Comparison of Nadir and Off-Nadir Multispectral Response Patterns for Six Tallgrass Prairie Treatments in Eastern Kansas

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Abstract

Ground-level spectroradiometer measurements taken at nadir and 45° off-nadir from four sensor view azimuths were used to examine the spectral reflectance patterns of six tallgrass prairie treatments in eastern Kansas. The six treatments included native prairie, burned, mowed, hayed, grazed, and unmanaged grasslands. Spectral reflectance patterns and biophysical measurements were made for each treatment. A red band (band center = 683.8 nm), a near-infrared (NIR) band (band center = 816.5 nm), and the NDVI were used in multivariate analysis of variance and analysis of variance to test for differences in spectral response among treatments. Correlation analysis was used to test for relationships between the spectral variables and plant cover and canopy height.

The native and unmanaged treatments were spectrally unique from the other four grassland treatments. View zenith and azimuth had no effect on the spectral separability among treatments. Across all treatments, only the off-nadir measurements taken at a 0° view azimuth (sun behind sensor) were significantly different from those taken at other view zenith-azimuth angles.

Introduction

Prior to the mid-1800s, the tallgrass prairies of North America extended from what is now north-central Oklahoma into south-central Canada (Küchler, 1974; USGS, 1967). Grasslands covered about 40 percent of the U.S. (Küchler, 1964), and are the largest of the Earth's four major vegetation types (Sims, 1988). The tallgrass prairies of the North American Central Plains are among the most biologically diverse grasslands in the world, with 250 to 300 species commonly found in remnant areas of approximately 250 hectares (Risser, 1988; Steiger, 1930). Central U.S. prairies have been highly fragmented by their conversion to croplands (Sims, 1988), and it is estimated that only 1 percent of these prairies still exist (Diamond and Smeins, 1988). The preservation of these remnant prairies is critical to several threatened and endangered plant and animal species, and to the biological diversity of this important biome (Risser, 1988).

The preservation of remaining tallgrass prairie fragments depends upon the ability of resource managers to locate these lands and protect them from destruction. The most practical means of mapping existing prairie locations over large areas is through the use of satellite remotely sensed data. Findings by Lauver and Whistler (1993) suggest that Landsat TM data provides a more efficient and accurate means of mapping tallgrass prairies than does interpretation of aerial photography.

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The objective of this study was to examine reflectance patterns of tallgrass prairies under six land management practices (treatments) and to determine how these patterns change as a function of sensor view zenith and azimuth angles. More specifically, we wished to determine (1) whether the six treatments could be spectrally separated using measurements from a ground-based spectroradiometer, and (2) whether one or more sets of off-nadir measurements, taken at one of four view azimuths, were better than nadir measurements for discriminating between the prairie treatments.

Our second objective is important because various current and future airborne and satellite-based sensors have capabilities for collecting data at multiple view angles: that is, use of a wide field of view in the across-track direction (e.g., NOAA's Advanced Very High Resolution Radiometer (AVHRR) and many airborne multispectral scanners), the along-track direction, or both; tilting a narrow-FOV sensor at several off-nadir angles, either across-track (e.g., SPOT High Resolution Visible (HRV) sensors) or along-track (e.g., NASA's airborne Advanced Solid-state Array Spectroradiometer (ASAS)); or by using multiple sensors pointing at different (fixed) along-track view angles (e.g., the Multi-angle Imaging Spectro-Radiometer (MISR), a part of the Earth Observing System (EOS) program) (Barnsley, 1994). Use of multiple-view imagery is expected to increase with the introduction of various instruments onboard EOS, generating interest in the effective use of multidirectional data for vegetation monitoring (Huete *et al.*, 1992). Examination of ground-level spectral data can help in determining the most useful combinations of view zenith and azimuth for characterization of vegetation from airborne and satellite-based sensors.

Studies of tallgrass prairie spectral response are primarily concentrated in the 1987 First International Satellite Land-Surface Climatology Project (ISLSCP) Field Experiment (FIFE) project conducted on the Konza Prairie near Manhattan, Kansas. The objective of FIFE was to examine the use of remotely sensed measurements for modeling and observing land-surface-atmosphere interactions at regional and global scales (Sellers *et al.*, 1992; Sellers *et al.*, 1990). Spectral response patterns of bare soil, senescent vegetation, and green vegetation were analyzed and described in work by Asrar *et al.* (1986) and Asrar *et al.* (1989). Briggs and Nellis (1991) used SPOT data to study seasonal variation in the texture of grazed and burned prairies.

Dyer *et al.* (1991) and Turner *et al.* (1992) examined the

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effects of prairie management on spectral reflectance patterns. The spectral and biophysical responses from grazed, burned ungrazed, and unburned prairies under different clipping and fertilization schemes were reported. The authors found a positive relationship between biomass and the Normalized Difference Vegetation Index (NDVI). During the first half of the growing season, NDVI values were lower for the grazed than for the burned and unburned prairies. After mid-season, however, it was higher for the grazed than for the unburned, while the grazed and burned had similar NDVI values.

Off-nadir spectral measurements of prairie treatments may improve our ability to distinguish between prairie land-use practices. Egbert and Ulaby (1972) noted the effects of solar and sensor view zenith and azimuth angles on target reflectivity. Colwell (1974) found that grass canopy reflectance changed with changes in solar zenith angle and view zenith and azimuth angles, and with changes in canopy characteristics. Many subsequent studies have detailed the effects of these same factors on vegetation canopies (e.g., Kimes, 1983; Shibayama and Wiegand, 1985).

Middleton (1992) studied the anisotropy of photosynthetically active radiation of grasslands, finding similar anisotropic patterns among three prairie treatments (burned, unburned, grazed) and two topographic positions (ridge-top and plateau). Walter-Shea *et al.* (1992) found that the grassland canopy bidirectional reflectance factors generally increased with increasing view zenith angles, and that along the solar principal plane, spectral vegetation indices (SVIs) were lowest in the backscatter direction and highest in the forwardscatter direction. Deering *et al.* (1992) examined the bidirectional reflectance patterns of burned prairie. In that study, multispectral measurements from four instruments were taken at 11 view zenith angles at six solar zenith angles along the solar principal plane. Results showed that both solar zenith angle and view zenith angle influenced prairie reflectance patterns.

Study Area

In 1956, the University of Kansas acquired 65 ha of land approximately 8 km north of Lawrence, Kansas (Fitch and Kettle, 1988). These lands have since been managed to study the effects of land use on prairie ecology (Fitch and Hall, 1978). Approximately 4 ha of the tract are unplowed native prairie composed mostly of native grasses and forbs. The remainder is plowed agricultural land reseeded in 1957 with a tallgrass seed mixture of big bluestem (*Andropogon gerardii*, Vitman), little bluestem (*Schizachryum scoparium*, Michx.), Indiangrass (*Sorghastrum nutans*, L. Nash), and switchgrass (*Panicum virgatum*, L.) (Fitch and Hall, 1978). In 1962, this reseeded land was subdivided into five parcels. Four of the parcels have since been subjected to a particular management practice: burning, grazing, annual haying, and annual mowing with the cut hay left on the ground. The remaining reseeded parcel, used as a control, is unmanaged.

Since 1962, treatment and management of these lands has been carefully controlled and documented. Both the native prairie and the burned parcels are burned in the spring every 2 to 3 years. During the course of this study, the native prairie was last burned in April, 1992, and the burned treatment was last burned in April, 1991. The vegetation on the hayed and mowed treatments is cut each year, usually in mid-July. The grazed treatment is stocked at a rate of 0.4 cattle per hectare from mid-June to mid-September. For clarification, when discussing the six land management types, the native prairie will sometimes be referred to as one of the treatments. Unlike the other five land parcels, however, the native prairie was never plowed or reseeded.

A 1989 plant species inventory of the six treatments showed differences in species composition, especially between the native prairie and the other five treatments (Kindscher *et al.*, 1993; Figure 1). The native prairie had more than twice as many species (175) as the burned treatment, which had the next highest number of species (87). The mowed treatment had only 68 species. All treatments had more than twice as many forb species as grass species. The native prairie had the highest number of forbs (126) and the mowed the fewest (42). The native prairie also had the highest number of grass and grass-like (e.g., carex and rush) species with 29, while the unmanaged had the fewest (13).

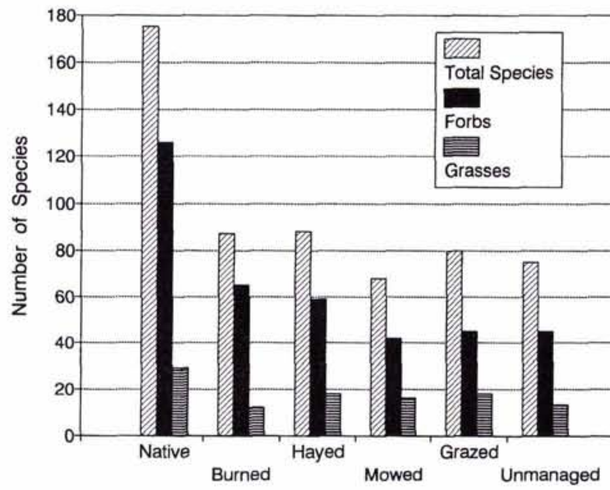

Figure 1. Number of plant species for the six treatments (1989 inventory). The graph shows the total number of species and the number of forbs and grasses by treatment. Grasses include grass-like species.

A comparison of aboveground biomass measurements made during independent studies in July of 1990 and 1992 showed similar biomass in each year for the native, burned, and hayed treatments (Figure 2). In these years, the native prairie also had the highest biomass. Biomass for the unmanaged treatment in July 1992 was more than twice that of July, 1990. Biomass measurements of the mowed and grazed treatments were not made during the 1992 study. During the spring of 1990 and 1992, the native prairie was burned, while the burned treatment was not. The native prairie produced the highest amount of aboveground biomass and the burned treatment the next highest (Figure 2). In another study, aboveground biomass measurements taken three times during the 1990 growing season (June, July, and October) showed that grasses produced 3 to 10 times as much biomass as forbs on all but the grazed treatment, which was similar for both life-forms (Price *et al.*, 1992).

Price *et al.* (1993) found two to three times greater total leaf moisture (g/m^2) for the native prairie in mid-July than for the other treatments, as well as a negative relationship between total leaf moisture and red reflectance. The unmanaged treatment was also found to be spectrally different from the other five treatments, having the highest near-infrared (NIR) reflectance and the lowest red reflectance of any treatment. The hayed, mowed, burned, and grazed treatments were not spectrally different from each other during the sampling period.

Soils in our study area are deep silty clay loams and clay loams found on gentle slopes of less than 8 percent. The climate is mid-continental temperate with an average annual temperature of 13° C, a mean monthly low temperature of

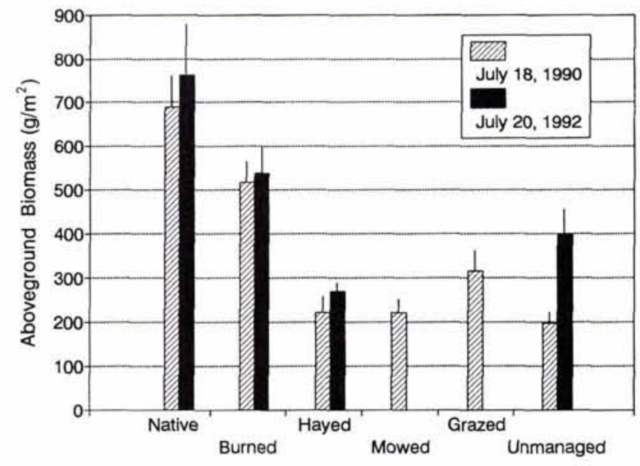

Figure 2. Average aboveground biomass by treatment for 18 July 1990 and 20 July 1992. These data were not collected as part of this study, but were collected from the same treatments used in this study. The native prairie had the greatest biomass. Biomass measurements were not taken for the mowed and grazed treatments during the 1992 field season. The error bars represent +1.0 standard error.

−2° C in January, and a high of 26° C in July. Average annual precipitation is 950 mm with over 70 percent falling during the growing season (USDA SCS, 1977).

Methods

A common constraint associated with field experiments within ecological reserves is the inability to collect replicate samples for each treatment. In spite of this limitation, data from these experimental areas can be very useful. Guthery (1987) wrote, "While we support true replications as a canon of research, we believe that data from experiments with unreplicated treatments can contribute to knowledge and guide future research efforts." Because the treatments at the Kansas Ecological Reserve are not replicated, the inferences derived from our results may pertain only to the sites within each treatment of our study.

Spectroradiometer Measurements

Spectroradiometer measurements were taken for each of the six prairie treatments between 13 and 22 August 1992. The mean spectral measurement for each treatment, except the native prairie, was based on an average of five readings derived from five replicates (sample plots) taken within a 10- by 10-m (100 m²) sampling area. Technical difficulties resulted in the collection of only four samples for the native prairie. The sample plots were located in the four corners and in the middle of the 100 m² sample area. To avoid edge effects, the sampling areas were located on flat areas near the middle of each treatment, in areas dominated by grasses and/or forbs. Individual sample plots were positioned away from larger shrubs and small trees to avoid changing the size of the area viewed by the spectroradiometer and to avoid the shadows cast by taller woody species. On the grazed treatment, cattle were excluded from the sample area until after field measurements were taken, and the hayed and mowed treatments were not mowed until after the August sampling period.

Spectral measurements were taken using an Analytical Spectral Devices Personal Spectrometer II, a hand-held spectroradiometer that measures 512 (about 1.4-nm-wide) bands within the 345-nm to 1075-nm region of the electromagnetic spectrum. The shape of each of the five sample plots was a circle of approximately 0.4 m radius (0.5 m² area), chosen to duplicate the shape of the field-of-view of the spectroradiometer. Readings were made using a 25° field-of-view. The readings were taken from nadir and from a 45° sensor view zenith angle at four view azimuths: 0°, 90°, 180°, and 270°, with 0° defined as having the sun directly behind the field-of-view of the instrument, and other azimuths proceeding from 0° in a clockwise direction (Figure 3).

The 45° off-nadir view zenith angle was chosen because it provided a large angular contrast from nadir, and is similar to the maximum view zenith angles of airborne instruments such as the Daedalus DS-1268 (43°) (Daedalus Enterprises, 1995) and NASA's ASAS (45°) (Barnsley, 1994; Irons *et al.*, 1991). The 45° view zenith angle has also been used previously in ground-based studies involving off-nadir reflectance (e.g., Jackson *et al.*, 1990; Shibayama and Wiegand, 1985; Kirchner *et al.*, 1982).

Spectroradiometer mounts used for the off-nadir measurements were placed 1.27 m high just outside of the circular plot of interest. This setup provided 45° off-nadir measurements of an elliptical ground area approximately 1.19 m by 0.8 m along its two axes (0.78 m²), with the minor axis corresponding in size to that of the nadir measurements, so that the off-nadir measurements would include all of the area included in the corresponding nadir measurements. For the nadir measurements, the sensor was located on a boom 1.8 m above the center of the plot, the height at which the spectroradiometer sensed a ground area of 0.5 m².

Spectroradiometer measurements were taken between 11 AM and 3 PM, CDT, on cloudless to near-cloudless days to minimize variations in solar zenith angle and atmospheric conditions (Bammel and Birnie, 1994; McCoy *et al.*, 1989). Each spectral measurement consisted of five spectra taken within approximately 5 to 10 seconds that were later averaged to provide the measurement used in the analysis. Spectral measurements from each sample plot were typically collected within five minutes. These spectra were collected using the instrument's percent-reflectance mode. A raw spectrum from a Spectralon white reference panel was taken be-

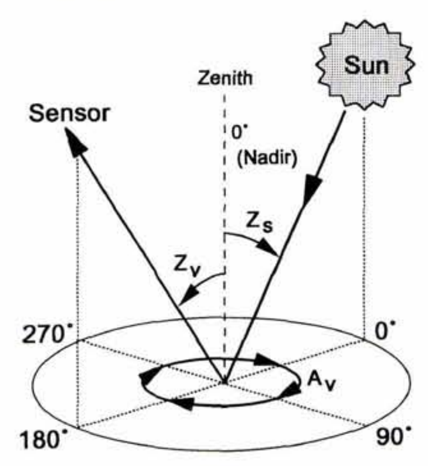

Figure 3. Geometry of spectral measurements. Z_v, view zenith angle; A_v, sensor view azimuth angle; Z_s, solar zenith angle. (After Shibayama and Wiegand, 1985.)

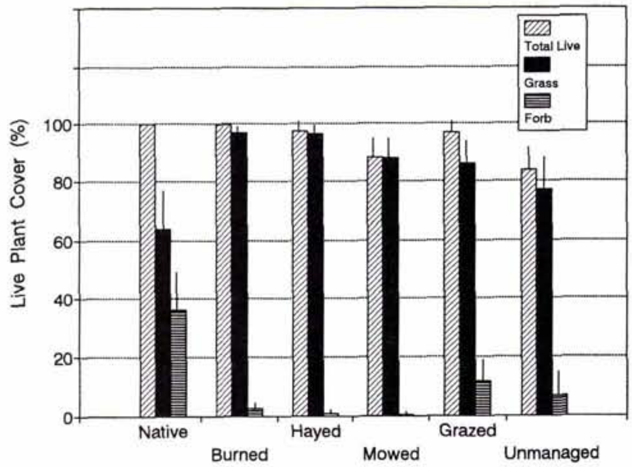

Figure 4. Average live plant cover (%) by treatment collected during the study. Cover estimates are represented by bars for total live plants, grasses, and forbs. The ratios of grasses to forbs by treatment were native, 1.8:1; burned, 37:1; hayed, 29:1; mowed, 88:1; grazed, 8:1; and unmanaged, 12:1. The error bars represent +1.0 standard error.

fore the set of spectra for each plot, and each subsequent plot spectrum was automatically divided by the white reference values to produce a percent-reflectance spectrum.

Plant and Spectral Variables

Plant canopy cover and height measurements were take for grasses (which included grass-likes such as carex and rushes) and forbs at each of the five 0.5-m^2 sample plots that were also used for collection of spectroradiometer measurements. Plant cover was estimated within each plot using 69 point measurements spaced 10 cm apart. Canopy height was measured to the nearest 5 cm at each of the 69 sample point locations. Measurements from the five sample plots were used to estimate average plant cover and height for each treatment.

Two spectroradiometer bands (red — band center at 683.8 nm; and NIR — band center at 816.5 nm) and the Normalized Difference Vegetation Index (NDVI) were selected for more detailed statistical analysis. The red and NIR spectral regions were chosen because they represent reflective wave bands commonly used for vegetation studies. Results from Pearson's product-moment correlation analysis showed that all of the visible and NIR spectroradiometer bands were highly intercorrelated within their respective spectral regions (r values were > 0.90). For this reason, only one band each from the visible (683.8-nm) and NIR (816.5-nm) regions were selected for further analysis. For the NDVI value, the Landsat TM band equivalents for the red (630- to 690-nm) and NIR (760- to 900-nm) wavelengths were simulated by integrating the spectroradiometer band values falling within these two TM band regions. NDVI was calculated using the simulated band values with the standard NIR−red/NIR+red formula (Tucker, 1979).

Statistical Analyses

The plant cover and canopy height measurements were analyzed to obtain summary statistics by treatment for these factors. Plant cover and canopy height, by treatment, for grasses and forbs were used to determine relationships between these biophysical factors and the three spectral variables (red, NIR, NDVI). The strengths of the relationships were tested using Pearson's product-moment correlation coefficients. Multivariate analysis of variance (MANOVA) was used to test the spectral variables for statistical differences among prairie treatment, view zenith-azimuth angle, and/or interaction between these two factors (Gill, 1978; Muzika *et al.*, 1990). Use of MANOVA was preferable to running separate one-way analysis of variance (ANOVA) for each dependent variable because MANOVA controls for intercorrelations among dependent variables and also controls for Type I error (Stevens, 1992). A significant interaction between prairie treatment and view zenith-azimuth angle would indicate that the spectral variables were different because of the combined effects of the treatment and view zenith-azimuth angle. If differences in spectral values were due to prairie treatment, view zenith-azimuth angle, or their interaction, multiple one-way ANOVAs were conducted using each spectral variable as a dependent variable, and prairie treatment, view angle, or interaction between these factors as the independent variables. The mean values for one-way effects were tested for statistical differences using Scheffe's test ($P \leq 0.05$).

Results and Discussion

Plant Cover and Canopy Height

Total live vegetation cover was between 97 and 100 percent for the native, burned, hayed, and grazed treatments (Figure 4). Total live cover was lower for the mowed and unmanaged treatments — 88 and 84 percent, respectively. The ratio of live grass to forb cover was very different for the native prairie than for the other treatments. The native prairie was dominated by grass cover, but had more forbs than the other treatments. Grasses were the dominant life-form for the other five treatments. The native and burned treatments had the highest mean canopy heights, 70 cm and 60 cm, respectively, while the hayed had the lowest mean height, 32 cm (Figure 5).

These results showed that the native prairie was most unique in terms of grass-forb cover composition, which influences canopy architecture (three-dimensional arrangement of the leaves, stems, and reproductive components). The unmanaged treatment was the next most unique, having the lowest percentage of live cover and one of the lowest grass-

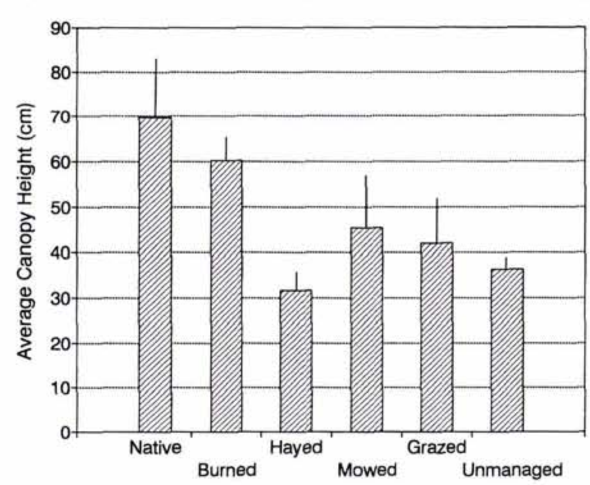

Figure 5. Average canopy height (cm) by treatment collected during the study. The error bars represent +1.0 standard error.

to-forb ratios. These differences, however, were not as obvious as those of the native prairie.

Spectral Differences Among Treatments and View Angles

Multivariate analysis of variance (MANOVA) revealed spectral differences among prairie treatments and among view zenith-azimuth angles (Wilk's lambda, $P < 0.0001$), indicating that there were spectral differences between at least two of the prairie treatments and between at least two of the view zenith-azimuth angles. No difference, however, was found for the prairie treatment-view angle interaction, meaning that sensor orientation had no effect on the ability to spectrally discriminate between any of the prairie treatments.

Because differences among effects were verified during the MANOVA analysis, one-way analyses of variance (ANOVA) were conducted on each spectral variable for prairie treatment and view zenith-azimuth angle separately, in order to determine which pairs of treatments and pairs of view zenith-azimuth angles were different. Results for the six treatments indicate that all three spectral variables were at least moderately successful in discriminating between treatments (Table 1). The NIR band (816.5 nm) performed best, differentiating 12 of 15 possible treatment pairs. The NDVI differentiated between 10 of 15 possible treatment pairs, and the red band (683.8 nm) differentiated between 8 of 15.

The native prairie was the most spectrally distinct of the six prairie treatments, showing differences from the other five treatments for all three spectral variables. The unmanaged treatment was different from all the treatments except the mowed in the red band. The remaining four treatments were less separable, all showing differences from both the native and unmanaged in all spectral variables, but not always separable from each other (Table 1).

ANOVA results for the five view zenith-azimuth angles indicated little separability among the view angles for the three spectral variables (Table 2). The off-nadir measurements taken at the 0° view azimuth differed from all others in the red band, as well as with nadir for the NIR band and 180° for the NDVI. No other pairs of view zenith-azimuth angles showed differences among spectral variable. The significant differences between the 0° view azimuth measurements and those taken at the other view zenith-azimuth angles suggest that the backscatter characteristics of the treatments were distinct from the nadir reflectance, forwardscatter, and sidescatter, which appeared indistinct among themselves based on the lack of significant differences among the other view zenith-azimuth angles.

Figure 6 shows the average nadir spectral response curves for the six treatments. The curve for the native prairie showed greater absorption in the red and much higher reflectance in the NIR than did the other treatments. It also showed much greater absorption in the minor water absorption band beginning at 960 nm, as noted by Hoffer (1978).

TABLE 2. SENSOR VIEW ZENITH-AZIMUTH ANGLE PAIRS SIGNIFICANTLY DIFFERENT FOR SPECTRAL VARIABLES (RED BAND CENTER = 683.8 NM; NIR BAND CENTER = 816.5 NM), USING ONE-WAY ANOVAS WITH SCHEFFE'S TEST ($P \leq 0.05$). EACH CELL SHOWS THE SPECTRAL VARIABLES FOR WHICH SIGNIFICANT DIFFERENCES WERE FOUND. ONLY THE VIEW AZIMUTHS ARE SHOWN FOR THE OFF-NADIR VIEW ZENITH-AZIMUTH ANGLES—ALL WERE TAKEN USING A 45° VIEW ZENITH ANGLE.

VIEW ANGLE	Nadir	0°	90°	180°	270°
Nadir	—				
0°	Red NIR	—			
90°	NONE	Red	—		
180°	NONE	Red NDVI	NONE	—	
270°	NONE	Red	NONE	NONE	—

Correlation Analysis

Because MANOVA showed no difference in reflectance caused by the interaction of treatment and view zenith-azimuth angle, the averages of the reflectance values for all five view zenith-azimuth angles for each plot were used in correlation analysis. Correlation results showed only one significant linear relationship between a spectral variable and a cover variable ($P \leq 0.05$, $r_{crit.} = \pm 0.977$). Percent cover by forbs was negatively correlated ($r = -0.984$) with the red band (683.8 nm) on the unmanaged treatment. This treatment was unique in that it had from 9 to 16 percent less live cover than four of the other treatments, and had one of the lowest ratios of grass to forb cover (Figure 4). The standard error bars in Figure 4 also show grass and forb cover to be the most variable within the grazed and unmanaged treatments. There was little or no variation in total live cover for the native, burned, hayed, and grazed treatments. The mowed treatment had about 10 percent less cover than these four treatments, but it had very little forb cover, unlike the unmanaged treatment. The lack of correlations between the spectral variables and plant cover factors may be explained by the small sample size and the lack of variation within treatments. The correlation between cover and the red band suggests that relatively small variations in cover can influence spectral response.

Conclusions

The native and unmanaged treatments were most spectrally distinct, with other treatments separable from few treatments other than the native or unmanaged (Table 1). The native prairie was also different from the other treatments in plant

TABLE 1. TREATMENT PAIRS SIGNIFICANTLY DIFFERENT FOR SPECTRAL VARIABLES (RED BAND CENTER = 683.8 NM; NIR BAND CENTER = 816.5 NM), USING ONE-WAY ANOVAS WITH SCHEFFE'S TEST ($P < 0.05$). EACH CELL SHOWS THE SPECTRAL VARIABLES FOR WHICH SIGNIFICANT DIFFERENCES WERE FOUND.

TREATMENT	Burned	Grazed	Hayed	Mowed	Native	Unmanaged
Burned	—					
Grazed	NONE	—				
Hayed	NONE	NIR NDVI	—			
Mowed	NIR	NIR	NONE	—		
Native	Red NIR NDVI	Red NIR NDVI	Red NIR NDVI	Red NIR NDVI	—	
Unmanaged	Red NIR NDVI	Red NIR NDVI	Red NIR NDVI	Red NIR	Red NIR NDVI	—

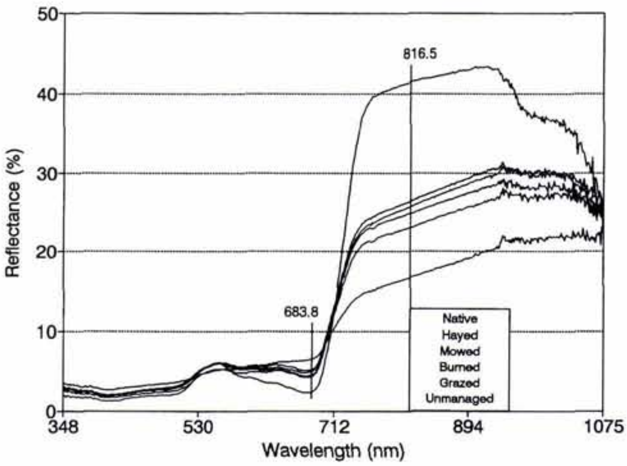

Figure 6. Nadir spectral response curves by treatment for 512 bands. The curve for each treatment is indicated at the NIR band (816.5-nm band center) by a vertical line; the box shows reflectance in this band from highest to lowest. The red band (683.8-nm band center) is also indicated by a vertical line through the curves. The unmanaged treatment had the highest reflectance at 683.8 nm, followed by the mowed, grazed, hayed, burned, and native, respectively. The native prairie had the highest absorption in the minor water absorption band beginning at approximately 960 nm.

species composition, proportion of grasses to forbs, aboveground biomass, and canopy height. The unmanaged treatment had the least amount of total living cover and one of the lower grass to forb cover ratios.

Differences in sensor view zenith-azimuth angle had no significant effect on the ability to spectrally discriminate among prairie treatments. Across all the treatments, only those taken off-nadir at a 0° view azimuth were significantly different from those taken at other view zenith-azimuth angles. This difference, however, indicates at least some degree of bidirectional reflectance anisotropy across the treatments. This finding supports grassland bidirectional studies reported by Colwell (1974), Deering *et al.* (1992), Middleton (1992), and Walter-Shea *et al.* (1992).

The unique reflectance properties of the native prairie suggest that similar land cover types might be spectrally distinguishable from other grassland types. The unmanaged treatment may share similar spectral characteristics with lands set aside by the U.S. Conservation Reserve Program (CRP). If so, CRP lands may be distinguished using remotely sensed data. Issues of scale and effects of atmospheric attenuation on spectral response patterns were not addressed by this study. These factors will influence the spectral separability of grasslands under different land management practices.

Our continuing research examines nadir and off-nadir spectral reflectance patterns over the growing season to identify optimal sampling periods for distinguishing among grassland management practices. In this work, we plan to investigate questions concerning optimal sensor orientation for discrimination of grassland management practices.

Acknowledgments

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