A MULTIVARIATE ANALYSIS OF BIOPHYSICAL PARAMETERS OF TALLGRASS PRAIRIE AMONG LAND MANAGEMENT PRACTICES AND YEARS

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Abstract. Six treatments of eastern Kansas tallgrass prairie – native prairie, hayed, mowed, grazed, burned and untreated – were studied to examine the biophysical effects of land management practices on grasslands. On each treatment, measurements of plant biomass, leaf area index, plant cover, leaf moisture and soil moisture were collected. In addition, measurements were taken of the Normalized Difference Vegetation Index (NDVI), which is derived from spectral reflectance measurements. Measurements were taken in mid-June, mid-July and late summer of 1990 and 1991. Multivariate analysis of variance was used to determine whether there were differences in the set of variables among treatments and years. Follow-up tests included univariate *t*-tests to determine which variables were contributing to any significant difference. Results showed a significant difference ($p < 0.0005$) among treatments in the composite of parameters during each of the months sampled. In most treatment types, there was a significant difference between years within each month. The univariate tests showed, however, that only some variables, primarily soil moisture, were contributing to this difference. We conclude that biomass and % plant cover show the best potential to serve as long-term indicators of grassland condition as they generally were sensitive to effects of different land management practices but not to yearly change in weather conditions. NDVI was insensitive to precipitation differences between years in July for most treatments, but was not in the native prairie. Choice of sampling time is important for these parameters to serve effectively as indicators.

Keywords: environmental monitoring, grassland management, NDVI, remote sensing, tall grass prairie

1. Introduction

Of the 1,000,000 km^2 of native tallgrass prairie ecosystem that once covered North America, less than 1% remains (Risser 1988). Much of the prairie has been converted to cultivated land, although some of this farmland has since been abandoned or enrolled in the U.S. Department of Agriculture's Conservation Reserve Program. Vast extents of grassland are used as range for livestock, while other areas are mowed and hayed. Prescribed burning of grasslands is a management tool commonly used on grazing lands. Understanding how these different management practices affect biophysical properties of grasslands serves to more effectively

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monitor and assess grassland status. Remotely monitoring the condition of grasslands using satellite data and determining land management practices on a parcel of grassland is enhanced if the biophysical differences between management practices are understood along with knowledge of how this affects spectral response of grasslands.

Monitoring is important if one wishes to assess ecological status and conditions, and to determine whether management actions and policies are having the desired effect (Griffith, 1998; Davis, 1993; Messer *et al*., 1991). Understanding seasonal and yearly variation of these parameters is essential to successfully monitoring grasslands and to using these parameters as indicators of ecological condition. Temporal variability is inherent to grassland systems due to changing weather and growing conditions. It is difficult to differentiate among the impacts of different land management practices when there are significant differences at a site under the same management practice among years. If variability between years in the same treatment is greater than the variability between treatments, determining whether changes are due to human impacts or natural variation will be difficult.

Perhaps the most impacting of the aforementioned practices are burning and grazing. Spring burning is a frequently used management tool on rangelands because it results in increased growth, nutrient content, and palatability of forage species (Collins and Gibson, 1992; Todd, 1996). Frequent spring burning also changes species composition and results in chronic soil nitrogen deficiency (Collins, 1992). Several studies have shown that following spring burning of grasslands, increased stem density, height, leaf area and productivity result (Knapp, 1984; Todd, 1996; Abrams *et al*., 1986). In one study, aboveground production was reduced 55% in unburned areas (Knapp, 1984) and in another study biomass and standing crop doubled in burned sites (Svejcar, 1990). Removal of standing dead material and detritus occurs with burning, having direct and indirect positive impacts on productivity (Briggs *et al*., 1994; Svejcar, 1990).

Grazing affects biomass removal, water infiltration via treading and soil compaction, and soil moisture evaporation through defoliation (Naeth and Chanasyk, 1995; Hassink, 1994). Noy-Meir (1993) documents both negative and positive effects of moderate grazing on plant growth. Barker *et al*. (1989) examined a gradient of range conditions in east Africa and observed that poor range conditions were characterized by decreases in vegetation cover, litter and grass cover, and increases in bare ground and pebbles. Naeth *et al*. (1991a) also found that grazing increased bare ground amounts in Alberta. Exclusion of grazing doubled community leaf area in some studies (Smith and Rushton, 1994; Belsky, 1992). Grazing affects soil chemical and physical parameters by decreasing organic matter, affecting structural stability, causing soil compaction and decreasing infiltration rate (Hassink, 1994; Lavado and Alconado, 1994).

Weather can play a large role in current season productivity and cause variability in grasslands (Allen *et al*., 1995). Benning and Seastedt (1997) found year-to-year patterns in plant productivity chaotic with high production followed by low production. Todd (1996) found that plant productivity and microbial biomass are greater in burned prairie under normal to wet conditions, but lower under dry conditions. The effect of burning on soil moisture can be different depending on rangeland condition and weather, with spring burning in dry years leading to lower soil moisture/temperature on degraded or brome fields than on big bluestem grassland (Willson and Stubbendieck, 1995). Even the previous year's above-ground plant material or previous year's rainfall can affect subsequent productivity. Abrams *et al*. (1986) found that dead biomass in a prairie was correlated with the prior year's precipitation. Lauenroth *et al*. (1992) reported forage production showed time lags of several years in responding to precipitation increases. The impacts of weather were considered greater than fire in year-to-year responses of tiller productions of prairie grasses (Glen-Lewin *et al*., 1990). Brady *et al*. (1989) believe long-term cyclical changes occur in addition to short-term influences of herbivory. Hence, for monitoring purposes, it is important to find biophysical parameters less sensitive to the noise of variable weather conditions and more sensitive to human actions that may degrade it.

In the past two decades, remote sensing technology has been used to more efficiently monitor and assess grassland status (Wessman, 1995; Minor *et al*., 1999). In particular, the normalized difference vegetation index (NDVI), which is roughly correlated to biomass and LAI, has been extensively examined. Using NDVI and other information derived from satellite imagery, areas of drought, overgrazing, or major land use changes in grasslands can be identified (Minor *et al*., 1999; Cridland *et al*., 1995; Roderich, 1995). Mapping of different land management types in grasslands using NDVI and other spectral information from satellites has also been evaluated (Asrar *et al*., 1986).

On a tract of reseeded grassland in northeastern Kansas, six different management practices were examined: untreated, hayed, mowed, grazed, burned, and native prairie. While many studies compare two or three management practices, this study concurrently examined six management practices, more closely reflecting actual land use conditions within the region. Objectives of this study were to:

(1) examine biophysical parameters of tallgrass prairie under six different management practices,
(2) investigate yearly changes in the biophysical properties of tallgrass prairie under different management conditions, and
(3) ultimately, enhance understanding of how these changes might affect the use of remotely sensed data to assess grasslands.

2. Methods

The study site lies within the Rockefeller Experimental Tract of the Kansas Ecological Reserves (KER) in northeastern Kansas (Figure 1). Mild to cold winters

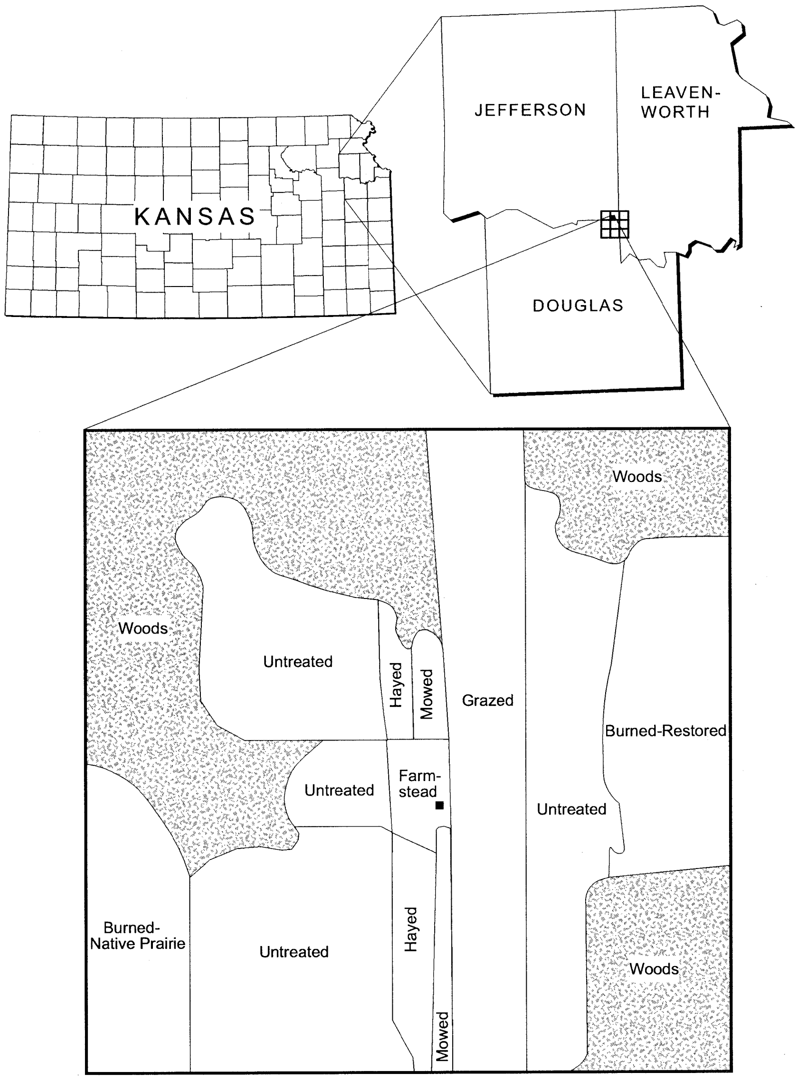

Figure 1. Location of the Rockefeller Experimental Tract study area in northeastern Kansas, U.S.A. The area of detail shows the type of land management practices on different sections of the Tract. The box showing the area of detail comprises about 65 ha, and the length of one side of the box is about 400 m. All areas except the native prairie have been restored from cultivated land.

and hot summers prevail with 70% of the annual 90 cm of precipitation falling during the growing season. Dominant native, warm-season grasses in the region are Big Bluestem (*Andropogon gerardii* Vitman), Little Bluestem (*A. scoparius* Michx.), Indiangrass (*Sorghastrum nutans* L.) and Switchgrass (*Panicum virgatum* L.). Dominant cool-season grasses are Smooth Brome (*Bromus inermis* Leyss.), Tall Fescue (*Festuca arundinacea* Schreb.), Kentucky Bluegrass (*Poa pratensis*

L.), and Orchardgrass (*Dactylis glomerata* L.). Soils consist of Pawnee and Grundy silty clay loams (finer montmorillonitic, mesic Aquic Argiudolls) (Kindscher and Tieszen, 1998). Fitch and Hall (1978) and Fitch and Kettle (1988) provide a detailed site description.

The 65 ha study area contains separate treatments under different management practices. Cultivation of much of the area occurred prior to 1956, but has since ceased with the prairie being restored. About 4 ha is native prairie that has never been cultivated. In 1957 much of the cultivated and grazed parts were sown to a native grass seed mixture. The tract was divided into six treatments: untreated-restored, mowed-restored, hayed-restored, grazed-restored, burned-restored and burned-native prairie (Figure 1). Hereafter, these will simply be referred to as untreated, mowed, hayed, grazed, burned-restored, and burned-native. Fires have historically been a natural and human disturbance in prairie ecosystems. Thus, to maintain the burned-native prairie and prevent woody plant intrusion, intentional spring burns every 1–3 yr are used as a management tool (Fitch and Kettle, 1988). In the mowed plot, the grass is left on the ground; in the hayed plot it is left to dry and removed as hay. While the untreated plot was reseeded, no burning, grazing or mowing occurs. During the study period, the burned-native site was last burned in April 1990; a wildfire occurred in the burned-restored treatment in February 1991. In 1990, the mowed and hayed sites were mowed in late July after the second sampling period. In 1991, the hayed treatment was mowed in late June (before the second sampling period) and the mowed treatment in mid-July (after the second sampling period). Moderate-intensity grazing (0.4 animals ha^{-1}) occurred on the grazed treatment from mid-June to mid-September. A common constraint associated with natural field experiments within ecological reserves is the lack of replicates for each treatment. In spite of this limitation, data from these experimental areas can be very useful (Guthery, 1987). As the treatments at the KER are not replicated, inferences derived from our results may pertain only to sites within each treatment of our study. We assume that no significant environmental degradation occurred in one year from the management practices.

2.1. Data collection

Within each treatment, measurements were taken from nine 0.5 m^2 quadrats located within a 30×30 m sample area. The 30 m areas were chosen based on sites that appeared representative of overall conditions (*e.g.*, mid-slope areas, avoidance of brome areas). The first 0.5 m^2 quadrat was randomly selected within the larger sampling area with the remaining quadrats arranged systematically relative to the first. At each site, measurements were collected on the following physical parameters at three times during the growing season in each of two years: leaf area index (LAI), leaf moisture (percentage of dry weight), soil moisture, plant biomass, cover, and the normalized difference vegetation index (NDVI) (Price *et al.*, 1993). The NDVI is derived from spectral reflectance data and is a ratio of infrared to red solar radiation reflectance (Rouse *et al.*, 1973; Jensen, 1996). The spectral data were collected within each quadrat using a Spectron Engineering SE590 field-portable spectroradiometer. In 1990, the sample periods began on June 21, July 18, and October 6, and in 1991 they began on June 11, July 15, and September 25 (the September/October sampling periods are hereafter referred to as 'late summer').

Sample size was constrained because spectral samples had to be collected within ± 2 hr of solar noon so no large differences in sun angle would affect the spectral measurements. Quadrat locations were moved each sample period, and shrub/small-tree areas were avoided. No other major disturbances were located near sample sites. Grass and forb cover was estimated using a point intercept technique described by Bonham (1989). Two 10×50 cm clip plots in each 0.5 m^2 quadrat were used to clip above-ground plant matter. Estimates of LAI and leaf moisture (g m^{-2} and %) were made using a Li-Cor LI3000A portable leaf area meter and the clipped plant materials. Percent soil moisture was derived from oven-dried soil samples (60 °C for 48 hr) extracted from the top 20 cm of the soil surface at each quadrat. Monthly climatological records (NOAA Climatological Records 1958–1991) from the Lawrence, KS weather station (3 km from study site) were used to calculate average precipitation for 1958–1989.

Multivariate analysis of variance (MANOVA) along with Hotelling's T^2 test statistic were used to determine whether there were significant differences on the composite of 6 biophysical variables among treatments and between years. These are referred to as the overall tests. Follow-up tests to the overall test included univariate *t*-tests to determine which individual variables were contributing to any significant differences (Stevens, 1996). Partial eta square (PES) was used to assess the relative differences of treatments and years and is equal to the between factors sums-of-squares divided by the within factors sums of squares (Sharma, 1996). High PES values suggest a substantial proportion of the variance in the dependent variables is accounted for by the differences between any of the groups (Sharma, 1996). PES ranges from 0 to 1 and guidelines for its interpretation are: 0.00 – 0.04, a weak effect size; 0.04–0.14, a moderate effect size; and above 0.14, a large effect size.

3. Results

Meteorological records for the two study years show that dryer conditions prevailed through much of 1991 (Figure 2). Figure 3 shows mean values by treatment for the data collected on biomass, LAI and NDVI. Figure 4 shows mean values by treatment for plant cover, percent leaf moisture and percent soil moisture. Sample size was $n = 9$ in each treatment on each of 3 dates over 2 yr. As numerous tests were performed, $\alpha \leq 0.01$ was used to determine statistical significance.

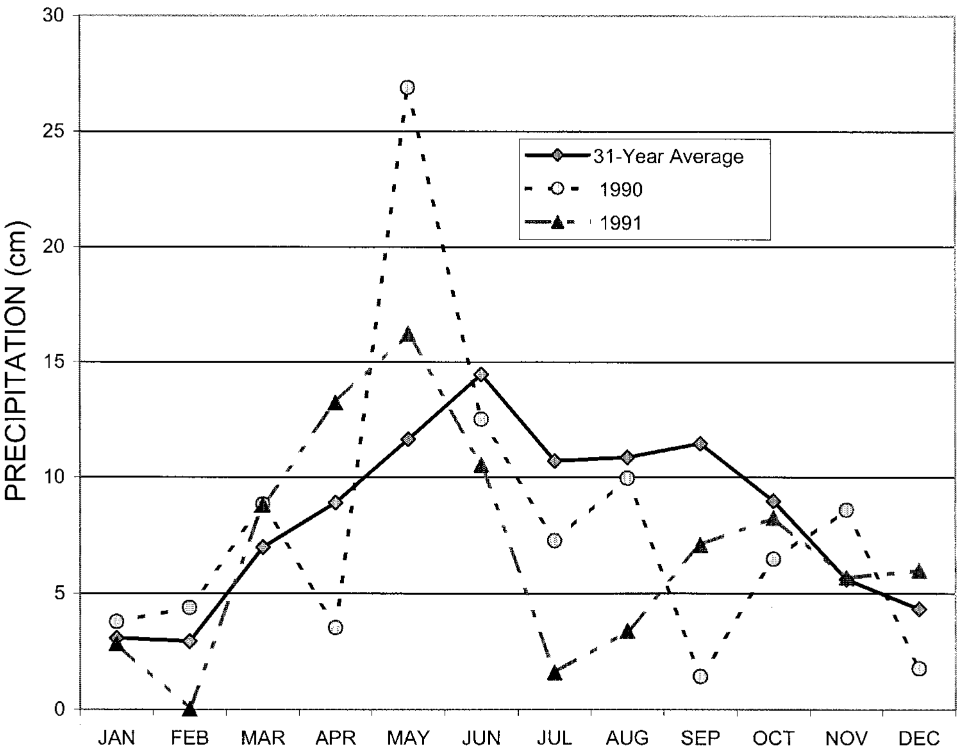

Figure 2. Precipitation at Lawrence, Kansas for 1990, 1991, and 31 yr average from 1958–1989. 1991 was the dryer year for the majority of the growing season.

3.1. Main effect of treatment within each mont

3.1.1. *1990 Sample Period*

Using the set of six variables, a significant difference among treatments was shown in the overall test, with strong effect sizes ($p < 0.0005$, PES values ≥ 0.238) (Table I). The univariate results showed that LAI contributed most to the difference among treatments in June, while it was biomass in July and cover in late summer.

3.1.2. *1991 Sample Period*

In the overall test, a significant difference among treatments existed based on the set of six variables, although effect sizes were smaller than in 1990 (Table I). Univariate results showed that cover contributed most to the overall difference in June, while biomass did in July and late summer.

3.2. Main effect of year

Most treatments using the composite of six variables were significantly different between years except for the burned-restored site in June (p = 0.014) and the grazed treatment (p = 0.185) and burned-native prairie (p = 0.030) in late summer

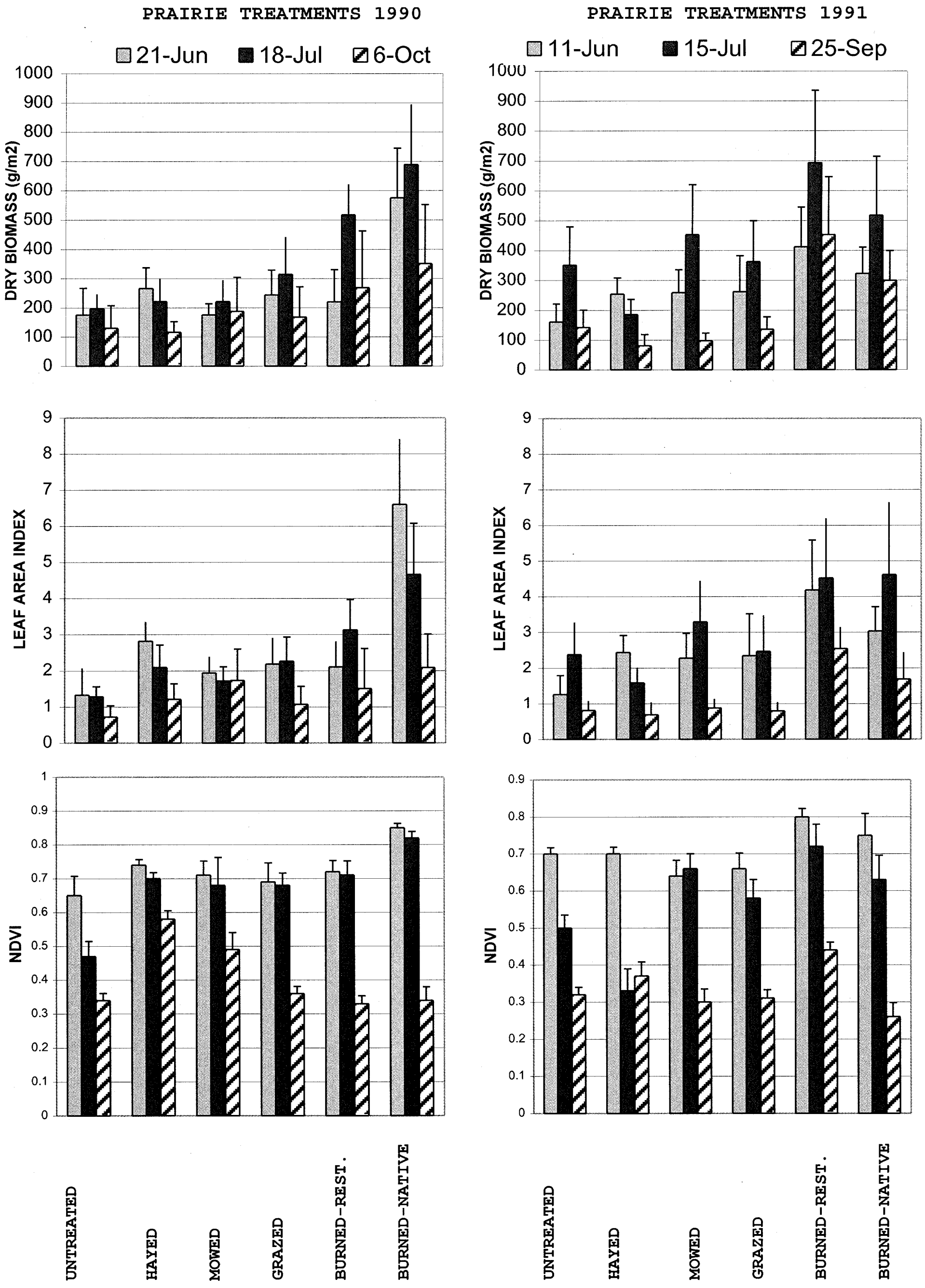

Figure 3. Biomass, Leaf Area Index, and NDVI by treatment for each sample date in 1990 and 1991. The error bars represent one standard deviation.

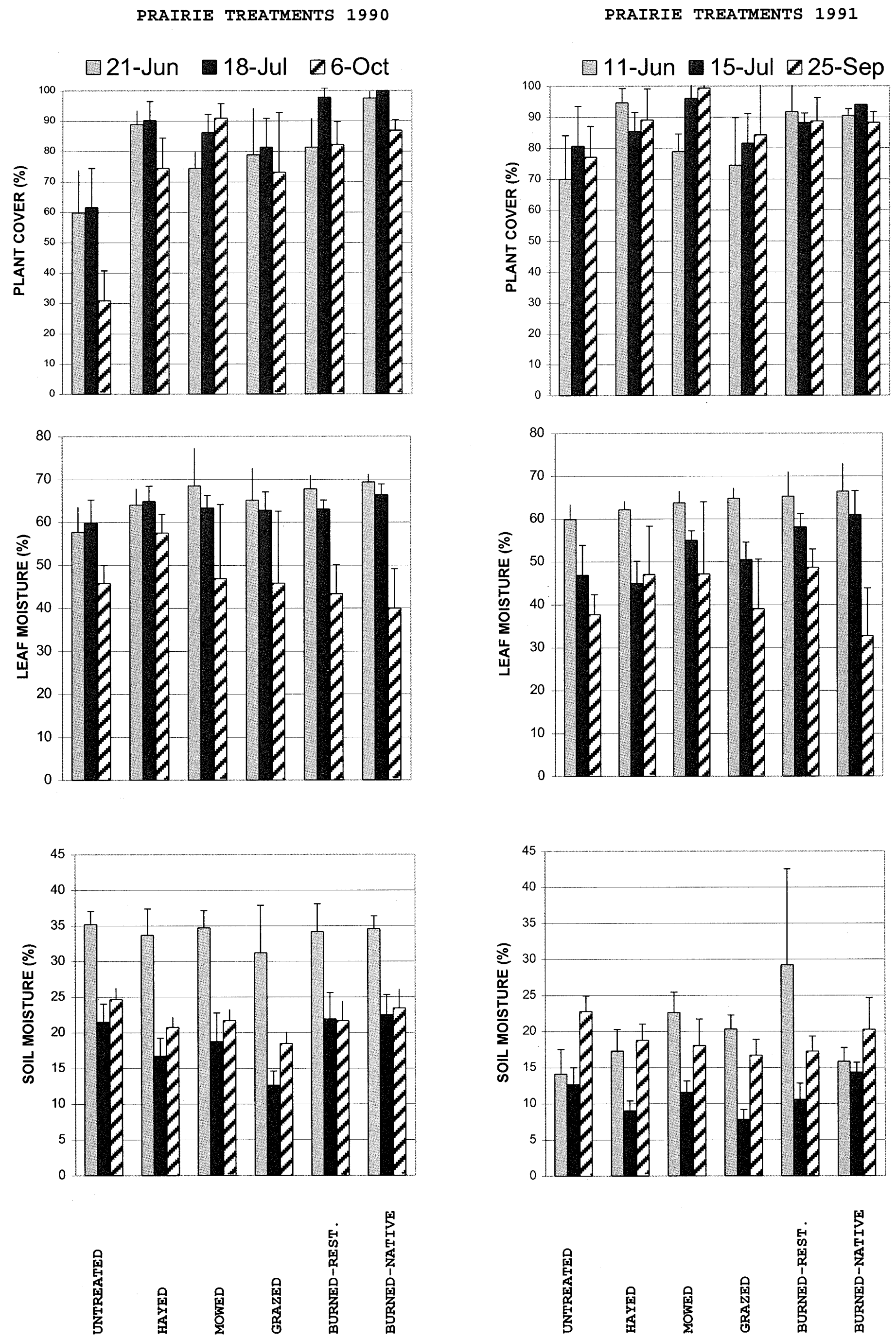

Figure 4. Plant cover, % Leaf Moisture, and % Soil Moisture by treatment for each sample date in 1990 and 1991. The error bars represent one standard deviation.

TABLE I

Main effect of treatment within each month in 1990 (wet year) and 1991 (dry year)

	Sampling time											
	June				July				Late Summer			
	p-value		PES		p-value		PES		p-value		PES	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Overall test	<0.0005	<0.0005	0.306	0.177	<0.0005	<0.0005	0.238	0.181	<0.0005	<0.0005	0.314	0.149
Univariate tests												
Biomass	<0.0005	0.029	0.275	0.081	<0.0005	<0.0005	0.399	0.272	0.002	<0.0005	0.119	0.211
Cover	<0.0005	<0.0005	0.300	0.288	<0.0005	0.001	0.344	0.134	<0.0005	<0.0005	0.551	0.168
Leaf Area Index	<0.0005	<0.0005	0.502	0.153	<0.0005	<0.0005	0.290	0.225	0.096	0.013	0.061	0.094
Leaf moisture %	0.302	0.876	0.040	0.012	0.903	0.027	0.011	0.082	0.045	0.023	0.074	0.085
NDVI	0.123	0.296	0.057	0.041	<0.0005	<0.0005	0.141	0.180	<0.001	0.316	0.127	0.039
Soil moisture	0.890	<0.0005	0.011	0.219	0.045	0.189	0.074	0.049	0.597	0.240	0.025	0.045

(Tables III–V). The primary variable, however, causing this difference was soil moisture.

3.2.1. *June*

All treatments except for the burned-restored site were significantly different between years on the composite of variables (Table II). The greatest magnitude of difference in the overall test was for the burned-native treatment. Soil moisture contributed most to the overall difference between years, except in the burned-restored treatment, in which biomass and LAI contributed most.

3.2.2. *July*

Each treatment was significantly different on the composite of variables between years (Table III). The hayed treatment had the largest magnitude of difference while the grazed treatment had the smallest. In all treatments soil moisture was one of the variables most different between years.

3.2.3. *Late Summer*

All treatments except for the burned-native prairie and grazed plot were significantly different between years on the composite of variables (Table IV). NDVI contributed most to the overall difference in all treatments except for the untreated site, for which it was cover.

4. Discusion

Differences in the composite of biophysical properties of the grassland treatments were found. These findings are consistent with other studies describing environmental impacts from various grassland practices (Asrar *et al*., 1988; Dunham and Price, 1996; Naeth *et al*., 1991b). Figures 3 and 4 show that the burned-native and burned-restored treatments seemed to change the most based on the set of selected biophysical variables over the season, particularly for LAI and biomass. This likely reflects the pulse of vegetation production affecting biomass and LAI that occurs after spring burning. Mechanisms for increased productivity include increased solar radiation reaching young shoots, increased availability of inorganic nutrients, and an increase in growing season length due to earlier warming of the soil (Hulbert, 1988; Asrar *et al*., 1988). Knapp *et al*. (1998a) summarize much of the research on similar grassland types performed at the Konza Prairie Long-Term Ecological Research Area. Perhaps the most important function of a spring fire is removal of old detrital biomass, which reduces light available to emerging shoots, results in leaves developing shade characteristics and keeps soil temperatures cooler in spring (Knapp *et al*. 1998b; Briggs *et al*., 1994; Seastedt and Ramundo, 1990). The ash-covered soil surface of burned prairies absorbs most of the solar energy while dead matter and standing litter reflect it. Detritus functions as

TABLE II

Main effect of year within June

	Treatment											
	Burned-native		Burned-restored		Grazed		Mowed		Hayed		Untreated	
	p-value	PES	p-value	PES	p-value	PES	p-value	PES	p-value	PES	p-value	PES
Overall test	<0.0005	0.543	0.014	0.180	0.004	0.179	<0.0005	0.390	<0.0005	0.372	<0.0005	0.454
Univariate tests												
Biomass	<0.0005	0.139	0.003	0.085	0.774	0.001	0.188	0.017	0.853	0.000	0.814	0.001
Cover	0.276	0.018	0.111	0.025	0.495	0.005	0.495	0.005	0.376	0.008	0.119	0.024
Leaf area index	<0.0005	0.214	0.003	0.084	0.813	0.001	0.627	0.002	0.565	0.003	0.911	0.000
Leaf moisture %	0.285	0.011	0.366	0.008	0.902	0.000	0.086	0.029	0.501	0.004	0.413	0.007
NDVI	0.001	0.100	0.006	0.074	0.241	0.014	0.018	0.054	0.179	0.018	0.064	0.034
Soil moisture	<0.0005	0.337	0.045	0.039	<0.0005	0.147	<0.0005	0.175	<0.0005	0.280	<0.0005	0.393

TABLE III
Main effect of year within July

	Treatment											
	Burned-native		Burned-restored		Grazed		Mowed		Hayed		Untreated	
	p-value	PES	p-value	PES	p-value	PES	p-value	PES	p-value	PES	p-value	PES
Overall test	<0.0005	0.345	<0.0005	0.439	<0.0005	0.288	<0.0005	0.354	<0.0005	0.580	<0.0005	0.481
Univariate tests												
Biomass	0.092	0.028	0.082	0.030	0.632	0.002	0.023	0.050	0.723	0.001	0.127	0.023
Cover	0.296	0.011	0.092	0.027	0.969	0.000	0.090	0.028	0.395	0.007	0.001	0.100
Leaf area index	0.945	0.000	0.055	0.036	0.780	0.001	0.030	0.046	0.475	0.005	0.128	0.023
Leaf moisture %	0.041	0.041	0.059	0.035	<0.0005	0.183	0.002	0.093	<0.0005	0.369	<0.0005	0.200
NDVI	0.001	0.110	0.790	0.001	0.045	0.039	0.713	0.001	<0.0005	0.340	0.574	0.003
Soil moisture	<0.0005	0.178	<0.0005	0.293	<0.0005	0.069	<0.0005	0.143	<0.0005	0.161	<0.0005	0.200

TABLE IV
Main effect of year within late summer

	Treatment											
	Burned-native		Burned-restored		Grazed		Mowed		Hayed		Untreated	
	p-value	PES	p-value	PES	p-value	PES	p-value	PES	p-value	PES	p-value	PES
Overall test	0.030	0.133	<0.0005	0.220	0.185	0.086	<0.0005	0.426	<0.0005	0.414	<0.0005	0.310
Univariate tests												
Biomass	0.487	0.005	0.013	0.060	0.659	0.002	0.219	0.015	0.629	0.002	0.864	0.000
Cover	0.862	<0.0005	0.401	0.007	0.149	0.021	0.272	0.012	0.058	0.035	<0.0005	0.266
Leaf area index	0.282	0.011	0.006	0.072	0.475	0.005	0.023	0.050	0.159	0.020	0.821	0.001
Leaf moisture %	0.202	0.016	0.342	0.009	0.234	0.014	0.961	0.000	0.065	0.033	0.151	0.020
NDVI	0.019	0.054	0.001	0.106	0.125	0.023	<0.0005	0.266	<0.0005	0.311	0.596	0.003
Soil moisture	0.036	0.043	0.004	0.080	0.237	0.013	0.017	0.055	0.197	0.016	0.217	0.015

a filter of solar energy, water and inorganic nitrogen, and generally has a negative effect on prairie productivity (Seastedt, 1985). Low soil temperatures may also contribute to the lower growth of prairie grasses on unburned sites. The removal of litter by fire can cause soils to warm to 25 °C a full month earlier than unburned sites (DeLucia *et al*., 1992). Growth of *A. gerardii* occurs in early April, but on unburned grasslands soil temperature at a depth of 10 cm does not reach optimal levels for growth until mid-June in Kansas (DeLucia *et al*., 1992). Bentivenga and Hetrick's (1991) alternative hypothesis is that mycorrhizal activity is stimulated by burning, possibly due to increased soil temperatures, thereby contributing to increased growth of warm-season grasses. The benefits to prairie grasses following burning occur rapidly and diminish by mid-season (Bentivenga and Hetrick, 1991, 1992). Our results support this; the PES effect size for burned-native prairie in June decreases later in the season, and the PES for biomass decreases (Tables III–V). In 1990, when the burned-native prairie was burned, it produced more than twice as much LAI in June as it did in June 1991, when it was not burned. Knapp (1984) also found a leaf area index of 4.2 and 2.8 for burned and unburned treatments, respectively. The effect of burning is observed with the burned-native prairie having triple the LAI of the burned-restored plot in June 1990 (Figure 3). When the burned-restored plot experienced a wildfire in 1991, its LAI was 30% higher in June than in the burned-native prairie, which did not experience fire that year. Notice, however, that the effect of fire is less dramatic by the July date. In July 1991, the burned-native site had virtually the same LAI as the burned-restored site even though the burned-restored site experienced fire that year.

Some investigators found soil moisture lower on burned compared to unburned sites due to higher evapotranspirational demand from both the earlier growth and bare soils, and increased leaf area and stomatal conductance in burned treatments (Knapp *et al*. 1998b; Ojima *et al*., 1990; Svejcar, 1990; Turner *et al*., 1997). Briggs and Knapp (1995) found soil moisture down to 100 cm lower in annually burned sites than in areas with low fire frequency. Living plant material and its litter increase infiltration by decreasing raindrop impact, improving soil structure through formation of larger soil aggregates, and creating a rougher microtopography that increases infiltration potential (Naeth *et al*., 1990). Others have found mean precipitation interception rates of 38 and 19% for unburned and burned prairie (Gilliam *et al*., 1987). Seastedt (1985) found that throughfall on unburned sites was 58% of precipitation while throughfall on annually burned sites was 76%. They maintained that standing dead matter and litter of tallgrass prairie reduce the amount of water reaching the soil surface (Seastedt, 1985; Gilliam *et al*., 1987). Burning did not appear to reduce soil moisture in our 2 yr period of study (Figure 4). In 1990, the burned-native prairie and burned-restored treatments had very similar soil moisture levels. In 1991, the burned-restored treatment in fact had higher soil moisture than the burned-native prairie in June. While these numbers were not statistically tested against each other, these differences may be partly explained by the fact that neither treatment is burned every year, and because of the short period of time in which soil moisture was monitored, it was not possible to establish a trend. Moreover, the burned-restored site is unlike the burned-native site in terms of plant species composition (Kindscher and Wells, 1995). The burned-native site is dominated by warm-season species that start active growth later in the growing season. This may account for some observed differences, such as the higher June 1991 moisture levels for the burned-restored treatment. The burned-restored plot had lower moisture levels than the burned-native site in July and late summer of 1991. Knapp *et al*. (1998b) and Knapp (1984) also found more water stress in burned sites later in the season, likely due to the removal of the protective 'mulch' of litter.

Grazing intensity can also reduce infiltration, soil moisture and fertility (Naeth and Chanasyk, 1995; Naeth *et al*., 1991b; Dormaar and Willms, 1998). Brady *et al*. (1989) found that soil water at depths to 50 cm decreased with increased grazing intensity. Greenwood and McNamara (1992) reported adverse effects of compaction on soil porosity, mechanical impedance and reduction of transmission of water and air and restriction of root growth associated with increased grazing intensity. Animal treading has been reported as a factor in physical deterioration of agricultural soils as it seals surfaces and decreases root channel size (Naeth and Chanasyk, 1995; Greenwood and McNamara, 1992). Our data generally corroborate findings of lower soil moisture under grazing. The grazed site in most cases had the lowest soil moisture (Figure 4). Naeth *et al*. (1991b) found the least difference during the summer months when evapotranspiration depleted water resources for all treatments. Our data also showed that soil moisture differences among treatments in 1991 were generally less later in the growing season and greatest earlier in the growing season (Figure 4).

4.1. Implications for monitoring and remote sensing

In each treatment, substantial seasonal differences occur within the composite of biophysical variables among months (Figure 3). As biomass, LAI, and leaf moisture % changed throughout the season, NDVI not surprisingly changed as well. Dyer *et al*. (1991) also found NDVI of tallgrass prairie changing significantly throughout the growing season. Our results are consistent with other studies that found NDVI or spectral measurements to be a poor indicator of canopy biomass, but useful for separating types of land management (Wessman *et al*., 1991; Dyer *et al*., 1991; Dunham and Price, 1996). In June of both years and late summer of 1991, however, NDVI was not significantly different among treatments. This example shows the importance of sampling dates, or index periods, to monitoring. The best time to examine NDVI for monitoring tallgrass prairie at these sites and discriminating management practices appears to be July, coincident with peak plant growth. At the geographic scale of our study, NDVI was insensitive to precipitation changes over the two years in July for most treatments except burned-native and hayed. The hayed plot was most likely affected by the mowing shortly before the

1991 sampling. Weiser *et al*. (1986) also found that the relationship of NDVI to biophysical variables was site-dependant and year-specific.

One can begin to determine which variables best distinguish treatments and then focus future research on how spectral response is affected. In the wet year (1990), the biophysical parameters most strongly differentiating treatments change between months. In June, LAI was the most strongly contributing variable to the overall difference while in late summer, cover was most important. Greatest differences in NDVI among treatments was in July. This is logical as biomass is at its peak before the effects of water stress and dessication occur. Price *et al*. (1999) also found July the best time to spectrally distinguish three management types from Thematic Mapper satellite imagery. In the dry year (1991), while differences among treatments were still significant, effect sizes in the overall tests were smaller. Several other studies have found biophysical differences less pronounced in drought years (Naeth *et al*., 1991b; Knapp, 1984; Todd, 1996). In the dry year, cover was the variable most highly contributing to differences in June, while it was biomass in July and late summer.

It is interesting to note whether NDVI values and their changes in significance mirror changes observed within the biophysical parameters. One example is NDVI in June and July. NDVI does not distinguish among treatments in June of either year, whereas cover, LAI, and biomass (in 1990) do (Table I). In July, however, all four of these variables contributed to a difference among treatments. Also in June, for the more ‘natural’ burned-native and burned-restored plots, biomass, LAI, and NDVI are significantly different between years, but are not in the other treatments (Table II). In July, however, NDVI is not significantly different between years for most treatments except the burned-native site and hayed site (which was affected by the pre-sampling cutting) (Table III). In June, biomass and LAI were significantly different between years in the burned-native and burned-restored plots, but were not significantly different between years in July. Although a relationship does exist between NDVI and biomass (Jensen, 1996; Price *et al*., 1992, 1993), they are not perfectly correlated under all management practices (Dyer *et al*., 1991; Wessman *et al*., 1997). NDVI and spectral reflectance respond to a number of factors besides canopy structural components including LAI, nitrogen status, chlorophyll concentration, and fraction of photosynthetically active radiation (Wessman, 1997). Temporal patterns found in this study show NDVI more similar to the pattern of LAI than biomass in 1990, and more similar to leaf moisture % in both years (Figures 3 and 4).

5. Summary and Conclusions

Results of this study can be summarized to show the ability of the six selected biophysical parameters to reveal differences among treatments, yet not be significantly different between a wet and dry year (Table V). This capability can indicate

TABLE V

Ability of biophysical parameters to differentiate among treatments and yet not be significantly different between a wet and dry year (using $\alpha \leq 0.01$)

Parameters	Are parameters sensitive to different treatments?	Are parameters insensitive to distortion between a wet and dry year?
Biomass	Yes, July/late summer both years	Yes, July/late summer
% Cover	Yes, both years	Yes (except for untreated, June/July)
Leaf Area Index	Yes, June/July both years	Yes (in July)
NDVI	Yes, July both years	grazed/untreated – all months burned-restored, mowed – July burned-native – late summer
Leaf Moisture (%)	No	Yes, in June/late summer
Soil Moisture (%)	No (except for June 1991)	No

a measured field parameter's ability to serve as an ecological indicator for use in long-term monitoring programs. Biomass separated treatments and was not significantly different between years except for the burned-restored and burned-native treatments in June. Cover discriminated among treatments and was not significantly different between years except for the untreated site in July/late summer. Leaf moisture (%) was less helpful in discriminating between management practices. In the dry year, soil moisture was significantly different among treatments only in June. Using soil moisture as an ecological indicator may be difficult without controlling for the effects of precipitation. Careful planning is necessary to determine appropriate sampling dates for some parameters, because conditions at the end of a growing season tend to even out differences among treatments in some parameters due to senescence and dessication. Separating land management practices based on biophysical parameters appears to be more difficult under dryer conditions. In fact, differences between management practices in this study were less distinct in late summer, when growing season conditions tend to be dryest. Since monitoring remaining native prairie regions is likely of considerable interest, more research is needed on whether other native prairies differ in NDVI between years having different precipitation amounts. Future research on using NDVI to monitor native or managed grasslands may improve with the launch of several new sensors (Sheffner and Stoney, 1999). These may improve the ability to stratify grasslands into management practices before undertaking monitoring and thus improve our ability to monitor condition and model biophysical characteristics. In conclusion:

- It is crucial when monitoring and remote sensing of grasslands to know the burning and grazing/defoliation history of a site, because these activities can affect whether certain biophysical parameters are significantly different between years, particularly for biomass.
- The treatments differed on the set of six biophysical parameters. In July, biomass contributed the most to the difference among treatments, while in late summer biomass and cover contributed most. Hence, it may be useful to focus on how these affect spectral response in grasslands for purposes of discriminating different land management practices using remote sensing techniques.
- In all months, the effect of year was significant, although it was primarily due to soil moisture in June and July, and NDVI in late summer. Several parameters did not differ from year to year in at least one of the sampling dates, thus showing potential as indicators of ecological condition.
- NDVI differed most among the management practices in July.

For monitoring purposes one would ideally identify variables that are insensitive to yearly variations in weather conditions but sensitive to degradation resulting from human actions. With the exception of soil moisture, several of the measured parameters were not significantly different between years on at least one sampling date, with biomass and plant cover being most robust. This occurred even with the different precipitation conditions in 1990 and 1991; hence, these parameters show potential as indicators for monitoring ecological condition of these sites. NDVI was significantly different between years for the burned-native prairie in June/July. In July, NDVI was not significantly different, however, between years for the grazed, mowed, hayed and untreated treatments. This raises the question of the utility of NDVI in long-term monitoring of native grasslands without controlling for the effects of precipitation. As soil moisture was often significantly different between years, it would also be useful to understand how it confounds spectral response when using remote sensing to monitor condition and discriminate land management types.

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