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June 1982

TECHNICAL REPORT

ANALYSIS OF THE PROFILE CHARACTERISTICS OF CORN AND SOYBEANS USING FIELD REFLECTANCE DATA

E.P. Crist

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16. Abstract

The typical patterns of spectral development (profiles) for corn and soybeans are presented, based on field-collected reflectance data transformed to correspond to Landsat-MSS Tasseled Cap coordinates. Reasonable variations in field conditions and cultural practices are shown to significantly influence profile features. The separability of the two crops is determined to be primarily related to the maximum value of the reflectance equivalent of Greenness, and to the plateau effect seen in corn Greenness profiles. The impact of changes in conditions on separability is described. In addition, association is made between profile features and stages of development for corn and soybeans. Corn is shown to peak at a stage well before tasseling or maximum LAI, while the characteristics of the soybean profile are shown to be unrelated to any particular stage of development.

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ANALYSIS OF THE PROFILE CHARACTERISTICS OF CORN AND SOYBEANS USING FIELD REFLECTANCE DATA

by

E. P. CRIST

This is an expansion of a paper submitted to the 16th International Symposium on Remote Sensing of Environment entitled "Cultural and Environmental Effects on Crop Spectral Development Patterns as Viewed by Landsat".

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June 1982

PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing program, AgRISTARS, is a program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Departments of Agriculture, Commerce, and the Interior, and the U.S. Agency for International Development. AgRISTARS consists of eight individual projects.

The research reported herein was primarily sponsored by the Inventory Technology Development (ITD) Project under the auspices of the Earth Resources Applications Division of the NASA/Johnson Space Center. Dr. Jon Erickson is the NASA Manager of the ITD Project and Mr. Lewis Wade was the Technical Monitor for the reported effort.

Included in this report is a summary of research sponsored by the Supporting Research (SR) Project under the auspices of the Earth Resources Research Division of the NASA/Johnson Space Center and previously documented within that project. Mr. Robert B. MacDonald was the NASA Manager of the SR Project and Dr. Glen Houston was the Technical Coordinator for the referenced effort.

The analysis of corn and soybean profile characteristics was performed within the Environmental Research Institute of Michigan's Infrared and Optics Division, headed by Marvin R. Holter, Vice-President of ERIM, under the technical direction of Robert Horvath, Program Manager and Richard C. Cicone, Task Leader.

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1
INTRODUCTION

Central to the successful use of remotely sensed data for agricultural inventories is the ability of human analysts or computer algorithms to detect differences in the spectral characteristics of various cover classes. Experience with Landsat data in the Large Area Crop Inventory Experiment (LACIE) and other studies has demonstrated that the use of multitemporal, spatially-registered data greatly enhances the ability to distinguish between various crop spectral patterns [1]. In recent years interest has been renewed in utilizing characterizations of the continuous patterns of crop spectral development over time, termed "profiles", in automatic crop identification techniques [2,3,4]. These and other automated approaches offer substantial gains in efficiency over manual techniques, and would therefore be of great value if their accuracies were similar to or better than those associated with human analysts.

One substantial cause of error in both automatic and manual crop labeling techniques is the deviation of a crop from its expected spectral pattern due to cultural or environmental influences (e.g., fertilization, moisture stress, changes in planting practices, etc.). This spectral deviation is the result both of physiological changes in the plants themselves, resulting in changes in the spectral properties of the plant parts, and of changes in the canopy geometry, including the orientation of plant parts, number and size of leaves or other plant parts, and amount of soil visible through the canopy. Particularly for computer algorithms, which lack the flexibility and adaptive capabilities of the human mind, it is essential that major external influences on crop spectral patterns be known in advance and taken into account, if the algorithms are to perform adequately over broad regions or many growing seasons.

Understanding the general patterns of crop spectral development, and the influences of field conditions on those patterns, is also essential for spectrally-based assessment of crop condition. When combined with a means of estimating the time of occurrence of key stages of crop development, such a capability could contribute substantially to our ability to accurately estimate yields.

This report presents the results of research aimed at characterizing and understanding the spectral development patterns of corn and soybeans, using field-collected reflectance data. Average profiles are described, as are the changes in those profiles brought about by changes in some major cultural and environmental factors. In addition, the association of profile features with stages of development of the two crops is discussed. Finally, the separability of corn and soybeans both in a general sense and in the context of particular field conditions is considered.

Development of the profile analysis technique described in Section 2, and the literature review and initial evaluation of cultural and environmental influences on Green Reflectance profile features which are included in Section 5, were carried out under the auspices of the Supporting Research project, and were reported in that project [5]. Some of the results in Section 6 were previously presented in an ITD report [6]. The present report extends and summarizes the entire analysis.

2
DESCRIPTION OF DATA

Evaluation of crop spectral characteristics can best be accomplished with data collected at frequent intervals over plots whose conditions are controlled or known. Such data have been collected for several years by and at Purdue/LARS as part of a field research program carried out for NASA. For the analyses reported in this report, data were selected from experiments carried out in the 1978 through 1980 growing seasons, which included as experimental treatments nitrogen fertilization, planting date, and plant population for corn and variety, planting date, and row spacing for soybeans [7,8,9]. Reflectance measurements were made on clear days, resulting in gaps between successive observations of several days to weeks. All reflectance data were collected as or converted to Landsat-MSS inband reflectance values,* and multiple observations of a single plot on a single day were represented by their mean.

A reflectance equivalent of the Tasseled Cap transformation [10] was used to provide spectral variables that were physically-interpretable. This transformation, in its Landsat-MSS form, captures 95% or more of the total data variability over agricultural areas in two variables. A rotation of the first two principle components in the reflectance data set was used to derive reflectance equivalents of the two variables [5], termed Green Reflectance and Bright Reflectance. These two variables contained 99% of the total variability in this data set. Green

*Note: After completion of these analyses, a preprocessing error (which occurred after receipt of the data from LARS) was discovered which invalidated the data collected using the Exotech 20C spectroradiometer (one of two instruments used). Of the experiments included in these analyses, only the corn nitrogen experiments contained such data, and these experiments also included useable data collected using the Exotech 100 Landsat-band radiometer. The effects of the bad data on the analysis results appear to be negligible.

Reflectance serves as a green vegetation indicator, while Bright Reflectance is related to soil brightness or plot albedo.

The total data set consisted of observations from 118 corn plots and 171 soybean plots. However, some plots were not suitable for all analyses, so the actual number used in any particular evaluation varied.

3
PROFILE ANALYSIS TECHNIQUE

Although the field reflectance data set provided more frequent observations and more detailed agronomic information than would be available using Landsat data, the problems of temporal gaps in spectral measurements and inexplicable data variations were still apparent. As a result, it was necessary to devise a technique by which profile values could be interpolated between actual measurements, and some smoothing of the measured values could be achieved. One approach to accomplishing these objectives is use of a mathematical model to describe the spectral development patterns [3]. Such models have been developed for and successfully applied to spring small grains [11,12]. However, the plateau feature commonly observed in corn Greenness and Green Reflectance data (Figure 1) cannot be adequately described by previously developed profile models [5], so some other approach - either a new model or a more general technique - was required.

Two techniques were selected for profile characterization. For analysis of soybeans, which exhibit a less complex profile shape in Green Reflectance, and for some analyses of corn, a cubic smoothing spline [13] was used. This method provided the desired degree of smoothing, and captured the plateau feature given that sufficient data points were present in that portion of the profile. However, when significant data gaps existed in critical periods, the cubic smoothing spline result for corn was less acceptable. Accordingly, a profile model form, developed at ERIM specifically for this purpose [5], was used on the corn data when the plateau feature was of prime interest.

For Bright Reflectance data, early season variations caused by soil moisture differences and other unknown factors rendered automatic curve fitting impractical. Figure 2 illustrates the soil moisture effect for bare soil plots. Therefore, Bright Reflectance profiles were derived for each plot manually, based on the available data points

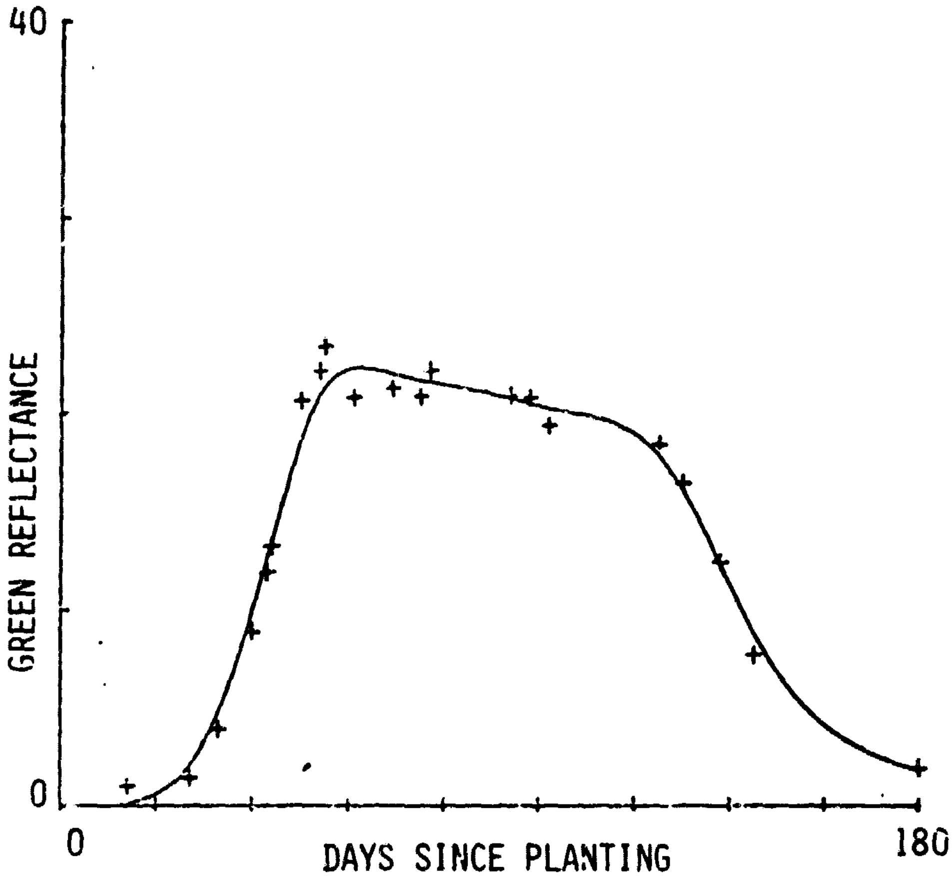

FIGURE 1. PLATEAU IN CORN GREEN REFLECTANCE PROFILE

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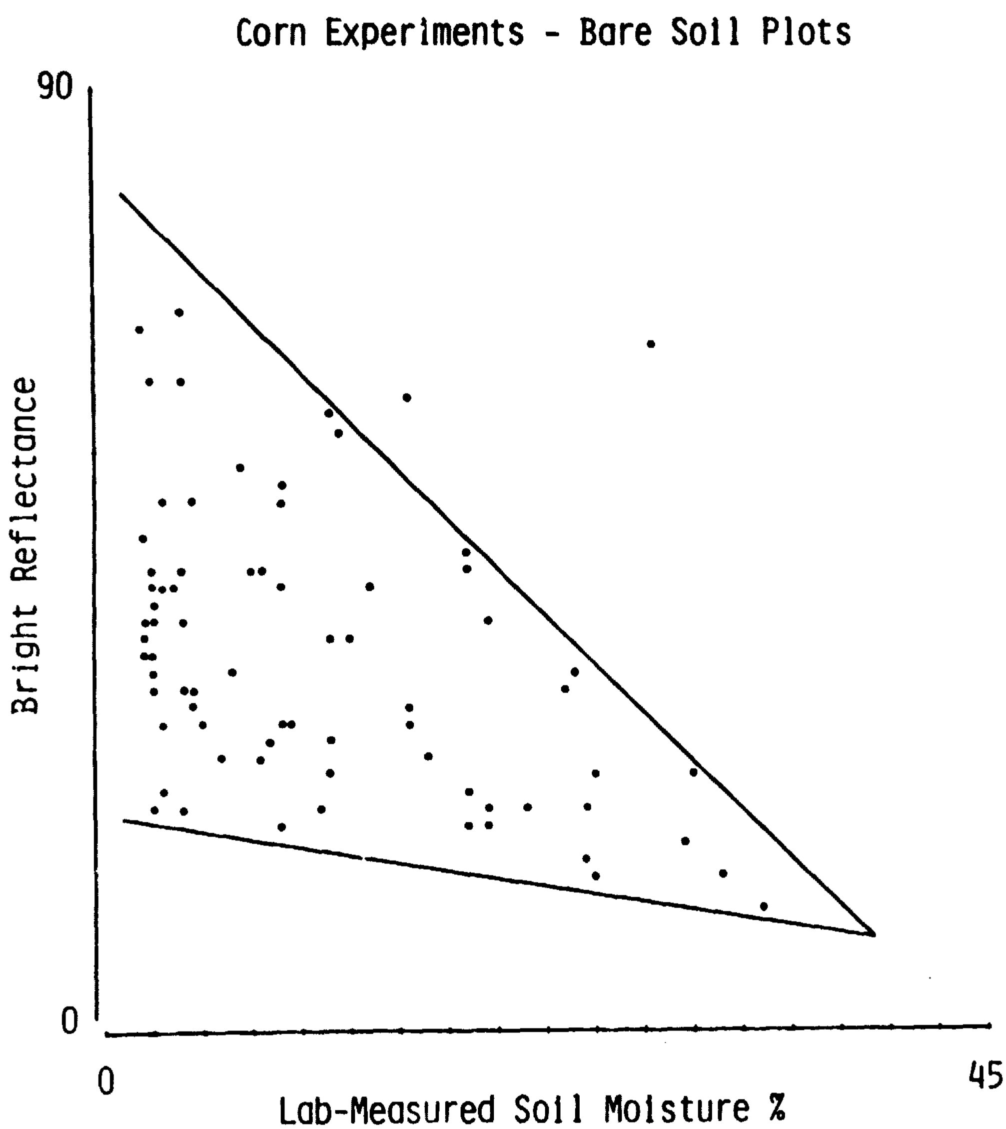


FIGURE 2. EFFECT OF SOIL MOISTURE ON BRIGHT REFLECTANCE

ERIM

and soil moisture information. Since planting dates were known, a "days since planting" time axis was used in describing the comparing both Green Reflectance and Bright Reflectance profiles.

In order to facilitate comparison of profiles, a set of features was defined which described their major characteristics. These features (illustrated in Figure 3) included the peak profile value (PMAX), the time at which the peak occurred (PT), the times of occurrence of one-half the peak value (HP1 and HP2), and the time intervals between HP1 and PT (SPAN1), PT and HP2 (SPAN2), and HP1 and HP2 (SPAN3). In Green Reflectance, these features are related to the maximum amount of green vegetation (PMAX), the rate of vegetative development (PT, HP1, SPAN1), the rate of senescence (SPAN2), and the overall development rate (HP2 and SPAN3). For corn, two additional features were used to describe the duration and slope of the plateau (Figure 4).

Features of Green Reflectance profiles were derived explicitly, and analyzed quantitatively by analyses of variance. For Bright Reflectance, the features were derived implicitly by visual analysis of the profiles, and compared qualitatively.

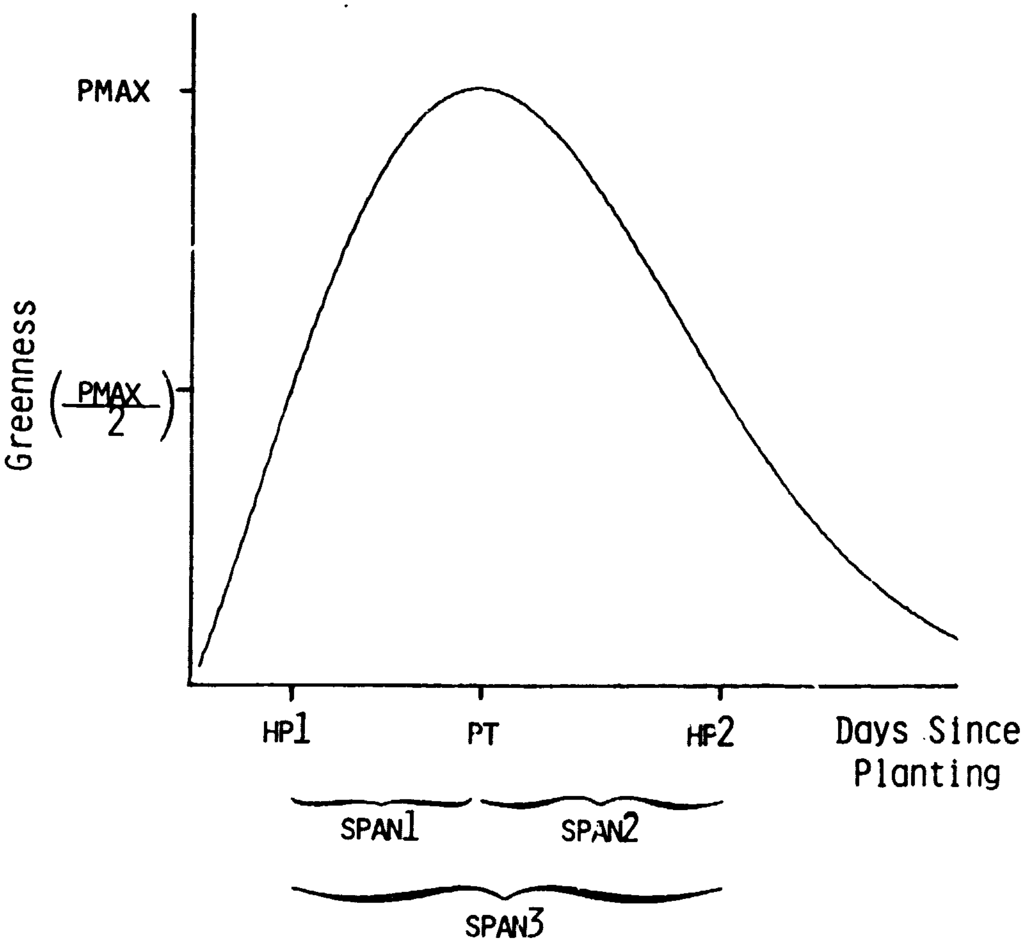
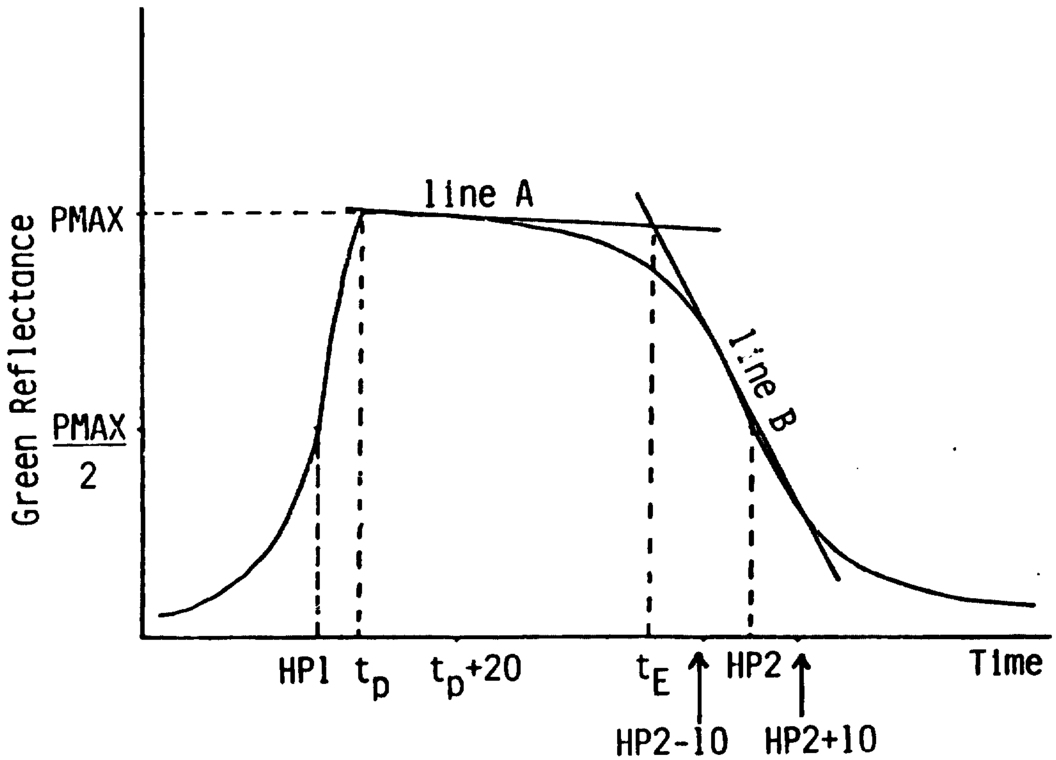


FIGURE 3. GREEN REFLECTANCE PROFILE FEATURES



T_E - time of plateau end - intersection of lines A and B where

line A - drawn through profile values at t_p and $t_p + 20$

line B - drawn through profile values at HP2-10 and HP2+10

Slope - slope of line drawn from t_p to t_E

FIGURE 4. ADDITIONAL CORN PROFILE FEATURES

4
NORMAL PROFILES

Figures 5 through 8 illustrate the average profiles of corn and soybeans, using the corn profile model results for 57 corn plots and the cubic smoothing spline results for 167 soybean plots. The dashed lines around the Green Reflectance profiles represent one standard deviation about the mean. The asymmetry of the soybean variability about the mean, most noticeable in the declining phase of the profile, is largely the result of differences in timing of leaf senescence between maturity classes.

The Bright Reflectance profiles, illustrated with a dark and light soil background, are delimited by dashed lines representing the range of mean profiles (by treatment) used to derive the overall average profiles. It should be noted that for corn, the very bright soil completely obscures the peak in the Bright Reflectance profile seen with darker soils. For both corn and soybeans, soil effects were undetectable in the latter portions of the profiles.

Figures 9 and 10 present the spectral trajectories of the two crops in Green Reflectance and Bright Reflectance, using the dark soil Bright Reflectance profiles. The plateau in corn Green Reflectance, when combined with the Bright Reflectance profile, is expressed as a movement away from and then back to the "Green Arm" of the Tasseled Cap. Figures 11 and 12 present the same trajectories using the bright soil profiles, and illustrate the substantial effect of soil reflectance on crop trajectories in the early portion of the growing season.

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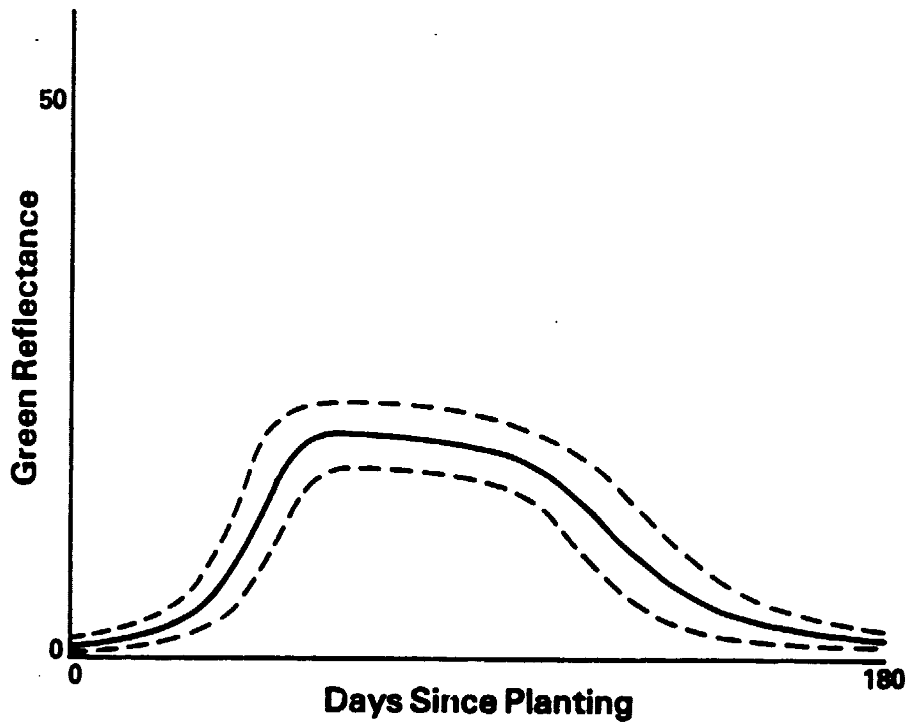

FIGURE 5. AVERAGE CORN GREEN REFLECTANCE PROFILE

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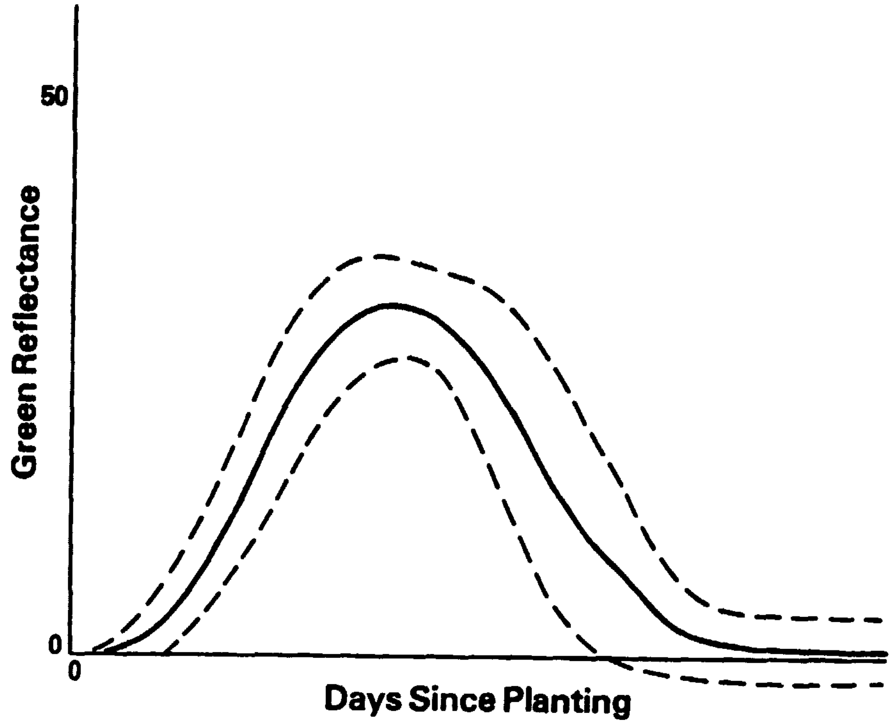

FIGURE 6. AVERAGE SOYBEAN GREEN REFLECTANCE PROFILE

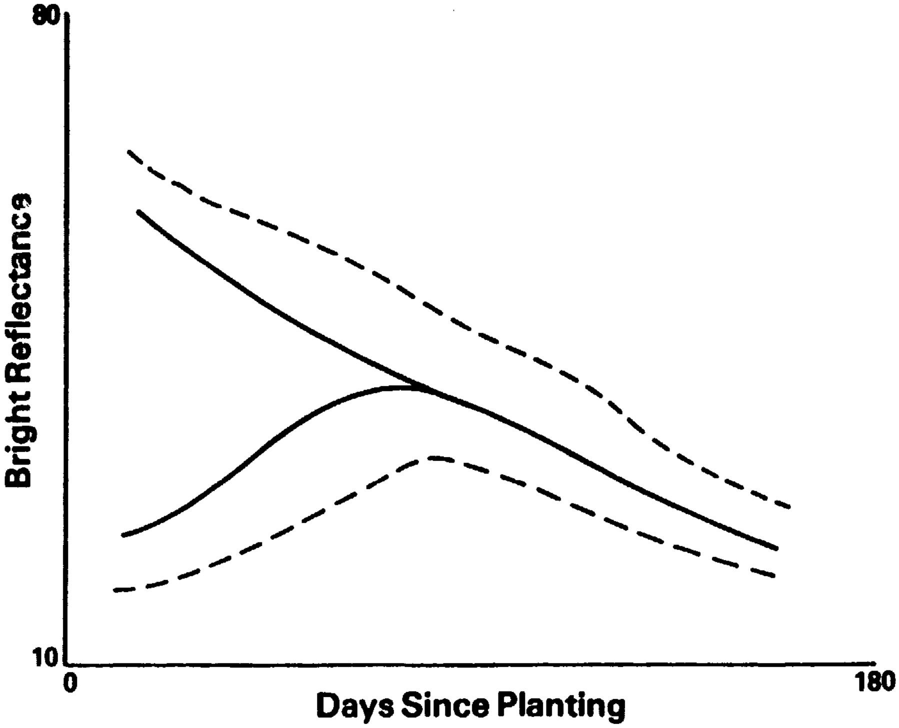

FIGURE 7. AVERAGE CORN BRIGHT REFLECTANCE PROFILE
(Light and Dark Soil)

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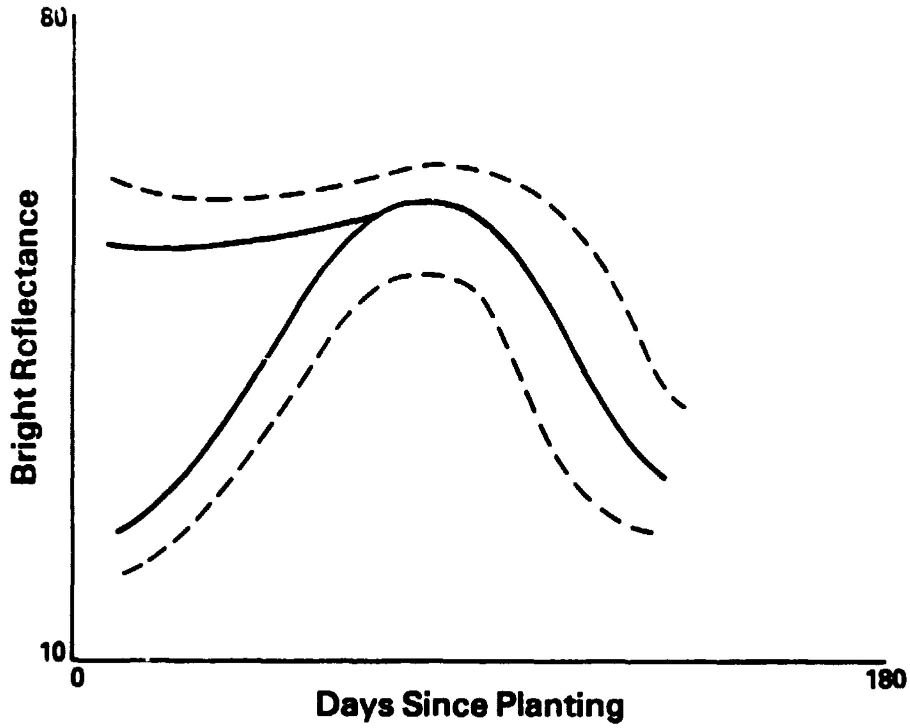

FIGURE 8. AVERAGE SOYBEAN BRIGHT REFLECTANCE PROFILE (Light and Dark Soil)

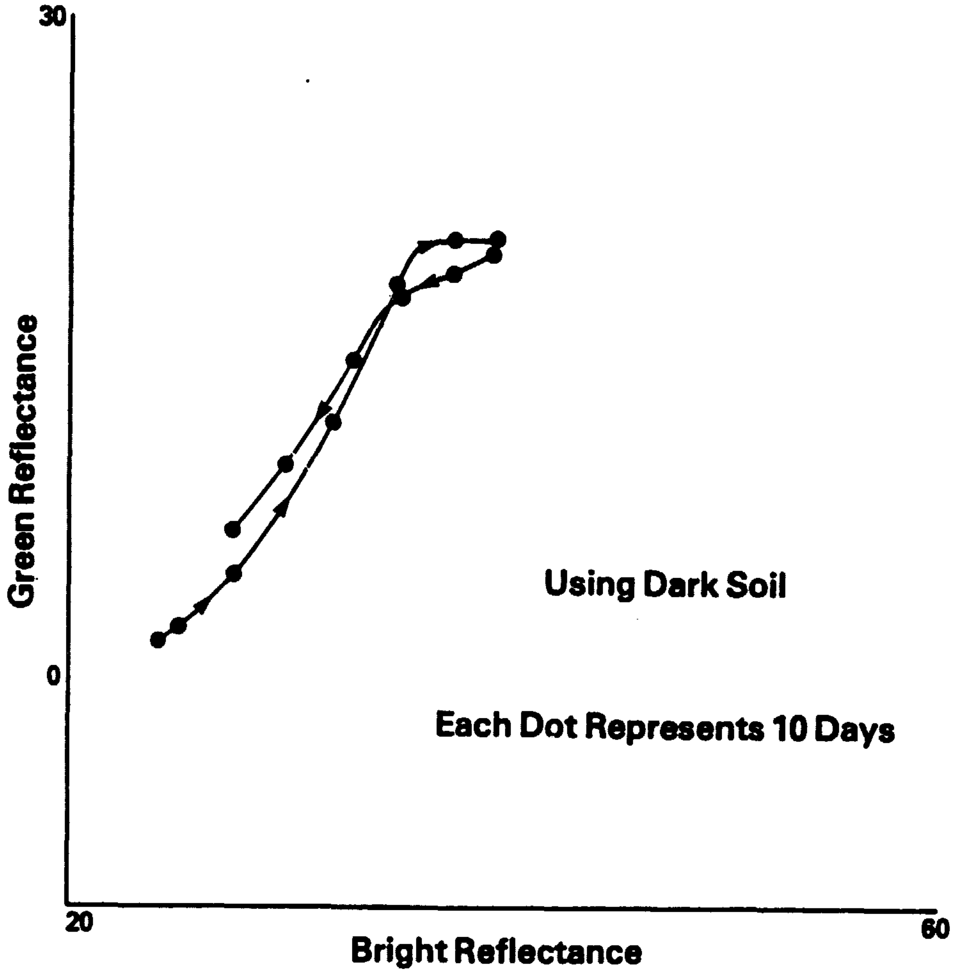

FIGURE 9. AVERAGE CORN GREEN REFLECTANCE/BRIGHT REFLECTANCE TRAJECTORY

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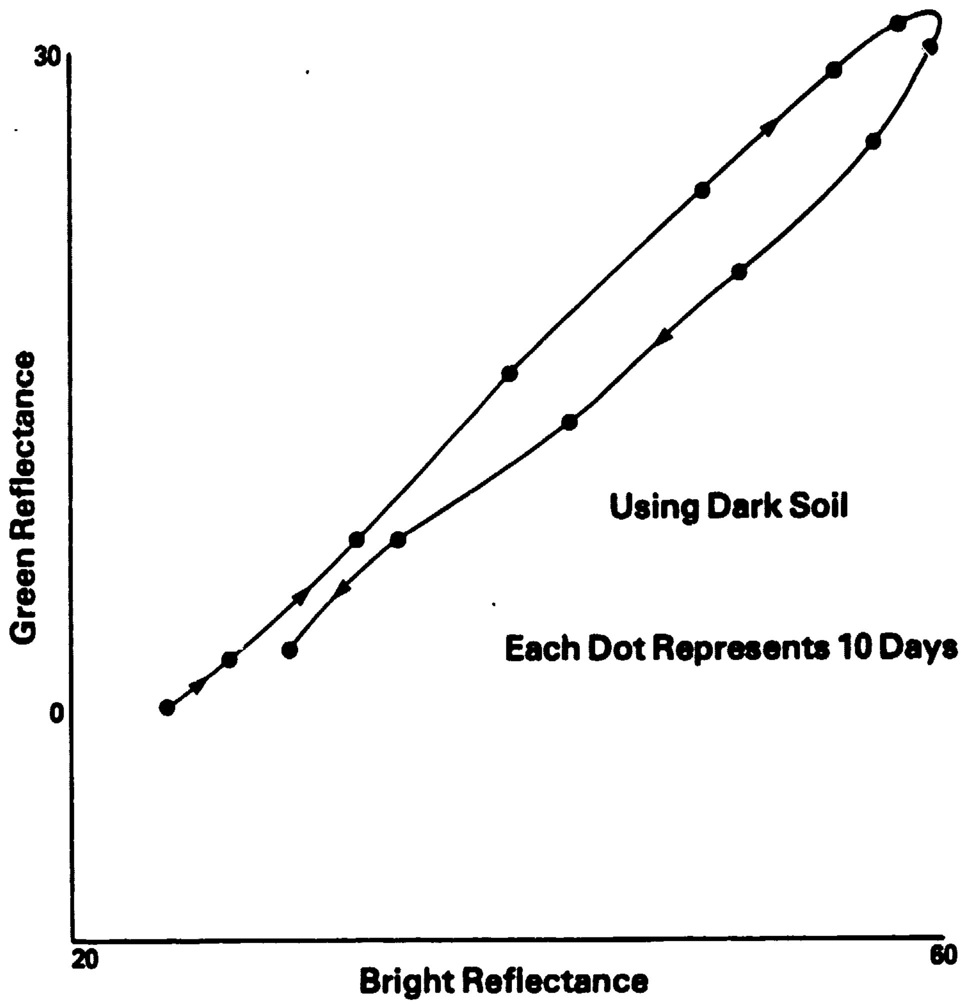

FIGURE 10. AVERAGE SOYBEAN GREEN REFLECTANCE/BRIGHT REFLECTANCE TRAJECTORY

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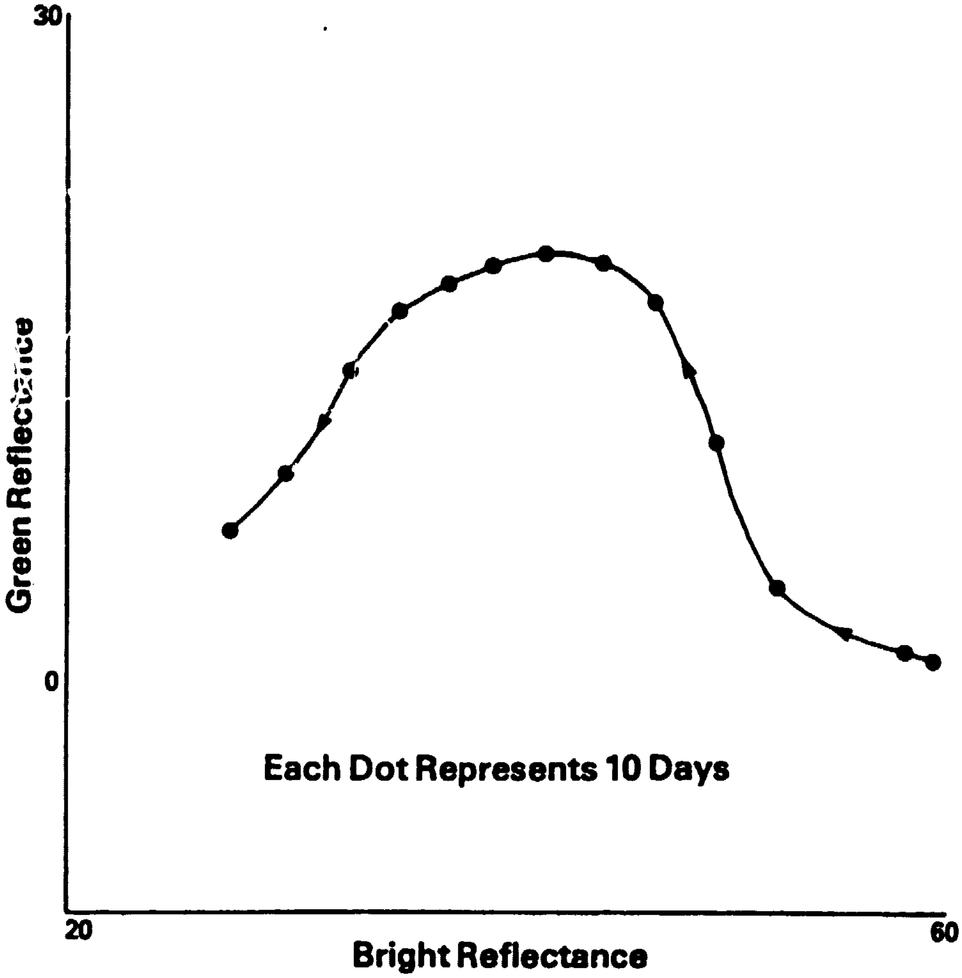

FIGURE 11. AVERAGE CORN TRAJECTORY USING BRIGHT SOIL

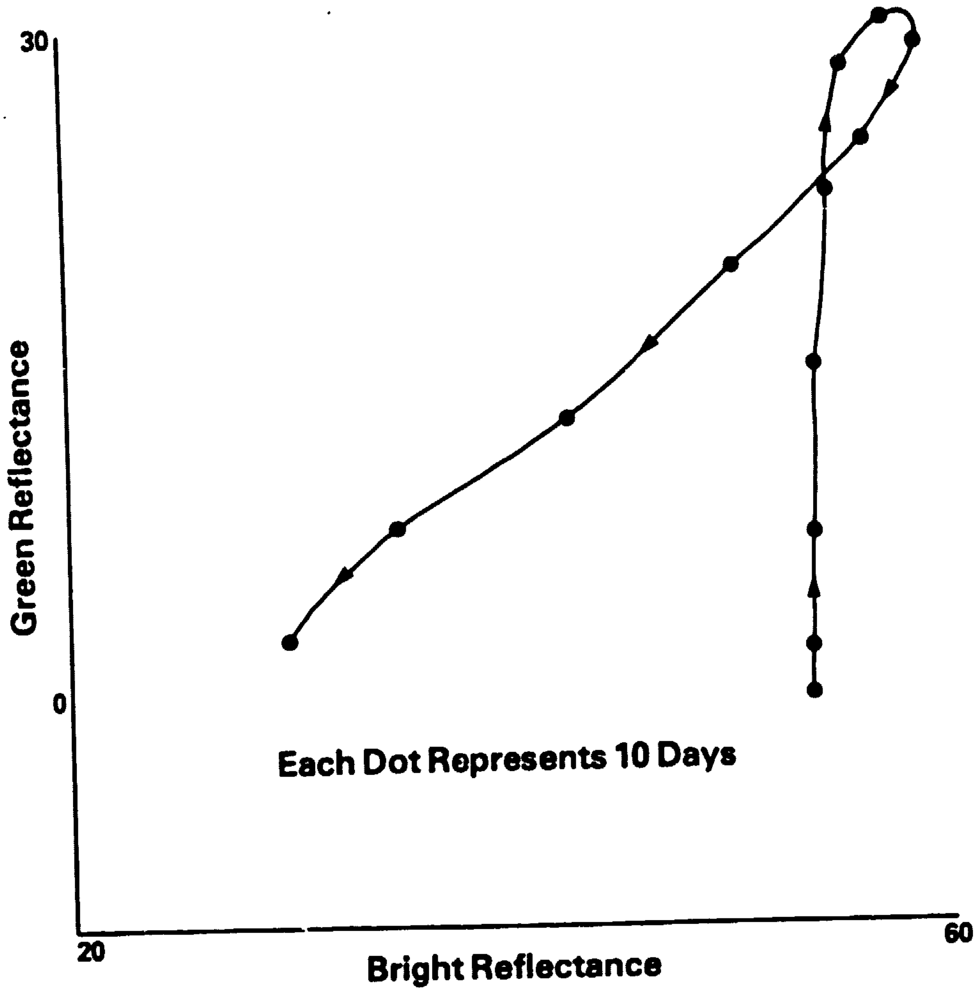

FIGURE 12. AVERAGE SOYBEAN TRAJECTORY USING BRIGHT SOIL

5
CULTURAL AND ENVIRONMENTAL EFFECTS ON PROFILE FEATURES

This section summarizes the results of both a literature review of the effects of environmental factors on corn and soybean characteristics and the profile features analyses. Reference [5] contains a more detailed description of many of the results. For Green Reflectance profiles, results reported are those found to be significant to the 0.9 level of confidence. Figures illustrating the effects of experimental treatments are intended to be descriptive rather than quantitative.

5.1 CORN EFFECTS

Nitrogen Fertilization. The availability of nitrogen, which is required for synthesis of chlorophyll, influences the vegetative development of corn. Abundant Nitrogen results in more and larger leaves, longer vegetative stages, and increased longevity of green leaf area. These effects were expressed in a later and higher peak Green Reflectance value and a longer and flatter plateau (Figure 13a). While the quality of Bright Reflectance data for these experiments was low, some indication of a higher peak Bright Reflectance value was observed (Figure 13b).

Planting Date. Later-planted corn experiences higher temperatures at any given stage of development than does earlier-planted corn. As a result, the rates of plant emergence and development are increased, as are the rates of leaf emergence and leaf area development. Very early planting exposes the plants to lower temperatures, and would thus be expected to delay emergence and retard early growth.

Both late and very early planting reduced the peak Green Reflectance profile value (Figure 14a), probably an indication of the less conducive growing conditions encountered. Both also reduced the overall development time (HP2). Late planting, in addition, hastened the

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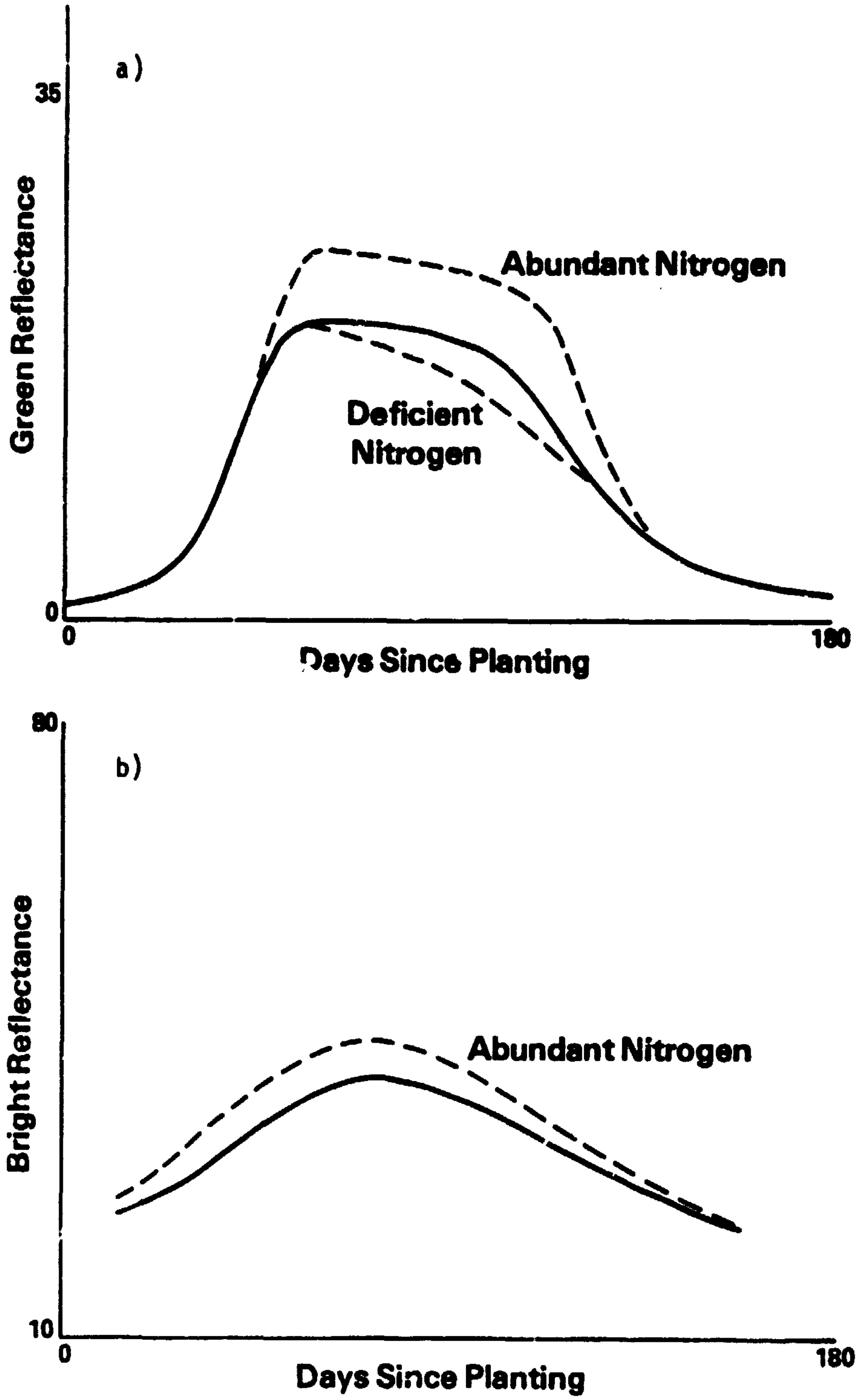

FIGURE 13. NITROGEN FERTILIZATION EFFECTS ON CORN PROFILES

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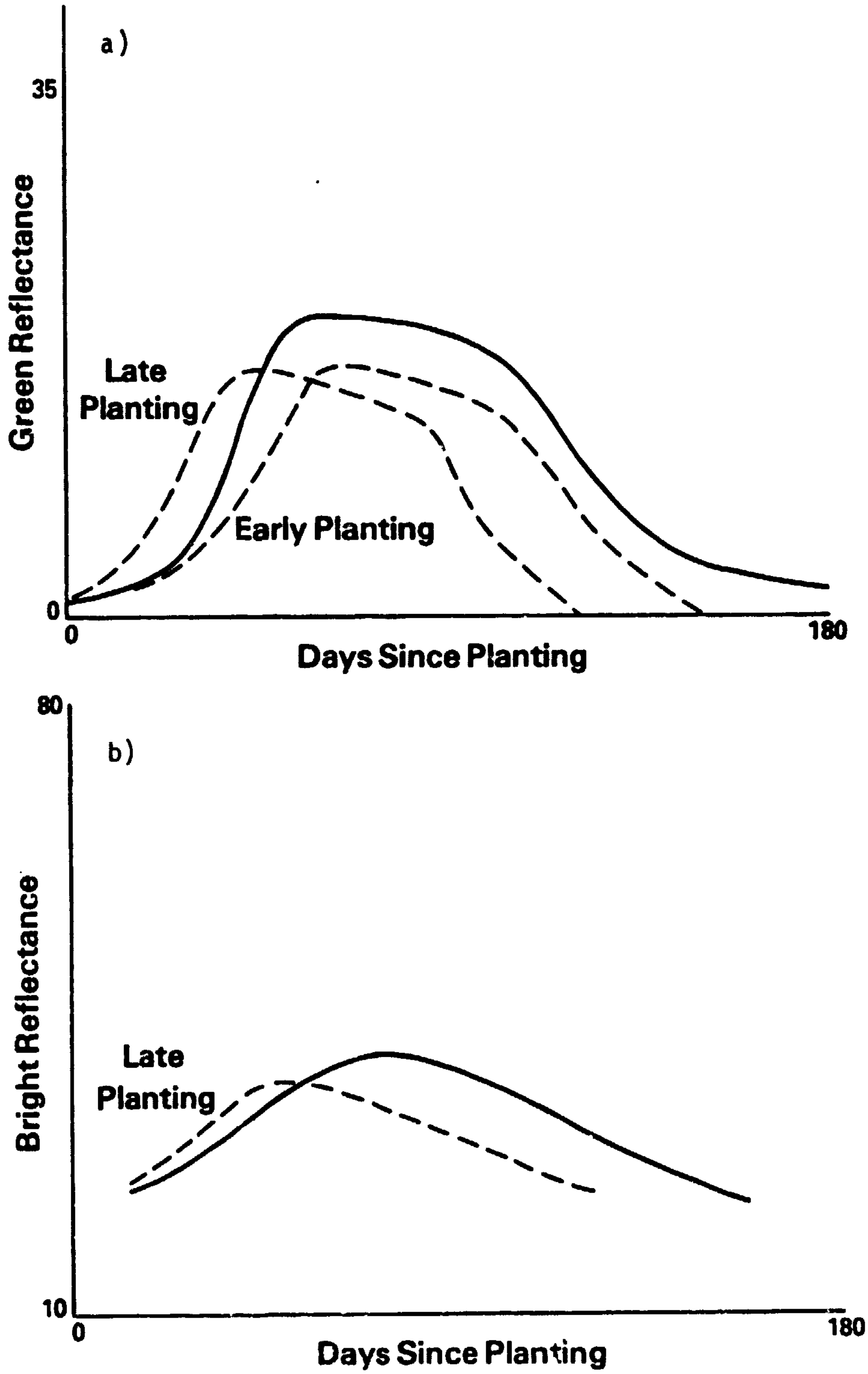


FIGURE 14. PLANTING DATE EFFECTS ON CORN PROFILES

rate of green-up, the time of peak, and the rate of green decline. Late planting similarly hastened the time of occurrence and reduced the value of the Bright Reflectance profile peak (Figure 14b).

Plant Population. Increases in corn plant population density cause reduced rates of leaf area production, faster early height increase, greater maximum leaf area index, and faster decline in LAI after peak. These effects were expressed in an earlier and higher peak Green Reflectance value, a faster rate of green-up, and a steeper plateau slope (Figure 15a). In Bright Reflectance, a higher peak value was observed, and the elimination of soil effects occurred earlier, indicating earlier canopy closure (Figure 15b).

5.2 SOYBEAN EFFECTS

Variety. Soybean varieties exhibit differences in days to maturity (maturity class), plant height, leaf size, number, and orientation, rate of accumulation and maximum leaf area, ability to achieve full closure, response to row spacing or planting delays, etc. Not surprisingly, all the profile features were significantly affected by varietal differences at some row spacing (Figure 16).

Planting Date. Both early and late planting tend to cause reductions in the final height of soybean plants, and to reduce the rate of canopy closure. The higher temperatures associated with later planting hasten emergence and early growth, and reduce the duration of the vegetative phase.

The peak Green Reflectance value was reduced with both early and late planting, and was substantially earlier for late planting (Figure 17a). In addition, late-planted soybeans had a faster rate of green-up and a shorter overall development time. Similarly, late-planted soybeans exhibited an earlier peak Bright Reflectance value and a more rapid increase in Bright Reflectance, as well as a reduced overall profile span (Figure 17b).

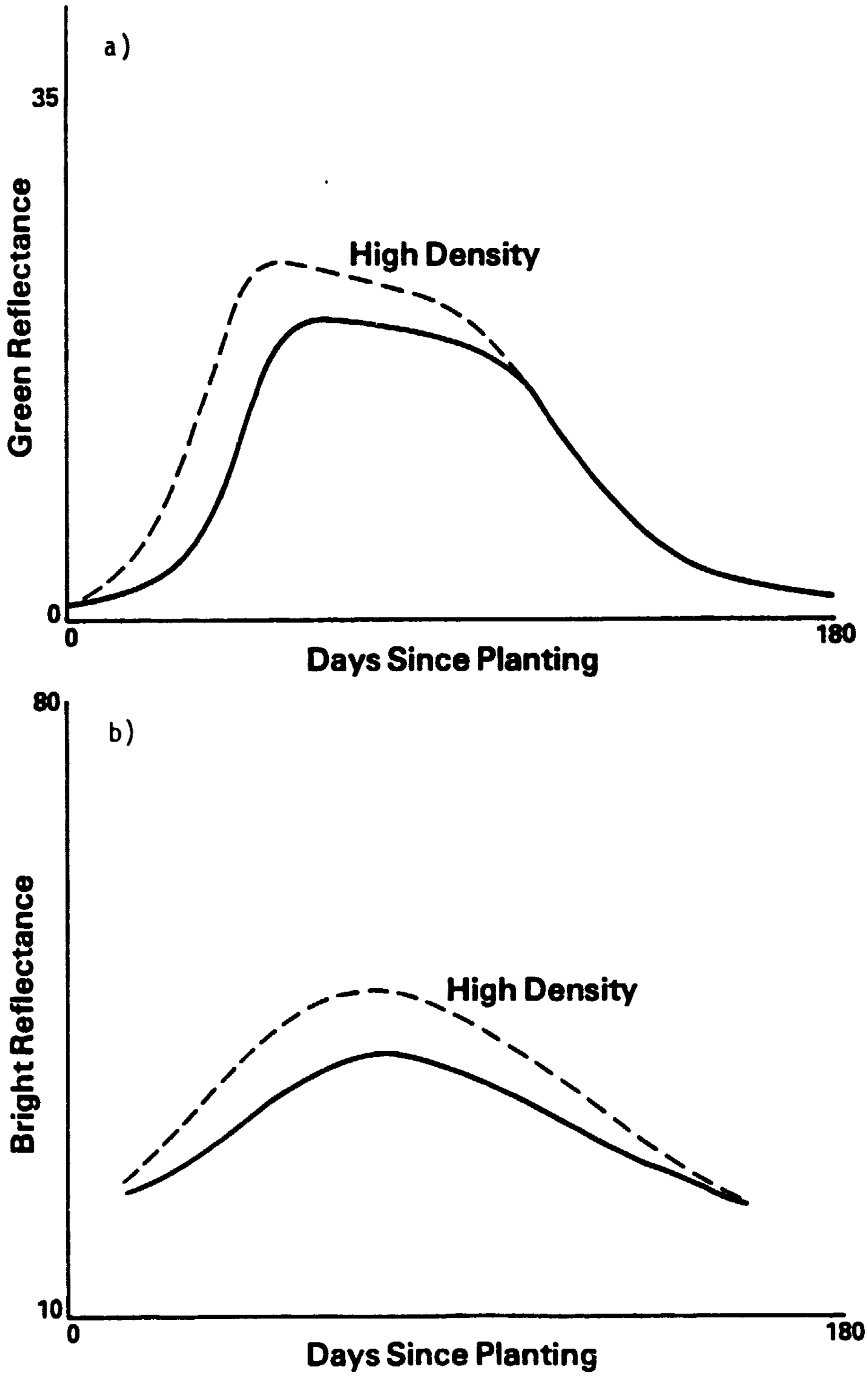


FIGURE 15. POPULATION DENSITY EFFECTS ON CORN PROFILES

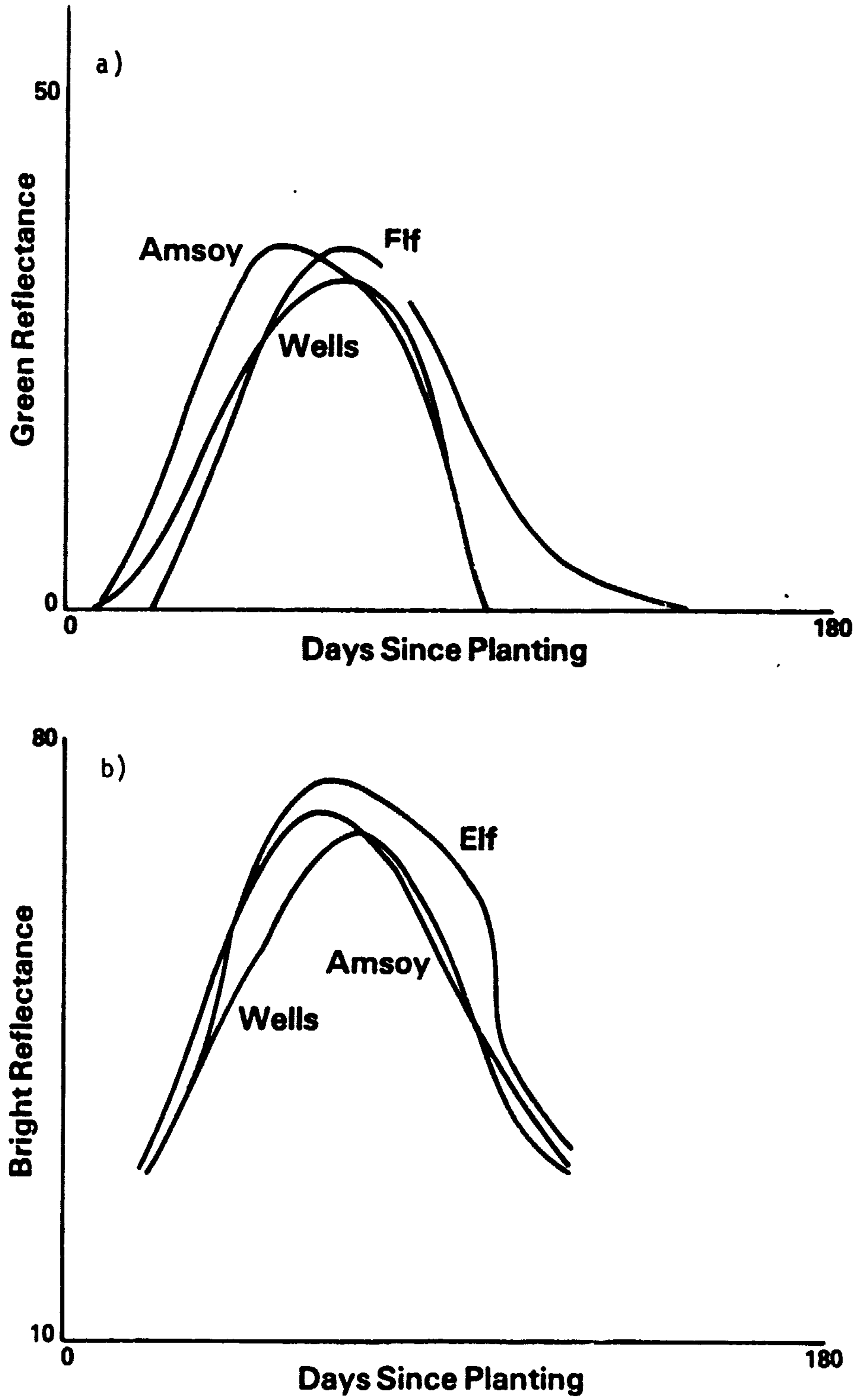


FIGURE 16. VARIETAL EFFECTS ON SOYBEAN PROFILES (CONSTANT ROW WIDTH)

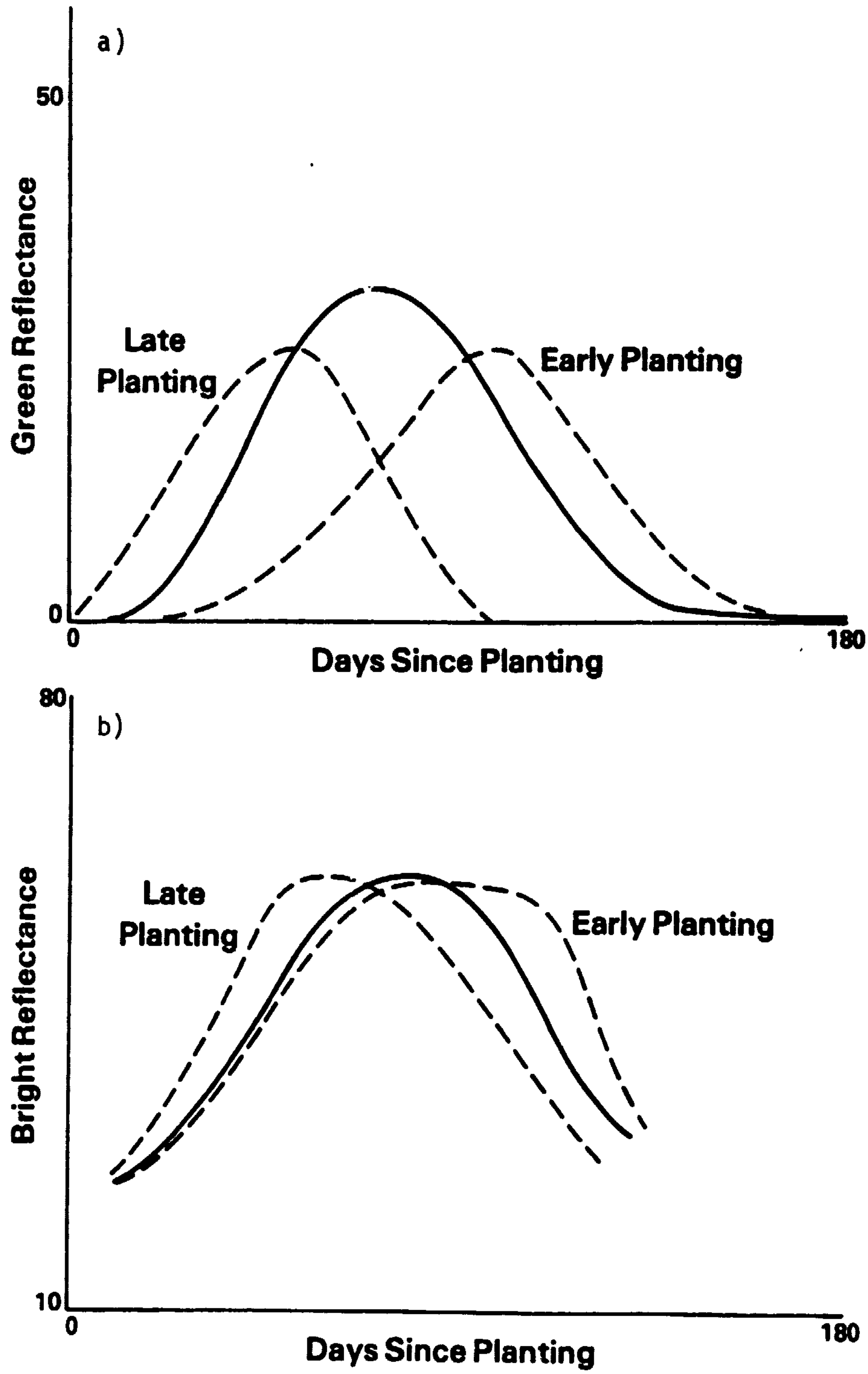
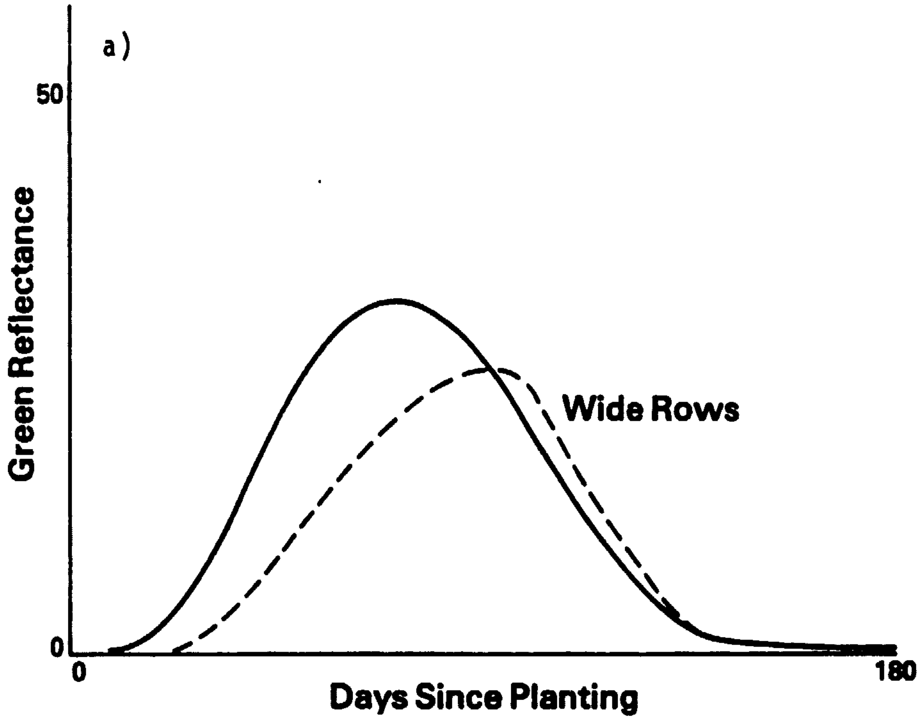


FIGURE 17. PLANTING DATE EFFECTS ON SOYBEAN PROFILES

Row Spacing. Soybean varieties differ in their response to row spacing. In general, however, wider rows tend to cause a reduction in the rate of leaf area accumulation and a delay in achievement of full canopy closure. These effects were expressed in lower and later peak Green Reflectance values and a slower rate of green-up (Figure 18). Also observed was a more rapid green decline after peak, probably an indication of the lower leaf area density, which allowed brown lower leaves or soil to show through the canopy sooner after the peak.



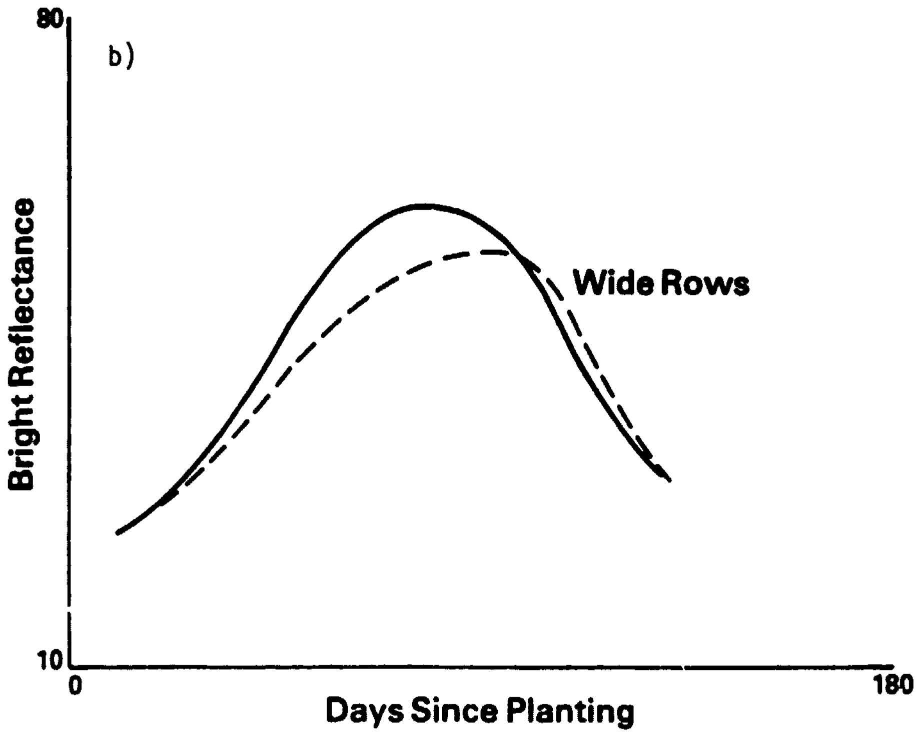


FIGURE 18. ROW WIDTH EFFECTS ON SOYBEAN PROFILES

6
ASSOCIATION OF SPECTRAL AND DEVELOPMENTAL EVENTS

Another aspect of understanding crop profiles is knowing the stages of development associated with some of the key profile features. Such knowledge allows development of crop identification techniques which utilize the most fundamental and therefore most stable differences between crops, and could aid the assessment of crop conditions or prediction of yield by providing a means of pinpointing certain key developmental events from spectral data.

In order to carry out this analysis, development stage data collected for the experimental plots were smoothed and interpolated by polynomial regression. The time of occurrence of each stage, or the stage at any particular time, could then be easily determined. Figure 19 illustrates the result of combining the development stage data with the Green Reflectance data for a typical corn plot.

6.1 CORN RESULTS

Stages of development defined by Hanway [14] were used for corn. Peak Green Reflectance was found to occur at stages 2.5 to 3.0, which correspond to 10 to 12 leaves fully emerged. These stages occur about two weeks prior to tassel emergence, and three weeks before the stage normally associated with peak LAI (stage 5 - silking). Percent cover data associated with the experimental plots suggest that the Green Reflectance peak occurred before maximum canopy closure. Although this result seems to contradict the normally expected correlation between vegetation indices and LAI or percent cover, a plausible, if hypothetical, explanation can be given.

At stage 2.5 to 3.0, all or nearly all the green leaf area is developed, but much of it is still furled into a pseudostem (Figure 20a). Because the stem itself is only about half as tall as the total corn plant at this point, there is a dense and fairly shallow layer of pure

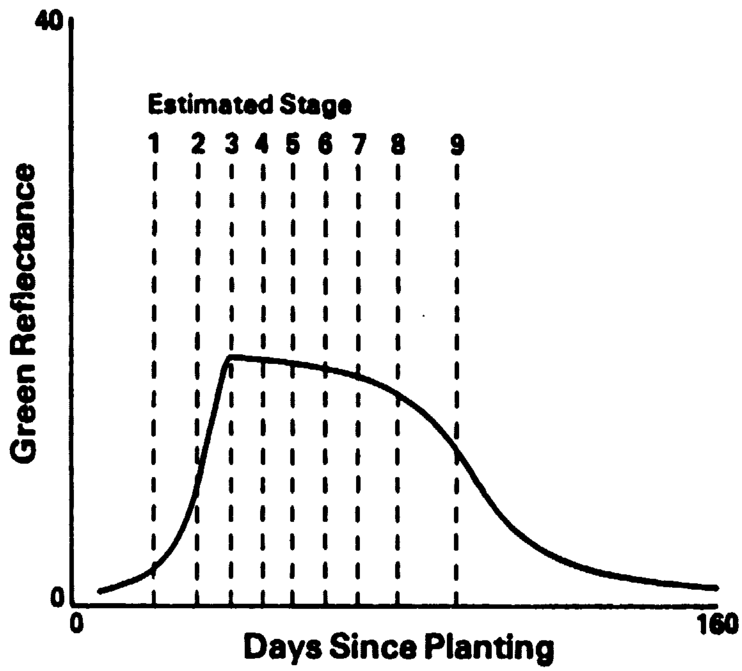


FIGURE 19. SAMPLE RESULT — PROFILE/STAGE ASSOCIATION

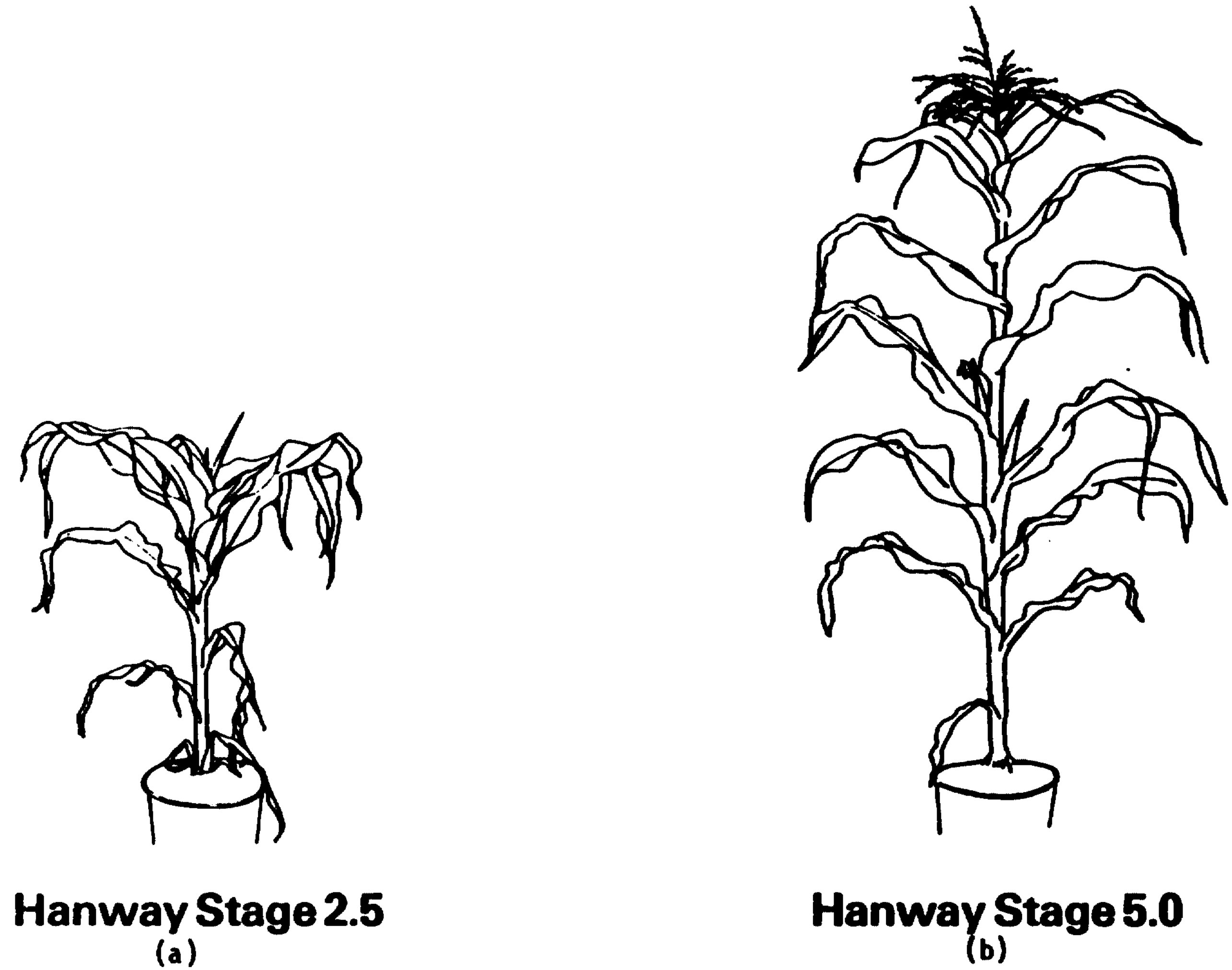


FIGURE 20. TYPICAL CORN PLANT GEOMETRY[1]

[1]Traced from Hanway, J.J. 1971. How a cor plant develops. Iowa State University, Cooperative Extension Service, Ames, Iowa.

green leaf matter at the top of the canopy, which contains all the green leaf matter that the plant will have. Development after this point, including continued stem elongation, changes in leaf angular orientation, and emergence of tassels, all serve to reduce Green Reflectance by increasing shadowing or changing the mix and distribution of plant parts in the canopy (Figure 20b).

The plateau in corn Green Reflectance ends around stage 8, the early dent stage. This stage falls about one month after initiation of rapid dry matter accumulation in the kernels, which would correspond to an accelerated rate of senescence in the vegetative parts. Since one would expect a time lag between onset of senescence, which proceeds from the bottom of the plant to the top, and any noticeable effect on the Green Reflectance of the canopy, the observed delay is not surprising.

6.2 SOYBEAN RESULTS

The stages of soybean development defined by Fehr and Caviness [15] were used. Since many varieties of soybeans are indeterminate, the Fehr/Caviness system provides separate vegetative and reproductive stage progressions.

Peak Green Reflectance occurred between vegetative stages 12 and 21 (12 to 21 nodes with fully emerged leaves), or reproductive stages 3.5 to 6 (beginning pod to full seed). The extremes of these stage ranges normally occur about 30 days apart, suggesting that there is little if any correlation between peak Green Reflectance and any particular soybean stage of development.

In some of the plots, peak Green Reflectance did coincide with the maximum vegetative stage reached, but in many others, the Green Reflectance peak occurred at a vegetative stage well before the maximum. In most of these cases, however, lodging was reported at the time of maximum vegetative development, and at all observation times after the peak. While the severity of lodging was not recorded, one can speculate that it was enough to reduce the Green Reflectance of the canopy by exposing more stems and changing the overall geometry.

It would appear, then, that maximum Green Reflectance in soybeans occurs at the end of vegetative development except when lodging occurs. When lodging was a factor in these data, the end of vegetative development sometimes occurred at a point well down the declining side of the Green Reflectance profile. Thus it must be concluded that Green Reflectance profile features, by themselves, can give little or no reliable information as to the stages of soybean vegetative or reproductive development.

If by some means it could be determined that a particular field, or a region in general, was planted with a determinate variety and/or that no lodging was present, then estimates of stage information might be extractable from the profile features. However, since in most regions one could expect to find both determinate and indeterminate varieties of several maturity classes and a range of susceptibilities to lodging, the likelihood of obtaining such information for any given field seems slight.

7
SEPARABILITY OF CORN AND SOYBEANS

Based on the profile-derived features for the entire set of experimental plots, an analysis of the separability of corn and soybeans profiles was carried out. Both the corn model and cubic smoothing spline were used to characterize corn Green Reflectance profiles, the model because it more accurately describes the actual spectral development pattern, and the spline because it more closely resembles the kind of approach that might be used in an operational setting where the crop type of a sample was not known. Each feature was histogrammed, and the histograms were compared to determine separability. Evaluation of Bright Reflectance profile separability was carried out qualitatively.

7.1 OVERALL RESULT

Using the corn model, the peak Green Reflectance profile value (PMAX), the time of occurrence of that peak (PT), the rate of vegetative development after emergence (SPAN1), and the rate of Green Reflectance decline after the peak (SPAN2) all provided substantial separability. Corn tended to reach a lower peak value earlier, had a more rapid relative green-up rate, and declined in Green Reflectance much more slowly than soybeans. The separability related to green decline was the result of the corn Green Reflectance plateau.

When the cubic smoothing spline was used for both crops, substantial separability was still found in the height of the Green Reflectance profile peak (PMAX), with reasonably good separation also in the rate of Green Reflectance decline (SPAN2). Most notably, in this data set 100% separability was achieved using the peak Green Reflectance profile value and the rate of Green Reflectance profile decline (Figure 21). While the peak value, or something similar to it, is a feature used in several current corn/soybean discrimination techniques [16], the plateau feature is little used at this time. However, apparent rates of green-up and

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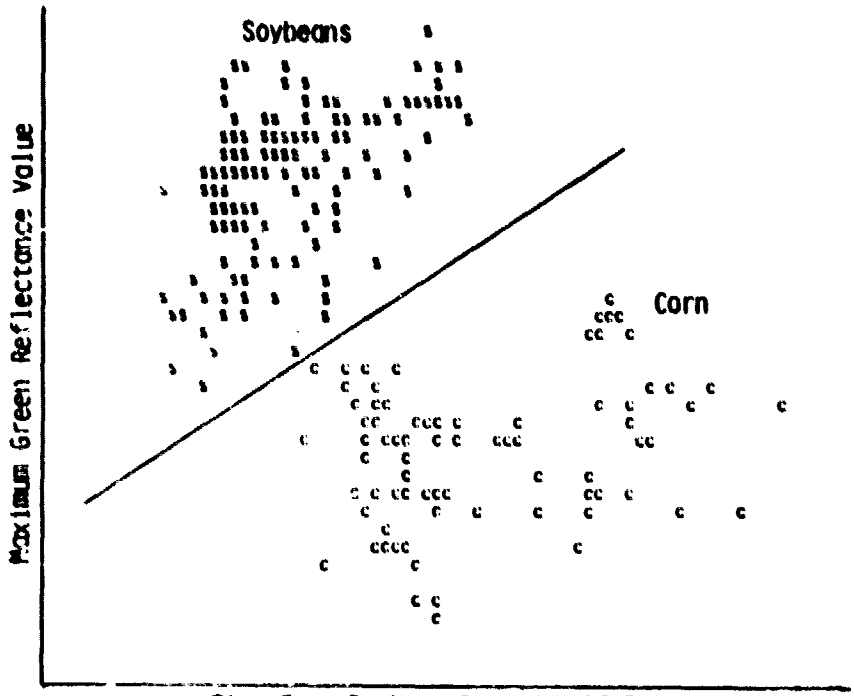

FIGURE 21. SEPARABILITY OF CORN AND SOYBEANS BASED ON SPLINE-DERIVED PROFILE FEATURES

decline, as derived by simpler profile models, are used in current techniques [17], and the separability found in these features is probably an indirect result of the corn plateau.

Early season features such as the rate of early vegetative development (HP1) provided little or no separability, particularly with the spline technique. In addition, comparison of the slopes of the ascending portions of the average corn and soybean profiles revealed little or no difference between the two crops in this respect (Figure 22). Planting date differences, ignored in this analysis, may provide a greater potential for separation, depending on local crop calendars, but there is little indication of purely spectral separability in the early season (i.e., before peak Green Reflectance).

In Bright Reflectance the only obvious source of separability was, again, the height of the profile peak. As can be seen by comparing Figures 9 and 10, this is an expression of the same phenomenon expressed in the Green Reflectance profile peak height - Soybeans moves farther up the "Green Arm" of the Tasseled Cap than does corn. This feature too has been used in crop identification techniques [18].

7.2 EFFECTS OF CHANGES IN FIELD CONDITIONS

Comparison of the results in Section 5 and 7.1 reveal that many of the environmental and cultural factors considered affect precisely those features most important in corn and soybean discrimination. Both nitrogen fertilization and increased planting density tend to raise the peak Green Reflectance value of corn, while early or late planting and wider row spacing tend to lower the peak soybean Green Reflectance value. Similarly, nitrogen deficiency and late planting tend to shorten or soften the plateau effect in corn. Under particular sets of conditions, then, one should expect a degradation in the separability of corn and soybeans.

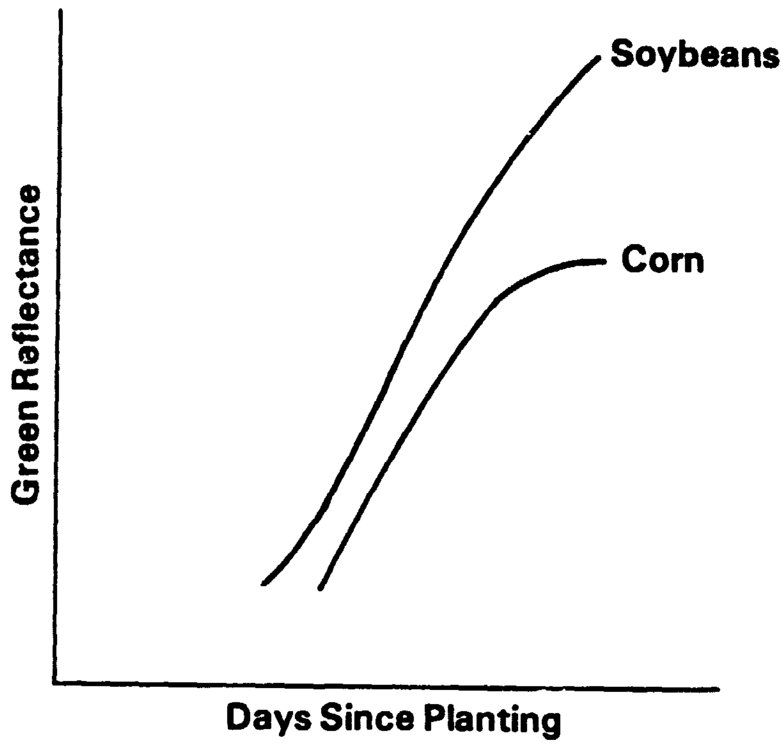

FIGURE 22. ASCENDING PORTIONS OF AVERAGE PROFILES

8
CONCLUSIONS

Comparison of the curves fit to each plot in the set of corn and soybeans transformed field reflectance data indicates that there are indeed characteristic profile shapes for these two crops, shapes which show some variation but which nonetheless retain characteristic attributes. At least some of the variation is caused by changes in field conditions and cultural practices, and it has been shown that variations in these factors within a range that could be reasonably expected in an operational setting cause significant changes in profile features. Furthermore, while corn and soybeans are distinguishable based on their profile features, the effects of changes in conditions or practices are such that separability could, under particular sets of circumstances, be substantially degraded.

The evaluation of development stage association with profile features shows a clear relationship between corn Green Reflectance features and stages of development, and further shows that the peak in corn Green Reflectance occurs earlier than would have been expected, before either maximum LAI or maximum canopy closure. Conversely, soybean Green Reflectance features cannot be associated with any particular stage of development. In the absence of lodging, a strong correlation can be seen between peak soybean Green Reflectance and maximum vegetative development.

The profiles described in this report, and the changes in those profiles attributable to field conditions and cultural practices, provide a foundation for development of automatic crop identification techniques using Landsat data. If, using meteorological or other available information, field conditions could be inferred for a particular region of interest, expectations regarding corn and soybean profile shapes could be modified based on the presented results, an approach which could yield a substantial increase in labeling accuracy. A technique adaptable in such a manner, and therefore applicable over wide regions and many years, would be of considerable value.

With regard to assessment of field conditions the results described in this report suggest that spectral data alone may not provide adequate information for determining the presence or absence of a particular physiological stress. For example, late planting and nitrogen deficiency, which primarily influence the physiological development of the individual plants, reduce the peak Green Reflectance value, but a similar result is seen when population density is reduced. Reduced plant population will affect individual plant growth to some degree, but its primary influence on the Green Reflectance profile is probably due to changes in the proportion of soil background as compared to vegetation or the density of the vegetation viewed by the sensor.

Although a thorough analysis of all profile features could allow discrimination between these various factors, it is most likely that the acquisition intervals provided by Landsat, and the potential for mixing several such factors in any given field, would only allow use of more gross characteristics such as the peak value.

The likely impact of this result on spectral contributions to yield estimation is uncertain, however, since the final goal is not accurate identification of the yield-affecting condition but rather accurate estimation of its effect. In the previous example, reduced population density may not be classified as a "stress", but it most probably will reduce the yield obtained from the particular field. In addition, the strong association observed between the Green Reflectance profile peak in corn and a particular stage of development suggests that a "critical time interval" for yield-affecting stresses could be estimated for each field. With this information, the likely impact on yield of stresses detected or forecast by other means could be more accurately predicted, allowing more accurate prediction of regional production.

REFERENCES

1. Hay, C.M. Manual Interpretation of Landsat Data. Proceedings of the Technical Sessions, Vol. I, the LACIE Symposium, NASA Johnson Space Center, Houston, Texas, 1979.

2. Badhwar, G.D. A Semi-Automatic Technique for Multitemporal Classification of a Given Crop. AgRISTARS Report SR-J0-00481, NASA Johnson Space Center, Houston, Texas, 1979.

3. Crist, E.P. and W.A. Malila. A Temporal-Spectral Analysis Technique for Vegetation Applications of Landsat. Proceedings of the 14th International Symposium on Remote Sensing of Environment, San Jose, Costa Rica, 1980.

4. Crist, E.P. and W.A. Malila. A Technique for Automatic Labeling of Landsat Agricultural Scene Elements by Analysis of Temporal-Spectral Patterns, Proceedings of the 15th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, 1981.

5. Crist, E.P. Cultural and Environmental Effects on the Spectral Development Patterns of Corn and Soybeans - Field Data Analysis, NASA Report SR-E2-04224, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 1982.

6. Crist, E.P. Association of Spectral Development Patterns with Development Stages of Corn. NASA Report IT-E2-04235, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 1982.

7. Bauer, M.E., M.H. Hixson, L.L. Biehl, C.S.T. Daughtry, B.F. Robinson and E.R. Stoner. Agricultural Scene Understanding, LARS Report 112578, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, 1978.

8. Bauer, M.E., L.L. Biehl, C.S.T. Daughtry, B.F. Robinson and E.R. Stoner. Agricultural Scene Understanding and Supporting Field Research, NASA Report SR-P9-00410, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, 1979.

9. Bauer, M.E., L.L. Biehl and B.F. Robinson. Field Research on the Spectral Properties of Crops and Soils. NASA Report SR-P0-04022, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, 1980.

REFERENCES (Continued)

10. Kauth, R.J. and G.S. Thomas. The Tasseled-Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by Landsat. Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, Indiana, 1976.

11. Badhwar, G.D. Crop Emergence Date Determination from Spectral Data, Photogrammetric Engineering and Remote Sensing, 46:369-377, 1980.

12. Cicone, R.C., E. Crist, R. Kauth, P. Lambeck, W. Malila and W. Richardson. Development of Procedure M for Multicrop Inventory, With Tests of a Spring Wheat Configuration. Final Report 132400-16-F, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 1979.

13. DeBour, C. A Practical Guide to Splines. Springer-Verlag, New York, 1978.

14. Hanway, J.J. Growth Stages of Corn (*Zea Mays*, *L.*). Agronomy Journal, 55:487-492, 1963.

15. Fehr, W.R. and C.E. Caviness. Stages of Soybean Development. Special Report 80, Iowa State University, Cooperative Extension Service, Ames, Iowa, 1977.

16. Metzler, M., R. Cate and J. Odenweller. Automatic Crop Inventory in Argentina with Multitemporal Landsat Data. Proceedings of the 16th International Symposium on Remote Sensing of Environment, Buenos Aires, Argentina, 1982.

17. Badhwar, G.D., J.G. Carnes and W.W. Austin. Use of Landsat-Derived Temporal Profiles for Corn-Soybean Feature Extraction and Classification. Remote Sensing of Environment, 12:57-79, 1982.

18. Roller, N., K. Johnson, J. Odenweller and C. Hay. Analyst Handbook for the Augmented U.S. Baseline Corn and Soybean Segment Classification Procedure (C/S-1A). NASA Report FC-E1-00723, Environmental Research Institute of Michigan, Ann Arbor, Michigan and University of California at Berkeley, Berkeley, California, 1981.