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# Hyperspectral reflectance from restored tallgrass prairie under different management.

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# HYPERSPECTRAL REFLECTANCE FROM RESTORED TALLGRASS PRAIRIE UNDER DIFFERENT MANAGEMENT

A Thesis
Presented to the
Department of Geography and Geology
And the
Faculty of the Graduate College
University of Nebraska

In Partial Fulfillment
Of the Requirements for the Degree
Master of Arts
University of Nebraska at Omaha

by
Sung-Jun Kim
April 2002

# THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College,
University of Nebraska, in partial fulfillment of the
requirements for the degree Master of Arts
University of Nebraska at Omaha

Committee

Jeffrey S. Peake

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Date April 23, 2002

# ABSTRACT

## HYPERSPECTRAL REFLECTANCE FROM RESTORED TALLGRASS PRAIRIE UNDER DIFFERENT MANAGEMENT

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University of Nebraska – Omaha, 2002

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Tallgrass Prairie has been highly fragmented and severely disturbed by overgrazing and land development with most of the tallgrass prairie remnants less than 100 hectares in size. The small size results in increased edge effects, potential invasion by undesirable or exotic species, low genetic diversity in local populations and increased extinction rates. To conserve tallgrass prairie remnants, some types of active management are needed. The most common management methods are prescribed burning, haying and mowing. It is essential to monitor the status of tallgrass prairie in order to determine if management objectives are being met. In this study, close-range hyperspectral remote sensing was used to distinguish spectral reflectance patterns of tallgrass prairie managed under different management regimes. Datasets were collected on July 13, 2001 and again on August 28, 2001. A total of five different treatments were examined at a restored tallgrass prairie near Mead, Nebraska.

Regression analysis using dummy variables was utilized to compare between treatments in terms of red edge position and reflectance values in the red and near-infrared regions of the electromagnetic spectrum. It was not possible to distinguish between all treatments based on the location of the red edge. By examining the spectral values in the near infrared it was possible to differentiate between all treatments.

# ACKNOWLEDGEMENTS

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# CHAPTER I

## Introduction

Prior to European settlement of North America, tallgrass prairie in the continental interior of North America extended from southern Manitoba through eastern North Dakota and western Minnesota southward to central Texas (Fig. 1) (Weaver, 1954; Küchler, 1974). Tallgrass prairie has the greatest differences in species deriving from north to south and has more dominant species than any other grassland formation in North America (Risser et. al., 1981; Barbour and Billings, 2000). It is also the most mesic of the Great Plains prairie environments. Precipitation occurs mostly during the growing season and ranges from 610 millimeters in the northwest to 991 millimeters in the east and south (Samson and Knopf, 1996). This environment is associated with high light intensity, high temperatures, and typically dry conditions in late summer (Samson and Knopf, 1996; Barbour and Billings, 2000).

C4 (warm-season) species, such as big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*) are the dominant native species (Weaver, 1954, 1968). Warm-season grasses green up later in spring than do cool-season species,

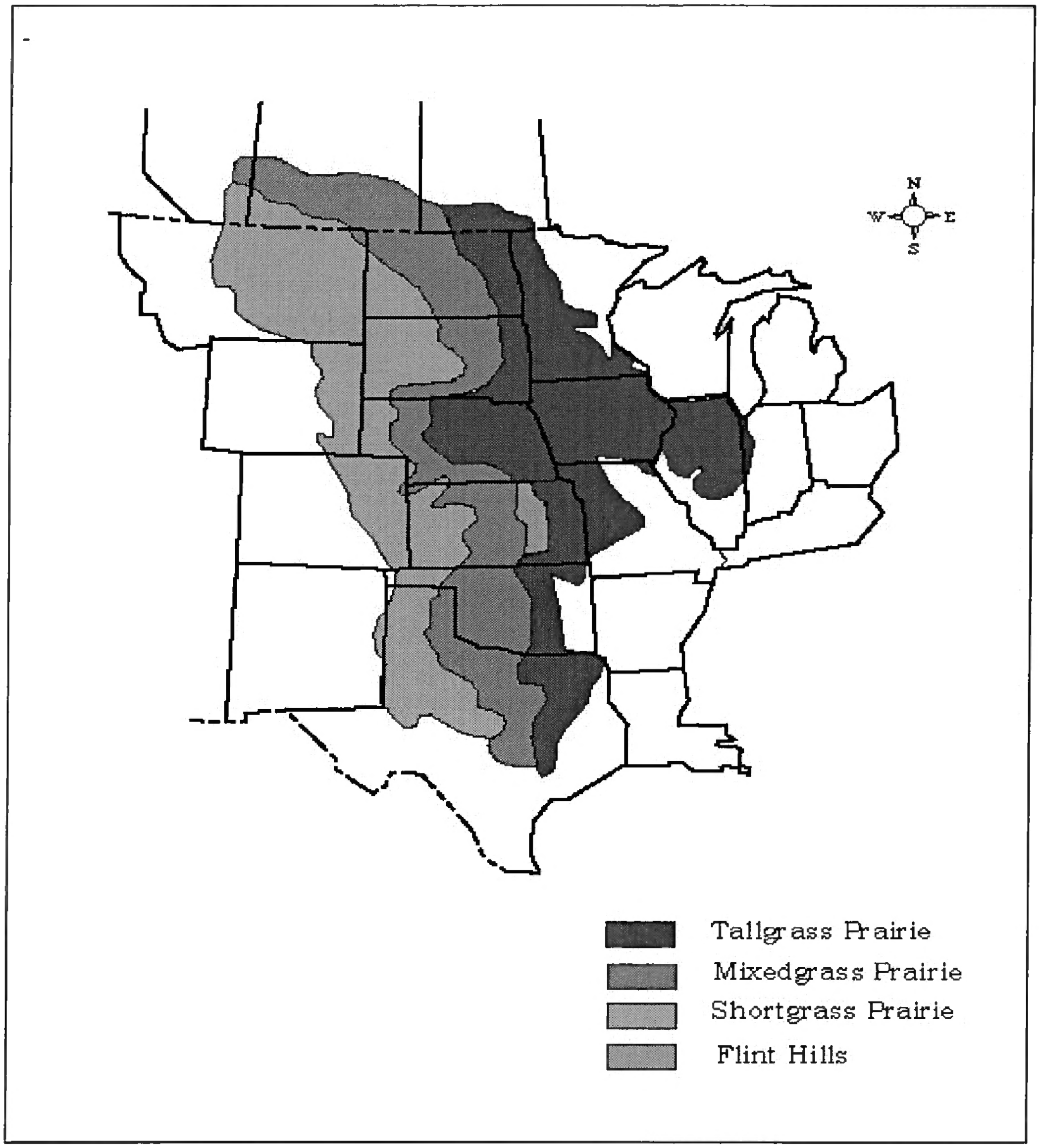


Figure 1. Prairie distribution prior to mid-1800s (Adapted from Reichman 1987).

producing much foliage in midsummer (Weaver, 1954; Reichman, 1987; Goodin and Henebry, 1997). Flowering and seed production of warm-season grasses extend from midsummer to autumn (Weaver, 1954; 1968). Tallgrass prairie also includes some cool-season (C3) species, such as porcupine grass (*Stipa spartea*), junegrass (*Koeleria pyramidata*), and sedges (*Carex spp.*) (Weaver, 1954, 1968; Reichman, 1987). Non-native, cool-season species that threaten native tallgrass prairie are smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) (Weaver, 1954, 1968). These grasses green up earlier in spring and reach their maximum development from late March to early June ( Weaver, 1954; Reichman, 1987; Goodin and Henebry, 1997).

Grasslands perform various ecosystem functions and have significant value for both the environment and humans. This is especially true for tallgrass prairie with its high biomass and productivity (Reichman, 1987; Samson and Knopf, 1996). Tallgrass prairie provides food for grazing livestock and habitat for wildlife. Significant recycling of nutrients, soil development and prevention of erosion are additional ecosystem functions provided by grasslands (Weaver, 1954, 1968 and Samson and Knopf, 1996). Native grasslands, recently reestablished on thousands of previously cultivated acres in the Great Plains, have significantly reduced erosion and provide substantial wildlife habitat (Samson and Knopf, 1996). Streams running through prairie areas are more likely to have less sediment in them and can handle intense rainfall more efficiently, eliminating the need for artificial flood control impoundments downstream (Samson and Knopf, 1996). Grasslands also provide recreational activities for humans such as hunting, fishing and general observation of nature.

**Nature of Problem**

Prior to the mid-1800s, tallgrass prairie was the dominant vegetation type in the eastern third of the Great Plains (Weaver, 1954; Samson and Knopf, 1996). It occupied approximately 60 million hectares (Table 1), forming a relatively narrow east-west distribution except in its central portion where the prairie extended eastward to the Illinois-Indiana border (Fig. 1)(Samson and Knopf, 1996).

Table 1. Estimated historic and current area of tallgrass prairie on a state basis in the U.S (Source: Adapted from Samson and Knopf 1994).

| State | Historic area (ha) | Current area (ha) | Decline (%) |
|---|---|---|---|
| Illinois | 8,900,000 | 930 | 99.9 |
| Indiana | 2,800,000 | 404 | 99.9 |
| Iowa | 12,500,000 | 12,140 | 99.9 |
| Kansas | 6,900,000 | 1,200,000 | 82.6 |
| Minnesota | 7,300,000 | 30,350 | 99.6 |
| Missouri | 5,700,000 | 30,350 | 99.5 |
| Nebraska | 6,100,000 | 123,000 | 98 |
| North Dakota | 1,200,000 | 1200 | 99.9 |
| Oklahoma | 5,200,000 | - | - |
| South Dakota | 3,000,000 | 449,000 | 85 |
| Texas | 7,200,000 | 720,000 | 90 |
| Wisconsin | 971,000 | 4,000 | 99.9 |

After European settlement, most of the tallgrass prairie, with its deep and organic-rich melanized soils, was converted to cropland (Risser, 1988; Lauver and Whistler, 1993). Currently, tallgrass prairie occupies around 2.5 million hectares, a decline of 96 percent since the mid-1800s (Table 1)(Samson and Knopf, 1994).

In addition to direct loss, tallgrass prairie remnants have been highly fragmented and severely disturbed by overgrazing and land development (Diamond and Smeins, 1988; Lauver and Whistler, 1993; Samson and Knopf, 1994; Risser, 1998). The small size of many tallgrass prairie remnants results in increased edge effects, potential invasion by undesirable or exotic species, low genetic diversity in local populations, and increased extinction rates (Samson and Knopf, 1996).

Preservation and conservation of the remnants of the tallgrass prairies are important from an ecological perspective. Simply leaving them alone in isolation is not enough to insure their preservation. Therefore, some type of active management is necessary to conserve these tallgrass prairie remnants. Prescribed burning, mowing with the cut grass left on the ground, and haying with the cut grass removed are the most common management practices. Prescribed burning, haying, and mowing may be applied annually, biannually, and quadrennially in spring, summer or fall. Prescribed fire is the best means by which to manage tallgrass prairie although mowing may be used when prescribed burning is not feasible.

If tallgrass prairie is to be effectively managed for conservation, it is essential to monitor the effects of treatment in order to determine if management objectives are being met. Remote sensing has the potential to provide this information through the combination of extensive spatial and frequent temporal data collection. However, most space-borne satellite sensors such as Landsat Thematic Mapper (TM) imagery are not useful for highly fragmented small patches of tallgrass prairies. This is due to the relatively coarse spatial and spectral resolution as compared to close-range hyperspectral remote sensing devices. Therefore, there is a need for different sensors and techniques for imaging the prairies.

## Research Objective

The objective of this research is to determine if spectral reflectance patterns of restored tallgrass prairies can be used to discriminate between them based on management regimes. Specifically, can boom mounted hyperspectral sensors be used to gather data that can be used to discriminate between reflectance patterns of prairies subject to prescribed burning, mowing, haying or no active management at all (control)? A secondary objective is to see if there is any temporal variation that will aid in this discrimination.

## Hypothesis and Rationale

It is hypothesized that it will be possible to differentiate between management regimes based on spectral reflectance patterns, especially in the near-infrared region. It is further hypothesized that it will be easiest to separate prairies subject to annual spring burning from those not subject to any active management. It should also be possible to separate the control and annual spring burning treatment from plots subject to quadrennial burning, quadrennial haying and quadrennial mowing.

Numerous studies in the literature provide evidence supporting the above hypothesis. Many studies have shown that spring burning increases plant growth and biomass (Risser et al., 1981; Knopf, 1984; Abrams et al., 1986; Hulbert, 1988; Asrar et al., 1989; Middleton, 1991; Price et al., 1993; Friedl et al., 1994; Dunham and Price, 1996; Samson and Knopf, 1996; Wessman et al., 1997; Bragg et al., 1999). The removal of standing dead and litter exposes the soil to more sunlight in the early season. The opening of the vegetation canopy and the addition of a dark layer of ashes may warm the surface and near surface soil layers. Studies have shown that daytime leaf temperatures are higher just above the soil in burned as compared to unburned plots (Risser et al., 1981; Knopf, 1984; Hope and McDowell, 1992). Prescribed burning prevents invasion by woody shrub species, reduces invasion of exotic species, and encourages native perennial species (Weaver, 1954; Risser, 1988; Bragg, 1995; Bragg et al., 1999). There is a strong, positive correlation between biomass and spectral reflectance in the near-infrared (NIR) region resulting from spring burning of native tallgrass prairie (Price et al., 1993 and Dunham and Price, 1996).

A conceptual model (Fig. 2) shows energy interactions with tallgrass prairies using close-range remote sensing. These energy interactions can be illustrated as:

$$Ei(\lambda) = Er(\lambda) + Ea(\lambda) + Et(\lambda) \qquad (1.1)$$

Where $\lambda$ = wavelength

$Ei(\lambda)$ = incident energy at $\lambda$

$Er(\lambda)$ = reflected energy at $\lambda$

$Ea(\lambda)$ = absorbed energy at $\lambda$

$Et(\lambda)$ = transmitted energy at $\lambda$

The reflected radiation can be derived from equation 1.1 as

$$Er(\lambda) = Ei(\lambda) - (Ea(\lambda) + Et(\lambda))$$

The reflectance characteristics of tallgrass prairie can be quantified by measuring the portion of incident radiation that is reflected. It is mathematically defined as

$$\rho\lambda = Er(\lambda) / Ei(\lambda) \times 100$$

Where $\rho\lambda$ = spectral reflectance (%)

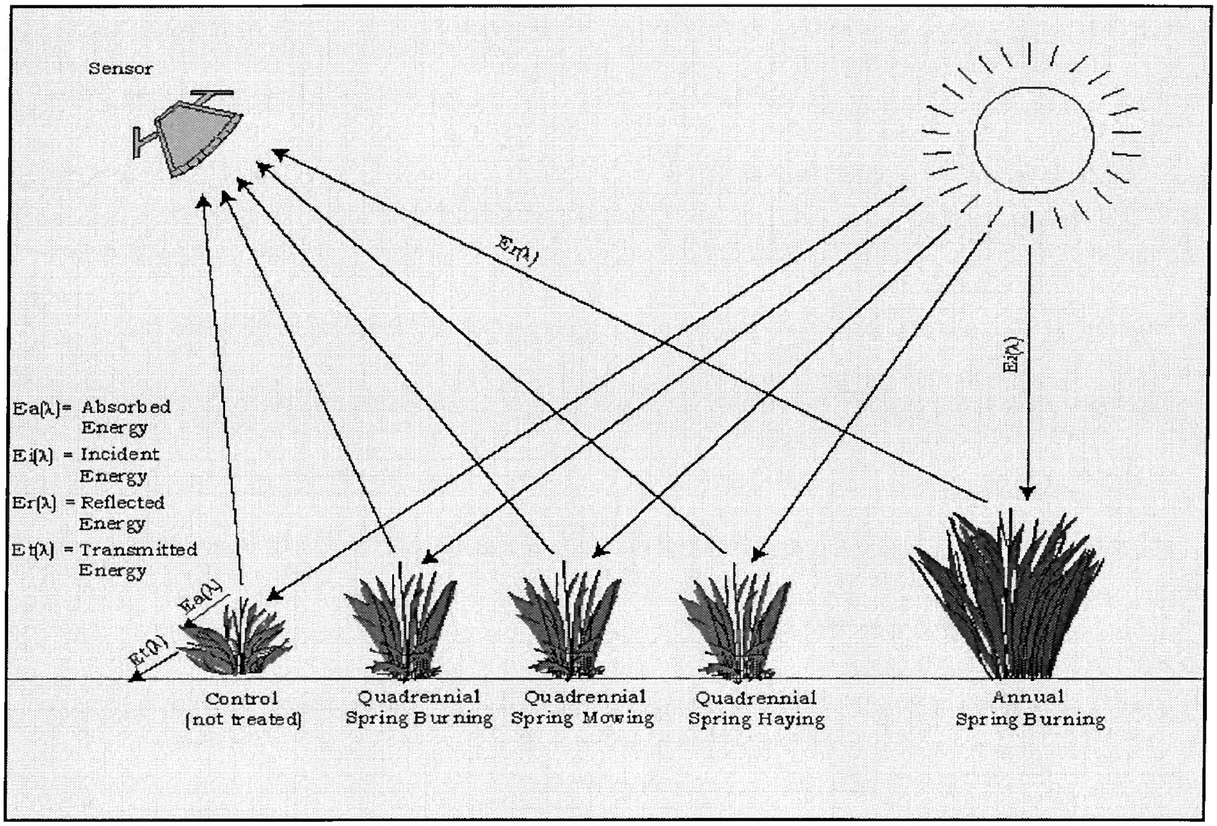


Figure 2. Conceptual Model for Remote Sensing in Tallgrass Prairie.

## Significance of Research

The significance of this study is that it is based on restored rather than on native tallgrass prairie in which most studies have been conducted (Dunham and Price, 1993, 1996; Price et al., 1993; Friedl et al., 1994; and Goodin and Henebry, 1996). This research provides spectral information gathered from a restored tallgrass prairie managed with fire, haying and mowing.

# CHAPTER II

## Literature Review

Tallgrass prairie remnants have been managed in many different ways: prescribed burning, grazing, haying and mowing. Hyperspectral remote sensing has been used to monitor some of these differently managed native tallgrass prairies (Asar et al., 1988; Dunham and Price, 1993; Price et al., 1993; Dunham and Price, 1996). Previous studies have shown that annual spring burning of tallgrass prairies produces distinct spectral reflectance patterns from other treatments (Dunham and Price, 1993; Price et al., 1993; Dunham and Price, 1996).

Asrar et al. (1988) evaluated the diurnal and seasonal spectral characteristics of a burned native tallgrass prairie and unburned restored tallgrass prairie. They measured spectral patterns through direct field measurements using a Barnes Modular Multiband Radiometer (MMR Model 12-1000). They found spectral reflectance values for the burned prairie were higher than those of the unburned prairie.

Dunham and Price (1993) examined combinations of nadir and off-nadir viewing with different azimuth angles (0°, 90°, 180°, 270°) to determine optimal angles for identifying the structural differences of tallgrass prairie under different management treatments. They also investigated the effects of different management techniques on canopy structure through sunfleck patterns. An Analytical Spectral Devices (ASD) Personal Spectrometer II (512 bands) was used to measure spectral reflectance. Dunham and Price found that an annually burned native tallgrass prairie had the highest reflectance values in the near-infrared region; untreated tallgrass prairie had lower values. Off-nadir spectral measurements proved slightly more effective in discriminating between different management treatments in terms of spectral responses than nadir measurements.

Price et al. (1993) studied the spectral reflectance patterns on native and restored tallgrass subject to six different management treatments (burned, grazed, hayed, mowed, untreated) in eastern Kansas in 1990 and 1991. Spectral measurements were taken using a Spectron Engineering SE 590 (252 bands). According to Price, native tallgrass prairies treated subject to burning had the highest reflectance values in the near-infrared for both 1990 and 1991 July measurements while untreated tallgrass prairies had the lowest. The native prairie subject to burning had the highest leaf area index (LAI), biomass, and percentage cover in 1991 while the untreated prairie had the lowest LAI, biomass, and percentage cover for both 1990 and 1991.

Dunham and Price (1996) investigated spectral reflectance patterns of tallgrass prairie under different management treatments. They evaluated sets of nadir and 45° sensor view zenith angle with different azimuth angles for the optimal view zenith and azimuth angles to discriminate spectral reflectance patterns among different prairie management techniques. They found that any combination of sensor view zenith angles and view azimuth angles did not significantly affect this ability to discriminate spectral responses among differently treated prairies. The native tallgrass prairie burned annually had the highest reflectance value in the near-infrared while untreated had the lowest.

All of the reviewed articles were significant for the conservation and management of tallgrass prairies. Tallgrass prairie remnants have been managed in different ways, and the studies provide information about how tallgrass prairies respond to the different treatments. Differently managed tallgrass prairies show different spectral reflectance patterns, demonstrating that each treatment has its own characteristics.

Statistical analysis for the reflectance values in the red and near-infrared region was based on few bands from each region in previous studies. My research utilizes not only thirty selected bands from the red and near-infrared region but also the red edge position that will provide more useful information.

# CHAPTER III

## Study Area

The research site is located at the University of Nebraska's Agricultural Research and Development Center (ARDC) in Saunders County, Nebraska (41°10'N 96°30'W). The study area is 4.5 ha of restored tallgrass prairie. Native, C4 (warm-season) grasses such as big bluestem (*Andropogon geraradii*), Indian grass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*), and switchgrass (*Panicum virgatum*) were seeded in 1964 (Bragg et al., 1999). Non-native, C3 (cool-season) grasses, Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*), have invaded portions of the seeded tallgrass prairie (Bragg et al., 1999).

The study area was divided into 42 quadrats, each 0.1 ha (Fig.3). Five different management treatments were randomly established on the site in 1982. The treatments included annual burning (AB) in spring, summer, or fall, quadrennial burning (QB) in spring, summer or fall, quadrennial mowing (QM) in spring, summer or fall, and quadrennial haying (QH) in spring, summer or fall, and control (C) (no treatment). Each treatment has three replicates. I utilized 12 of the spring treatment plots as well as control plots (Fig. 3).

The dominant soils of the study area are Mollisols, which are

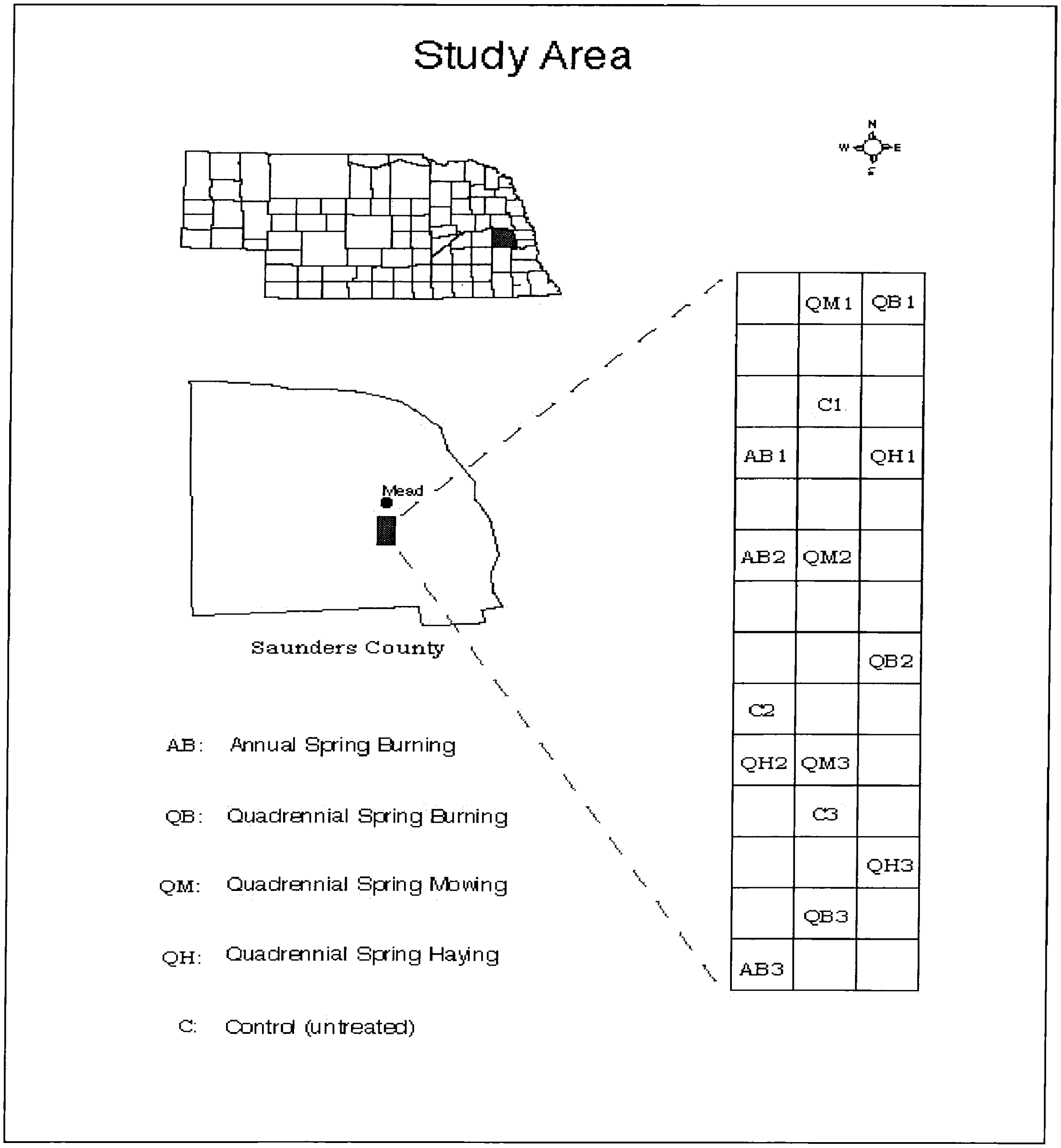


Figure 3. Study Area (ARDC) at near Mead.

dark in color with rich organic matter (Bragg, 1995). Average annual precipitation is 699 millimeters, and the mean temperature of the growing season from March to October is 16 °C (High Plains Climate Center, 2002).

In March of 2001, the entire research site was accidentally burned. This fire removed all litter from every treatment. This meant that despite a long history of consistent treatment all plots were subject to spring burning. It was decided to proceed with the study plan based on the assumption that the residual effects of past treatment would still be detectable. A comparison of data from 1994, the last analysis before the accidental burn, and the fall of 2001, indicates (Table 2) that the fire did not substantially alter species cover. The only exception was a decline in smooth brome in QH1 and which had already been occurring before 1994 (Bragg et al., 1999).

Table 2. Percent canopy cover for species between 1994 and 2001 (Source: 1994 and 2001 data from T. Bragg (unpublished) using procedures from Bragg et al. (1999).

| Species | AB1 | | C1 | | QB1 | | QH1 | | QM1 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | '94 | '01 | '94 | '01 | '94 | '01 | '94 | '01 | '94 | '01 |
| Big bluestem | 89 | 89 | 38 | 42 | 52 | 18 | 83 | 87 | 91 | 77 |
| Kentucky bluegrass | 0 | 2 | 64 | 52 | 0 | 5 | 18 | 28 | 50 | 55 |
| Smooth brome | 0 | 14 | 89 | 89 | 79 | 94 | 52 | 18 | 62 | 82 |

# CHAPTER IV

## Methodology

The general methodological design is shown in Figure 4.

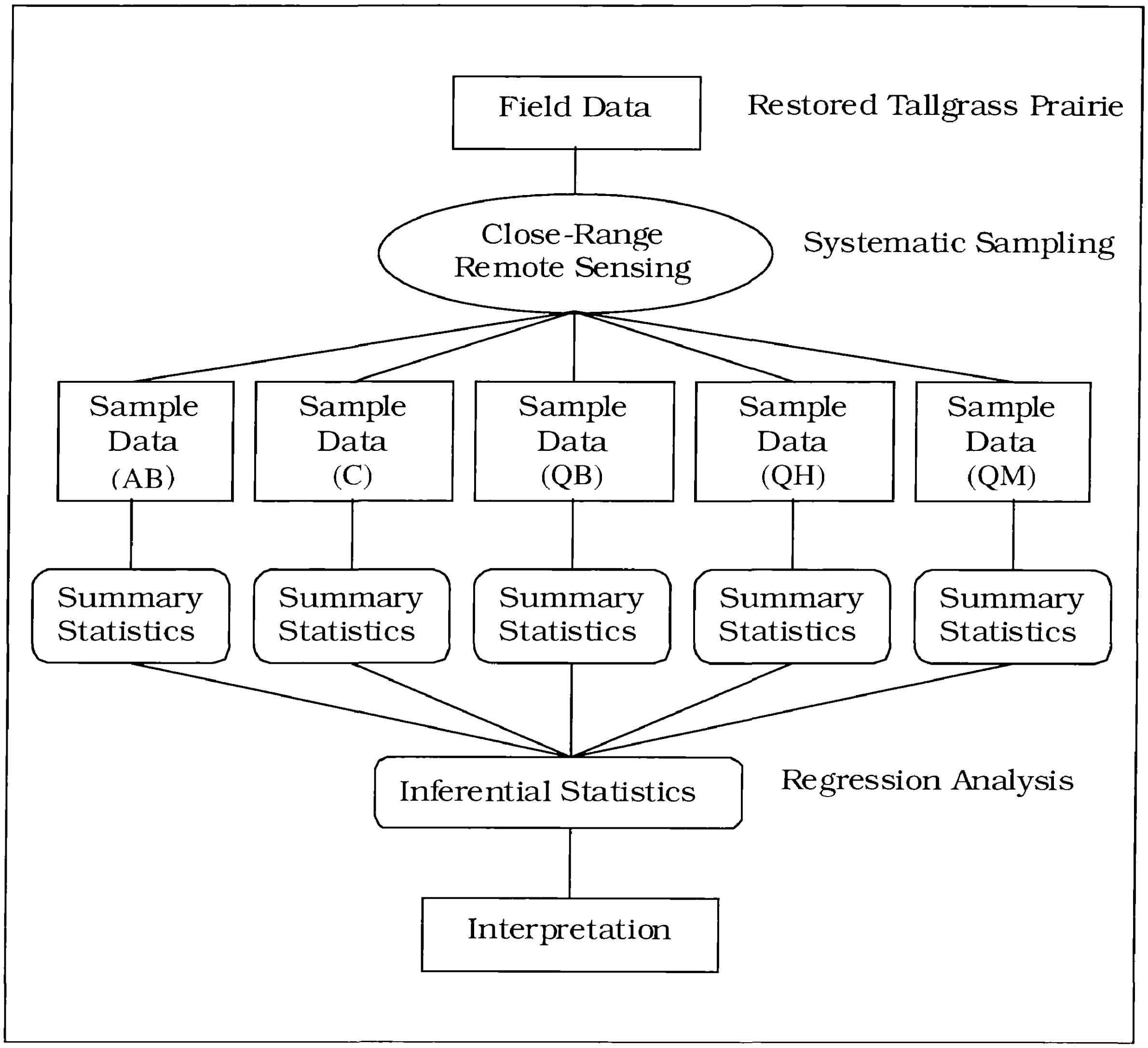


Figure 4. Methodological Design. AB: Annually burned prairie, C: Control (untreated) prairie, QB: Quadrennially burned prairie, QH: Quadrennially hayed prairie, QM: Quadrennially mowed prairie.

## Data Collection

A systematic sampling design was used for data collection (Fig.5). This design was utilized to avoid edges of the site and to accommodate the equipment limitations. Each sample was collected approximately 6 meters apart. The 6 m distance between sample points was based on a study by Goodin and Henebry (1998) that measured semivariograms to determine spatial dependency in tallgrass prairie canopy.

Spectral measurements of 5 samples for each plot were taken using an Ocean Optics USB2000 (350-1000 nm (blue – near-infrared region), 2048 discrete bands) with two fiber-optic cables, one for measuring incoming radiation and the other for reflected. The instrument was mounted on the boom of the Field vehicle 6.8 m above the ground to yield a ground area of 7.06 $m^2$ (Fig.6). The readings were taken from nadir view with a 25° field-of-view between 12:00 p.m. and 3:00 p.m., CDT, on two cloudless to near-cloudless days to minimize variations in solar zenith angle in July 13 and August 28, 2001.

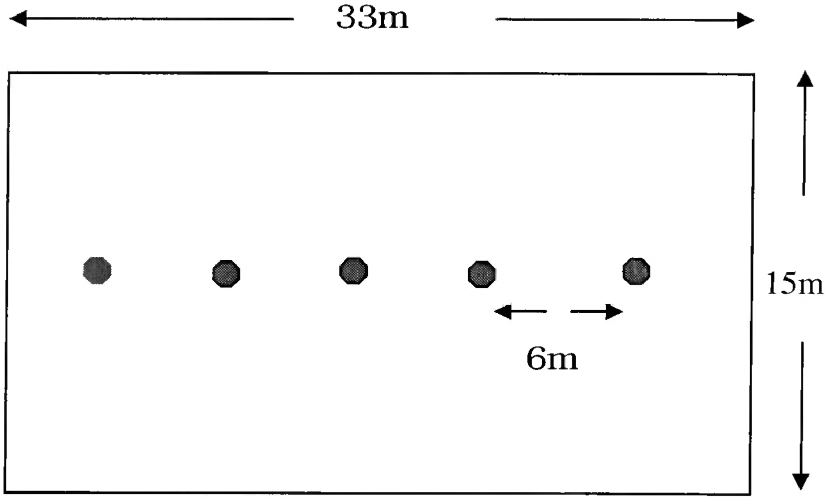


Figure 5. Sample point location for each plot.

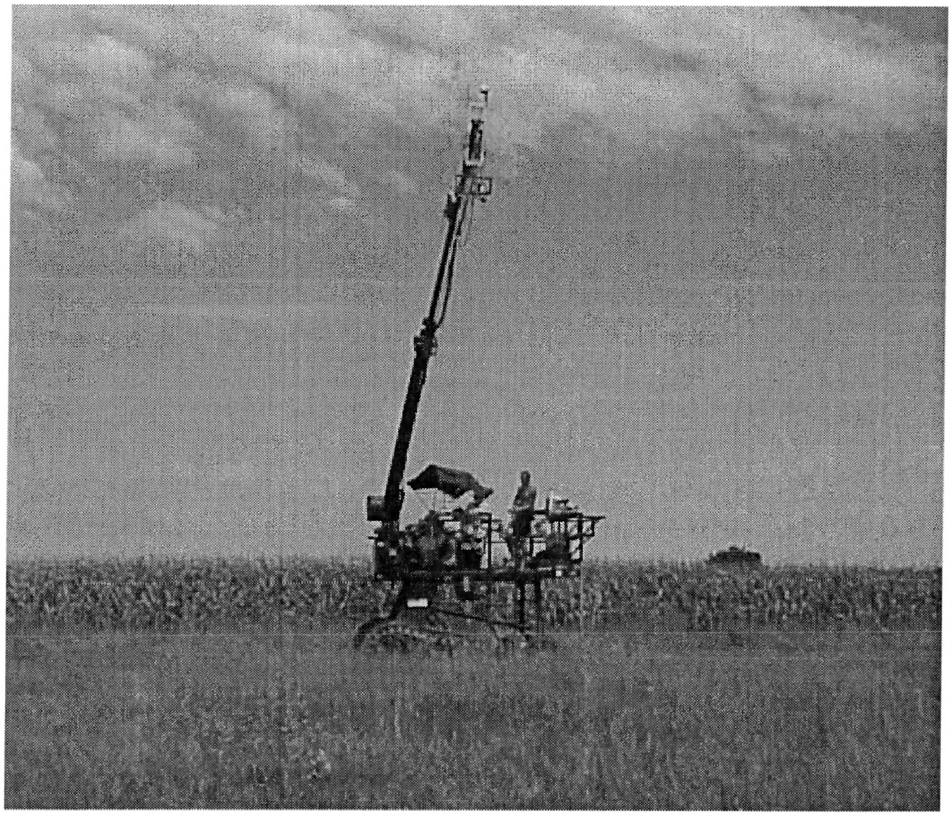


Figure 6. Field Vehicle Data Collection.

For treatment comparison, only one plot for each treatment, AB1, C1, QB1, QH1 and QM1 (Fig. 3) were used for statistical and red-edge analysis. They were all located in the northern part of the research site. These plots were chosen for analysis because they were located near each other, they were on a relatively flat surface, and they were covered with more vegetation than the other two plots with the same treatment. The plots which were excluded had much more exposed soil, which contributed to higher reflectance in the red portion of the spectrum and less reflectance in the near infrared portion. Spectral curves for each treatment (including the excluded treatments) are presented as Figures 7 and 8

## Statistical Analysis

Thirty spectral bands from the red and thirty from the near-infrared (NIR) region were selected for statistical analysis based on variance of mean reflectance values calculated across the five treatments. These bands were selected because the red and the near-infrared regions are commonly used for vegetation studies and are the best bands to discriminate spectral reflectance patterns for differently treated tallgrass prairies (Dunham and Price, 1993; Price et al., 1993; Dunham and Price, 1996).

The red edge is the point where the maximum slope on the spectral reflectance curve of vegetation occurs between the red and the near-infrared region. This usually occurs between 680-740nm where the reflectance changes from very low energy absorption by chlorophyll in the red region to very high energy absorption by chlorophyll in the near-infrared region (Horler et al., 1983; Vogelmann et al., 1993; Filella and Peñuelas, 1994; Pinar and Curran, 1996; Dawson and Curran, 1998). Studies have shown that the first derivative of spectral reflectance values of vegetation are effective in locating the red edge position on the spectral curve (Horler et al., 1983; Vogelmann et al., 1993; Filella and Peñuelas, 1994; Pinar and Curran, 1996; Dawson and Curran, 1998). Dawson and Curran (1998) calculated the first derivative using the following equation:

$$D\lambda\ (j) = R\lambda\ (k + 1) - R\lambda\ (k)/\Delta\lambda$$

Where $D\lambda\ (j)$ = the first-difference transformation at a wavelength j mid-point between k and k + 1

$R\lambda\ (k)$ = the reflectance at wavelength k

$\Delta\lambda$ = difference in wavelengths between k and k+1

Summary statistics generated all the information about the data. Regression analysis using dummy variables for selected bands of the red and the near-infrared regions and red edge position of each selected treatment was used to determine whether two treatments were significantly different. The Statistical Package for the Social Sciences (SPSS10.1) for Windows was utilized for regression analysis. A dummy variable is a numerical variable used to distinguish different treatments such as, 0 for treatment 1 and 1 for treatment 2. The advantage of using dummy variables in regression analysis is that one to multiple treatment comparisons are possible conducting one-way analysis of variance and t-test at the same time. The following equation is a simple linear regression using dummy variables:

$y = b_0 + b_1X + e$

for treatment1 ( X) = 0 and assuming error term(e) averages to 0

$y1 = b_0$

for treatment2 (X) = 1 and assuming error term(e) averages to 0

$y2 = b_0 + b_1(1)$

The difference between two treatments is $b_1$, the regression coefficient. Procedure for hypothesis test using t-test for reflectance values in the red and near-infrared region and red edge position for two differently managed tallgrass prairies follows:

- Null hypothesis (Ho): $b_1 = 0$
- Alternative hypothesis (Hα): $b_1 \neq 0$
- Level of significance (α) = 0.05

# CHAPTER V

## Results and Discussion

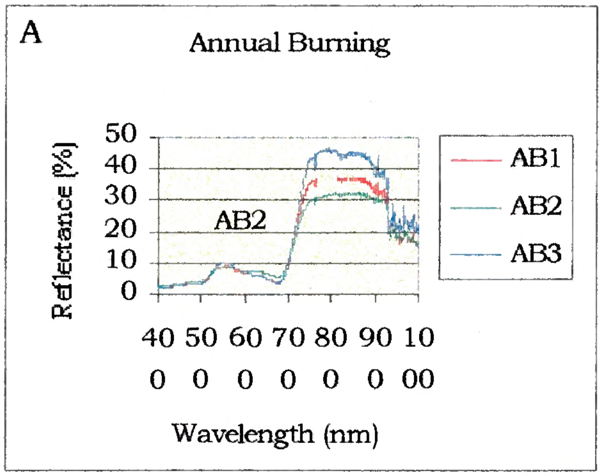
Considerable variation in spectral characteristics exists between July and August data for identical plots (Tables 3 and 4). In general, maximum reflectance values were higher in the green and near-infrared region (NIR) region for the July data. Most treatments had lower minimum reflectance values in the red region in July than in August. This pattern is indicative of more actively growing green vegetation in July. Specifically, plots AB2, C2, QB3, QH2 and QM3 had higher reflectance values in the red region and lower reflectance values in NIR region when compared to the other plots of the same treatment. These plots had substantial amounts of exposed soil, resulting in higher reflectance than expected in the red and lower reflectance values than expected in NIR region (Tables 3-4 and Fig.7-8).

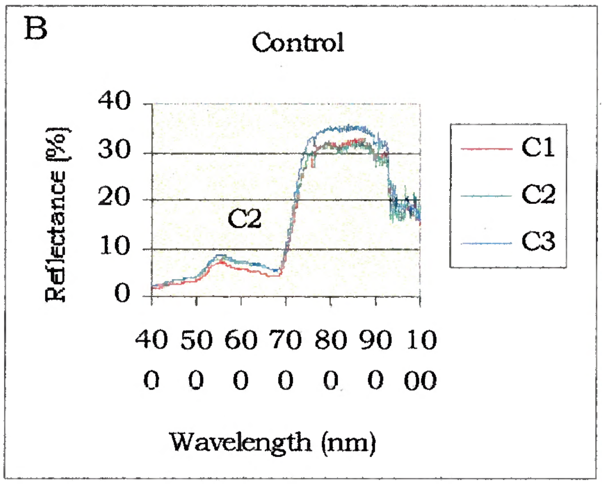
Table 3. Peak reflectance values for the Red and NIR region for July 13, 2001 data. AB = Annually Burned, C = Control, QB = Quadrennially Burned, QH = Quadrennially Hayed, QM = Quadrennially Mowed prairie, WL = Wavelength, HR (%) = Highest Reflectance Valve, LR = Lowest Reflectance Value, Plots for statistical analysis (*).

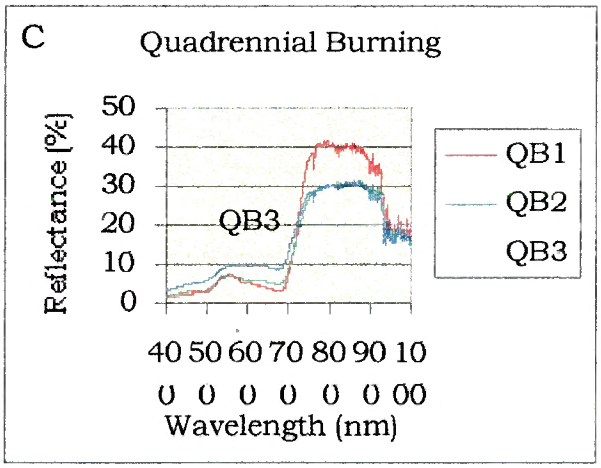
| Peak Value | Green Region | | Red Region | | NIR Region | |
|---|---|---|---|---|---|---|
| Treatment | WL(nm) | HR(%) | WL(nm) | LR(%) | WL(nm) | HR(%) |
| AB1* | 555.5 | 9.01 | 675.8 | 3.77 | 802.2 | 38.12 |
| AB2 | 556.8 | 8.83 | 675.6 | 5.46 | 808.5 | 32.30 |
| AB3 | 556.1 | 10.15 | 675.8 | 3.54 | 792.9 | 46.81 |
| C1* | 556.2 | 7.06 | 672.4 | 4.04 | 863.8 | 33.27 |
| C2 | 558.6 | 7.99 | 673.5 | 5.39 | 870.2 | 32.92 |
| C3 | 557.2 | 8.70 | 674.4 | 5.28 | 850.4 | 35.71 |
| QB1* | 554.8 | 7.31 | 674.4 | 2.94 | 805.3 | 42.47 |
| QB2 | 558.5 | 6.97 | 671.9 | 4.85 | 863.0 | 31.98 |
| QB3 | 559.3 | 9.72 | 672.5 | 8.58 | 865.0 | 31.56 |
| QH1* | 554.6 | 8.06 | 675.1 | 3.12 | 835.0 | 41.17 |
| QH2 | 562.1 | 10.70 | 665.9 | 11.26 | 874.3 | 30.94 |
| QH3 | 556.8 | 8.45 | 675.3 | 4.58 | 799.4 | 37.58 |
| QM1* | 554.6 | 7.32 | 674.4 | 3.02 | 857.1 | 40.61 |
| QM2 | 555.6 | 6.82 | 675.5 | 3.54 | 865.3 | 35.15 |
| QM3 | 558.5 | 9.57 | 673.7 | 7.34 | 865.7 | 36.59 |

Table 4. Peak reflectance values for the Red and NIR region for August 28, 2001 data. Plots for statistical analysis (*).

| Peak Value<br>Treatment | Green Region | | Red Region | | NIR Region | |
|---|---|---|---|---|---|---|
| | WL(nm) | HR(%) | WL(nm) | LR(%) | WL(nm) | HR(%) |
| AB1* | 558.9 | 6.94 | 675.7 | 4.77 | 857.4 | 28.20 |
| AB2 | 560.1 | 7.01 | 674.2 | 5.44 | 871.9 | 26.62 |
| AB3 | 559.0 | 7.85 | 675.6 | 4.74 | 859.7 | 32.79 |
| C1* | 575.1 | 5.19 | 670.3 | 5.01 | 885.4 | 18.90 |
| C2 | 566.9 | 6.60 | 671.2 | 5.46 | 867.4 | 26.33 |
| C3 | 560.6 | 6.92 | 674.0 | 6.04 | 874.6 | 27.13 |
| QB1* | 558.5 | 6.28 | 674.4 | 4.10 | 871.7 | 26.59 |
| QB2 | 559.1 | 5.89 | 672.2 | 4.65 | 875.5 | 23.64 |
| QB3 | 588.1 | 8.25 | 658.3 | 8.56 | 879.9 | 24.87 |
| QH1* | 558.0 | 6.65 | 676.4 | 4.03 | 858.6 | 29.79 |
| QH2 | 588.0 | 8.43 | 653.8 | 8.87 | 873.7 | 24.21 |
| QH3 | 560.2 | 7.18 | 674.0 | 5.64 | 876.0 | 26.21 |
| QM1* | 558.8 | 5.99 | 675.0 | 4.34 | 872.5 | 25.05 |
| QM2 | 557.1 | 5.91 | 673.8 | 4.01 | 871.1 | 27.39 |
| QM3 | 573.8 | 7.23 | 660.8 | 6.50 | 864.2 | 26.43 |


A
Annual Burning
Reflectance (%)
50
40
30
20
10
0
AB2
40 50 60 70 80 90 10
0 0 0 0 0 0 00
Wavelength (nm)
AB1
AB2
AB3


B
Control
Reflectance (%)
40
30
20
10
0
C2
40 50 60 70 80 90 10
0 0 0 0 0 0 00
Wavelength (nm)
C1
C2
C3


C
Quadrennial Burning
Reflectance (%)
50
40
30
20
10
0
QB3
40 50 60 70 80 90 10
0 0 0 0 0 0 00
Wavelength (nm)
QB1
QB2
QB3

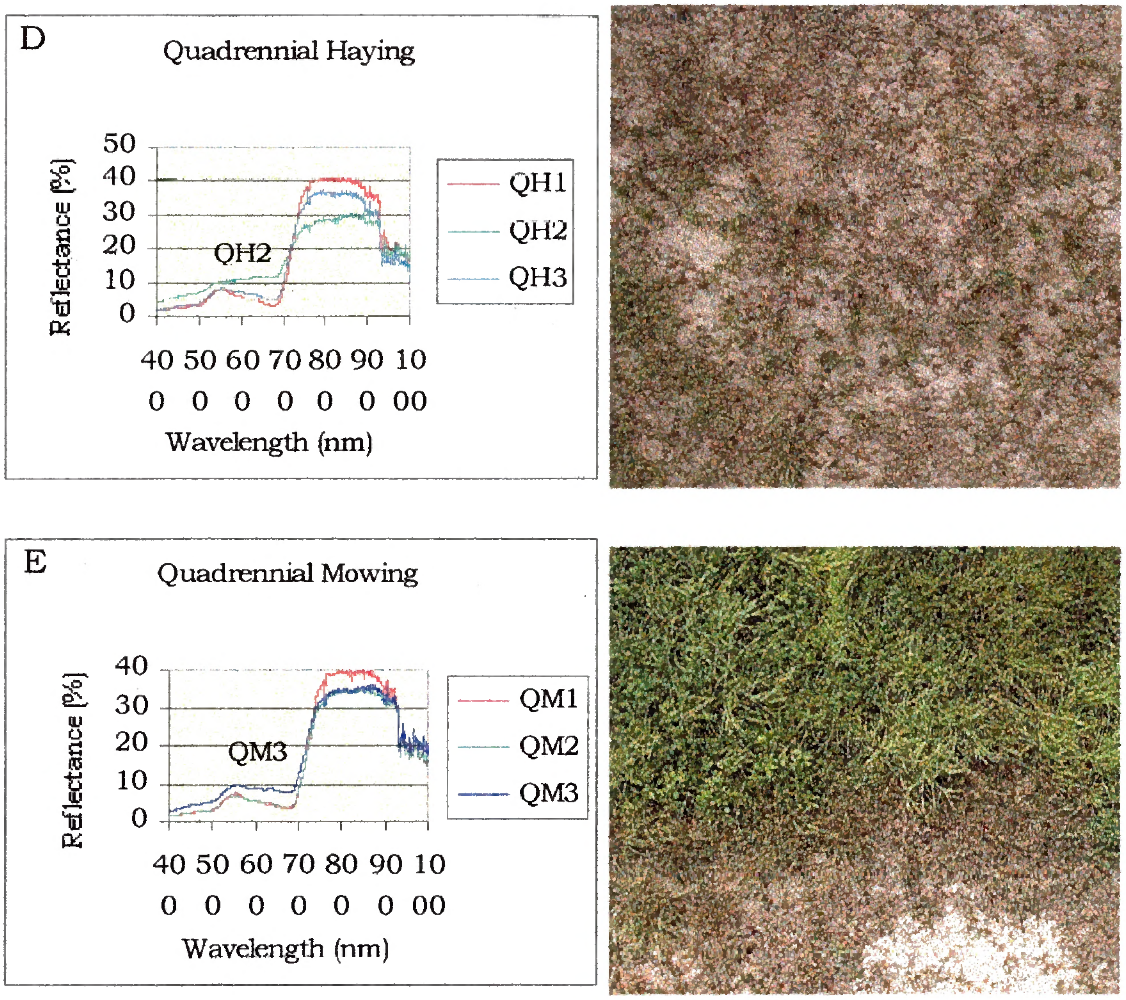


Figure 7. July Spectral Reflectance Curves for Each Treatment. A: Annually burned plots, B: Control plots, C: Quadrennailly burned plots, D: Quadrennially hayed plots, E: Quadrennially mowed plots. Images on the right are of plots with high soil exposure to Spectroradiometer. Plot number of the images shown are located on the appropriate graph.

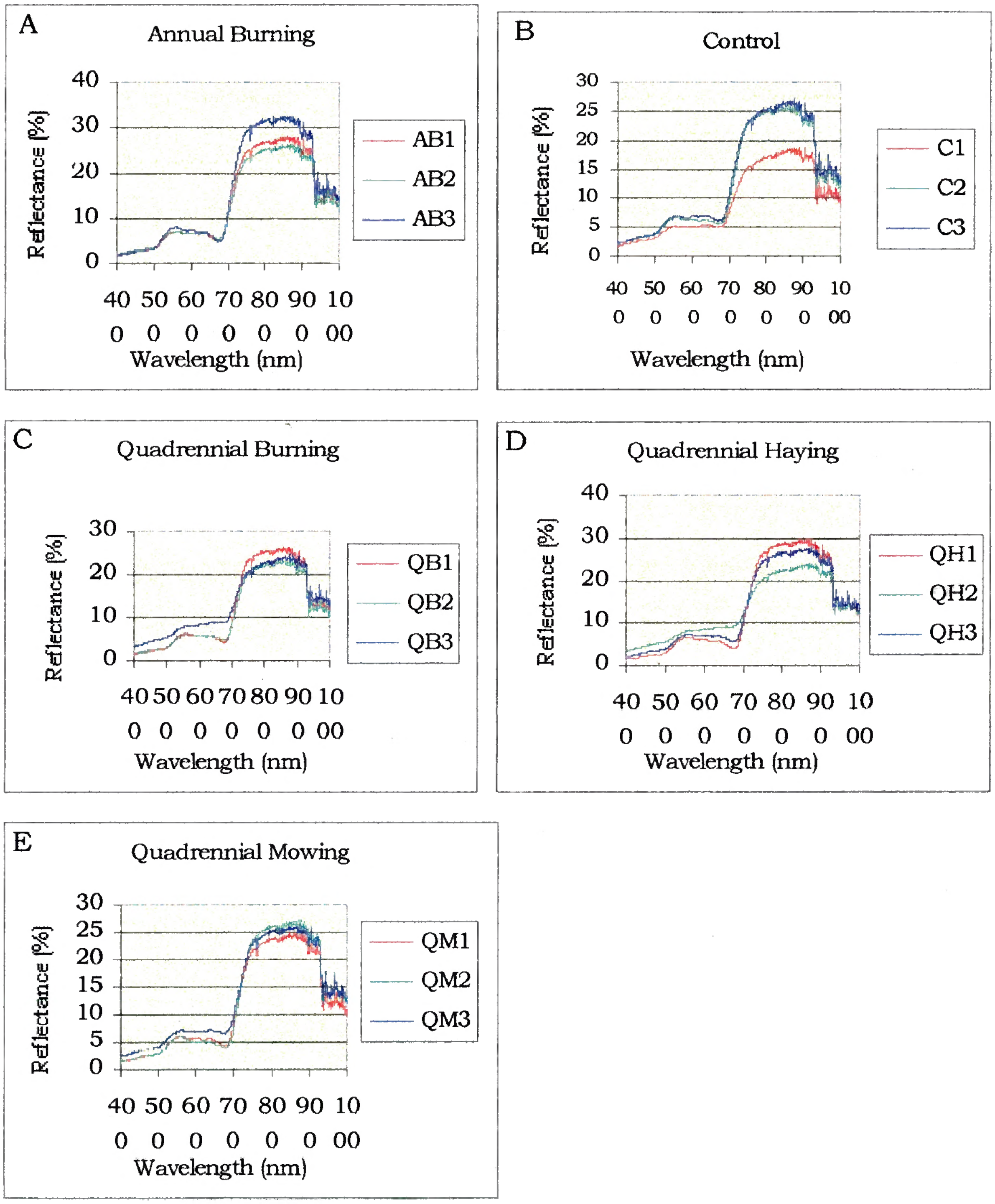


Figure 8. August Spectral Reflectance Curves for Each Treatment.
A: Annual burning, B: Control, C: Quadrennial burning, D: Quadrennial haying, E: Quadrennial mowing.

## Statistical Comparison of Red Edge Position

The red edge position (REP) for the five treatment plots not excluded due to excessive soil reflectance, shifted from longer wavelengths in July to shorter wavelengths in August (Table 5). In addition, the red edge position of annually burned prairie for July was significantly different from quadrennially burned and quadrennially mowed prairie ($p<0.05$). The control plot (untreated) differed significantly from all other treatments except the annually burned plot and quadrennially burned prairie differed from quadrennially mowed prairie in July (Table 5). Separation of treatment plots using August data was less successful. Pairs of AB-QH, QB-QM, and QH-QM indicated statistically significant differences in the red edge position (Table 5).

These results indicated that the red edge position was less useful for discriminating between treatments in August than in July. Six of ten pairs could be separated in July while only four of ten could be separated in August (Table 5). These results suggest that the canopy chlorophyll content in some, but not all treatment plots changed substantially between mid-summer and late summer. This conclusion is based on previous studies which have shown that chlorophyll content was one of the main causes of the red edge position shift (Horler et al., 1983; Vogelmann et al., 1993; Filella and Peñuelas, 1994; Pinar and Curran, 1996; Dawson and Curran, 1998). The position of the red edge also has

1996; Dawson and Curran, 1998). The position of the red edge also has been used as an indicator of stress and senescence (Vogelmann et al., 1993; Filella and Peñuelas, 1994). August was particularly dry in 2001 and plants were showing moisture stress and were beginning to senesce.

Table 5. Results of regression analysis for the red edge position (REP). *b*1 = regression coefficient, β = standardized coefficient. Mean REP (nm) for July measurements: AB = 722.14, C = 719.34, QB = 722.52, QH = 724.78, QM = 726.9. Mean REP (nm) for August measurements: AB = 700.08, C = 700.28, QB = 701.5, QH = 702.16, QM = 699.22.

| Treatment | REP (July 13) | | | REP (August 28) | | |
|---|---|---|---|---|---|---|
| | *b*1 | β | Sig. | *b*1 | β | Sig |
| AB : C | 0.90 | 0.452 | 0.188 | 0.72 | 0.219 | 0.543 |
| AB : QB | 0.389 | 0.163 | 0.652 | 1.42 | 0.566 | 0.088 |
| AB : QH | 2.64 | 0.688 | 0.000 | 2.08 | 0.683 | 0.029 |
| AB :QM | 4.76 | 0.883 | 0.001 | -0.86 | -0.332 | 0.349 |
| C : QB | 3.18 | 0.416 | 0.021 | 1.22 | 0.321 | 0.168 |
| C : QH | 5.44 | 0.712 | 0.000 | 1.88 | 0.495 | 0.041 |
| C : QM | 7.56 | 0.989 | 0.000 | -1.06 | -0.279 | 0.227 |
| QB : QH | 2.26 | 0.455 | 0.056 | 0.66 | 0.174 | 0.477 |
| QB : QM | 4.38 | 0.842 | 0.002 | -2.28 | -0.664 | 0.036 |
| QH : QM | 2.12 | 0.426 | 0.071 | -2.94 | -0.774 | 0.007 |

## Statistical Comparison of Red and NIR Region

The results of the regression analysis of selected treatment plots indicated that the reflectance values of annually burned and control (untreated) treatments differed significantly ($P < 0.05$) from all other treatments in the red and near-infrared region both in July and in August (Table 6 and 7). In July, all the pairs indicated significant differences in reflectance values in the red and near-infrared region, except for the pairs of QB-QM and QH-QM in the red region (Table 6). In August, all the pairs showed significant differences in reflectance values in the red and near-infrared region, except for the pair of QB-QH.

Table 6. Results of regression analysis of July13, 2001 data. Mean reflectance value for Red Region (%): AB = 4.05, C = 4.30, QB = 3.17, QH = 3.35, QM = 3.25. Mean reflectance value for NIR Region (%): AB = 37.32, C = 31.57, QB = 40.79, QH = 40.46. QM = 39.15.

| Treatment | Red Region | | | NIR Region | | |
|---|---|---|---|---|---|---|
| | $b_1$ | $\beta$ | Sig. | $b_1$ | $\beta$ | Sig. |
| AB : C | 0.256 | 0.468 | 0.000 | -5.749 | -0.994 | 0.000 |
| AB : QB | -0.876 | -0.879 | 0.000 | 3.472 | 0.979 | 0.000 |
| AB : QH | -0.703 | -0.823 | 0.000 | 3.134 | 0.972 | 0.000 |
| AB :QM | -0.801 | -0.859 | 0.000 | 1.829 | 0.952 | 0.000 |
| C : QB | -1.132 | -0.939 | 0.000 | 9.221 | 1.078 | 0.000 |
| C : QH | -0.959 | -0.829 | 0.000 | -8.884 | -0.779 | 0.000 |
| C : QM | -1.057 | -0.895 | 0.000 | 7.579 | 0.886 | 0.000 |
| QB : QH | 0.173 | 0.149 | 0.006 | -0.337 | -0.030 | 0.004 |
| QB : QM | 0.008 | 0.063 | 0.219 | -1.642 | -0.92 | 0.000 |
| QH : QM | -0.01 | -0.227 | 0.081 | -1.305 | -0.114 | 0.000 |

Table 7. Results of regression analysis of August 28, 2001 data. Mean reflectance values for the Red Regions: AB = 5.09, C = 5.25, QB = 4.39, QH = 4.32, QM = 4.62. Mean reflectance values for the NIR Region: AB = 26.37, C = 16.67, QB = 24.98, QH = 28.18, QM = 23.37.

| Treatment | Red Region | | | NIR Region | | |
|---|---|---|---|---|---|---|
| | $b_1$ | $\beta$ | Sig. | $b_1$ | $\beta$ | Sig. |
| AB : C | 0.162 | 0.319 | 0.013 | -9.706 | -0.992 | 0.000 |
| AB : QB | -0.704 | -0.771 | 0.000 | -1.390 | -0.750 | 0.000 |
| AB : QH | -0.770 | -0.790 | 0.000 | 1.436 | 0.424 | 0.001 |
| AB :QM | -0.477 | -0.653 | 0.000 | -3.000 | -0.923 | 0.000 |
| C : QB | -0.866 | -0.895 | 0.000 | 8.316 | 0.991 | 0.000 |
| C : QH | -0.932 | -0.808 | 0.000 | 11.518 | 0.920 | 0.000 |
| C : QM | -0.639 | -0.628 | 0.000 | 6.706 | 0.563 | 0.000 |
| QB : QH | -0.066 | -0.057 | 0.367 | 3.202 | 0.256 | 0.000 |
| QB : QM | 0.227 | 0.223 | 0.002 | -1.61 | -0.135 | 0.000 |
| QH : QM | 0.293 | 0.486 | 0.000 | -4.812 | -0.97 | 0.000 |

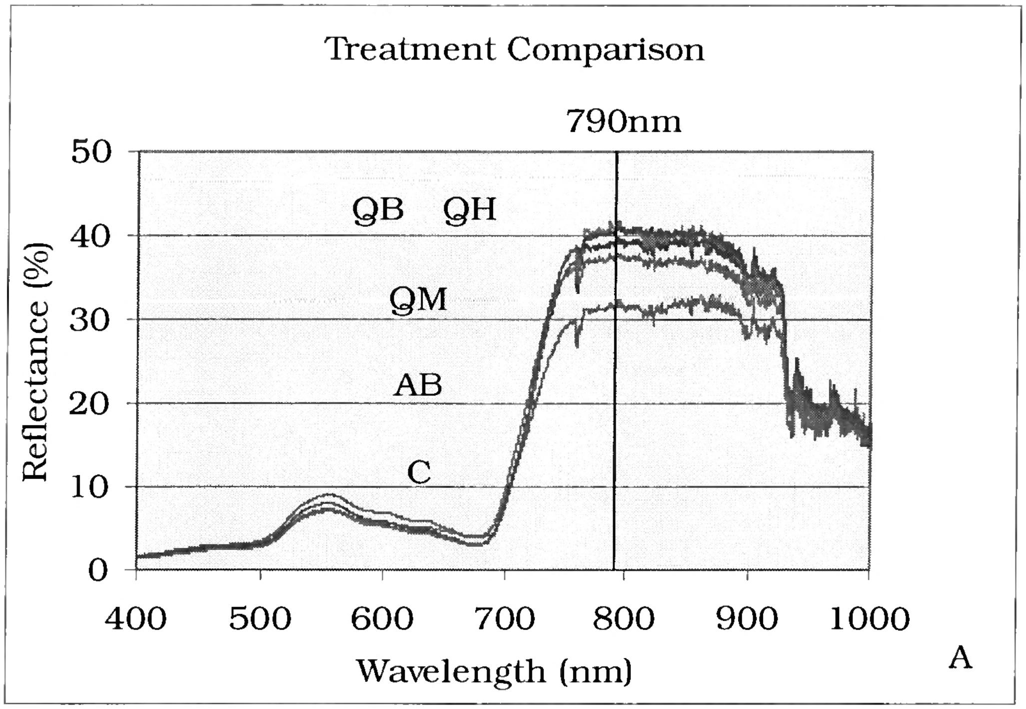
These results indicate at this site that differently managed restored tallgrass prairies have different spectral reflectance values. This is especially true between annually burned and untreated prairie. The red region was less effective in discriminating spectral reflectance values between treatments than the near-infrared region.

**Spectral Reflectance Comparison**

Spectral reflectance patterns for differently managed restored tallgrass prairies both in July and in August measurements are shown in Figure 9. The control treatment indicated the lowest reflectance values in the near-infrared region (700-900nm) for both July and August. In

July (Fig 9-A), QB and QH were very similar in terms of their reflectance patterns throughout the entire spectrum and showed the highest reflectance values in the near-infrared region. In August, QH continued to show the highest reflectance values in the near-infrared region, followed by AB, QB, QM, and C. In July, the highest reflectance values in the near-infrared regions occurred around 790nm while in August the highest values occurred around 865nm (Fig. 9).

These data indicate that, based on reflectance values, restored prairies subject to quadrennial burning and quadrennial haying treatments respond similarly in July but differently in August. This may be because of moisture stress or senescence in late August and/or variation in species cover.



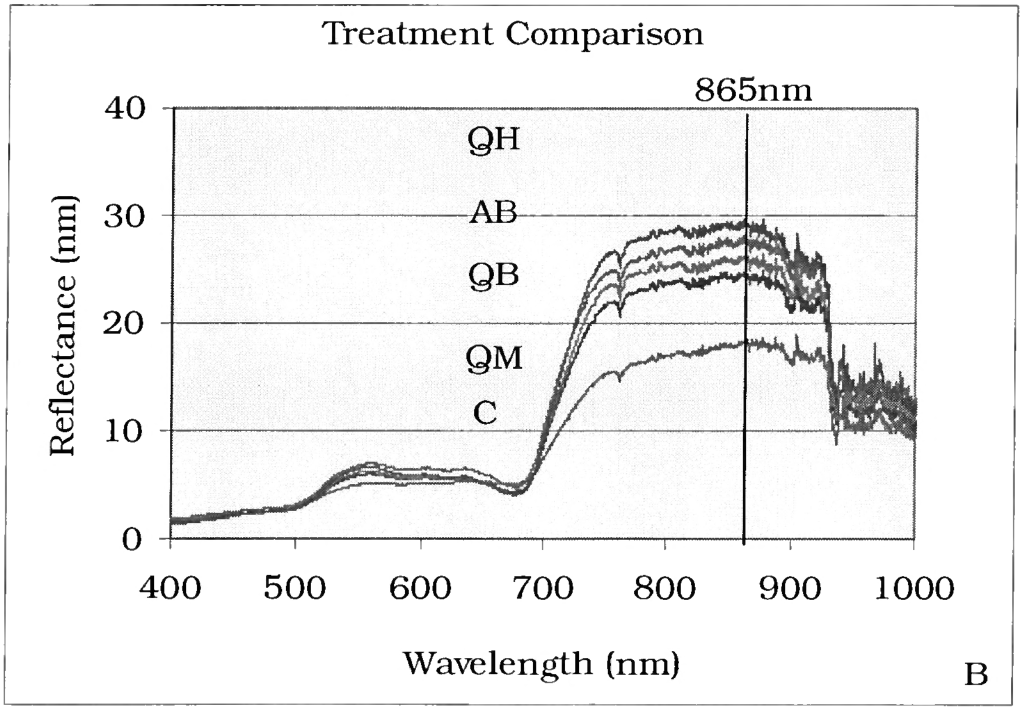


Figure 9. Spectral reflectance patterns for differently managed restored tallgrass prairies (A: July13 measurements, B: August 28 measurements; plots shown on the graph relate to reflectance in the NIR (700-900nm)).

# CHAPTER VI

## Conclusion

Examination of reflectance values in the visible and near-infrared region was effective in discriminating between treatments in both July and August. The near-infrared region was more useful than the red region of the spectrum. In the near-infrared it was possible to distinguish between all treatments.

Based on previous published work it was expected that the highest reflectance values in the near-infrared would be found in the plot subject to annual burning while the control treatment would have the lowest values in the near-infrared for both July and August. Instead, it was found that the quadrennial haying treatment had higher reflectance values than the annual burning treatment in both months. In July, plots managed by quadrennial burning and quadrennial mowing were more reflective than the plot subject to annual burning. The control plot had the lowest reflectance values in both months.

Effective management is important in maintaining the diversity and composition of remnant tallgrass prairies. Many different management techniques are utilized but much is still unknown about their effectiveness in prairie maintenance. Regular monitoring of the spectral characteristics of prairies by hyperspectral remote sensing techniques might be an effective tool not only in discriminating between treatments but also in describing some of the biophysical characteristic of the prairies.

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