five locations along the transect for a total of five bulk density measurements. These five measurements were then averaged to determine an overall average bulk density for each transect sampled.

Wet Aggregate Stability

Composite samples were collected following burning in the fall of 2011. Samples were then taken prior to burning and following burning starting in the spring of 2012 at randomly selected study sites. Additional samples were collected in the fall of 2012, and in the spring of 2013 to determine effect of burning on aggregate stability. Samples from the top 0 to 5 cm soil depth were air-dried and sieved to collect aggregates >4.75 and <8 mm in size for determination of percent water-stable aggregates (WSA) and mean weight diameter (MWD) following the wet-sieving method of Kemper and Rosenau (1986). A 40 g subsample of >4.75 mm aggregates was oven dried at 105°C for 48 h to obtain gravimetric moisture content. A 50 g subsample was subjected to wet-sieving with a mechanical device that oscillated four sets of nested sieves through a vertical displacement of 35 mm at 30 oscillations min^{-1} (Grainger, Inc., Lake Forest, IL). Each nest had five sieves of 127 mm diameter and a 40 mm depth with wire mesh openings of 4.75, 2.00, 1.00, 0.50, and 0.25 mm (Newark Wire Cloth Company, Clifton, NJ). The air-dry aggregates were placed on the top (4.75 mm) sieve, saturated by capillarity with water for 10 min, and then mechanically sieved in water for 10 min. The soil remaining on each sieve after oscillation was washed into pre-weighed glass jars and oven dried at 105°C for 48 h to obtain soil mass. The oven-dry soil was soaked in a 13.9 g L^{-1} sodium hexametaphosphate solution for 48 h to facilitate the separation of soil particles and coarse fragments. The dispersed samples were then washed through the corresponding sieves in order to collect and account for coarse fragment content. Percent WSA and MWD were calculated in accord with Stone and Schlegel (2010) as:

$$\text{WSA} = (m_m - m_f)/(m_t - m_f)$$

where m_m is the oven-dry mass of material on a sieve after sieving, m_f is dry mass of fragments on the same sieve after dispersion, and m_t is total sample dry mass, and:

$$\text{MWD} = \Sigma \text{ (i=1, to 6) } (w_i/m_a)x_i$$

where w_i represents the over-dry mass of aggregates (w_1 through w_5) determined for each of the five sieve sizes (aggregates and fragments after sieving [m_m] minus fragments on the same sieve after dispersion [m_f]) and dry mass (w_6) of material passing through the sieve with 0.25 mm opening during sieving (Kemper and Rosenau, 1986), x_i represents the mean diameter of each of the six size fractions (size of smallest fraction [x_6] was calculated as 0.25mm/2), and m_a is the total dry mass of aggregates (sum of w_1 through w_6).

Statistical Analysis

A completely randomized design with 2 treatments were applied along the 100 m transects used for vegetation sampling at each site. The two treatments consisted of prescribed burning and no burning.

All data were analyzed for analysis of variance using the PROC MIXED feature of SAS 9.2 (SAS Institute, 2008). Differences between least squares means were tested using 0.10 probability level (SAS Institute, 2008). Results of effective sampling were analyzed separately per point-in-time, sampling date, due to variability in state of soil throughout the shifts in seasons. Treatment comparisons were made across study sites due to soil, climate, and management similarities among sites. The soil surface textures were all found to be silt loam, with the exception of one study plot, training area 86 transect 2, which was found to have a silty clay loam (Table 2.2). However, since the total amount of clay was found to be just beyond the threshold between silt loam and silty clay loam, and there were no apparent differences in topography and management history, this site was included in statistical analysis.

Results

Bulk Density

There was no significant impact due to burning for any sampling period on differences in soil bulk densities (Table 2.4, 2.5). Soil bulk density tended to be lower on plots burned compared to unburned sites, with the exception of samples taken in the fall of 2011 (Table 2.4).

Wet Aggregate Stability

Mean Weight Diameter

The MWD of water-stable aggregates tended to be higher in burned treatments compared to unburned treatments, with the exception of samples taken in the fall of 2012. The only significant difference between burned and unburned plots occurred for the sampling period in the fall of 2011, where MWD on burned plots were greater than unburned plots by 0.44 mm (Tables 2.4, 2.5).

Percentage of Water-Stable Aggregates by Size Fraction

Burning tended to increase the percentage of >4.75 mm aggregate size fraction across all burn treatments and years (Table 2.4). The sampling period of the fall 2011 showed a significantly higher percentage of this aggregate size fraction on burned plots in comparison to unburned plots (Table 2.4, 2.5).

The 2.00 to 4.75, 1.00 to 2.00, 0.50 to 1.00, and 0.25 to 0.50 mm WSA fractions displayed a pattern where those plots burned were observed to have a lower percentage of each fraction than unburned plots, with the exception of the 0.50 to 1.00 and 0.25 to 0.50 mm WSA were higher on burned plots than unburned plots in the fall of 2012 (Table 2.4). In the fall of 2011, burned plots showed reduced 2.00 to 4.75, 0.50 to 1.00, and 0.25 to 0.50 mm aggregate size fractions (Tables 2.4, 2.5). Due to the increased percentage of macroaggregates on burned plots, resulting decreases for the smaller aggregate size fractions on burned plots is apparent.

The total aggregate fraction of WSA and the <0.25 mm aggregate size fraction were found to be inversed on all sampling periods. On all burn treatments except samples taken in the fall of 2012, the total WSA fraction tended to be higher on burned sites than unburned sites, and burned sites tended to have a lower percent of <0.25 mm size fraction than unburned sites (Table 2.4). The exception, fall of 2012, showed a lower total WSA fraction on unburned sites and a higher percent of <0.25 size fraction on burned sites. Differences in the total aggregate fraction of WSA and the <0.25 mm aggregate size fraction were found to be significant in the fall of 2011 (Table 2.5). During this sampling period, total WSA was found to be greater on burned sites by 2.1%, and the <0.25 mm size fraction was found to be lower by 1.7% on burned sites (Table 2.4, 2.5).

Discussion and Conclusions

Effects of burning on physical soil properties depended upon timing of burn and climatic factors leading up to post-burn sampling. No significance was observed between burned and unburned sites for soil bulk density to a depth of 5 cm during this 2 yr study. Owensby and Wyrill (1973) also concluded that fire did not affect bulk density of the soil, and, while some physical changes should occur from burning, they were so slight that they could not be detected by bulk density measurements. The only increase, non-significant, in bulk density for any burn treatment and sampling period was those sites burned in the fall of 2011. These results coincide with the findings of O’Dea and Guertin (2003), who observed an increase in bulk density on plots with a prescribed burn. However, all additional sampling periods in this study observed decreases, non-significant, of ≤ 0.03 g cm^{-3} bulk density on plots burned. The differences between this study and that of O’Dea and Guertin (2003) can be attributed to geographic regional climatic factors and soils and their textures studied in Arizona. Since there was no significant differences in bulk density for all sampling periods, post-burn, observed in this study, there is no warranted concern regarding compaction and soil quality within the time after burning that sampling was completed. The fact that lower bulk densities and higher MWD tended to be on burned sites could potentially lead to increased infiltration rates, thus leading to less runoff and surface erosion following burning.

Prescribed burning has been shown to increase structure stability because of the formation of the hydrophobic film on the external surface of aggregates (Mataix-Solera and Doerr, 2004). Likewise, higher mean weight diameters on burned sites occurred in this study. Furthermore, prescribed burned sites showed a higher amount of large WSA (>4.75 mm), thus, lower amounts of small WSA (<4.75 mm). The significant differences due to burning for the fall of 2011 may be attributed to time of year sampled and precipitation factors. The five months preceding the fall 2011 sampling date had a total of 24.87 cm of precipitation. The five months preceding the fall 2012 burn sampling data had a total of 34.70 cm. However, the results following the fall 2012 burns were similar to what was expected to occur on burned sites; a lower MWD and increased smaller aggregates. This can be attributed to the differences found between the fall 2012 and fall 2011 data. Fall burning may leave a soil surface bare most of the fall and winter, but because precipitation during winter in the Great Plaints is not usually in the form of heavy rains, and soil surfaces are frozen, increased erosion rates should not be of concern. A soil’s state in the spring can be attributed to the low precipitation, freeze-thaw cycles, and freeze-drying periods that work to break down aggregates in the soil, in comparison to the differences that occurred due to burning on this study.

Aldous (1934) pointed out that the upper 3 feet of burned bluestem range were drier than those of adjacent unburned range and speculated that increased runoff caused the reduction. Anderson (1965) reported that if burning is practiced, do it in the late spring rather than earlier. Plots burned in the late spring not only had higher herbage yields, but also had more soil water than those burned earlier (Anderson, 1965). Therefore, it can reasonably be assumed that burns conducted in the fall would lead to reduced soil moisture as well.

Results from this study suggest that on these loess soils in Kansas, prescribed burns in the fall and spring do not adversely impact soil physical properties in the immediate months following a burn. In fact, an increase in MWD and decrease in bulk density is beneficial to forages and water movement into the soil. The alterations in soil properties due to burning were not found to be of a concern for increased erosion susceptibility. This is due to the rapid heating of the soil for a very short period of time, during which time the heat is rising. Investigations of prescribed burning on a wide variety of soils and burn dates are warranted in order to better determine threshold timing of burns that do not increase erosion ability of soils on a regional scale. It is also recommended that more detailed sampling should be conducted where soils are sampled on a monthly or bi-monthly basis post-burn for a year in order to observe possible differences following spring reductions in non-capillary pore space.

Figures and Tables

Figure 2.1 A) Location of Fort Riley Military Installation, KS. B) Map of boundaries of Fort Riley Military Installation, 40,434 ha. C) Example of map for soil determination of each line transect.

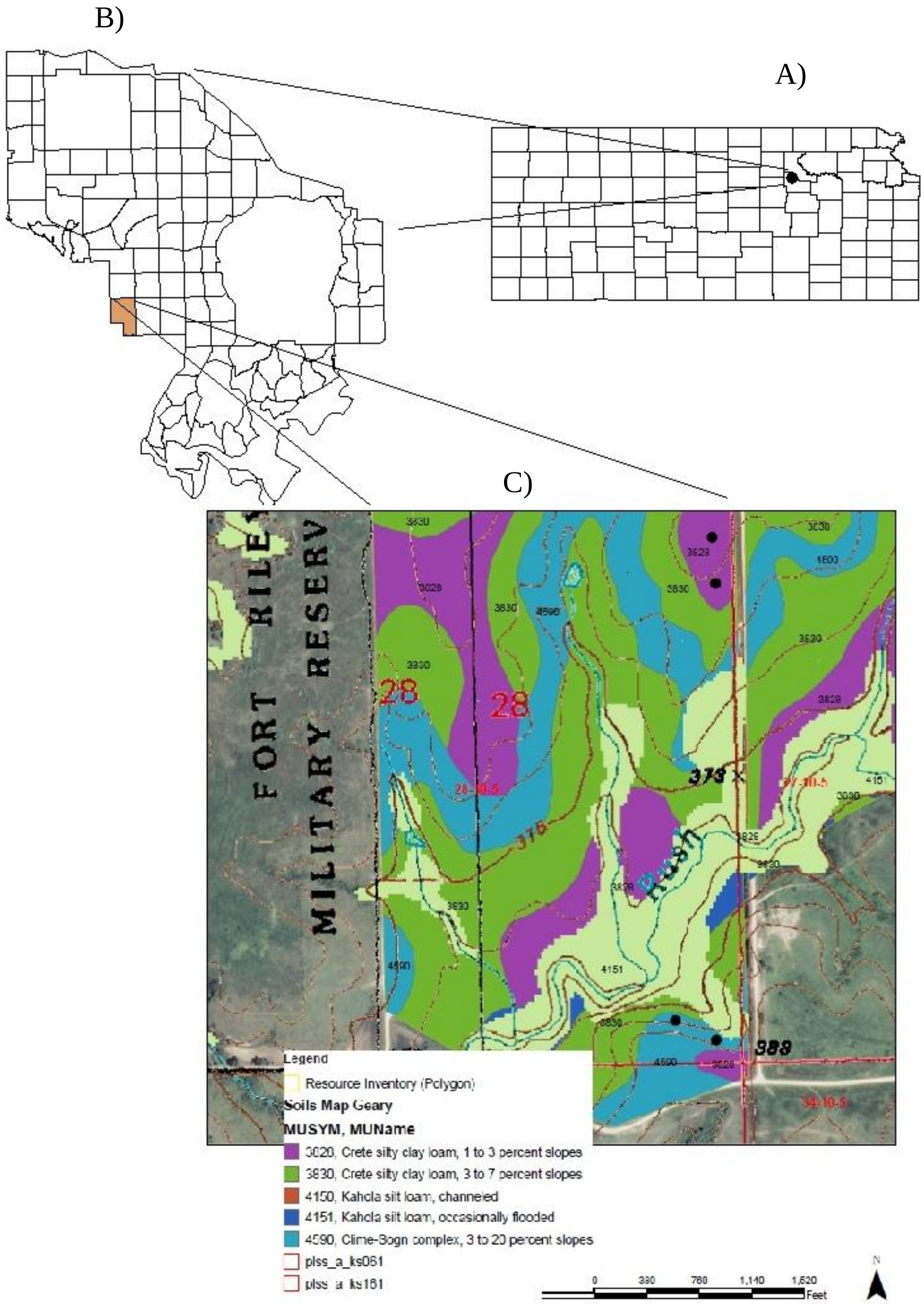

Table 2.1 Percent slopes of line transects where "." denotes missing data.

Area	Transect	Percent Slope
25A	1	6.1
25B	2	2.0
26A	1	5.9
37A	1	2.9
40A	1	0.5
40B	2	3.7
44A	1	3.3
44B	2	3.7
47A	1	3.5
47B	2	15.2
48A	1	4.1
48B	2	2.6
49A	1	0.5
49B	2	3.1
51A	1	1.7
51B	2	1.4
52A	1	0.9
52B	2	1.2
54A	1	4.9
54B	2	3.1
65A	1	4.7
65B	2	4.5
74A	1	.
74B	2	.
85A	1	4.9
85B	2	0.9
86A	1	2.5
86B	2	2.0
93A	1	.
93B	2	.
97A	1	2.8
97B	2	8.4

Table 2.2 Total sand, silt, and clay fractions of line transects and textural class.

Area	Transect	Total Sand	Total Silt	Total Clay	Textural Class
25A	1	19.5	67.5	13.0	Silt Loam
25B	2	11.9	70.4	17.7	Silt Loam
26A	1	9.9	66.0	24.1	Silt Loam
37A	1	6.8	72.6	20.6	Silt Loam
40A	1	11.7	74.8	13.5	Silt Loam
40B	2	13.3	67.4	19.3	Silt Loam
44A	1	13.9	63.3	22.8	Silt Loam
44B	2	13.0	66.7	20.3	Silt Loam
47A	1	9.3	64.4	26.3	Silt Loam
47B	2	17.9	68.3	13.8	Silt Loam
48A	1	16.5	60.5	23.0	Silt Loam
48B	2	11.9	66.4	21.7	Silt Loam
49A	1	8.0	71.2	20.8	Silt Loam
49B	2	7.6	72.9	19.5	Silt Loam
51A	1	8.0	72.6	19.4	Silt Loam
51B	2	9.3	72.6	18.1	Silt Loam
52A	1	18.9	63.4	17.7	Silt Loam
52B	2	8.8	76.2	15.0	Silt Loam
54A	1	6.5	67.9	25.6	Silt Loam
54B	2	8.3	70.7	21.0	Silt Loam
65A	1	13.3	74.4	12.3	Silt Loam
65B	2	20.3	60.0	19.7	Silt Loam
85A	1	7.3	78.9	13.8	Silt Loam
85B	2	9.5	73.8	16.7	Silt Loam
86A	1	12.8	74.2	13.0	Silt Loam
86B	2	5.2	63.5	31.3	Silty Clay Loam
93A	1	7.0	74.2	18.8	Silt Loam
93B	2	4.8	74.7	20.5	Silt Loam
97A	1	6.8	72.5	20.7	Silt Loam
97B	2	6.8	69.6	23.6	Silt Loam

Table 2.3 Calendar date of each prescribed burn performed across line transects.

Area	Transect	Treatment	Burn 1	Burn 2
26A	1	Unburned	N/A	N/A
37A	1	Unburned	N/A	N/A
44B	2	Unburned	N/A	N/A
49A	1	Unburned	N/A	N/A
51A	1	Unburned	N/A	N/A
52A	1	Unburned	N/A	N/A
52B	2	Unburned	N/A	N/A
86B	2	Unburned	N/A	N/A
40A	1	Fall Burn	10/6/2012	N/A
40B	2	Fall Burn	10/6/2012	N/A
85A	1	Fall Burn	9/29/2012	N/A
85B	2	Fall Burn	9/29/2012	N/A
25A	1	Fall Burn	10/1/2011	N/A
25B	2	Fall Burn	10/1/2011	N/A
49B	2	Fall Burn	8/11/2011	N/A
51C	1	Spring Burn	12/3/2012	N/A
51B	2	Spring Burn	12/3/2012	N/A
52C	2	Spring Burn	12/3/2012	N/A
54A	1	Spring Burn	3/29/2013	N/A
54B	2	Spring Burn	3/29/2013	N/A
97A	1	Spring Burn	3/14/2013	N/A
97B	2	Spring Burn	3/14/2013	N/A
44A	1	Spring Burn	1/24/2012	N/A
47A	1	Spring Burn	4/9/2012	N/A
47B	2	Spring Burn	4/9/2012	N/A
65A	1	Spring Burn	3/4/2012	N/A
65B	2	Spring Burn	3/4/2012	N/A
86A	1	Spring Burn	4/16/2012	N/A
48A	1	Successive Spring Burns	4/9/2012	3/29/2013
48B	2	Successive Spring Burns	4/9/2012	3/29/2013
74A	1	Successive Spring Burns	4/1/2012	12/1/2012
74B	2	Successive Spring Burns	4/1/2012	12/1/2012
93A	1	Successive Spring Burns	4/1/2012	12/1/2012
93B	2	Successive Spring Burns	4/1/2012	12/1/2012

Table 2.4 Means of soil bulk density (g cm^{-3}), mean weight diameter (MWD) (mm), and water stable aggregate (WSA) size classes (%) for sampling periods of study.

Property	Sampling Period							
	Fall 2011		Fall 2012		Spring 2012		Spring 2013	
	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned
Bulk Density	0.83	0.94	1.11	1.08	1.09	1.07	1.14	1.12
MWD	5.20	5.64	4.99	4.97	4.44	4.77	4.75	5.04
WSA Size Class								
>4.75 mm	73.4	83.1	69.4	69.7	54.5	61.4	64.3	71.2
2.00-4.75 mm	12.3	7.9	12.5	11.6	23.8	21.2	14.3	11.1
1.00-2.00 mm	4.6	3.2	6.3	5.3	6.9	6.5	7.2	5.2
0.50-1.00 mm	3.4	2.1	4.3	4.5	4.3	3.9	4.9	4.1
0.25-0.50 mm	2.0	1.2	2.7	3.5	2.7	2.0	3.5	2.9
Total Ag	95.1	97.2	94.9	94.4	92.1	94.8	94.0	94.2
<0.25 mm	4.2	2.5	4.8	5.4	7.7	5.0	5.8	5.4

Table 2.5 Table of p-values of comparisons between soils burned and unburned on Fort Riley. Soil physical properties include bulk density, mean weight diameter (MWD), and water stable aggregates (WSA) size classes for soil sampling periods post-burn. Post-burn sampling dates are as follows: fall 2011 (7 November 11), spring 2012 (31 August 2012), fall 2012 (13 November 2012), and spring 2013 (28 May 2013).

Property	Sampling Period			
	Fall 2011	Fall 2012	Spring 2012	Spring 2013
Bulk Density	0.11	0.12	0.62	0.44
MWD	0.03	0.95	0.40	0.29
WSA Size Class				
>4.75 mm	0.03	0.98	0.43	0.28
2.00-4.75 mm	0.02	0.82	0.52	0.37
1.00-2.00 mm	0.11	0.66	0.81	0.25
0.50-1.00 mm	0.07	0.88	0.69	0.42
0.25-0.50 mm	0.06	0.23	0.39	0.46
Total Ag	0.02	0.80	0.24	0.91
<0.25 mm	0.03	0.76	0.23	0.82

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Appendix A - Effects of Prescribed Burning on Vegetation

Additional ANOVA Tables

Table A.1 ANOVA table of mean changes of sericea lespedeza plant composition the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.26	0.77
Ecological Site	1	28	0.24	0.63
Year	1	28	0.08	0.77
Burn Treatment x Ecological Site	2	28	0.05	0.95
Burn Treatment x Year	2	28	0.15	0.86
Ecological Site x Year	1	28	0.97	0.33

Table A.2 ANOVA table of mean changes of sericea lespedeza plant composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.80	0.21
Ecological Site	1	10	0.03	0.87
Burn Treatment x Ecological Site	1	9	0.02	0.89

Table A.3 ANOVA table of mean changes of sericea lespedeza plant composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	2.00	0.18
Ecological Site	1	10	0.02	0.89
Burn Treatment x Ecological Site	1	9	0.02	0.90

Table A.4 ANOVA table of mean changes of sericea lespedeza plant density the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.16	0.85
Ecological Site	1	28	0.24	0.63
Year	1	28	0.08	0.78
Burn Treatment x Ecological Site	2	28	0.25	0.78
Burn Treatment x Year	2	28	0.02	0.98
Ecological Site x Year	1	28	0.50	0.48

Table A.5 ANOVA table of mean changes of sericea lespedeza plant density for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.45	0.72
Ecological Site	1	11	0.28	0.61
Burn Treatment x Ecological Site	2	9	0.06	0.94

Table A.6 ANOVA table of mean changes of sericea lespedeza plant density for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	1.44	0.28
Ecological Site	1	11	1.37	0.27
Burn Treatment x Ecological Site	2	9	0.17	0.84

Table A.7 ANOVA table of mean changes of sericea lespedeza plant frequency for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	0.95	0.45
Ecological Site	1	10	0.57	0.47
Burn Treatment x Ecological Site	1	9	0.23	0.64

Table A.8 ANOVA table of mean changes of sericea lespedeza plant frequency for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	0.26	0.85
Ecological Site	1	10	2.71	0.13
Burn Treatment x Ecological Site	1	9	1.88	0.20

Table A.9 ANOVA table of mean changes of sericea lespedeza plant foliar cover the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.07	0.93
Ecological Site	1	28	1.12	0.30
Year	1	28	1.04	0.32
Burn Treatment x Ecological Site	2	28	0.38	0.69
Burn Treatment x Year	2	28	1.18	0.32
Ecological Site x Year	1	28	0.14	0.71

Table A.10 ANOVA table of mean changes of sericea lespedeza plant foliar cover for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.80	0.52
Ecological Site	1	11	0.08	0.79
Burn Treatment x Ecological Site	2	9	0.59	0.58

Table A.11 ANOVA table of mean changes of sericea lespedeza plant foliar cover for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.89	0.48
Ecological Site	1	11	3.04	0.11
Burn Treatment x Ecological Site	2	9	0.72	0.51

Table A.12 ANOVA table of mean changes of rough-leaf dogwood plant density for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.68	0.58
Ecological Site	1	11	1.34	0.27
Burn Treatment x Ecological Site	2	9	0.97	0.42

Table A.13 ANOVA table of mean changes of rough-leaf dogwood plant density for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.68	0.58
Ecological Site	1	11	0.01	0.92
Burn Treatment x Ecological Site	2	9	0.10	0.90

Table A.14 ANOVA table of mean changes of rough-leaf dogwood plant frequency the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.72	0.49
Ecological Site	1	28	0.00	0.95
Year	1	28	1.96	0.17
Burn Treatment x Ecological Site	2	28	1.01	0.38
Burn Treatment x Year	2	28	0.56	0.58
Ecological Site x Year	1	28	1.20	0.28

Table A.15 ANOVA table of mean changes of rough-leaf dogwood plant frequency for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	2.55	0.11
Ecological Site	1	10	0.27	0.61
Burn Treatment x Ecological Site	1	9	0.00	0.95

Table A.16 ANOVA table of mean changes of rough-leaf dogwood plant frequency for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	2.40	0.13
Ecological Site	1	10	0.44	0.52
Burn Treatment x Ecological Site	1	9	0.36	0.56

Table A.17 ANOVA table of mean changes of rough-leaf dogwood plant foliar cover the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.11	0.90
Ecological Site	1	28	0.15	0.70
Year	1	28	0.03	0.87
Burn Treatment x Ecological Site	2	28	0.52	0.60
Burn Treatment x Year	2	28	1.13	0.34
Ecological Site x Year	1	28	0.02	0.90

Table A.18 ANOVA table of mean changes of rough-leaf dogwood plant foliar cover for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	0.72	0.56
Ecological Site	1	10	0.17	0.69
Burn Treatment x Ecological Site	1	9	0.01	0.91

Table A.19 ANOVA table of mean changes of rough-leaf dogwood plant foliar cover for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	0.48	0.71
Ecological Site	1	10	0.00	0.99
Burn Treatment x Ecological Site	1	9	0.02	0.90

Table A.20 ANOVA table of mean changes of additional woody plant density for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	1.08	0.40
Ecological Site	1	11	1.49	0.25
Burn Treatment x Ecological Site	2	9	0.95	0.42

Table A.21 ANOVA table of mean changes of additional woody plant frequency for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	1.93	0.18
Ecological Site	1	11	1.18	0.30
Burn Treatment x Ecological Site	1	10	2.10	0.18

Table A.22 ANOVA table of mean changes of additional woody plant foliar cover the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.13	0.88
Ecological Site	1	28	0.14	0.71
Year	1	28	0.09	0.77
Burn Treatment x Ecological Site	2	28	0.08	0.91
Burn Treatment x Year	2	28	0.07	0.93
Ecological Site x Year	1	28	0.24	0.63

Table A.23 ANOVA table of mean changes of additional woody plant foliar cover for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.57	0.64
Ecological Site	1	11	0.00	0.95
Burn Treatment x Ecological Site	2	9	0.17	0.85

Table A.24 ANOVA table of mean changes of additional woody plant foliar cover for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	11	0.39	0.76
Ecological Site	1	11	0.47	0.51
Burn Treatment x Ecological Site	2	9	0.38	0.69

Table A.25 ANOVA table of mean changes of warm-season grass composition for the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	0.57	0.57
Ecological Site	1	28	0.76	0.39
Year	1	28	0.42	0.52
Burn Treatment x Ecological Site	2	28	0.95	0.40
Burn Treatment x Year	2	28	0.32	0.73
Ecological Site x Year	1	28	0.03	0.87

Table A.26 ANOVA table of mean changes of warm-season grass composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.39	0.30
Ecological Site	1	10	0.13	0.73
Burn Treatment x Ecological Site	1	9	2.75	0.13

Table A.27 ANOVA table of mean changes of warm-season grass composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.11	0.39
Ecological Site	1	10	0.09	0.77
Burn Treatment x Ecological Site	1	9	0.36	0.56

Table A.28 ANOVA table of mean changes of cool-season grass composition for the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	1.51	0.24
Ecological Site	1	28	0.03	0.87
Year	1	28	0.18	0.68
Burn Treatment x Ecological Site	2	28	0.43	0.65
Burn Treatment x Year	2	28	0.10	0.90
Ecological Site x Year	1	28	0.38	0.54

Table A.29 ANOVA table of mean changes of cool-season grass composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.21	0.36
Ecological Site	1	10	0.06	0.81
Burn Treatment x Ecological Site	1	9	0.24	0.64

Table A.30 ANOVA table of mean changes of cool-season grass composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.68	0.23
Ecological Site	1	10	0.80	0.39
Burn Treatment x Ecological Site	1	9	0.03	0.87

Table A.31 ANOVA table of mean changes of total forb composition for the first growing season after burning in the fall 2011, spring 2012, fall 2012, and spring 2013. Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	2	28	1.31	0.29
Ecological Site	1	28	0.73	0.40
Year	1	28	0.23	0.64
Burn Treatment x Ecological Site	2	28	0.89	0.42
Burn Treatment x Year	2	28	0.82	0.45
Ecological Site x Year	1	28	1.14	0.30

Table A.32 ANOVA table of mean changes of total forb composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the growing season pre-burn (summer 2011) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.53	0.27
Ecological Site	1	10	0.18	0.68
Burn Treatment x Ecological Site	1	9	2.77	0.13

Table A.33 ANOVA table of mean changes of total forb composition for burns conducted on plots in the fall 2011, spring 2012, successive burns spring 2012 and 2013, and unburned 2011. Changes measured were between the first growing season post-burn (summer 2012) and the second growing season post-burn (summer 2013). Num DF is the numerator degrees of freedom and Den DF is the denominator degrees of freedom for factorial analysis.

Source of Variation	Num DF	Den DF	F Value	Pr > F
Burn Treatment	3	10	1.59	0.25
Ecological Site	1	10	0.01	0.94
Burn Treatment x Ecological Site	1	9	0.33	0.58