INT. J. REMOTE SENSING, 2002, VOL. 23, NO. 23, 5015–5030

Taylor & Francis
Taylor & Francis Group

Discriminating between cool season and warm season grassland cover types in northeastern Kansas

D. L. PETERSON

Kansas Applied Remote Sensing (KARS) Program, University of Kansas, 2335 Irving Hill Road, Lawrence, KS 66045, USA; e-mail: dpete@ku.edu

K. P. PRICE

Department of Geography and Kansas Applied Remote Sensing (KARS) Program, University of Kansas, 2335 Irving Hill Road, Lawrence, KS 66045, USA; e-mail: price@ku.edu

and E. A. MARTINKO

Department of Ecology and Evolutionary Biology, Kansas Applied Remote Sensing (KARS) Program, and Kansas Biological Survey, University of Kansas, 2335 Irving Hill Road, Lawrence, KS 66045, USA; e-mail: martinko@ku.edu

(*Received 5 January 2000; in final form 29 October 2001*)

Abstract. This study assesses the ability of multitemporal Landsat Thematic Mapper (TM) data and the normalized difference vegetation index (NDVI) to spectrally separate grazed cool season and warm season grassland cover types in Douglas County, Kansas. Biophysical data collected during the summer of 1997 suggest that differences in the per cent of total living vegetation cover, per cent of senescent vegetation, and proportion of forb cover between the two grassland cover types could make cool season and warm season grassland cover types spectrally distinct. The results show that the two grassland cover types were spectrally different in several spring (May) and mid-summer (July) bands, but not in any fall (September) bands. Furthermore, the two grassland cover types could be discriminated with a high level of accuracy. Accuracy assessments of the three single dates showed that the mid-summer (July) image and NDVI discriminated between the grassland cover types most accurately (81.8%). The multitemporal TM and NDVI data did not improve the spectral discrimination of the two grassland cover types over the mid-summer image or NDVI and had classification accuracy levels of 63.6% and 68.2%, respectively.

1. Introduction

The tallgrass prairie has been identified as one of the more biologically diverse grasslands in the world (Risser 1988). However, only a small percentage of tallgrass prairie remains in the United States (Risser 1988). Fragmentation of the tallgrass prairie in the eastern Great Plains has resulted from European settlers who converted prairie to croplands and cool season grasslands for grazing by domesticated animals. Prairies remain almost exclusively on rocky substrates that are unable to undergo the plough (Holecheck *et al.* 1989). Most of the Great Plains and eastern

International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160210142833

forest tallgrass prairie is privately owned and subjected to a variety of land management practices used by landowners (Owensby 1993). A primary land use for these prairie remnants has been for grazing by domestic ungulates. With only an estimated 1% of pre-European prairies remaining (Diamond and Smeins 1988), identification and monitoring of these prairie remnants are critical to ensure their preservation.

Traditionally, vegetation mapping and assessment techniques have been based primarily on field observation and data collection. These traditional mapping and assessment techniques are considered time-consuming, subjective, and economically inefficient for relatively large areas (Briggs and Nellis 1989, Friedl *et al.* 1994). Meanwhile, the use of imagery that has been remotely sensed by satellites 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 Landsat Thematic Mapper (TM) data to estimate and assess biophysical characteristics of grasslands including biomass and leaf area index (LAI) (Asrar *et al.* 1986, Weiser *et al.* 1986, Briggs and Nellis 1989, Friedl *et al.* 1994, Chen and Brutsaert 1998). In addition, remotely sensed data have been used to evaluate the effects of different land management practices on spectral characteristics (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 'Systeme Pour l'Observation del la Terre' (SPOT) High Resolution Visible (HRV) and Landsat TM data to differentiate among grassland communities (Briggs and Nellis 1991, Lauver and Whistler 1993). Further, Kansas land cover mapping studies by Egbert *et al.* (1995) and Price *et al.* (1997) revealed that a classification approach using multitemporal imagery better discriminated and classified agricultural and grassland areas than the one which used single date Landsat TM images (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 sensor data to distinguish between cool season and warm season grassland cover types. Discriminating between cool season and warm season grassland cover types will provide accurate estimates of remaining tallgrass prairie remnants. In addition, once these grassland cover types can accurately be discriminated, tailored monitoring and assessment techniques can be developed for sustainable management. The primary objective of this study, therefore, is to evaluate the feasibility of using Landsat TM data to discriminate between grazed cool season and warm season grassland cover types in Douglas County, Kansas. This study identifies the best single date image that most accurately discriminates between the two grassland cover types. In addition, this study assesses whether NDVI or multitemporal data improve the separability of the two grassland cover types.

2. 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 temperatures of −6°C in January and mean high temperatures of 32°C in July. Precipitation often exceeds evapotranspiration rates in the region with average annual precipitation levels at 86 cm. The majority of the precipitation falls during the growing season (April to September) and rain patterns during the growing

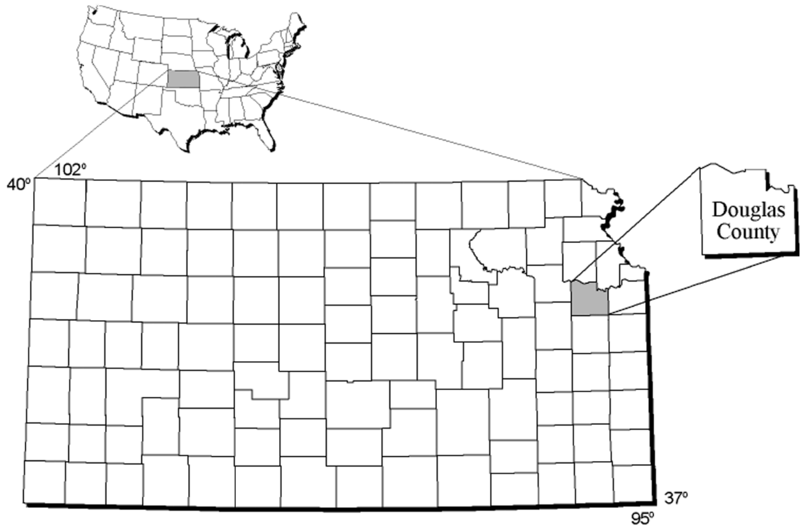

Figure 1. The state of Kansas with county boundaries. The study area, Douglas County, is highlighted in the eastern part of the state.

season are generally short intense rains that create a regular occurrence of surface runoff (USDA 1977). For 1997, reported temperatures were average and reported average annual precipitation levels were slightly below average (79.73 cm) (NCDC 1999).

Approximately 41% of the county area is grassland (native or non-native) (KARS 1999). A 1992 Census Report stated that an estimated 32 779 ha in Douglas County are used as rangeland (USDA 1998). Cropland is the predominate land cover type in Douglas County with 58 243 ha harvested in 1997 (USDA 1998).

Cool season and warm season grasslands are the two grassland cover types present in Douglas County, Kansas. Cool season plant species fix carbon via C_3 photosynthesis while warm season plant species fix carbon via C_4 photosynthesis. As a result, cool and warm season plants differ in their physiological behavior and growth patterns. In this study area, cool season species begin photosynthetic activity in early spring, reach peak productivity in late spring, and become semi-dormant by mid-summer. Cool season species often experience a second, yet smaller growth period in early fall (Weaver 1954). While warm season species also begin photosynthetic activity in spring, the period of rapid growth occurs when temperatures increase in late spring and early summer. Warm season species reach peak productivity in mid-summer, and experience little growth in early fall before senescing (Weaver 1954).

Within the study area, cool season grassland cover types are dominated by introduced cool season grass 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. Warm season grassland cover types 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 cover types will be referred to based on their dominant vegetation.

3. Methods

3.1. Data acquisition

3.1.1. *Field data*

Field data were collected to detect biophysical differences between cool season and warm season grassland cover types that may affect spectral characteristics as measured by the Landsat TM sensor. A total of 22 randomly selected study sites were used for this study, 10 warm season and 12 cool season.

Field data were collected in early July, August, and September of 1997. Collection times were scheduled to coincide with the Landsat 5 overpasses (approximately five days before and after the overpass dates). A hand-held Garmin Plus II Global Positioning System (GPS) unit was used to record the map coordinate location of the study sites.

Five $0.25\,m^2$ quadrats were positioned within a $90\,m \times 90\,m$ study plot to collect data for each study site. The first quadrat was positioned in the centre of the study plot and the other four quadrats were positioned systematically in the study plot corners to represent a sample from 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 $90\,m \times 90\,m$ sampling area during a ten-minute period. Species richness within the two grassland cover types was used as a general indicator of plant species compositional homogeneity, which may influence spectral characteristics of the grasslands. For example, grasslands dominated by two or three species may have a different spectral response than grasslands made up of more species and different compositional mixtures of grass and forbs. Grassland cover types with greater compositional variation would probably be more spectrally variable as well. The average vegetation canopy height was also measured to the nearest cm at each quadrat to determine whether differences in canopy architecture had an influence on spectral response patterns.

Total living biomass was measured at 16 of the 22 sites during the July 1997 field visit. Live biomass was clipped and removed from the five $0.25\,m^2$ quadrats at each study site. The biomass was then dried at 64°C for at least 40 hours and then weighed to the nearest gram.

3.1.2. *Derived index*

The presence X frequency (P X F) index (Curtis 1959) 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 study sites.

3.1.3. *Satellite data and 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 15 May, 2 July and 4 September

1997 to represent spring, summer and fall, respectively, for the 1997 vegetation 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 May, July, and September 1997 subsets of the images were then converted from brightness values to radiance values. The thermal infrared band was excluded from the analysis due to its coarser spatial resolution. Chavez's (1988) Improved Dark Object Correction Technique was used to normalize radiance values and minimize 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.

The July image was geometrically referenced to a Universal Transverse Mercator (UTM) projection using 38 ground control points (GCPs) and the nearest neighbor interpolation algorithm. The transformation model estimated the geographic location of each pixel to within 0.35 pixels (10.5 m) of the ground control points. The other two images were geographically registered to the rectified image. After georegistering all images to the same coordinate system, an 18-band data file was created using the six bands from the three image dates. Reflectance values for each study site were extracted for a nine pixel area (3×3 pixels) located within the middle of each site and these values were used for subsequent analyses.

NDVI values were calculated using the standard equation (Rouse *et al.* 1973):

$$\mathrm{NDVI} = \frac{(\mathrm{TM4} - \mathrm{TM3})}{(\mathrm{TM4} + \mathrm{TM3})} \tag{1}$$

3.2. *Statistical analysis*

The extracted pixel values for all study sites were imported into SPSS statistical software for statistical analysis. Summary statistics were generated for the biophysical and spectral data. Multiple analysis of variance (MANOVA) was used to test for spectral differences between the two grazed grassland cover types (warm season versus cool season). Discriminant analysis was used to examine the spectral separability of the two grassland cover types. Preliminary results revealed that the inclusion of all eighteen TM bands in the discriminant analyses produced inconsistent and unreliable statistical results. In order to produce reliable results, the blue band (TM band 1 from spring, summer, and fall images), the band most affected by atmospheric attenuation, was excluded from the analyses. Subsequently, fifteen bands were entered into the MANOVA and discriminant analyses.

Discriminant analysis was used to determine which single date image best discriminated between cool season and warm season grassland cover types and whether the use of multitemporal data and NDVI improved the spectral separability. Discriminant functions generated during the analysis were used to assign study sites to one of the two grassland cover types. With a large sample size, one sample can be used to develop the 'in-sample' classification function and the second sample can be used to externally check the validity of the classification function. Due to the small sample size of this study, however, the 'jack-knife' procedure developed by Lachenbruch (1967) was used to cross-validate the classification results. The jack-knife procedure classifies each site based on a classification statistic of the remaining sites (n–1) (Stevens 1996). Reflectance from the fifteen TM bands and NDVI were entered into discriminant analysis. Using error matrices generated from discriminant analysis, accuracy assessments were calculated based on guidelines described by Congalton (1991).

4. Results and discussion

4.1. *Biophysical characteristics*

Summary statistics for the field data show that in mid-summer (July), cool season grasslands had slightly more total living biomass than warm season grasslands with $263.5\,g\,m^{-2}$ compared to $231.5\,g\,m^{-2}$, respectively. Warm season grassland cover types, however, had greater percentages of total living cover than cool season grassland cover types (figure 2). The greatest difference in the percentages of total living cover between the two grassland cover types was observed in late summer (August) when warm season sites had an average of 81.9% and cool season had 56.9% total living cover. The discrepancies between per cent cover and biomass suggest that vegetation in warm season grassland cover types were high in cover, but low in biomass. However, the discrepancies may be due to the timing of field data collection. Measurements were taken in early July and this may have been too early for warm season grass species to reach peak biomass. In addition, the study sites were also grazed by domestic ungulates, which alters vegetation biomass and cover (Dyer *et al.* 1991).

Species composition by lifeform cover also differed between the grassland cover types (figure 2). While sites for both grassland cover types consisted of at least 50% grass species, warm season sites had the greatest percentage of forb cover. Warm season grassland cover types had at least 20% forb cover while cool season grassland cover types had a maximum of 11.8% forb cover in late summer (August). The difference in forb cover explains the greater percentage estimates of total living cover observed in warm season grassland cover types. It is probable that a plant community

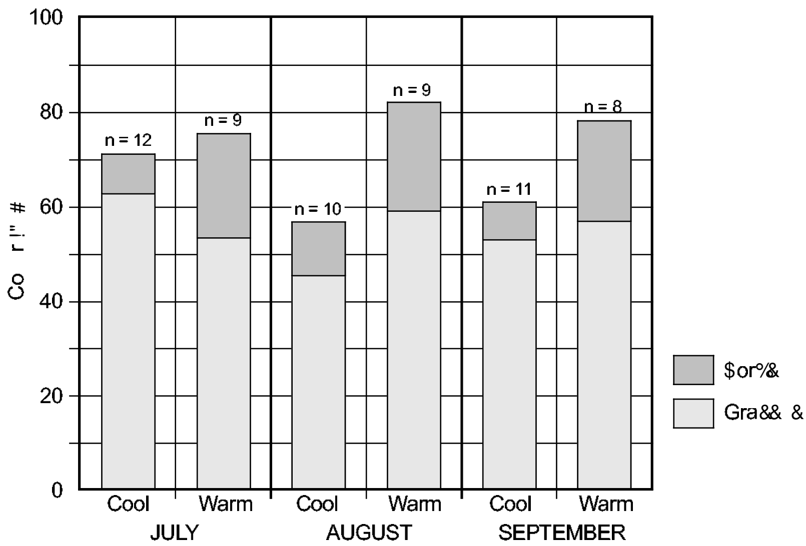

Figure 2. Cover estimates by lifeform for cool season and warm season grassland cover types in Douglas County, Kansas. The warm season sites had lower percentages of grass cover in July, but consistently had higher percentages of forb cover. A comparison of total living cover (grass and forb cover combined) shows that warm season sites consistently had higher percentages.

composed of forbs and grasses creates a more closed vegetation canopy structure while a plant community composed primarily of grass species creates a more open vegetation canopy structure. Shrubs did not constitute a significant portion of the vegetation cover (less than 1%) in either grassland cover type.

Warm season grasslands consistently had less non-living or senescent vegetation present during the three field visits (figure 3). Cool season sites had 27% or more senescent vegetation cover present while warm season sites had less than 10% non-living cover vegetation present. The lower proportion of senescent vegetation cover in warm season grass sites is explained by burning of warm season grasslands, which removes the previous year's vegetation. Prescribed burning is a commonly used grassland management practice and is important for the maintenance of tallgrass prairie vegetation (Hulbert 1969, Duffey 1974, Collins and Gibson 1990). The per cent of bare ground in warm season grasslands (>9.0%) was slightly greater than cool season grasslands (<9.0%), however, bare ground represented a relatively small portion of the total cover estimates (figure 3).

The dominant plant species also differed between the grassland cover types as illustrated through the P X F index (figure 4). The index values reveal that the warm season grass and forb species bluestem (*Andropogon* spp.) and common ragweed (*Ambrosia artemisiifolia* L.) largely dominated warm season grassland cover types in this study area. Meanwhile, the cool season grasses smooth brome (*Bromus inermis* Leyss.) and tall fescue (*Festuca arundinacea* Schreb.) dominated cool season grassland cover types. Neither grassland cover type consists exclusively of warm or cool season species.

Species richness was slightly different between the two grassland cover types. Warm season sites had an average of 25, 21, and 24 species present for July, August and September, respectively (figure 5). Meanwhile, cool season sites had an average

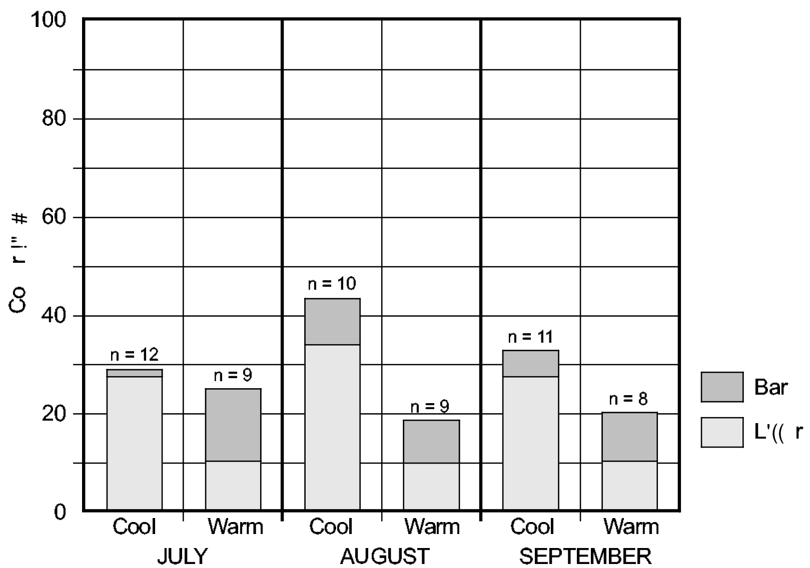

Figure 3. Cover estimates for bare ground and litter for cool season and warm season grassland cover types in Douglas County, Kansas. The graph shows that warm season sites had higher percentages of bare ground while cool season sites had higher percentages of litter.

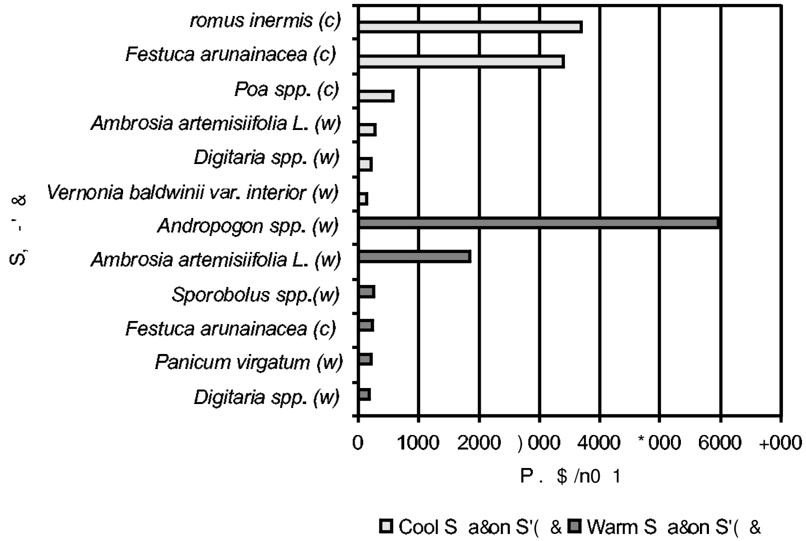

Figure 4. Dominant species list for cool season and warm season grassland cover types (c = cool season spp. and w = warm season spp). While neither grassland cover type was composed of warm or cool season species exclusively, the two grassland cover types were clearly dominated by different species.

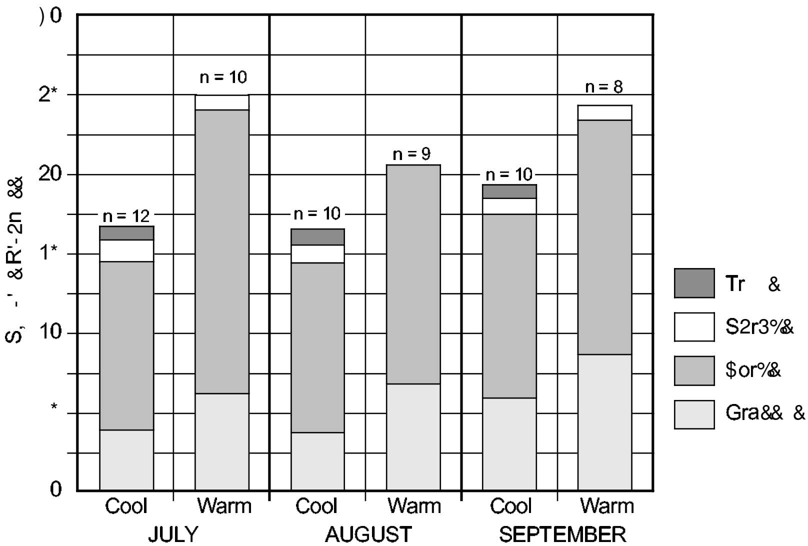

Figure 5. Species richness estimates by lifeform for cool season and warm season grassland cover types in Douglas County, Kansas. The graph shows that cool season sites had fewer species present compared to warm season sites. In addition, warm season sites had more grass and forb species present while cool sites consistently had more tree species present.

of 17, 17, and 19 species present for the respective months. There were more grass species present in warm season grasslands and more tree species present in cool season grasslands. These results reflect different management practices. Cool season grasslands in the study area are planted with a limited number of grass species such as fescue and brome and, therefore, there would not be a great number of grass species present. The higher number of tree species found in cool season grasslands is explained by the lack of burning on these grassland cover types. Prescribed burning is not among the management practices employed on these cool season grassland sites. Consequently, trees have a better chance to establish in cool season grassland cover types.

Warm season grasslands had taller vegetation than cool season grasslands (figure 6). This can be explained by the growth characteristics of the dominant plant species within each grassland cover type. At times, warm season grasses such as big bluestem reaches heights of 214 cm (Weaver 1954) while cool season grasses such as fescue reaches heights of only 121 cm (Stubbendieck *et al.* 1995). The tallest vegetation for both grassland cover types was measured in late summer (August). Plant height will vary year-to-year and is dependent on a variety of environmental factors (Weaver 1954).

4.2. *Spectral characteristics*

The spectral reflectance patterns of cool season and warm season grasslands reflect phenologic and compositional differences in the vegetation (figure 7). The spectral response curves show that the greatest differences between the two grassland cover types occur in the near-infrared (NIR) (TM band 4) and middle-infrared (MIR) (TM band 5) bands.

In spring (May), cool season sites had higher NIR reflectance values than warm season sites. This is due to the early spring growth of cool season grasses that dominate cool season sites (Weaver 1954). In mid-summer (July), warm season sites had higher NIR and lower MIR reflectance values than cool season sites (figure 7). The peak productivity period for warm season grasslands is mid-summer and this

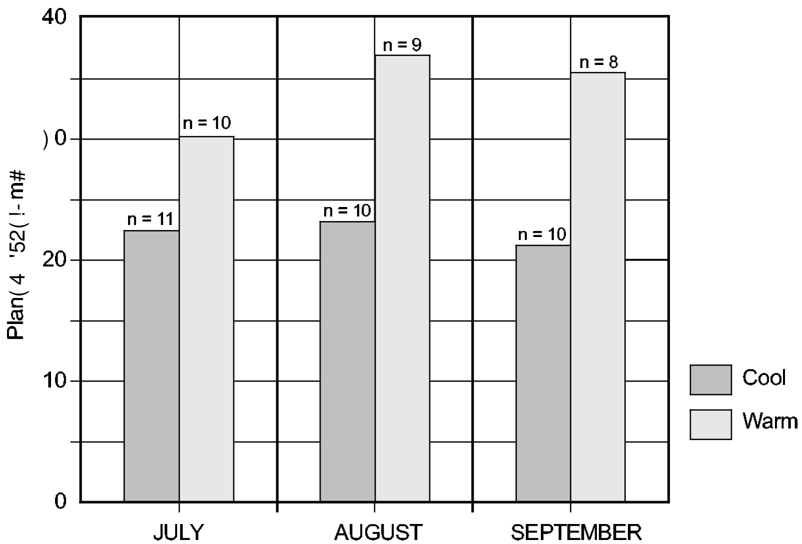

Figure 6. Plant height (cm) for cool season and warm season grassland cover types in Douglas County, Kansas. The graph shows that warm season sites had taller vegetation than cool season sites for all three dates.

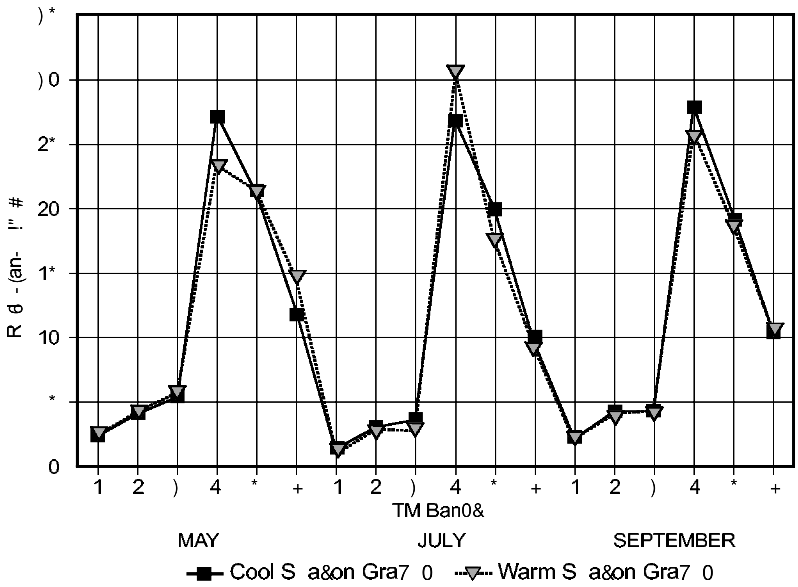

Figure 7. Multitemporal Landsat TM spectral response curves for cool season and warm season grassland sites in Douglas County, Kansas. The largest difference between the two grassland types for the three TM scenes appears to be in band 4 (NIR). There are also noticeable differences in May TM band 7 (MIR) and July TM band 5 (MIR).

is also the time when cool season grasses are semi-dormant (Weaver 1954). In fall (September), spectral differences between the two grassland cover types appear to narrow. Warm season sites had a slightly lower NIR reflectance (26.1%) than cool season sites (27.8%). During the late summer and early fall most species in both cool season and warm season grasslands undergo senescence to varying degrees that results in less plant moisture, less chlorophyll production, and less biomass production. The cool season species dominating cool season grassland cover types often experience growth rejuvenation in early fall if soil moisture is sufficient to support growth.

Previous studies of tallgrass prairies have shown NDVI to be related to the amount of total living biomass (Tucker 1980, Briggs and Nellis 1989). Using NDVI as a measure of biomass, the spectral data suggests that the cool season sites had larger amounts of total living biomass than warm season sites in spring (May) and fall (September) while the warm season sites had larger amounts of total living biomass than cool season sites in mid-summer (July) (figure 8). Conversely, field measurements reveal that the cool season sites had larger amounts of total living biomass than warm season sites in July. It is important to note, however, that total living biomass was highly variable for both grassland types with standard deviations exceeding $100\,g\,m^{-2}$.

4.3. *Spectral differences between grassland cover types*

Spectral differences between cool season and warm season grassland cover types were tested using the single date and multitemporal TM data. Comparing the results from the MANOVA tests, the two grassland cover types spectrally differed only in mid-summer (MANOVA, $p=0.004$, table 1). No significant spectral differences were

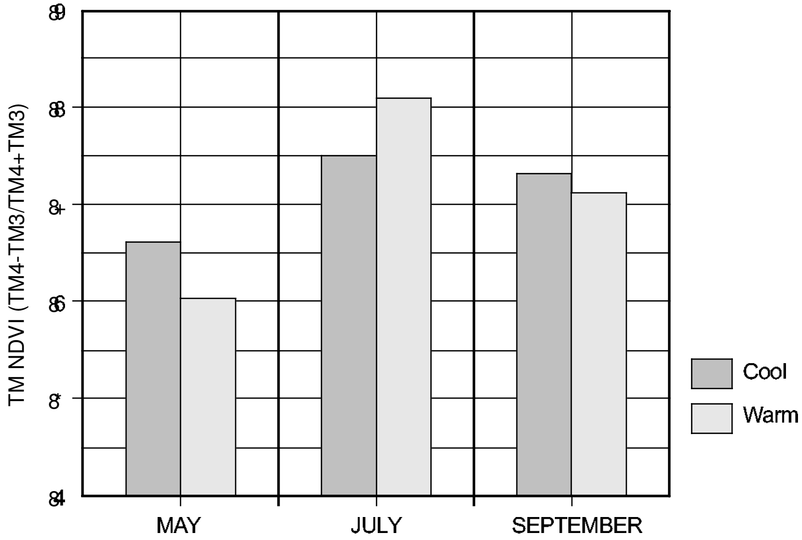

Figure 8. TM NDVI values for cool season and warm season grassland cover types in Douglas County, Kansas. The graph shows that cool season sites had higher NDVI values in May and September. In July, warm season sites had higher NDVI values.

found between the two grassland cover types when testing the spring, fall, and multitemporal data.

Between band tests show that the two grassland cover types were significantly different in TM band 4 (NIR) from the spring (May) image and in TM bands 3 (red) and 5 (MIR) from the mid-summer (July) image. Differences between the grassland cover types in the NIR band may be due to differences in plant phenology. Differences in TM band 3 and 5 could be attributed to differences in internal leaf properties such as chlorophyll and plant moisture content, respectively, which are associated with differences in plant phenological states or water availability. In mid-summer, cool season grassland cover types are semi-dormant and thus have lower chlorophyll and leaf moisture content resulting in less energy absorption in the red (TM band 3) and MIR (TM band 5) bands. In contrast, warm season grassland cover types are at peak productivity in mid-summer and, because these grasslands are better adapted to hotter environmental temperatures, they have higher chlorophyll and leaf moisture content and a corresponding increase in energy absorption in the red (TM band 3) and MIR (TM band 5) bands.

These results concur with other research. Knipling (1970) showed that water moisture content in living vegetation reduced the reflectance in TM band 5 (MIR region, 1.55–1.75 μm). Further, Tucker (1980) showed that TM band 5 was an indicator of water content or status in vegetation. A study by Walthall and Middleton (1992) also showed similar results where the red and MIR bands were most sensitive to spatial and seasonal changes in grasslands and that the NIR band (TM band 4) was among the least important bands. Levels of chlorophyll and water content influenced the red and MIR region spectral responses, respectively. Buttner and Csillag (1989) also illustrated the usefulness of TM band 5 by comparing classification accuracy levels between SPOT HRV and TM data. It was found that TM data were better than SPOT HRV data for classifying crop types due to the inclusion of TM band 5.

Table 1. MANOVA results for testing differences between the single date and multitemporal TM and NDVI data for cool season and warm season grassland cover types. Multivariate tests showed that the July TM bands were significantly different between the two grassland types while between subjects tests showed that May TM band 4 and July TM band 3 and 5 were significantly different between the two grassland cover types.

Test	Date	Bands	F	Sig
Multivariate	Spring (May)	5 bands	2.551	0.070
	Mid-summer (July)	5 bands	5.515	0.004**
	Fall (September)	5 bands	1.224	0.343
	Multitemporal	15 bands	3.025	0.090
	3-date NDVI	3 NDVI	2.911	0.063
Between subjects	Spring (May)	TM 2	0.100	0.756
		TM 3	0.582	0.454
		TM 4	12.717	0.002**
		TM 5	0.066	0.799
		TM 7	3.074	0.095
	Mid-summer (July)	TM 2	0.023	0.880
		TM 3	4.503	0.047*
		TM 4	3.079	0.095
		TM 5	5.756	0.026*
		TM 7	0.097	0.758
	Fall (September)	TM 2	0.260	0.616
		TM 3	0.011	0.918
		TM 4	1.829	0.191
		TM 5	0.783	0.387
		TM 7	0.003	0.960
	Spring (May)	NDVI	3.886	0.063
	Mid-summer (July)	NDVI	3.818	0.065
	Fall (September)	NDVI	0.472	0.500

*Significant at alpha = 0.05; **Significant at alpha = 0.01.

The two grassland cover types were not statistically different for any of the six TM bands from the fall (September) image (table 1). As discussed previously, the spectral differences may be suppressed by senescence. Although cool season grasses are known to experience a second green-up or growth period in the fall, this period is dependent on a variety of environmental factors including available soil moisture. In addition, the fall green-up period is not the peak growth period for cool season grasses and, therefore, the relative vegetation growth may not be sufficient to reflect large differences in spectral responses of the two grassland cover types.

Differences in NDVI between native warm season and non-native cool season grazed sites were tested and no significant differences were found (MANOVA, $p = 0.063$, table 1). The normalized difference vegetation index has been interpreted as a measure of biomass and these results indicate that the two grassland types were not significantly different in total living biomass throughout the growing season. As noted earlier, July total living biomass measurements were not substantially different between the two grassland types. In July, cool season grasslands have already experienced their peak growth stage or greenness period and have relatively large amounts of vegetation. Meanwhile, warm season grasslands are experiencing their peak growth stage, which possibly explains the similarity in biomass measurements between the two grassland types and why the July and September NDVI values were not significantly different.

4.4. *Classification of grassland cover types*

The results showed that the mid-summer (July) image produced the highest single date classification accuracy. Using the in-sample and jack-knife verification approaches, the mid-summer (July) image had overall accuracy levels of 90.9% and 81.8%, respectively (tables 2 and 3). Meanwhile, the spring (May) image had in-sample and jack-knife overall classification accuracy levels of 81.8% and 72.7%, respectively and the fall (September) image had in-sample and jack-knife overall accuracy levels of 72.7% and 45.5%, respectively. The accuracy assessment using the jack-knife verification approach reveals that the mid-summer (July) image was approximately 9% more accurate at separating the two grassland cover types than the spring image and approximately 36% more accurate than the fall image.

The MANOVA results revealed the two grassland cover types were significantly different in TM bands 3 and 5 of the mid-summer (July) image. The results suggest that differences in chlorophyll and moisture content of the vegetation may have been greatest

Table 2. Accuracy assessments using in-sample classification methods for single date, multitemporal TM data and NDVI. The multitemporal TM data had the highest in-sample overall accuracy level and the mid-summer (July) image had highest single date overall accuracy level.

Data used	Overall (%)	Producer's (%)		User's (%)		Kappa (%)
		Cool	Warm	Cool	Warm	
Spring TM	81.8	83.3	80.0	83.3	80.0	63.3
Mid-summer TM	90.9	85.7	100.0	100.0	80.0	81.4
Fall TM	72.7	80.0	66.7	66.7	80.0	45.9
Spring, mid-summer, & fall TM	100.0	100.0	100.0	100.0	100.0	100.0
Spring NDVI	59.1	63.6	54.5	58.3	60.0	18.2
Mid-summer NDVI	81.8	83.3	80.0	83.3	80.0	63.3
Fall NDVI	54.5	60.0	50.0	50.0	60.0	9.8
Spring, mid-summer, & fall NDVI	77.3	88.9	69.2	66.7	90.0	55.3

Table 3. Accuracy assessments using 'jack-knifing' classification methods for single date, multitemporal TM data and NDVI. Mid-summer (July) TM and NDVI had highest overall accuracy levels.

Data used	Overall (%)	Producer's (%)		User's (%)		Kappa (%)
		Cool	Warm	Cool	Warm	
Spring TM	72.7	71.4	75.0	83.3	60.0	44.1
Mid-summer TM	81.8	83.3	80.0	83.3	80.0	63.3
Fall TM	45.5	50.0	40.0	50.0	40.0	0.01
Spring, mid-summer, & fall TM	63.6	70.0	58.3	58.3	70.0	27.8
Spring NDVI	59.1	63.6	54.5	58.3	60.0	18.2
Mid-summer NDVI	81.8	83.3	80.0	83.3	80.0	63.3
Fall NDVI	54.5	60.0	50.0	50.0	60.0	9.8
Spring, mid-summer, & fall NDVI	68.2	77.8	61.5	58.3	80.0	37.4

in mid-summer (July). The classification results support the MANOVA findings in that the differences were greatest in mid-summer allowing the two grassland cover types to be spectrally separated. Furthermore, the MANOVA results revealed that the two grassland cover types were not significantly different in any of the fall (September) TM bands. The classification results again support the MANOVA findings in that the two grassland cover types were not spectrally distinct in the fall.

The overall classification accuracy levels using the jack-knife verification show that the spring and summer single date images were more accurate at separating the two grassland cover types than the multitemporal image (table 3). In-sample and jack-knife accuracy levels for the multitemporal image were 100% and 63.6%, respectively. The results suggest that spectral differences between the dominant vegetation in the two grassland cover types were maximized in mid-summer and biophysical characteristics of warm and cool season study sites may have been too similar in the spring and fall. In addition, species composition may also add spectral confusion with each study site composed of a mixture of warm and cool season species. While grassland classification using multitemporal imagery is not yet very common, most studies employing a multitemporal approach have reported increased classification accuracy levels over the single image approach (Lo *et al.* 1986, Egbert *et al.* 1995, Price *et al.* 1997).

With the exception of spring (May) NDVI, NDVI discriminated between the two grassland cover types as accurately if not more accurately than the raw TM data (table 3). Fall (September) and multitemporal NDVI separated the two grassland cover types 9% and 5% more accurately than the corresponding TM data. Furthermore, mid-summer NDVI separated the two grassland cover types as accurately as the mid-summer scene (table 3).

Comparing the NDVI classifications shows that mid-summer NDVI was approximately 22% more accurate at separating the two grassland cover types than spring NDVI, 27% more accurate than fall NDVI, and 14% more accurate than multitemporal NDVI. Previous studies have shown NDVI to accurately estimate biophysical characteristics of grasslands including LAI and biomass (Briggs and Nellis 1989, Gamon *et al.* 1993, Todd *et al.* 1998) and this study shows that mid-summer (July) NDVI is as effective as mid-summer (July) TM data for discriminating between cool season and warm season grassland cover types in Douglas County, Kansas.

5. Conclusions

This study compared single date and multitemporal classification approaches as alternatives to the traditional field observation approach for identifying cool and warm season grassland cover types. The traditional field observation approach generally requires substantial input of manpower and time. Meanwhile, the single date image approach offers advantages over the traditional approach, and may be able to detect subtle differences in the vegetation types. However, selection of the single best date may be difficult. Although not demonstrated in this study, a multitemporal approach may maximize the spectral separability between land cover types, but it is also more expensive.

Field data showed differences in total living cover and senescent vegetation between the grassland cover types. While the field data indicated that living biomass was similar between the grassland cover types, biomass was highly variable. There were differences in species composition, with warm season study sites having more species present within the study plots and a greater percentage of forb cover. The results suggest that the differences in the phenological and compositional characteristics in mid-summer allowed warm and cool season grassland cover types to be accurately discriminated using Landsat TM data. Multitemporal data did not improve accuracy levels obtained using the mid-summer (July) image or mid-summer NDVI suggesting that the two grassland cover types were not spectrally distinct in spring and fall.

Acknowledgments

The authors would like to acknowledge the Kansas Applied Remote Sensing (KARS) program where the research was conducted. Additionally, the authors would like to thank Mike Houts and Xulin Guo for their field and lab assistance and Jerry Whistler and the anonymous reviewers for their valuable review comments.

References

Asrar, G., Weiser, R. L., Johnson, D. E., Kanemasu, E. T., and Killeen, J. M., 1986, Distinguishing among tallgrass prairie cover types from measurements from multispectral reflectance. *Remote Sensing of Environment*, **19**, 159–169.

Asrar, G., Myneni, R. B., Li, Y., and Kanemasu, E. T., 1989, Measuring and modeling spectral characteristics of a tallgrass prairie. *Remote Sensing of Environment*, **27**, 143–155.

Briggs, J. M., and Nellis, D., 1989, Thematic Mapper digital data for predicting aboveground tallgrass prairie biomass. In *Proceedings of the Eleventh North American Prairie Conference*, edited by T. B. Bragg and J. Stubbendieck, 7–11 August 1988, (Lincoln, Nebraska: University of Nebraska Printing), pp. 53–55.

Briggs, J. M., and Nellis, M. D., 1991, Seasonal variations of heterogeneity in the tallgrass prairie: A quantitative measure using remote sensing. *Photogrammetric Engineering and Remote Sensing*, **57**, 407–411.

Buttner, G., and Csillag, F., 1989, Comparative study of crop and soil mapping using multitemporal and multispectral SPOT and Landsat Thematic Mapper data. *Remote Sensing of Environment*, **29**, 241–249.

Chavez, P., 1988, An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing of Environment*, **24**, 459–479.

Chen, D., and Brutsaert, W., 1998, Satellite-sensed distribution and spatial patterns of vegetation parameters over a tallgrass prairie. *Journal of the Atmospheric Sciences*, **55**, 1225–1238.

Collins, S. L., and Gibson, D. J., 1990, Effects of fire on plant community structure in tallgrass prairie. In *Effects of Fire on Tallgrass Prairie Ecosystems*, edited by S. L. Collins and L. L. Wallace (Norman, Oklahoma: University of Oklahoma Press), pp. 81–98.

Congalton, R. G., 1991, A review of assessing the accuracy of classification of remotely sensed data. *Remote Sensing of Environment*, **37**, 35–46.

Curtis, J. T., 1959, *The Vegetation of Wisconsin* (Madison, Wisconsin: University of Wisconsin Press).

Daubenmire, R., 1959, A canopy-cover method of vegetation analysis. *Northwest Science*, **33**, 43–46.

Diamond, D. D., and Smeins, F. E., 1988, Gradient analysis of remnant true and upper coastal prairie grasslands of North America. *Canadian Journal of Botany*, **66**, 2152–2161.

Duffey, E., 1974, *Grassland Ecology and Wildlife Management* (London: Chapman & Hall).

Dunham, J. W., and Price, K. P., 1996, Comparison of nadir and off-nadir multispectral response patterns for six tallgrass prairie treatments in eastern Kansas. *Photogrammetric Engineering and Remote Sensing*, **62**, 961–967.

Dyer, M. I., Turner, C. L., and Seastedt, T. R., 1991, Mowing and fertilization effects on productivity and spectral reflectance in *bromus inermis* plots. *Ecological Applications*, **1**, 443–452.

Egbert, S. L., Price, K. P., Nellis, M. D., and Lee, R., 1995, Developing a land cover modelling protocol for the high plains using multi-seasonal Thematic Mapper imagery. In *Proceedings, ASPRS/ACSM Annual Meeting*, 27 February–2 March, (Charlotte, North Carolina: American Society for Photogrammetry and Remote Sensing), pp. 836–845.

Friedl, M. A., Michaelsen, J., Davis, F. W., Walker, H., and Schimel, D. S., 1994, Estimating grassland biomass and leaf area index using ground and satellite data. *International Journal of Remote Sensing*, **15**, 1401–1420.

Gamon, J. A., Field, C. B., Roberts, D. A., Ustin, S. L., and Valentini, R., 1993, Functional patterns in an annual grassland during an AVIRIS overflight. *Remote Sensing of Environment*, **44**, 239–253.

Holecheck, J. L., Pieper, R. D., and Herbel, C. H., 1989, *Range Management Principles and Practices* (New Jersey: Prentice Hall).

Hulbert, L. C., 1969, Fire and litter effect on undisturbed bluestem prairie. *Ecology*, **50**, 874–877.

KARS (Kansas Applied Remote Sensing), *Kansas Land Cover Mapping Project*. 11/96, [http://gisdasc.kgs.ukans.edu/kanview/landcov/html/Douglas/html], (10 May 1999).

Knipling, E. B., 1970, Physical and physiological basis for the reflectance of visible and near-infrared radiation. *Remote Sensing of Environment*, **1**, 155–159.

Lachenbruch, P. A., 1967, An almost unbiased method of obtaining confidence intervals for the probability of misclassification in discriminant analysis. *Biometrics*, **23**, 639–645.

Lauver, C. L., and Whistler, J. L., 1993, A hierarchical classification of Landsat TM imagery to identify natural grassland areas and rare species habitat. *Photogrammetric Engineering and Remote Sensing*, **59**, 627–634.

Lo, T. H. C., Scarpace, F. L., and Lillesand, T. M., 1986, Use of multitemporal spectral profiles in agricultural land-cover classification. *Photogrammetric Engineering and Remote Sensing*, **52**, 535–544.

NCDC (National Climatic Data Center), *Global Historical Climatology Network (GHCN)*. [http://www.ncdc.noaa.gov/cgi-bin/res40.pl], (25 July 1999).

Owensby, C. E., 1993, *Introduction to Range Management* (Manhattan, Kansas: Department of Agronomy, Kansas State University).

Price, K. P., Pyke, D., and Mendes, L., 1992, Shrub dieback in a semiarid ecosystem: the integration of remote sensing and geographic information systems for detecting vegetation change. *Photogrammatic Engineering and Remote Sensing*, **58**, 455–463.

Price, K. P., Varner, V. C., Martinko, E. A., Rundquist, D. C., and Peake, J. S., 1993, Influences of land management and weather on plant biophysical and hyperspectral response patterns of tallgrass prairies in northeastern Kansas. In *PECORA12*, 24–26 August (Sioux Falls, South Dakota: American Society for Photogrammetry and Remote Sensing), pp. 441–450.

Price, K. P., Egbert, S. L., Nellis, M. D., Lee, R., and Boyce, R., 1997, Developing a land cover modelling protocol for the High plains using multi-seasonal Thematic Mapper imagery. *Transactions of the Kansas Academy of Science*, **100**, 21–33.

Risser, P. G., 1988, Diversity in and among grasslands, In: *Biodiversity*, edited by E. O. Wilson, (Washington, DC: National Academy Press), pp. 176–180.

Stevens, J., 1996, *Applied Multivariate Statistics for the Social Sciences* (New Jersey: Lawrence Erlbaum Associates).

Stubbendieck, J., Friisoe, G. Y., Bolick, M. R., 1995, *Weeds of Nebraska and the Great Plains* (Lincoln, Nebraska: Nebraska Department of Agriculture).

Todd, S. W., Hoffer, R. M., and Milchunas, D. G., 1998, Biomass estimation on grazed and ungrazed rangeland using spectral indices. *International Journal of Remote Sensing*, **19**(3), 427–438.

Tucker, C. J., 1980, Remote sensing of leaf water content in the near infrared. *Remote Sensing of Environment*, **10**, 23–32.

United States Department of Agriculture, 1977, *Soil Survey of Douglas County* (Washington, DC: Soil Conservation Service in Cooperation with Kansas Agricultural Experiment Station).

United States Department of Agriculture, 1998, *1997 Kansas County Profiles: Douglas County*. [http://www.nass.usda.gov/ks/coflyer/1997/045.htm], (1 December 1998).

Walthall, C. L., and Middleton, E. M., 1992, Assessing spatial and seasonal variations in grasslands with spectral reflectances from a helicopter platform. *Journal of Geophysical Research*, **97**, 18 905–18 912.

Weaver, J. E., 1954, *North American Prairie* (Lincoln, Nebraska: Johnsen Publishing Company).

Weiser, R. L., Asrar, G., Miller, G. P., and Kanemasu, E. T., 1986, Assessing grassland characteristics from spectral measurements. *Remote Sensing of Environment*, **20**, 141–152.

Whistler, J. L., Egbert, S. L., Jakubauskas, M. E., Martinko, E. A., Baumgartner, D. W., and Lee, R. Y., 1995, The Kansas land cover mapping project: regional scale land use/land cover mapping using Landsat Thematic Mapper data. In *Proceedings, ASPRS/ACSM Annual Meeting*, 27 February–2 March, (Charlotte, North Carolina: American Society for Photogrammetry and Remote Sensing), pp. 773–785.