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The Effects of Fire Versus Mowing on Prairie Plant Communities

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16. Abstract (Limit: 200 words)

The primary goals of this project are to discover management processes which benefit a restored prairie and reduce the need for prescribed burning. Moreover, because of the interdependence of the plants and soil, there is a strong focus on the soil community as a driving force of the vegetation. Consequently, our objectives were to assess the effects of manipulation (burning, mowing) on: (1) the vegetative community, (2) the belowground mycorrhizal fungal community, and (3) on soil parameters.

Prescribed burning has the strongest effects on plant community composition and is the most effective method to increase aboveground plant biomass in a restored tallgrass prairie. Burning especially favors warm season grasses (WSG) and legume species, though it also favors certain annual species. Spring haying is an acceptable alternative to spring burning, though its effects are less dramatic than the burn. In particular, haying does not favor WSG as extensively and may not damage cool-season species as thoroughly as burning. Adding lime to hayed prairie may help benefit the cool-season plants, native and exotic. However, utilizing mowing instead of burning probably does not differ much from leaving the prairie untreated.

The process of removing litter seems to be the most important cause of the ecosystem response to prescribed burning. Hayed plots are the most similar to burned plots in terms of soil moisture, temperature, and litter quantity. Hence, litter removal by haying will likely be a sufficient practice to replace prescribed burning at many sites.

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The Effects of Fire Versus Mowing on Prairie Plant Communities

Final Report

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Executive Summary

The Minnesota Department of Transportation (Mn/DOT) is responsible for establishing and maintaining extensive tracts of roadside grassland in Minnesota. Although several studies address the maintenance of prairies, few of them have investigated the establishment and maintenance of restored prairies. Furthermore, limited information is available about the maintenance of native species of restored prairie plant communities along roadways.

Hence, the primary goals of this project are to discover management processes to benefit a restored prairie and reduce the need for prescribed burning. Moreover, because of the interdependence of the plants and soil, there is a strong focus on the soil community as a driving force of the vegetation. Consequently, our objectives were to assess the effects of manipulation (burning, mowing) on: (1) the vegetative community, (2) the below-ground mycorrhizal fungal community, and (3) soil parameters.

Prescribed burning has the strongest effects on plant community composition and is the most effective method to increase aboveground plant biomass in a restored tallgrass prairie. Burning especially favors warm season grasses (WSG) and legume species, though it also favors certain annual species. In addition, burning helps to control some exotic species, especially those that are green at the time of the burn. Spring haying is an acceptable alternative to spring burning, though its effects are less dramatic than the burn. In particular, haying does not favor WSG as extensively and may not damage cool-season species as thoroughly as burning. Adding lime to hayed prairie may help to benefit the cool-season plants, native and exotic. A longer study period will be necessary to conclusively determine the effects of haying as well as any potential benefits of lime in combination with haying. However, utilizing mowing instead of burning probably does not differ much from leaving the prairie untreated. Therefore, in order to mimic prescribed spring burning, haying in the spring may be the best technique available.

Adding arbuscular mycorrhizal inoculum to soils with low mycorrhizal inoculum potential may have long-term benefits. Such results were obtained at the JES research site, which was inoculated as part of a previous study in the mid-nineties. In addition, removal of vegetation by burning or haying appears to be the most effective way to increase the mycorrhizal structures associated with prairie vegetation.

The process of removing litter seems to be the most important aspect that causes the ecosystem response to prescribed burning. Hayed plots are the most similar to burned plots in terms of soil moisture, temperature, and litter quantity. Consequently, nitrogen levels, which are likely to affect plant diversity, are similar between these two treatments. Liming did not seem to produce any measurable effects on nutrient levels, though changes in soil pH may affect plant uptake of these nutrients. Ultimately, burning and haying eliminate high carbon litter and create warmer, drier soil. This helps contribute to an increase in plant productivity found on burned plots. Therefore, litter removal by haying will likely be a sufficient practice to replace prescribed burning at many sites.

Chapter 1. Introduction

Management is a crucial component of the establishment of native vegetation and the development of a diverse and healthy plant community. For the Minnesota Department of Transportation (Mn/DOT), management techniques are particularly important for controlling erosion and preventing undesirable plant species within roadside vegetation. It is these objectives that make native plants ideally suited for the highways systems of Minnesota. The common and easily established native prairie grasses have deeper roots (1) and grow better in toxin-contaminated soils than most non-native grasses, especially brome-grass (2). Furthermore, many of the commonly planted non-native plant species, are becoming weed problems and have been added to noxious weed lists in several states (3).

Native species, especially the dominant warm-season grasses, also help discourage weeds. These aggressive competitors rapidly utilize soil nutrients, thereby preventing the establishment of invasive and noxious plant species (4). Besides native grasses, various plant species have different requirements and specialize in different habitats or microhabitats, known as niches (4). By maintaining a wide array of native plants that fill an assortment of niches, there is less likelihood of an undesirable species becoming established in the community (4). Furthermore, if noxious species are established, a diverse native community will help prevent their rapid expansion by utilizing all of the available niches.

The best management practice used on prairies to help promote the native species is prescribed burning. Burns are usually performed in the spring because this is the most practical time of year. It is beneficial to the dominant native grasses and helps control many undesirable exotic plants. However, prescribed burns can be difficult and expensive to perform safely near traffic and in urban areas. Therefore, this research seeks to develop alternative methods of management to favor a diverse native plant community and control undesirable species.

The primary goals of this project are to discover management processes to benefit a restored prairie and reduce the need for prescribed burning. Moreover, because of the interdependence of the plants and soil, there is a strong focus on the soil community as a driving force of the vegetation. Consequently, our objectives were to assess the effects of manipulation (burning, mowing) on:
(1) The vegetative community.
(2) The belowground mycorrhizal fungal community.
(3) Soil parameters.
Chapters 2 and 3 address objective 1; chapter 4 focuses on objective 2; and chapter 5 satisfies objective 3.

Three experiments were designed to test management methods at three separate sites. First, we utilized two sites that had been used in the past for prairie research; the JES Research Site near Cambridge, Minnesota and the Shakopee Research Site, in Shakopee, Minnesota. At the JES site, burns were performed and the plots then compared to untreated plots. The Shakopee site compared spring burning to spring haying, which involves mowing and then removal of the litter. In the late summer at Shakopee, several plots were mowed, without removal, and several were hayed to test the difference in seasonality of the management methods.

A third site, Murphy Lake Prairie, was chosen specifically for this experiment at Murphy-Hanrehan Regional Park in Savage, Minnesota. This site compared prescribed burning and untreated plots to plots that were hayed and some that were mowed. All of the treatments at Murphy Lake Prairie were performed twice on each plot, once each in the spring of 2001 and 2002. Additionally, lime was added at the beginning of the project to many of the plots that were hayed and mowed to test for the benefits of this soil amendment. Thus, this experiment tests the use of haying as an alternative to spring prescribed burning on a restored tallgrass prairie. To improve haying as a technique, lime was added as a possible substitute for ashes that fall on the soil during a fire. Mowing, on the other hand, was tested because this management method is simpler and more practical during the spring than haying.

The effects of the treatments at all sites are discussed in the following chapters. Since the treatments that were performed at each site overlap with other sites, the results from all sites are used to support conclusions that can be drawn from these experiments. Therefore, many of these conclusions are very robust, especially when similar significant differences were measured for the same variable on all three sites. Contradictory results were rarely found for any variables between two sites. The use of these three sites was, consequently, very beneficial to this project.

Chapter 2 describes data obtained that concerns plant community composition at each of the sites. Measurements were made of percent cover for each species found at the sites. Cover is an estimation of the amount of ground area that a species conceals beneath its leaves and stems. Next, flowering stems were counted for each species in each plot to estimate the abundance of healthy, reproductively active plants occur at the site. This data is also important because perennial plants that are flowering are well established at the site and are likely to contribute to the future population of that species. These plants also contribute to habitat for animals that feed on nectar, pollen, and fruit; thus, they are quite important to the entire biological community. Finally, the plant community was assessed by frequency, or how often a certain species occurs in a given area. This tells how common a plant is within each treatment, even if the individual plants are very small and do not reproduce.

Plant community composition on prairies changes frequently and may be affected by a large variety of ecosystem processes and characteristics. Management practices are certainly one of the most important catalysts of vegetation change. In particular, spring prescribed burning is known to favor the dominant warm-season grasses and control woody plants and exotic cool-season grasses. In addition, burning damages many of the forb, or wildflower, species (5) and promotes the germination of many seeds (6). The primary cause of these effects from burning is the removal of dead aboveground plant material, litter (7). The goal of chapter 2 is to compare community composition on each mow, hay, and lime treatment against burned and untreated prairies. This will reveal the feasibility of using these treatments to accomplish the same management objective as burning in terms of desirable or undesirable plant species.

An extension of plant community composition is plant productivity, which tells the rate that the plants are growing. This data is shown in Chapter 3 and is measured by harvesting aboveground plant material from each plot and finding the mass of the dried biomass. Material was collected for the entire community in late August of each year. In addition, collections were made three times in 2002 for the most abundant species: big bluestem, Indian grass, and bergamot. The biomass samples were only collected at the Murphy Lake Prairie; however, plant heights of the common species were taken to supplement this data at all three sites.

The purpose of Chapter 3 is to compare the growth rates of the plant community as well as that of important individual species between burning and the other treatments. Burning has been shown to increase plant productivity because of the removal of aboveground litter (8). This removal process increases light levels at the soil surface, thereby warming the soil and providing more energy for the growth of many of the species (8). The data presented here will show whether haying causes a similar response to burning. Lime additions will reveal the influence of soil pH on this productivity.

Chapter 4 addresses the influence of the treatments on mycorrhizal fungi, an important aspect of the plant community that is poorly understood. Arbuscular mycorrhizae are symbioses between plant roots and soil fungi. The fungus helps the plant acquire nutrients, especially phosphorus, and the plant provides the fungus with carbon in the form of sugar (9). The fungi colonize segments of the plant roots. Colonization is measured as a percentage of the length of roots that harbor fungi (10). Mycorrhizal colonization data for Chapter 4 is measured based on the various types of fungal structures that are found in the roots for each treatment. There are few studies analyzing the effects of aboveground management treatments on mycorrhizae. One important experiment found no influence of burning or mowing on mycorrhizal colonization but determined that burning increased the number of fungal spores in the soil (11). Therefore, data presented here represent an important foundation for the future of community management.

The effects of manipulation on soil parameters are discussed in Chapter 5. These data were collected from the Shakopee and Murphy Lake Prairie sites to compare the effects of the treatments on soil nutrients, moisture, and temperature. In addition, nitrogen mineralization rates were measured to analyze changes of this important biological process. This rate is the net release of inorganic nitrogen, nitrate and ammonium, from organic matter during decomposition. It is significant because it represents the amount of nitrogen being made available for plant uptake. Nitrogen usually limits plant productivity and is a major factor in determining plant composition on prairies (4, 12). Nitrogen mineralization rates are affected by other soil properties such as moisture, pH, and temperature (13). Consequently, these measurements will help show the subsequent affect of each property on soil nitrogen.

Burning is especially important to the nitrogen cycle in prairie ecosystems because the fire removes nearly all of the nitrogen that is present in the aboveground biomass at the time of the burn. Nitrogen is volatilized into the atmosphere as a gas. Haying will remove this nitrogen, but it also removes other nutrients present in the plant biomass. Specifically, nutrients that are not lost in a fire are the basic cations, calcium and magnesium, which are returned to the soil in ash. The lime addition is used to replace these cations in order to maintain soil pH after haying treatments. Soil pH is a significant constraint on the suitability of many plant species to given soils. Chapter 5 discusses the effects of management practices on the soil factors because soil nitrogen and pH are central determinants of plant composition and productivity.

Chapter 2. The effects of fire versus mowing on plant composition

2.1 Overview

Prescribed burning on native prairie is often difficult, but its effects on the plant community are considered essential to the diversity and character of the ecosystem (14). Studies on native prairies have shown that manual removal of aboveground biomass results in plant communities nearly identical to those burned at the same time (7, 15). Removal in these experiments was performed on small plots and clipped by hand to the soil surface, which is not very practical for vegetation managers. Perhaps haying, mowing several inches above the soil surface then raking the fallen litter, could serve a similar function and be accomplished mechanically on broad areas to replace or supplement prescribed burns

Prescribed burning is not necessarily an ideal management treatment, especially when it is performed in the spring, because it tends to favor warm-season grasses (WSG) at the expense of many forb species (14, 16). Restorations are frequently low in forb abundance and diversity because of the high cost to include forbs in seed mixes and difficulty growing many of the species. As a result, burning may be conflict with the goals of many restoration managers that are trying to create a diverse plant community. Many forbs emerge before spring burns, so the fire damages the aboveground plant tissues (16). Haying may avoid damaging these plants because the mower will cut above low-growing and newly-emerged plants.

In this chapter we discuss the plant community response to an experiment that tests spring haying versus prescribed burning. In addition, because of the difficulties and expenses related to the inclusion of forb species into seed mixes for restoration, we have added treatments that may improve plant diversity on restored prairies. First, we have mowed plots without removing the litter. This treatment is expected to decrease available nitrogen in the soil because of the relatively high carbon in the stems of the abundant WSG (17, Chapter 5). Decreasing soil nitrogen is expected to increase overall plant diversity (4). Conversely, litter is also expected to decrease plant germination and establishment (6, 18); perhaps existing forbs plants will increase in size and vigor under such conditions.

Next, we have added lime to some hayed plots and some mowed plots in order to favor conditions suitable to many forb species and to return calcium to the soil. Whereas the native grasses tend to have a broad soil pH range for optimal growth, many forbs are quite restricted by pH and most tend to do well in soil between pH 6.5 and 7 (1). Thus, the lime addition treatments were designed to favor many of the forb species in order to get diverse populations established. Secondly, lime contains calcium, which is present in the plant material that is taken from the plot by haying. In a prescribed burn calcium and other basic cations are returned to the soil in ash. Liming is meant to counteract this removal on hayed prairie.

2.2 Methods

2.2.1 Murphy-Hanrehan Site

The Murphy Lake Prairie is a restored tallgrass prairie in Murphy-Hanrehan Regional Park, Credit River Township, Scott County, Minnesota. The prairie is dominated by big bluestem (*Andropogon gerardii* Vitman) and Indian grass (*Sorghastrum nutans* (L.) Nash). Other common species are little bluestem (*Schizachyrium scoparium* (Michx.) Nash), wild bergamot (*Monarda fistulosa* L.), black-eyed Susan (*Rudbeckia hirta* L.), Canada wild rye (*Elymus canadensis* L.), and horseweed (*Conyza canadensis* (L.) Cronq). A list of the common species at this site is included in Appendix A. The area selected for study is on the Dakota loam soil series, an Argiudoll, with less than 2 percent slopes. A small portion of the site also lays on the Zimmerman soil series, a Udipsamment.

In the summer of 2000, 60 plots were established on the restored prairie in two sets of grid systems. The plots are all 100 meters^2 with a 2-meter buffer between them. Six treatments, performed in the spring of 2001 and 2002, are assigned to each plot such that each treatment occurs once in each block of 6 plots (see Appendix B). Thus, each treatment is replicated ten times in the blocking pattern. Treatments were performed in 2001, May 4-9, and in 2002, April 23-30. For the entire site each year, 10 plots were burned and 40 plots were mowed, 20 of which were raked (hayed). In addition, burned lime was added to 10 each of the mowed and hayed plots. Finally, 10 plots were left untreated as the control.

Mowing was performed with a Billy Goat brand Outback® brush cutter mower; this rotary blade mower essentially laid the vegetation down after cutting. Haying followed the mow treatment within a day or two by hand raking the litter to the edges of each plot. Raking was complete when most of the loose litter was removed and most of the bare soil exposed.

Ten of the 20 hayed plots and ten of the 20 mowed plots had lime added in 2001. Vertical pulverized quicklime from the Mississippi Lime Company, known as burned lime or Calcium Oxide, CaO, was added at 11.34 kg per plot (25 lbs/plot) or 1134 kg/ha (1012 lbs/acre). This is the neutralizing equivalent of 2025 kg/ha $CaCO_3$ (1807 lbs/acre ag-lime): 0.56 kg CaO is equivalent to 1 kg $CaCO_3$ (19). Lime was only added one year because of this powerful neutralizing ability.

Burns were completed by trained burn crews from Three Rivers Park District Natural Resources Management Division. Each fire was started with a drip torch at the downwind edge of the plot, once the fire had moved about two meters into the plot a head fire was started on the upwind side. Each plot burned for less than 4 minutes with flames commonly 3 meters high. All burns were thorough, with no living green tissue left in the plots.

Vegetation measurements were taken with several different techniques. The first method is a cover estimation using modified Daubenmire (20) plots. A 2-meter by 2-meter permanent cover plot was established in each plot. Every species that was found in this cover plot was placed into one of 10 cover classes: 1) present but does not contribute significant cover; 2) less than 1%; 3) 1-5%; 4) 5-10%; 5) 10-25%; 6) 25-40%; 7) 40-60%; 8) 60-75%; 9) 75-95%; and 10) 95-100%. For each plot, the total may exceed 100% since there are multiple layers of vegetation. In 2002, the 2 by 2-meter permanent cover plot was divided into four 1 square-meter quadrats to give more accurate cover and increase statistical power.

The second method for vegetation analysis uses a 1-meter by 1-meter quadrat at 10 random locations throughout each plot. Within each quadrat, the number of stems with one or more flowers was counted for each species to give flowering-stem density. Flowering stems of big bluestem and Indian grass were only counted in one-quarter square-meter quadrat because of the high number of flowering stems. Any species that was present in the square-meter quadrat was counted as present. Plant species frequency is determined by the percent of 1-square-meter quadrats in which each plant species occurs. In 2002, frequency data also included the four quadrats in the permanent cover plot. Since one permanent cover plot was also used for flower counts there were a total of thirteen 1 square-meter quadrats for frequency in that year. Dandelion flowering stems were not counted because of the difficulty following this species for the season.

2.2.2 Shakopee Site

The Mn/DOT Shakopee Roadside research site is located south of the intersection of Highways 101 and 169, in the city of Shakopee. The present study plots were first established in 1997 for Mn/DOT Final Report 2000-30 (21). The overall plant community has changed since the previous research. Therefore, a list of the most common species in 2001 and their average cover on the whole site is shown in Appendix C. On this site, 25 of the existing 60 plots have been assigned to one of five treatments: April prescribed burn, April hay, August mow, August hay, and an untreated control. The plots are laid out in a randomized block pattern with 5 blocks, thus there are five replicates of each treatment. Each plot is 2-meters by 2-meters in a grid with 2-meter buffers between plots. April treatments occurred on April 24, 2000 and August treatments occurred on August 28, 2000. Prescribed burns were performed by fires set into the wind with kerosene drip torches to thoroughly burn all existing vegetation. Fires were deliberately allowed to burn into buffer zones to minimize edge effects within the plot.

Vegetation was measured with two different sampling techniques. The first vegetation method was the density of flowering stems of WSG species. The number of flowering stems in each plot was counted for all species of WSG in September of 2000, 2001, and 2002. Any stem with a flowering head was counted. Second, cover estimations were made for every species in each plot. This technique is the same as the method used at Murphy Lake Prairie in 2000 and 2001 (see section 2.2.1).

2.2.3 JES

The JES site is located on the Anoka sand plain, north of Cambridge, MN. The plots are dominated by big bluestem with Indian grass and little bluestem. This site was the location of previous experiment done in relation to prairie restoration described in detail in Mn/DOT Final Report 96-16 (22, 23). The previous experiment, established in June 1995, involved applying mycorrhizal inoculum to 1/3 of the plots.

On this site, there are 24 randomized plots, each measuring 1 by 2 meters. The plots were paired according to previous treatments, such that each plot was paired with another plot, its nearest neighbor, which had received the identical treatment. Burns were conducted on May 2nd, 2000 on one plot of each of these pairs, 12 plots in all. Vegetation analysis was done in the summer and fall of each year. The summer analysis was done to record the forbs and CSG. The fall analysis was done to accurately determine late flowering plant species and differentiate the WSG. The summer analysis took place in mid-July of 2000-2002; and the fall analysis occurred from late September to early October of 2000-2002. Percent cover was analyzed as described in section 2.2.1. In addition, during the fall analyses, big bluestem and Indian grass flowering stems were counted for each plot.

2.2.4 Analysis

For many analyses, plant species have been placed into functional groups. These groupings are used to capture community responses according to groups of species that tend to respond similarly to the designed treatments and that have similar life history and phenological traits. For this study, plants are divided into either exotic species or native species. Natives are assembled into five functional groups: warm-season grasses (WSG), cool-season graminoids (CSG), forbs, legumes, and annuals/biennials. Woody plants were too rare to be analyzed. WSG include annual and perennial grasses with the C4 photosynthetic pathway, whereas CSG have C3 photosynthesis and include sedges, *Carex* spp. Forbs in this study are perennial, broad-leaved, herbaceous plants; this group is comprised of dicots and one monocot, *Tradescantia ohiensis* (Raf.), spiderwort. The forb group excludes the legumes, which contains all members of the family Fabaceae, including woody and annual species. Other annuals and biennials assemble into their own functional group. Native cool-season plants include all species with C3 photosynthesis. At these sites, this encompasses all CSG, all forbs, including annual and biennial forbs, as well as woody species. Legumes are excluded due to differing responses to each treatment. Plant names and the native/exotic distinction are determined by Gleason and Cronquist (24).

For some analyses, forbs were split based on flowering times; Howe (25) has used this grouping previously. The divisions here are based on when a plant begins flowering at this site using Gleason and Cronquist (24) as a reference. Plants that begin flowering before mid-June are included in the early-flowering species, those that begin to flower after mid-July are considered late-flowering: whereas, the others are placed in a mid-flowering group.

All data have been tested using ANOVA with the MacAnova software package (26) for differences between treatments. Statistical design is a randomized complete block. Since most data sets have multiple samples per plot, a split-plot design is used for analysis. Therefore, all data points are used, but comparisons are made between the averages for each plot within each block. Pairwise comparisons used the Tukey HSD method to separate treatment effects. Significant differences occur when the p-value is less than 0.05, though trends are also noted when the p-value is less than 0.1.

2.3 Results

2.3.1 Murphy Lake Prairie

The burn treatment had the strongest effect on functional group cover. CSG contributed significantly less cover on burned plots than on the control in 2001 (Figure 2.1). After the second treatment, in 2002, CSG on burned plots were also less abundant than on mow and hay/lime plots. WSG showed no significant difference between treatments, but there was a strong trend ($p<0.1$) suggesting burning benefits these plants compared to the untreated control. Burning significantly favors native annual species, as well. In 2002, the benefit to these annuals was also significant for other removal treatments, hay and hay/lime.

Burning also had the most compelling consequences for cover of individual species. The three most abundant WSG had no significant differences in cover by treatment (Figure 2.2). Canada wild rye had the same response as all CSG (Figure 2.1). Since it was the only abundant native CSG at this site, its response dominates the CSG response. Bush clover, a native perennial legume, was significantly more abundant on burned plots than all other treatments except for haying. Common ragweed and black-eyed Susan benefited from the removal treatments, burned or hayed, compared to those without removal, mowed or untreated. For each species though, the cover of these on hay/lime plots did not differ significantly from the mow plots. The exotic perennial dandelion was less abundant on burned plots than on either mowed or untreated plots. Finally, an unknown grass was found to have the greatest cover on hay/lime plot, significantly more than burn, mow/lime, and control plots.

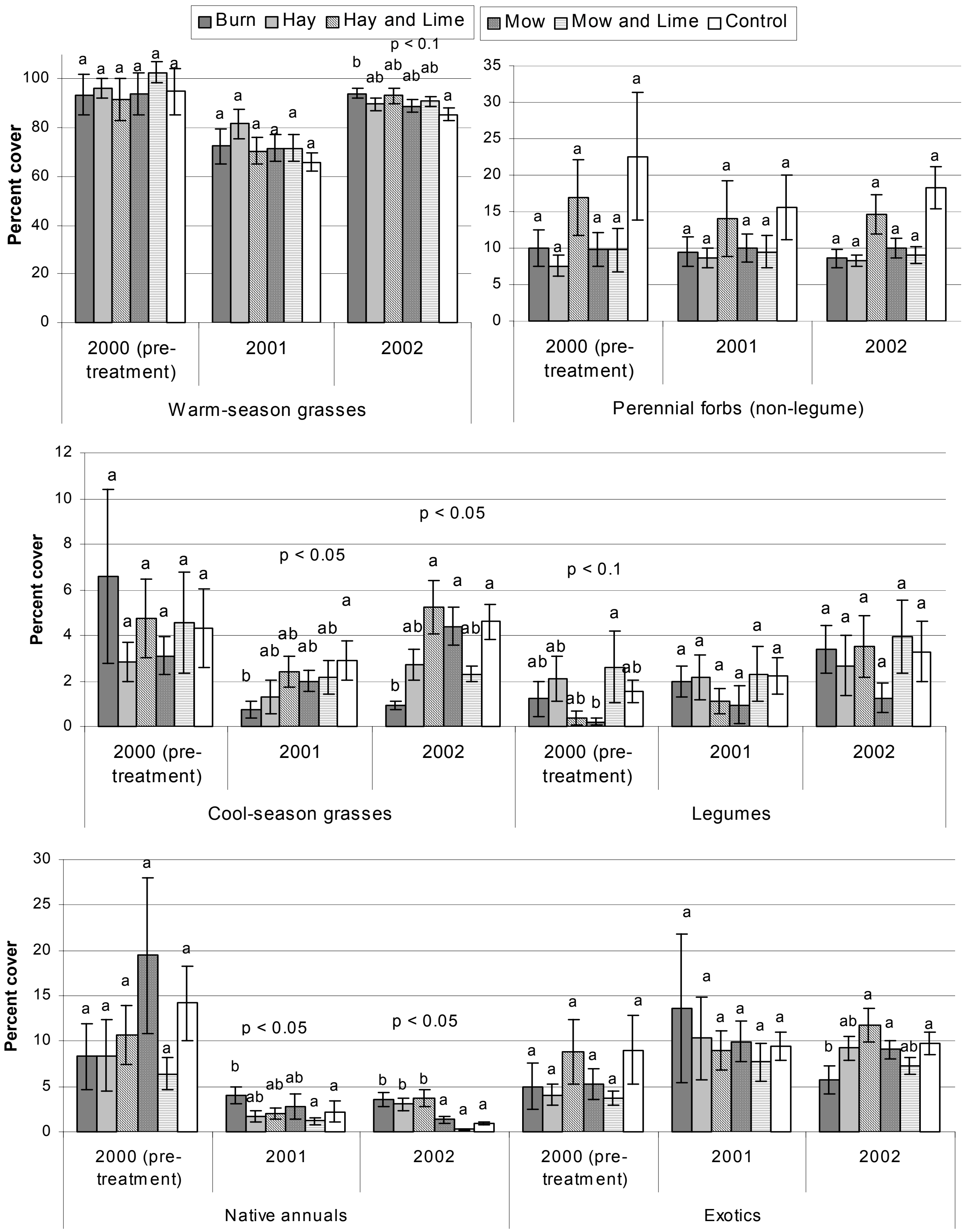

Figure 2.1 – Percent cover of functional groups at Murphy Lake Prairie 2000-2002. Letters represent significant differences by Tukey HSD pairwise comparisons at designated p-value.

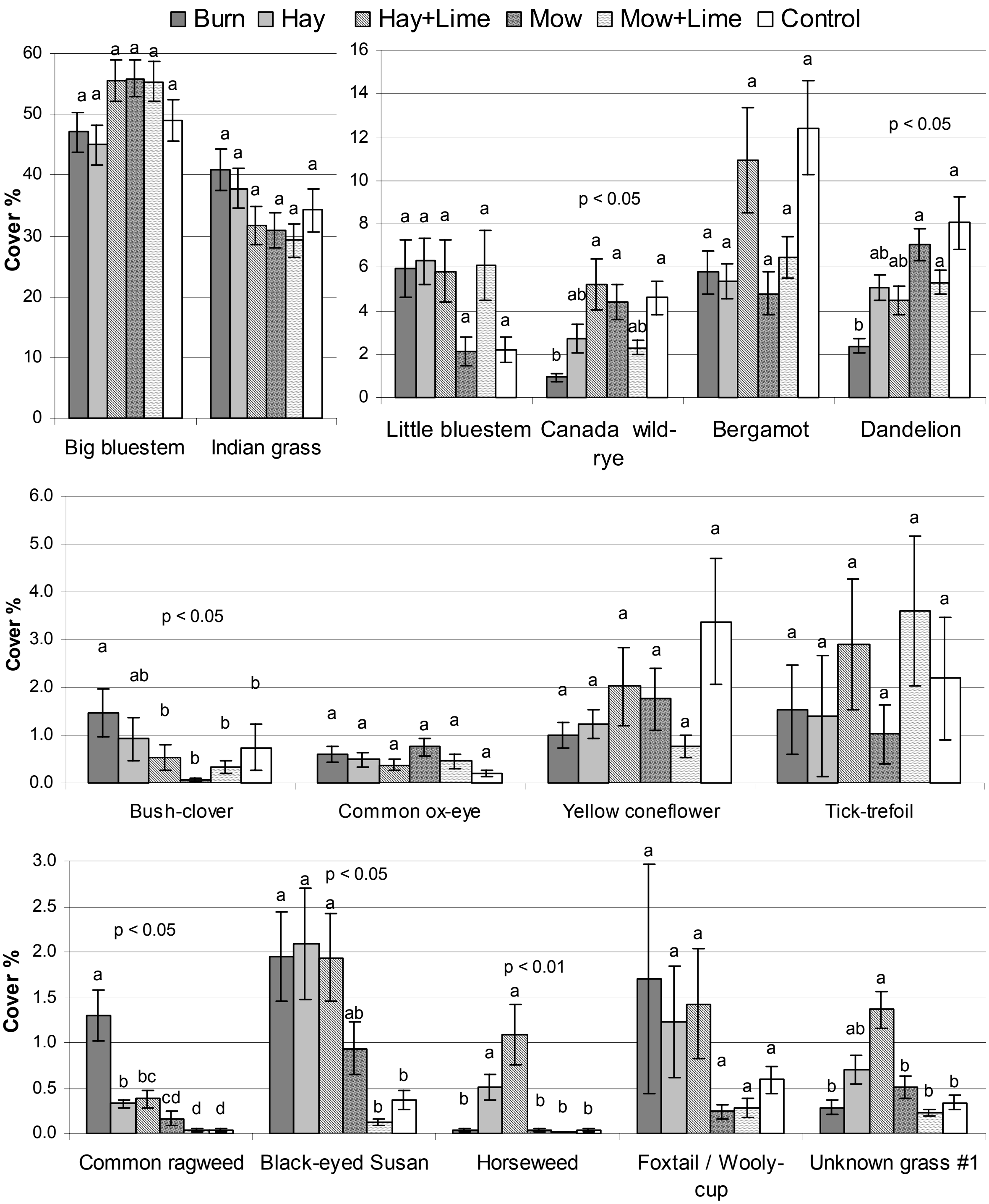

Figure 2.2 – Percent cover of common species at Murphy Lake Prairie in 2002, after two spring hay, mow, or burn treatments. Letters represent significant differences by Tukey HSD pairwise comparisons at designated p-value.

Although cover values were relatively similar, burning and other forms of spring removal greatly benefited WSG. Flower stem density was over 50% greater on burned plots than on any treatment without removal (Figure 2.3). Both hay treatments also had significantly greater stem density for WSG than the control, but still fewer than the burned plots. This is especially apparent for the tallgrasses, big bluestem and Indian grass. Native CSG produced fewer flowering stems on burned plots than on the hay/lime treatment and there was no statistical difference from the control, primarily because of Canada wild rye (Figure 2.4). Native annuals were more abundant on the removal treatments than those without removal. There are no significant differences in flower stem density for exotics species, native legumes, or native non-legume perennial forbs. Although, bergamot has more flower stems on hay/lime plots than on burned plots (Figure 2.4). When the CSG, forbs, and annual/biennial groups are combined the burned plots have fewer flowering stems of this group of cool-season plants compared to the hay/lime, mow, and untreated plots (Table 2.1).

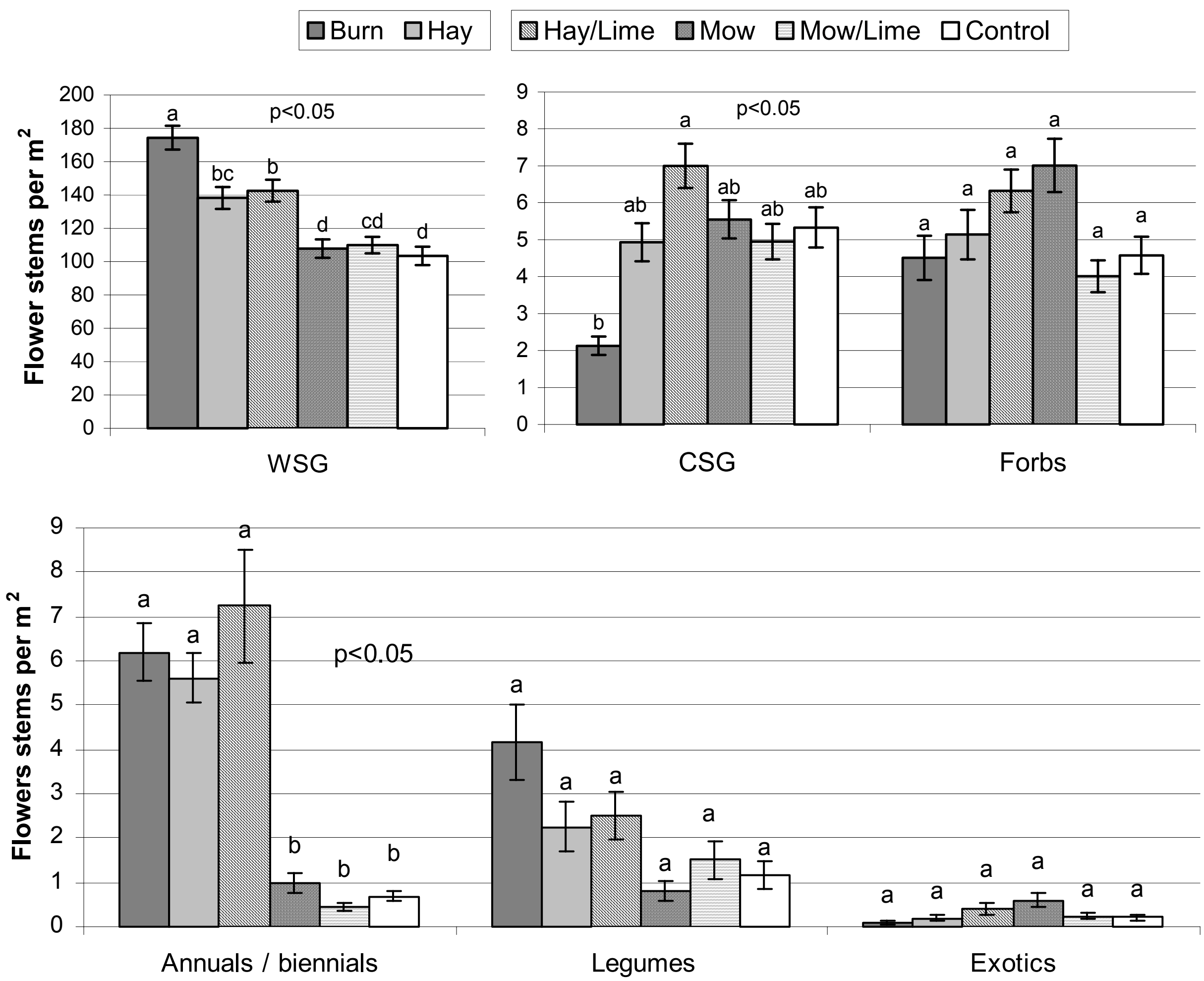

Figure 2.3 - Flower stem densities of functional groups at Murphy Lake Prairie in 2002, after two-spring hay, mow, or burn treatments. Letters represent significant differences by Tukey HSD pair wise comparisons at designated p-value

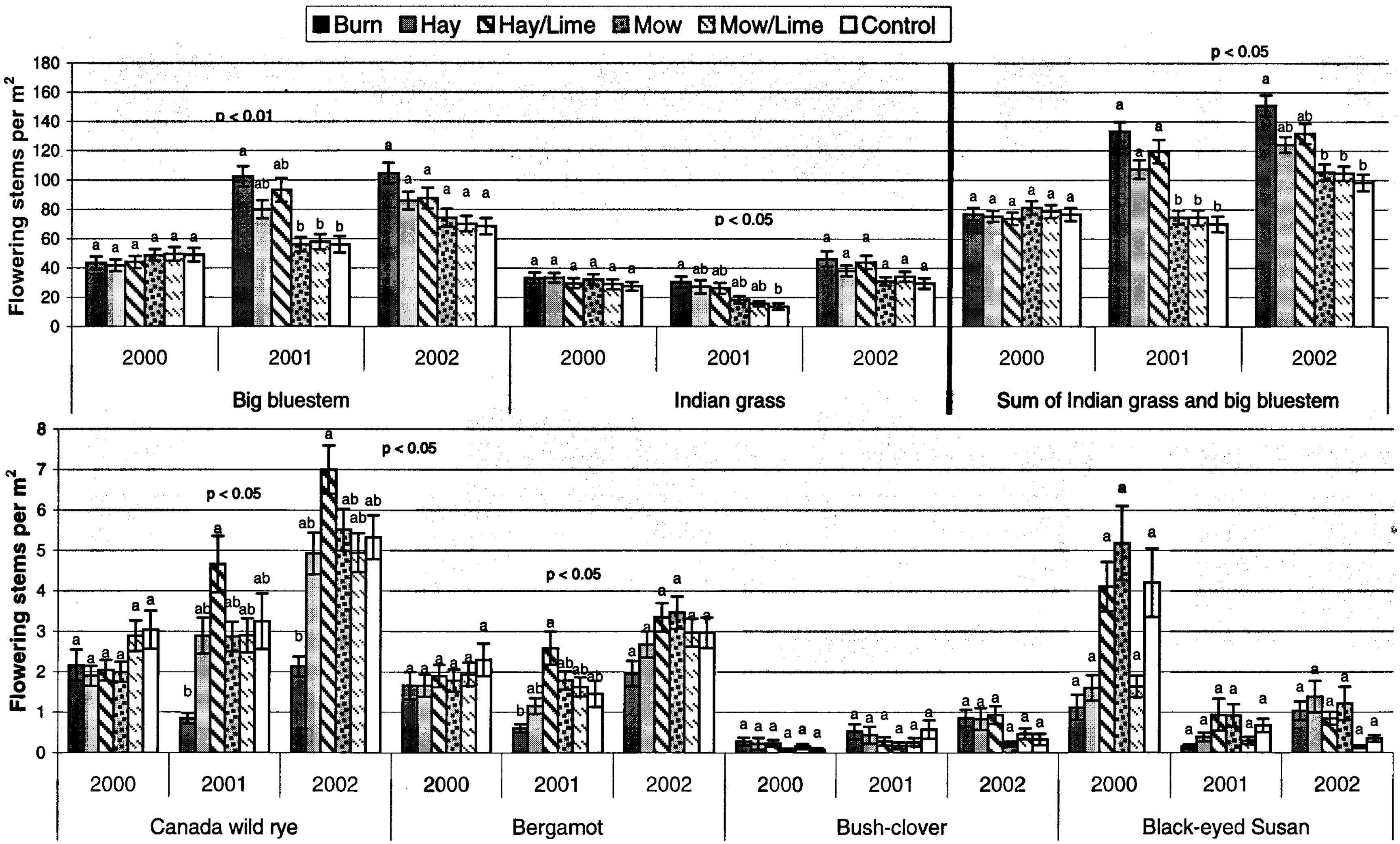

Figure 2.4 - Flowering stems per square-meter at Murphy Lake prairie for 2000-2002. Letters represent significant differences by Tukey HSD pairwise comparisons at designated p-value.

Table 2.1 - Flower stems per square-meter for native cool-season species except legumes, at Murphy Lake Prairie for 2000-2002.

	2000 (pre-treatment)		2001			2002		
	Flower stems/m^2	St.Err.	Flower stems/m^2	St.Err.	$p<0.05$	Flower stems/m^2	St.Err.	$p<0.05$
Burn	4.8	0.67	2.4	0.36	b	5.6	0.62	b
Hay	4.0	0.45	4.6	0.54	ab	8.7	0.77	ab
Hay/Lime	4.8	0.46	8.6	0.99	a	12.5	0.96	a
Mow	4.7	0.46	5.9	0.53	a	11.3	0.92	a
Mow/Lime	5.3	0.59	5.0	0.54	ab	8.8	0.69	ab
Control	6.2	0.74	5.4	0.77	ab	9.6	0.71	a

Frequency is a measure of the commonness of each group of plants in a one square meter quadrat. Two groups had a representative in every quadrat regardless of treatment: WSG and native perennial forbs. The WSG were left out of the frequency analysis; whereas, the native perennial forbs were divided into group based on flowering times. Late-flowering forbs began flowering after mid-July; these plants were most common on burned plots (Figure 2.5). The mid-season flowering plants included wild bergamot, which was very common. So there was a member of this group in every quadrat regardless of treatment. The early flowering species began flowering before mid-June and no effect of treatment was found for these species. Exotic perennial forbs were present in every quadrat when dandelion was included in this group; thus, this species was removed for these analyses. Without it, the results suggested a trend that the hay/lime treatment benefits this group compared to the control.

Native legumes and native annuals appeared to benefit from removal treatments (Figure 2.5). Legumes were most common on burned plot; whereas, they were least common on the mowed plots. They were less common on hay/lime plots than on burned plots, though on hayed plots there was not a significant difference from burning. Native annuals were present in all removal samples, except one in the hayed treatment. Thus, annuals were significantly more common in the removal treatments than the control or mow treatment plots.

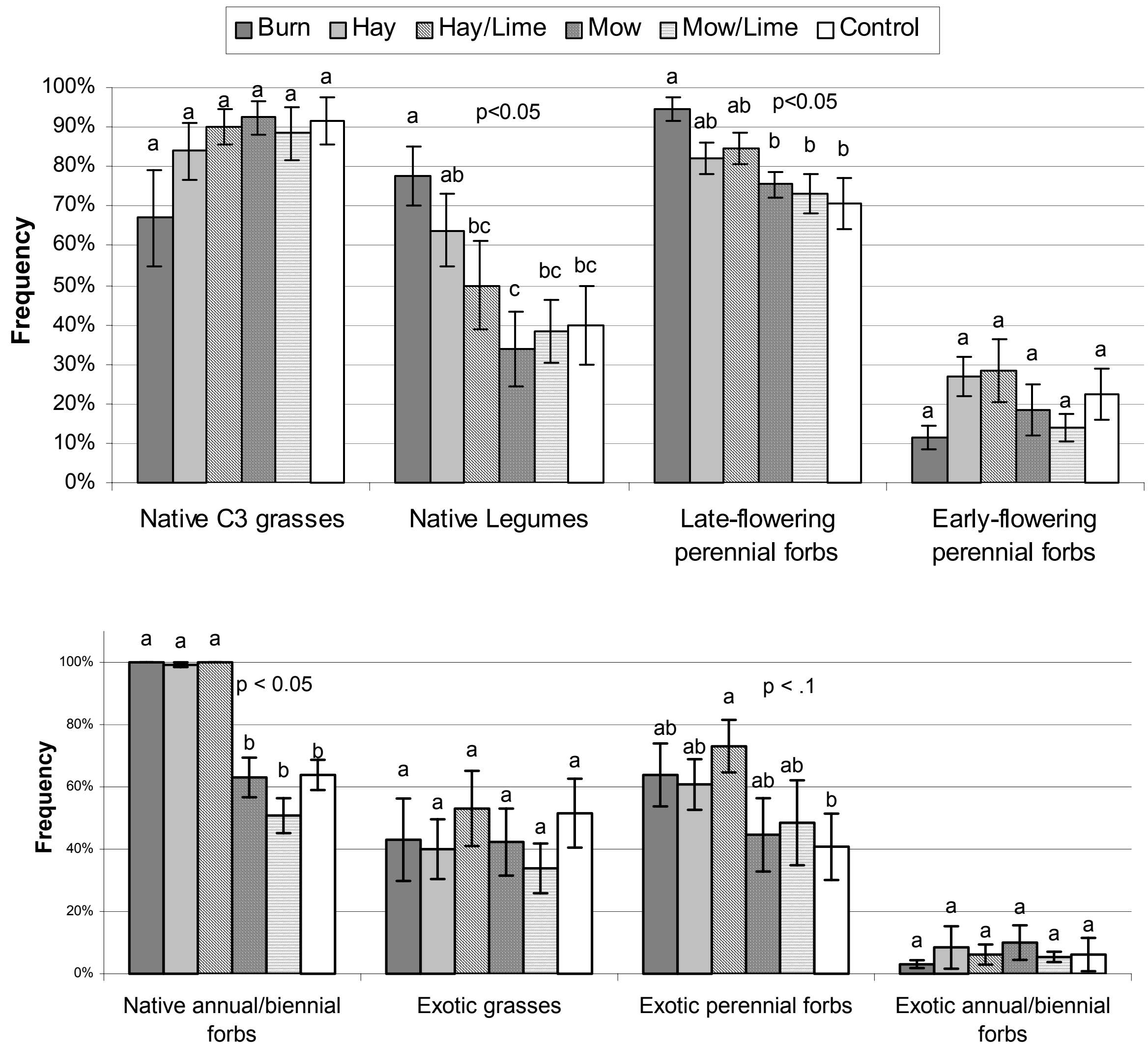

Figure 2.5 - Frequency of important groups of species in 2002. Exotic perennial forbs does not include dandelion (it was present in every plot). Letters represent significant differences by Tukey HSD pair wise comparisons at designated p-value.

A number of species exhibited changes in frequency according to treatment (Table 2.2). This was especially true in 2002, after two hay, mow, or burn treatments. Most notably were the differences for bush clover, a native legume, and common ragweed, a native annual. Both species responded positively to burning and removal treatments, though bush clover was not more common on hay/lime plots than the control and mowed treatments. In addition, yellow coneflower was more common on hay/lime plots than on the burn plots and Canada wild rye was more frequent on mowed plots than the burn treatment.

Table 2.2 - Percent frequency of common plant species at Murphy Lake Prairie between 2000 and 2002. Treatments were performed in the spring of 2001 and 2002. Lime was added in 2001 only. Letters represent significant differences by tukey pairwise comparisons. (continued on page 15)

		Burn	Hay	Hay/Lime	Mow	Mow/Lime	Control
2000	Little bluestem	0.51	0.63	0.47	0.54	0.51	0.56
	St. err.	0.152	0.123	0.132	0.110	0.119	0.119
2001	Little bluestem	0.51	0.61	0.42	0.40	0.41	0.35
	St. err.	0.105	0.128	0.128	0.088	0.115	0.108
2002	Little bluestem	0.62	0.65	0.51	0.38	0.35	0.38
	St. err.	0.119	0.130	0.132	0.096	0.102	0.101
		ab	a	ab	ab	b	ab
2000	Canada wild-rye	0.53	0.55	0.62	0.71	0.64	0.80
	St. err.	0.121	0.132	0.129	0.077	0.112	0.082
2001	Canada wild-rye	0.39	0.54	0.73	0.68	0.62	0.69
	St. err.	0.105	0.115	0.124	0.087	0.095	0.103
2002	Canada wild-rye	0.67	0.84	0.90	0.93	0.89	0.92
	St. err.	0.122	0.074	0.044	0.037	0.061	0.060
	p<0.05	b	ab	ab	a	ab	ab
2000	Common ox-eye	0.14	0.28	0.29	0.33	0.21	0.23
	St. err.	0.062	0.068	0.075	0.076	0.066	0.076
	p<0.1	b	ab	a	a	ab	ab
2001	Common ox-eye	0.23	0.24	0.26	0.27	0.22	0.23
	St. err.	0.058	0.072	0.056	0.072	0.066	0.070
2002	Common ox-eye	0.42	0.45	0.45	0.45	0.43	0.35
	St. err.	0.079	0.063	0.067	0.086	0.043	0.070
2000	Wild bergamot	0.90	0.82	0.84	0.81	0.86	0.84
	St. err.	0.042	0.081	0.085	0.067	0.062	0.054
2001	Wild bergamot	0.95	0.90	0.89	0.93	0.93	0.94
	St. err.	0.040	0.033	0.059	0.040	0.030	0.031
2002	Wild bergamot	0.96	0.98	0.98	0.97	0.96	0.98
	St. err.	0.024	0.015	0.016	0.013	0.021	0.016
2000	Yellow coneflower	0.10	0.11	0.37	0.34	0.20	0.32
	St.err.	0.026	0.035	0.073	0.099	0.042	0.070
	p<0.1	b	b	a	ab	ab	ab
2001	Yellow coneflower	0.30	0.36	0.53	0.45	0.39	0.49
	St.err.	0.077	0.048	0.090	0.085	0.060	0.091
2002	Yellow coneflower	0.43	0.55	0.71	0.57	0.50	0.58
	St.err.	0.074	0.083	0.079	0.072	0.037	0.092
	P<0.05	b	ab	a	ab	ab	ab

Table 2.2 - Continued.

		Burn	Hay	Hay Lime	Mow	Mow/Lime	Control
2000	Canada goldenrod	0.09	0.03	0.04	0.15	0.05	0.09
	St.err.	0.031	0.021	0.022	0.060	0.022	0.028
	p<0.1	ab	b	ab	a	ab	ab
2001	Canada goldenrod	0.07	0.09	0.14	0.12	0.06	0.13
	St.err.	0.034	0.038	0.048	0.057	0.031	0.034
2002	Canada goldenrod	0.12	0.18	0.29	0.25	0.18	0.20
	St.err.	0.035	0.037	0.066	0.065	0.061	0.045
	p<0.1	b	ab	a	ab	ab	ab
2000	Showy tick-trefoil	0.11	0.08	0.04	0.06	0.11	0.07
	St.err.	0.064	0.051	0.022	0.040	0.035	0.026
2001	Showy tick-trefoil	0.19	0.16	0.10	0.08	0.16	0.16
	St.err.	0.084	0.058	0.042	0.042	0.050	0.062
2002	Showy tick-trefoil	0.25	0.13	0.21	0.12	0.22	0.22
	St.err.	0.101	0.057	0.074	0.049	0.051	0.080
2000	Bush-clover	0.14	0.08	0.11	0.09	0.10	0.06
	St.err.	0.031	0.048	0.033	0.069	0.028	
2001	Bush-clover	0.19	0.14	0.13	0.15	0.14	0.11
	St.err.	0.059	0.050	0.056	0.064	0.052	0.038
2002	Bush-clover	0.73	0.56	0.38	0.23	0.25	0.18
	St.err.	0.075	0.092	0.109	0.064	0.083	0.052
	p<0.01	a	ab	bc	c	c	c
2000	Black-eyed Susan	0.22	0.36	0.49	0.51	0.45	0.46
	St.err.	0.063	0.092	0.104	0.092	0.097	0.060
2001	Black-eyed Susan	0.13	0.25	0.29	0.32	0.15	0.31
	St.err.	0.052	0.048	0.085	0.079	0.031	0.078
2002	Black-eyed Susan	0.95	0.94	0.99	0.43	0.23	0.46
	St.err.	0.020	0.032	0.008	0.089	0.063	0.067
	p<0.05	a	a	a	bc	c	b
2000	Common ragweed	0.03	0.03	0.03	0.02	0.02	0.07
	St.err.	0.021	0.021	0.021	0.020	0.013	0.030
2001	Common ragweed	0.93	0.30	0.47	0.22	0.32	0.20
	St.err.	0.030	0.065	0.087	0.042	0.077	0.049
2002	Common ragweed	0.97	0.75	0.75	0.33	0.23	0.19
	St.err.	0.017	0.046	0.058	0.055	0.041	0.035
	p<0.01	a	b	b	c	c	c

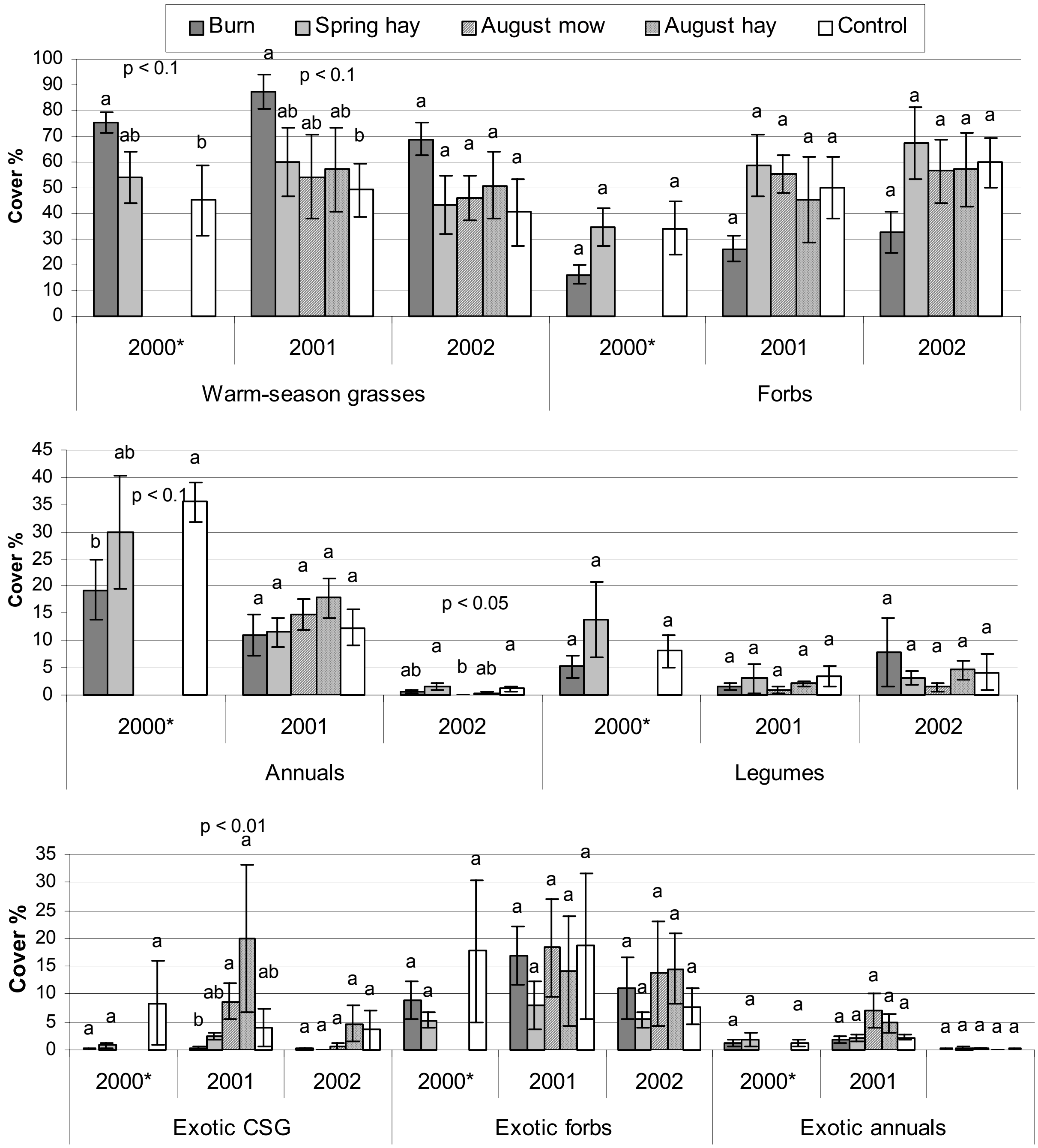

Figure 2.6 - Cover at the Shakopee Research site for functional groups of species. *Treatments occurred in 2000, April and August, thus the data for the August treatments are not included. Letters represent significant differences by Tukey HSD pairwise comparisons at designated p-value.

2.3.2 Shakopee

A few trends existed at the Shakopee site in the response of functional groups to the treatments (Figure 2.6). First, burned plots tended to have greater cover of WSG compared to the control plots; this trend remained for the second year after the treatments. Next, spring burned plots tend to have less cover of native annual/biennial species in the first growing season. By 2002, the plots mowed in August seem to have less annual/biennial plants than the control and April hayed plots. Finally, exotic CSG were significantly less abundant ($p < 0.01$) on burned plots than on either of the August treatments.

Flowering stems of WSG at Shakopee exhibit a similar pattern as they do at Murphy Lake Prairie (Table 2.3). Big bluestem had significantly more flowering stems on burned plots than on the control ($p<0.01$), but hayed plots do not differ from either burn or control. The second season after the burn, 2001, the hayed plots had significantly fewer flowering stems than the burned plots, but the control did not differ from either ($p<0.05$). The treatments had no effect on Indian grass flowering density in any year or big bluestem flowering stems in 2002.

Table 2.3 - The number of flowering stems per plot of WSH at the Shakopee Research site, from 2000-2002. Letters indicate significant differences by Tukey HSD pairwise comparisons. *These treatments were excluded from analysis because the plots were treated after the stems counted in 2000.

	Big bluestem							
	2000			2001			2002	
	Average	St. Err.	p < 0.01	Average	St. Err.	p < 0.05	Average	St. Err.
April Burn	56.20	29.41	a	147.40	16.10	a	80.20	17.30
April Hay	14.00	7.77	ab	58.20	14.64	b	46.60	13.65
August Mow	7.20	7.20	*	95.00	35.65	ab	43.80	8.96
August Hay	5.60	2.91	*	76.20	19.38	ab	64.40	12.96
Control	4.00	2.77	b	77.00	25.52	ab	49.80	17.16
	Indian grass							
	2000			2001			2002	
	Average	St. Err.		Average	St. Err.		Average	St. Err.
April Burn	7.80	1.69		40.60	7.37		10.20	2.08
April Hay	8.40	4.12		27.80	11.23		9.80	3.15
August Mow	2.40	2.16	*	17.20	10.86		4.20	1.80
August Hay	12.20	7.84	*	29.00	22.80		7.00	1.87
Control	3.40	1.89		15.80	5.91		4.40	2.06

2.3.3 JES

The forb cover at JES was less than 3% for any one species. Many of the forb species did not appear in a majority of the plots and therefore meaningful comparisons between the burned and control plots could not be made. A few species appeared in almost all of the plots and statistical analyses were done on these, but no significant differences could be found between treatments (Figure 2.7).

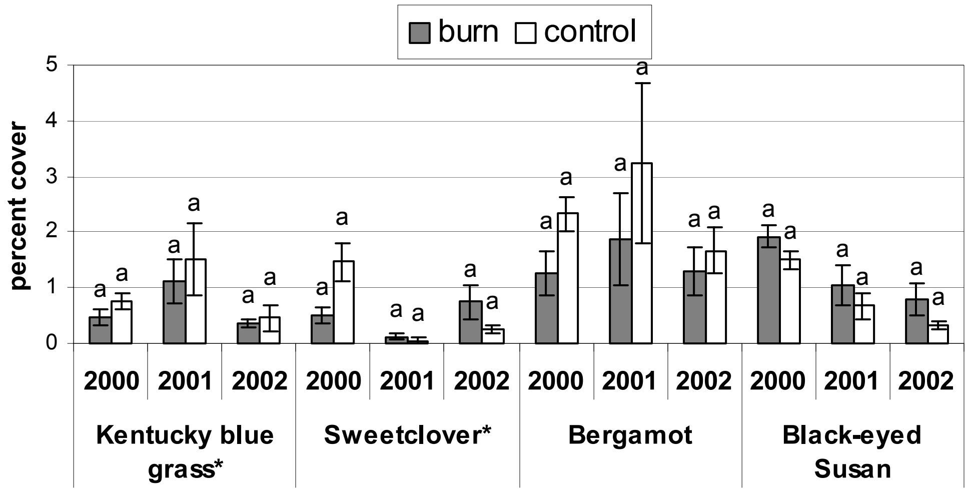

Figure 2.7 - Percent cover of common species at JES from 2000 to 2002 following a spring burn in May 2000. Error bars represent standard error of the mean. An asterisk indicates a non-native species.

Percent cover of the 3 primary native WSG showed a significant, short-lived effect of burning (Table 2.4). In the first growing season after treatment in 2000, big bluestem tended to be more abundant on burned plots than on untreated plots, though this was only significant as a trend ($p<0.1$). Little bluestem, however, was significantly more common on unburned plots ($p<0.05$), whereas Indian grass did not show any significant differences.

Table 2.4. Percent cover of the warm season grasses at JES. Burns were performed in Spring 2000. Letters represent significant differences by Tukey HSD pairwise comparisons at designated p-value.

	Big bluestem		
	Burn	Control	p - value
2000	49.58a	33.75b	p < 0.1
2001	66.04	70.42	
2002	64.58	66.04	
	Indian grass		
	Burn	Control	
2000	4.292	5.167	
2001	0.917	1.458	
2002	0.167	0.333	
	Little bluestem		
	Burn	Control	
2000	20.83b	36.25a	p < 0.05
2001	18.75	17.08	
2002	18.33	14.42	

In 2000, big bluestem produced significantly more flowering stems in the burned plots as compared to the unburned plots ($p < 0.05$) (Figure 2.8). Indian grass showed a similar response to burning (Figure 2.9). Again, these differences only lasted for the first season after the burns.

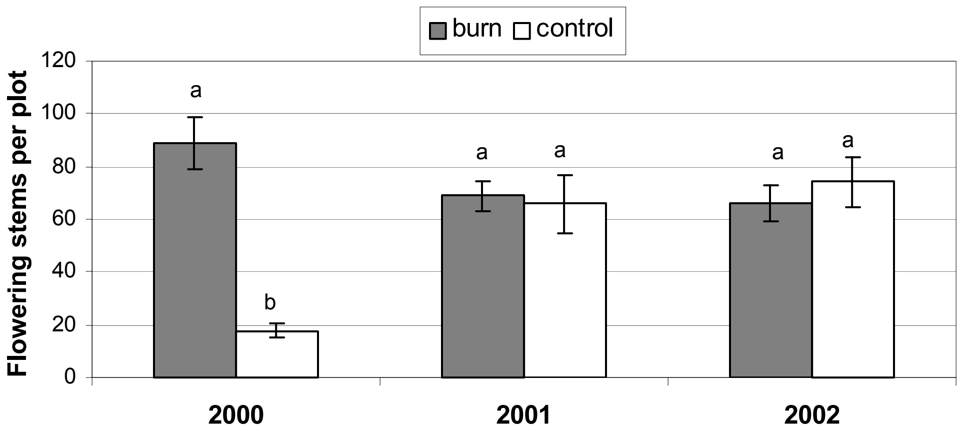

Figure 2.8 - Number of flowering stems of big bluestem in each plot at JES following a spring burn in May 2000. Letters represent significant differences within each year using pairwise comparisons ($p<0.05$).

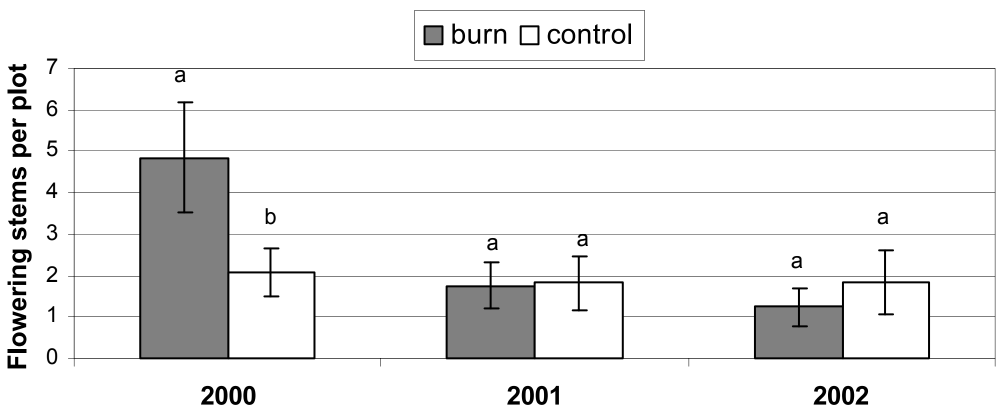

Figure 2.9 - Number of flowering stems of Indian grass in each plot at JES following a spring burn in May 2000. Letters represent significant differences within each year using pairwise comparisons ($p<0.05$).

2.4 Discussion

2.4.1 Spring Vegetation Removal

The two major groups of grasses, WSG and CSG, tend to have differing responses to prescribed spring burns. WSG are favored by litter removal (Figure 2.3; Figure 2.4; Figure 2.6; Figure 2.8; Figure 2.9; Table 2.4), whereas CSG are more abundant on plots without spring litter removal (Figure 2.1; Figure 2.3; Figure 2.5; and Figure 2.6). These opposite effects have been shown previously (27, 20) and are a common reason for the application of spring prescribed burns. Spring burns are often designed to control non-native CSG and create a community dominated by native WSG. The timing of these treatments usually precludes spring initiation by the WSG, whereas CSG have begun growth and, therefore, are damaged by the fire (27).

In general, any form of spring vegetation removal favors WSG, especially burning (Figure 2.3; Figure 2.4; Figure 2.6; Figure 2.8; Figure 2.9; Table 2.4). Hulbert (7) found that spring manual aboveground vegetation removal was very similar to burning in terms of productivity of all species and groups of species. Therefore, it is accepted that the most important cause of fire effects is due to the removal of aboveground vegetation (7). For the spring haying treatment though, the mower blade cuts about 5 cm above the soil, leaving some green material. Thus, the haying treatment does not favor WSG as much as spring burning or significantly harm CSG (Figure 2.1; Figure 2.2; Figure 2.3; Figure 2.4; Figure 2.5; Figure 2.6; Table 2.2).

Legumes generally do very well with frequent burning (Figure 2.2; Figure 2.5; Table 2.2). This is likely due to increased light levels and soil temperatures, which favor nitrogen-fixing symbiosis in legume roots (13). Haying also increases these parameters (Chapter 5), but the positive response by the legumes is less on hayed plots than on burned plots (Figure 2.2; Figure 2.5; Table 2.2). Perhaps shading from the incomplete biomass removal on hayed plots limits the growth of the legumes. Alternatively, the heat or ash from the burn may positively affect seed germination or promote legume growth in a manner that has not yet been measured.

There are differing results between flowering stem density and frequency for legumes and a few other species. Legume flowering stem density is not significantly different between any treatments (Figure 2.3; Figure 2.4). In addition, black-eyed Susan, a biennial, is more abundant on burned plots at Murphy Lake Prairie (Figure 2.2; Table 2.2), but does not have significantly more flowering stems (Figure 2.4). Annual species, though, are more abundant on burned or hayed plots, including common ragweed and horseweed (Figure 2.2; Table 2.2). Hence, it seems the plants on the removal plots that are increasing are increasing in the number of small individuals rather than large plants with more flower stems. In fact, litter has previously been shown to inhibit germination and plant establishment in grasslands (6, 18). Thus, it seems that litter removal is promoting seed germination, at least for these species, rather than benefiting the expansion of existing plants.

The response of two common annuals is dependent on the type of removal treatment applied. Ragweed is more common and more abundant on the burned plots than on hayed plots; whereas, horseweed is more common on hayed plots than burned plots (Figure 2.2; Table 2.2). This should be interpreted with caution; although neither plant is desirable, the plants that occurred at this site are very small, less than 15 cm (6 inches) (personal observation). Thus, there should be little concern about an increase in these plants after spring litter removal on a prairie with abundant native WSG.

The removal treatments have few significant effects on native forbs. Species that flower after mid-July were more common on burned plots than on the control (Figure 2.5). It has been shown that plants that flower earlier in the season are often damaged by spring burning (25); this may be avoided by burning before the emergence of desirable species. Conversely, late-spring burns may tend to have a larger impact on the early emergent plants and may be more useful for controlling cool-season grasses. The late-flowering species may have a competitive advantage after spring fires because of the damage to other species, or they may benefit from an extended growing season as do the late-flowering WSG (16).

Exotic species contributed less cover to the burned plots than on the control (Figure 2.1). Much of this response may be due to dandelion. This species was conspicuous at the time of the treatments, so it was likely damaged by the fires (Figure 2.10). Since no other species were apparent at the time of the treatments, it was likely the only species directly damaged by burning. This may account for the lack of significant differences for other plant species.

Overall, haying provides a very similar community response to prescribed burning. The most important aspect of the burn seems to be the removal of aboveground vegetation (7), which is supported here. However, haying is not as thorough at removal as burning. This may account for dissimilarity between haying and burning, such as WSG flowering stems, and greater resemblance between the untreated and hayed plots, as with CSG and legume frequency.

Figure 2.10 - Photo taken on hayed plot immediately after treatments had been performed. Notice the broad leaves of common dandelion; this is the only live green vegetation in the photo.

2.4.2 Mowing without removal

The removal aspect of these treatments accounts for most of the differences in the plant community. The vegetation on mowed plots was very similar to that on the untreated plots. The mowing treatment only knocks dead plant material to the ground. Even if the material had been chopped finely, it is likely that the litter would have this effect. Thus, on mowed plots the litter layer is likely shallower than on untreated plots, but the quantity of litter is the same (Figure 3.1). Other research has shown that plant litter suppresses germination and establishment of new plants (6). This seems to be the case for mowed plots as well as the control, especially in terms of annuals and legumes as described earlier (Section 2.4.1).

2.4.3 Lime addition

The addition of lime after haying was predicted to benefit many forb species, because these species tend to have optimal growth in near neutral pH (1). The pH change would increase nutrient availability for plants, especially phosphorus and nitrogen, which are most available near pH 7 (28). The soil predictions are discussed in chapter 5, but forb response was only minimal and increased a few species on plots that had been hayed before the lime application. In addition, the different values only existed between burned plots and hay/lime plots.

The lime application after haying seems to have some slight affects on the plant community compared to burning. First, the hay and lime treatment has significantly more flowering stems of native cool-season plants than the burned plots (Table 2.1). Only two perennial forbs may show such a response: Canada goldenrod and yellow coneflower (Table 2.2). However, the goldenrod data only reveals a slight trend ($p<0.1$), whereas the yellow coneflower differences may result from the pre-treatment trend. Other C3 species with similar significant results are common dandelion, Canada wild rye and unknown grass #1, likely a cool-season in the genus *Poa*; these species thrive on hayed plots with lime (Figure 2.2; Figure 2.4; Table 2.2).

According to these results, the addition of lime may benefit undesirable species: non-natives and CSG. In addition, some land managers select strongly against Canada goldenrod because of its tendency to exclude many other more desirable natives (Larry Gillette, personal communication). The major difficulty in managing prairie for diversity is controlling the exclusivity of WSG against the benefits of favoring desirable C3 species, without favoring invasive C3 species. Howe (25) recommends varying the seasons of prescribed burns to favor early-flowering species that are damaged by spring burning. However, such treatments can favor certain invasive species as well; consequently, there is no best management formula. Burns should be timed to help control problematic species at a site. Spring haying with lime addition may be used to benefit cool-season plants, provided aggressive species are under control.

2.5 Conclusions

Prescribed burning has the strongest effects on plant community composition. It especially favors WSG and legume species, though it also favors certain annual species. In addition, burning helps to control some exotic species, especially those that are green at the time of the burn. Spring haying is an acceptable alternative to spring burning, though its effects are less dramatic than the burn. In particular, haying does not favor WSG as extensively and may not damage as many cool-season species as burning. Adding lime to hayed prairie may help to benefit the cool-season plants, native or exotic. However, utilizing mowing instead of burning probably does not differ much from leaving the prairie untreated. Therefore, in order to mimic prescribed spring burning, haying in the spring may be the best technique available.

2.6 Recommendations

1. Spring burning is the best management practice to favor warm-season native grasses and some legumes. Furthermore, this practice helps control some exotic species.
2. Spring haying at the same time as the burn has many similar effects on the plant community that burning does, but to a lesser extent. It did not control the exotic species at these sites, nor did it have much affect on cool-season grasses.
3. Haying, with periodic lime addition, will benefit many cool-season plant species, including forbs, compared to burning. However, there may be some cool-season exotic plants that are favored by this treatment.
4. Mowing the prairie in the spring has a similar affect on the plant community as no management. It is only useful for the control of woody species.

Chapter 3. The effects of fire versus mowing on plant productivity

3.1 Overview

In a newly restored prairie, maintenance is key to long-term success. Historically, fire played a major role in the spread and maintenance of grasslands. Not surprisingly, burning is now a commonly used maintenance tool in prairie restorations. The removal of litter by burning or artificial raking has been shown to enhance grassland productivity (8). Warm season grasses (WSG) such as big bluestem and Indian grass usually dominate annually burned sites. However, infrequently burned sites have fewer WSG but a higher occurrence of forbs and C_3 grasses, resulting in higher diversity and heterogeneity (14).

Net primary productivity is a measure of the rate at which carbon is stored or incorporated into living tissues. Aboveground net primary productivity can conveniently be measured as the change in biomass through time. Biomass is the dry weight of plant material present at any point in time (29), and it is a useful tool in studying grassland productivity.

The purpose of this study is to measure the effectiveness of different maintenance techniques, including vegetation removal via burning and haying, by measuring net primary productivity from aboveground biomass and plant vigor from stem heights.

3.2 Materials and Methods

3.2.1 Murphy Lake Prairie

The Murphy-Hanrehan site is described in detail in Methods, chapter 2.2.1. Aboveground plant productivity measurements were made from field collected biomass samples taken in late August or early September of each year. Four samples were collected from each plot in 10 cm by 50 cm quadrats. The vegetation was clipped thoroughly and put into paper bags. For pre-treatment data in 2000, the live vegetation and dead litter were not sorted, giving an overall biomass figure for a baseline before treatments. Post-treatment collections separated litter from material that had grown in the current season. This gave a value for litter as well as aboveground net primary productivity (ANPP) for each growing season. Samples of plant material were taken back to the lab and stored in a cooler at 4°C until they could be put into a drier. Plants were dried at 50-60°C for at least one week, to constant mass. Then, they were removed from the drier and allowed to equilibrate to room temperature for 1-2 hours. Mass was measured to the nearest 1/100 gram in the bag. For each day samples were weighed, the mass of empty bags was taken for at least 15 bags; this average was subtracted from all of the samples for that day. Bag masses were within a range of 2 grams, or less than 4% variation each day.

An additional productivity measurement was made in 2002 on four treatments: burn, hay, hay plus the addition of lime, and the control (no treatment). Each treatment had seven replicates. Aboveground biomass production was measured of the three most common species: big bluestem, Indian grass, and bergamot. Plots were sampled at the end of July, August, and September. The current season's biomass was measured by clipping 3 randomly placed quadrats per plot. The quadrats for the two warm-season grasses were 0.25 m^2 each, and the quadrat for bergamot was 0.5 m^2 each because this species occurred less often than the grasses. All measurements were taken at least one meter away from the plot's edge to eliminate any edge effect. Species were sorted in the field, placed into paper bags, and labeled. Care was taken to sample only the current year's growth. Plant samples were then taken back to the lab and dried at 50-60ºC to constant mass. Before weighing, samples were allowed to equilibrate to room temperature for at least one hour. Growth was measured to the nearest 1/100 gram in each bag.

Weights of each treatment for each species were analyzed using MacAnova software package (26) using a split plot analysis of a repeated measures design.

The heights of the three most abundant species were also measured. In early July of 2001 and 2002, five random points were selected in each plot. The nearest stem of bergamot and big bluestem was measured from ground to the highest point of the plant. This process was repeated in September for big bluestem and Indian grass. These warm-season grasses were usually in a cluster of multiple stems; from each cluster, the tallest stem was measured.

3.2.2 *Shakopee*

The Shakopee site description is in Section 2.2.2. For big bluestem and bergamot, the height of the five tallest individual plants in each plot was measured. Measurements were taken in late June of 2000. In 2001, height measurements were taken for bergamot in July and big bluestem in September. Height measurements were also taken for big bluestem in September of 2002. For each type of plant, the tallest five stems in each plot were recorded. In 2000, bergamot was not present in the August mow plot in block one before that treatment had occurred.

3.2.3 *JES*

The JES site is described in Section 2.2.3. The heights of big bluestem were measured on September 29, 2000, October 4, 2001, and August 27, 2002. To measure plant heights, the plots were divided into quarters, and the tallest plant in each section was measured. The data were then analyzed using Statistix version 3.5 (30), with four observations per plot.

3.3 Results

3.3.1 *Murphy Lake Prairie*

There were no significant differences for total biomass in 2000 before treatments, which were applied the following spring (Figure 3.1). After the first treatment in 2001, aboveground net primary productivity (ANPP) did not differ significantly between treatments. However, in 2002, after the second treatment, ANPP on burned plots was greater than the control ($p<0.05$). For both years, there was significantly ($p<0.05$) less litter on the removal treatments: burn, hay, and hay/lime. In 2001, the burn plots had less litter than either of the hay treatments ($p<0.05$).
Big bluestem produced taller stems in July of each year on the removal plots (Table 3.1). After July, the stems on the mow and control plots seemed to recover and achieve nearly the same height as those on the removal plots. In September 2002, there were no significant differences between treatments ($p>0.1$). In fact, the average rate of growth of this species was significantly greater in the second half of the season on control and mowed plots than on those with removal ($p<0.05$).

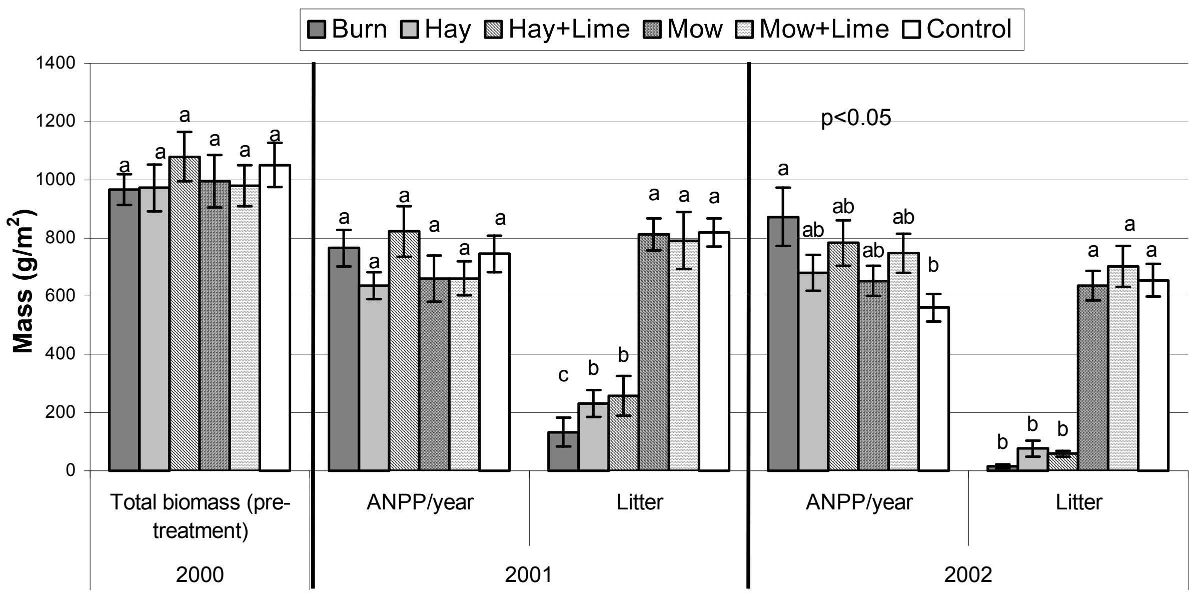

Figure 3.1 - Aboveground biomass and annual net primary production at Murphy Lake Prairie. Biomass includes litter; this is pre-treatment data. Live vegetation represents annual aboveground primary productivity average for each treatment. Letters represent significant differences at $p < 0.05$ for Tukey pairwise comparisons.

Table 3.1 - Average height of big bluestem at Murphy Lake Prairie. Letters represent significant differences in Tukey Pairwise comparisons.

	Early July (cm)	StErr	p<0.05	September (cm)	StErr	p<0.05	Growth (Jul to Sep) (cm)	StErr	p<0.05
2001									
Burn	105.1	6.00	a	148.7	4.28	a	42.7	5.57	abc
Hay	107.5	5.06	a	146.3	3.87	ab	38.2	4.56	c
Hay+Lime	109.0	5.24	a	149.9	3.95	a	40.1	4.95	bc
Mow	74.7	5.22	b	136.0	3.11	bc	60.8	7.07	ab
Mow+Lime	72.0	5.48	b	133.1	3.64	c	59.1	5.37	abc
Control	70.1	4.86	b	134.0	3.11	bc	63.8	5.50	a
2002									
Burn	107.4	3.34	a	182.2	2.08		74.8	3.62	b
Hay	98.2	3.27	a	176.4	2.37		78.1	3.91	b
Hay+Lime	107.3	3.18	a	181.7	2.25		74.4	3.24	b
Mow	75.6	2.69	b	179.9	2.04		104.3	2.86	a
Mow+Lime	73.6	2.18	b	178.5	1.83		104.9	2.70	a
Control	79.6	3.09	b	180.6	1.87		101.0	3.76	a

Table 3.2 - Average heights of bergamot and Indian grass at Murphy Lake Prairie. Letters represent significant differences in Tukey Pairwise comparisons.

	2001 (cm)	StErr	p<0.05	2002 (cm)	StErr
Bergamot					
Burn	30.1	2.88	b	47.4	2.30
Hay	38.1	3.57	ab	48.8	2.62
Hay+Lime	42.8	3.76	a	52.2	2.28
Mow	41.1	3.43	a	50.1	2.53
Mow+Lime	35.5	2.56	ab	48.7	2.16
Control	40.0	2.99	ab	51.0	2.51
Indian grass					
Burn	109.7	3.47		170.8	2.09
Hay	112.7	3.46		163.2	2.40
Hay+Lime	109.9	3.61		171.7	2.26
Mow	110.0	3.78		162.8	2.07
Mow+Lime	108.7	3.31		165.8	1.79
Control	104.8	3.59		165.0	2.03

In 2001, bergamot stems were significantly shorter on burned plots than those on hay/lime and mowed plots (Table 3.2); this effect did not occur in 2002. Indian grass did not show any significant effect of the treatments in terms of heights in either season.

In the 2002 seasonal study, there were no significant differences in the biomass of big bluestem (Figure 3.2), Indian grass (Figure 3.3), or bergamot (Figure 3.4) among any of the treatments in July, August, or September. However, over the season, the Indian grass burn, hay, and hay/lime plots had significantly greater biomass than the control plots ($p < 0.001$).

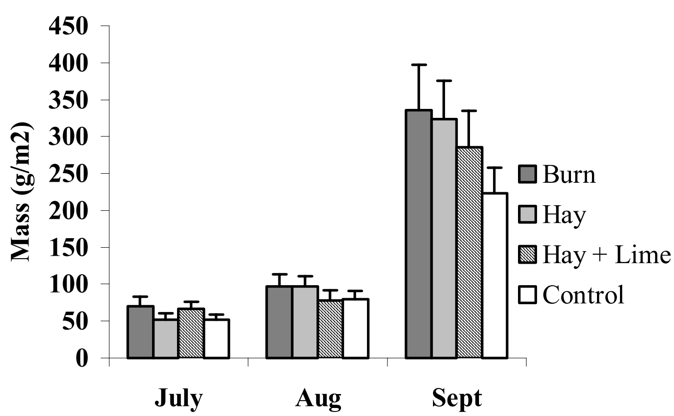

Figure 3.2 - 2002 seasonal aboveground biomass and annual net primary production of big bluestem at Murphy Lake Prairie. No significant differences are present.

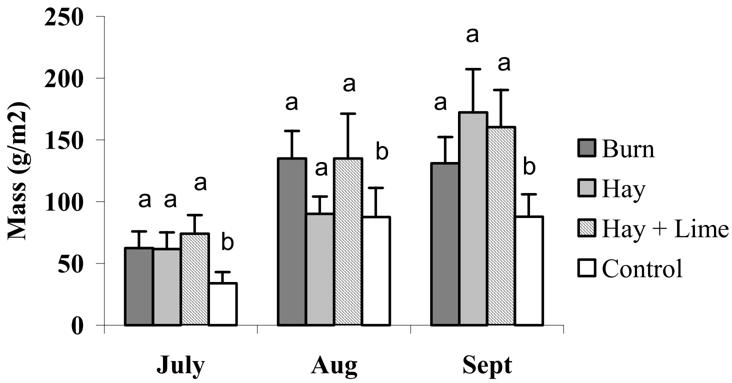

Figure 3.3- 2002 seasonal aboveground biomass and annual net primary production of Indian grass at Murphy Lake Prairie. Letters represent significant differences in Tukey Pairwise comparisons.

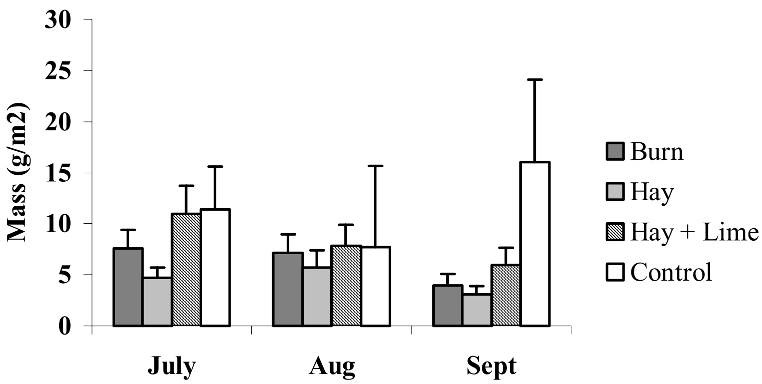

Figure 3.4- 2002 seasonal aboveground biomass and annual net primary production of bergamot at Murphy Lake Prairie. No significant differences are present.

3.3.2 *Shakopee*

Big bluestem heights in the burn plots were significantly taller than the control plots in July of 2000 and all treatments in September of 2001. No significant differences were seen in September of 2002. In July of 2000, big bluestem heights in the control plots were significantly taller than the burn plots. No significant differences were observed in July of 2001 (Table 3.3).

3.3.3 *JES*

Big bluestem was significantly taller in the burned plots than the control plots in the fall of 2000. This difference was not observed in 2001 or 2002 (Figure 3.5).

Table 3.3 - Average heights of big bluestem and bergamot at Mn/DOT Shakopee research site. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

Big bluestem								
	Jul-00	St.Err.	p<0.01	Sep-01	St.Err.	p<0.05	Sep-02	St.Err.
Burn	74.4	2.18	b	189.2	7.03	a	181.9	6.52
Hay	68.4	2.39	ab	163.8	5.82	b	177.8	6.52
August Mow				168.7	6.17	b	170.9	6.24
August Hay				164.7	6.09	b	177.4	6.45
Control	64.4	1.29	a	171.1	6.40	b	170.7	6.20

Bergamot					
	Jul-00	St. Err.	p < 0.05	Jul-01	St. Err.
Burn	64.4	4.85	a	93.1	3.53
Hay	87.8	1.50	ab	107.2	4.06
August Mow				103.3	4.08
August Hay				109.2	4.08
Control	95.1	2.17	b	91.7	3.92

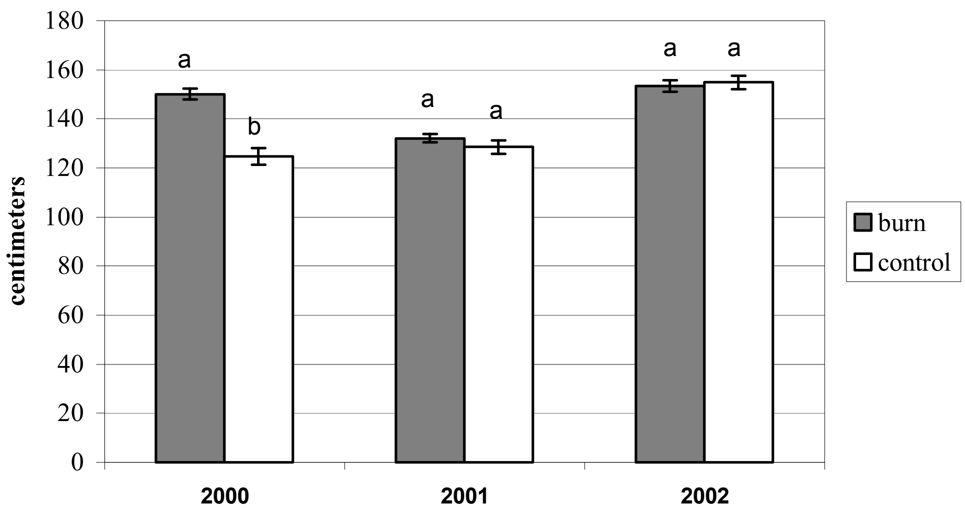

Figure 3.5 - Heights of big bluestem at JES after 2000 spring burn. Error bars represent standard error of the mean. Different letters within a year represent significant differences ($p \leq 0.001$).

3.4 Discussion

The 2002 ANPP results (Figure 3.1) are consistent with other tallgrass prairie studies that have documented an increase in aboveground production due to fire (31, 32). Heights of big bluestem at the Shakopee site in 2000 and September of 2001 (Table 3.3) also indicate the increased plant vigor in the burn plots. Many different factors have been suggested that affect a grassland's response to burning, but surface light, soil surface temperature, and soil nitrogen are particularly important factors (7). Additionally, evidence has shown that vesicular-arbuscular mycorrhizal root colonization is temporarily stimulated by burning (33). The combination of some or all of these factors probably contributed to the significant difference in ANPP between the burned and control plots in 2002.

In 2002, each removal treatment resulted in increased productivity of Indian grass over the season. One cause of decreased productivity of WSG has been attributed to shading by standing dead material (7), and shading can be attributed as one of the likely factors of reduced productivity of the control plots of Indian grass in this study.

Indian grass and big bluestem are both WSG and would be expected to respond similarly to treatments. However, the seasonal trend was not significant between the control and other treatments of big bluestem (Figure 3.2). The ANPP results between WSG species during a season can be variable. In a two-year study performed on a native Kansas tallgrass prairie, Hulbert (7) found significantly greater productivity of big bluestem in burned plots as compared to clipped and unburned plots. The same study showed significantly higher amounts of the biomass of Indian grass in burned plots compared to unburned plots the first year. Conversely, the following year had greater productivity in clipped plots than untreated plots. Because of the number of factors that can affect productivity, a variation in WSG biomass is not uncommon.

One of the removal treatments was the hay/lime treatment. Since all the removal treatments resulted in higher seasonal biomass over the control in Indian grass, the addition of lime in the hay/lime treatment could possibly have played a role, especially in a former farm field like the Murphy Lake Prairie. Tillage, fertilization, and similar practices promote nitrification, and irrigation can leach base cations from the soil. In these cases, annual harvests can remove the bases from the soil and result in soil acidification making lime application necessary (34). More time will be necessary, however, to conclusively determine the efficacy of lime application in former farm fields.

The heights of bergamot in the mow and hay/lime plots were significantly taller at Murphy Lake Prairie in 2001, but those differences were not noted in 2002 (Figure 3.1). No significant differences were observed in Indian grass. However, heights of bergamot and Indian grass were measured only once during each year. Indian grass was difficult to identify in early July since it had not begun to bolt. Bergamot plants did not seem to grow after the early July measurement, and most had begun flowering at this time.

No significant seasonal differences appeared for bergamot productivity in 2002. Although spring haying tends to favor annuals and cool season species like bergamot (Chapter 2, 35, 36), these are not a large component at Murphy Lake Prairie at this point in time. The lack of a significant seasonal variation in 2002 of bergamot, the most commonly occurring cool-season forb, may be because of the relatively lower occurrence of this species.

In 2002, bergamot biomass and plant heights at Murphy Lake Prairie may have been limited by competition from WSG. Data collected in a tallgrass prairie over a 19-year period showed that when water stress reduces grass productivity, forb productivity responds positively to the reduction in competition (37). At Murphy Lake Prairie, the summer of 2002 was unusually wet, especially the latter half of the summer. Heights of big bluestem in 2002 on the removal plots were greater in the first half of the season (Table 3.1), but this pattern was reversed by the end of the season. This discrepancy is probably due to the increase in precipitation in 2002 and probably resulted in the WSG out-competing the bergamot. Thus, due to high precipitation in 2002, any significant differences among treatments were probably masked.

In the 2002 seasonal study, the lack of significant differences between months can also probably be attributed to precipitation. Although we expected to see differences between the hay, burn, and control plots in all three species, precipitation could have moderated the differences between months. The inter-annual variability in productivity of any species is unpredictable and is a product of light, water, and nutrients and is affected by fire history, topography and climate (37). Thus, it is safe to assume that the intra-annual variability in a one-year study can be even higher.

3.5 Conclusions

Periodic removal of standing dead vegetation by burning is the most effective method to produce the greatest amounts of aboveground plant biomass in a restored tallgrass prairie. When immediate cover of warm season grasses is desired, burning is the most effective method. However, the fact that a significant seasonal difference appeared between the burn, hay, and hay/lime plots as compared to the control plots of Indian grass is evidence that vegetation removal via haying may serve a similar purpose as burning. A longer study period will be necessary to conclusively determine the effects of haying as well as any potential benefits of lime in combination with haying on big bluestem, Indian grass, and bergamot.

3.6 Recommendations

1. When immediate grass cover is desired, burning is the best maintenance technique available to increase grassland productivity.
2. When burning is not an option, haying may be the next best alternative. The addition of lime may be important to consider on restorations of former agricultural lands.

Chapter 4. Monitoring the effects of treatments on inoculum potential or percent colonization

4.1 Overview

An important component of the prairie community is the arbuscular mycorrhizal fungi that form symbiotic relationships with most prairie plants. Changes in the soil (38) can affect the mycorrhizal population, which can influence the plant community. Furthermore, the plant community affects mycorrhizae, creating feedback between the fungal and plant communities (11). This segment of the study addresses immediate effects of these treatments on arbuscular mycorrhiza inoculation potential or percent root colonization.

4.2 Materials and Methods

4.2.1 Murphy Lake Prairie

Murphy Lake Prairie research plots and treatments are described in Section 2.2.1. To assess the mycorrhizae at the this site, four of the ten blocks were chosen randomly, each block containing six plots. Soil samples for this experiment were taken June 4 (4 weeks post-treatment). At this site, mycorrhizal inoculation potential (MIP) was assessed. After each sampling period, an inoculation potential experiment was established in the greenhouse. To set up this experiment each soil sample was mixed 50/50 with sterilized sand and four cone-tainers (Ray Leach "Cone-tainers" Hummert International , Earth City, MO 63045) were filled with this mixture. This was repeated for each of the 24 plots. Big bluestem (*Andropogon gerardii*) was planted into each cone-tainer. The cone-tainers were placed in the greenhouse, watered regularly and allowed to grow for 35 days. After this time the plants were removed from the cone-tainers and the soil washed from the roots. The roots were cleared, stained following methods modified from Phillips and Hayman (39) and Koske and Gemma (40) and stored in 50% glycerol in preparation for determining mycorrhizal inoculation potential.

To determine MIP, slides were made of the stained roots. To make the slides, the root samples that had been cleared and stained were rinsed in water, cut into 1 centimeter pieces, mixed in the water to randomize, and then placed on slides. One slide was made for each the 96 cone-tainers. The slides were viewed with a microscope to determine if the roots contained mycorrhizae. The slides were scanned in a regular manner and whenever a root section was intersected by a crosshair in the microscope eyepiece, the root was assessed to determine if it contained a mycorrhizal structure. If mycorrhizae were present then the mycorrhizal structure encountered was noted. The mycorrhizal structures that were counted were arbuscules, vesicles, and coils. Two hundred intersections of root were randomly examined for mycorrhizal structures from the big bluestem grown in soil from each of the plots (10).

4.2.2 Shakopee

This site and the treatments are described in detail in Section 2.2.2. At the Shakopee research site, soil samples were taken from each of the 25 plots on April 18, 2000 (pre burn), May 4 (2 weeks post burn), May 19 (4 weeks post burn). At this location percent colonization was done. Roots were isolated from all the soil samples and the root samples were cleared, stained and stored in 50% glycerol in preparation for determining percent colonization. Slides were made and examined as described in 4.2.1. Four slides were made for each plot that was sampled at each sampling date. Fifty intersections of randomly selected root from each slide was examined to determine if mycorrhizal colonization was present (10). From these data the percent colonization was calculated.

4.2.3 JES

The JES research site and manipulations are described in section 2.2.3. Soil samples were taken from each of the 24 plots on April 28, 2000 (pre burn), May 17 (2 weeks post burn), June 2 (4 weeks post burn). At this site percent colonization was done. After each coring date, roots were isolated from each sample, cleared, stained, and stored in 50% glycerol in preparation for determining percent colonization as described above.

To determine percent colonization, slides were made of the stained roots as described in 4.2.1. For each soil sample, representing each of the 24 plots, four slides were prepared. Fifty sections of randomly selected root from each slide was examined to determine if mycorrhizal colonization was present (10). From these data the percent colonization was calculated.

4.3 Results and Discussion

The mycorrhizal structures counted were arbuscules, vesicles, and coils. Arbuscules are sites where active transfer of nutrients takes place between plant roots and the mycorrhizae (9). Coils are also thought to have a similar function as the arbuscules. The vesicles are considered to be storage structures for the mycorrhizal fungi.

4.3.1 Murphy Lake Prairie

No differences were found for mycorrhizal inoculation potential of the soil at four weeks post-treatment (Figure 4.1). Changing the pH of the soil by liming has been found to alter the species composition of arbuscular mycorrhizal fungi in subterranean clover (41). However, this study did not determine species composition of the arbuscular mycorrhizal fungi although examination of species is suggested for future studies.

4.3.2 Shakopee

By the second week post-treatment, there were more mycorrhizal coils in roots from the treated plots as compared to the control (Figure 4.2). This difference was also present at the four-week post-treatment sampling. Smith and Read (9) point out that, in addition to arbuscules, intracellular coils may be the sites for carbon transfer to the plant. Hence, the increase in coils may benefit the growth and development of plants, particularly after a treatment that deceases plant cover.

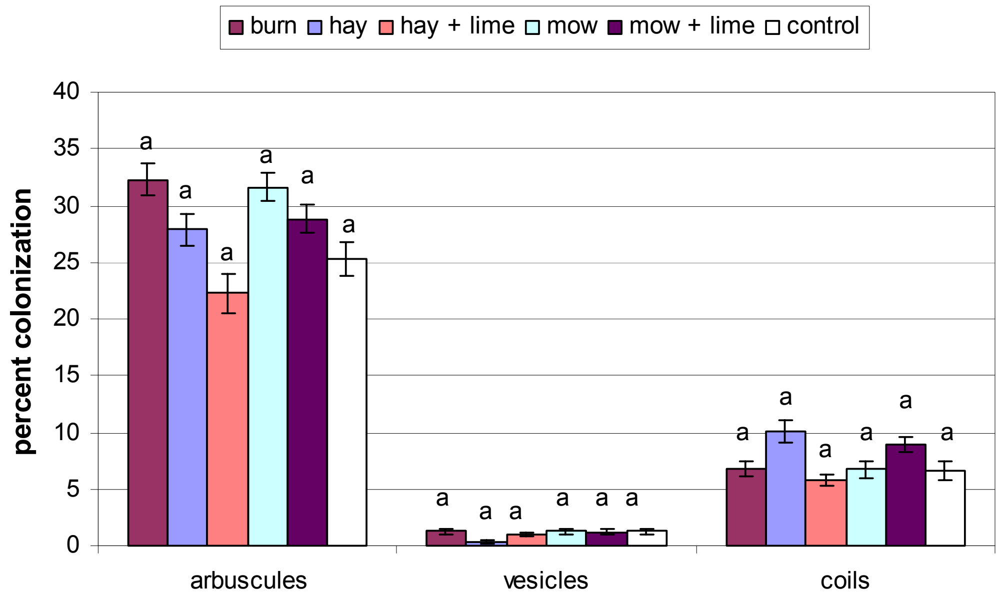

Figure 4.1 - Percent colonization of arbuscular mycorrhizal structures found in big bluestem grass grown in soil from the treated plots at Murphy Lake Prairie. Error bars represent standard error of the mean. Different letters within a year represent significant differences ($p \leq 0.05$).

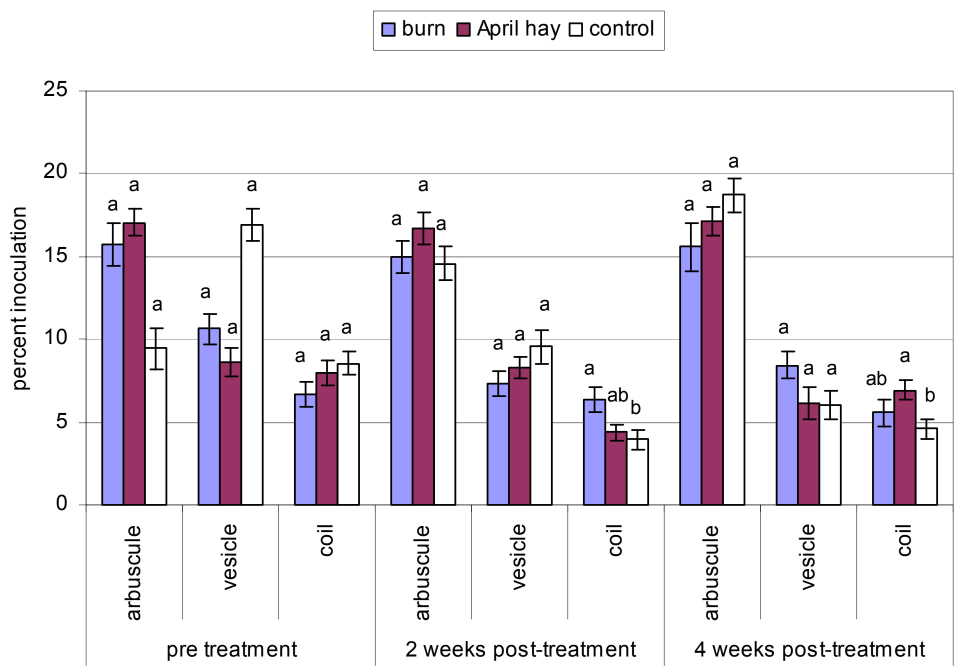

Figure 4.2. - Percent colonization of arbuscular mycorrhizal structures found in field roots taken from plots at Shakopee research site. Error bars represent standard error of the mean. Different letters within a year represent significant differences ($p \leq 0.05$).

4.3.3 JES

By four weeks post-treatment there were more coils in roots from the treated plots than from the untreated plots (Figure 4.3). These differences were seen also in the Shakopee field roots at 2 and 4 weeks post-treatment. These results may indicate that there is an increase in mycorrhizal structures as a result of burning and haying, which in turn may enhance plant growth and survival.

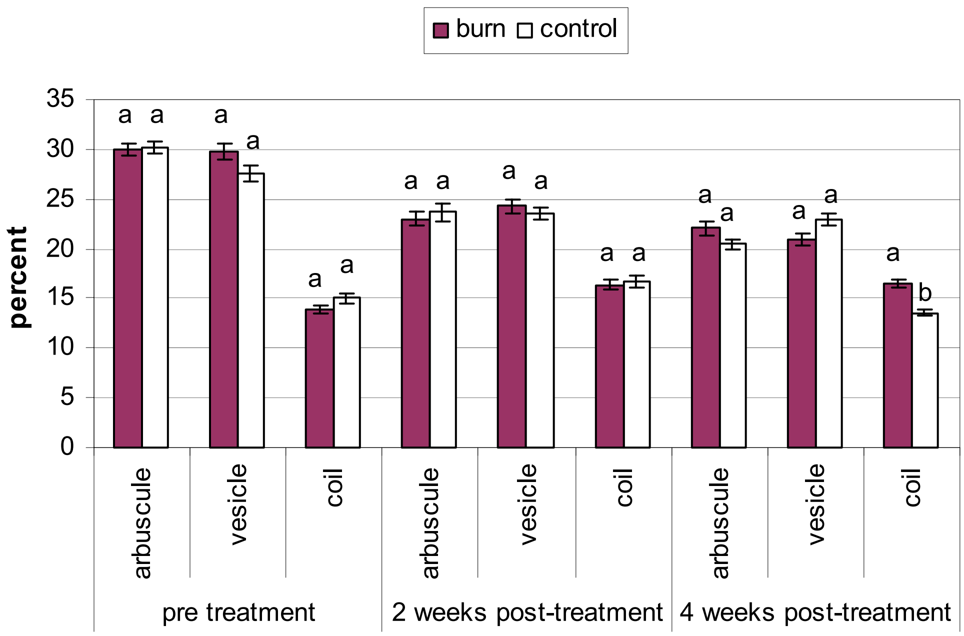

Figure 4.3 - Percent colonization of arbuscular mycorrhizal structures found in field roots taken from plots at JES research site. Error bars represent standard error of the mean. Different letters within a year represent significant differences ($p \leq 0.05$).

4.3.4 Long-lasting Benefit of using Arbuscular Mycorrhizal Inoculum

In June of 1995, five years prior to the present experiment, one-third of the plots were treated with arbuscular mycorrhizal spores, which were produced by Smith et al. (23). When the results of the mycorrhizal counts were grouped according to these previous treatments (23, 42), it was found that there were still significantly more vesicles in the plots that had been treated with the inoculum in 1995 (Figure 4.4). Since vesicles are storage structures for the fungi, these results indicate a possible long-lasting benefit of using inoculum to aid in establishing prairie in areas where there is little or no mycorrhizal inoculum in the soil.

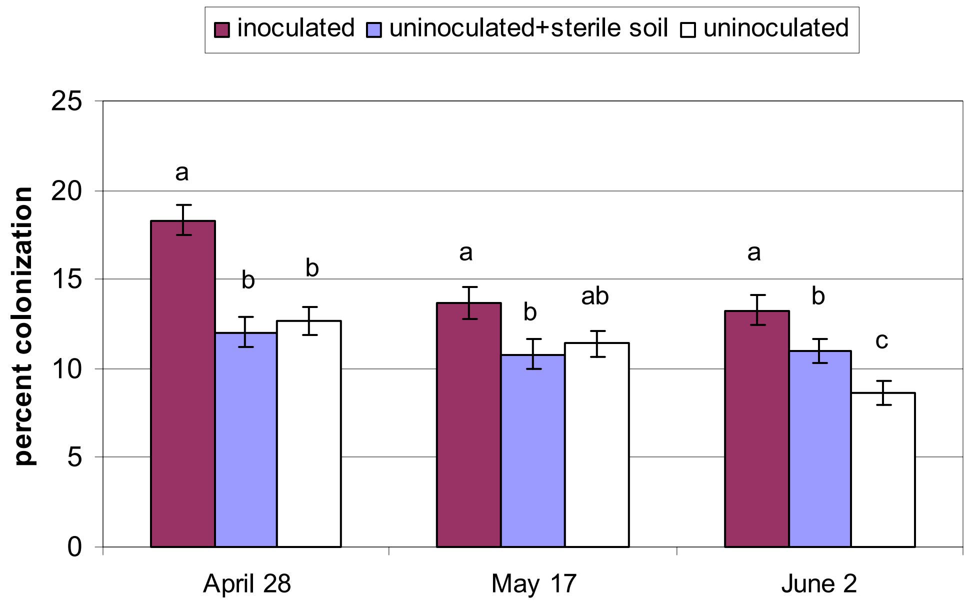

Figure 4.4 - Percent colonization of vesicles in field roots from the JES research site. Plots were treated with inoculum in June of 1995. Error bars represent standard error of the mean. Different letters within a year represent significant differences ($p \leq 0.05$).

4.4 Conclusions

Removal of vegetation by burning or haying appears to be the most effective way to enhance the arbuscular mycorrhizal fungal structures associated with prairie vegetation. This effect may be due to increased plant productivity on the removal plots.A long-lasting benefit of using inoculum to aid in establishing prairie in areas where there is little or no mycorrhizal inoculum in the soil is indicated by results obtained from a study established at JES in 1995.

4.5 Recommendations

1. Of the treatments tested, burning and haying provided the greatest increase in arbuscular mycorrhizal fungal structures, which may correspond to the increases in plant growth on these treatments.
2. In prairie restoration, addition of arbuscular mycorrhizal inoculum appears to provide long-term benefits.

Chapter 5 - The effects of fire versus mowing on the soil

5.1 Overview

Prescribed burns on prairie communities have considerable effects on soil properties, both physical and chemical. The removal of litter by the fire warms the soil and decreases soil moisture (43). The ash content, although it has been shown to have no effect on the vegetation (15, 7), contains basic cations that may increase the soil pH (13) and inorganic phosphorus (13, 44). However, the only confirmed increase in prairie soil pH is measurements on sites burned annually for 20 years compared to an unburned prairie (45, 46). Thus, the effect of the ash seems to be minimal.

Soil nitrogen is important in prairie soil because this nutrient often limits plant productivity and is an important determinant of plant species composition (4). Burning greatly affects nitrogen in the soil as well as the rate of decomposition, during which organic nitrogen is mineralized to inorganic forms, nitrate (NO_3) and ammonium (NH_4). Fires volatilize most of the nitrogen in the aboveground plant material, thereby removing it from the system (47). After the burn, the warmer soil conditions favor the release of NO_3 and NH_4 from organic matter in the soil, known as nitrogen mineralization (48). Research on remnant prairies in Kansas has shown that nitrogen mineralization soon declines after repeated annual burns 49, 48). These effects have not been shown on restored prairies, on which the soils are often formerly agricultural and rich in nitrogen and other nutrients (50).

The causes of the effects of burning on the vegetation are attributed to the removal of the aboveground biomass (7), however this has not been tested for soil nutrients. Therefore, this part of the project tests aboveground vegetation removal by burning or haying (mowing then raking) on soil parameters. If vegetation removal is the primary cause of the changes in soil properties following prescribed fires, hayed plots should maintain similar soil conditions to burned plots.

Burned lime was added to half of the hayed and mowed plots in 2001 to increase soil pH. Continual removal of aboveground vegetation will deplete basic cations from the soil causing a decline on hayed plots. This effect is part of a process known as cultural acidification. Many agricultural soils experience this form of soil acidification, which is exasperated by fertilization and tillage (34). Since prairies are commonly restored from agricultural land, lime addition may also help restore historic soil pH levels. Unfortunately, since soil pH is extremely site-specific, there is no way to determine the pre-agricultural levels. Instead, the effects of the lime addition on soil nutrients will be compared against the burn treatment to test if the lime creates conditions more similar to burning than with haying alone.

The mowing treatments are predicted to cause a decrease in available nitrogen due to immobilization by microorganisms. Immobilization is negative mineralization; instead of releasing inorganic nitrogen from organic matter, decomposers remove inorganic nitrogen from the surrounding soil for their own metabolism (13). This occurs when there is a high amount of carbon relative to nitrogen, the microbes need more nitrogen to decompose the existing carbon (50). Lowering nitrogen availability at a site may be a useful means of controlling many weedy species (51, 52).

This experiment was designed to determine management methods that favor plant diversity. It is understood that greater soil nutrients, especially nitrogen in temperate grasslands, lower plant diversity and favor weedy species (51, 52). Thus, the main objective of this chapter is to find which treatments decrease soil nitrogen and mimic the effects of burning. Although, the results in this chapter may not coincide with which treatment most benefits the plant community, these data will be useful to predict management that will least favor undesirable plants.

5.2 – Methods

5.2.1 – Murphy Lake Prairie

Soil was sampled at five random points in each plot in September of 2000 (pre-treatment), 2001, and 2002. Soil samples were taken with a 2 cm diameter probe to 15 cm deep. The five samples from each plot were combined and analyzed for Bray's extractable phosphorus (53) at the University of Minnesota Research Analytical Laboratory (RAL). In September 2002, soil pH was tested at various depths in the soil using 2:1 water to soil mixture, by mass (54). This was performed in the field by sectioning the soil samples in the probe into 0-1 cm deep, 1-6 cm deep, and 6-12 cm deep. These results determined the extent of the incorporation of the lime in the soil from the surface application in May 2000.

Net nitrogen mineralization was measured in the field using *in situ* mineralization cores (55). At one random point in each plot, a 10 cm diameter by 17 cm long PVC pipe with a sharpened end was driven into the ground to 10-15 cm deep and capped. Litter was included in the core to mimic natural decomposition processes. Small holes were drilled into the side of each core near the soil surface to allow gas exchange. Upon placing each core into the ground, four soil samples were taken from within 20 cm of the PVC core. This soil was used to determine the initial amount of inorganic nitrogen, N_i, present. After approximately 30 days, D, the PVC cores were removed and a sub-sample of the soil was analyzed for the final level of inorganic nitrogen, N_f. Total net nitrogen mineralized per day was determined by $(N_f - N_i) / (D)$. Inorganic nitrogen was determined calorimetrically (56, 57) from a 2M potassium-chloride (KCl) extraction (58) by RAL. From the initial samples taken for the N-mineralization data, soil moisture was analyzed to determine the N on a dry mass basis (59). Soil moisture values were analyzed statistically from these values. The mineralization core incubations were run three times each year starting at the following dates: May 16, June 15, and July 23, 2001 and May 7, June 6, and July 5, 2002.

Immediately after treatments at the Murphy Lake site in 2001, temperature data-loggers (HoboXT Temperature loggers, Onset Computer Corporation) were placed into the hayed, burned, and control plots on 5 of the 10 blocks. The temperature probe was trenched into the soil at 6 cm deep, with soil replaced to minimize surface damage. Each data-logger recorded soil temperature every hour from May 10 to August 14, 2001. Data were collected periodically from the data-loggers throughout the season. These data were compressed into values for daily average, maximum, and minimum temperatures.

5.2.2 Shakopee Site

At the Shakopee site, soil samples were taken on May 19 (4 weeks post burn) and June 15 (8 weeks post burn). Soil samples were taken from four random locations in each plot. The soil was analyzed by RAL for Olsen extractable phosphorus (53). Olsen's was used at this site because it is preferable on sites with soil pH greater than 7.3. In addition, analyses were performed at RAL for inorganic N, soil moisture, and soil pH using the same technique described for the Murphy Lake Prairie (Section 4.2.1). Soil temperatures were measured for 3 blocks for all treatments in 2000 from April 24 to June 28. The data from August treatment plots, hayed and mowed, were combined with data from the control plots since they had received no treatment before these measurements.

5.3 Results

Lime addition was the only treatment to significantly affect soil pH at Murphy Lake Prairie (Figure 5.1); whereas, there were no measurable effects at the Shakopee site (Figure 5.2). The single surface application of lime, in May 2001, significantly increased soil pH to 12 cm deep, at least for the mow/lime treatment ($p<0.05$). Soil phosphorus levels were unaffected by treatment at either study site (Figure 5.3; Figure 5.4). Soil temperatures from each site are shown in Figure 5.5, Murphy Lake Prairie, and Table 5.1, Shakopee Research Site. For each site, the vegetation removal contributes to warmer soil than on control plots, although at Shakopee burning caused the only significant difference ($p<0.05$).

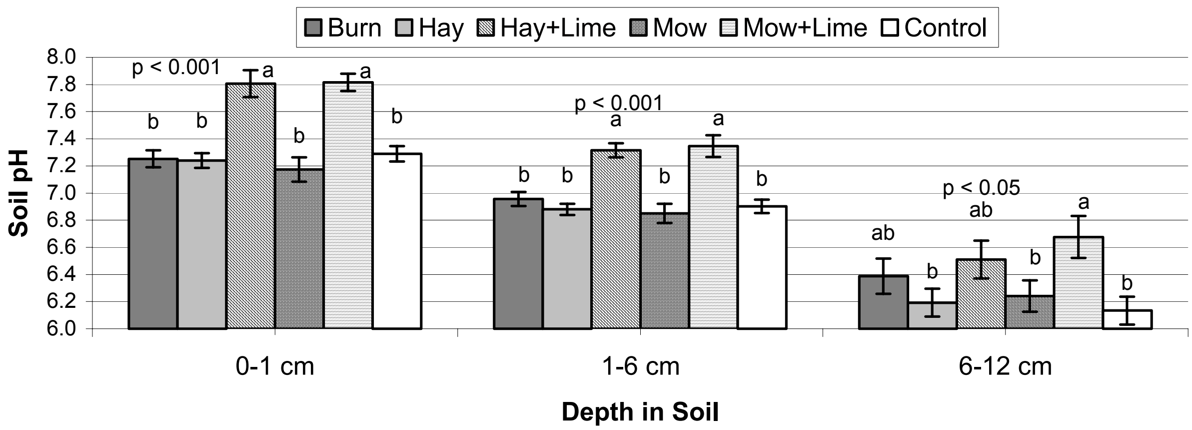

Figure 5.1 - Soil pH at certain depths at Murphy Lake Prairie, September 2002. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

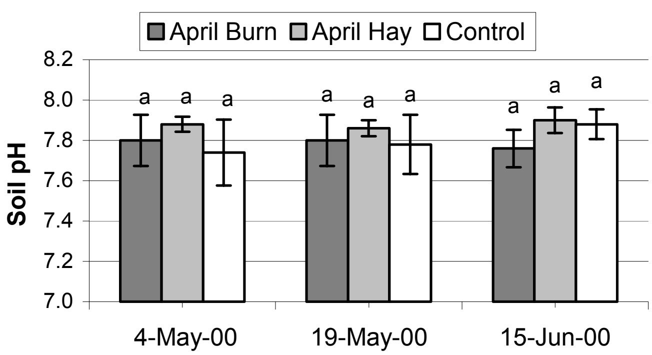

Figure 5.2 - Soil pH at Shakopee Site. Soil collected before August treatments, so these are excluded. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

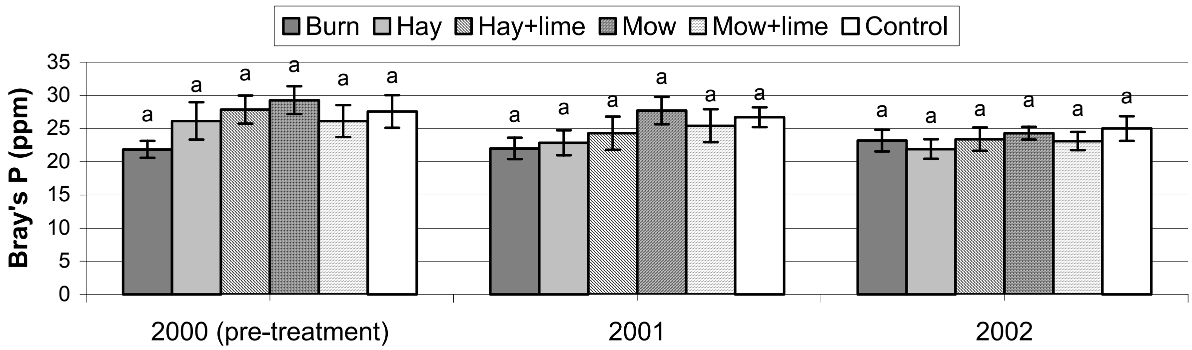

Figure 5.3 - Bray extractable phosphorus at Murphy Lake Prairie from soil collected in September of each year including before treatment application. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

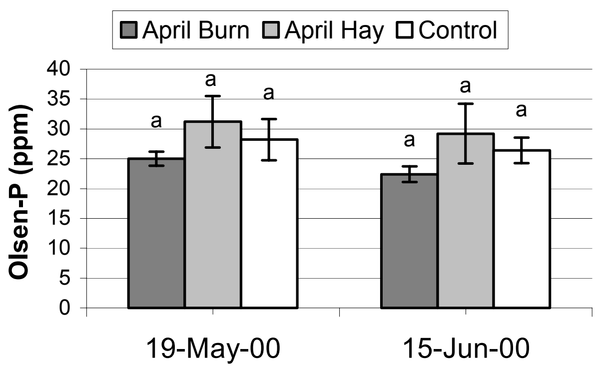

Figure 5.4 - Olsen extractable phosphorus at Shakopee Research Site in 2000. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

Table 5.1 - Average soil temperatures for the season and average daily maximum and minimum temperatures at Shakopee site. Significance determined by repeat measures analysis for entire measurement period (April 24 to June 28, 2000). Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

Shakopee Research Site, 2000								
	Average temperature			Daily maximum temperature		Daily minimum temperature		
	Avg	St. Err.	p<0.1	Avg	St. Err.	Avg	St. Err.	p<0.05
April Burn	16.9	0.19	a	20.4	0.22	13.9	0.23	a
April Hay	16.5	0.20	ab	20.2	0.22	13.2	0.24	ab
Control	15.7	0.13	b	18.7	0.15	13.1	0.16	b

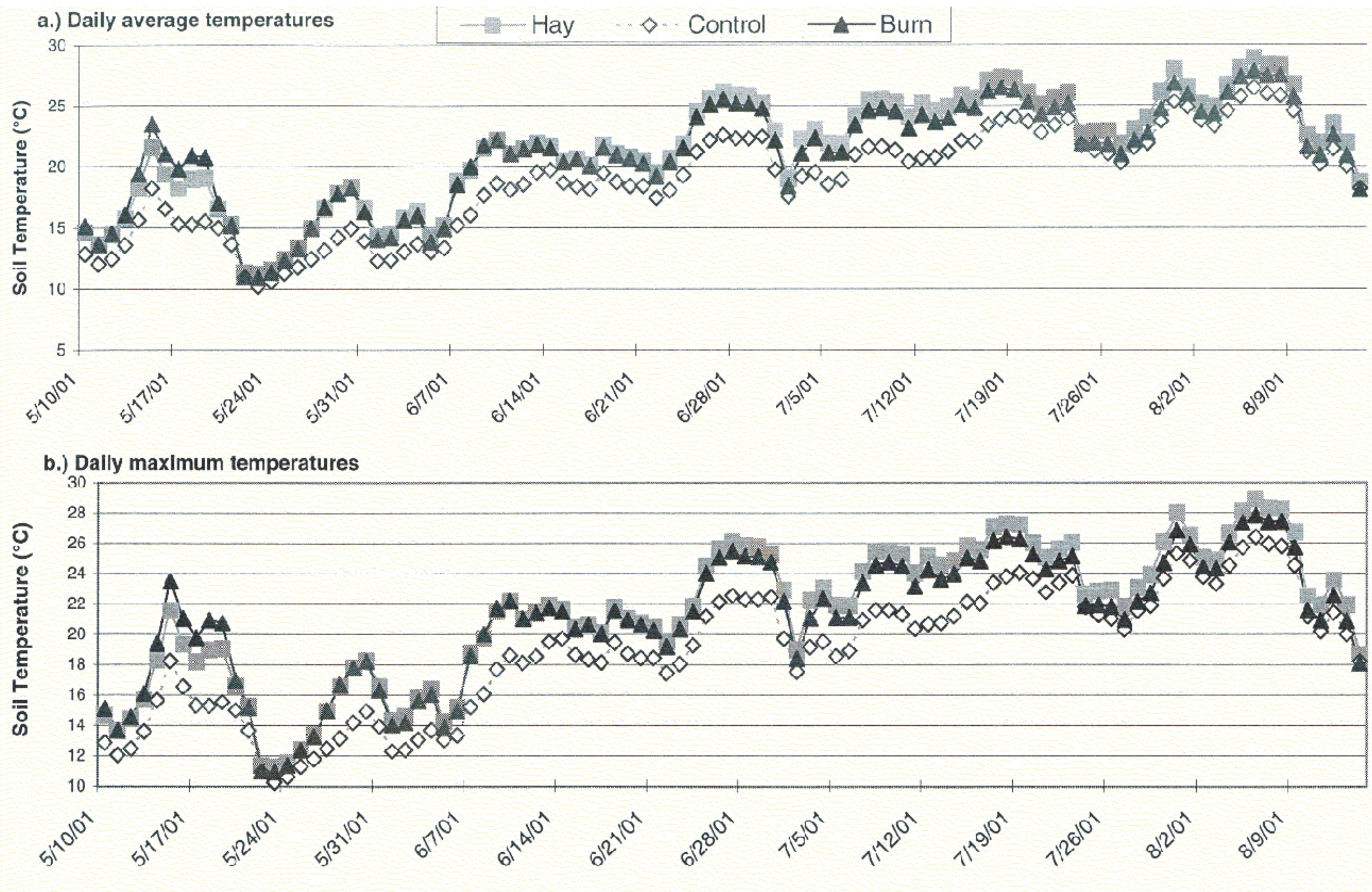

Figure 5.5 - Soil temperatures at 6 cm deep in 2001 at Murphy Lake Prairie. a.) Daily average temperatures; burn and hay temperatures are significantly greater than the control for the entire period. b.) Daily maximum temperatures; burn and hay temperatures are significantly greater than the control for the entire period.

Soil moisture levels on burned plots were significantly lower than the control within two weeks after the treatments each year (Figure 5.6). The mow treatment plots tended to remain the wettest, though, according to the pre-treatment data, these plots may have been somewhat wetter initially. No significant differences in soil moisture were measured at Shakopee Research Site (Figure 5.7).

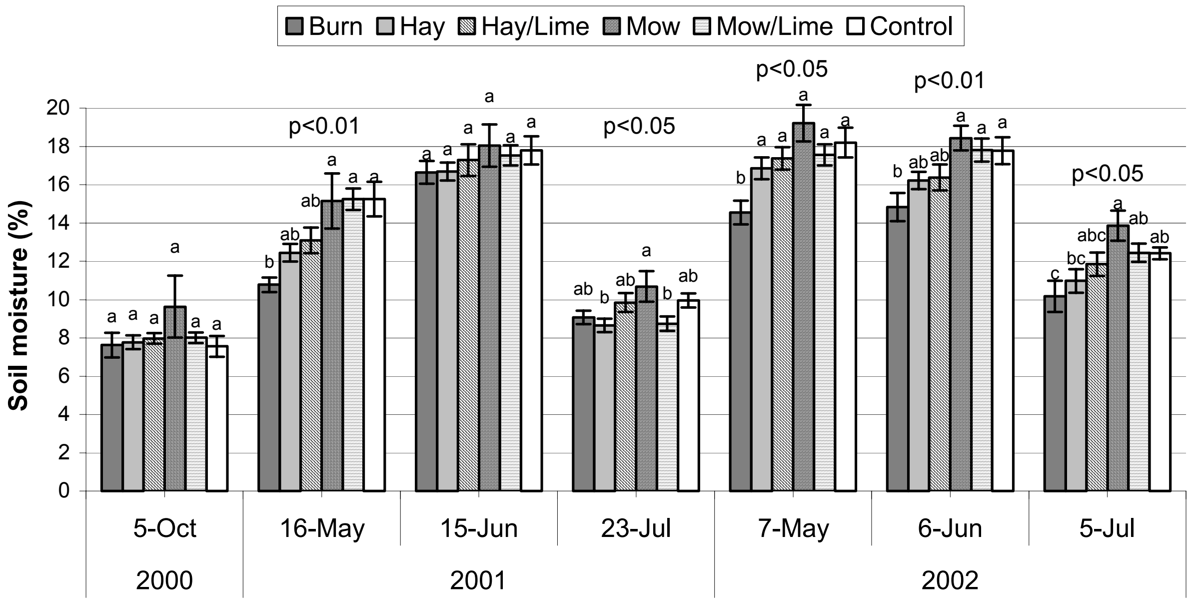

Figure 5.6 - Percent soil moisture by mass at Murphy Lake Prairie. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

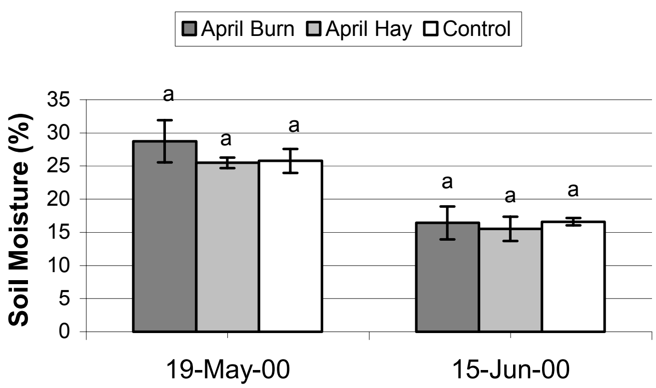

Figure 5.7- Percent soil moisture by mass at the Shakopee Site. Soil collected before August treatments, hay and mow, so these are excluded. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

Nitrogen mineralization rates at Murphy Lake Prairie were significantly greater on burn and hay/lime plots compared to the mowed plots in 2001 (Figure 5.8). This result changes in 2002, during which only the control seems to have a slower mineralization rate than the mowed plots. The data points for the entire season are shown in Figure 5.9, showing that the greatest differences occur in late summer of each year. The absolute level of inorganic nitrogen in the soil at the beginning of each mineralization incubation shows no differences at Murphy Lake

Prairie (Figure 5.10). However, in 2002, the control plots at Murphy Lake Prairie have significantly greater ammonium than all other treatments except the hay/lime. No differences were found in 2000 at the Shakopee site for inorganic nitrogen levels (Figure 5.11).

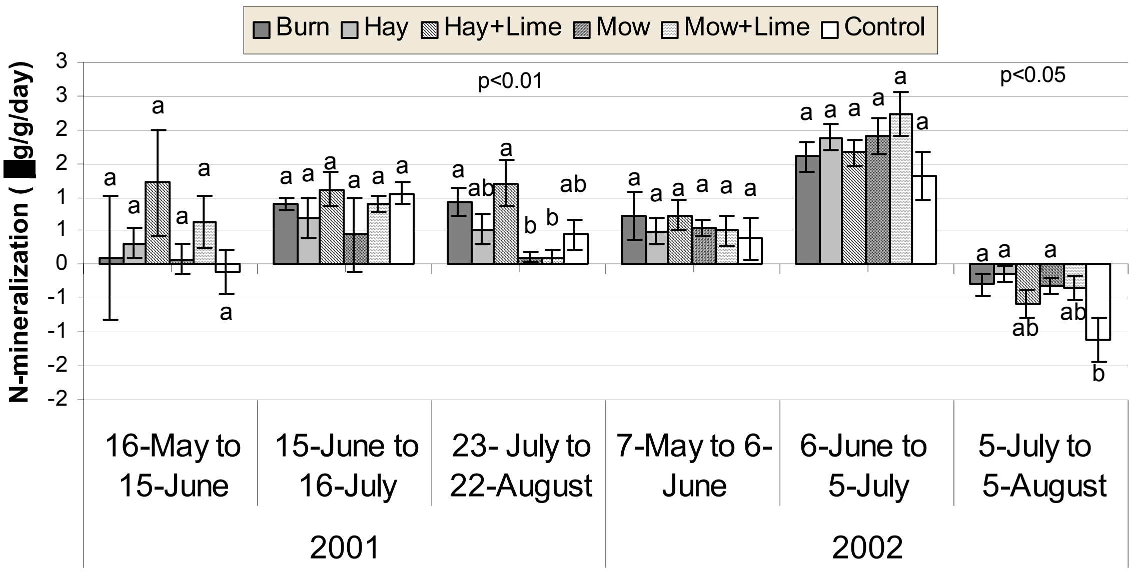

Figure 5.8 - Nitrogen Mineralization at Murphy Lake Prairie by month-long period. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

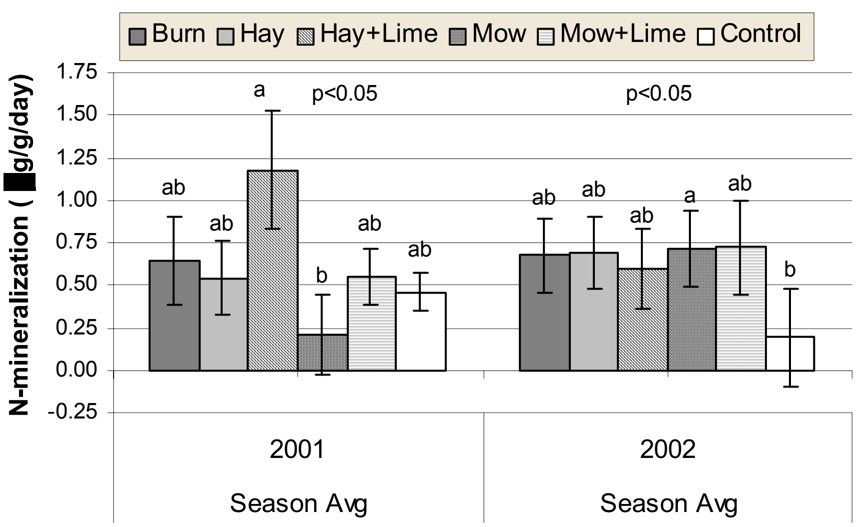

Figure 5.9 - Nitrogen mineralization at Murphy Lake Prairie, an average for the entire season. Analyzed with repeat-measures design. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons.

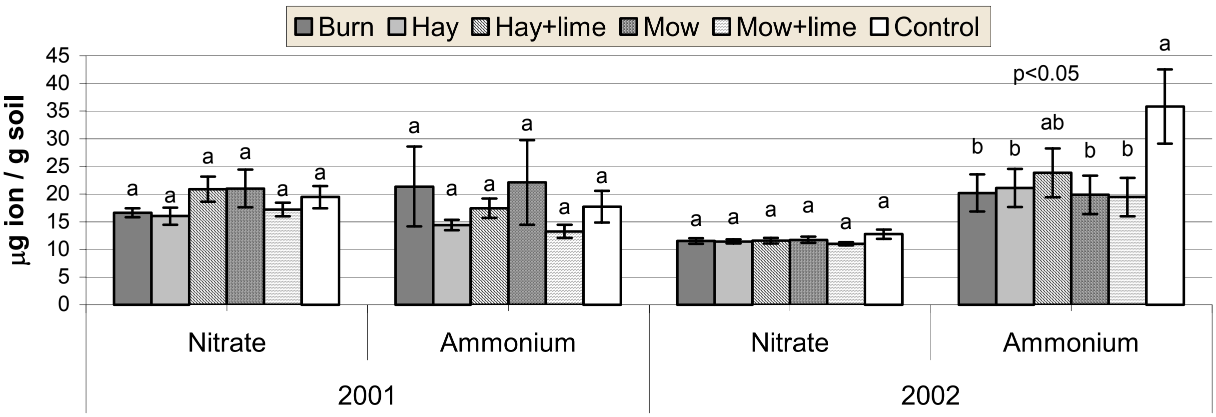

Figure 5.10 - Inorganic nitrogen present in the soil at Murphy Lake Prairie. Data shown are the averages of 3 samples taken from each plot at 3 different times during the growing season: early May, early June, and mid July of each year. Letters represent significant differences between treatments using Tukey HSD pairwise comparisons of a repeat-measures design.

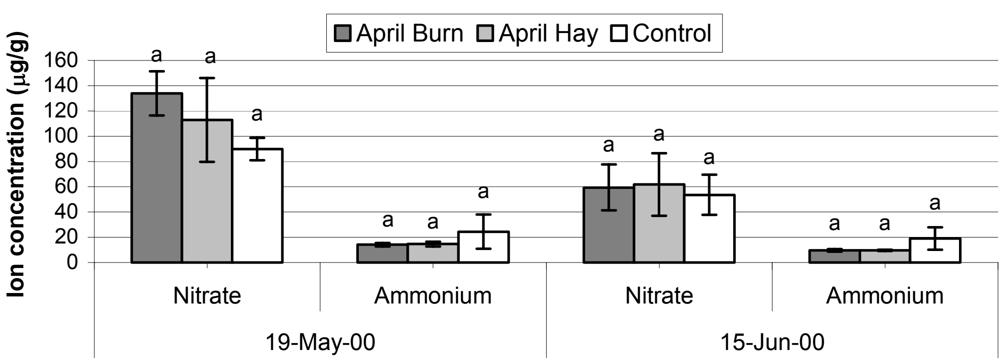

Figure 5.11 - Inorganic nitrogen ions in soil at Shakopee site. Soil collected before August treatments, so these are excluded. No significant differences present.

5.4 Discussion

5.4.1 Lime addition and soil pH

Lime addition affected soil pH to as deep as 12 cm, at least in the mow/lime plots (Figure 5.1). Therefore, a single surface application of burned lime was effective at increasing pH after 2 years. This was a concern of the researchers because most forms of lime are not expected to move into the soil unless incorporated by plowing (George Rehm, personal communication). Ash from the two spring burns, however, did not affect soil pH, even in the top centimeter of soil (Figure 5.1; Figure 5.2). Thus, there is no reason to believe that cations in ash affect soil pH in the short-term.

5.4.2 Nitrogen

Nitrogen mineralization rates reveal how much of this important nutrient is being released from organic material and made available to plants. If large amounts of nitrogen are available in the soil there tends to be a loss of diversity and an increase in cool-season grasses and weedy plant species (4, 52). Litter quantity on the surface of the soil affects nitrogen mineralization rates. The decomposition of litter results in a predictable response by soil nutrients. First, microorganisms accumulate nutrients from elsewhere in the soil as their population multiplies in response to the new material. This phase, known as immobilization, is longer and more pronounced in high carbon litter. Next, the microbial growth slows and nutrients begin to be released, mineralized, from the litter as the microbial population declines (13). In 2001, the immobilization phase may be exhibited by the low nitrogen mineralization rates on the mowed plots (Figure 5.8; Figure 5.9). Burn and hay/lime plots may have greater nitrogen mineralization rates than the mow plots because of the lack of litter present on these plots (Figure 5.9).

Another important factor that affects nitrogen mineralization and soil processes is soil pH. The pH differences that were discussed previously do not seem to have an apparent affect on nitrogen mineralization. In 2001, the mineralization rate on the hay/lime plots is significantly greater than on the mowed plot (Figure 5.9), however, there is no evidence that hay/lime differs from haying alone. Since decomposition rates are maximized at near neutral pH (50), lime may decrease mineralization rates in the shallow soil, which is basic, but increase it deeper in the profile, where the soil is more acidic (Figure 5.1).

After the second season of treatments, soil nitrogen mineralization rates are higher on burned prairie than on similar unburned prairie (Figure 5.8; Figure 5.9). In contrast, there is more ammonium ion (NH_4) in the untreated soil at a given time than there is in soil under unburned prairie (Figure 5.9). This suggests that there is more nitrogen present on untreated plots, yet it is not being generated as rapidly from decomposition. The NH_4 may be more abundant on untreated plots because of the decreased uptake by plants. This can be inferred from the lower aboveground productivity on untreated plots compared with the burned plots (Figure 3.1).

The slower nitrogen mineralization rates on the untreated plots may be due to differences in other soil characteristics, especially soil temperature. Burned plots tended to be the driest and warmest of all the treatments, though rarely differing from the hayed plots (Figure 5.3; Figure 5.4; Figure 5.5; Table 5.1). Decomposition and mineralization rates tend to be highest in warm, moderately moist soil (50). Therefore, the tendency for hayed and burned plots to have higher rates of mineralization suggests the importance of litter removal in warming the soil and perhaps drying it out.

Two consecutive years of burning or haying helps to remove nitrogen from the plant community and decrease available nitrogen in the soil, yet favors the rate of mineralization from decomposition. Thus, these treatments help limit nitrogen availability to plants especially when performed often. Since high soil nitrogen favors aggressive weedy plants and cool-season grasses (4), haying and burning should be used often to help limit nitrogen levels and benefit native warm-season grasses (Chapter 2).

5.5 Conclusions

The process of removing litter seems to be the most important aspect that causes the ecosystem response to prescribed burning. Hayed plots are the most similar to burned plots in terms of soil moisture, temperature, and litter quantity. Consequently, nitrogen levels and nitrogen mineralization rates, which are most likely to influence plant community differences, are similar between these two treatments. Burning and haying eliminate the litter and create warmer, drier soil, which favors nitrogen mineralization and likely helps contribute to an increase in plant productivity found on burned plots. After consecutive annual treatments the nitrogen levels on the removal plots would be expected to decline due to the removal of nitrogen from the system each year. Therefore, litter removal by haying will likely be a sufficient practice to replace prescribed burning at many sites. On frequently hayed plots, however, the removal of plant material eliminates cations and phosphorus as well as nitrogen. Thus, lime may be needed to maintain soil pH on these sites.

5.6 Recommendations

1. Spring haying seems to be a legitimate substitute to spring prescribed burning in order to remove litter periodically.
2. Frequent burning or haying should be performed in order to prevent the accumulation of inorganic soil nitrogen, which may favor many weedy species.
3. If haying is used instead of burning, soil pH should be tested periodically to detect acidic soil. Although this did not become apparent on this experiment, it may occur on long-term hayed grasslands. Acidification may lead to decreases in certain plant populations or losses in productivity.
4. Mowing may decrease nitrogen mineralization rates temporarily. This may help to prevent invasive species but is not likely to do so if mowed annually.

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Appendix A

Species list at Murphy Lake Prairie

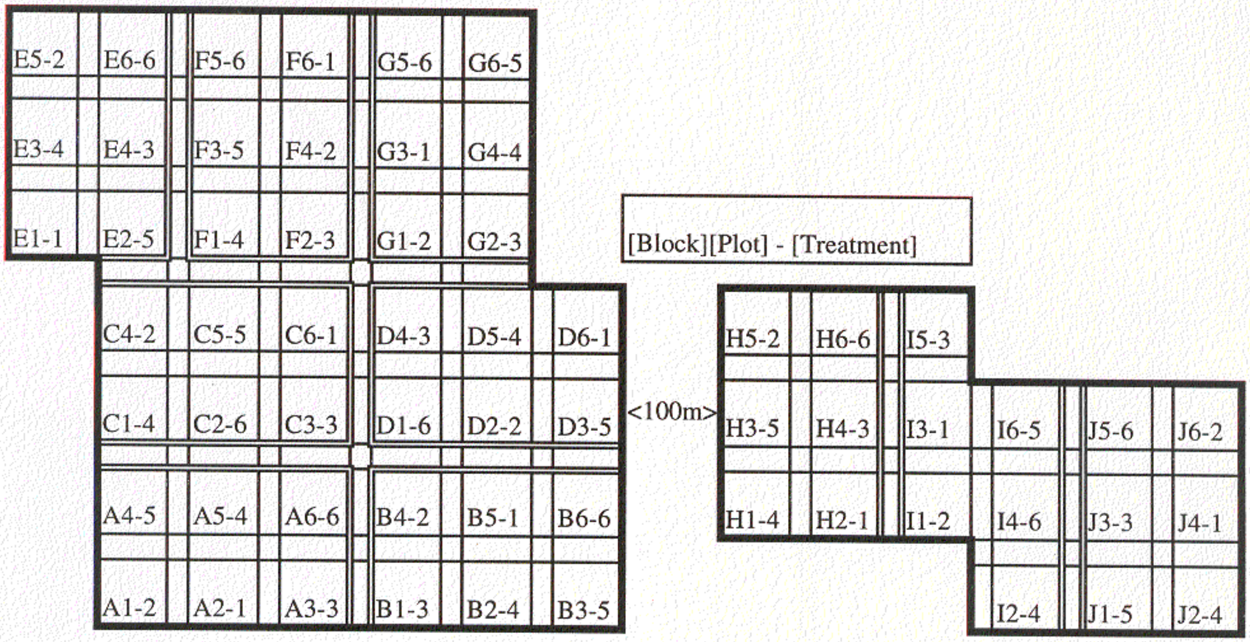
Appendix A - List of the most common species at Murphy Lake Prairie by average cover on the entire site. The type of plant shows the functional group, in which each plant was analyzed.

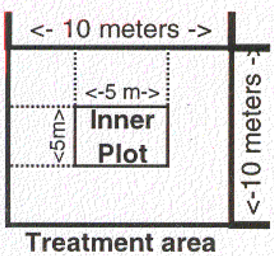
Species name	Common name	Type of plant	Average cover	Volunteer
Andropogon gerardii	Big bluestem	Native WSG	51.3	
Sorghastrum nutans	Indian grass	Native WSG	34.1	
Monarda fistulosa	Bergamot	Native perennial forb	7.6	
Taraxacum officianale	Dandelion	Exotic perennial forb	5.4	Yes
Schyzachyrium scoparium	Little bluestem	Native WSG	4.7	
Elymus canadensis	Canada Wild rye	Native CSG	3.4	
Desmodium canadense	Showy tick-trefoil	Native forb	2.1	
Ratibida pinnata	Yellow coneflower	Native perennial forb	1.7	
Rudbeckia hirta	Black-eyed Susan	Native biennial forb	1.2	
Trifolium repens	Red Clover	Exotic legume	1.1	Yes
Setaria spp/*Eriochloa* spp.	Foxtail / Cup grass	Exotic annual grasses	0.91	Yes
Lespedeza capitata	Bush clover	Native legume	0.68	
Unknown grass #1		Grass?	0.57	?
Cirsium arvensis	Canada thistle	Exotic forb	0.52	Yes
Heliopsis helianthoides	Common ox-eye	Native forb	0.48	
Melilotus spp.	Sweet clover	Exotic legume	0.45	Yes
Solidago canadensis	Canada goldenrod	Native forb	0.38	Yes
Ambrosia artemisiifolia	Common ragweed	Native annual forb	0.37	Yes
Aster oolentagiensis	Sky blue Aster	Native perennial forb	0.31	
Conyza canescens	Horseweed	Native forb	0.29	Yes
Helianthus grasseratus	Sawtooth sunflower	Native perennial forb	0.26	
Erigeron anuus	Daisy fleabane	Native biennial forb	0.24	Yes
Calystegia sepium	Hedge bindweed	Native? perennial forb	0.20	Yes
Dalea purpurea	Purple prairie clover	Native legume	0.17	
Aster lanceolatus	Eastern lined aster	Native perennial forb	0.16	
Panicum virgatum	Switch grass	Native WSG	0.13	
Aster novae-angliae	New England aster	Native perennial forb	0.10	
Oxalis stricta	Yellow wood sorrel	Native perennial forb	0.078	Yes
Agastache foeniculum	Purple giant hyssop	Native perennial forb	0.061	
Cirsium vulgaris	Bull thistle	Exotic perennial forb	0.054	Yes
Coreopsis palmata	Tickseed	Native perennial forb	0.044	
Trifolium arvensis	White clover	Exotic legume	0.044	Yes
Dianthus armeria	Deptford pink	Exotic biennial forb	0.035	Yes
Aster laevis	Smooth aster	Native perennial forb	0.029	
Verbena stricta	Hoary vervain	Native perennial forb	0.027	
Aster sagittitifolius	Arrow-leaved aster	Native perennial forb	0.027	
Lactuca pulchella	Prickly lettuce	Exotic annual forb	0.025	Yes
Asclepias syriaca	Common milkweed	Native perennial forb	0.023	Yes
Gentiana andrewsii	Closed Gentian	Native perennial forb	0.023	
Pycnanthemum virginianum	Virgiana mountain mint	Native perennial forb	0.023	
Liatris spp.	Blazing star	Native perennial forb	0.019	
Elytrigia repens	Quack grass	Exotic CSG	0.019	Yes
	35 other species		0.200	

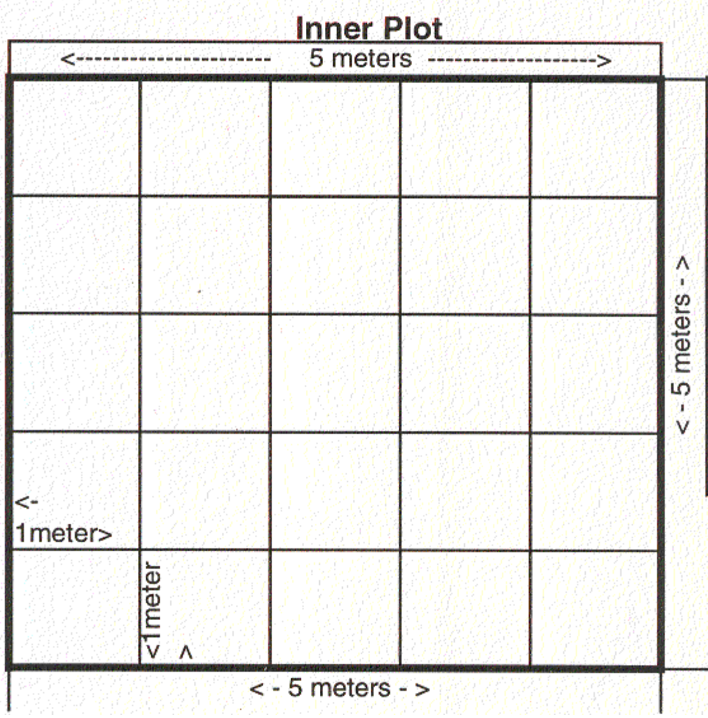
Appendix B

Plot maps at Murphy Lake Prairie

Appendix B - Plot maps and treatment assignments at Muphy Lake Prairie.







Treatments	
1	Control
2	Burn
3	Hay
4	Hay + Lime
5	Mow
6	Mow + Lime

Appendix C

Species list at Mn/DOT Shakopee research site

Appendix C - Most common species at Mn/DOT Shakopee Research site in 2001, based on average cover in each plot regardless of treatment.

Species name	Common names	Type of plant	2001 Average Cover	Volunteer
Andropogon gerardii	Big bluestem	Native WSG	44.7%	
Monarda fistulosa	Bergamot	Native perrennial forb	21.1%	
Sorghastrum nutans	Indian grass	Native WSG	18.9%	
Rudbeckia hirta	Black-eyed Susan	Native biennial forb	9.3%	
Ratibida pinnata	Yellow coneflower	Native perrennial forb	8.5%	
Euphorbia esula	Leafy spurge	Exotic forb	7.4%	Yes
Solidago canadensis	Canada goldenrod	Native perrennial forb	5.2%	
Heliopsis helianthoides	Common ox-eye	Native perrennial forb	4.4%	
Cirsium arvensis	Canada thistle	Exotic forb	4.2%	Yes
Setaria glauca	Yellow foxtail	Exotic WSG	1.8%	Yes
Tradescantia ohiensis	Spiderwort	Native perrennial forb	1.8%	
Taraxacum officianale	Dandelion	Exotic forb	1.8%	Yes
Schyzachyrium scoparium	Little bluestem	Native WSG	1.8%	
Desmodium canadense	Showy tick-trefoil	Native legume	1.7%	
Lactuca pulchella	Prickly lettuce	Exotic forb	1.6%	Yes
Solidago gigantea	Tall goldenrod	Native perrennial forb	1.2%	Yes
Phalaris arundinacea	Reed-Canary grass	Native CSG	1.2%	Yes
Cirsium discolor	Field thistle	Native biennial forb	1.1%	Yes
Hypericum perforatum	St. Johnswort	Exotic forb	0.8%	Yes
Secale cereale	Rye	Exotic CSG	0.8%	Yes
Ambrosia artemisiifolia	Common ragweed	Native annual forb	0.6%	Yes
Solidago rigida	Stiff goldenrod	Native perrennial forb	0.5%	
Astragalus canadensis	Canada milk-vetch	Native legume	0.5%	
Aster novae-angliae	New England aster	Native perrennial forb	0.4%	
Stachys hispida	Hedge-nettle	Native perrennial forb	0.4%	Yes
Carex spp.	Sedge	Native CSG	0.3%	Yes
Physalis heterophylla	Ground Cherry	Native perrennial forb	0.3%	Yes
Berteroa incana	Hoary allyssum	Exotic forb	0.2%	Yes
Conyza canescens	Horseweed	Native annual forb	0.2%	Yes
Panicum capillare	Witch-grass	Native CSG	0.2%	Yes
Muhlenbergia mexicana	Wirestem muhly	Native CSG	0.2%	Yes
Dalea purpurea	Purple prairie clover	Native legume	0.2%	
Dalea candida	White prairie-clover	Native legume	0.2%	
Ambrosia trifida	Giant ragweed	Native annual forb	0.2%	Yes
Achillea millefolium	Yarrow	Native perrennial forb	0.2%	
	Other		3.4%	