Investigating Grazing Intensity and Range Condition of Grasslands in Northeastern Kansas Using Landsat Thematic Mapper Data

Dana L. Peterson
Kansas Applied Remote Sensing (KARS) Program
2335 Irving Hill Road, University of Kansas
Lawrence, Kansas 66045, U.S.A.

Kevin P. Price
Kansas Applied Remote Sensing (KARS) Program
2335 Irving Hill Road, University of Kansas
Lawrence, Kansas 66045, U.S.A.
and
Geography Department
University of Kansas, Lindley Hall
Lawrence, Kansas 66045, U.S.A.

Edward A. Martinko
Kansas Biological Survey (KBS)
Kansas Applied Remote Sensing (KARS) Program
2335 Irving Hill Road, University of Kansas
Lawrence, Kansas 66045, U.S.A.
and
Department of Ecology and Evolutionary Biology
University of Kansas, Haworth Hall
Lawrence, Kansas 66045, U.S.A.

Abstract

Grazing changes plant species composition of grassland ecosystems by selective removal and trampling. Grazing also alters soil physical and biogeochemical properties and can dramatically change hydrologic processes that can impact water budgets and quality. For these reasons, practical means are needed to assess grazing management practices and its impacts upon the land. This study examines whether a grazing intensity and range condition gradient can be detected in spectral reflectance characteristics of grasslands in northeastern Kansas. Multitemporal Landsat Thematic Mapper (TM) data, the normalized difference vegetation index (NDVI), and field data collected concurrent with the TM overpasses, were used in the analysis. Correlation analysis was used to examine relationships between spectral data and biophysical data. Next, the study sites within each grassland type were classified into three spectrally similar clusters. Grazing intensity, range condition, and biophysical characteristics were summarized for each spectral cluster and compared.

The results suggest that NDVI may be used as a surrogate for living biomass for both grassland types and may be useful for predicting grazing intensity in native warm season grasslands. And while there appeared to be relationships between total living and non-living cover, and TM NIR and MIR bands, there were no direct relationships between spectral characteristics and grazing intensity or range condition.

Introduction

Grazing of grasslands can change species composition of these ecosystems directly, by causing physical alterations to soil, and indirectly by causing shifts in biogeochemical cycles (Duffey 1974; Jaramillo and Delting 1988; Collins and Steinauer 1998; Ritchie *et al* 1998). Biogeochemical changes include the removal of nutrients from the ecosystem when vegetation is consumed and nutrients are redistributed as fecal material (Jarvis *et al*. 1989). Plant species composition is also affected by physical damage caused by livestock trampling. In addition, grazing affects the compositional structure of species in grasslands through selective removal, intensity of grazing, and frequency of grazing (Duffey 1974; Gillen *et al*. 1991; Anderson and Briske 1995; Collins and Steinauer 1998; Gillen *et al*. 1998).

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The impact of grazing on plant communities depends upon how resistant species within the community are to grazing. Factors affecting a plant's response to grazing include properties such as morphological characteristics, growth form, reproductive strategies, and palatability (Owensby 1993). Furthermore, if grazing pressure is prolonged, it can cause native grasslands to be invaded by weeds or exotics (Risser *et al*. 1981; Sims 1988). Grazing can also alter the hydrologic processes in a grassland ecosystem by removing vegetation and increasing soil compaction thereby reducing water infiltration rates and increasing surface overland flow (Branson and Owen 1970).

The primary goal of a grazing system should be the long-term maintenance of sustainable levels of vegetation and animal production (Owensby 1993). Maintaining the health or condition of vegetation minimizes changes in plant communities that may result in ecosystem degradation. A grazing system, defined as the control strategy of animals in time and space, is governed by several factors including stocking rate, timing and frequency of use, type of grazer, and grazing distribution (Sims 1970). Range managers often regulate stocking rates to maximize short-term production instead of long-term gains or sustainable management (Joern and Keeler 1995). Vegetation type, wildlife needs, and climate are factors that should be considered when developing a grazing system (Holecheck *et al*. 1989).

Most of the Great Plains and eastern forest tallgrass prairie is privately owned and subjected to a variety of land management practices (Owensby 1993). The development of an assessment and monitoring strategy for native prairies used as rangeland, would help land owners and government agencies make decisions for sustainable range management. Additionally, the development of sustainable land management strategies for both native warm season and non-native cool season grasslands would also prevent management problems such as overgrazing and soil erosion.

Traditional vegetation mapping and assessment techniques have been based primarily on field observation and data collection. These traditional mapping and assessment techniques are time-consuming, subjective, and economically inefficient for relatively large areas (Briggs and Nellis 1989; Friedl *et al*. 1994; Egbert *et al*. 1995). For these reasons, many rangelands in the United States which are monitored using the traditional approaches, are seldom directly monitored (USDA 1998b).

The use of satellite remotely sensed imagery has become a cost-effective method to identify and map various types and characteristics of grassland and agricultural communities. Previous studies have successfully used spectroradiometer and satellite data to estimate and assess biophysical characteristics of grassland ecosystems including biomass and leaf area index (Tucker *et al*. 1985; Asrar *et al*. 1986; Briggs and Nellis 1989; Friedl *et al*. 1994; Chen and Brutsaert 1998). In addition, remotely sensed data have been used to discriminate among land cover and grassland types (Asrar *et al*. 1989; Dyer *et al*. 1991; Price *et al*. 1992; Price *et al*. 1993; Dunham and Price 1996). Textural algorithms have also been used on System Pour l'Observation de la Terre (SPOT) High Resolution Visible (HRV) and Landsat Thematic Mapper (TM) data to discriminate among grassland communities (Briggs and Nellis 1991; Lauver and Whistler 1993).

Several studies have shown the usefulness of multitemporal data (Buttner and Csillag 1989; Dyer *et al*. 1991; Egbert *et al*. 1995; Price *et al*. 1997). Egbert *et al*. (1995) and Price *et al*. (1997) showed that land cover mapping projects using multitemporal imagery better discriminated and classified cropland and grassland in Kansas than one using single date imagery (Whistler *et al*. 1995).

While previous studies have used spectral data from satellites and spectroradiometers to estimate biophysical characteristics of grasslands and to discriminate among major land cover types, little research has focused on using satellite data to assess grazing intensity or range condition in grassland ecosystems of the Great Plains. The objective of this study therefore is to examine the influences of grazing intensity and range condition of native warm season and non-native cool season grasslands of the Great Plains tallgrass ecosystem on spectral reflectance characteristics over a growing season.

Study Area

Douglas County, in northeastern Kansas covers an area of 122,768 ha (474 square miles) (Figure 1). Douglas County has a mid-continental temperate climate with an average annual temperature of 13 (C. Seasonal temperatures are highly variable with mean low monthly temperatures of -2(C in January and mean high of 26(C in July. Precipitation often exceeds evapotranspiration rates in the region with average annual precipitation levels of 86 cm. The majority of the precipitation falls during the growing season (April to September) and rain patterns during the growing season are generally short intense rains frequently causing surface runoff (USDA 1977). Reported temperatures were average for 1997 and reported average annual precipitation levels were slightly below average (79.7 cm) (NCDC 1999).

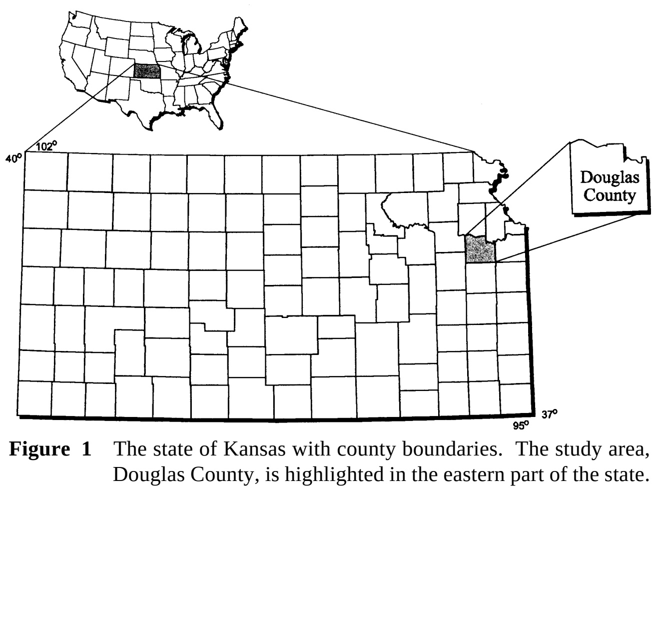

Figure 1 The state of Kansas with county boundaries. The study area, Douglas County, is highlighted in the eastern part of the state.

Approximately 41% of the county area is grassland (non-native cool season and native warm season) (KARS 1996). A 1992 Census Report stated that an estimated 32,779 ha in Douglas County are used as rangeland (USDA 1998a). Cattle and, to a lesser extent, horses are the dominant domestic ungulates on the grasslands in Douglas County, Kansas. Generally, the domestic ungulates are placed on the grasslands in May and are removed in the late summer or early fall months, depending largely on vegetation condition and livestock prices. Cropland is another prominent land cover type in Douglas County with 58,243 ha harvested in 1997 (USDA 1998a).

Non-native cool season and native warm season grasslands are the two grassland cover types present in Douglas County, Kansas. Non-native grasslands consist of introduced cool season species such as smooth brome (*Bromus inermis* Leyss.) and tall fescue (*Festuca arundinacea* Schreb.). These grassland cover types are planted and are typically used for hay and pasture purposes. Native grasslands in this region are tallgrass prairie and consist of a mixture of warm and cool season grass and forb species. Tallgrass prairies are heavily dominated by warm season grass species such as big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* Michx. Nash), yellow indiangrass (*Sorghastrum nutans* L. Nash), and switchgrass (*Panicum virgatum* L.). While neither grassland cover type consists exclusively of cool or warm season species, for convenience, the grassland types will be referred to based on their dominant vegetation.

Methods

Data Acquisition

Field Data. Field data were collected to detect biophysical differences between native warm season and non-native cool season grasslands that may affect spectral characteristics as measured by the Landsat TM sensor. A total of 25 randomly selected study sites were used; 11 native warm season and 14 non-native cool season. Three of the 25 study sites were ungrazed; one native warm season and two non-native cool season. To ensure that the sampling sites would be detected in the TM imagery, land areas less than 6.1 ha were not selected. Field sites were categorized as either non-native cool season or native warm season grasslands based on the dominant vegetation present at the study sites.

Field data were collected in early July, August, and September of 1997. Data collection time was scheduled to coincide as closely as possible with the Landsat 5 overpasses (approximately five days before and after the overpass date). All field measurements were made during the July sampling period to capture vegetation conditions around the peak growth period. Biomass measurements were not collected in August or September. A hand-held Garmin Plus II Global Positioning System (GPS) unit was used to record the map coordinate location of each study site.

Five 0.25 m^2 quadrats were positioned within each study site to collect data within a 90×90 m study plot. The first quadrat was positioned in the center of the study plot and the other four quadrats were positioned systematically in the study plot corners to represent a total of five different pixels as seen from Landsat TM imagery.

Ocular cover estimates were made to obtain information regarding species composition and total cover of vegetation versus bare ground, litter, or standing dead vegetation (Daubenmire 1959). Plant species richness was calculated by counting the number of species within the 90 x 90 m study plot that were observed during a ten-minute period. Species richness within the two grassland types was used as an indicator of plant species compositional homogeneity, which may influence spectral characteristics of the grasslands. The average vegetation canopy height was also measured to the nearest centimeter at each quadrat to determine whether differences in canopy architecture had an influence on spectral response patterns.

Living biomass was measured at 18 of the 25 study sites during the early July 1997 field visit. Live biomass was clipped and removed from the five 0.25 m^2 quadrats. The biomass was then dried at 64ºC for at least 40 hours before being weighed to the nearest gram.

Satellite Data & Preprocessing. A previous study by Price *et al*. (1993) suggested that a combination of spring, summer, and fall images were best for differentiating among land cover and land use practices. For this reason, images were acquired for the May 15, July 2, and September 4 to represent the 1997 growing season.

The three TM images were subset to an area slightly larger than Douglas County. The spectral values (excluding the thermal band) from the three subset scenes were then converted from brightness to radiance values using guidelines outlined by Chavez (1989). The thermal infrared band was excluded from the analysis due to its coarser spatial resolution. Chavez's (1988) Improved Dark Object Subtraction Technique was used to normalize radiance values by minimizing the effect of atmospheric backscatter on the data. Radiance values for the three scenes were then converted to reflectance to normalize for changes in solar/earth distance and solar zenith angle at the time of each satellite overpass (Markham and Barker 1986).

The July image was geometrically transformed to a Universal Transverse Mercator (UTM) projection. The other two images were geographically registered to the rectified image. The transformation model was used to estimate the geographic location of each pixel for the three scenes estimated locations to within 0.35 pixels (10.5 m) of the GCP's. After georegistering all images to the same coordinate system, an 18-band data file was created using the six optical bands for the three image dates. Reflectance values for each study site were extracted for a nine pixel area (3 x 3 pixels) located within the middle of each site and these values were used for subsequent analyses. The normalized difference vegetation index (NDVI) was calculated for the nine pixel area using the standard equation: [(TM4-TM3)/(TM4+TM3)] (Rouse *et al*. 1973).

Derived Variables

The presence X frequency (P X F) index (Curtis 1959; Anderson 1964) was used to identify the dominant species found at the study sites. This index is derived by multiplying the percent presence (% of time a species is found at the study site) by the percent frequency (% of time a species is located within the quadrats used at each site). The P X F index is used as a means of ranking species by dominance across all study sites. Species with the highest P X F index were selected for subsequent analysis. The average number of species identified at the two grassland types (20 species) was used to determine the number of species to include in the subsequent statistical analysis (Curtis 1959).

While the P X F index identifies the dominant vegetation at the study sites, a grazing intensity index was used to characterize and quantify the 1997 grazing pressure. Grazing intensity was calculated as the number of grazing or animal units (AU's) per unit area per unit time. Grazing units as defined by Holecheck *et al*. (1989) were used to account for consumption differences among grazers. For example, a horse consumes more forage than a cow or a yearling and equals 1.80 grazing units while a cow and a yearling are equivalent to 1.00 and 0.75 grazing units, respectively (Holecheck *et al*. 1989).

While grazing intensity can be used to quantify the effects of grazing over the current year, long-term effects of grazing may not be represented by the index. Range condition measures the general health of the range or pasture and reflects long-term effects of grazing (Owensby 1993). The species response to grazing approach, which factors in grazing selectivity and species response by changes in plant vigor or health, was used to quantify range condition of the native warm season study sites (Dyksterhuis 1949). Since non-native cool season grasslands are planted with selected palatable species that are maintained as a part of the management practice, vegetation in the non-native grasslands was not characterized by its response to grazing.

To understand range condition of the native grassland study sites, dominant species, identified by the P X F index, were characterized by their response to grazing as an increasing, decreasing, or invading species (Weaver and Hansen 1941; Dyksterhuis 1949; Weaver 1954; Curtis 1959). Decreasers consist of preferred forage species by livestock, while increasers often range from being fair to good forage species. Decreaser species have a competitive advantage over increaser species in undisturbed situations (Owensby 1993). The dominant species list was also used to calculate the percentage of native and non-native species and the percentage of annuals and perennials present at each native warm season study site and was used to help characterize range condition.

Statistical Analysis

Bivariate correlation analysis was used to examine relationships between grazing intensity, living biomass, and NDVI values to determine whether living biomass was an effective indicator of grazing intensity. In addition, the correlation coefficients would indicate whether NDVI could be used as a surrogate for living biomass to estimate grazing intensity.

For data reduction and decorrelation purposes, cover, biomass, and plant height data for the native and non-native grasslands were entered into Principal Components Analysis (PCA). The TM data for native and non-native grasslands were entered into a different PCA for the same purposes. The biophysical and spectral components produced from PCA were entered into cluster analysis, which was used as a hierarchical classification technique to cluster study sites based on their biophysical and spectral similarities. The agglomerative classification technique was used to group the clusters.

A total of four dendograms, that visually depict the similarity among the study sites, were produced (two for each grassland type; the first based on the biophysical properties and the second on the spectral properties). A visual assessment of each dendogram was used to further group each site into one of three clusters. After the three clusters were defined, the cluster groupings derived using the biophysical data were visually compared to the cluster groupings derived using the spectral data. Summary statistics were then calculated to determine how biophysical characteristics varied among the three spectral clusters.

The arithmetic means from each spectral cluster were entered into a multivariate analysis of variance (MANOVA) test to determine if there were significant differences among the cluster's spectral characteristics. Due to the large numbers of variables relative to the few clusters (large variable-to-cluster ratio), the spectral variables were partitioned into groups of variables before being entered into the MANOVA tests. Alpha levels were adjusted based on the number of MANOVA tests used. MANOVA tests were run for each group of variables for each grassland type. For example, all of the May TM spectral variables for non-native cool season grasslands were entered into one MANOVA test, just as all of the July TM spectral variables for native warm season grasslands were entered into a separate MANOVA test. MANOVA test results and summary statistics were evaluated to determine if a grazing intensity or range condition gradient emerged among the spectral clusters within each grassland type.

Results and Discussion

Correlation Analysis

The results show that while NDVI may be used as a surrogate for biomass for native and non-native study sites ($r = 0.55$), biomass may not be an effective indicator of grazing intensity in non-native cool season study sites ($r = 0.64$). If biomass were an effective indicator of grazing intensity, a strong negative correlation between biomass and grazing intensity would exist (as grazing intensity increases, the amount of live biomass would decrease) (Table 1). The lack of a negative correlation may be due to the fact that when a site is grazed, it is generally not grazed evenly, but is usually

Table 1 Pearson's correlation coefficients (r-values) for native warm season and non-native cool season study sites.

Type	Variables	Grazing Intensity	Live Biomass	Live Cover	TM NDVI
Cool & Warm Season	Grazing Intensity	-	.459*	0.880**	0.175
	Biomass	-	- 0.619**	0.554*	
	Cover	-	-	-	0.833**
	NDVI	-	-	-	-
Cool Season	Grazing Intensity	-	0.639*	0.377	0.552*
	Biomass	-	-	0.607*	0.625*
	Cover	-	-	-	0.812**
	NDVI	-	-	-	-
Warm Season	Grazing Intensity	-	-0.812**	-0.655*	-0.297
	Biomass	-	-	0.853**	0.651*
	Cover	-	-	-	0.857**
	NDVI	-	-	-	-

Two-tailed test
* Significant at alpha = 0.05
** Significant at alpha = 0.01

grazed in patches. While range managers generally take steps to obtain a uniform grazing distribution, this task is quite complex and efforts are not always successful. Topography, pasture size and shape, water and shade locations, and range burning are among the factors that influence grazing patterns (Owensby 1993). Dyer *et al*. (1991) points out that most grasslands are not grazed evenly and it may be difficult to rely on an instantaneous snap-shot of biomass especially if taken on ungrazed areas in the grazed sites. In their study, Dyer *et al*. showed that in a *Bromus inermis* grassland, grazed plots had as much as 70% lower standing crop than ungrazed plots, but that grazed plots compensated for the defoliation and produced more season-long biomass than ungrazed plots.

The lack of a negative correlation may also be related to differences in land management practices. In this study area, some cool season sites were fertilized while others were not. Perhaps fertilized study sites are able to rejuvenate more quickly with the essential nutrients readily available than unfertilized study sites. Compositional differences among the study sites may also complicate the relationship between grazing intensity and biomass. The proportions of brome and fescue grasses varied among study sites and may be influencing foliage consumption. Some study sites were primarily comprised of fescue, a species that is only fair in palatability (Stubbendieck *et al*. 1995). Meanwhile, other study sites were comprised of brome, a highly palatable species (Stubbendieck *et al*. 1995).

While the data suggest that biomass may not be an effective indicator of grazing intensity for non-native cool season grasslands, the strong negative correlation between grazing intensity and living biomass in native warm season grasslands suggests the opposite (r = -0.81). Furthermore, the strong positive relationship between living biomass and TM NDVI values suggests that TM NDVI values could potentially be used to indicate grazing intensity for native warm season grasslands. Our correlation results, however, do not confirm this (r = -0.297). A factor possibly confounding the correlation analysis results between biomass, grazing intensity, and TM NDVI is the difficulties in estimating grazing intensity. Landowners base management practices on climatic and economic factors; factors that are quite dynamic throughout a growing season. During the study period, landowners often adjusted stocking rates and the timing and duration of grazing in response to current vegetation conditions and market prices making it difficult to calculate grazing intensity.

Data Reduction

It is often difficult to interpret the components derived from PCA. Factor loadings were used to interpret the biophysical and spectral components produced for the two grassland types (Table 2, Table 3). The first three biophysical principal components were used for the non-native study sites to explain 67.7% of the variation in the original data set

Table 2 Non-native cool season and native warm season principal components derived using biophysical measurements. Three non-native cool season principal components and four native cool season principal components were interpreted and used in subsequent analysis.

Type		Component	Variables Contributing
Cool Season	1	Grass	% Grass Cover
	2	Biodiversity	Sp. Richness % Forb Cover
	3	Vegetation architecture	Height
Warm Season	1	Greenness	% Total Living Cover
	2	Inverse Ratio of Forbs to Grass	Negative % Forb Cover Positve % Grass Cover
	3	Not interpretable	Mix of variables
	4	Inorganic	% Bare ground % Non-living vegetation cover

Table 3 Non-native cool season and native warm season principal components derived using multitemporal TM data. Four non-native cool season principal components and five native cool season principal components were interpreted and used in subsequent analysis.

Type		Component	Variables Contributing
Cool Season	1	Chlorophyll Absorption	May TM band
	2	Vegetation Condition	July TM bands
	3	Senescence	September TM bands
Warm Season	1	Chlorophyll Absorption	July TM bands
	2	Vegetation Condition	May TM bands
	3	Senescene	September TM bands
	4	Moisture	July MIR September MR

(Table 2). Meanwhile, the first four biophysical components were used for the native warm season grasslands to explain 83.8% of the variation in the original data set.

The first three principal components derived from the spectral data were used for non-native cool season sites and the first four principal spectral components were used for native warm season sites (Table 3). The spectral components for the non-native and native study sites explained 85.3% and 93.5%, respectively, of the total variance in the original 18-band TM multitemporal data set.

Cluster Analysis

The dendograms produced during cluster analysis were used to assign each study site for the non-native cool season and native warm season grasslands to one of three clusters. Cluster analysis grouped the study sites within each grassland type into three classes based on biophysical and spectral data. The clusters were analyzed for similarities in biophysical and spectral properties among study sites. The dendograms shown in Figures 2 and 4 illustrate the biophysical similarities among non-native and native sites, respectively. Based on the rescaled distance, Cluster 1 for both the non-native cool season and native warm season types contains sites that were more similar with respect to their biophysical properties than Cluster 2 and Cluster 3 (Figure 2). The dendograms shown in Figures 3 and 5 illustrate the spectral similarities among the non-native cool season and the native warm season study sites, respectively. Cluster 3 for both grassland types (Figure 3, Figure 5) contains four sites and are spectrally less similar to one another than sites in Clusters 1 and 2.

One might assume that sites with similar biophysical characteristics might also have similar spectral characteristics. Comparing the cluster analysis results using the biophysical components with the cluster analysis results using the spectral components tested this notion. The dendograms produced from cluster analysis were compared to determine whether the study sites clustered together based on the biophysical characteristics were also clustered together based on the spectral characteristics (Lewis 1994). The dendograms show several similarities in the way sites were clustered based on the biophysical and spectral characteristics for non-native cool season study sites (Figure 2, Figure 3). There was, however little similarity between the dendograms produced using the spectral and biophysical data for native warm season sites with only a few sites that were clustered together in both dendograms (Figure 4, Figure 5). For example, sites 15 and 17 were clustered together in both the spectral and biophysical dendograms. Meanwhile, site 42 appeared to be dissimilar to site 15 spectrally, but appeared to be very similar to site 15 biophysically (Figure 4, Figure 5). These results contrast those obtained by Lewis (1994) where cluster analysis results for biophysical characteristics were quite similar to cluster analysis results for spectral characteristics.

Biophysical characteristics. One way of determining what biophysical characteristics might be influencing the spectral response patterns is to summarize the biophysical field measurements according to the cluster analysis results for the spectral data. The results of summarizing the biophysical field measurements in this way showed considerable variability among the clusters (Table 4). For native warm season study sites, Cluster 1 had taller vegetation and a higher percentage of its vegetation characterized as decreaser species than Cluster 2 and Cluster 3 (Table 4). Cluster 2 had more total living vegetation, forb species, and vegetation cover characterized as annual, invader, and increaser species as compared to the other clusters (Table 4). According to the field data, Cluster 3, on average, had lower amounts of total living vegetation cover, and smaller amounts of living biomass as compared to the other two clusters (Table 4).

There were also observed differences in the biophysical characteristics of the non-native cool season spectral clusters. Canopy heights were similar between Clusters 1 and 2, while Cluster 3 had relatively lower vegetation canopy heights (Table 4). Cluster 2 tended to have higher proportions of total living vegetation, lower proportions of senescent vegetation, and larger amounts of living biomass. Species richness tended to be similar among the clusters and averaged around 15 species.

Spectral Characteristics. To determine if the clusters formed using the spectral data were significantly different from one another, the spectral responses for each cluster were entered into a MANOVA test. The MANOVA test showed that the spectral clusters for native warm season grasslands were significantly different in July. Between subject effects revealed that TM bands 1 and 5 (MIR) significantly differed among the spectral clusters (Table 5). Reflectance patterns in July TM band 5 appeared to relate to live biomass for Clusters 1, 2, and 3. Cluster 1 had the highest amount of living biomass and the lowest MIR reflectance (Figure 6, Table 4). Cluster 3 had the lowest amount of living biomass and the highest percentage of MIR

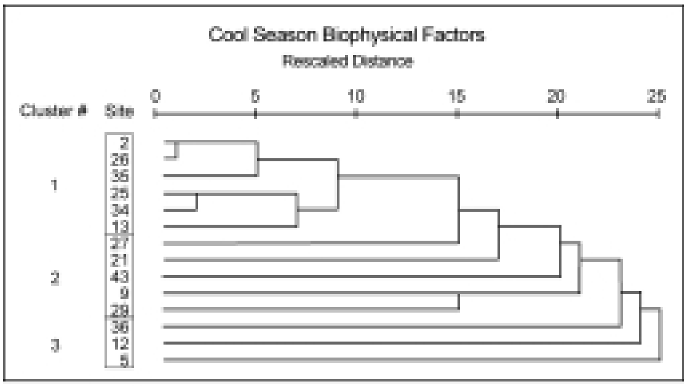

Figure 2 Dendogram showing cluster relationships generated from the biophysical factors of the non-native cool season sites. The dendogram shows the three biophysical clusters that were formed.

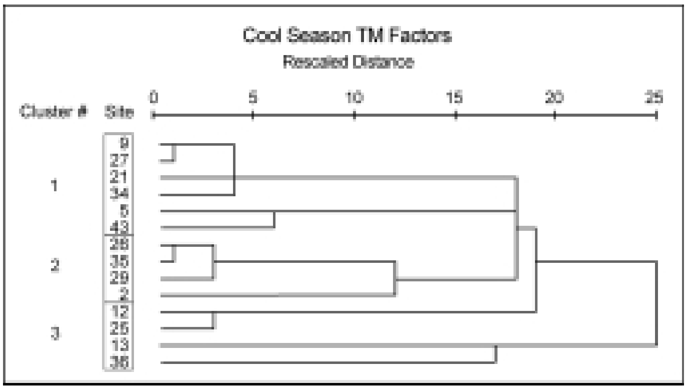

Figure 3 Dendogram showing cluster relationships generated from the spectral factors of the non-native cool season sites. The dendogram shows the three spectral clusters that were formed.

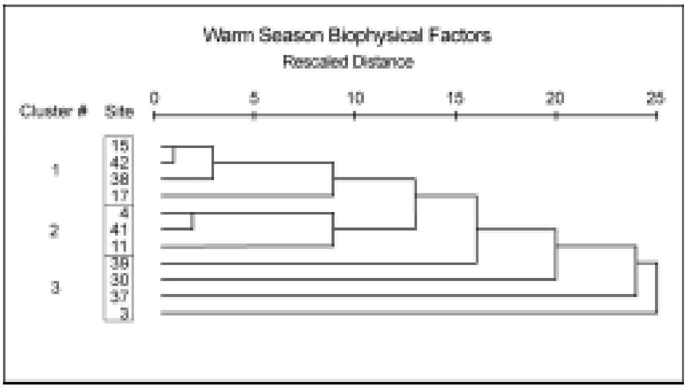

Figure 4 Dendogram showing cluster relationship generated from the biophysical factors of the native warm season sites. The dendogram shows the three biophysical clusters that were formed.

reflectance (Figure 6, Table 4). The lower MIR reflectance associated with Cluster 1 was most likely associated with sites that had more moisture due to increased live biomass. Conversely, the higher MIR reflectance associated with Cluster 3 was associated with sites that had the lowest live biomass and thus less leaf moisture. Tucker (1980) found leaf water status to be related to MIR reflectance characteristics. Water absorption in TM band 5 (1.55-1.75 (m region) causes reflectance patterns to be lower with increased leaf moisture content (Knipling 1970).

While not significantly different, reflectance patterns in July TM band 4 appeared to correlate with the amount of total living cover among the spectral clusters. In July, Cluster 2 had the highest percentage of NIR reflectance and the highest percentage of total living cover while Cluster 3 had the lowest percentage of NIR reflectance and the lowest percentage of total living cover (Figure 6, Table 4). In addition, Cluster 2 consistently had the highest NIR reflectance and the highest proportion of cover by forb species ((30%) as compared with Clusters 1 and 3. This cluster also had the highest percentage of cover by annual, introduced, increaser, and invader species (Table 4). These results suggest that those differences in total living cover and species composition may influence the spectral response in the NIR region. Lauver and Whistler (1993) showed that total living vegetation cover appeared to be one of the parameters allowing high and low quality grasslands to be spectrally separated.

Non-native cool season spectral clusters were significantly different in both July and September (MANOVA, P = 0.000, P = 0.003, Table 5). Between subject effects revealed July TM band 7 and September TM bands 3 and 7 statistically differed among the spectral clusters. Interestingly, study sites in Cluster 3 repeatedly had the highest spectral response in TM band 7 in May, July and September while sites in Cluster 2 tended to have the lowest spectral response in TM band 7 (Figure 7). The spectral responses observed in TM band 7 may be corresponding to the amount of live biomass and/or proportions of living and non-living vegetation present. Cluster 2 consistently had the lowest percentage of non-living vegetation, the highest percentage of total living vegetation, the highest amount of live biomass, and generally the lowest spectral response in TM bands 5 and 7 (Figure 7, Table 4). Senescent vegetation is nearly void of leaf moisture and is perhaps causing higher reflectance patterns observed in TM band 7 (Miller *et al*. 1984; Asrar *et al*. 1986).

A grazing intensity or range condition gradient does not emerge from the observed significant differences in biophysical and spectral characteristics of the clusters for either grassland type. Grazing intensity did not appear to correlate with any of the spectral characteristics of the clusters. Intuitively, live biomass and cover would decrease with increased grazing intensity, however, this trend did not occur within the clusters. Several biophysical components for sites in the spectral clusters for both native warm season and non-native cool season grasslands were highly variable which may also complicate the interpretation of the results.

Spectral and biophysical differences observed within the two grassland types may not be a function of the grazing system alone and instead, could be a function of

Table 4 The calculated means of the biophysical data for non-native cool season and native warm season spectral clusters.

		Cool Season			Warm Season		
Date	Measurement	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
July	Grazing Intensity	21.59	28.67	90.00	16.66	27.91	15.26
	Biomass (g/m^2)	213.73	320.40	302.60	333.60	220.00	181.60
	Height (cm)	26.68	29.65	18.92	34.89	29.17	29.89
	Species Richness (#/site)	17.17	13.75	19.00	25.25	23.67	29.25
	Grass (%)	52.50	76.65	54.70	63.65	50.60	41.80
	Forb (%)	6.67	0.10	15.95	16.15	32.20	18.67
	Shrub (%)	0.00	0.00	1.00	0.00	0.00	4.07
	Bare (%)	2.90	1.90	1.00	15.45	8.60	21.33
	Total Non-living (%)	40.83	21.35	27.35	4.75	8.60	14.13
	Total Living (%)	58.33	76.75	71.65	79.80	82.80	64.53
Aug	Height (cm)	27.43	26.29	18.97	36.62	39.45	38.16
	Species Richness (#/site)	15.00	15.33	15.67	19.00	20.33	23.50
	Grass (%)	32.73	57.20	42.73	72.80	53.20	54.10
	Forb (%)	11.70	6.87	9.00	6.87	37.60	23.80
	Shrub (%)	0.00	0.00	0.00	0.00	0.00	0.00
	Bare (%)	7.03	11.47	6.33	16.27	4.13	7.35
	Total Non-living (%)	31.87	24.47	41.93	4.07	5.07	14.75
	Total Living (%)	53.32	64.07	51.73	79.67	90.80	77.90
Sept	Height (cm)	23.62	25.27	15.92	38.52	28.07	42.08
	Species Richness (#/site)	15.50	17.75	20.00	23.67	22.00	28.00
	Grass (%)	32.53	75.15	55.13	69.87	40.27	62.50
	Forb (%)	12.60	2.50	3.00	13.60	36.60	10.30
	Shrub (%)	0.00	0.00	0.00	0.00	0.00	0.00
	Bare (%)	3.90	6.75	2.80	11.93	12.00	11.80
	Total Non-living (%)	34.30	15.60	39.07	4.60	11.13	15.40
	Total Living (%)	54.16	77.65	58.13	83.47	76.87	72.80
Grazing Indicators							
	Perennial (%)	-	-	-	57.43	56.02	39.49
	Annual (%)	-	-	-	6.40	26.81	16.43
	Native (%)	-	-	-	57.63	13.60	53.22
	Introduced (%)	-	-	-	8.82	11.67	7.42
	Increaser (%)	-	-	-	11.70	28.95	12.77
	Decreaser (%)	-	-	-	47.35	38.59	36.04
	Invader (%)	-	-	-	6.07	70.90	6.90

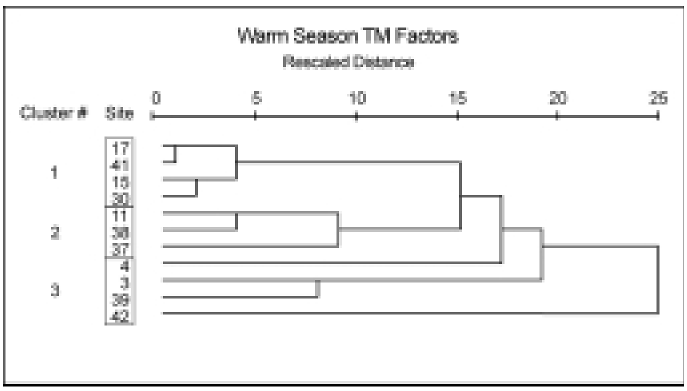

Figure 5 Dendogram showing cluster relationships generated from the spectral factors of the native warm season sites. The dendogram shows the three spectral clusters that were formed.

other underlying factors such as soil type, land management practices such as burning, haying, mowing, and fertilization practices, or a combination thereof. Gibson *et al*. (1993), for example, indicated that soil type was the most important discriminator of plant communities on large-scale plots. Briggs and Knapp (1995) found that aboveground biomass was influenced by a combination of topography, fire history, and climate. Further, Vinton *et al*. (1993) showed that livestock grazing patterns were heavily influenced by burning regimes with a grazing preference for burned areas. Therefore, if sites were burned at a variety of frequencies, cattle may not be grazing unburned areas as intensely as sites that were regularly burned. Hobbs *et al*. (1991) found that without burning, there was an increased likelihood of a vegetation patch being regrazed.

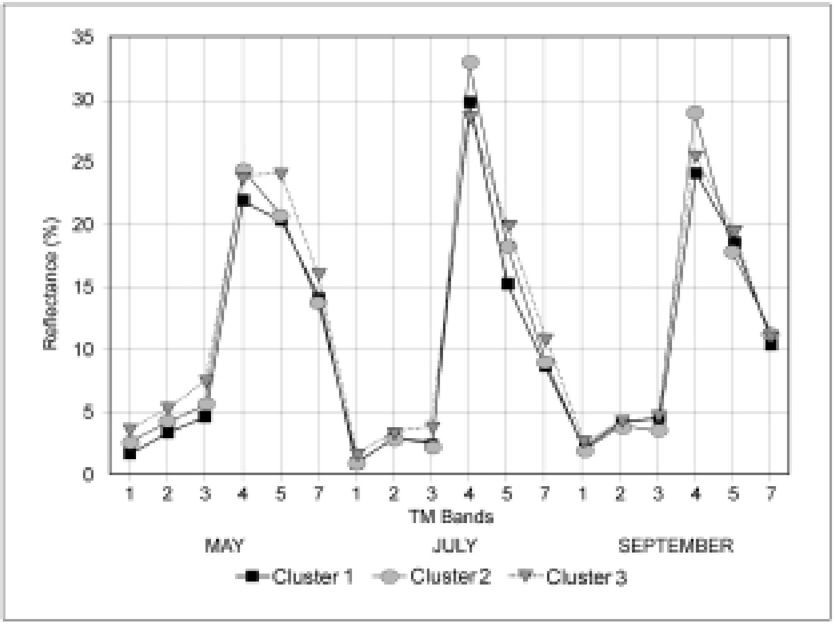

Figure 6 Multitemporal Landsat TM mean spectral response for the three native warm season spectral clusters.

Table 5 MANOVA results for non-native cool season and native warm season spectral clusters.

Type		Measurements	F	Sig
Cool	Multivariate Test	May TM Bands	2.416	0.086
	Multivariate Test	July TM Bands	286.745	0.000*
	Between Subjects	1	0.001	0.999
		2	0.076	0.927
		3	0.092	0.913
		4	1.872	0.200
		5	0.310	0.740
		7	4.903	0.030*
	Multivariate Test	September TM Bands	5.731	0.003*
	Between Subjects	1	2.614	0.118
		2	1.547	0.256
		3	4.024	0.049*
		4	0.446	0.651
		5	2.354	0.141
		7	15.817	0.001*
Warm	Multivariate Test	May TM Bands	1.036	0.539
	Multivariate Test	July TM Bands	812.679	0.000*
	Between Subjects	1	4.610	0.047*
		2	4.207	0.056
		3	3.099	0.101
		4	0.513	0.617
		5	6.521	0.021*
		7	0.789	0.487
	Multivariate Test	September TM Bands	5.338	0.025

<u>Multivariate</u>: Cool Season * Significant at alpha = 0.017
Warm Season * Significant at alpha = 0.017
<u>Between Subjects</u>: * Significant at alpha = 0.05

Several study sites, both native and non-native, were mowed or hayed during the growing season making the effects of grazing on spectral characteristics even more difficult to evaluate. The frequency and timing of fertilization varied for non-native cool season grasslands as well as the frequency and timing of burning of native warm season grasslands. Dyer *et al*., (1991) showed that fertilization on *Bromus inermis* plots produced 67% more foliage than unfertilized plots.

Conclusion

The results suggest that while NDVI may be used as a surrogate for living biomass for non-native cool season and native warm season grasslands, biomass may not effectively indicate grazing intensity in non-native cool season grasslands. Meanwhile, a strong positive relationship between living biomass and TM NDVI values suggests that TM NDVI values could potentially be used to indicate grazing intensity in native warm season grasslands.

Summary statistics of biophysical field measurements for the spectral clusters, however, did not show that grazing intensity was directly related to biomass. There were, however, relatively large variations in the measured biophysical variables within each spectral cluster indicating that a larger sample size may be needed to assess grazing intensity and range condition in non-native cool season and native warm season grasslands.

The dendograms derived from the cluster analysis on the biophysical data illustrate how different the study sites were within each grassland type, and the problems and complexity involved in assessing grazing intensity in this study area. And while the summary statistics of the spectral clusters show some relationships with particular TM bands, there was not a consistent relationship between spectral characteristics and grazing intensity or range condition. More information regarding the historical land management practices for these study sites may be needed to completely understand the long-term implications of grazing or the cumulative impacts of multiple land management practices employed on native warm season and non-native cool season grasslands in northeastern Kansas.

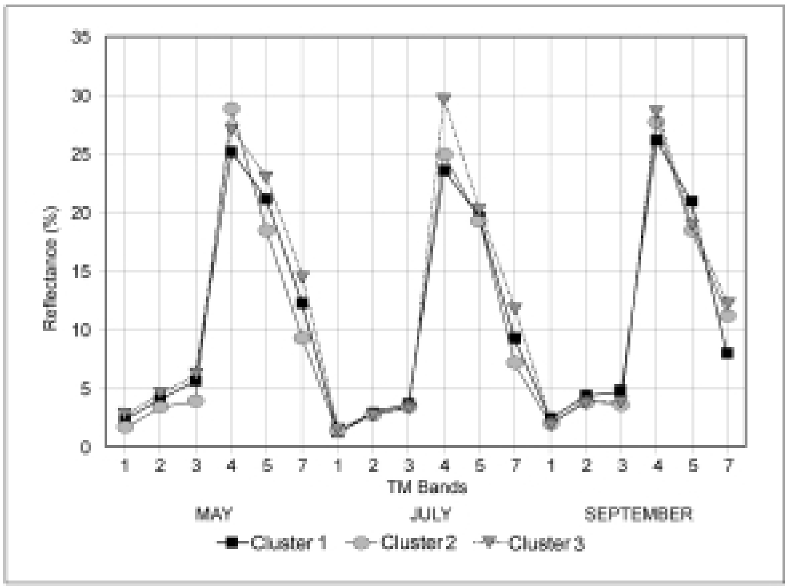

Figure 7 Multitemporal Landsat TM spectral response for the three non-native cool season spectral clusters.

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