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THEMATIC MAPPER CROP SPECTRAL SEPARABILITY AS DETERMINED BY FIELD RADIOMETRY

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ABSTRACT

If single acquisition Landsat Thematic Mapper data is to be useful for land cover/land use classification in agricultural regions, it is necessary to determine which crops are spectrally different at any particular time of the growing season. <u>In situ</u> measurement with field portable radiometers obviates the need to acquire imagery from the whole season, and allows preliminary assessment of the information derivable from Thematic Mapper wavebands. In the present experiment, three sites in three to six fields of ten crop types were observed throughout the 1984 growing season with a truck mounted Barnes Modular Multispectral 8-band Radiometer (in a TM simulation configuration). At each site, crops were photographed and agronomic data were recorded. Data analyses indicate that any pair of crop types are spectrally different at some time of the year, but there is no single time of year at which all crops are different from each other.

INTRODUCTION

Background/Objectives

The Thematic Mapper (TM) onboard Landsats 4 and 5 incorporates several improvements in its design relative to the Multispectral Scanner (MSS) flown on all Landsat missions to date. These improvements include better spatial, spectral and radiometric resolution, as well as increased geometric fidelity. In short, the TM has 30m vs. 80m spatial resolution in its visible/reflected infrared bands. It has 6 narrow spectral bands in the visible/reflected infrared spectrum, compared to the 4 relatively broad bands of the MSS. Three of the TM's visible/reflected infrared bands (1,5,7) measure reflected radiation in spectral regions previously unsampled by the MSS, and band 6 produces data in a 120m resolution thermal infrared band. All data are digitized with 8 bit vs. 6 bit radiometric resolution. The geometric correction applied to the data relates observations to ground geodetic positions to within a nominal accuracy of ±0.5 pixel.

All of the above improvements in the design of the TM sensor should contribute to an increase in the accuracy and specificity of agricultural land cover classification. However, the fundamental spectral characteristics of various crops in the TM bands as a function of crop phenology, management, and condition are only beginning to be explored (e.g. Crist and Cicone, 1984). In the present study our aim was to document the spectral characteristics (in the TM bands) of several crops common to southern Wisconsin. We sought to describe how the visible and reflected infrared reflectance of these crops varied over the course of a typical growing season. This knowledge is needed to answer such basic questions as what crops are spectrally differentiable, when, and with what degree of accuracy. The state of Wisconsin is interested in answering these questions not only in the general context of land cover mapping, but also in the specific context of potentially utilizing TM data to support statewide soil conservation planning activities.

Approach

In situ reflectance measurement with a mobile radiometer system formed the heart of the data acquisition activity in this study. Field radiometry afforded several distinct advantages over actual TM data for our purposes. First, data collection is not constrained to the 16 day observation frequency characteristic of Landsat. Second, weather problems are minimized when the time of observation can be varied. Third, corrections for atmospheric path effects are not necessary in the data analysis. Fourth, the cost and availability of actual TM data are problematic. (One TM scene was acquired to support our study under NASA/NOAA's "Special Acquisition" program but was not available at the time of this writing).

MATERIALS AND METHODS

Site

The study sites included non-experimental production fields at the Arlington Experimental Farms (University of Wisconsin) and nearby commercial fields in southern Columbia County, Wisconsin. Dairying is still the predominant land use in this area but there is an increasing trend toward cash grain and vegetable production. Land formerly used for forage production is being continuously planted in corn and soybeans.

The silt loams of the study area are deep prairie soils formed in loess over glacial till (fine-silty, mixed, mesic Typic Argiudolls). They have high natural fertility and available water capacity. The surface layer is black (10 YR 2/1) or very dark brown (10 YR 2/2). Most fields used in the study had 0% to 2% slopes, the steepest had a 6% slope.

Soil moisture and rainfall were adequate throughout the growing season with the exception of an eleven day period in late July and early August. Some corn on eroded or coarse textured soil showed signs of drought stress.

Experimental Design

A total of 612 observations from ten crop types were used in the analysis reported herein. Crops and numbers of fields observed were: corn (6), soybeans (3), peas (3), snapbeans (4), winter wheat (3), potatoes (3), established alfalfa (4), permanent pasture (3), direct seeded alfalfa (3), and oats/alfalfa (3). Oats are generally used as a nurse crop to establish alfalfa in this area. The same 3 locations in each field were observed on up to 8 dates between May 29 and September 15, 1984. The data were subsequently divided into six temporal groups based on the developmental phenology of the area's main crops - corn and alfalfa.

The radiometer used in this study is a Barnes Model 12-1000 Modular Multiband Radiometer (MMR). A detailed description of this instrument can be found in Robinson, et al. (1981). The MMR includes eight radiometric channels, seven of which match the bands of the TM. We limited our analysis to the six reflected wavelength bands. Radiometer voltage responses, sensor temperatures, and times of acquisition were recorded on a Model 516 Polycorder (Omnidata International).

The radiometer was operated on a fully extended pickup truck mounted boom eight meters above the canopy. This resulted in a two meter ground cell size about 9 m. from the field edge. A teflon calibration panel mounted above the truck on a collapsible platform was observed every 20 to 30 minutes to measure solar irradiance. Reflectance from row crops was measured twice on row and twice off row. Forages and small grains were measured thrice on the same spot at each location. These multiple observations were averaged in the calculation of percent reflectance.

Field notes were collected on boom azimuth and elevation, and on soil, plant, and sky conditions. Plant height, growth stage, and stand counts were measured and soil surface moisture and percent canopy cover were estimated for each location. All of the observations were supplemented by thirty-five millimeter oblique or vertical photographs.

The time from solar noon of an acquisition (as a surrogate for sun angle effects) was not a significant factor in analyses of between crop variability. Accordingly, the simple ratio of radiometer voltage response on target to voltage response on the calibration panel was the percent reflectance used in this analysis, rather than the Bidirectional Reflectance Factor accounting for the sun-target-sensor angle effects called for by Robinson and Biehl (1979).

RESULTS

With the ultimate goal of determining which crops are spectrally separable at what times of the year, several graphic and statistical data analysis techniques were examined. All analyses were done with the aid of SAS statistical package using a VAX 11/780 computer.

Spectral Reflectance Plots

Plots of multispectral crop reflectance were useful for showing which bands were most important for crop discrimination at any particular time. Figure 1 shows the mean, minimum and maximum percent reflectance in the six analyzed bands for various crops observed on June 11, 14, or 19, 1984. The inclusion of minimum and maximum values on the plots provided a means to deduce the distribution of values contributing to the mean. In partially closed canopies, there tended to be a skewed distribution, depending on the variability of plant vs. soil predominance in the fields of view.

In Figure 1a. (the row crop plot), reflectances from peas were substantially different from the other crops. At this time, the pea canopy was almost closed while the other crops covered less than 25% of the ground. The wide range of values for peas in band 4 is due to including observations from a field with large storm washouts and manifesting stress from root rotting organisms. The regular ordered relation of the other crops to each other is essentially the result of differences in soil moisture.

The need to have separate classes for mature and recently cut pasture and alfalfa can be seen in Figure 1b. As expected, the closed canopies (A,U) have substantially higher near infrared reflectance than the recently cut or grazed canopies. The relation reverses in the mid-IR, suggesting these new TM bands may contain information not previously detected by the MSS. However, canonical analysis of the data from this date showed that bands 5 and 7 could be used to explain very little of between crop variation, due to the large within crop variability in the test data.

The similarity of reflectance from oats/alfalfa with winter wheat seen in Figure 1b. suggests that oats/alfalfa should be classified as a small grain at this time of the year. The large range in wheat reflectance is due to differences in physiological maturity. Growth stage ranged from Feekes scale (Large 1954) value of 10.4 (three-quarters of heading completed) to 10.5.3 (flowering over).

Kauth-Thomas Transformations

Temporal trajectories have proven quite useful in charting crop reflectance changes over time. The Kauth and Thomas (1976) brightness/greenness transformation is one way to reduce the dimensionality of the data for plotting. Crist (1985) has adapted this transformation for radiometer data in a way that preserves the correlation of transformed variables and physical and physiological phenomena. This is the transformation shown in Figure 2.

The row crops start on a soil line (zero greenness) and do not show appreciable greenness until the July readings. Closer row spacing, flatter canopy geometry, and greater leaf area indices (LAI) of soybeans results in greater greenness and brightness throughout the summer. The large variance in soybean values is attributable to the inclusion of a field containing a variety of weeds. When over this area's dark soils, both crops decline in greenness and brightness with senescence. The result is a trajectory resembling the character "2" rather than a "tassel cap."

The alfalfa observations occur in a narrow ellipse of high brightness and greenness. This is even more apparent in plots of individual observations. Dense canopies appear at the upper right of a diagonal that slopes down to newly regreening canopies at the lower left of the plots. This co-variance is evident in plots of the third transformed component ("wetness," Crist (1983)) as well.

Winter wheat shows a steady decline in greenness throughout the season. As the lower leaves senesce, shadows become a larger component of the field of view, so brightness also declines until the crop is harvested.

Discriminant Analyses

Two tools frequently used in selection and refinement of training sets for image classification are tables of pairwise transformed divergence and confusion matrices for training or test areas. Similar information is provided by discriminant analysis in terms of Mahalanobis distance and posterior classification probabilities. Results of such an analysis for the data collected in early August are presented in Tables 1 and 2.

By early August, the canopy of the direct-seeded alfalfa is well developed. In six-dimensional space, it is quite close to the full canopy alfalfa and pasture. Both winter wheat and oats/alfalfa are fields of stubble at this time, so they cluster near each other. The only caveat from Table 1 is the relatively low divergence of corn from the forages. Corn is closest to ungrazed pasture. The pastures were about 70% brome grass (60-80 cm.) with mature seedheads and about 20% flowering alfalfa understory. This created a canopy with deep shadows, high LAI and non-green components similar to the stage 6 "blister" corn (Hanway 1963). The next closest class to corn is low cover alfalfa. Table 2 shows that this also resulted in one observation being misclassified. This observation was from a plot showing visible curling of leaves from drought stress.

CONCLUSIONS

The general conclusions about crop spectral separability in this study are no different than those that could be deduced by someone familiar with local crop phenology. Row crops are most separable from forages and small grains in the spring before the row crops have developed an appreciable canopy cover. Early August, just after oats and winter wheat are harvested, will be the best time to separate these small grains from all the other crops. Reflectance from forages will be variable throughout the growing season. If a single date is used to classify satellite data for land cover, it will be imperative to have separate classes based on some variable indicative of canopy condition such as growth stage, percent cover, or leaf area index.

It would not be prudent to make predictions about specific crop reflectance in TM data from this radiometer data. We feel that an increase in the number of observations made within each field is needed for a more statistically significant measure of within field variability. Likewise, a greater number of fields of each crop should be measured to fully account for between field (within crop) variability. The data are useful as a general indicator of separability, not to predict the relation of one crop to another.

Several types of information have yet to be extracted from these data. The correlation of reflectance with variables of agronomic interest is largely unexplored, as is the physical explanation of the third canonical or "tassel-cap" variable. A geographically extensive subset of the data acquired on the day of the satellite overpass should be useful in determining atmospheric effects and within crop variability over space.

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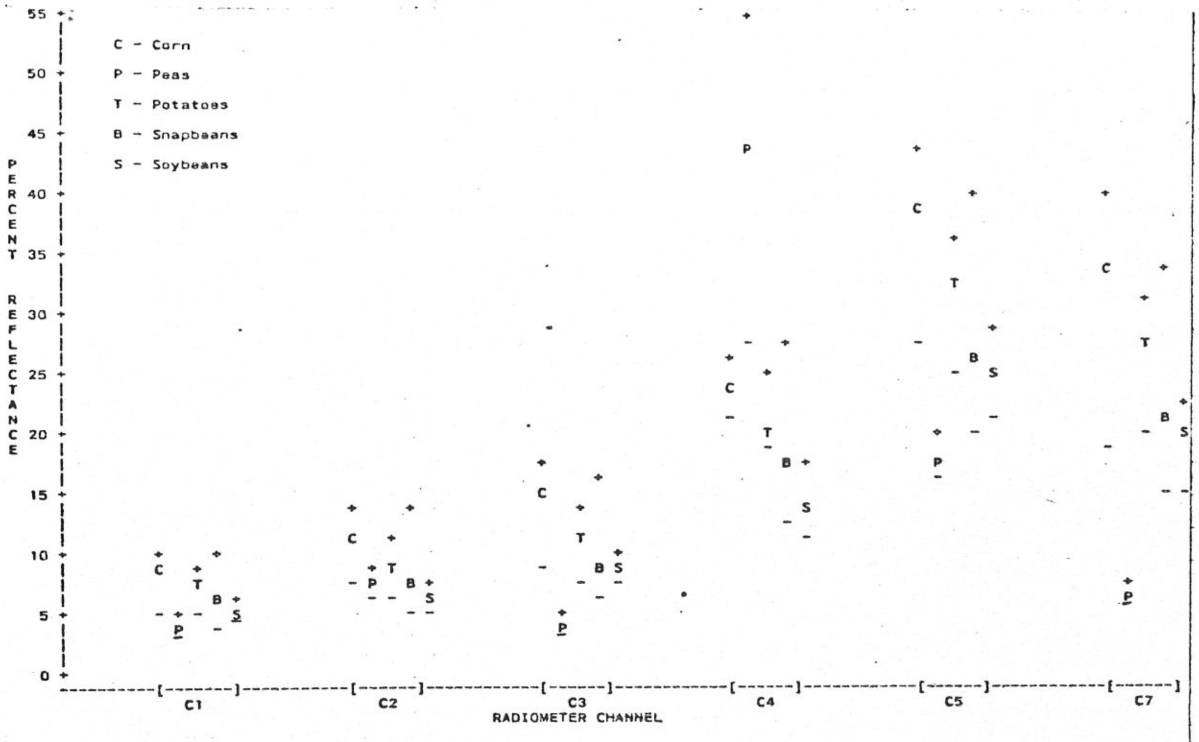
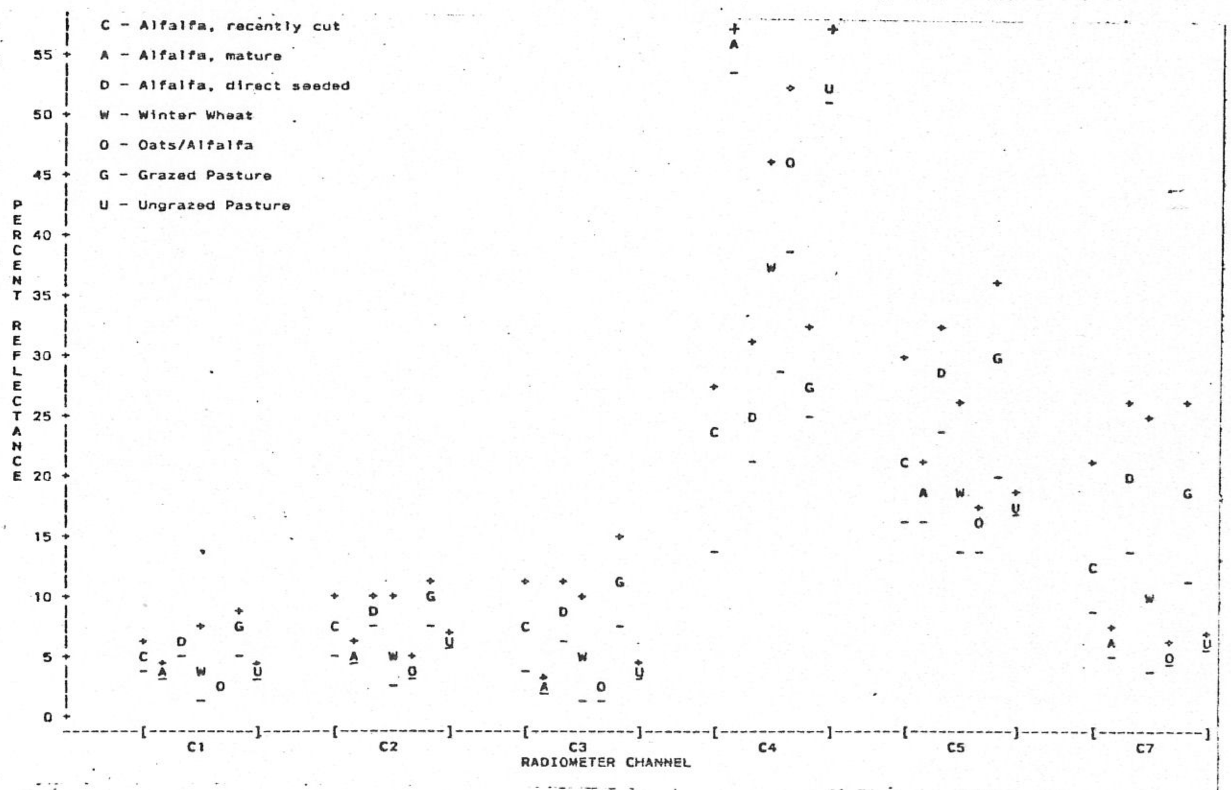


a.



b.

Figure 1 - Percent reflectance of row crops (a) and small grains and forages (b) in six TM equivalent reflectance bands for June 11 to 19, 1984. Letter, +, and - mean, maximum, and minimum value respectively.

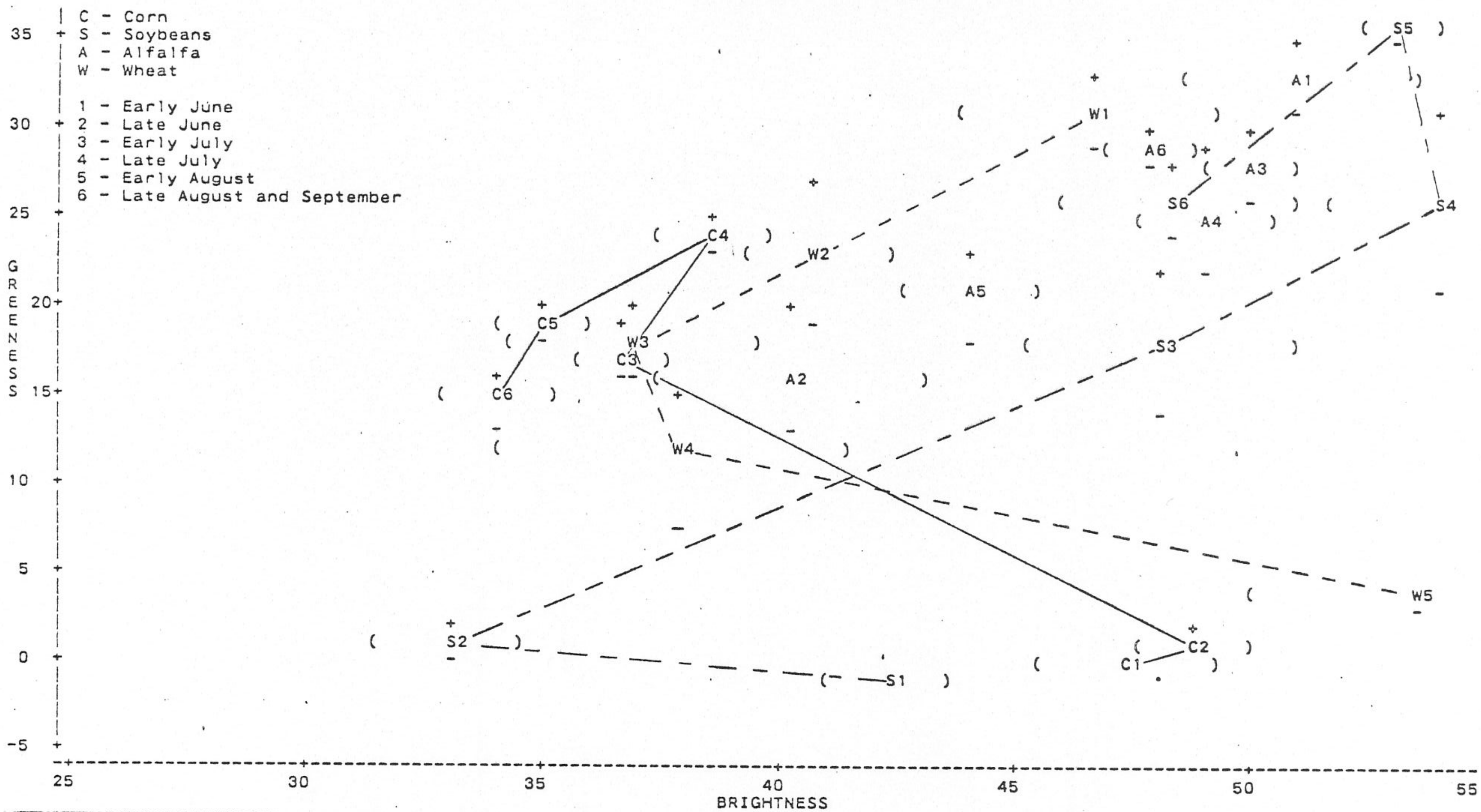


Figure 2 - Temporal trajectories in terms of first two Tassel Cap equivalent variables. Letter, ( ), and + - are mean, standard error of brightness mean, and standard error of greenness mean respectively.

	Corn	Bare Soil	Soy Beans	Winter Wheat	Low Cover Alfalfa	High Cover Alfalfa	Direct Seed Alfalfa	Oats/ Alfalfa	Grazed Pasture	Un-grazed Pasture
C	0.0	167.5	73.9	183.9	27.9	39.5	44.4	137.1	29.8	18.4
B	167.6	0.0	318.6	280.4	93.8	267.7	294.2	260.2	205.1	233.4
S	73.9	318.6	0.0	242.2	141.8	54.1	27.2	177.3	110.1	41.4
W	183.9	280.4	242.2	0.0	142.6	314.5	289.8	9.5	212.5	241.1
L	27.9	93.8	141.8	142.6	0.0	105.3	108.0	116.2	37.9	67.9
H	39.5	267.7	54.1	314.5	105.3	0.0	8.1	233.2	42.9	6.4
D	44.4	294.2	27.2	289.8	108.0	8.1	0.0	213.9	47.2	7.1
O	137.1	260.2	177.3	9.5	116.2	233.3	213.9	0.0	156.9	174.3
G	29.8	205.1	110.1	212.5	37.9	42.9	47.2	156.9	0.0	26.2
U	18.4	233.4	41.4	241.1	67.9	6.4	7.1	174.3	26.2	0.0

Table 1 - Generalized pairwise squared distances between crops for August 2 to 13, 1984.

	Corn	Bare Soil	Soy beans	Winter Wheat	Low Cover Alf.	High Cover Alf.	Direct Seed Alf.	Oats/ Alf.	Grazed Pasture	Un grazed Pasture	total
C	22	0	0	0	1	0	0	0	0	1	24
B	0	3	0	0	0	0	0	0	0	0	3
S	0	0	9	0	0	0	0	0	0	0	9
W	0	0	0	9	0	0	0	0	0	0	9
L	0	0	0	0	9	0	0	0	0	0	9
H	0	0	0	0	0	9	0	0	0	0	9
D	0	0	0	0	0	0	11	0	0	1	12
O	0	0	0	1	0	0	0	8	0	0	9
G	0	0	0	0	0	0	0	0	6	0	6
U	0	0	0	0	0	0	0	0	0	6	6
total	22	3	9	10	10	9	11	8	6	8	96

Table 2 - Classification results based on posterior probabilities of membership in class for August 2 to 13, 1984. Vertical axis is known class, horizontal axis is classification result.