Reprinted from

Eighth International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Crop Inventory and Monitoring

July 7-9, 1982

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

CULTURAL AND ENVIRONMENTAL INFLUENCES ON TEMPORAL-SPECTRAL DEVELOPMENT PATTERNS OF CORN AND SOYBEANS

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I. ABSTRACT

A technique for evaluating crop temporal-spectral development patterns is described and applied to the analysis of cropping practices and environmental conditions as they affect reflectance characteristics of corn and soybean canopies. Typical variations in field conditions are shown to exert significant influences on the spectral development patterns, and thereby to affect the separability of the two crops.

II. INTRODUCTION

The use of Landsat data for identification of cover types, as for example in a crop inventory system, has undergone a steady evolution over the life of the Landsat sensors. Early techniques based on data collected on a single date were replaced by multitemporal approaches as spatially-registered data became more readily available. The spectral development patterns of crops are now key features in many crop identification techniques, and the additional information gained by inclusion of the time domain has been of considerable importance.[1]

More recently, increased attention has been given to the use of characterizations of the continuous patterns of crop spectral development (termed "profiles") from which Landsat observations are sampled.[2] Just as the advance from unitemporal to multitemporal analysis removes much of the confusion caused by temporal crop differences (e.g., single date differences in the spectral appearance of two corn fields resulting from differences in planting date) and allows more detailed description of the spectral pattern of development of a crop or field, so the use of profiles provides even greater reduction in temporal sensitivity and greater detail in spectral description.

However, virtually all crop identification techniques, whether unitemporal, multitemporal, or profile-based, rely on the ability to detect consistent characteristic spectral features of a particular crop. Consequently, all these techniques are likely to be substantially and adversely affected by differences in the spectral characteristics of a crop resulting from changes in cultural or environmental conditions. Such differences are the expression of physiological changes in the plants themselves, resulting in changes in the spectral characteristics of the plant parts, and also of changes in canopy geometry, including the orientation and distribution of plant parts, and the relative mix of plant parts and soil in the sensor field of view.

To effectively use multitemporal data or profiles in crop identification procedures, it is essential to understand the impact of key cultural and environmental factors on crop spectral characteristics, and their expression in temporal-spectral development patterns. This paper describes a technique for deriving and evaluating profile characteristics, and presents the results of its application to the analysis of changes in corn and soybean profiles resulting from changes in a selection of cultural and environmental factors, using field reflectance data.

III. DESCRIPTION OF DATA

Reflectance and associated measurements of experimental plots have been collected for several years as part of a field research program carried out for NASA by Purdue/LARS. Experiments included in this analysis were carried out in 1978 through 1980, and featured as experimental treatments Nitrogen fertilization, planting date, and plant population for corn, and variety, planting date, and row spacing for soybeans.[3,4,5] Reflectance data were collected as or converted to Landsat-MSS inband reflectance values. These data were then converted to reflectance equivalents of Tasseled Cap variables[6], using a rotation of the principle components derived from the reflectance values.[7] The resulting variables, termed Green Reflectance and Bright Reflectance, are associated with the amount of green vegetation and albedo or soil brightness respectively.

IV. PROFILE ANALYSIS TECHNIQUE

Because even field-collected data are intermittent in nature, with gaps ranging from a few days to weeks between successive observations, and because differences in plot treatments result in differences in stages of development on any given observation day, comparison of treatment effects between plots and description of the overall patterns of spectral development are still difficult. Accordingly, a technique was devised for analysis of the reflectance data which consists of two elements: 1) curve-fitting to interpolate between observations and smooth extraneous data variation, and 2) description of the resulting profiles by means of a set of derived features, which reduces data volume and allows quantitative comparison of plots.

The curve-fitting was accomplished by one of two methods. A cubic smoothing spline was used in many of the analyses for evaluation of both corn and soybean profiles. This approach provided a general purpose technique which gave the desired balance of data smoothing and accurate characterization of the profiles. However, corn Greenness and Green Reflectance profiles include an unusual plateau or flattened region just after the peak profile value (Figure 1), which the cubic smoothing spline could not always adequately fit. As a result, a special mathematical model form was derived which included such a plateau feature.[7] Where the plateau of corn was of prime importance, this model was used instead of or in addition to the cubic spline.

Once profiles were determined, they were described by means of the following seven features: maximum or peak value (PMAX), time of maximum (PT), times of occurrence of half the peak value (HP1 and HP2), time from HP1 to PT (SPAN1), time from PT to HP2 (SPAN2), and time between half-peak values (SPAN3). Times to peak and half-peaks were measured from the planting date. For Green Reflectance profiles, these features can be related to rate of vegetative development (HP1, SPAN1, PT), maximum amount of green matter (PMAX), rate of senescence (SPAN2), and overall development rate (HP2, SPAN3). Two additional features were used to describe the plateau in corn Green Reflectance: the time of plateau end (TEND), computed by the intersection of lines approximately tangent to the plateau and the descending portion of the profile, and the slope of the plateau.

The significance of treatment effects on these profile features was determined qualitatively by visual analysis of the profiles themselves, and quantitatively by analyses of variance.

For evaluation of Bright Reflectance profiles, the influence of soil moisture and other unexplained factors on signal values in the first half of the profile span was so severe that the curve-fitting approach was not feasible. As a result, these profiles were derived manually and only evaluated qualitatively.

V. CULTURAL AND ENVIRONMENTAL EFFECTS ON PROFILES

The impact of the experimental treatments included in the LARS experiments will be discussed individually, first for corn and then for soybeans. A brief review of the physiological and canopy-geometric effects of the particular treatment will be given, based on review of agronomy literature. This will be followed by a description of the effects on profile features which were found to be statistically significant (to the .9 level) in this analysis.

A. CORN EFFECTS

Nitrogen Fertilization. The availability of Nitrogen, which is required by plants for the synthesis of chlorophyll, affects the quality of the vegetative parts of the plants. Nitrogen deficiency in corn causes stunting, leaf chlorosis, and premature senescence of lower leaves, while abundance of Nitrogen promotes lush green vegetation, including increases in the size and number of leaves, rate of leaf emergence, and longevity of green leaf area.

In corn Green Reflectance profiles, the effects of abundant Nitrogen, as compared to little or no Nitrogen, included higher and later peak Green Reflectance values, longer and flatter plateaus, and faster rates of profile increase (green-up).

While useable Bright Reflectance data were limited, some increase in peak Bright Reflectance with increased Nitrogen fertilization was detected.

Planting Date. Planting date effects are largely those of temperature, with later-planted crops experiencing higher temperatures at a given vegetative development stage than those encountered by earlier-planted crops. These higher temperatures stimulate more rapid plant emergence and development, and more rapid leaf area development.

In corn, very early planting (cooler temperatures) reduced the peak Green Reflectance value, the rate of green-up, and the overall development time. Late planting (warmer temperatures) also reduced the peak Green Reflectance value, but increased the rate of green-up, hastened the time of peak, and hastened senescence.

In Bright Reflectance, late planting reduced the maximum value, hastened the time of its occurrence, and hastened the time of apparent canopy closure (elimination of soil effects).

Population Density. Increases in corn plant population tend to increase the rate of production, maximum value, and longevity of green leaf area, increase the rate of early growth, and decrease the final height of the plants.

In Green Reflectance, these effects were expressed by a higher and earlier peak value, a faster rate of green-up, and a steeper plateau slope. High population plots also had higher peak Bright Reflectance values, and showed some tendency toward earlier elimination of soil effects in the Bright Reflectance profiles.

B. SOYBEAN EFFECTS

Variety. Many characteristics of soybean plants show varietal association. Days to maturity, final plant height, leaf size, number, and orientation, ability to achieve complete closure, rate of accumulation and maximum leaf area, and response to row spacing, planting delays, and other such factors all differ with variety. Thus, as expected, all the Green Reflectance profile features were significantly different for some combination of varieties at some row spacings. This result was found even though the varieties included in the experiments represent only a small portion of the total variability in soybean varieties over a region. Similarly, most of the characteristics of the Bright Reflectance profiles showed the influence of varietal differences.

Planting Date. The influence of planting date (temperature) on soybeans include reduced rates of canopy closure and plant height (early or late planting), and increased rates of emergence and early growth and reduced duration of the vegetative phase (late planting). Early planting reduced the peak Green Reflectance value, and delayed its achievement. Late planting similarly reduced the peak Green Reflectance value, but caused it to occur earlier. In addition, late planting hastened green-up, and reduced overall Green Reflectance development time.

In Bright Reflectance, late planting caused a faster increase in profile values, and an earlier achievement of peak value, while early planting seemed to cause a flatter peak in the Bright Reflectance profile.

Row Spacing. A wide range of responses to row spacing can be observed among soybean varieties. In general, wider rows are associated with slower accumulation of leaf area, and delays in achieving full canopy closure. In Green Reflectance, wider rows resulted in lower peak values, slower green-up and later achievement of peak, and faster green decline after peak. Similarly, wider rows were associated with lower and later peaks in Bright Reflectance profiles.

VI. SEPARABILITY OF CORN AND SOYBEANS

Using the profile features derived as previously described, an evaluation of the spectral separability of corn and soybeans was undertaken. As with the previously described analyses, profiles were derived with a "days since planting" time axis, so planting date differences between the two crops were ignored.

A. GREEN REFLECTANCE

Both the corn profile model and the cubic smoothing spline were used in this study, the former because it more accurately depicts the overall corn spectral development pattern, and the latter because it more closely resembles the type of approach which might be used in an operational system dealing with samples of unknown crop type. For reference, Figures 2 and 3 present average corn and soybean profiles, as derived from the set of reflectance data.

Corn Model. Substantial separability was found between corn and soybeans based on time and value of peak (PT and PMAX), rate of later vegetative development (SPAN1), and rate of Green Reflectance decline after the peak (SPAN2). Corn reached its peak earlier, achieved a lower peak, and maintained high Green Reflectance values longer than soybeans. The separability associated with the rate of decline is a result of the plateau effect in corn. Early green-up rates were essentially the same for the two crops, as were the slopes of the ascending portions of the Green Reflectance profiles (based on visual comparison). Thus little early season spectral separability was found in this data set.

Cubic Smoothing Spline. The primary distinguishing features using this technique were the value of the Green Reflectance peak (PMAX) and the rate of Green Reflectance decline (SPAN2). The separability related to rate of green-up found using the profile model was not evident using the spline. However, 100% separability was achieved using PMAX and SPAN2 as derived from spline profiles (Figure 4).

B. BRIGHT REFLECTANCE

The major source of separability in Bright Reflectance was the value of the profile peak, with soybeans achieving much higher Bright Reflectance values than corn (compare Figures 5 and 6). This difference is strongly correlated to the difference in peak Green Reflectance, both of which express the tendency of soybeans to move farther up the "green arm" in Tasseled Cap space than corn (Figures 7 and 8). This is the very feature used in many current techniques for distinguishing corn and soybeans in Landsat-MSS data.[8]

C. CULTURAL AND ENVIRONMENTAL EFFECTS ON SEPARABILITY

Many of the field conditions evaluated and described in Section V. affect the maximum profile values in Green and Bright Reflectance. Since this is a key feature for distinguishing corn and soybeans, one should expect that certain combinations of planting dates, row spacings, nutritional states, etc. would reduce separability. For example, highly fertilized corn achieved peak Green Reflectance values very close to or higher than those of late-planted or widely-spaced soybeans.

The other primary distinguishing feature, the rate of Green Reflectance decline, was also influenced by some of the factors evaluated. Again, lack of Nitrogen or late planting could shorten the plateau of corn such that the rate of decline feature was very similar to that of soybeans.

VI. CONCLUSIONS

It is clear from these analyses that variations in cropping practices and/or field conditions which are typically seen over relatively small regions can significantly affect the profile features of corn and soybeans. In addition, while various factors show some differences in their specific effects or combinations of effects on the profiles, many of them tend, at least on a gross level, to influence the same key profile features.

For crop condition assessment, this seems to suggest that it will be difficult, based on temporal-spectral data alone, to distinguish Nitrogen-deficient corn from corn planted at low population levels, or early-planted soybeans from soybeans planted in wide rows. However, with additional information such as meteorological data, the spectral profile features could be useful as a means of confirming the predictions of crop condition made for a particular region.

For crop identification, these analyses have both confirmed the importance of features currently used in corn/soybean discrimination and indicated the potential utility of additional profile-related features in separating these two crops. While the spectral effects of some field conditions are such that separability of corn and soybeans may be degraded in certain situations, the knowledge of the changes in profile features likely to occur in response to those conditions can allow development of techniques which adapt the expectations of crop profiles to the prevailing conditions in the region of interest, and thereby maximize the accuracy of crop identification, even in the presence of such confounding factors.

Note: This work was sponsored under Contracts NAS9-15476 and NAS9-16538 by the U.S. National Aeronautics and Space Administration, NASA Johnson Space Center, Houston, Texas 77058.

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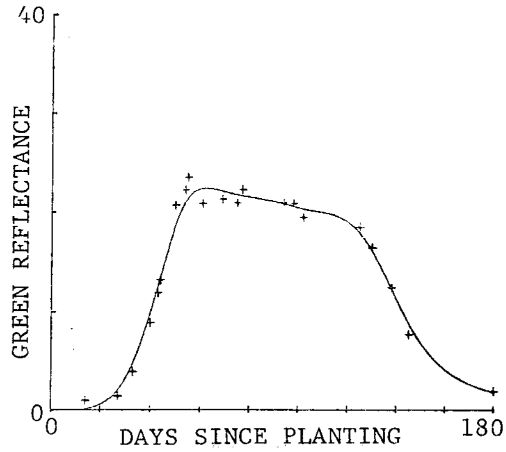

Figure 1. Plateau in Corn Green Reflectance Profile

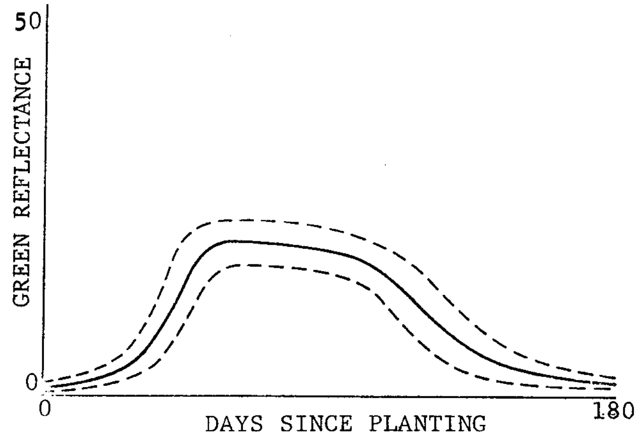

Figure 2. Average Corn Green Reflectance Profile

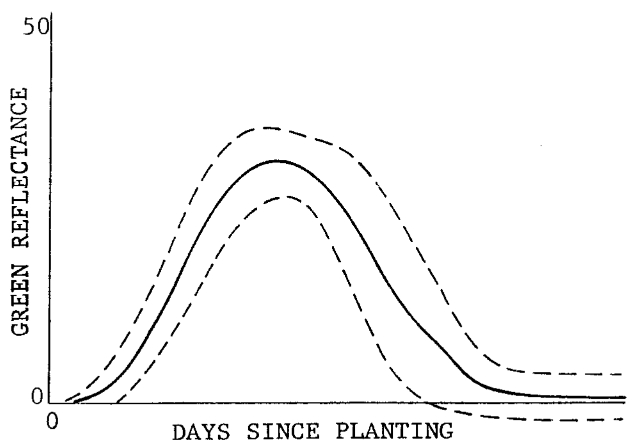

Figure 3. Average Soybean Green Reflectance Profile

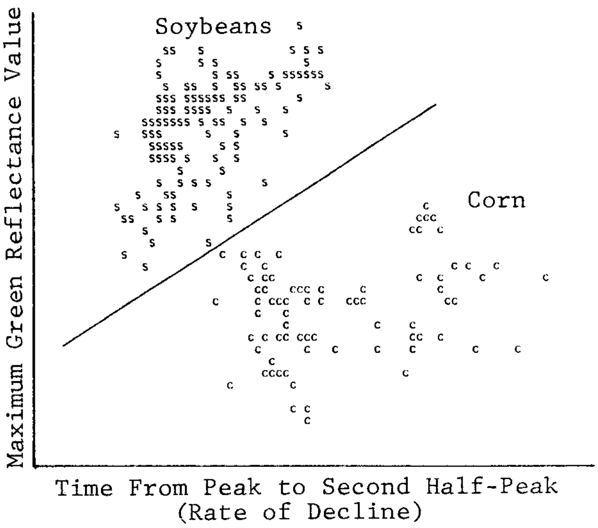

Figure 4. Separability of Corn and Soybeans Based on Spline-Derived Profile Features

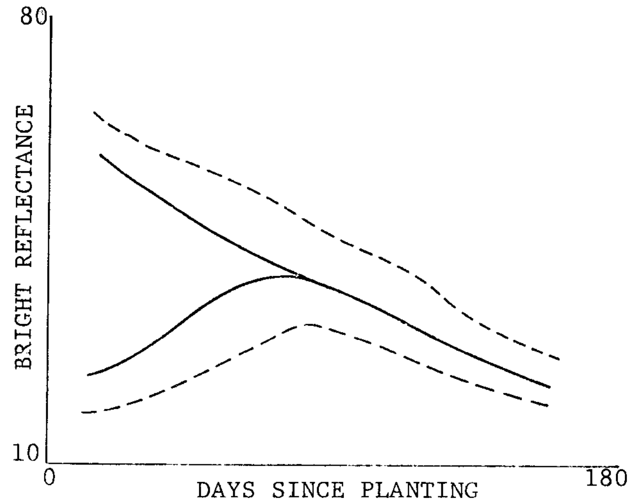

Figure 5. Average Corn Bright Reflectance Profile (Light and Dark Soil)

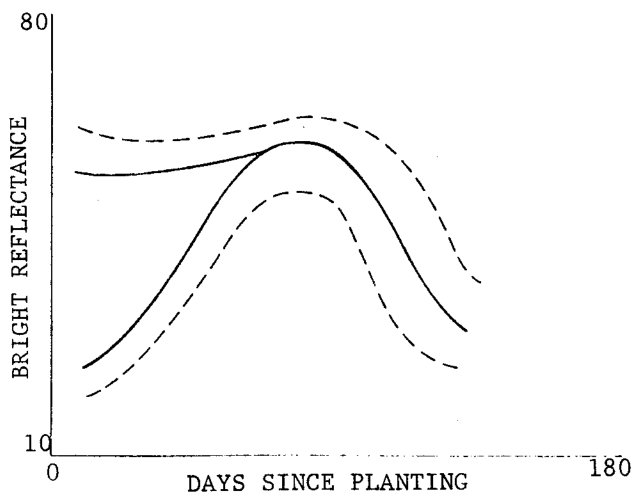

Figure 6. Average Soybean Bright Reflectance Profile (Light and Dark Soil)

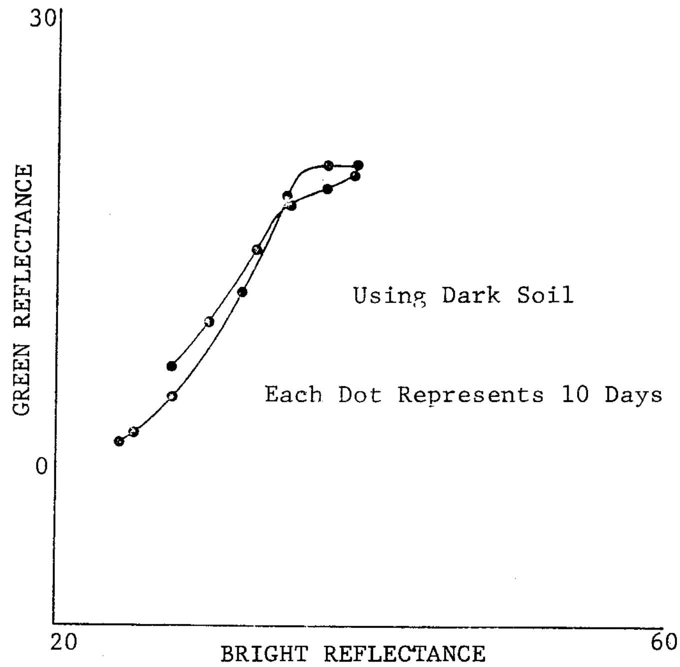

Figure 7. Average Corn Green Reflectance/Bright Reflectance Trajectory

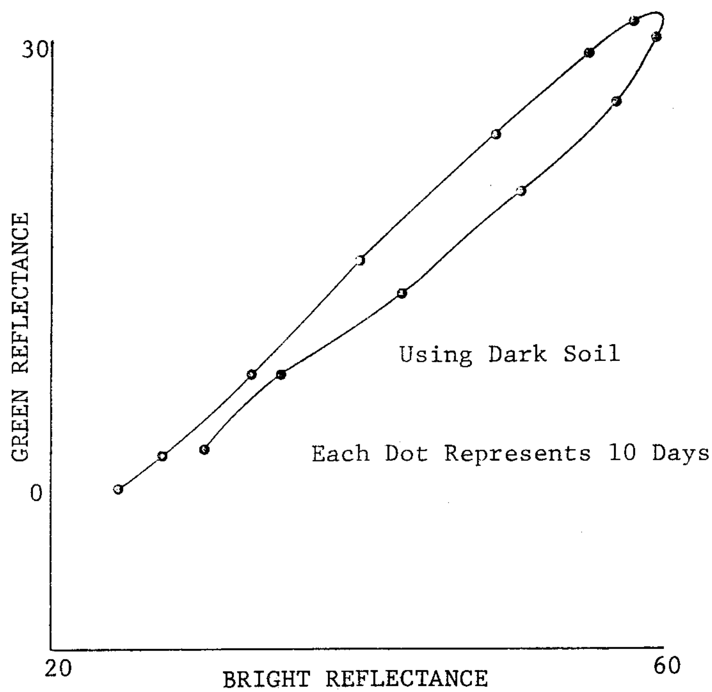

Figure 8. Average Soybean Green Reflectance/Bright Reflectance Trajectory

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