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APPLICABILITY OF SELECTED WHEAT REMOTE SENSING TECHNOLOGY TO CORN AND SOYBEANS

DANIEL P. RICE, ERIC P. CRIST, and WILLIAM A. MALILA

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ENVIRONMENTAL
RESEARCH INSTITUTE OF MICHIGAN
FORMERLY WILLOW RUN LABORATORIES, THE UNIVERSITY OF MICHIGAN
BOX 8618 • ANN ARBOR • MICHIGAN 48107

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16. Abstract

The objectives of this research effort were to begin to (1) examine the applicability to corn and soybeans of multispectral remote sensing technology developed for wheat and other small grains under the Large Area Crop Inventory Experiment (LACIE) and follow-on research and (2) investigate the detection thresholds of these crops. A 1978 set of field-measured reflectance data was the basis for the analyses. Corn data acquisitions were insufficient for the desired analyses, so the work concentrated on soybeans. Temporal-spectral profile models were fit to the data and crop calendar shifts were estimated; agrophysical phenomena were found to be correlated with differences in profile shapes. The profile technology appears applicable to soybeans, although further development work is indicated. The threshold of detection for soybeans in terms of vegetative cover was not found to be appreciably different from that determined previously for wheat.

17. Key Words Threshold of Detection, Detection Threshold, Crop Calendar Shift, Temporal-Spectral Profiles, Landsat, Agricultural Inventory, Remote Sensing	18. Distribution Statement

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ERIM

PREFACE

This document reports progress achieved during a one-year period on an analysis effort conducted by the Environmental Research Institute of Michigan (ERIM) for the purpose of providing technical support to the US/USSR Joint Study of Vegetation, Soils and Land Use. This effort further represents a small portion of ERIM's support of agricultural crop inventory activities of NASA's Lyndon B. Johnson Space Center, Houston, Texas.

The focus of the work reported herein was examination of the applicability to corn and soybeans of remote sensing technology that has been developed for wheat and other small grains.

The research was performed under Contract NAS9-15082, during the period November 1, 1978, through November 30, 1979. Dr. Michael C. McEwen initially served as the NASA Contract Technical Monitor, succeeded by Dr. David E. Pitts. At ERIM, the work was performed within the Infrared and Optics Division, headed by Richard R. Legault, Vice President of ERIM, in the Analysis Department which is headed by Robert Horvath. Dr. Quentin A. Holmes and Dr. William A. Malila served as Co-Principal Investigators. Daniel P. Rice and Eric P. Crist carried out the majority of the analysis reported.

We acknowledge the contribution made by personnel of Purdue University's Laboratory for Applications of Remote Sensing in acquiring and providing the field measurement data used in our analyses.

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INTRODUCTION

1.1 OBJECTIVES

The overall objective of the research reported herein was to begin to examine the applicability to corn and soybeans of multitemporal remote sensing technology that was developed for wheat and other small grains under the Large Area Crop Inventory Experiment (LACIE) and subsequent follow-on activities.

The first specific technology examined was characterization of temporal-spectral profiles that are the observable manifestations of crop phenology in Landsat multispectral scanner data. One goal was to begin to characterize the green development patterns of corn and soybeans. Another was to test and, if possible, demonstrate the feasibility of using existing profile fitting techniques for feature extraction and estimation of crop calendar shifts using corn and soybeans data. A third goal was to begin to understand relationships between the profile characteristics and agrophysical phenomena.

The second technology examined was investigation of the threshold of detection for corn and soybeans in Landsat data and comparison to results of last year's analysis for wheat [1].

1.2 BACKGROUND

The Large Area Crop Inventory Experiment (LACIE) addressed the problem of inventorying wheat and other small grains by using multidate Landsat data and employing analyst-interpreters to identify training data [2]. Variations in crop development stage among fields within individual 5x6-mile segments were sources of confusion and error in the labeling and identification process. Subsequently, techniques were developed to correlate multidate observations from individual fields and characterize profiles of green development versus time, in such a way that differences in small grain development stage could be measured and utilized [3-6]. The work reported here somewhat parallels work carried out by Badhwar [7] in extending the techniques to corn.

Another issue, important to mid-season and end-of-season estimates of crop acreage, is knowledge of the development stage or growth condition at which vegetation just becomes detectable as different from bare soil. Last year under this contract, a study of the detection threshold of wheat was conducted using field measurement and Landsat data acquired as part of the LACIE project, as well as simulation data [1].

2
APPROACH

The approach taken consisted of three major steps, as described in the subsections that follow.

2.1 SELECT AND PREPROCESS DATA

The overall approach was based on an analysis of field-measured reflectance data. The selected set contained measurements made with filters that simulated those in the Landsat multispectral scanner (MSS). Agronomic observations, including percent soil cover, were made along with the spectral measurements.

It was desired to conduct the analysis with spectral variables analogous to those produced by the Tasseled-Cap transformation of Landsat data [8]. A previously developed transformation of reflectance data [9] was utilized to create reflectance Brightness and Greenness variables. The transformation coefficients used are presented in Table 1; these coefficients were not developed for general use and do not account for band-to-band calibration differences, yet they do provide a close enough approximation for use in this preliminary analysis.

2.2 DETERMINE AND ANALYZE TEMPORAL-SPECTRAL PROFILES

Techniques were developed in References 4-6 for fitting analytic model forms to temporal sequences of Landsat observations, with prime emphasis on fitting the Green development profiles of small grain crops, as manifested in the Greenness variable.

The second model form of Reference 6 was used as the profile form for this investigation and was fit to values of reflectance Greenness. This form is:

TABLE 1. TASSELED-CAP-LIKE TRANSFORMATION
OF REFLECTANCE DATA IN LANDSAT BANDS [9]

$$\begin{bmatrix} \text{Brightness} \\ \text{Greenness} \end{bmatrix} = \begin{bmatrix} 0.32362 & 0.48521 & 0.56304 & 0.60949 \\ -0.48935 & -0.61249 & 0.17289 & 0.59538 \end{bmatrix} \begin{bmatrix} \text{Band 4} \\ \text{Band 5} \\ \text{Band 6} \\ \text{Band 7} \end{bmatrix}$$

Notes: (a) These coefficients were not developed for general use and do not account for the band-to-band calibration differences in Landsat.

(b) The development data set consisted of 1975-1976 reflectance data acquired by the NASA/JSC helicopter-borne FSS spectroradiometer in an early part of the LACIE Field Measurements Program [10] and was calibrated by use of a canvas panel as a secondary (transfer) reflectance standard through measurements by a truck-mounted spectroradiometer. Some differences were noted between calibrations of this truck-mounted instrument and another used extensively in the program.

$$F(t) = \begin{cases} a\,e^{b_1(t-t_p)^2}, & t < t_p \\ a\,e^{b_2(t-t_p)^2}, & t \geq t_p \end{cases}$$

where $F(t)$ = Greenness

t = day of year

t_p = day of peak Greenness

a, b_1, b_2 = model parameters

Observations for several fields (test plots) were fit to the model and one profile was chosen as a preliminary reference profile to compute crop calendar shifts for the other fields.

The crop calendar shift estimation concept is illustrated in Figure 1, which was extracted from Reference 5. When observed through time, a pixel or field of an annual crop could exhibit a temporal-spectral pattern like that shown in Figure 1a. One might expect neighboring fields of that crop to have similar appearances when observed at identical times. However, observations usually show a high degree of variability, as illustrated in Figure 1b. The underlying assumption in crop calendar shift estimation is that a large part of this variation is a result of differences in stage of development at the times of observation. Figure 1c represents the reference profile and Figure 1d its fit to the three individual fields. Figures 1e and 1f illustrate how a shifting of the observations to the time scale of the reference profile can remove or account for this source of variability. Variations in peak magnitude also can be present due to differing maximum vegetation densities. The cross-correlation calculation we use in determining the optimum shifts is insensitive to such scale differences [5]. Other residual variations may be present due to differing development patterns.

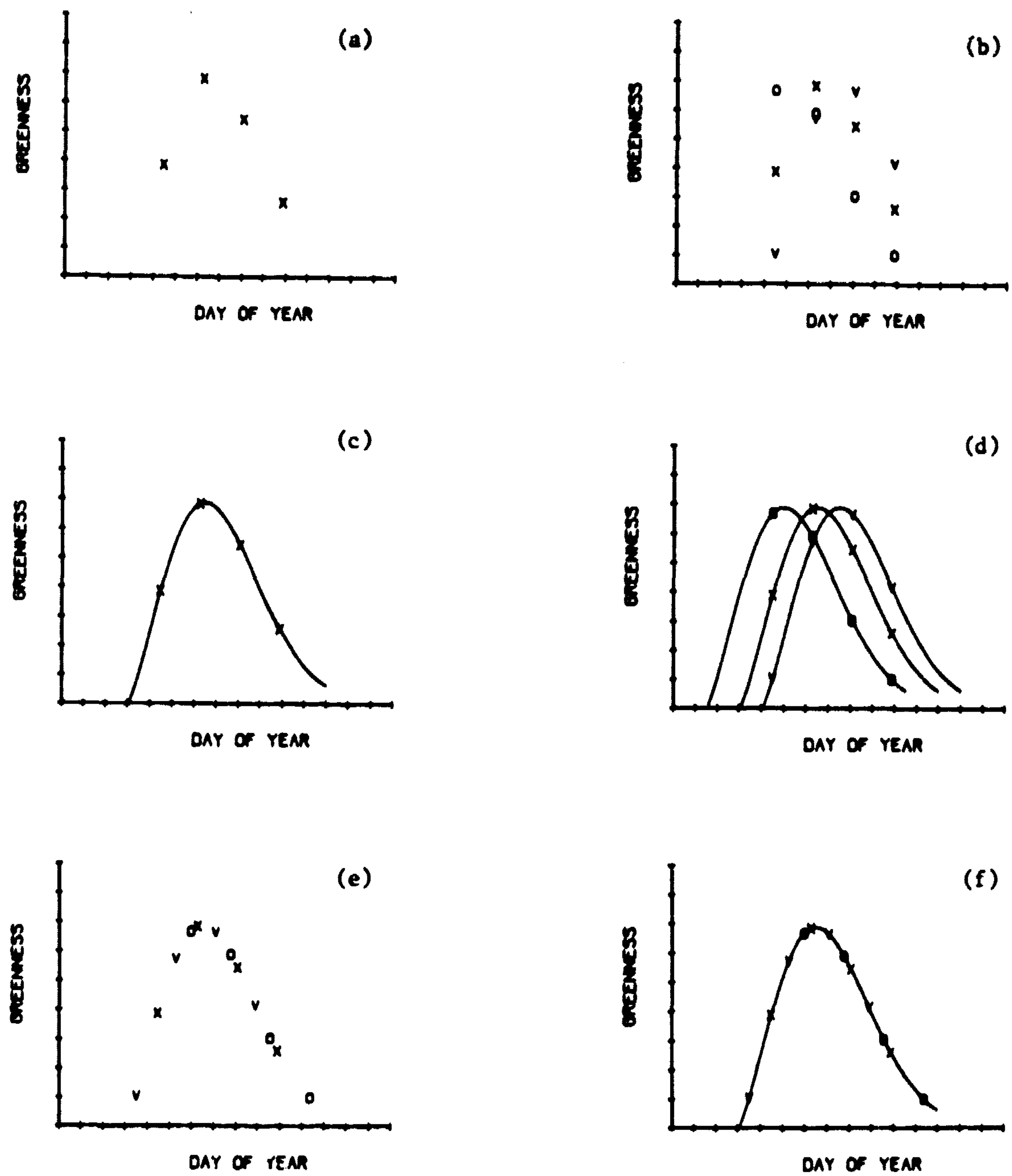


FIGURE 1. BASIC CONCEPT OF CROP CALENDAR SHIFT BASED ON GREEN DEVELOPMENT PROFILE

Having computed a crop calendar shift (effectively, the day of peak Greenness) for each of the other fields, individual profile fits were made to each field's observations, using a non-linear regression technique. Goodness of fit was computed as follows:

$$\text{Goodness of Fit} = 1 - \frac{\sum_i [F(t_i) - G_i]^2}{\sum_i [G_i - \bar{G}]^2}$$

where $F(t_i)$ = reference profile value for the day associated with the i^{th} observation,

G_i = i^{th} data value, occurring on shifted day t_i,

and $\bar{G}$ = mean of all data values.

Plots of data before and after shift were produced, as well as graphs of the individual model fits. A comparative analysis of the graphical products then was made, with reference to the agronomic observations made during data acquisition.

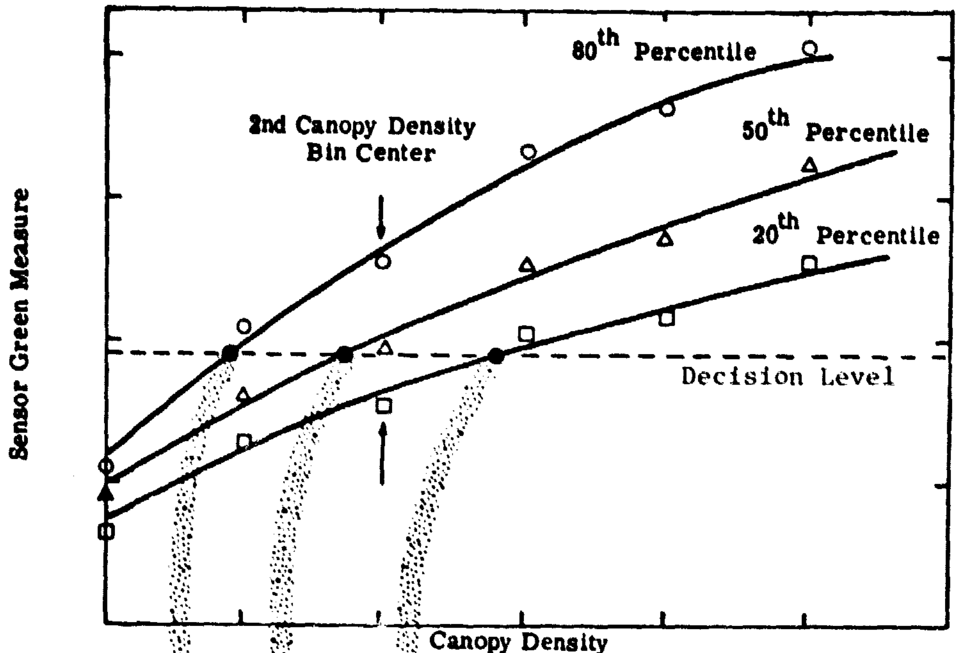
2.3 INVESTIGATE THRESHOLD OF DETECTION

A definition of the threshold of detection (TOD) is "that value of vegetation canopy density at which fields can be distinguished from bare soil with a specified accuracy or probability". Canopy density can be measured by a variety of parameters, such as percent cover, leaf area index (total or horizontal), bio-mass, and the like. In this report, we use only green vegetative percent cover as the canopy variable and reflectance Greenness (defined in Section 2.1) as the remotely sensed green measure.

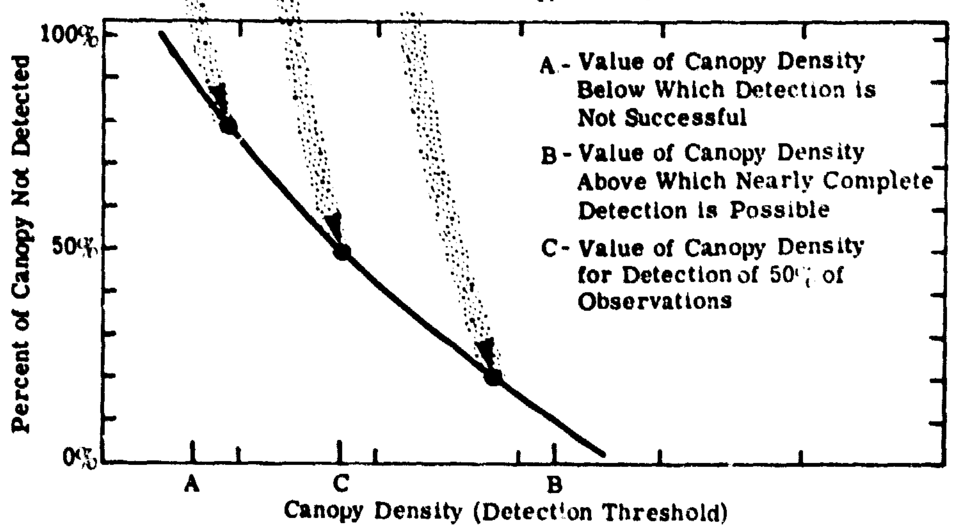
The following procedure was used to determine threshold of detection functions and is similar to the one we used for wheat in Reference 1. First, a scatter diagram of reflectance Greenness versus percent cover was produced. The data were divided into bins of percent cover, each bin covering equal-sized intervals of percent cover. Within each bin, a histogram of Greenness was produced and the green measures corresponding to specific percentiles (e.g., 20^{th}, 50^{th}, and 80^{th}) of the data values were determined. Then polynomial curves were fit to the points for each percentile level. This step is illustrated in Part (a) of Figure 2. (The percentile values actually used were from 5% to 95% in increments of 10%.)

The next step was to select levels of the green measure that could serve as decision levels separating the expected distribution of values for bare soil from those of the crop of interest. See Figure 3.

For each selected decision level, a threshold of detection curve was established by plotting the points of intersection between the bare-soil-rejection decision level and the various percentile curves, as illustrated in Part (b) of Figure 2. With such a curve, one can then determine a threshold value of canopy density for any given rate of detection, and conversely, determine the probability of not detecting a canopy of any given threshold density.



(a) Percentiles of Sensor Green Measure Histograms Within Each Canopy Density Bin



(b) Threshold of Detection Curve. Threshold is Value of Canopy Density for any Specified Detection Rate.

FIGURE 2. ILLUSTRATION OF HOW THRESHOLD OF DETECTION IS DETERMINED

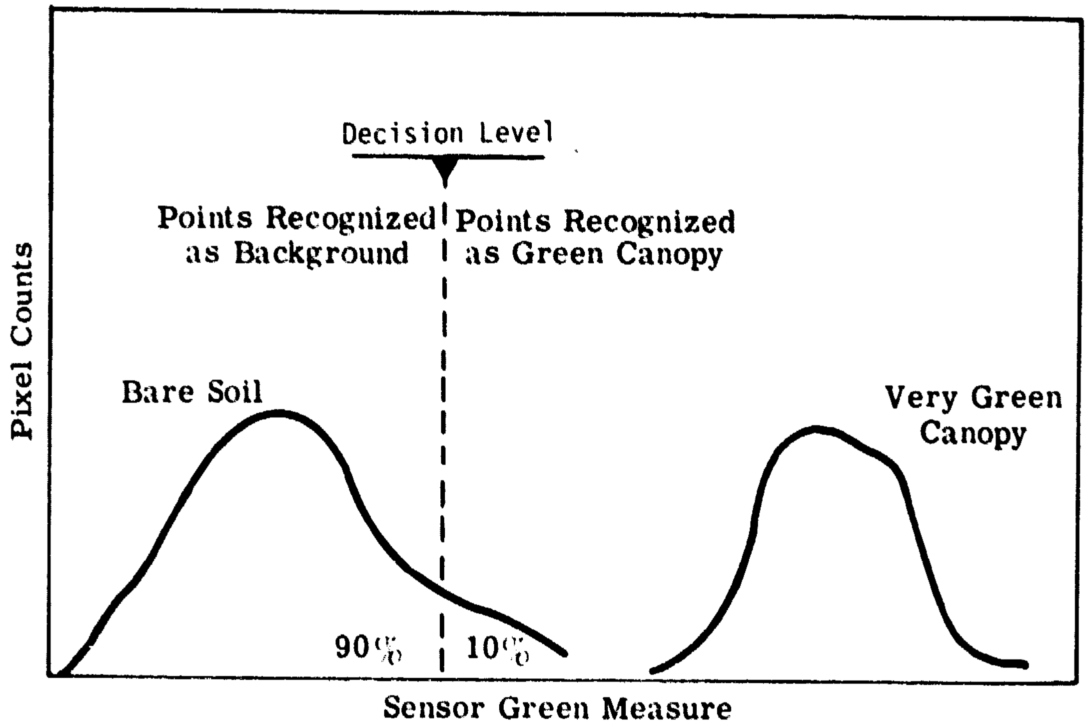


FIGURE 3. CHARACTERIZATION OF THE BACKGROUND-REJECTION DECISION LEVEL

3
RESULTS

3.1 DATA SELECTION AND PREPROCESSING

The data set selected for analysis was composed of inband (Landsat MSS) reflectance measurements made by personnel of Purdue University's Laboratory for Applications of Remote Sensing at the Purdue Agronomy Farm during the Summer of 1978. As shown in Table 2, both corn and soybeans fields were measured, although the acquisition history for soybeans was more complete and more fields were measured. One of the agronomic variables present in the data set was the percent of soil covered by vegetation; these values had been determined by use of a sampling grid on vertical photographs taken over the test fields.

An examination of the data, both before and after the Tasseled-Cap transformation was applied, verified that the components conformed reasonably to previous experience. For example, Figure 4 presents a scatter diagram of reflectance Greenness values versus percent cover for 81 soybeans fields in the soybean management experiment. The only anomalous-appearing values are those in the lower right-hand corner. Upon investigation, they were found to correspond to Day 262 (See Figure 5) on which the affected fields were said to have experienced leaf drop. Apparently, the percent cover values were not appropriately updated for that date.

3.2 TEMPORAL-SPECTRAL PROFILE ANALYSIS RESULTS

Only the soybeans data were subjected to temporal-spectral profile analysis since there are substantial gaps in the acquisitions for corn, especially at and around the expected time of peak Greenness.

TABLE 2. DATA SET USED

- Purdue Agronomy Farm, 1978
- Exotech 100 Landsat-Band Radiometer
- 151 Fields (Plots): 48 Corn, 102 Soybeans
- 3077 Observations: 955 Corn, 2003 Soybeans
- Days of Year: 173-278 for Corn
173-290 for Soybeans
- Extensive Agronomic Observations
- Varieties of Soybeans:

  Wells - Group 2 Maturity Class
  Amsoy71 - Group 2 Maturity Class
  Elf - Group 3 Maturity Class

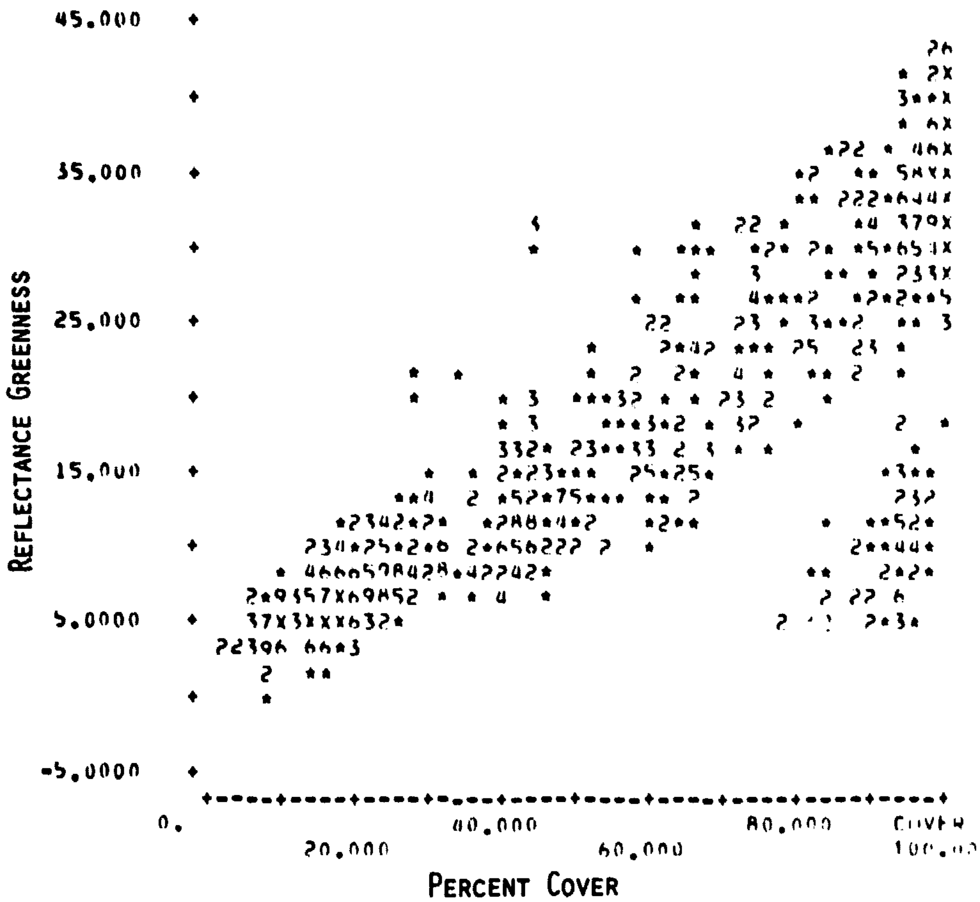


FIGURE 4. RELATIONSHIP OF GREENNESS TO PERCENT COVER FOR SOYBEANS (SOIL MANAGEMENT EXPERIMENT)

(1978 EXOTECH 100 DATA, PURDUE AGRONOMY FARM)

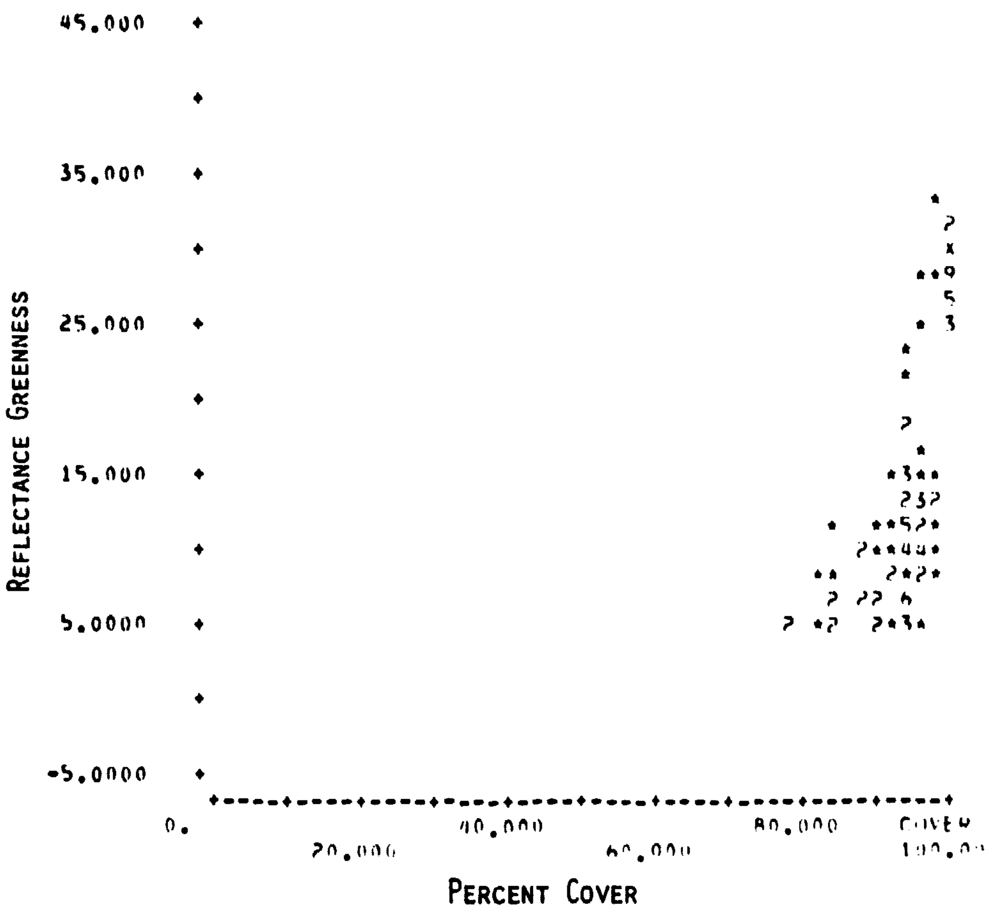


FIGURE 5. GREENNESS VERSUS PERCENT COVER FOR SELECTED SOYBEANS FIELDS ON DAY 262 (FIELDS WERE NOTED TO HAVE DROPPED MANY OF THEIR LEAVES)

Data from a single field (Plot 501) were selected to establish a reference profile for soybeans. A time of peak Greenness was estimated manually and then model parameters were calculated using a non-linear regression technique. Figure 6 presents the reflectance Greenness values and the continuous curve fit to them.

The effectiveness of the crop calendar shift calculations made for 14 other fields in the Soybean Management Experiment is evident in the "before" and "after" scatter diagrams presented in Figures 7(a) and 7(b). Shifts ranging from -10 to +4 days from the reference profile were computed, with an average of -1.5 days and a standard deviation of 3.4 days. It is interesting to note that these fields were all planted on the same date. Thus, the estimated differences in time of peak Greenness must be due to other factors. More analysis is needed to better understand the factors affecting crop calendar shift and the overall shapes of soybean development profiles.

Figure 8 presents the individual curve shapes fitted individually to the 15 fields after crop calendar shift. The goodness of fit was quite high, averaging 0.93. Two observations can be made from these curves. First, a difference in peak values is evident. These were found to be correlated to row width -- the wider rows had lower maximum vegetation cover percentages and, consequently, lower peak values. The peak values also were correlated to variety -- Elf had a higher peak than Wells and Amsoy71 which were about equal, as shown in Figure 9 by average profiles fit to more than 20 fields per variety. The Wells and Amsoy71 varieties are taller and less bushy than the Elf variety.

Another observation about the profile curves in Figure 8 is that differences are evident in the profile shapes. Some have a sharper, shorter peak, declining more rapidly than others. This difference too was found to be associated with variety. Some differences can be seen between the average varietal curves in Figure 9, but the actual

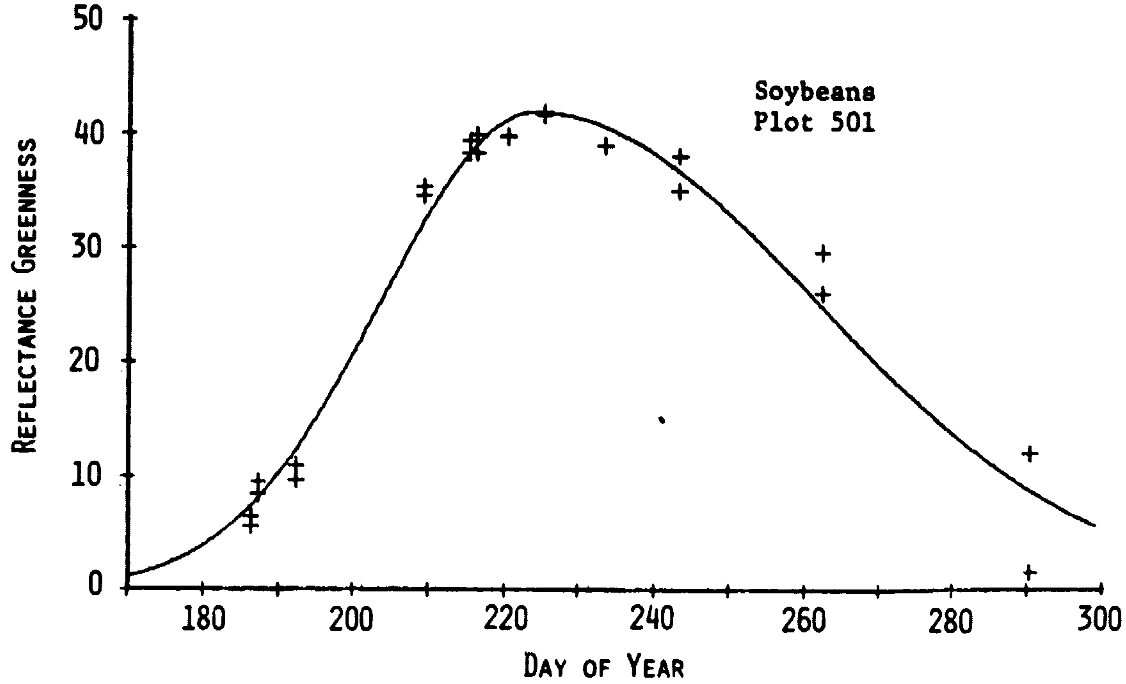


FIGURE 6. REFERENCE PROFILE FOR SOYBEANS

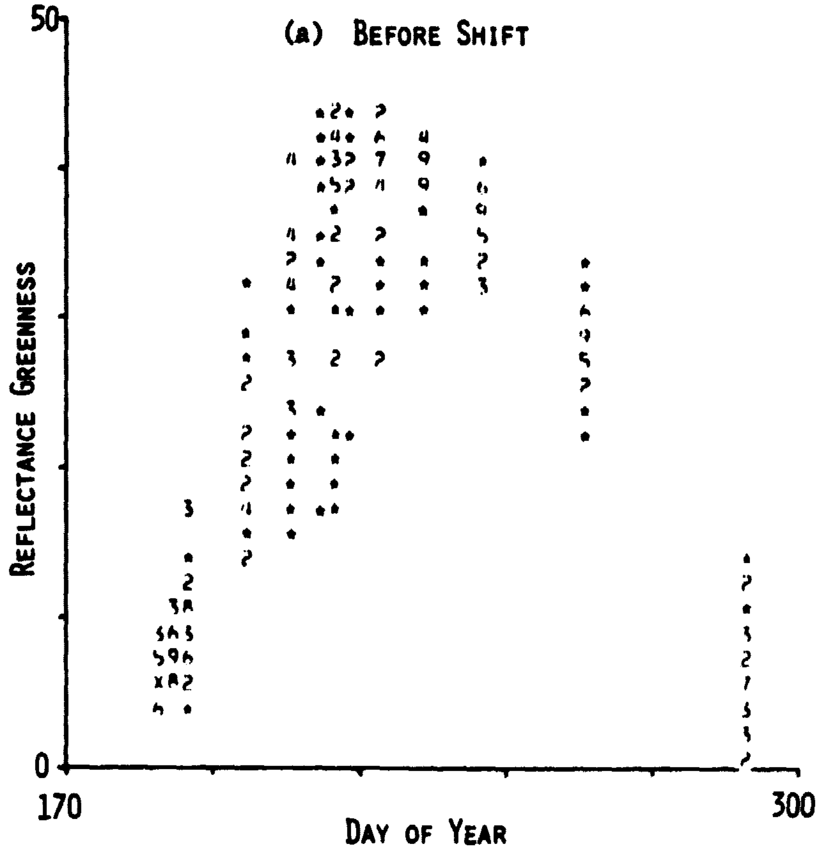


FIGURE 7. EFFECT OF CROP CALENDAR SHIFT CALCULATIONS ON DISTRIBUTION OF SOYBEAN REFLECTANCES

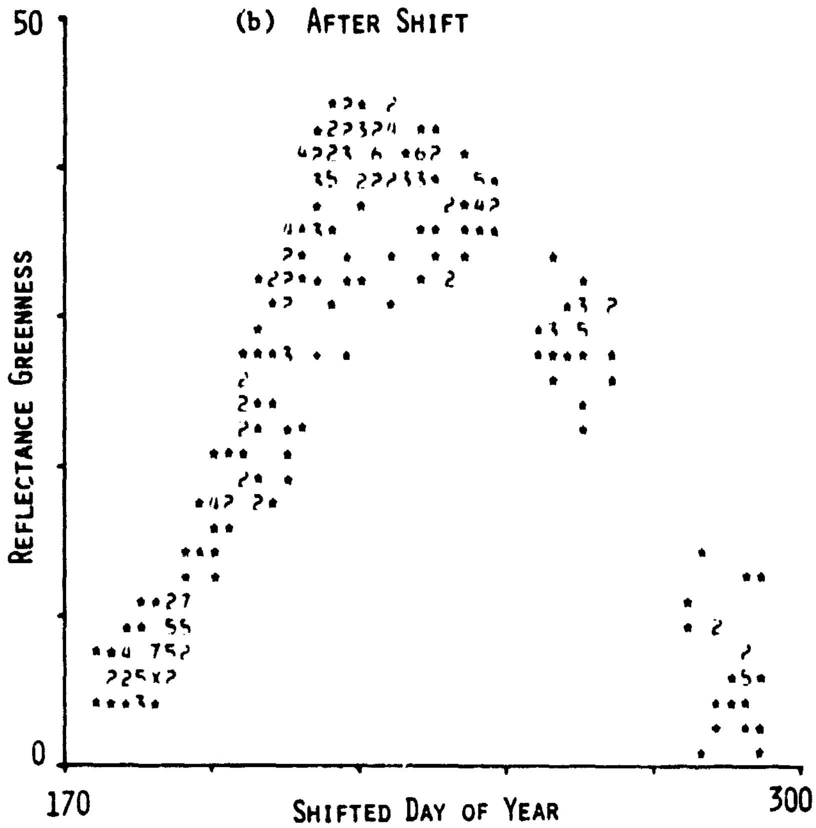


FIGURE 7. EFFECT OF CROP CALENDAR SHIFT CALCULATIONS ON DISTRIBUTION OF SOYBEAN REFLECTANCES (Cont'd)

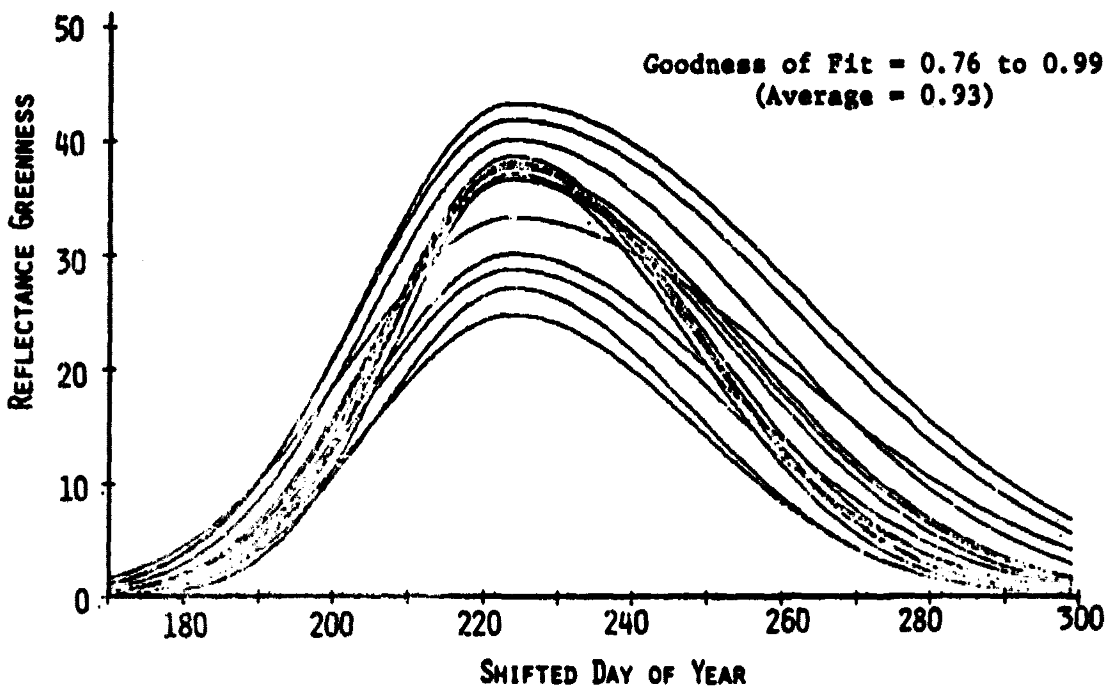


FIGURE 8. GREEN DEVELOPMENT PROFILE FITS FOR INDIVIDUAL SOYBEAN FIELDS

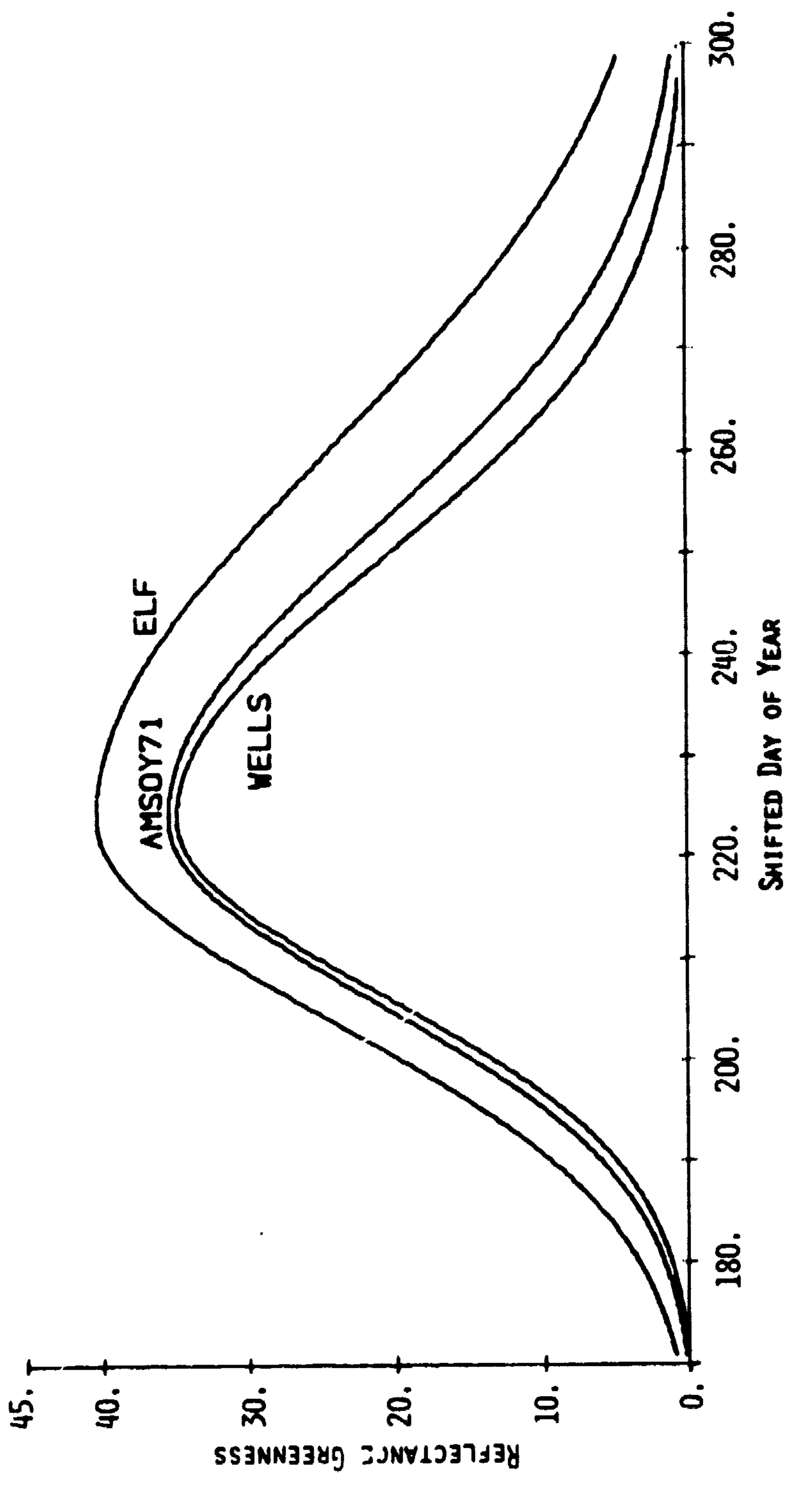


FIGURE 9. COMPARISON OF GREEN DEVELOPMENT PROFILES FOR SOYBEAN VARIETIES

differences are more striking in scatter plots of the data values that produced those curves. Figure 10 presents these scatter plots. The Greenness values for the Elf variety around Day 260 are double those of the other two varieties. The agronomic comments for that date are that "Amsoy71 and Wells have dropped most of their leaves; Elf is still green". From an agronomic standpoint, it can be noted that the Elf variety is in the Group 3 maturity class, whereas Wells and Amsoy71 varieties are in Group 2. Group 2 varieties mature sooner than Group 3.

Figure 10 also shows that the model form used does not represent the average spectral profile values as well as one might desire, tending to fall off after the peak faster than the data values and yet not reach the next lower values. This points to a need for further development of profile modeling techniques for soybeans. Nevertheless, the results obtained here show sufficient promise to warrant extension to Landsat data.

One additional note is that the field selected to form the reference profile for soybeans for this study can be seen to be of the Elf variety by comparing Figure 6 to Figure 10.

3.3 THRESHOLD OF DETECTION ANALYSIS RESULTS

The data used for the threshold of detection analysis are presented in Figure 11 for soybeans and Figure 12 for corn, as scatter diagrams of reflectance Greenness versus percent cover. These data are from the greenup phase of the crops' development.

Following the procedure outlined in Section 2.3, threshold of detection curves were established for soybeans for several different soil background decision levels: Greenness = 4, 5, 6, 7, 8, and 10; these curves are presented in Figure 13. The corn data were too sparse at low percent covers to allow a reliable set of curves to be defined for that crop.

(a) Variety: ELF

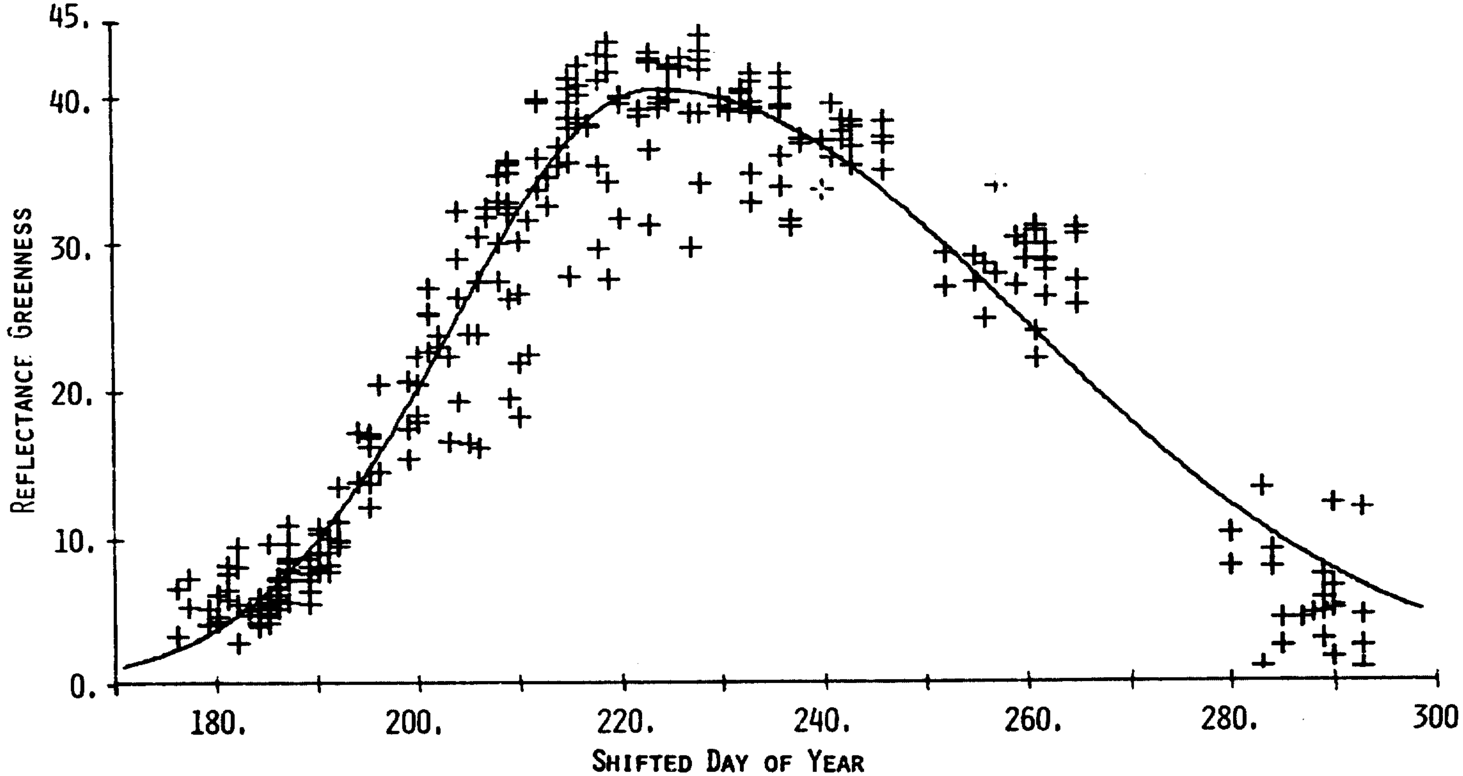


FIGURE 10. COMPARISON OF GREEN DEVELOPMENT DATA VALUES FOR SOYBEAN VARIETIES (Cont'd)

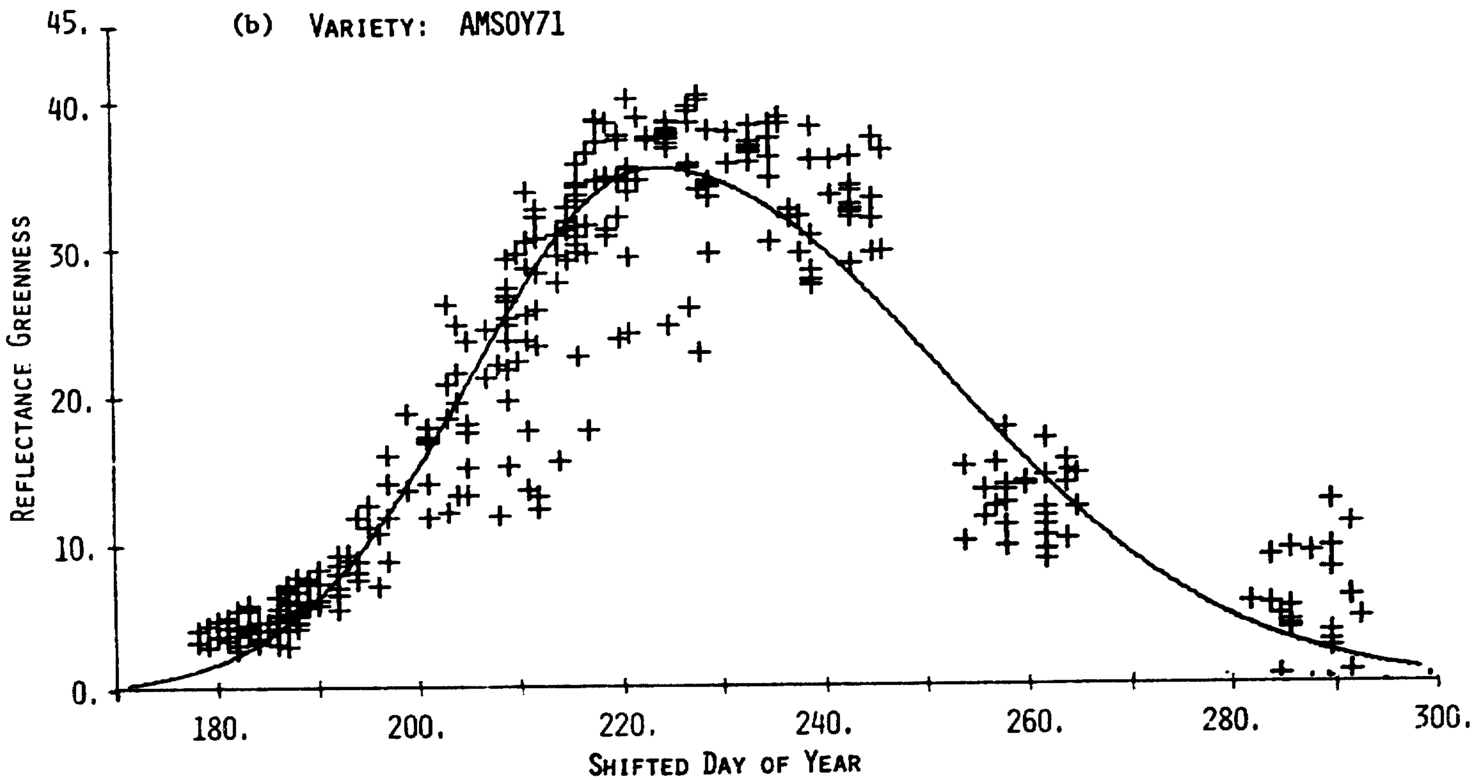


FIGURE 10. COMPARISON OF GREEN DEVELOPMENT DATA VALUES FOR SOYBEAN VARIETIES (Cont'd)

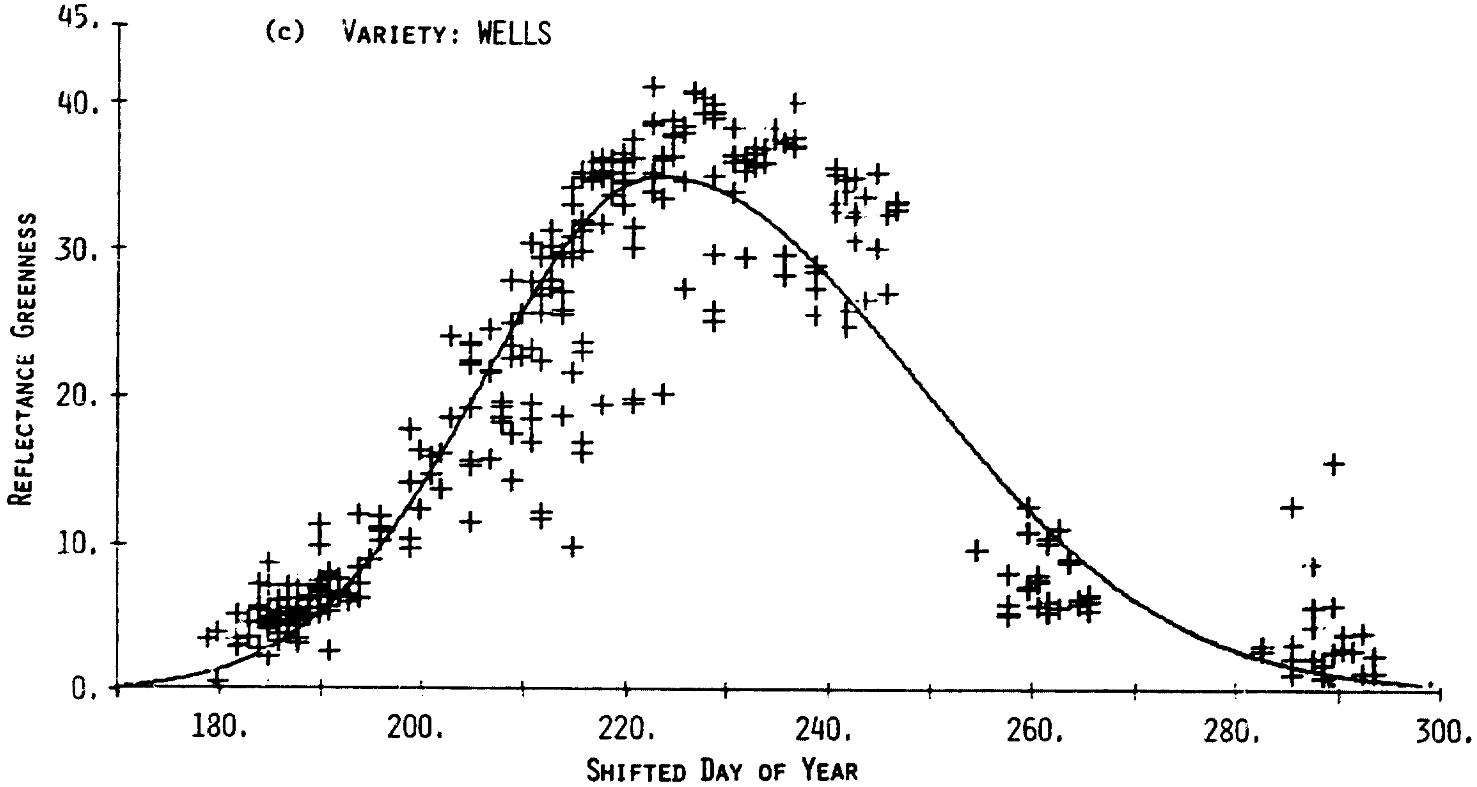


FIGURE 10. COMPARISON OF GREEN DEVELOPMENT DATA VALUES FOR SOYBEAN VARIETIES (Cont'd)

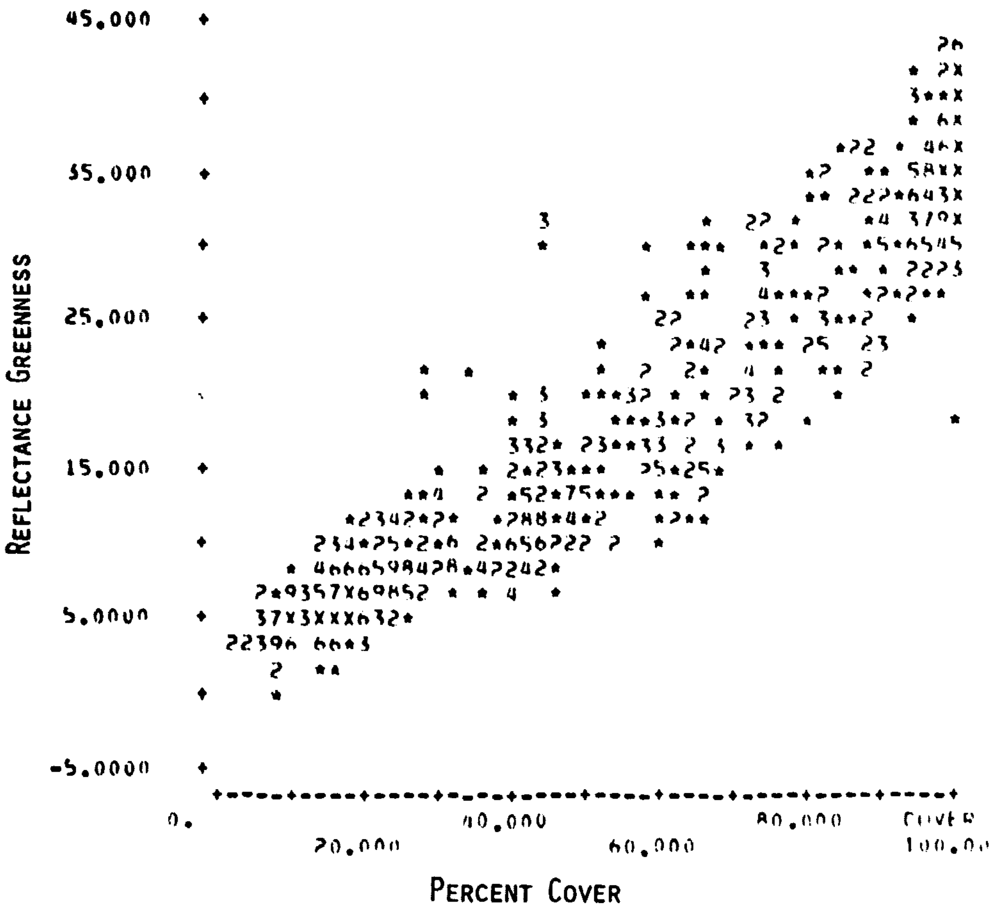


FIGURE 11. GREENNESS VERSUS PERCENT COVER FOR SOYBEANS, WITHOUT DAY 262

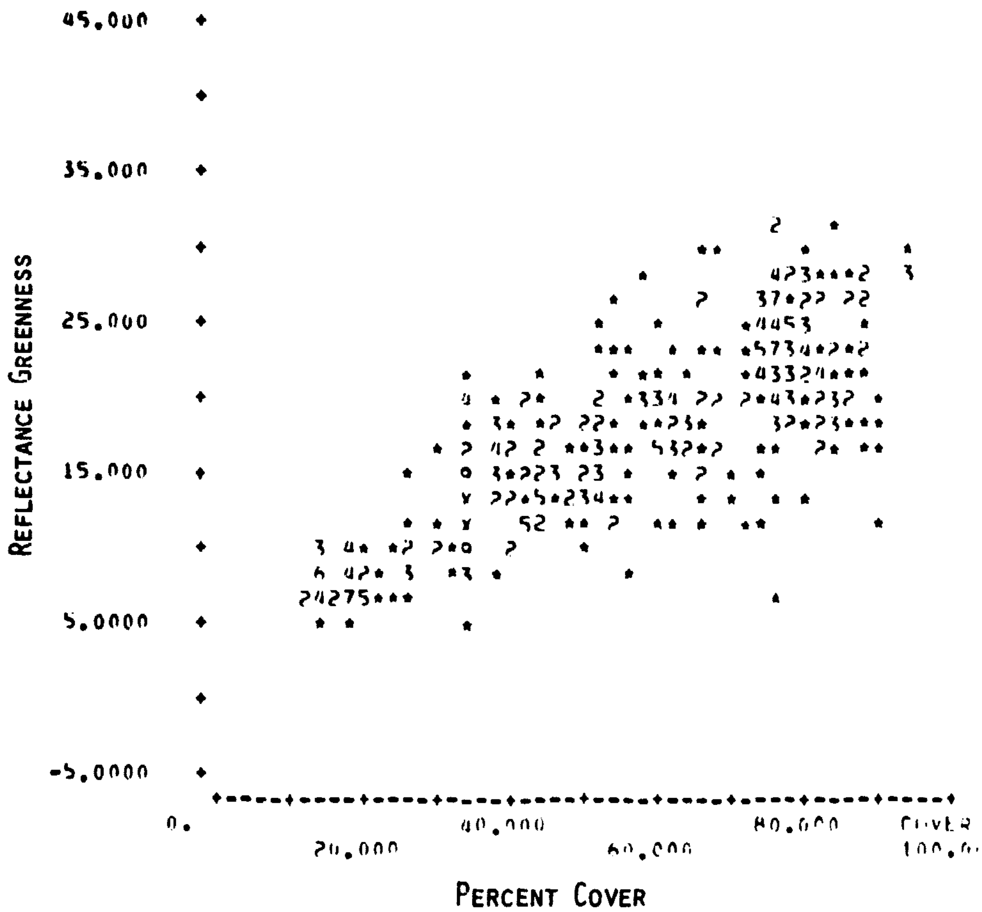


FIGURE 12. GREENNESS VERSUS PERCENT COVER FOR CORN

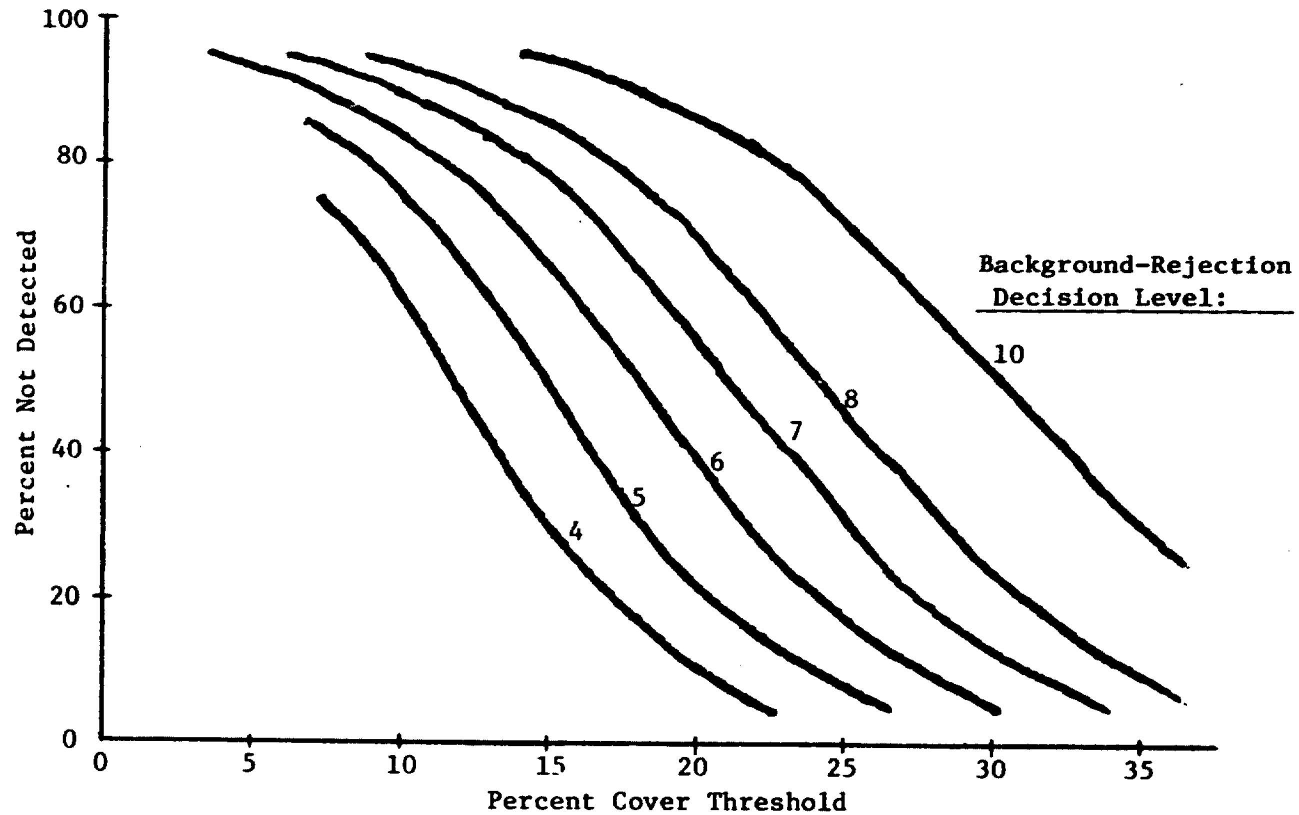


FIGURE 13. THRESHOLD OF DETECTION CURVES FOR SOYBEANS

The parametric set of curves was produced for soybeans because the data set itself did not contain enough soil data to make an independent choice of the soil-rejection decision level. Furthermore, an extension to the Landsat situation should include variability due to atmospheric and sensor sources. Extrapolation of this Greenness distribution down to zero percent cover gives a decision level of 4 to 5, which gives a 50% detection probability at 12 to 14 percent cover for soybeans. In last year's study of reflectance data for wheat [1], 50% detection probability was estimated to occur at a leaf area index (LAI) of 0.29; while the relationship between percent cover and LAI for emerging wheat is not well established, it was estimated that LAI = 0.29 corresponds to a cover of 10 to 15%.

4
CONCLUSIONS AND RECOMMENDATIONS

On the basis of the exploratory analysis results reported herein, it is concluded that:

(1) Green development profile fitting and crop calendar shift estimation technology appears to be fully applicable to soybeans data in Landsat spectral bands.

(a) Soybean fields appear to have characteristic green development patterns that are amenable to profile modeling, although further development is desirable for improved fits.

(b) Soybean profile shapes are noticeably different from those of small grains.

(c) Crop calendar shift calculations appear to improve the correlation of key features in soybean development profiles.

(d) At least some of the variations in profile characteristics of soybeans had clearly identifiable correlations with agrophysical phenomena, such as variety and row spacing.

(2) Detection thresholds for soybeans do not appear to be substantially different from those determined for wheat.

It is recommended that:

(1) Development of profile model forms be continued for soybeans and be initiated for corn.

(2) Investigation of agrophysical interpretations of profile characteristics, including crop calendar shift estimates, be expanded.

(3) Analyses of temporal-spectral profile technology be extended to Landsat data acquired from multicrop segments during the transition years between LACIE and AgRISTARS.

(4) Detection threshold studies for corn and soybeans be extended to other data sets, including Landsat sets with periodic ground observations.

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