A COMPARISON OF SPECTRAL MIXTURE ANALYSIS AND NDVI FOR ASCERTAINING ECOLOGICAL VARIABLES

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1.   INTRODUCTION

In this study, we compare the performance of spectral mixture analysis to the Normalized Difference Vegetation Index (NDVI) in detecting change in a grassland across topographically-induced nutrient gradients and different management schemes. The Konza Prairie Research Natural Area, Kansas, is a relatively homogeneous tallgrass prairie in which change in vegetation productivity occurs with respect to topographic position in each watershed (Schimel et al. 1991). The area is the site of long-term studies of the influence of fire and grazing on tallgrass production and was the site of the First ISLSCP (International Satellite Land Surface Climatology Project) Field Experiment (FIFE) from 1987 to 1989.

Vegetation indices such as NDVI are commonly used with imagery collected in few (<10) spectral bands. However, the use of only two bands (e.g. NDVI) does not adequately account for the complex of signals making up most surface reflectance. Influences from background spectral variation and spatial heterogeneity may confound the direct relationship with biological or biophysical variables (Choudhury 1987, Huete and Jackson 1988). High dimensional multispectral data allows for the application of techniques such as derivative analysis and spectral curve fitting, thereby increasing the probability of successfully modeling the reflectance from mixed surfaces. The higher number of bands permits unmixing of a greater number of surface components, separating the vegetation signal for further analyses relevant to biological variables.

2.   METHODS

AVIRIS imagery was acquired for the Konza Prairie in August 1990. Field data were collected from 12 watersheds in 1990 as part of the annual primary production measurements made by the NSF Long-Term Ecological Research (LTER) program. The LTER watershed estimates are derived as an average of biomass values collected from sites on the ridges and lowlands. (Values are not acquired in the slope regions; sampling in this way does not consider the variation in production across the watersheds.) These estimates are broken down into components of: live (grass), forbs (herbs), current dead, litter, total live (live + forbs) and biomass (total live + current dead).

The AVIRIS image cube was atmospherically corrected using the ATmospheric REMoval Program (ATREM) (Version 1.1, 1992) and filtered in the frequency domain using a Butterworth filter (Hamming 1989). ATREM retrieves "scaled surface reflectance" from image spectrometer data using atmospheric absorption features of atmospheric gases.

The endmembers for the mixture analysis were selected manually using an interactive tool to explore the eigenvector space for endmembers (Bateson and Curtiss 1993). The AVIRIS cube was unmixed twice. Wavelengths were restricted to the visible region (bands 5 to 30 and 33 to 43) for the first unmixing and the shortwave-infrared region (SWIR; bands 45 to 56, 62 to 76, 82 to 89, 104 to 148, 179 to 186) for the second. NDVI was computed using bands 28 (665 nm) and 43 (776 nm) for the entire image.

The concentrations computed from the unmixed data and the NDVI values were regressed against the ground data. The ground data were normalized by dividing all values by the sum of biomass and litter to derive concentration values comparable to the scene component concentrations and NDVI. Sensitivity of the remote sensing data to spatial variation in surface characteristics was tested by plotting values for endmember concentrations and NDVI along transects extracted from unburned and burned watersheds. Comparisons were also made between the images for each endmember fraction and a map of the Konza Prairie research treatments (including fire and grazing treatments).

3.   RESULTS AND DISCUSSION

Five scene endmembers (soil, vegetation, litter, shade, and a second vegetation) were selected in fourth dimensional space of the visible portion of the spectrum using the endmember selection tool (Figure 1). These endmembers were identified by visual comparison with known library and field endmembers.
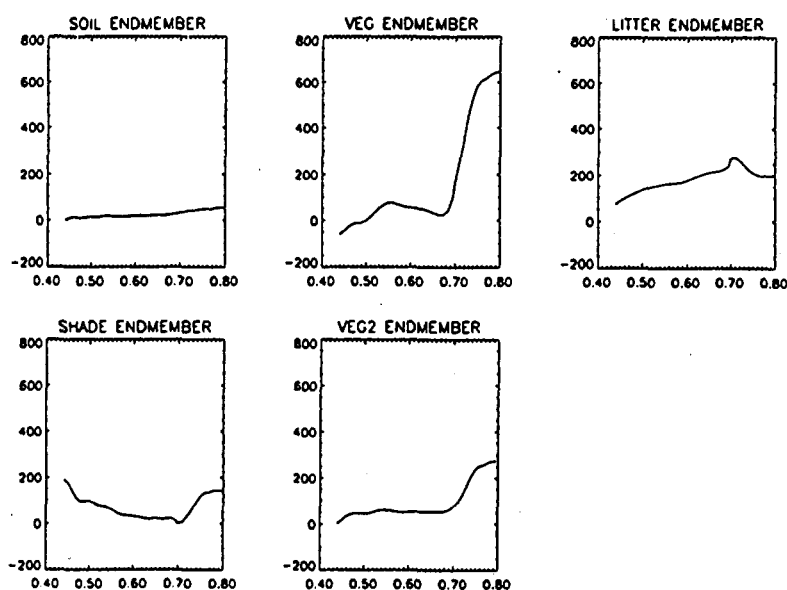

Figure 1. Five endmembers derived from the Konza image cube using the manual endmember selection tool.

The SWIR region consists of more subtle absorption features, necessitating less subjective identification methods. Four endmembers were differentiated: one resembling liquid water, a second resembling leaf "lignin" and two of unknown origin. To verify the identity of the "lignin" and liquid water endmembers, the endmember spectra derived from the image were curve fitted to various laboratory endmember spectra. To do this curve fitting, we used a variant of the method in McKenzie and Johnston (1982). In the curve fit, we assume there is only one endmember, since we are trying to identify each derived endmember with one library endmember. The logs of both the library and derived endmembers are computed to obtain the absorption coefficients. In McKenzie and Johnston (1982), a regression line is fitted to the absorption coefficients of the derived endmember over a short wavelength interval and the deviations of the coefficients from the line are regressed against the deviations similarly computed for the library endmember. Since the endmembers in our analysis span several band segments, we fit separate lines to each segment.

Two of the derived endmembers were fitted with various library endmembers. To identify the endmembers, we used two criteria: small RMS and large correlation

coefficient. The derived water endmember best fit to the library water spectrum with r = 0.96 and RMS = 12.25 (Fig. 2a). The best fit for the "lignin" endmember was a spectrum from weathered, highly leached leaves believed to consist largely of highly recalcitrant materials such as lignin (r = 0.52 and RMS = 7.06; Fig. 2b). Although the correlation coefficient is not impressive, the plot of the fit is very convincing. The reason for this discrepancy lies in the fact that the correlation coefficient is computed in log-log space. The next closest fit was with a laboratory starch spectrum with r = 0.51 and RMS = 7.03. Although r and RMS of the starch spectrum are close to that of the "grey leaves" spectrum, the relative positions of the curve segments in the laboratory starch spectrum do not agree with those of the "lignin" endmember.
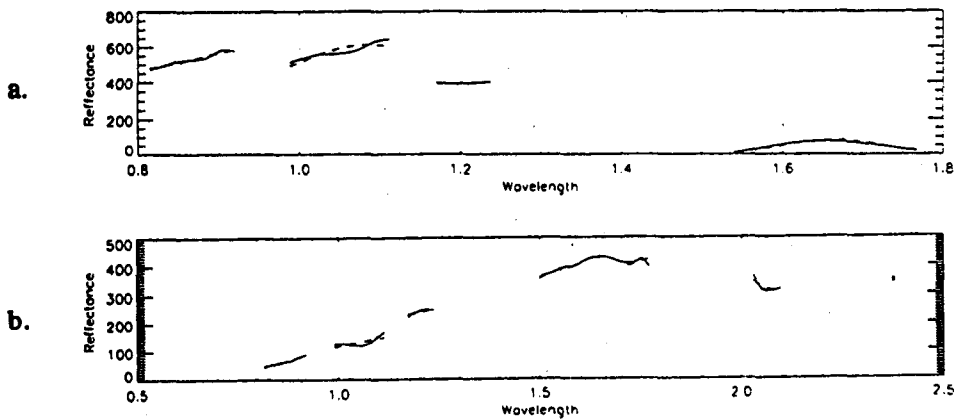

Figure 2. Curve fit of (a) water laboratory spectrum to derived water endmember and (b) "grey leaves" laboratory spectrum to the derived "lignin" spectrum.

Endmember concentrations and NDVI were regressed against the ground data. Green vegetation had a correlation coefficient with total live biomass of r = 0.73 (p = 0.007) compared with an r of 0.56 (p = 0.059) for NDVI. Hence, a significant correlation was achieved by removing background influences through spectral unmixing. The "lignin" concentration had a significant correlation with litter (r = 0.73, p = 0.007) and a highly significant correlation with biomass + litter (r = 0.82, p = 0.001). This suggests that the "lignin" endmember is tracking green and standing dead vegetation as well as litter; lignin is present in live and dead plant material.

Concentration images for the landscape constituents exhibit spatial patterns that reflect expected distributions with respect to the research treatments. For example, figure 3 shows transect plots of green vegetation, water, litter, soil and "lignin" concentrations for the burned watershed 1B. The drainage channel of the watershed occurs between coordinate positions 250 and 260. As expected, vegetation and water endmember fractions are highest in the drainage channel. Litter, "lignin", and soil fractions are highest on the ridges. There are notably strong correlations between "lignin" and litter concentrations (r = 0.87) and between water and vegetation concentrations (r = 0.88). The transect plots for the unburned watershed UB show similar relationships except that the correlation between litter and "lignin" concentrations is stronger (r = 0.91) and the correlation between water and vegetation concentrations is weaker (r = 0.67). In the Konza image, vegetation concentrations are generally higher in the burned and ungrazed areas and in the lowlands of each watershed. The litter endmember is sensitive to many of the unburned areas and the soil concentrations are highest on the ridge tops.

The most remarkable image is that of the "lignin" endmember, which clearly distinguishes between the research treatments. Higher concentrations are seen in the unburned, ungrazed watersheds just as expected. We conjecture that the sensitivity of the "lignin" endmember to actual lignin concentrations is due to the fact that it is based on more than a narrow wavelength interval, as is the case with other methods for detecting

lignin. Figure 4 (Slide 6) is a two-band image showing the spatial relationship between the derived lignin and water fractions across the site. While the two variables covary to a certain degree, the combination discriminates among fire and grazing research treatments in a unique way:
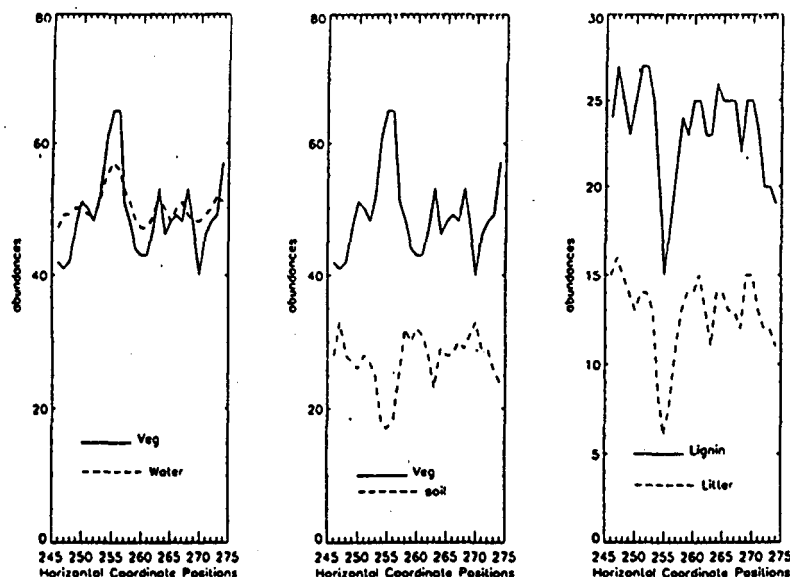

Figure 3. Transect plots of fraction values of green vegetation, water, soil, lignin and litter endmembers for the burned watershed. Drainage channel occurs between coordinate positions 250 and 260.

4.   SUMMARY

Spectral image analysis using visible wavelengths and endmembers derived from the AVIRIS image produced more meaningful information about the Konza research area than did the vegetation index NDVI. However, the most promising results were obtained by using shortwave-infrared wavelengths to obtain information on the chemistry within the scene. The so-called "lignin" endmember appears to be responding to variable conditions induced by different fire and grazing regimes. Our separation of the visible and infrared wavelengths for mixture analysis of the AVIRIS imagery revealed possible inroads to the ecological structural of the Konza landscape not present other image transformations.

5.   REFERENCES

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