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The effects of mowing and fertilizing on species richness and species diversity in a new prairie reconstruction

by

Meredith Hope Borchardt

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree
MASTER OF SCIENCE

Major: Botany (Ecology)
Major Professor: Thomas W. Jurik

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Graduate College
Iowa State University

This is to certify that the Master's thesis of

Meredith Hope Borchardt

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

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INTRODUCTION

The state of Iowa has less of its pre – European settlement vegetation remaining than any of the other 49 states in the United States. Only about two percent of Iowa's native vegetation has endured the extensive alterations of the landscape imposed by human activity over the past two centuries. More than 90 percent of the state's wetlands, 60 percent of its eastern deciduous forests, and 99.9 percent of the tallgrass prairies are gone (Iowa Department of Natural Resources 2000). Tallgrass prairie was the dominant native ecosystem of Iowa, accounting for approximately 12,150,000 hectares (roughly 30 million acres), or 5/6 of the state's area. On a national scale, prairie once stretched across a vast north-south swath of the central United States, from north Texas through parts of Oklahoma, Missouri, Colorado, Nebraska, Iowa, Illinois, Ohio, Wyoming, the Dakotas, Minnesota, and Montana into Canada. This region includes tallgrass prairie on the east, shortgrass plains to the more arid west, and the intermediate mixed - grass prairie at their transition. In Iowa, less than 0.1 percent of the original tallgrass prairie – around 12,150 hectares (30,000 acres) – remains today.

As public awareness of these staggering losses grows, interest in recreating native ecosystems is increasing. In Iowa and the Midwest, prairie reconstruction in particular is gaining in popularity. The establishment of native prairie plant communities is a good starting point for reconstructing the ecosystem. The use of native prairie species in roadside plantings is rising, the retail prairie seed business is growing, and more and more people are becoming prairie hobbyists. The State of Iowa's Department of Natural Resources recently changed its Division of Forestry to the Division of Forests and Prairies and is adding a native seed harvest unit to its system of wildlife units. The Natural Resource Conservation Service, a branch of the United States Department of Agriculture, continues its very popular C.R.P.

(Conservation Reserve Program) in which private landowners receive financial incentives to take land out of traditional row crop production and plant it to perennial vegetation. One option for landowners is to plant native prairie species. In addition, Neal Smith National Wildlife Refuge near Prairie City, Iowa, the largest federal prairie reconstruction project ever attempted, is completing its first decade of returning prairie to the landscape it once dominated.

Multiple terms have been used to describe the process of returning historical vegetation to the landscape. Here I use the following definitions: reconstruction is the appropriate word to describe the establishment of prairie vegetation on a site devoid of existing components of that community. Rehabilitation, on the other hand, takes place on a site where there is a degraded, existing remnant community that can be nursed back to health with active management. Restoration, as defined by the Ecological Society of America, includes both reconstruction and rehabilitation (Packard and Mutel 1997). The prairie of my research project is correctly referred to as a reconstructed prairie.

With the increased public interest in recreating prairie plant communities, there is a need for research on methods of establishment and management of prairies. Many roadside and natural resource managers have had to learn things by trial and error. The knowledge gained by applied research will create reliable baseline information and help save future managers from 'reinventing the wheel.'

Over the last several decades, many aspects of reconstructing prairie, such as treatment of seed before planting, seeding techniques, mowing, and burning have been studied (see Moeller 1998). The first research of this kind was done in the 1930's on pastureland at the University of Wisconsin – Madison Arboretum under the direction of Aldo Leopold. In addition, research has been done on the effects of various treatments on established sites – including burning (Turner et al. 1997), grazing (Tilman 1995), and fertilizing (Foster and Gross 1998). Much of this information is collected in guides such as those by Packard and Mutel (1997) or Shirley (1994). In addition, a vast amount of research has been done on these techniques as they relate to enhancing productivity of rangeland, although not all such studies are pertinent to ecological restoration. An apparent gap in the research exists on the effects of fertilizing at the establishment stage; I was unable to find any published papers on the effects of fertilizing new prairie reconstructions.

One difficulty in the reconstruction process is that it often takes several years for a diverse community of plants to become established. A historic native prairie ecosystem in this region probably had about 30 species of grass and over 250 forb species, which would include multiple plant communities such as wet prairie and dry prairie (Shirley 1994). While richness of this magnitude is beyond the scope of most prairie reconstruction efforts, it is not impossible that with adequate time and resources, a similarly rich assemblage of prairie plants could be reconstructed. For instance, the scale of prairie reconstruction that is occurring at Neal Smith National Wildlife Refuge includes savanna and prairie on thousands of hectares and could one day potentially reach richness levels present in the native ecosystem. A rich and diverse community will better fill both root and shoot zones and is thought to be more resilient and stable than a plant community of low diversity and richness.

Susceptibility to invasion by weeds is an impediment to the successful establishment of prairie. In addition, the unsightly appearance of a weedy planting is a further societal barrier to prairie establishment. In particular, getting a high number of native forbs established in the first two – three years has proved difficult. This research project will attempt to address this problem by examining the effects of two variables on new prairie reconstructions. The two factors are the addition of fertilizer, which is expected to increase the rate of plant growth, and mowing treatments, which have been shown to have significant effects on increasing richness and diversity.

It is commonly thought that fertilizing is bad for prairie reconstructions. The view is based on the idea that prairie plants are able to exist and thrive on nutrient - poor soils, while many weedy species are not. Hence, soils amended with fertilizer presumably are more likely to support weedy species in prairie plantings than are soils without added nutrients. This research project was designed, in part, to test this perception.

In addition to these anecdotal ideas, several studies on the effects of fertilizing on established vegetative communities provide potentially relevant data. Foster and Gross (1998) showed that addition of nitrogen fertilizer to a successional grassland in southwest Michigan increased productivity (in grasses particularly) and decreased species richness. Both plant biomass and litter increased in fertilized plots, causing shading and an increase in competition for light, which prevented seedling establishment of forb species. In another study by Wilson and Shay (1990), the addition of N to a mixed grass prairie in Manitoba, Canada resulted in a decrease in overall species diversity. Two species, in particular, showed an increase in abundance – a grass and a sedge, *Bouteloua gracilis* and *Carex obtusata*, respectively. Finally, Tilman (1987) found that by adding a high amount of N to old fields, on average greater than 60% of species were displaced as overall richness decreased.

In the initial stages of reconstructing a prairie, removal of existing vegetation and disturbance of the soil prior to or at planting leaves a site exposed and open to weed invasion. A likely outcome is a very dense canopy of weeds. This weed canopy shades the ground and prevents newly emerging prairie species from receiving the light they need to photosynthesize. This ultimately prevents them from surviving. Prairie species grow initially slowly above ground, instead developing a relatively large below ground root mass in the first few years. Many weedy species, in contrast, grow more rapidly above ground and get taller than native species in the first few years, while creating relatively little below ground root mass. Thus, mowing should reduce competition of prairie species with weedy species for light by increasing light penetration through the canopy. With mowing, a greater number of native species may get established. Kurtz (1994) compared plots that were mowed intensively the first year (cut to 7.6 cm when 30.5 cm), mowed less the second year (cut to 25.4 cm twice), and unmowed the third year to unmowed plots near Ames, Iowa. He found three times as many native species in the mowed plots as compared to unmowed. Gibson et al. (1993) found the lowest forb species richness in unburned unmowed plots, as compared with plots that were burned, mowed, or both. Moeller (1998) tested the effects of different seeding treatments and mowing treatments on community composition in new prairie reconstructions. With regards to mowing, he concluded that mowing to shorter heights and more frequent mowing had the overall effect of increasing richness and diversity. Specifically, keeping the vegetation within a range of 10 – 25 cm., i.e. cutting it to 10 cm. when it grew as high as 25 cm, produced higher richness and diversity than in treatments with less frequent and higher mowing or no mowing.

This research project attempted to replicate mowing treatments used by Moeller (1998), with the possibility of strengthening his findings by repeating them on a site that differs in latitude and landform. If competing weeds are controlled by mowing, fertilizing could potentially allow prairie species to grow faster. Even though prairie species grow better than weeds on lower – fertility soils, they do typically grow faster on fertile soils if not inhibited by competitors. Thus a fertilizer / mowing combination may speed up growth and establishment of a richer prairie plant community.

The central question of this research project is:

Will the addition of fertilizer and the application of a mowing treatment for two years increase the diversity and / or richness of native prairie species in a newly planted prairie reconstruction?

The overall goal of the project is to improve early management techniques for reconstructing prairie vegetation. The null hypothesis is that no single mowing treatment, fertilization treatment, or combination of the two will have a significantly different effect on species richness or diversity over two years than any other treatment. I tested the effects of fertilization and mowing on plant community characteristics in a newly reconstructed prairie using a 3 x 2 factorial design. Three different mowing treatments were crossed with two fertilization treatments, for a total of six different treatment combinations. The effects of these treatments on species richness and species diversity were measured. The project was done in the first and second growing seasons, 1999 and 2000, of a reconstructed prairie near Mason City, Iowa.

MATERIALS AND METHODS

Study Area

Field studies were conducted at the Lime Creek Nature Center (LCNC) in north – central Iowa, near Mason City, in Cerro Gordo county. The Cerro Gordo County Conservation Board headquarters is housed at the LCNC. Staff members have been planting prairie on the land to establish a high quality, diverse seed source for future roadside plantings. Geologically, north central Iowa is part of the Des Moines Lobe land formation. This is the most recently glaciated part of the state; the Wisconsin glacier retreated approximately 14,000 to 12,000 years ago. Drainage patterns are not yet well - established, the topography is quite flat, and the soils are derived from glacial till parent material (Prior 1991). The site is located on the extreme eastern boundary of this landform region, a zone transitional with the Iowan surface, which covers much of Northeast Iowa (see Figure 1). The Iowan surface is much older and more eroded; the last glaciers were pre- Illinoian, present 300,000 years ago. This highly eroded region is characterized by broad flat plains and well - established drainage networks (Prior 1991).

Historically, the north – central Iowa area comprised tallgrass prairie, intermixed with shallow depressions called prairie potholes that had wet prairie or wetland vegetation. Along rivers were typical riparian woody species and floodplain forest. Much of the prairie pothole region has been drained with underground tile and plowed and is currently farmed in row crops. The state of Iowa has thick, rich topsoil, mainly due to decomposition of native prairie plant roots, and the Des Moines Lobe has some of the most fertile soils in the state.

The region has a continental climate; the average total annual precipitation recorded in Mason City is 76.78 cm (30.23 inches). Of this, most of the rainfall (~ 58.42

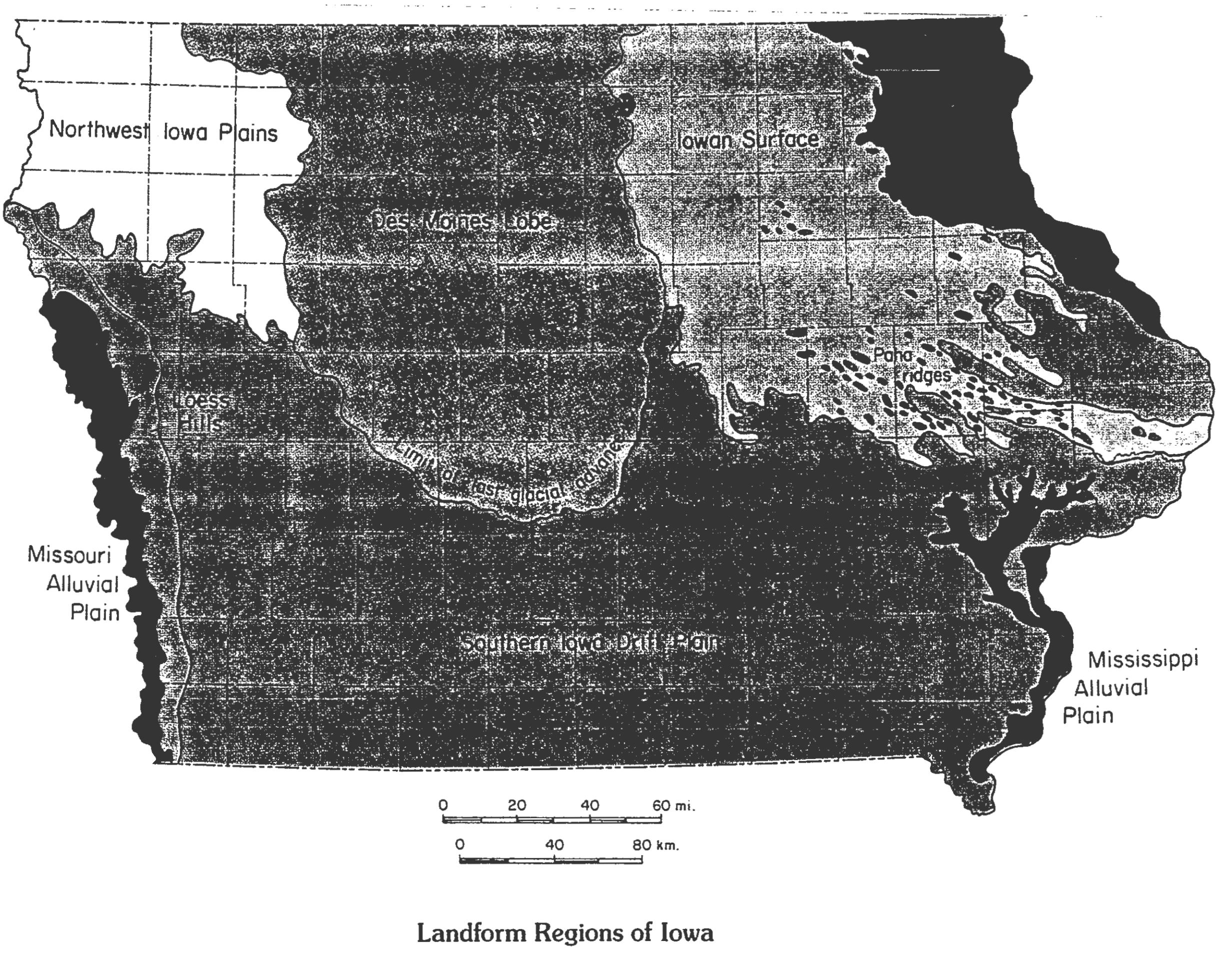

Figure 1. Map of Iowa landform regions from Prior (1991). Asterisk indicates location of study site.

cm) occurs between April and September. Average seasonal snowfall is 93.98 cm. Average mean temperature is 6 C (44.8 F). In winter the average daily temperature is -8 C (17 F), while in summer it is 21 C (70 F) (DeWitt 1981).

The Lime Creek Nature Center area comprises approximately 160 hectares (400 acres) of floodplain forest, old agricultural fields, wildlife plantings, limestone bluffs, recreational trails, and reconstructed prairie. It is located just north of the county seat, Mason City. The Winnebago River makes up the north and east boundaries, while state highway 65 makes up the west border (see Figure 2). It is located at 43° 10' north latitude, and 93° 10' west longitude. The site is approximately 370 m (1200 feet) above sea level.

The field site is located in the north part of the Lime Creek Conservation Area, in Lime Creek Township, section 27, the southwest quarter section. The land was most recently in brome grass pasture, and a 1980 aerial photo shows the area in row crops. No further land use history is known, though it can be presumed the site was used for agricultural purposes since the area was first settled.

Generally, the soils are of the Rockton – Sogn – Mattland association, which are nearly level to very steep, well – drained and somewhat excessively drained soils that formed in loamy sediment over limestone bedrock (DeWitt 1981). Specifically, the soils of the study area are of the Rockton series, fine – loamy, mixed, mesic Typic Argiudolls. They are of the soil order Mollisols, typical of areas with native prairie vegetation (DeWitt 1981). The research site is in the southeast corner of a 0.8-hectare (2-acre) area seeded in 1999. The site was relatively uniform in soil moisture, topography, and prior vegetation.

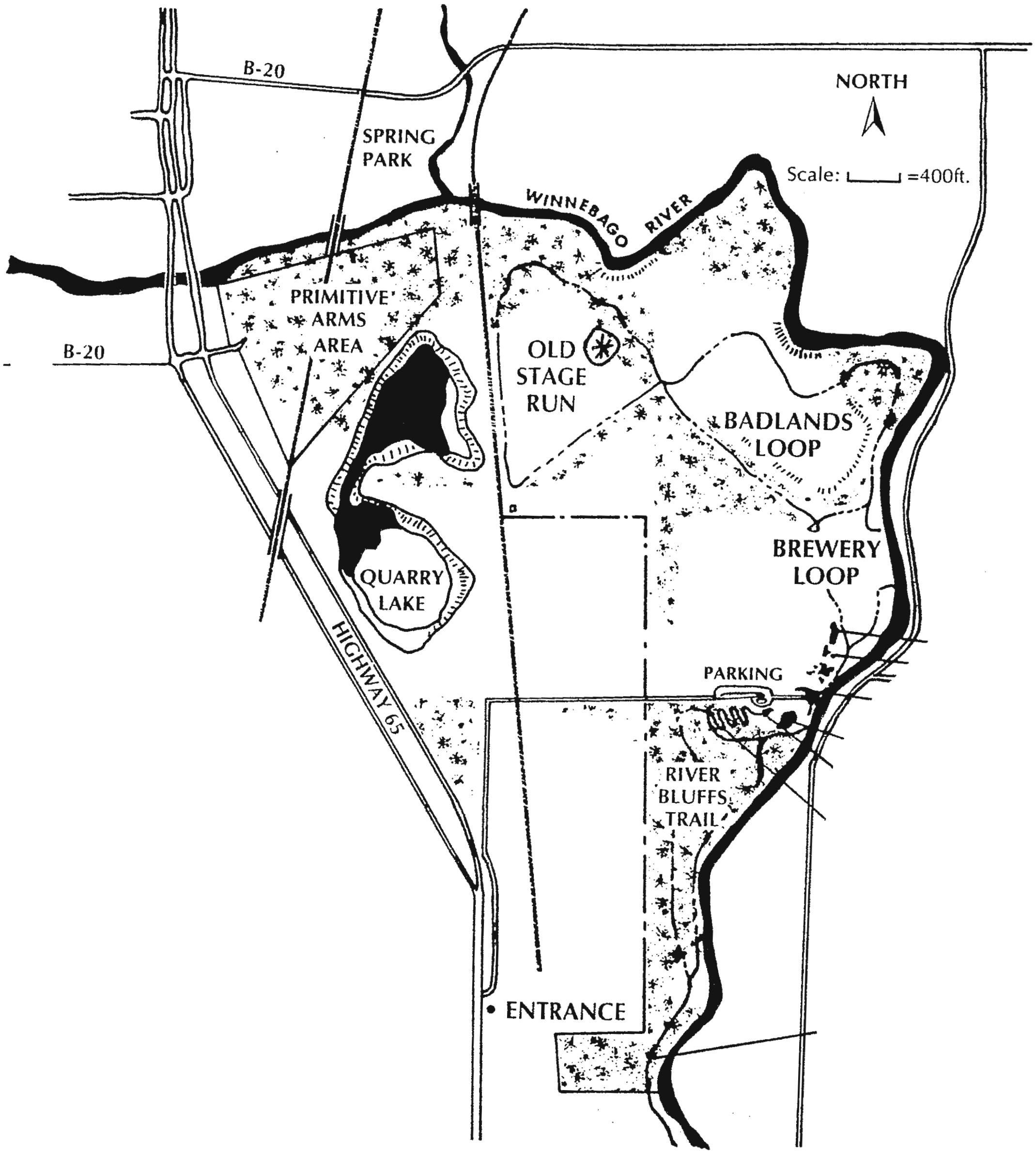

Figure 2. Map of Lime Creek Nature Center from Cerro Gordo County Conservation Board (1998). Study site location is indicated with circled asterisk.

Site Preparation

Site preparation was done in May and June, 1999. Mike Webb, manager of parks and wildlife areas for the county conservation board, operated the equipment. On May 3 the area was mowed with a rotary mower; on May 26 it was treated with the herbicide Round-up Ultra to remove existing brome grass vegetation. On June 8 the land was disked to level the microtopography; gopher mounds were numerous. The same day it was seeded at a rate of 4.7 kg ha $^{-1}$ (5 pounds per acre) of forbs and 7.9 kg ha $^{-1}$ (8.5 pounds per acre) of grasses. Thirty-five native forb species and five native grass species characteristic of mesic to dry habitats made up the mix (See Appendix A for species planted). A Truax seed drill was used to plant the seeds approximately 1.27 cm (0.5 inches) deep. Following the seeding, the area was cultipacked the same day, June 8, to enhance soil - to - seed contact.

Experimental Treatments

Eight replicate blocks were arranged in two rows of four running east and west, in a randomized complete block design. Each block was 12 m by 8 m. A 5 - m buffer, mowed at an intermediate height, was established between and around all blocks. There were six plots within each block, one for each of the six treatment combinations. Each plot was 4 m x 4 m in size (see Figure 3).

Three mowing treatments were used. In the “10 / 25” treatment, the vegetation was allowed to grow to an average height of 25 cm and then mowed to 10 cm. Similarly, with the “10 / 45” treatment, when vegetation reached an average height of 45 cm, it was cut to 10 cm. The third mowing treatment was “no mow”; the plots were never mowed. The mowing heights were selected based on research by Moeller (1998) at Neal Smith National Wildlife

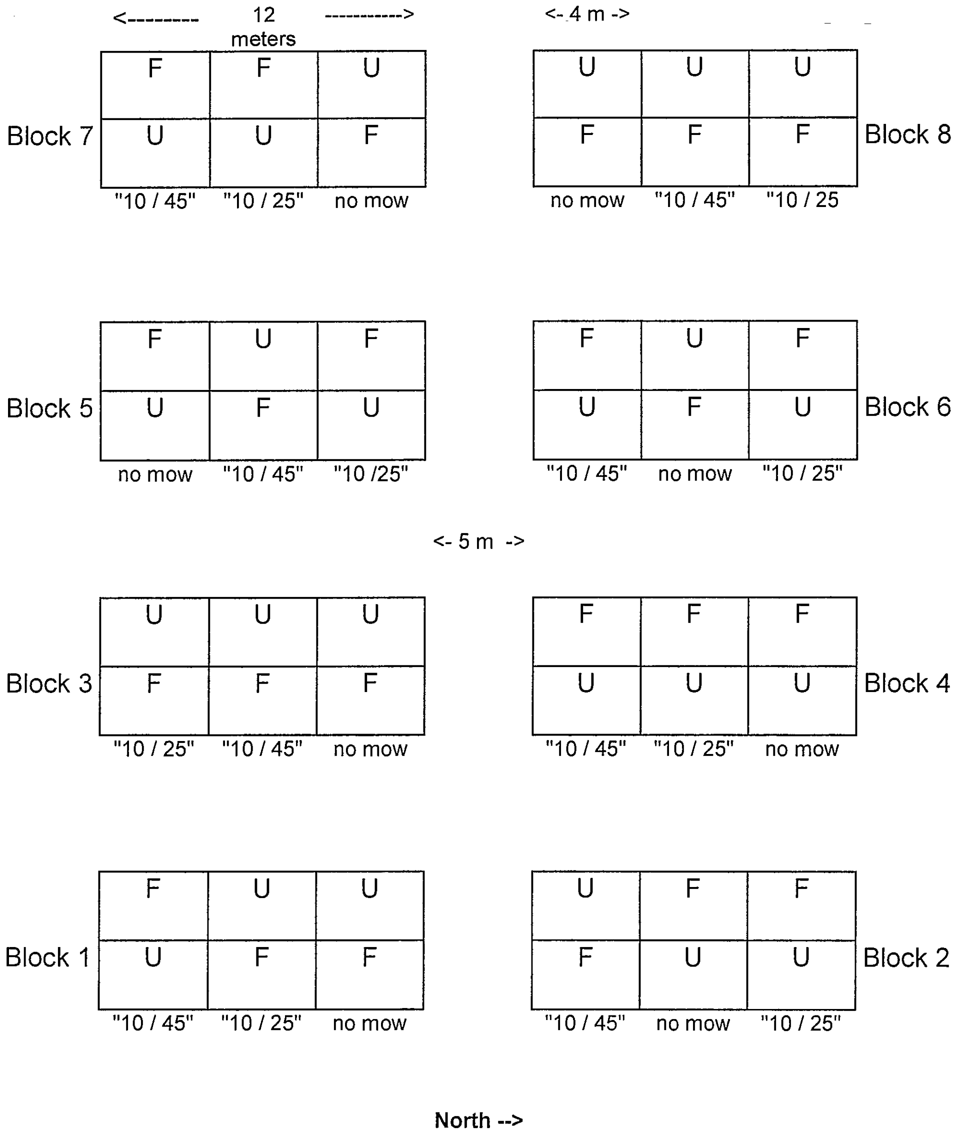

Figure 3. Diagram showing the layout of blocks and plots at the Mason City field site. Plots were either fertilized (F) or unfertilized (U). Mowing treatments (10 / 25, 10 /45, no mow) are defined in the text. Each block was 8 m x 12 m, and each plot was 4 m x 4 m. There was a 5 m buffer between blocks.

Refuge, Prairie City, Iowa, which showed mowing to a height of 10 cm maximized richness and diversity in new prairie plantings.

The two fertilizer treatments were fertilized and unfertilized. The fertilizer was a custom mix from Land O' Lakes, Inc. that contained nitrogen (NH_4NO_3), phosphorus (P_2O_5), and potassium (K_2O potash), with the formulation 35–44-83. It was applied at a rate of 33.7 kg ha^{-1} (30 lb/acre) N, 56.1 kg ha^{-1} (50 lb/acre) P, and 33.7 kg ha^{-1} (30 lb/acre) K, or a combined rate of 123.5 kg ha^{-1} (110 lb/acre). On a per plot basis, the rate was 164.6 grams (5.76 oz.) per 4 m x 4 m plot. Other studies where prairies have been amended with fertilizer typically have reported fertilization rates in units of g m^{-2}. For comparison, nitrogen was here added at a rate of 3.4 g m^{-2}, P at a rate of 5.6 g m^{-2}, and K at a rate of 3.4 g m^{-2}. The rate was determined by consulting with an Iowa State University crop fertility specialist about recommended rates for fertilizing perennial pasture with legumes, an agricultural plant community similar in growth form to prairie. In addition, the intent of this applied research project was to improve early management of newly established prairie vegetation. Thus, a rate was used that could potentially be a reasonable rate for managers to apply, as opposed to using an extremely high rate that would not be feasible, for cost reasons, for use by land managers.

Within each block, there were three pairs of plots along the north/south axis (Figure 3). Each mowing treatment was randomly assigned to one of the three pairs of plots. Each pair of plots was randomly assigned one fertilized plot and one unfertilized plot (Figure 3).

Treatment Application

I made the first of two fertilizer applications on June 12, 1999. The fertilizer was slow- release and in a dry granular form; I applied it using a commercial lawn fertilizer push spreader. The second fertilizer application was made on August 6, 1999, using the same formulation and rate. In the second growing season, a single fertilizer application was made on May 8, 2000, using the same formulation and rate as in 1999.

After seeding in early June, the 10 / 25 plots were first mowed on July 27, 1999 and once more that year on August 13. The 10 / 45 plots were mowed just once that year, on August 3, 1999. On August 28, vegetation height was measured and neither the 10 / 25 nor the 10 / 45 plots were quite up to mowing height, so no further mowing was done. A John Deere model 318 riding lawn mower with belly - mounted mower was used for mowing. The flap directing cut vegetation was rigged open, to minimize piling of vegetation. However, when vegetation was quite thick, especially in the 10 / 45 treatment, there were unfortunately nearly windrows of vegetation along the edge of some plots.

The same mowing treatments were applied in 2000, although mowing was started much earlier than in 1999. The 10 / 25 treatment was mowed on May 22, June 27, and July 31. The 10 / 45 treatment was mowed on June 13 and July 31. No mowing was done after July 31.

Soil Nutrient Analysis

Nutrient content of the soil in selected plots was analyzed to determine the effect of fertilization on N, P, and K content of the soils in fertilized plots. Two samples were taken in September, 1999 from each block, for a total of 16 samples. Within each block the two samples came from a pair of plots that received the same mowing treatment, i.e. from one plot that had been fertilized and one that had not. The pair of plots within each block was randomly selected over all blocks; each of the three mowing treatments was included. I used a circular bulb planter to remove approximately 150 grams of soil from the top 10 cm of soil in each plot. The soil from each plot was placed in a sealed plastic container, labeled, and transported back to the lab. The samples were weighed and then placed in a 65 C oven for 20 days, cooled, and reweighed to calculate percent moisture. Percent organic matter, ppm N, ppm P, and ppm K were determined by the Iowa State University Soil Testing Laboratory. Appendix B contains these values.

Vegetation Sampling Scheme

Similar vegetation sampling schemes were used in both 1999 and 2000. In 1999, I sampled between September 6 and 11, and in 2000 the sampling was completed on August 19 – 21. In 1999, four quadrat samples were taken per plot, using a 0.5 m x 0.5 m quadrat frame made of PVC plastic tubing. Based on the 1999 data, I determined that three samples per plot were sufficient to provide the desired information on plant community composition. Thus, only three quadrats per plot were sampled in 2000. For each species observed within the quadrat, percent cover at ground level was estimated and recorded. Marks on each edge of the quadrat aided in visual subdivision of the quadrat, making the job of estimating cover much easier and more accurate. I decided not to measure the number of stems, though for some tall, slender species such as *Dalea candida* and *Dalea purpurea* (white and purple prairie clover), it might have given a more accurate value of relative biomass. However, percent cover was recorded because it allows easier comparison between all species. On the unmowed plots a three-sided quadrat was used, which more easily fitted into the taller vegetation.

A Latin square sampling design was used to distribute sample quadrats evenly within plots. Each plot is 4 m by 4 m; subtracting the outer 0.5-m (which was more likely to be affected by accumulated duff, variable mowing, etc.) leaves a 3 m by 3 m area to be sampled. The letters A, B, and C were assigned to columns, and X, Y, and Z to rows. For each plot I randomly assigned three combinations of these sets of letters, so that each row and each column had one sample. For example, samples might be taken from AX, BZ, and CY (see Figure 4). The sample quadrat was arbitrarily located in the assigned 1 m x 1 m area. In 1999, when I took four samples per plot, a fourth randomly chosen column – row location was also used. Sample locations were randomly assigned before going to the field. Locations were reassigned in the second sampling year, using the same methods.

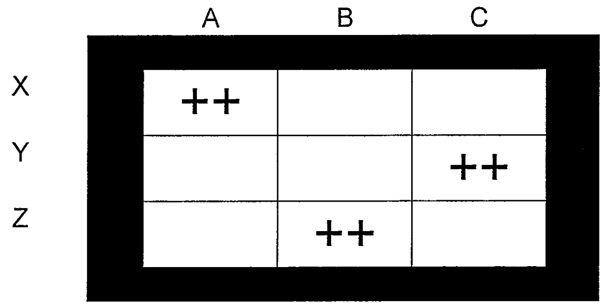

Figure 4. Diagram of a 4 m x 4 m plot showing the 0.5 m outside edge (dark) that was not sampled and the 3 x 3 Latin square design for samples in the remaining 3 m x 3 m space.

Data Analyses

I classified vegetation as desirable (native prairie species, planted) or undesirable (non-prairie, not planted). A list of all species recorded and their designation as desirable or undesirable is in Appendix C. Cover values for the three (or four) quadrats were averaged to give a single value for each species for a plot. Richness (total number of species) and diversity were calculated based on the combined quadrat data for a plot. Diversity takes into account both the number of species and their abundance. For example, a plot with three species of 33 percent cover each is more diverse than a plot with three species of 90, 5, and 5 percent cover, according to the Shannon – Weiner index. Using the Shannon – Weiner index, diversity was calculated using the following formula:

$$H' = -\sum p_i * \ln(p_i),$$

where p_i is the fractional cover (0 – 1) of species i.

H' was calculated on a per plot basis using the average fractional cover values. Total diversity and total richness were calculated using all species found in a plot. Desirable species diversity, undesirable species diversity, desirable species richness and undesirable species richness were also calculated.

Treatment means, standard error of the mean, and significant differences between treatments using analysis of variance were calculated using SAS (Statistical Analysis Software) version 6.1. If ANOVA indicated a significant treatment effect, the Student - Newman - Keuls (SNK) test was used to determine if the treatment means were significantly different from one another.

RESULTS

Table 1 contains ANOVA results for all treatment factors; all treatment means on a per - plot basis are in Tables 2, 3, and 4. Six summary statistics were calculated: total species richness, desirable species richness, undesirable species richness, total species diversity, desirable species diversity, and undesirable species diversity.

A total of 58 species was recorded over both growing seasons. Twenty -five of these species were classified as desirable and 33 as undesirable. A list of the species, their presence or absence in 1999 and 2000, and their characterization as desirable or undesirable is given in Appendix D. All species planted were considered desirable, as well as a few native prairie species that were recorded but not in the seed mix. Examples of the latter include evening primrose (*Oenthera biennis*) and tall boneset (*Eupatorium altissimum*), which are native but were not planted. Presumably their seed spread from nearby native prairie reconstructions; both were observed in the area. Twenty desirable species and 31 undesirable species were recorded on the mowed plots. Appendices E and F give average percent cover values for all species per plot for each treatment combination in 1999 and 2000, respectively.

There was higher than average rainfall in 1999 in Mason City, as compared to average rainfall between 1951 – 1973 (DeWitt 1981). April, May, June, and July all had higher than average rainfall, cumulating in 36.5 cm of additional precipitation spread fairly evenly over the first growing season (see Appendix G). There was near normal rainfall in 2000, with just 1.4 cm more than the average in the months April through August (DeWitt 1981).

Table 1. Anova results of treatment effects on community composition. P values < 0.05 are listed; others > 0.05 are noted 'ns' (not significant).

1999 Total Richness

Effect	df	F Value	Pr > F
Block	7, 12	3.52	0.0058
Mow trt.	2, 12	5.33	0.0095
Fert trt.	1, 12	0.5	ns
mow * fert.	2, 12	0.22	ns

2000 Total Richness

Effect	df	F Value	Pr > F
Block	7, 12	2.26	ns
Mow trt.	2, 12	1.51	ns
Fert trt.	1, 12	0.79	ns
mow * fert.	2, 12	2.5	ns

1999 Desirable Richness

Effect	df	F Value	Pr > F
Block	7, 12	6.62	0.0001
Mow trt.	2, 12	4.19	0.0234
Fert trt.	1, 12	0.82	ns
mow * fert.	2, 12	1.47	ns

2000 Desirable Richness

Effect	df	F Value	Pr > F
Block	7, 12	2.12	ns
Mow trt.	2, 12	2.57	ns
Fert trt.	1, 12	1.15	ns
mow * fert.	2, 12	0.08	ns

1999 Undesirable Richness

Effect	df	F Value	Pr > F
Block	7, 12	0.72	ns
Mow trt.	2, 12	2.4	ns
Fert trt.	1, 12	0.01	ns
mow * fert.	2, 12	0.34	ns

2000 Undesirable Richness

Effect	df	F Value	Pr > F
Block	7, 12	1.25	ns
Mow trt.	2, 12	7.57	0.0018
Fert trt.	1, 12	0.04	ns
mow * fert.	2, 12	3.27	ns

1999 Total Diversity

Effect	df	F Value	Pr > F
Block	7, 12	2.13	ns
Mow trt.	2, 12	1.51	ns
Fert trt.	1, 12	0.53	ns
mow * fert.	2, 12	0.29	ns

2000 Total Diversity

Effect	df	F Value	Pr > F
Block	7, 12	1.63	ns
Mow trt.	2, 12	2.41	ns
Fert trt.	1, 12	0.37	ns
mow * fert.	2, 12	1.57	ns

1999 Desirable Diversity

Effect	df	F Value	Pr > F
Block	7, 12	3.43	0.0068
Mow trt.	2, 12	3.91	0.0294
Fert trt.	1, 12	1.52	ns
mow * fert.	2, 12	0.61	ns

2000 Desirable Diversity

Effect	df	F Value	Pr > F
Block	7, 12	2.04	ns
Mow trt.	2, 12	10.57	0.0003
Fert trt.	1, 12	0.56	ns
mow * fert.	2, 12	0.95	ns

1999 Undesirable Diversity

Effect	df	F Value	Pr > F
Block	7, 12	0.63	ns
Mow trt.	2, 12	0.32	ns
Fert trt.	1, 12	0.09	ns
mow * fert.	2, 12	0.03	ns

2000 Undesirable Diversity

Effect	df	F Value	Pr > F
Block	7, 12	2.76	0.0217
Mow trt.	2, 12	5.34	0.0095
Fert trt.	1, 12	0.03	ns
mow * fert.	2, 12	0.23	ns

Combined Effects of Mowing and Fertilizing

A two – way ANOVA model with a mowing * fertilization interaction was evaluated to look at the interaction between these two factors. Two ANOVAs were evaluated, using data for the two years separately. There was no significant interaction ($\propto = 0.05$) between mowing and fertilizing for any of the six community composition measures in either year (Table 1). Since there was no significant interaction between mowing and fertilization, each of these factors was next analyzed individually. Fertilization showed no effect on the measures whereas mowing did have some significant effects. Thus, mowing was the dominant factor in shaping richness and diversity characteristics of the newly planted prairie.

A randomized complete block design was used in this experiment to remove some of the experimental error that might be caused by spatial variation. I used eight replicate blocks in order to account for potential spatial variation. The ANOVA indicated that for four of twelve characteristics there were blocking effects (Table 1).

Soils Tests Results

Soil nutrient analysis did not show a consistent trend that fertilized soils had higher N, P, and K nutrient content (Table 2). Percent organic matter varied widely, as did moisture. Soil analysis revealed that blocks 5 and 6 had only about half the moisture of the other six blocks (Table 2). These same two blocks had much lower % organic matter compared to all other blocks also and may have contributed to spatial variation.

Fertilization Effects on Richness and Diversity

Over all mowing treatments, there were no significant effects of fertilization on any of the six summary statistics (Table 3). Visually, there were no effects on color of

Table 2. Effect of fertilizing on soil nutrient content at Lime Creek Nature Center in 1999. Treatments are defined in the text. One sample per plot was taken in two of 6 plots per block, thus values listed are actual values not mean values (n = 1).

Block	Treatment	% moisture	ppmN	ppmP	ppmK	% org. matter
1	no mow / F	11.1	2	72	270	8.6
1	no mow / U	11.9	3	51	273	8
2	no mow / F	9.7	1	104	314	7
2	no mow / U	5.5	<1	27	143	6
3	10 / 45 / F	10.5	1	23	142	5.7
3	10 / 45 / U	10	17	56	159	8
4	10 / 45 / F	11.3	<1	37	171	5.2
4	10 / 45 / U	7.9	4	45	131	8.4
5	10 / 25 / F	3.4	4	59	288	5.1
5	10 / 25 / U	6	4	39	206	4.6
6	10 / 25 / F	3.4	2	28	140	5
6	10 / 25 / U	4.3	4	36	151	
7	10 / 45 / F	8.9	5	68		
7	10 / 45 / U	10.9	5	56		
8	no mow / F	8	2			
8	no mow / U	10.6	4			

Table 3. Effects of fertilization on plant community characteristics at Lime Creek Nature Center in 1999 and 2000. Treatments are defined in the text. Mean values are per plot (n = 24); standard error of the mean is in parentheses. Means in the same row with the same letter were not significantly different.

1999

	Fertilized	Unfertilized
Total Richness	11.4a (0.68)	10.9a (0.55)
Desirable Richness	6.1a (0.55)	5.6a (0.47)
Undesirable Richness	5.3a (0.36)	5.3a (0.33)
Total Diversity	1.2a (0.05)	1.3a (0.05)
Desirable Diversity	0.6a (0.04)	0.6a (0.05)
Undesirable Diversity	0.7a (0.04)	0.6a (0.03)

2000

	Fertilized	Unfertilized
Total Richness	11.5a (0.46)	11a (0.44)
Desirable Richness	5.3a (0.26)	4.8a (0.33)
Undesirable Richness	6.3a (0.41)	6.2a (0.33)
Total Diversity	1.6a (0.04)	1.6a (0.06)
Desirable Diversity	0.9a (0.05)	0.9a (0.06)
Undesirable Diversity	0.7a (0.04)	0.7a (0.04)

vegetation, density of vegetation, or dominance by grass, which were all expected to show some noticeable effect.

Mowing Effects on Richness and Diversity

In 1999 mowing had a statistically significant ($p < 0.05$) positive effect on total richness, desirable richness, and desirable diversity, but no effect on undesirable richness, total diversity, or undesirable diversity (Table 4). In the second field season, 2000, mowing had significant ($p < 0.05$) effects on undesirable richness, desirable diversity, and undesirable diversity, but no effect on total richness, desirable richness, or total diversity (Table 4). In most cases, one or both of the mowing treatments had a higher value than the unmowed treatment. One exception to this was with desirable diversity in 2000, when the unmowed plots were significantly higher than the mowed plots. Figures 5 and 6 give a visual interpretation of the mowing treatment effects on all six community composition measures.

Mowing had the effect of increasing desirable species richness and diversity in the first year. The 10 / 25 and 10 / 45 mow treatment plots both had a significantly greater number of species than the unmowed treatment plots in 1999 ($p < .05$). Mean species richness for the 10 / 25 and 10 / 45 plots were 12.5, with a standard error of 0.5, and 11.2, SEM 0.7, respectively. In comparison, mean species richness for unmowed plots was 9.7 with a standard error of 0.8. In the second year, the ANOVA did not show a significant effect of mowing on total richness.

My study did not find the two mowing treatments to be statistically different in total richness. In the first year the 10 / 25 treatment was higher than the 10 / 45 in total species richness, while in 2000 the reverse was true.

Table 4. Effects of mowing on plant community characteristics at Lime Creek Nature Center in 1999 and 2000. Treatments are defined in the text. Mean values are per plot (n = 16); standard error of the mean is in parentheses. Means in the same row with the same letter were not significantly different.

1999

	(10 - 25)	(10 – 45)	No mow
Total Richness	12.5a (0.54)	11.2a (0.74)	9.7b (0.82)
Desirable Richness	6.9a (0.42)	5.5b (0.57)	5.2b (0.77)
Undesirable Richness	5.6a (0.46)	5.7a (0.41)	4.5a (0.37)
Total Diversity	1.3a (0.04)	1.3a (0.06)	1.2a (0.07)
Desirable Diversity	0.7a (0.03)	0.6a (0.05)	0.5b (0.06)
Undesirable Diversity	0.6a (0.04)	0.7a (0.03)	0.7a (0.05)

2000

	(10 - 25)	(10 - 45)	No mow
Total Richness	11.3a (0.66)	11.8a (0.52)	10.6a (0.42)
Desirable Richness	4.6a (0.32)	4.9a (0.38)	5.6a (0.36)
Undesirable Richness	6.8a (0.41)	6.9a (0.41)	5.0b (0.37)
Total Diversity	1.5a (0.06)	1.6a (0.06)	1.7a (0.06)
Desirable Diversity	0.8b (0.05)	0.8b (0.05)	1.0a (0.08)
Undesirable Diversity	0.8a (0.05)	0.8a (0.04)	0.6b (0.06)

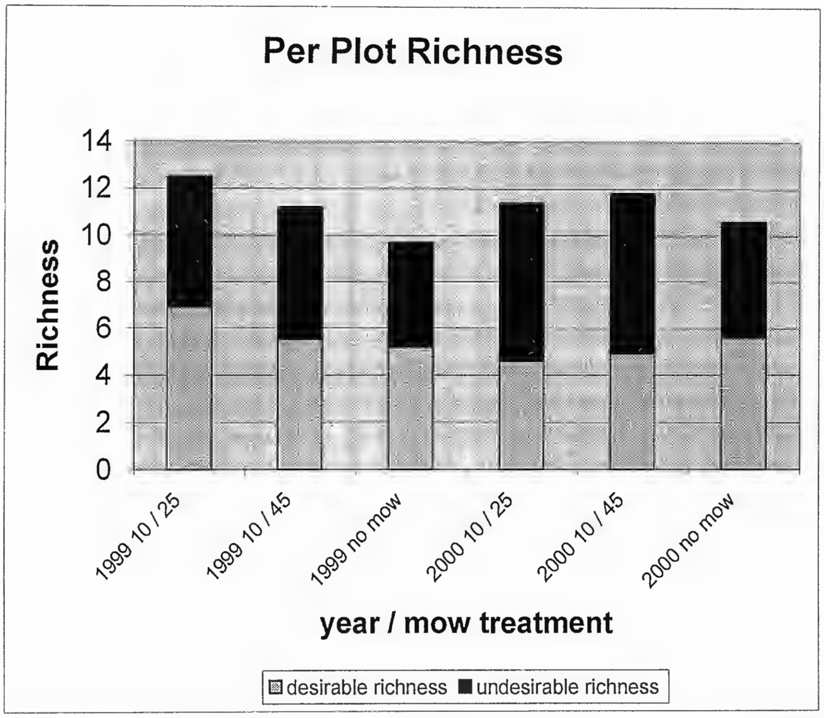

Figure 5. Graph showing per plot richness of the three mowing treatments in 1999 and 2000.

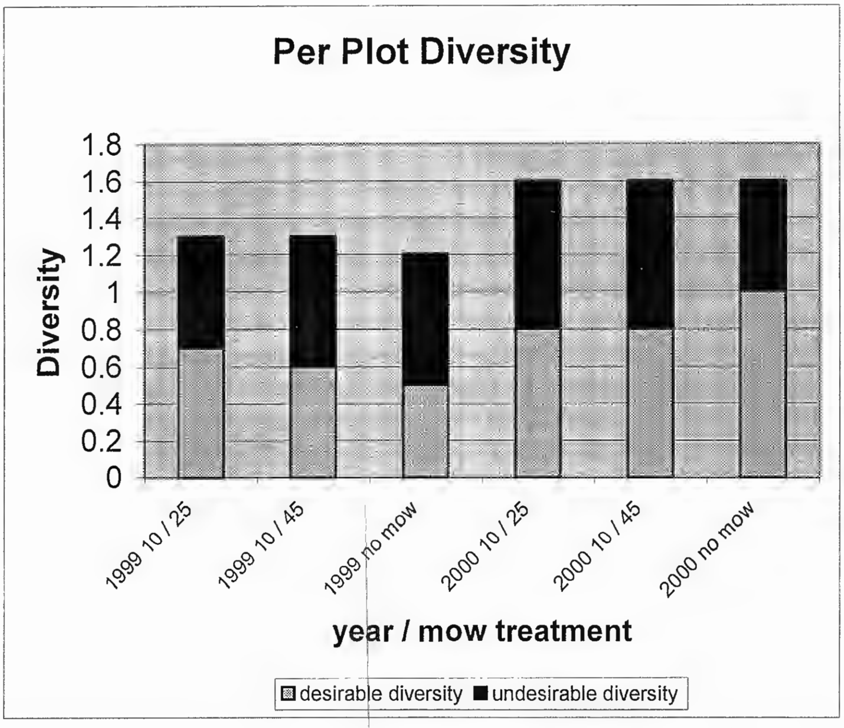

Figure 6. Graph showing per plot diversity of the three mowing treatments in 1999 and 2000.

To further assess the effects of mowing on richness, we can look at desirable and undesirable richness to determine if the effects of mowing were mainly due to species that were planted or weedy species on the site. In 1999, the 10 / 25 mowing treatment had a significantly higher ($p < 0.05$) desirable species richness than either the 10 / 45 mow or the no mow treatments (Table 4). There were no significant differences in undesirable richness amongst the three treatments. In 2000 the results were quite different (Table 4). There were no significant differences between the three treatments in terms of desirable richness. On the other hand, both mowing treatments had a significantly higher ($p < 0.05$) undesirable species richness than the no mow.

Mowing had less pronounced effects on diversity than on richness. There were no significant effects on total diversity in either year, and the mean total diversity values were very close in value (Table 4). In contrast, in 1999 both mowing treatments had a significantly higher desirable species diversity than the unmowed treatment. In 2000, however, desirable species diversity was higher in unmowed plots than in plots of either of the two mow treatments ($p < 0.05$). Also in 2000, mowed plots were significantly higher in undesirable diversity than unmowed plots.

Effects of Individual Treatment Combinations

Table 5 lists means of the six individual treatment combinations. To explore further the original question of whether mowing and fertilizing increase richness and / or diversity over two years, I performed t – tests comparing specific treatment combinations over both years. I compared the total species richness in mowed plots vs. unmowed plots over both years (11.7 vs. 10.2 respectively) and found them to be significantly different ($p < 0.01$). The same did not hold for desirable richness, however. In this case,

Table 5. Effects of six individual treatment combinations on plant community characteristics at Lime Creek Nature Center in 1999 and 2000. Treatments are defined in the text. Mean values are per plot (n = 8); standard error of the mean is in parentheses.

1999

	(10 / 25) / F	(10 / 25) / U	(10 / 45) / F
Total Richness	13.0 (0.82)	12.0 (0.71)	11.1 (1.29)
Desirable Richness	7.5 (0.60)	6.3 (0.53)	5.1 (0.79)
Undesirable Richness	5.5 (0.57)	5.8 (0.75)	6.0 (0.73)
Total Diversity	1.3 (0.04)	1.3 (0.06)	1.2 (0.10)
Desirable Diversity	0.6 (0.05)	0.7 (0.05)	0.5 (0.07)
Undesirable Diversity	0.6 (0.06)	0.6 (0.06)	0.7 (0.05)

	(10 / 45) / U	No mow / F	No mow / U
Total Richness	11.3 (0.82)	10.0 (1.25)	9.4 (1.11)
Desirable Richness	5.9 (0.85)	5.6 (1.24)	4.8 (0.98)
Undesirable Richness	5.4 (0.38)	4.4 (0.50)	4.6 (0.56)
Total Diversity	1.3 (0.09)	1.2 (0.10)	1.2 (0.10)
Desirable Diversity	0.7 (0.08)	0.5 (0.09)	0.5 (0.10)
Undesirable Diversity	0.6 (0.03)	0.7 (0.08)	0.7 (0.08)

Table 5. (continued)

2000

	(10 / 25) / F	(10 / 25) / U	(10 / 45) / F
Total Richness	12.1 (1.04)	10.5 (0.78)	12.4 (0.60)
Desirable Richness	4.9 (0.52)	4.3 (0.41)	5.1 (0.44)
Undesirable Richness	7.3 (0.62)	6.3 (0.53)	7.3 (0.37)
Total Diversity	1.6 (0.09)	1.5 (0.08)	1.6 (0.06)
Desirable Diversity	0.8 (0.07)	0.7 (0.07)	0.8 (0.06)
Undesirable Diversity	0.8 (0.06)	0.7 (0.08)	0.8 (0.02)

	(10 / 45) / U	No mow / F	No mow / U
Total Richness	11.3 (0.86)	10.0 (0.38)	11.3 (0.70)
Desirable Richness	4.8 (0.65)	5.8 (0.37)	5.5 (0.65)
Undesirable Richness	6.5 (0.76)	4.3 (0.53)	5.8 (0.41)
Total Diversity	1.6 (0.10)	1.6 (0.08)	1.8 (0.10)
Desirable Diversity	0.8 (0.07)	1.0 (0.11)	1.2 (0.11)
Undesirable Diversity	0.8 (0.08)	0.6 (0.11)	0.6 (0.05)

desirable richness in mowed plots, 5.5, vs. desirable richness in unmowed plots, 5.4, were not significantly different ($p < 0.05$).

In addition I compared the 10 – 25 mow treatment with the unmowed treatment over both years to see if a <u>specific</u> mow treatment significantly increased richness over two years. Similarly to the above comparisons, mean total species richness over both years for the 10 –25 treatment, 11.9, was significantly higher than the unmowed treatment, 10.2 ($p < 0.05$). Mean desirable species richness in the 10 – 25 treatment (5.8) and the unmowed treatment (5.4) were not significantly different ($p < 0.05$). There were no significant differences using these same comparisons for any diversity measures over both years.

DISCUSSION

The original question proposed for this research project was "Will the addition of fertilizer and the application of a mowing treatment for two years increase the richness and / or diversity of native prairie species in a newly planted prairie reconstruction?" I first looked at the combined effects of the two treatment factors with a two – way ANOVA. The lack of interaction between mowing and fertilization indicated that the effect of each treatment was the same for each level of the other treatment. One of the preliminary ideas of this project was that the mowing effect might be enhanced by the fertilization factor. That is, the combination of mowing with fertilizing might show a stronger effect on some measure of community composition than just mowing. However, that response did not occur.

Fertilization showed no significant effect on any of the twelve community composition characteristics (including both years). Mowing had a significant effect on six of twelve characteristics (Table 1).

Many of the species planted were recorded over the first two years. There were 25 desirable species recorded out of 35 species of forbs and five species of grass planted. In addition, I did not differentiate between the native grass species when I recorded species, so the actual number of desirable species found is likely to be 27 – 28. Of these, 20 desirable species and 31 undesirable species were found on mowed plots. One possible factor that aided in the high number of species established is the higher than normal rainfall in the first growing season, 1999 (Appendix G), and near ideal planting conditions.

In comparison, the tallgrass prairie ecosystem that existed before European settlement in much of the state and on this study site likely contained over 30 species of grasses and 250 species of forbs (Shirley 1994). A current 'CP – 25 standard mix' recommended by the USDA for CRP plantings of native prairie plants includes six grasses and nine forbs. A third perspective comes from the seeding mixes offered from Ion Exchange, a leading supplier of native prairie seed and plants in the Midwest. Their recommended mixes range from the 'prudent prairie mix' which includes four grass species and 37 forbs to a mix with five grasses and 63 forbs. The prairie at LCNC falls somewhere in between the native tallgrass prairie ecosystem and a 'bare bones' approach in the government farm program. Realistically, in two years it is not possible to reconstruct the prairie ecosystem, which includes multiple plant communities, and also other elements such as associated invertebrate pollinators, grazing ungulates, and different soil processes. However, in two years, one can hope to reconstruct a rich, diverse plant community of prairie species. The LCNC prairie, in general, is the start of a very fine prairie, high in desirable species richness. It should be considered a success thus far, in the scope of prairie reconstruction, and its appearance resembles a native prairie with a number of different grass species and several forb species.

Effects of Mowing

Clearly, mowing was the dominant treatment effect in this experiment. In the first year, particularly, the shorter and more frequent mowing yielded a higher total and desirable species richness and higher desirable species diversity as compared to the no mow treatment. These findings are consistent with a study by Moeller (1998), who found that shorter and more frequent mowing (specifically mowing to a height of 10 cm when the vegetation got to 25 cm) increased total species richness on three different sites of newly reconstructed prairies. Thus the study does confirm Moeller's findings, by repeating the same mowing treatments on a site that differs in landform and latitude, with similar results. In a study of a seeding of grass species in Eastern Nebraska, mowing was an important factor in encouraging early forb seed germination and establishment and thus in (weedy) forb success (Becic and Bragg 1978). Kurtz (1994) compared unmowed plots to plots that were mowed intensively the first year (cut to 7.6 cm when 30.5 cm), mowed less the second year (cut to 25.4 cm twice), and unmowed the third year near Ames, Iowa. He found three times as many native species in the mowed plots as compared to unmowed. Gibson et al. (1993) found the lowest forb species richness in unburned unmowed plots, as compared with plots that were burned, mowed, or both. Finally, in a reconstructed prairie in Eastern Iowa, O'Keefe (1995) applied three different mowing treatments similar to my experiment – no mowing, more frequent mowing, and less frequent mowing – and found the highest desirable species richness in the plots with the most frequent mowing.

Mowing consistently through the growing season opened up the canopy, allowing light to penetrate. This likely prevented a small number of species from dominating the planting by outcompeting less vigorous plants for light. In this study, foxtail grass (*Setaria* spp.) was quite dominant in unmowed plots the first year, with an average percent cover of 44.4 % and 46.3 %, respectively for the unmowed / F and unmowed / U plots in 1999. In the four treatment combinations with mowing, foxtail cover ranged from 9.6 % to 17.5 %. Keeping its growth in check by mowing presumably allowed more species to become established. In the second year, the foxtail cover dropped by about half, to 3.7 % - 6.0 %, in the mowed plots. Interestingly, in the unmowed plots where it accounted for nearly half the cover the first year, it virtually disappeared the second year; the unmowed / U and unmowed / F plots had 0.8% and 0% foxtail cover, respectively, in 2000.

Fertilization Comparisons

The amount of fertilizer applied may have been insufficient to cause significant effects. I used an application rate of 11.1 g m $^{-2}$ of NPK 35-44-83 twice a year. Several studies of the effects of N addition to established prairies used considerably higher amounts of nitrogen. I applied 1.3 g N m $^{-2}$ twice a year, as compared to a nitrogen enrichment study done by Foster and Gross (1998) who used two applications of 24 g m $^{-2}$ year $^{-1}$ of N on a successional grassland in southwest Michigan. They found that nitrogen enrichment increased plant production overall (particularly on grass species) and decreased species richness. This decrease was caused by increased plant biomass and litter, both of which limited light penetration and prevented forb seedling establishment. Ten g m $^{-2}$ year $^{-1}$ of N was used in another study of a tallgrass prairie in Kansas (Turner et al 1997). Those researchers found that adding nitrogen for a year increased the aboveground net primary productivity. A third study, by Wilson and Shay (1990), applied 6.4 g m $^{-2}$ year $^{-1}$ of N to a mixed – grass prairie in Manitoba, Canada. Overall species diversity decreased on fertilized plots, while two species, *Carex obtusa* and *Bouteloua gracilis*, (a sedge and a grass) increased in abundance on those plots.

Soil nutrient analysis did not show a consistent trend that fertilized soils had higher N, P, and K nutrient content in September of 1999 (Table 2). Percent organic matter varied widely, as did percent moisture. Taking more samples per plot may have revealed different soil nutrient content among treatments. More likely, however, is that the amount of fertilizer added was too low to cause any effects on nutrient content of the soil, and in turn too low to cause any effects on community composition.

T – tests comparing Individual Treatment Combinations

T – tests comparing various individual treatment means yielded some further insights on trends over both years. Total species richness in mowed plots was significantly higher than in unmowed plots over both years ($p < 0.01$). The same trend did not hold for desirable richness, however, which is the more important factor. In this case, desirable richness in mowed plots vs. unmowed plots was not significantly different ($p < 0.05$).

To get at the original question of the project, which asks if a *particular treatment* significantly increased desirable richness or diversity over two years I compared the 10 – 25 mow treatment with the unmowed treatment over both years. While a unique fertilization / mowing treatment did not have these effects due to the lack of any significant fertilization effect, perhaps a particular mowing treatment showed consistent positive results on community composition over both years. Similar to the above comparisons, mean total species richness over both years for the 10 –25 treatment was significantly higher than the unmowed treatment ($p < 0.05$). Mean desirable species richness in the 10 – 25 treatment, however, did not differ significantly from the unmowed treatment ($p < 0.05$). There were no significant differences using these same comparisons for any diversity measures over both years. Thus the most positive effects of mowing were found only in the first year. I cannot conclude, based on this study, that a single treatment significantly increased native species richness and / or diversity over two years. While total richness was consistently higher over both years on 10 / 25 plots as compared with unmowed plots, the more important measure of community composition is desirable species richness.

Translating the Findings to Management Guidelines

A goal I had in this project was to translate the findings of this study into practical, usable management guidelines for newly reconstructed prairies. The clearest finding to meet this goal is that mowing was an important factor in enhancing overall species richness. In particular, mowing to a height of 10 cm when the vegetation reached 25 cm increased desirable species richness and desirable species diversity in the first year. The most important recommendation I would make, then, is to mow to this height the first year; I would further recommend mowing in the second year, though perhaps less frequently.

I would not recommend fertilizing. Fertilization did not have a negative impact, though one might have expected fertilization to enhance the competitive advantage of grasses, and thus decrease richness or diversity. At the same time, in mowed plots, fertilizing did not have the positive effect of accelerating growth and causing a richer and more diverse community to become established quicker. Overall, its effects were so minimal, good or bad, that it would not be a cost - effective measure to implement.

APPENDIX A - SPECIES PLANTED

	Scientific name		**Common name**
1	*Agastache*	*foeniculum*	Anise Hyssop
2	*Agropyron*	*smithii*	Western wheatgrass
3	*Amorpha*	*canescans*	Leadplant
4	*Anemone*	*cylindrica*	Thimbleweed
5	*Asclepias*	*tuberosa*	Butterfly milkweed
6	*Aster*	*ericoides*	Heath aster
7	*Aster*	*azureus*	Sky blue aster
8	*Aster*	*ptarmicoides*	upland white aster
9	*Bouteloua*	*curtipendula*	Side - oats grama
10	*Bouteloua*	*gracilis*	Blue grama
11	*Cassia*	*fasiculata*	Patridge pea
12	*Dodecatheon*	*meadii*	Midland shooting star
13	*Echinacea*	*pallida*	Pale purple coneflower
14	*Eryngium*	*yuccifolium*	Rattlesnake master
15	*Gentiana*	*quinquefolia*	Stiff gentian
16	*Helinathus*	*mollis*	Ashy sunflower
17	*Helianthus*	*occidentalis*	Western sunflower
18	*Helopsis*	*helianthoides*	Ox - eye sunflower
19	*Lespedeza*	*capitata*	Roundheaded bushclover
20	*Liatris*	*aspera*	Rough blazingstar
21	*Monarda*	*fistulosa*	Bergamot
22	*Parthenium*	*integrifolium*	Wild quinine
23	*Petalostemum*	*candidum*	White prairie clover
24	*Petalostemum*	*purpureum*	Purple prairie clover
25	*Phlox*	*pilosa*	Prairie phlox
26	*Potentilla*	*arguta*	Prairie cinquefoil
27	*Ratibida*	*pinnata*	Yellow coneflower
28	*Rosa*	*sp.*	Wild rose
29	*Rudbeckia*	*hirta*	Black - eyed Susan
30	*Rucbeckia*	*triloba*	Brown - eyed Susan
31	*Schizachyrium*	*scoparium*	Little bluestem
32	*Silphium*	*laciniatum*	Compass plant
33	*Solidago*	*nemoralis*	Old field goldenrod
34	*Solidago*	*rigida*	Stiff goldenrod
35	*Solidago*	*speciosa*	Showy goldenrod
36	*Tephrosia*	*virginiana*	Goat's rue
37	*Tradescantia*	*ohlensis*	Ohio spiderwort
38	*Verbena*	*stricta*	Hoary vervain
39	*Zizea*	*aptera*	Heartleaf golden Alexander

APPENDIX B. SOIL NUTRIENT ANALYSIS

Block	Treatment	% moisture	ppmN	ppmP	ppmK	% org. matter
1	no mow / F	11.1	2	72	270	8.6
1	no mow / U	11.9	3	51	273	8
2	no mow / F	9.7	1	104	314	7
2	no mow / U	5.5	<1	27	143	6
3	10 / 45 / F	10.5	1	23	142	5.7
3	10 / 45 / U	10	17	56	159	8
4	10 / 45 / F	11.3	<1	37	171	5.2
4	10 / 45 / U	7.9	4	45	131	8.4
5	10 / 25 / F	3.4	4	59	288	5.1
5	10 / 25 / U	6	4	39	206	4.6
6	10 / 25 / F	3.4	2	28	140	5.4
6	10 / 25 / U	4.3	4	36	151	4.6
7	10 / 45 / F	8.9	5	68	331	7.3
7	10 / 45 / U	10.9	5	56	416	7.8
8	no mow / F	8	2	96	158	8
8	no mow / U	10.6	4	49	180	7.8

APPENDIX C. SPECIES RECORDED

	Scientific name		Common name	1999	2000	Desireable / Undesireable
1	*Anemone*	*cylindrica*	Thimbleweed	x	x	d
2	*Asclepias*	*tuberosa*	Butterfly milkweed	x	x	d
3	*Asclepias*	*verticillata*	Whorled milkweed	x	x	d
4	*Cassia*	*fasiculata*	Patridge pea	x	x	d
5	*Cirsium*	*altissimum*	Tall thistle		x	d
6	*Echinacea*	*pallida*	Pale purple coneflower	x	observed	d
7	*Eupatorium*	*altissimum*	Tall boneset		x	d
8	*Helopsis*	*helianthoides*	Ox - eye sunflower	x	x	d
9	*Lespedeza*	*capitata*	Roundheaded bushclover	x	x	d
10	*Monarda*	*fistulosa*	Bergamot	x	x	d
11	*Native*	*grass*	Native grass	x	x	d
12	*Oenthera*	*biennis*	Evening primrose		x	d
13	*Petalostemum*	*candidum*	White prairie clover	x	x	d
14	*Petalostemum*	*purpureum*	Purple prairie clover	x	x	d
15	*Potentilla*	*arguta*	Prairie cinquefoil	x	x	d
16	*Ratibida*	*pinnata*	Yellow coneflower	x	x	d
17	*Rosa*	*sp.*	Wild rose	x		d
18	*Rucbeckia*	*triloba*	Brown - eyed Susan		x	d
19	*Rudbeckia*	*hirta*	Black - eyed Susan	x	x	d
20	*Silphium*	*laciniatum*	Compass plant	x		d
21	*Solidago*	*nemoralis*	Old field goldenrod	x	x	d
22	*Tephrosia*	*virginiana*	Goat's rue	x		d
23	*Tradescantia*	*ohlensis*	Ohio spiderwort	Obs.	Obs.	d
24	*Verbena*	*stricta*	Hoary vervain	x	x	d
25	*Zizea*	*aptera*	Heartleaf gold Alexander		x	d
26	*Amaranthus*	*retroflexus*	Redroot pigweed	x		u
27	*Amaranthus*	*tuberculatus*	Waterhemp	x		u
28	*Ambrosia*	*artemisiifolia*	Common ragweed	x	x	u
29	*Asclepias*	*syriaca*	Common milkweed	x	x	u
30	*Aster*	*pilosus*	Hairy aster		x	u
31	*Berteroa*	*incana*	Alyssum	x	x	u
32	*Bromus*	*inermis*	Smooth brome grass	x	x	u
33	*Carduus*	*nutans*	Musk thistle		x	u
34	*Chenopodium*	*album*	Lambsquarters	x	observed	u
35	*Cirsium*	*arvense*	Canada thistle	x	x	u
36	*Cirsium*	*vulgare*	bull thistle	x	x	u
37	*Convolvulus*	*arvensis*	field bindweed	x	x	u
38	*Conzya*	*canadensis*	horseweed	x	x	u
39	*Digitaria*	*sanguinalis*	large crabgrass	x		u
40	*Erigeron*	*strigosus*	Daisy fleabane	x	x	u
41	*Latuca*	*serriola*	prickly lettuce	x	x	u
42	*Medicago*	*lupulina*	black medic		x	u
43	*Melilotus*	*spp.*	sweetclover		x	u
44	*Nepeta*	*cataria*	catnip	x	x	u
45	*Oxalis*	*stricta*	wood sorrel	x	x	u
46	*Panicum*	*capillare*	witchgrass	x		u

APPENDIX C. (CONT.)

47	*Physalis*	*heterophylla*	rough ground cherry	x	x	u
48	*Physalis*	*subglabrata*	smooth ground cherry	x	x	u
49	*Plantago*	*lanceolata*	buckhorn plantain	observed		u
50	*Plantago*	*rugelii*	common / blackseed plantain	x	x	u
51	*Rhamnus*	*spp.*	buckthorn tree seedling	x	x	u
52	*Rumex*	*crispus*	curly dock	x		u
53	*Setaria*	*spp.*	foxtail	x	x	u
54	*Solanum*	*ptycanthum*	E. black nightshade	x		u
55	*Sonchus*	*oleraceus*	sowthistle		x	u
56	*Thlaspi*	*arvense*	field pennycress	x		u
57	*Trifolium*	*spp.*	red / white clover		x	u
58	*unk*		unknown	x	x	u
59	*Verbascum*	*thapsus*	common mullein	x	x	u

APPENDIX D. SPECIES PRESENCE PER MOWING TREATMENT

			1999			2000		
				mow trt.			mow trt.	
Scientific name		**Common name**	"10/25"	"10/45"	no mow	"10/25"	"10/45"	no mow
Anemone	*cylindrica*	Thimbleweed	x		x	x		
Asclepias	*tuberosa*	Butterfly milkweed	x		x	x		
Asclepias	*verticillata*	Whorled milkweed	x	x	x	x	x	x
Cassia	*fasiculata*	Patridge pea	x	x	x			x
Cirsium	*altissimum*	Tall thistle					x	
Echinacea	*pallida*	Pale purple coneflower	x	x	x			x
Eupatorium	*altissimum*	Tall boneset						x
Helopsis	*helianthoides*	Ox - eye sunflower	x	x	x	x	x	x
Lespedeza	*capitata*	Roundheaded bushclover	x	x	x		x	x
Monarda	*fistulosa*	Bergamot	x	x	x	x	x	x
Native	*grass*	Native grass	x	x	x	x	x	x
Oenthera	*biennis*	Evening primrose						x
Petalostemum	*candidum*	White prairie clover	x	x	x	x		
Petalostemum	*purpureum*	Purple prairie clover	x	x	x	x	x	x
Potentilla	*arguta*	Prairie cinquefoil			x			
Ratibida	*pinnata*	Yellow coneflower	x	x	x	x	x	x
Rosa	*sp.*	Wild rose			x			
Rucbeckia	*triloba*	Brown - eyed Susan						x
Rudbeckia	*hirta*	Black - eyed Susan	x	x	x	x	x	x
Silphium	*laciniatum*	Compass plant		x				
Solidago	*nemoralis*	Old field goldenrod		x	x		x	x
Tephrosia	*virginiana*	Goat's rue	x					
Tradescantia	*ohlensis*	Ohio spiderwort						
Verbena	*stricta*	Hoary vervain	x	x	x	x	x	x
Zizea	*aptera*	Heartleaf golden Alexander				x		
Amaranthus	*retroflexus*	Redroot pigweed	x	x	x	x	x	x
Amaranthus	*tuberculatus*	Waterhemp	x		x			
Ambrosia	*artemisiifolia*	Common ragweed	x	x	x			
Asclepias	*syriaca*	Common milkweed	x	x	x	x		
Aster	*pilosus*	Hairy aster			x			x
Berteroa	*incana*	Alyssum	x	x	x	x	x	x
Bromus	*inermis*	Smooth brome grass	x		x			x
Carduus	*nutans*	Musk thistle				x	x	
Chenopodium	*album*	Lambsquarters	x	x	x			
Cirsium	*arvense*	Canada thistle	x					
Cirsium	*vulgare*	bull thistle	x	x		x	x	
Convolvulus	*arvensis*	field bindweed	x	x		x	x	x
Conzya	*canadensis*	horseweed	x			x	x	x
Digitaria	*sanguinalis*	large crabgrass	x					
Erigeron	*strigosus*	Daisy fleabane	x	x		x	x	
Latuca	*serriola*	prickly lettuce	x	x	x		x	x
Medicago	*lupulina*	black medic				x	x	x
Melilotus	*spp.*	sweetclover					x	x
Nepeta	*cataria*	catnip	x	x	x	x	x	x
Oxalis	*stricta*	wood sorrel		x	x	x	x	

APPENDIX D. (CONT.)

			1999			2000		
			mow trt.			mow trt.		
Scientific name		**Common name**	"10/25"	"10/45"	no mow	"10/25"	"10/45"	no mow
Panicum	*capillare*	witchgrass	x	x	x			
Physalis	*heterophylla*	rough ground cherry	x	x	x	x	x	x
Physalis	*subglabrata*	smooth ground cherry	x	x	x	x	x	x
Plantago	*lanceolata*	buckhorn plantain		x				
Plantago	*rugelii*	Blackseed plantain	x			x	x	
Rhamnus	*spp.*	buckthorn tree seedling			x		x	x
Rumex	*crispus*	curly dock		x				
Setaria	*spp.*	foxtail	x	x	x	x	x	x
Solanum	*ptycanthum*	E. black nightshade			x			
Sonchus	*oleraceus*	sowthistle					x	x
Thlaspi	*arvense*	field pennycress	x	x	x		x	
Trifolium	*spp.*	red / white clover		x	x	x	x	x
unk		unknown		x		x		
Verbascum	*thapsus*	common mullein	x	x	x	x	x	x

APPENDIX E. AVERAGE PERCENT COVER BY TREATMENT, 1999

			Treatment									
			10 / 25, F		10 / 25, U		10 / 45, F		10 / 45, U		No mow/F		No mow/U	
Scientific name		Common name	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Anemone	*cylindrica*	Thimbleweed	0.1	0.07	0	0.03					0.1	0.06	0	0.03
Asclepias	*tuberosa*	Butterfly milkweed	0.1	0.07							0.1	0.13		
Asclepias	*verticillata*	Whorled milkweed	0.5	0.25	0.6	0.32			0.3	0.25	1.4	0.73	4.6	2.34
Cassia	*fasiculata*	Patridge pea	0.3	0.13	0.1	0.06	0.6	0.33	0.1	0.07	0.4	0.29	0.3	0.21
Cirsium	*altissimum*	Tall thistle												
Echinacea	*pallida*	Pale purple cone.			0.4	0.38	0.3	0.25	0.3	0.25	0.1	0.13		
Eupatorium	*altissimum*	Tall boneset												
Helopsis	*helianthoides*	Ox - eye sunflower	0.5	0.27	0.2	0.13	0.6	0.3	0.1	0.13	0.3	0.25	0.5	0.5
Lespedeza	*capitata*	Roundheaded b clover	0.1	0.06	0.1	0.13	0	0.03	0.1	0.07	0.1	0.07	0	0.03
Monarda	*fistulosa*	Bergamot	0.1	0.36	0.1	0.08	0.1	0.07	0.8	0.37	0.5	0.25	0.3	0.16
Native	*grass*	Native grass	2.8	0.7	4.5	0.97	1.8	0.69	2.8	0.88	0.8	0.3	1.1	0.64
Oenthera	*biennis*	Evening primrose												
Petalostemum	*candidum*	White prairie clover	0.1	0.06	0.1	0.06	0.1	0.07			0.3	0.18	0.1	0.04
Petalostemum	*purpureum*	Purple prairie clover	0.7	0.35	1	0.21	0.5	0.23	1.3	0.81	0.2	0.13	0.4	0.22
Potentilla	*arguta*	Prairie cinquefoil											0.1	0.13
Ratibida	*pinnata*	Yellow coneflower	1.6	0.35	1.4	0.69	0.7	0.37	1.9	0.46	1.4	0.52	0.6	0.42
Rosa	*sp.*	Wild rose											0	0.03
Rucbeckia	*triloba*	Brown - eyed Susan												
Rudbeckia	*hirta*	Black - eyed Susan	16	3.01	18	2.96	21	3.17	16	1.89	12	4.13	11	2.54
Silphium	*laciniatum*	Compass plant							0.1	0.06				
Solidago	*nemoralis*	Old field goldenrod							0.5	0.25	0.5	0.38		
Tephrosia	*virginiana*	Goat's rue	0	0.03										
Tradescantia	*ohlensis*	Ohio spiderwort												
Verbena	*stricta*	Hoary vervain	0.2	0.08	0.1	0.13	0.2	0.13			0.2	0.13	0.3	0.16
Zizea	*aptera*	Heartleaf g. Alexander												
Amaranthus	*retroflexus*	Redroot pigweed	0.8	0.41	0.3	0.25	0.9	0.64	0.3	0.25			0.1	0.13
Amaranthus	*tuberculatus*	Waterhemp									0.1	0.13		
Ambrosia	*artemisiifolia*	Common ragweed	0.3	0.25	0.1	0.13	0.3	0.16	1	0.68	0.4	0.26		
Asclepias	*syriaca*	Common milkweed	0.1	0.06			0.3	0.16			0.5	0.38		
Aster	*pilosus*	Hairy aster												
Berteroa	*incana*	Alyssum	0.9	0.58	1.1	0.74			1.1	0.61	0.1	0.13	0.6	0.42
Bromus	*inermis*	Smooth brome grass	0.1	0.13	0.6	0.63					0.9	0.94		

			Treatment									
			10 / 25, F		10 / 25, U		10 / 45, F		10 / 45, U		No mow /F		No mow /U	
			Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Carduus	*nutans*	Musk thistle												
Chenopodium	*album*	Lambsquarters			0.4	0.26	0.3	0.16			0.1	0.13	0.3	0.16
Cirsium	*arvense*	Canada thistle	0.1	0.13										
Cirsium	*vulgare*	bull thistle			0.1	0.13	0.1	0.13						
Convolvulus	*arvensis*	field bindweed	0.6	0.2	0.6	0.49	0.7	0.23	0.3	0.13				
Conzya	*canadensis*	horseweed			0.4	0.27								
Digitaria	*sanguinalis*	large crabgrass			0.1	0.13								
Erigeron	*strigosus*	Daisy fleabane	1.6	0.5	2.3	0.62	1.5	0.5	5.9	3.52	0.1	0.13	0.8	0.4
Latuca	*serriola*	prickly lettuce	0.4	0.19	0.3	0.16	0.8	0.49	0.4	0.44			0.3	0.16
Medicago	*lupulina*	black medic									0.3	0.16		
Melilotus	*spp.*	sweetclover												
Nepeta	*cataria*	catnip	0.6	0.63	0.7	0.37	0.6	0.26	0.8	0.3	1.1	0.44	1.4	0.68
Oxalis	*stricta*	wood sorrel							0	0.03			0.1	0.06
Panicum	*capillare*	witchgrass			0.3	0.16	0.4	0.38	1.3	0.92	0.6	0.63	1	0.94
Physalis	*heterophylla*	rough ground cherry			0.6	0.72	1.3	1.03	0.4	0.38	1.9	1.22	0.1	0.13
Physalis	*subglabrata*	smooth ground cherry	6.6	1.94	4.1	0.63	4.1	1.25	3.8	1.06	5.8	2.04	5.6	2.1
Plantago	*lanceolata*	buckhorn plantain					0.1	0.13						
Plantago	*rugelii*	blackseed plantain			0.3	0.25								
Rhamnus	*spp.*	buckthorn seedling											0.3	0.25
Rumex	*crispus*	curly dock					0.3	0.25						
Setaria	*spp.*	foxtail	12	2.89	9.6	1.9	18	3.46	16	3.19	44	6.38	46	7.64
Solanum	*ptycanthum*	E. black nightshade									0.1	0.13		
Sonchus	*oleraceus*	sowthistle												
Thlaspi	*arvense*	field pennycress	0.5	0.33	0.7	0.37	0.1	0.13	0.4	0.26	0.5	0.27	0.3	0.25
Trifolium	*spp.*	red / white clover							0.3	0.25			2.6	2.66
unk		unknown					0.2	0.19	0.7	0.56				
Verbascum	*thapsus*	common mullein	1.6	0.46	1.3	0.62	1.5	0.53	0.4	0.26			0.3	0.16

(A 0 value indicates the average was less than 0.0 % cover.)
(A blank space indicates the species did not appear in any quadrats.)

APPENDIX F. AVERAGE PERCENT COVER BY TREATMENT, 2000

			Treatment											
			10 / 25, F		10 / 25, U		10 / 45, F		10 / 45, U		Unmowed/F		Unmowed/U	
Scientific name		**Common name**	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Anemone	*cylindrica*	Thimbleweed	0	0.02										
Asclepias	*tuberosa*	Butterfly milkweed	0.1	0.06										
Asclepias	*verticillata*	Whorled milkweed	0.2	0.11	0.2	0.11			0	0.02	0.6	0.43	0.4	0.33
Cassia	*fasiculata*	Patridge pea									0	0.03	0	0.03
Cirsium	*altissimum*	Tall thistle							0.1	0.06				
Echinacea	*pallida*	Pale purple coneflower												
Eupatorium	*altissimum*	Tall boneset									0.1	0.11	0.2	0.17
Helopsis	*helianthoides*	Ox - eye sunflower			0.2	0.17	0.1	0.06	0.1	0.06	0.1	0.11	0.4	0.42
Lespedeza	*capitata*	Roundheaded bushclover					0.1	0.06	0.1	0.06	0.3	0.28		
Monarda	*fistulosa*	Bergamot	0.4	0.28	0.2	0.12	0.7	0.28	0.6	0.22	0.8	0.33	0.4	0.34
Native	*grass*	Native grass	2.4	0.98	2	0.55	2.8	0.53	1.6	0.55	2.1	0.98	5.6	1.06
Oenthera	*biennis*	Evening primrose									0.3	0.28		
Petalostemum	*candidum*	White prairie clover	0.1	0.06										
Petalostemum	*purpureum*	Purple prairie clover	0.2	0.13	0.3	0.14	0.2	0.11	0.4	0.18			0.2	0.12
Potentilla	*arguta*	Prairie cinquefoil												
Ratibida	*pinnata*	Yellow coneflower	3.8	0.8	2.4	0.63	2.7	0.41	2.8	0.42	1.4	0.48	2.3	0.62
Rosa	*sp.*	Wild rose												
Rucbeckia	*triloba*	Brown - eyed Susan									0.4	0.42	0.7	0.69
Rudbeckia	*hirta*	Black - eyed Susan	1.4	0.5	1.3	0.31	1.3	0.22	2.3	0.9	6.8	0.7	4.7	0.8
Silphium	*laciniatum*	Compass plant												
Solidago	*nemoralis*	Old field goldenrod					0.1	0.06			0.1	0.06	0.2	0.11
Tephrosia	*virginiana*	Goat's rue												
Tradescantia	*ohlensis*	Ohio spiderwort												
Verbena	*stricta*	Hoary vervain	0.2	0.12			0.2	0.19	0.2	0.17	0.3	0.19	0.6	0.42
Zizea	*aptera*	Heartleaf golden Alexand	0	0.02										
Amaranthus	*retroflexus*	Redroot pigweed	2	0.84	2.8	0.96	1	0.38	1.8	0.52	0.7	0.23	1.5	0.48
Amaranthus	*tuberculatus*	Waterhemp												
Ambrosia	*artemisiifolia*	Common ragweed												
Asclepias	*syriaca*	Common milkweed	0.1	0.11										
Aster	*pilosus*	Hairy aster									0.2	0.17		
Berteroa	*incana*	Alyssum	0.4	0.19	0.2	0.12	0.4	0.25	0.2	0.12	0.1	0.11	0.2	0.17
Bromus	*inermis*	Smooth brome grass									0.2	0.17	1	0.71
Carduus	*nutans*	Musk thistle	0.2	0.12	0	0.02	0.1	0.06	0.1	0.11				

			Treatment											
			10 / 25, F		10 / 25, U		10 / 45, F		10 / 45, U		unmowed, F		unmowed, U	
			Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Chenopodium	*album*	Lambsquarters												
Cirsium	*arvense*	Canada thistle												
Cirsium	*vulgare*	bull thistle	0.2	0.11	0.1	0.06	0.1	0.06	0.4	0.42				
Convolvulus	*arvensis*	field bindweed	0.2	0.11	0.1	0.04	0.2	0.08	0.1	0.04	0	0.03	0.1	0.03
Conzya	*canadensis*	horseweed	0.4	0.17	0.5	0.28	1.1	0.47	1	0.31	1.1	0.5	2.2	0.87
Digitaria	*sanguinalis*	large crabgrass												
Erigeron	*strigosus*	Daisy fleabane	0.3	0.14	0.2	0.12	0.7	0.22	1.1	0.66	1.1	0.43	1.4	0.06
Latuca	*serriola*	prickly lettuce					0.1	0.06	0.1	0.06	0.1	0.11	0.1	0.06
Medicago	*lupulina*	black medic	2.1	0.55	1	0.54	0.7	0.21	2.7	1.56	0.9	0.65	0.3	0.14
Melilotus	*spp.*	sweetclover							0.1	0.11				
Nepeta	*cataria*	catnip	0.4	0.19	0.4	0.27	1.2	0.44	0.7	0.38	3.2	1.36	0.8	0.25
Oxalis	*stricta*	wood sorrel			0.2	0.19	0.1	0.06	0.1	0.06				
Panicum	*capillare*	witchgrass												
Physalis	*heterophylla*	rough ground cherry	0.2	0.13	0.3	0.21	0.4	0.28	0.1	0.06			0.3	0.32
Physalis	*subglabrata*	smooth ground cherry	1.1	0.45	0.5	0.22	0.8	0.3	0.6	0.2	1.8	0.63	0.8	0.28
Plantago	*lanceolata*	buckhorn plantain												
Plantago	*rugelii*	common / blackseed plantain			0.1	0.11	0.1	0.11						
Rhamnus	*spp.*	buckthorn tree seedling					0.1	0.11					0.1	0.11
Rumex	*crispus*	curly dock												
Setaria	*spp.*	foxtail	5.3	0.94	6	1.17	3.7	0.74	4.9	0.95			0.8	0.33
Solanum	*ptycanthum*	E. black nightshade												
Sonchus	*oleraceus*	sowthistle					0.2	0.12	0.1	0.11	0.3	0.19	0.4	0.33
Thlaspi	*arvense*	field pennycress												
Trifolium	*spp.*	red / white clover			1.8	1.71	0.3	0.19	0.4	0.33	0.2	0.14	0.1	0.06
unk		unknown			0	0.03								
Verbascum	*thapsus*	common mullein	0.4	0.18	0.9	0.5	0.1	0.11	0.7	0.34	1	0.59	0.4	0.2

(A 0 value indicates the average was less than 0.0 % cover.)

(A blank space indicates the species did not appear in any quadrats.)

APPENDIX G. MONTHLY RAINFALL DATA IN MASON CITY

Month	Actual rainfall (cm)	Normal rainfall (cm)	Difference (cm)
Apr-99	19.7	7.5	12.2
May-99	19.2	10.4	8.8
Jun-99	13.1	11.5	1.6
Jul-99	28.3	10.9	17.4
Aug-99	5	10.5	-5.5
total	**85.3**	**50.8**	**34.5**
Apr-00	4.3	7.5	-3.2
May-00	12.1	10.4	1.7
Jun-00	13.2	11.5	1.7
Jul-00	14.3	10.9	3.4
Aug-00	8.3	10.5	-2.2
total	**52.2**	**50.8**	**1.4**

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