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A COMPARATIVE STUDY OF THE THEMATIC MAPPER AND LANDSAT SPECTRAL BANDS FROM FIELD MEASUREMENT DATA

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ABSTRACT

Principal component and factor analysis techniques have been applied to the spectral data collected over 27 field plots of various crops under varying agronomic conditions. The spectral data was integrated over the proposed Thematic Mapper bands and the Landsat MSS spectral bands. The results have been examined to compare the discrimination power of the Thematic Mapper using existing techniques.

I. INTRODUCTION

Landsat-D is scheduled to be launched in July 1982 into a Sun-Synchronous orbit of a nominal altitude of 705 km with a repeat-period of 16 days. The principal observing instrument on Landsat-D would be the Thematic Mapper. This instrument will have considerably greater spatial, spectral, and radiometric resolution over the multispectral scanner (MSS) on Landsat-2 and Landsat-3. The Thematic Mapper (TM) will have seven spectral bands--0.45 to 0.52, 0.52 to 0.60, 0.63 to 0.69, 0.76 to 0.90, 1.55 to 1.75, 2.08 to 2.35, and 10.4 to 12.5 μm [1].

A number of studies have been done in regards to the placement of the spectral bands for their ability to discriminate vegetation. Markham and Barker[2], using field spectral reflectance data recorded over corn and soybean plots in 1978, have examined the question of whether the TM bands provide improvements over the MSS bands for vegetative targets. Using the percentage canopy cover as a measure of the crop status, they concluded that (1) the expected performance improvements of the TM over the MSS due to improved spectral and radiometric resolution were not conclusively evident, and (2) the added value of the new TM bands--TM1: .45 to .52 μm; TM5: 1.55 to 1.75 μm; and TM6: 2.08 to 2.35 μm--appears limited except, perhaps, as an additional independent measure of the canopy cover or plant canopy status. Holmes[3], using a variety of targets (vegetation, soils, rocks, etc.), indicated that no more than four TM bands appear to be linearly independent.

Ungar and Goward[4] have recently examined FSS helicopter data from Webster County, Iowa, in individual TM-bands and indicate that the ability to separate corn and soybeans in TM2 and TM5 spectral bands changes as a function of the time of year measurements are taken.

Ungar and Bradley[5] have examined the possibility of using the TM4/TM3 ratio instead of the MSS7/MSS5 ratio as an indicator of vegetation. While it was expected that TM4/TM3 would be a better indicator than MSS7/MSS5 due to the avoidance of the 0.95 μm water absorption band, their results do not support this idea.

In the present work, data obtained in the Supporting Field Research Project have been examined to see if the TM bands can provide improved vegetative discrimination over the MSS bands of Landsat. Instead of choosing a particular measure of improvement, principal component analysis and factor analysis have been applied to the data as a means of determining information content.[6]

This method of data analysis does not necessarily determine the most meaningful information in all cases. There may be better ways of getting at the information content depending on particular circumstances. This point should be kept in mind in the discussion concerning general relationships of information content and spectral bands.

II. ANALYSIS OF DATA

The basic data used in the present study were acquired using a helicopter-mounted Field Spectrometer System (FSS) over Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota. The FSS instrument has a field-of-view of the ground of 22 meters, a spectral resolution of 20°A from 0.4 to 1.1 μm, and a resolution of 50°A from 1.1 to 2.4 μm. The basic measurements are the bidirectional reflectance values throughout the growing season. Additional data collected over cornfield plots at the Purdue Agronomy Farm, West Lafayette, Indiana, using an EXOTECH model-100, were also used in the analysis.

A complete description of the data sources, crop conditions, and instruments is given by Bauer et al.[7] Twenty-seven field plots in North Dakota, South Dakota, Kansas, and Indiana taken in 1976 and 1978 were analyzed. This data was integrated over the reflective TM bands and the MSS bands for detailed analysis. However, because of a current calibration uncertainty in the wavelength region of 0.67 to 0.70, the TM3 band was integrated only from 0.63 to 0.67 μm, and MSS band 6 was integrated from 0.60 to 0.67 μm.

The attempt of this study was to look at an ideal situation. Thus, unlike other studies[2,3,5], this data set was not extrapolated using an atmospheric model. However, the data were examined after converting the bidirectional reflectance into radiance using the solar irradiance values calculated from the tables of Thekaekara et al.[8] for each of the spectral bands.

A. TM BANDS DATA ANALYSIS

Table 1(a) gives the correlation matrix of the 27 field plots with a total of 5268 spectra. This includes data from all observation days, from planting to harvest; however, the predominant part of the data is in vegetative development. This table shows a very high degree of correlation between TM1, TM2, and TM3. This high correlation should be expected since TM1 is sensitive to chlorophyll and carotinoid concentrations, TM2 is sensitive to chlorophyll and green reflectance characteristics, and TM3 is sensitive to chlorophyll concentration. The observed high degree of correlation between TM5 and TM6 bands is not surprising because both of these bands are sensitive primarily to water in plant leaves. The TM4 band, which is sensitive to vegetational density (or biomass), shows little or no correlation with any of the other TM bands. Thus, it is not surprising that only three groups of TM bands--Group 1: TM1, TM2, TM3; Group 2: TM4; and Group 3: TM5, TM6--carry almost all of the signal power because of the high correlation between channels in each group.

It should also be noted from this table that the correlation between TM1 and TM6 is very high also. (The results of a factor analysis for each of the crops analyzed in this data set shows no dependence on crop type). It shows that the TM6 band accounts for only about 8% of variance over and above that already accounted for by TM1 and TM4 bands. The high degree of correlation between TM1 and TM6 is observed for the corn experiment, with and without nitrogen stress treatments. Similar results are observed in the case of drought stress.

Independent evidence of this relationship can be seen in figure 1. It is a plot of measured water concentration against the nitrogen concentration from cornfield plots. The points correspond to different days throughout the growing cycle. The solid circles are nitrogen stress (OkgN/Ha) and the crosses are for adequate nitrogen (202 kgN/Ha). It is clearly seen that the measurements are high correlated, giving R^2 of 0.945 and 0.874 for seven data points.

Since nitrogen concentration can be expected to be proportional to chlorophyll concentration and negatively proportional to reflectance in TM1 or TM3, and since water concentration is expected to be negatively proportional to TM5 or TM6 reflectance, the observed correlation of water content and nitrogen concentration from the corn experiment provides an independent confirmation of a high correlation between reflectance in TM1 and TM6. Maranvill and Paulsen[9] confirmed from carefully controlled experiments that moisture stress (reduced water content) results in reduced chlorophyll concentration, a result earlier reported by Virgin[10] who postulated that moisture stress affects the formation of chlorophyll by slowing the formation of protochlorophyll, an immediate precursor of chlorophyll. Johannsen[11] measured the effect of decreasing moisture contents on the reflectance of corn and soybean leaves. He showed that the green color response and chlorophyll absorption (0.53 μm and 0.64 μm) have a high negative correlation with leaf moisture and that changes in leaf moisture affect the pigments in the leaf in a short period of time.

It was indicated earlier that the correlation coefficient of TM1 (or TM2 or

TM3) with TM6 (or TM5) is high. However, this correlation is not as high as that between TM1, TM2, and TM3 or TM5 and TM6. In the discussion above it is shown that there is reason to believe that there should be a correlation between chlorophyll and water absorption bands. However, since the effect of water stress does not show up in the chlorophyll band instantaneously but has a certain time delay, it is expected that the correlation with TM6 at time t will be more highly correlated with TM1 at time $t+\tau$ ($\tau>0$). From the current data, one can show that $0<\tau<18$ days. This value of the correlation between Group 1 and Group 3 should be interpreted with this point in view.

There is an indication of this effect in the results presented by Ungar and Goward[4], who analyzed the time profile of reflectance in TM2 and TM5 bands for both corn and soybeans. It was shown that the resolution between these crops in band TM2 is larger early in the growing season, when the resolution in TM5 is small; however, later in the growing season the reverse is true.

Thus, it is seen that in all cases examined there is an underlying physical reason for the observed high correlation between the TM bands for vegetative targets. The results show that virtually all of the variance is contained in three of the TM bands. Table 1(b) gives the results of applying a principal component analysis of this data. It again shows very nearly the same results as shown by the factor analysis in Table 1(c)[6].

B. MSS BANDS DATA ANALYSIS

Table 2(a) presents the correlation matrix, Table 2(b) presents the results of the principal component analysis, and Table 2(c) presents the factor analysis of all the field and corn plots, with the analysis being performed in MSS bands.

It is seen here that two components carry almost all of the variance. Since the MSS4 and MSS7 bands provide nearly the same spectral information as TM2 and TM4, the only additional information is expected from the TM6 band. TM6 (or TM5) has been translated to provide an indication of moisture stress, a point discussed earlier in the paper.

C. TEMPORAL DATA ANALYSIS

The current techniques used in the discrimination of vegetative targets depend heavily on the change in the relative reflectance as a function of time in the crop growth period. Thus, in order to see the improvement in discrimination power, the time behavior of the reflectance must be examined. Since the principal components provide a comparatively better description of the data than each band, it is the time behavior of the eigenvector expressed in radiance that has been examined for all of the 27 fields. For the purpose of illustration only, figure 2 shows a plot of six principal components from TM data and four principal components from the MSS data for the spring wheat field 441 as a function of the day of year.

The eigenvectors are obtained from the mean of each band and all of the scans over the given field. The values of the standard deviation/mean vary from about 5-10% on any given day of the year with a typical value of about 7%. It is quite obvious from figures 2 and 3 that only the principal components 1, 2, and 3 differ much from a nonzero value. A more careful examination reveals that the principal component 3 does not change within one standard deviation as one goes across time, and this is equivalent to a d.c. component and cannot in any likelihood carry much information about the crop. Therefore, components 1 and 2 carry the real information about the crop and its status.

Comparisons of figures 2 and 3 show that this is also the case for the MSS data. The interpretation of the TM's principal component is essentially analogous to the Kauth-Thomas[12] components and the TM's principal components 1, 2, and 3 can be interpreted as brightness, greenness, and yellowness, whereas the nonsuch components can be any one of components 4, 5, and 6. If the first data point (the data point before the crop emergence) is ignored, then, except for a constant offset and within the standard deviation/mean of about 7%, the two principal components of these fields (and all 27 fields) have essentially the same magnitude and time behavior.

It is then expected that the power of discrimination of vegetative targets after the crop has emerged is very nearly the same from the two sensors. This behavior is found even for the nitrogen fertilization experimental plots and water stress fields. It should be pointed out that the time behavior of TM4/TM3 and MSS7/MSS4 shows the same kind of behavior[5]; however, the conclusion drawn here does not apply to discrimination of soil type or to the classification of techniques that are essentially unitemporal in nature.

However, the conclusion drawn depends on the current analysis procedures. This has already been indicated by the results of Ungar and Goward[4] who have shown TM2 and TM5 provide corn-soybean separation at different times. Operationally, this would indeed be useful.

It should be stressed again that the present study does not examine the effects of the improved signal-to-noise ratio of TM over MSS or the improvements in the atmospheric correction algorithms that the additional TM bands may provide.

III. CONCLUSION

There is a very high degree of correlation between reflective TM bands, and these can be explained by physical phenomena. The expected performance improvements of TM over the MSS due to improved reflective region spectral characteristics do not seem to be evident for vegetative targets using current techniques. An exhaustive study that includes the effect of larger TM scan angles, atmospheric effects, improved signal-to-noise, and unitemporal classification procedures should be undertaken. New technique may need to be enclosed to extract any new information. An example of this would be work of Ungar and Goward[4].

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Table 1. Factor and Principal Component Analysis of Thematic Bands

(a) Correlation matrix

Bands	TM1	TM2	TM3	TM4	TM5	TM6
TM1	1.000					
TM2	0.967	1.000				
TM3	0.934	0.969	1.000			
TM4	0.004	0.155	0.0316	1.000		
TM5	0.885	0.802	0.775	-0.112	1.000	
TM6	0.786	0.654	0.652	-0.3183	0.941	1.0

(b) Principal component analysis

	Thematic Mapper Bands						
Bands	TM1	TM2	TM3	TM4	TM5	TM6	Cumulative %
1.	0.982	0.942	0.930	-0.060	0.943	0.864	72.6
2.	0.090	0.273	0.172	0.960	-0.134	-0.372	92.4
3.	0.080	0.179	0.293	-0.273	-0.276	-0.320	98.7
4.	-0.141	-0.041	0.136	0.016	0.028	0.029	99.4
5.	-0.018	0.007	-0.017	-0.021	0.125	-0.106	99.9
6.	-0.041	0.062	-0.025	-0.006	-0.005	0.011	100.0

(c) Proportion of variance extracted by each band

Bands	Proportion Variance	Cumulative Proportion
TM1	0.702	0.702
TM4	0.190	0.892
TM6	0.077	0.969

Table 2. Factor and Principal Component Analysis of MSS Bands

(a) Correlation matrix

Bands				
MSS4	1.000			
MSS5	0.992	1.000		
MSS6	0.138	0.0593	1.000	
MSS7	-0.194	-0.268	0.932	1.000

(b) Landsat 2 and 3 MSS bands

Bands	MSS4	MSS5	MSS6	MSS7	Cumulative %
MSS4	-0.831	-0.872	0.432	0.704	53.3
MSS5	0.553	0.487	0.899	0.706	99.5
MSS6	0.000	0.027	0.078	-0.010	99.5
MSS7	0.049	-0.046	-0.010	100.0	

(c) Proportion of variance extracted by each band

Bands	Proportion variance	Cumulative proportion
MSS4	0.510	0.510
MSS7	0.481	0.991
MSS5	0.003	0.993
MSS6	0.007	1.000

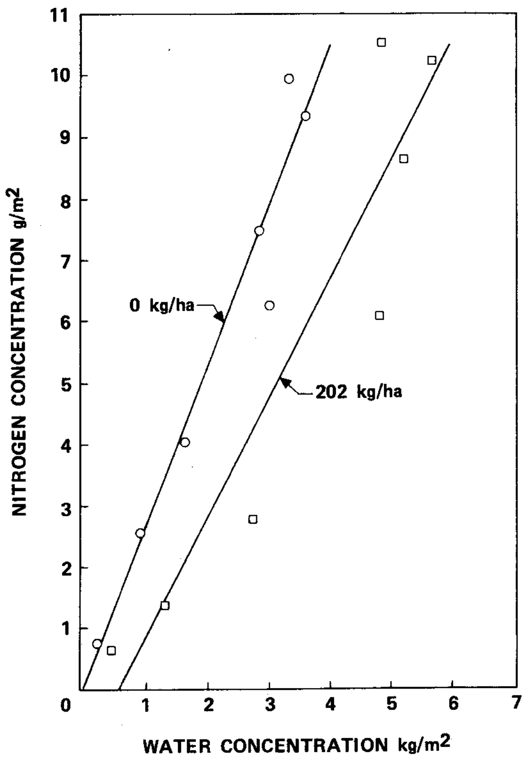

Figure 1. A plot of water concentration in kg/m^2 versus the nitrogen concentration in flag leaves g/cm^2 from well fertilized (202 kg/ha) and not fertilized (0 kg/ha) corn plots.

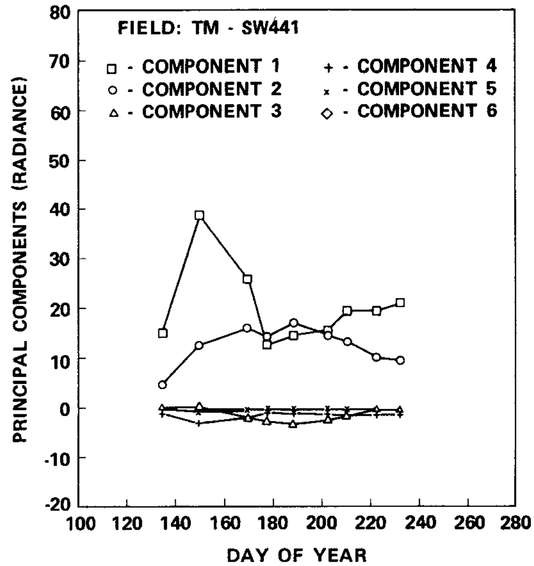

Figure 2. A plot of the six principal components of a spring wheat field as a function of the day of year. No. 4, 5, 6 almost have no time dependence.

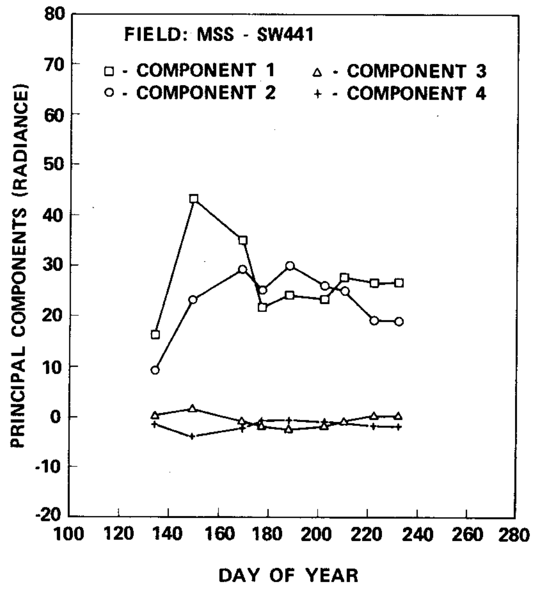

Figure 3. Same plot as in Figure 2 except of MSS bands.

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