General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

7.9 - 10.14.7.

NASA CR-151880
ERIM 124000-5-P

NASA

Progress Report

THE THRESHOLD OF DETECTION OF VEGETATIVE CANOPIES USING REMOTELY SENSED DATA

D.P. RICE, W.A. MALILA, and R.F. NALEPKA
Infrared and Optics Division

JANUARY 1979

(E79-10147) THE THRESHOLD OF DETECTION OF VEGETATIVE CANOPIES USING REMOTELY SENSED DATA Progress Report, 1 Feb. - 31 Oct. 1978 (Environmental Research Inst. of Michigan) 30 p HC A03/MF A01 CSCL 08F G3/43

N79-18411

Unclas
00147

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Space Center
Earth Observations Division
Houston, Texas 77058
Contract No. NAS9-15082
Technical Monitor: M. C. McEwen/SF3

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

NOTICE

Sponsorship. The work reported herein was conducted by the Environmental Research Institute of Michigan under Contract NAS9-15082 for the National Aeronautics & Space Administration, Johnson Space Center, Houston, Texas 77058. Dr. Michael C. McEwen was Technical Monitor for NASA. Contracts and grants to the Institute for the support of sponsored research are administered through the Office of Contracts Administration.

Disclaimers. This report was prepared as an account of Government sponsored work. Neither the United States, nor the National Aeronautics & Space Administration (NASA), nor any person acting on behalf of NASA:

(A) Makes any warranty expressed or implied, with respect to the accuracy, completeness, or usefulness of the information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA or employee of such contractor prepares, disseminates, or provides access to any information pursuant to his employment or contract with NASA, or his employment with such contractor.

Availability Notice. Request for copies of this report should be referred to:

National Aeronautics & Space Administration
Scientific & Technical Information Facility
P.O. Box 33
College Park, Maryland 20740

Final Disposition. After this document has served its purpose, it may be destroyed. Please do not return it to the Environmental Research Institute of Michigan.

PREFACE

This document reports progress achieved during a one-year period on a modest analysis effort conducted by the Environmental Research Institute of Michigan (ERIM) in support of agricultural crop inventory activities of NASA's Lyndon B. Johnson Space Center, Houston, Texas. This effort represents one portion of ERIM's support of those activities.

The focus of the work reported herein was the problem of determining the threshold of detection of developing crop canopies using remotely sensed data. As such it employed Field Measurement data acquired as part of the LACIE project, Landsat data, and simulation data.

The research was performed under Contract NAS9-15082, during the period November 1, 1977, through October 31, 1978. Dr. Michael C. McEwen served as the NASA Contract Technical Monitor. At ERIM, the work was performed within the Infrared and Optics Division, headed by Richard R. Legault, Vice President of ERIM, in the Information Systems and Analysis Department, headed by Dr. Quentin A. Holmes. Mr. Richard F. Nalepka and Dr. William A. Malila served as Co-Principal Investigators. Mr. Daniel Rice carried out the majority of the analysis reported. Useful counsel was received from R. Horvath and R. Kauth, while the data base was assembled through efforts of J. Gleason and A. Ehrlich.

CONTENTS

PRECEDING PAGE BLANK NOT FILMED

FIGURES

TABLES

1
INTRODUCTION AND SUMMARY

The technical objective of this contract is to investigate the threshold of detection of agricultural canopies using remotely sensed data. This issue is a critical one for the development of large area inventory systems in that it addresses how soon a crop may be surveyed, and quantifies the extent to which a canopy may be detected as a function of its growth.

The approach used to address this issue has four general parts and makes use of a data base that contains data from both background soils and vegetation canopies of varied densities. The four parts of the approach are:

1. Characterize the background distribution, including the range of soil variation expected in bare soil areas, and determine a decision rule that separates most of the distribution from green canopies.
2. Order and stratify canopies in the data base according to their relative amounts of vegetative development (or density).
3. For each stratum or level of vegetative development, determine the percent of canopies within it that would be classed as "background" by the established decision rule.
4. Express the threshold of detection (level of vegetative development) as a function of the percentage of canopies that would not be detected by the established rule.

In following the above approach, more fully discussed in Section 2, three classes of data sets were used. First, field measurement data were used to measure the threshold of detectability for a localized area and to begin an examination of cause and effect relationships and the effects of using different sensors. Second, actual Landsat data sampled across the U.S. Northern Great Plains were used to measure the confusion present due to variability of many parameters over a vast area, and due to variability of the atmosphere and satellite sensor. And, finally, simulated spectral data were generated for conditions not represented in the empirical data and used to answer questions regarding how the threshold varies with respect to important parameters such as sun angle and haze level.

Based on activities using these data sets, we began to see the overall "threshold of detection" picture. The following results indicate the nature of the threshold under varying circumstances:

1. Computed thresholds of detection varied from 10% to 33% green vegetative cover, depending on the sources of variability included.

   a) When all variability present in Landsat data from the U.S. spring wheat area was considered, wheat canopies were found to need a percent cover of roughly 33% in order to be detected (with half the fields of this percent cover recognized as different from the background).

   b) Using data that covered the variability present in a relatively small area of several square miles, and that did not include all the variability associated with viewing through the atmosphere, a wheat canopy condition of only 10 to 15 percent cover was required for 50% detection using Landsat bands.

2. The use of Thematic Mapper bands with reflectance data led to detection at a smaller degree of vegetative cover than did the use of Landsat bands for the same data set.

3. The amount of haze and its variation had a significant impact on the threshold of detection. Sun and view geometry appears to have relatively little effect, given the range expected throughout the U.S. Great Plains in mid-spring for Landsat (but not including the very low sun angle condition found in high latitudes early or late in the year).

2
TECHNICAL APPROACH

In this section we cover in more detail the general method of computing the threshold of detection, followed by specific analyses used for each data set.

2.1 DEFINING THRESHOLD OF DETECTION

We define threshold of detection (TOD) as the minimum canopy density which can be distinguished from backgrounds of bare soils. Canopy density can be measured by parameters such as percent cover, leaf area index, horizontal leaf area index, biomass and the like. In this report we are interested primarily in green vegetative cover and leaf area index.

The term "distinguished" in the definition is subject to many interpretations. For example, one remote sensing activity may attempt to detect the vanguard of greening up of a crop, but another may attempt to measure the area in a scene of a crop that has good vegetative development. In the first case, only a fraction of the scene elements (pixels) need to be separable from the background, but in the latter, nearly all of the pixels must be separable. Because of this problem of interpretation, we have taken the approach of expressing TOD as a function of the percent of pixels that would be confused with the background.

2.2 DETERMINING A TOD CURVE

In order to determine the TOD function, a data set is required that possesses data points consisting of sensor signal values and canopy density values. The density values must span the range from bare soil to sufficient cover that the sensor would have little difficulty detecting the canopy. The number of observations should be sufficient to characterize the distribution of signal values for each interval of canopy density. The observations must be taken over the range of measurement conditions (latitude, longitude, sun and view geometry, crop type, atmospheric conditions, soil types, etc.) to be studied. These factors comprise the most important data set requirements.

Once a suitable data set was established, the background was characterized as follows. For each observation with little or no vegetative cover (bare soil), a measure of vegetative cover (called sensor green measure) was computed from the sensor channel values, and a histogram of this measure was produced. A value of this measure was selected such that 90% of the bare soil observations have a smaller sensor green measure, as illustrated in Figure 1. This value then was used as a decision boundary.

The decision boundary and all the observations were used to produce a TOD curve in a process described below and illustrated in Figure 2. The range of canopy densities present in the data set was divided into a convenient number of intervals (approximately 20). The data within each interval was then aggregated into a histogram of the sensor green measure values which provided a statistical characterization for the interval. Several percentile values (5th percentile, 15th percentile, 25th percentile...95th percentile) were computed for the actual distribution found in each canopy condition interval. For example, the 55th percentile value for a particular canopy density interval is that value of the sensor green measure for which 55% of the sensor green measure values therein are smaller. These percentile related green values for each interval were then plotted at interval centers (symbols in Figure 2a).

In most cases the number of observations in each canopy density interval was limited. The resultant scatter in data points made necessary to smooth the percentile values. This was done by fitting a first- or second-order polynomial curve through the values at each given percentile over all the canopy condition intervals (curves in Figure 2a). This smoothing was applied to all intervals, including the zero-cover canopy condition.

Having fit a curve for each percentile, the intersection of this curve with the decision boundary was next determined. The result is a value of

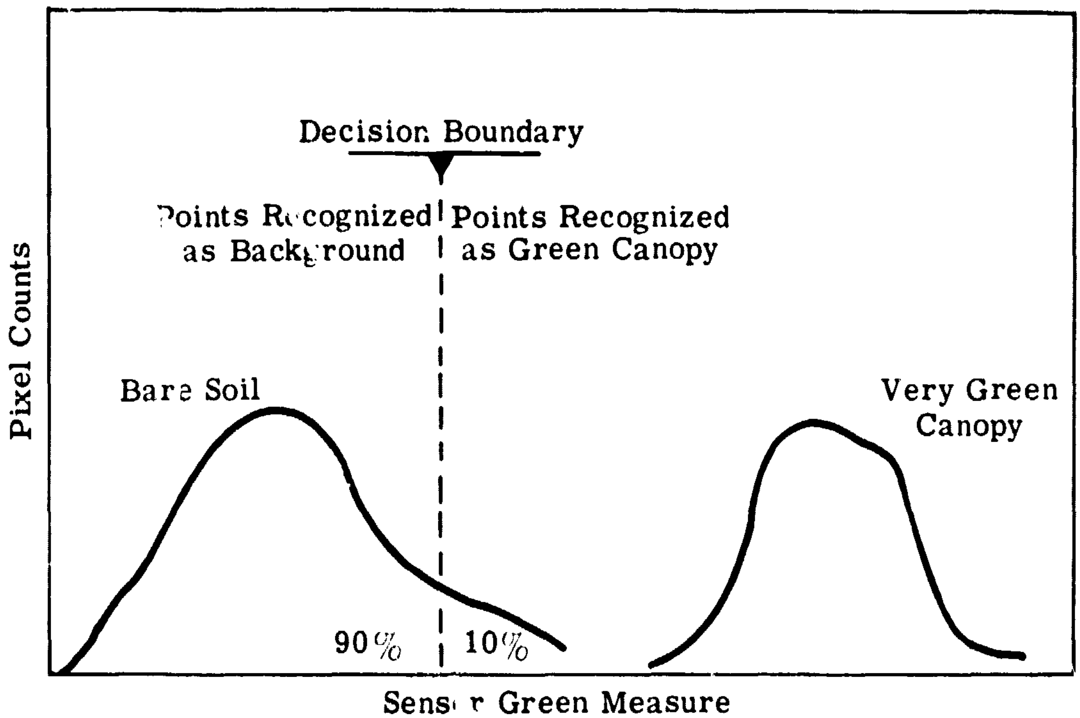

FIGURE 1. CHARACTERIZATION OF BACKGROUND DECISION RULE

ORIGINAL PAGE IS
OF POOR QUALITY

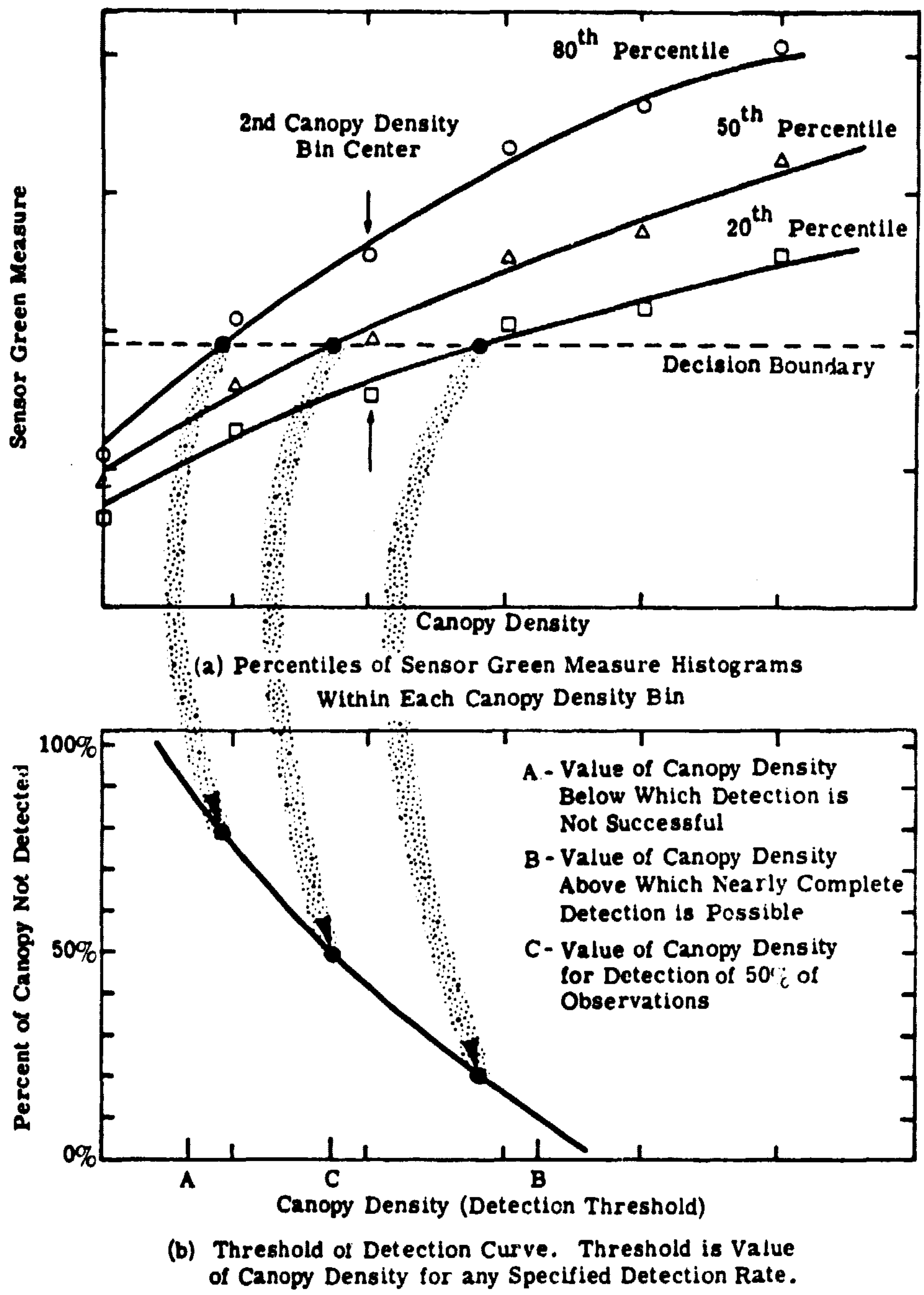

FIGURE 2. ILLUSTRATION OF HOW THRESHOLD OF DETECTION IS DETERMINED

canopy density for which the percentile specifies the percentage of observations detectable at that level. This and similar intersection points were then plotted to produce each TOD curve of the type shown in Figure 2b.

2.3 ANALYSIS OF FIELD MEASUREMENT DATA

Data acquired in 1976 by the LACIE Field Measurements Program at the Williston, North Dakota, Agriculture Experiment Station [1] were used to determine the threshold of detectability of spring wheat by the method described above. This site featured 48 spring wheat plots and bare soil plots, each measuring 3.5 m x 15.3 m. On these plots spectral measurements had been made at intervals throughout the growing season using a truck-mounted EXOTECH 20C spectrometer. This spectrometer measured the spectral response of each plot in a number of relatively narrow wavelength bands covering the visible and near IR portions of the spectrum. In conjunction with these spectral measurements, several canopy parameters were measured, including leaf area index, height, maturity, and others, as a function of time of year, variety, fertilization, etc. In all, a total of 910 observations of wheat canopies were made; each observation included both spectral data and canopy condition variables.

From the data, inband Landsat and Thematic Mapper reflectance values were computed by performing a numeric integration after multiplication by the spectral response functions of the sensor bands. No attempt was made to incorporate sensor noise or atmospheric variation into this data set.

A green measure consisting of the square root of an infrared/red band ratio (0.8 to 1.1 μm/0.6 to 0.7 μm) was computed for all observations used. Past experience had found this green measure to consistently show a strong relationship with canopy density and to compare favorably with other candidate green measures [2]. Results obtained using this data set are discussed in Section 3.

2.4 ANALYSIS OF LANDSAT DATA

In order to understand the nature of the detection threshold as observed from space, use was made of actual Landsat data taken from several sites throughout the U.S. Northern Great Plains. In each site a small sample of pixels was selected from up to 15 fields per site for which subjective percent cover data were collected. The pixel selection was carried out using a systematic grid that picked every 5th line and point in each data set, assuming the pixel fell within a useable field. In all, 1276 pixels were used from 356 fields in 32, 5 x 6 mile sites throughout the four-state area.

2.5 INVESTIGATION OF THRESHOLD AS FUNCTIONS OF SIGNIFICANT PARAMETERS

In addition to using field measurement and Landsat data to investigate the threshold of detection, we employed simulation techniques. The purpose of employing simulation is to isolate and measure the effects of some of the important parameters that affect detected signals, such as sun angle, view angle, differing canopies, haze level, and others. For example, it would be difficult or impossible to collect an actual data set in which sun zenith angle varied over a wide range, while all other parameters such as time of day, maturity stage, and atmospheric condition were fixed. Because of this problem, the use of simulation clearly is needed to effectively address some of the questions of interest.

As a first attempt, we employed the combination of a canopy model developed by Suits [3] and an atmospheric model developed by Turner [4]. A careful description of the combined model is given in Malila, et al [5]. By way of introduction to the combined model, Table 1 lists the major parameters involved in the modeling.

This initial study was designed to begin to answer some of the important questions, such as:

-- How much does the threshold depend on sun angle?

-- How important is haze level?

-- What is the effect of view angle?

TABLE 1. QUANTITIES USED IN THE ERIM COMBINED CANOPY/ATMOSPHERIC MODEL

Spectral Qualities of One or More Soil Classes
Spectral Qualities of Canopy Components
Wavelengths
Canopy Structures
Canopy Densities
View Angles
Sun Angles
Relative Azimuth Angles Between Sun and View
Optical Thicknesses
Background Albedos
Sensor Response Functions

Table 2 presents the parameter settings used in this experiment. Not all of the significant variables or sources of variation were incorporated in this initial simulation. For example, the variability of canopy structure, additional canopy types, and sensor noise were not included. The latter quantity is believed to be significant at extremely low sun angles where the general signal level is small.

While soil variability is not accounted for by the model parameter ranges and does not appear in Table 2, it was found to be fundamentally important in the TOD (Threshold of Detection). A lack of variability at the low canopy cover situations led at first to an extremely low estimate of TOD using the simulation data. Therefore, soil variation was incorporated into the analysis. This was accomplished as follows.

After the modeled data was generated and transformed to produce a simulated Landsat green measure (as described below), the range of soil reflectance variation reported by Condit [6], was transformed so that the variation in the direction of the green measure was known. Then the histograms to be used in the TOD calculation (described earlier in this chapter) representing little or no canopy cover were filtered so as to incorporate this soil reflectance variation. Then the revised histograms were used in the TOD procedure as before.

In future tests, soil variability and other parameters should be included as part of the model calculations.

The green measure used for this simulation was the Tasselled Cap green component [7]. This green measure has shown consistent correlation with canopy characteristics, as have other green measures. We selected this measure over that used in other tests because fewer approximations were required to carry out the soil variability calculations.

TABLE 2. PARAMETER SETTINGS USED IN THE SIMULATION

	Parameter	No. of Values	Range of Values
Parameters Varied for This Study	Percent Cover	12	0-44%
	Sun Elevation	11	37° (Northern USSR, May) - 59° (Northern Texas, May)
	View Angles	7	±4° from Nadir
	Haze Level (Visual Range)	3	Moderately Clear (23 km), Somewhat Hazy (10 km), Extreme Haze (4 km)
Other Parameters Specified	Canopy Structure	1	Emergence Through Jointing
	Soil Class	1	Condit [6] Average (See Text)
	Relative Azimuth	-	Appropriately selected for each sun angle/view angle combination for a May Landsat pass
	Background Albedo	1	Bare Soil, Condit Average
	Sensor Response Functions	-	Appropriate for Landsat and for Thematic Mapper Bands
	Wavelengths	-	Sufficient for Characterizing Sensor Response Functions

3
RESULTS AND CONCLUSIONS

In the preceding section, we described the TOD (Threshold of Detection) calculations that were carried out. We now describe the results of these calculations.

3.1 GENERAL RESULTS

The Threshold of Detection curve for the field measurements data set (Williston, N.D. 1976) is given in Figure 3. In this data set, the available canopy condition measured was LAI (Leaf Area Index). As shown on the curve, detection was reliable above a leaf area index of 0.42, and impossible below 0.22. In subsequent discussions, we will speak of the 50% recognition point (LAI = 0.28) as the TOD, recognizing however that it is but one point on the curve.

We believe that the data set used is limited in terms of the variability that would usually be present in a practical remote sensing problem, since there was little areal extent of the site, since the site represents little soil variability, and since careful uniform management practices are employed at the experiment station. Therefore, the threshold that was determined may be interpreted as an optimistic estimate compared to that of a typical application.

The threshold determined in terms of LAI does not translate directly into percent cover, since the two quantities are not measures of the same variable. LAI measures total leaf area, whereas percent cover measures the amount of ground covered by the horizontal projections of the leaves. The relationship varies somewhat as a function of canopy structure. However, we attempted to express the threshold explained above in terms of percent cover, based on knowledge of the approximate relationship between LAI and percent cover [7]. The detection threshold so determined for this data set is approximately 10 to 15 percent cover.

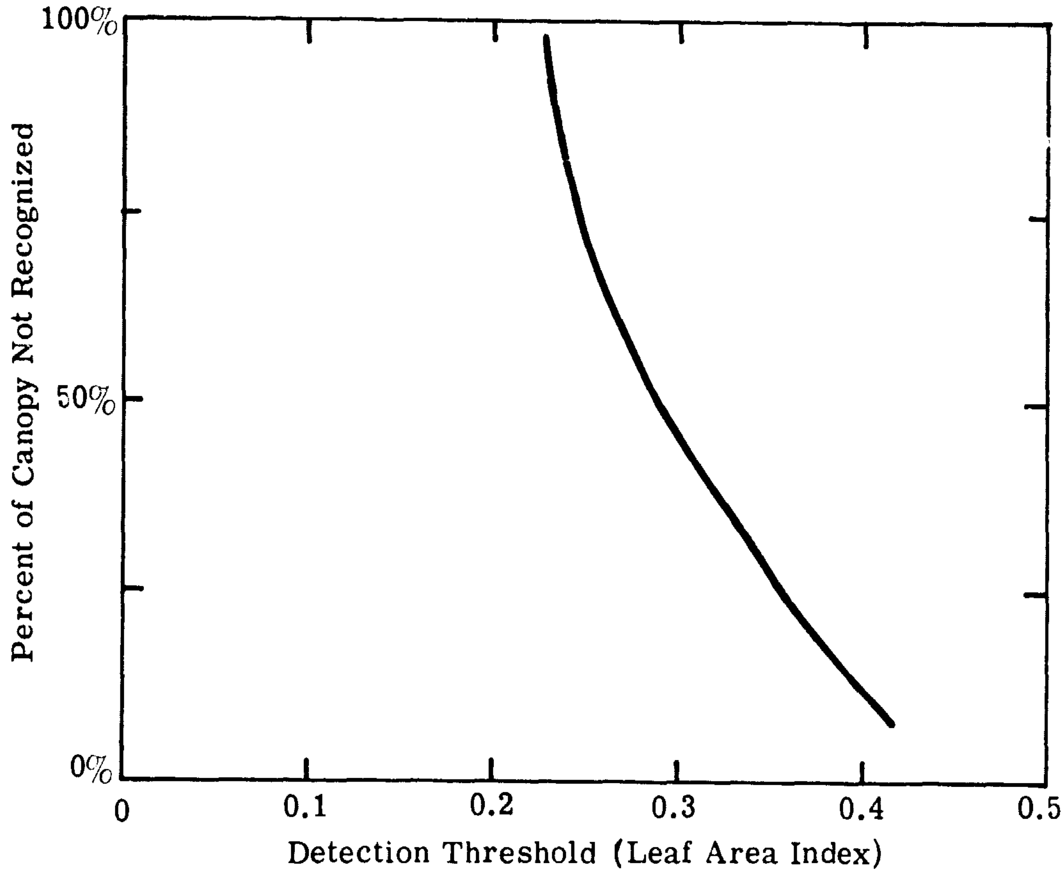

FIGURE 3. THRESHOLD OF DETECTION USING 1976 WILLISTON, NORTH DAKOTA SPECTROMETER DATA

On the other hand, the Landsat wheat data set, which resulted in the TOD curve shown in Figure 4, was generated from a data base that encompassed real satellite data over a very large region. Because the region is much larger than might be used for many remote sensing problems (e.g., larger than a typical LACIE stratum), the TOD of 33% cover may be considered a somewhat pessimistic (high) estimate. An additional source leading to the high estimate of TOD is that percent cover was subjectively estimated by field personnel into five broad categories (0-20%, 20-40%, 40-60%, 60-80% and 80-100%), which tended to overestimate the confusion between a given canopy and a bare soil canopy.

However, the curve in Figure 4 is very significant in that actual sensor data were used, and that a near maximum amount of variability is present, so that a candidate wheat remote sensing activity can be reasonably assured of success if operated within the implied limitations of this result.

3.2 COMPARISON OF LANDSAT AND THEMATIC MAPPER BANDS

One important question addressed by this investigation is how much better are the Thematic Mapper (TM) (Landsat D) bands than current Landsat MSS bands. The green measure formed by taking the square root of a ratio of near-infrared to red bands was computed both for Landsat inband reflectance values (Band 7/Band 5, e.g., 0.8-1.1 μm band/0.6-0.7 μm band) and TM inband values (0.76-0.90 μm band/0.63-0.69 μm band) where the inband values were derived by applying the spectral response functions of the bands to the field spectrometer data, as previously described. A TOD curve was computed for both green measures as before, and the curves were compared. As shown in Figure 5, the TM bands out-performed the Landsat bands by reducing the TOD (50% recognition) from a leaf area index of 0.29 to 0.24.

This reduction was accomplished even though the Landsat green measure is one found to be among the best through years of experience with the Landsat bands, whereas its simple extension to the TM bands may not take full advantage of all the information in the TM bands that can be used

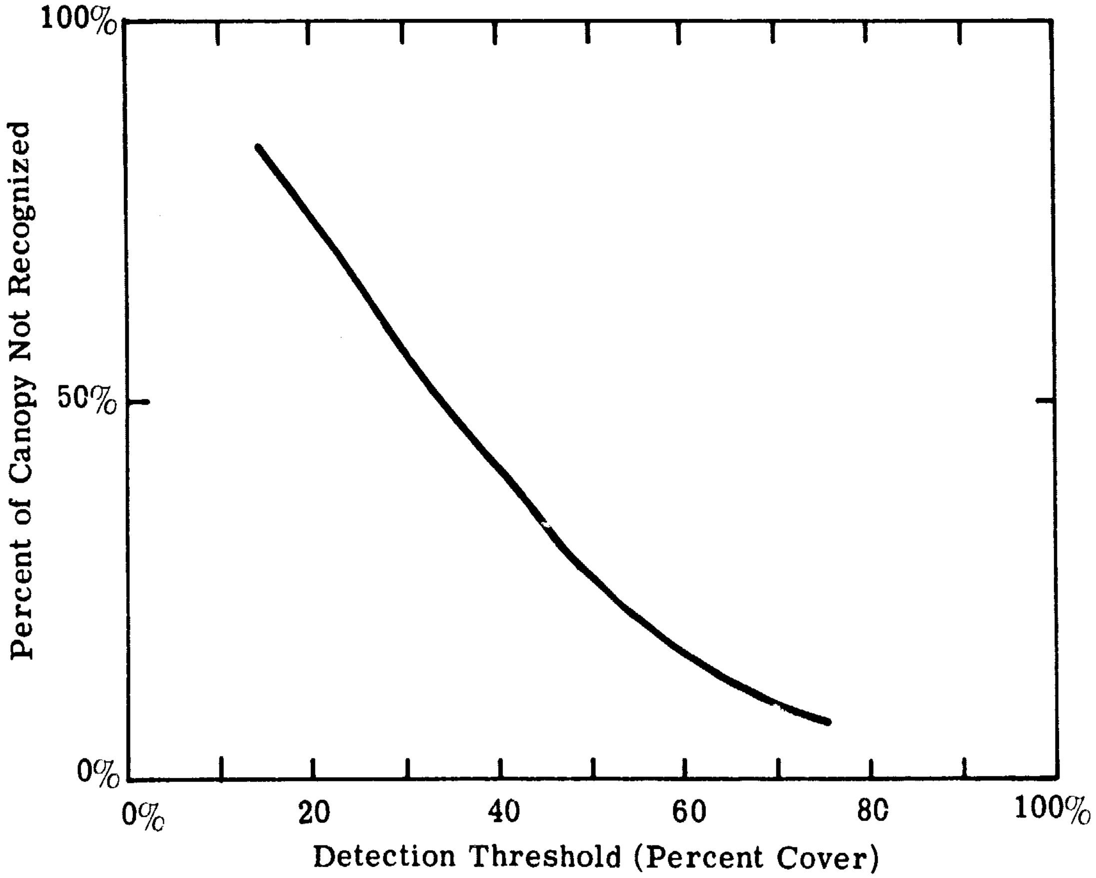

FIGURE 4. THRESHOLD OF DETECTION USING ACTUAL LANDSAT DATA FOR 32 SEGMENTS THROUGHOUT THE U.S. NORTHERN GREAT PLAINS

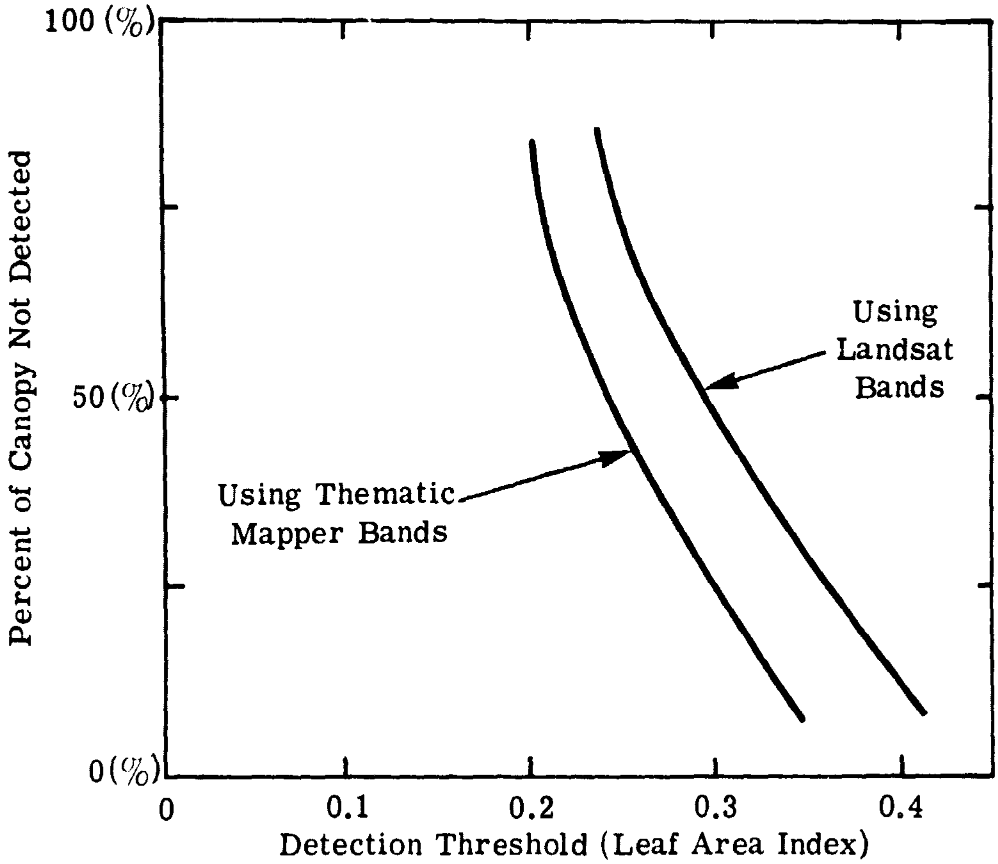

FIGURE 5. COMPARISON OF DETECTION THRESHOLD FOR TM BANDS AND LANDSAT BANDS, USING 1976 WILLISTON, NORTH DAKOTA FIELD SPECTROMETER DATA

to measure green vegetative development. Thus even greater improvement in the TOD may be possible after more experience with the TM bands is attained.

3.3 PARAMETER VARIATION STUDY

To answer the questions regarding the effect on TOD of several parameters (listed in Section 2.3), TOD curves were determined using the modeled data set and subsets of that data set representing fixed values of the parameters under study.

As a basis of comparison, the TOD curve representing all the variability incorporated into the modeled data set is given in Figure 6. We believe that in the simulation efforts so far, not all desired variation of parameters is included, and therefore that this curve is a low estimate of the TOD for a data set encompassing a large region. However, since the same situation is true in subsequent curves, the comparisons made below are considered valid.

Next, let us compare this curve with the TOD curves for the largest and smallest sun elevation angles used in the simulation, as shown in Figure 7. The fact that only very small differences occur in this figure, and between this figure and Figure 6, implies that differences in sun angle are well compensated by the green measure used. In fact this is not entirely unexpected, since much of the sun angle effect is multiplicative (a cosine effect) consistent for all channels, such that a ratio or similar green measure can normalize the effect.

This result held over the range of sun angles likely to be encountered in a worldwide wheat survey using Landsat in the month of May. However, of particular interest is the question of sun angle effects during the Fall portion of the wheat growing season. During this period, at high latitudes such as encountered in some U.S.S.R. wheat growing regions, the sun elevation can become quite low. The current modeling effort does not currently provide all the information needed to address this question, but we hope to remove this deficiency in our future work.

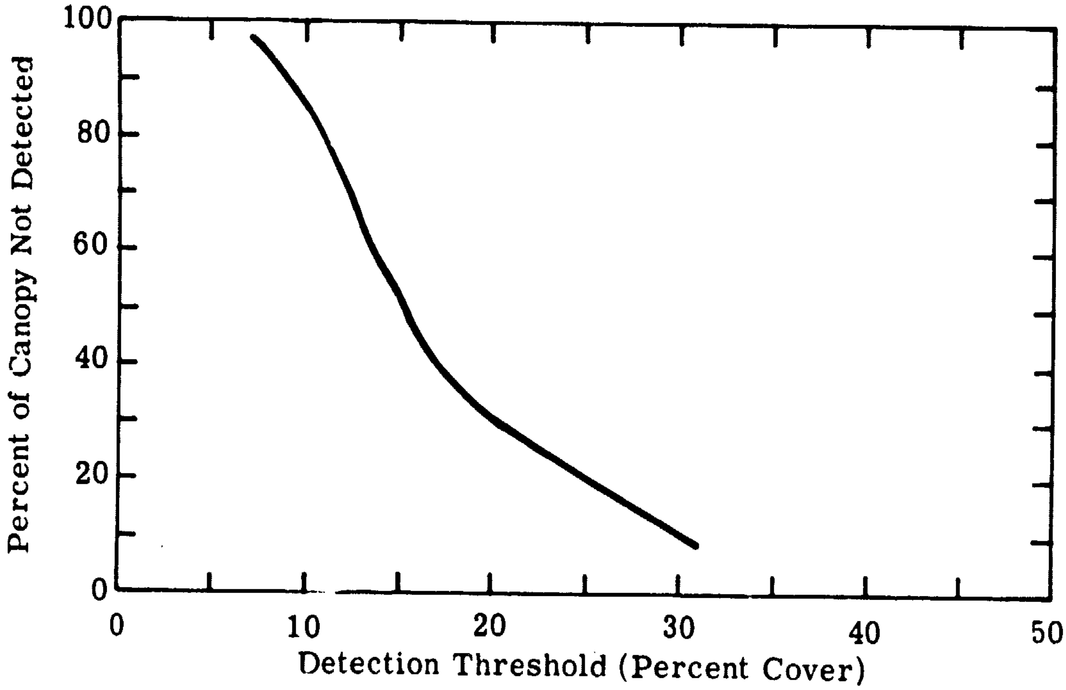

FIGURE 6. DETECTION THRESHOLD USING ENTIRE SIMULATED DATA SET

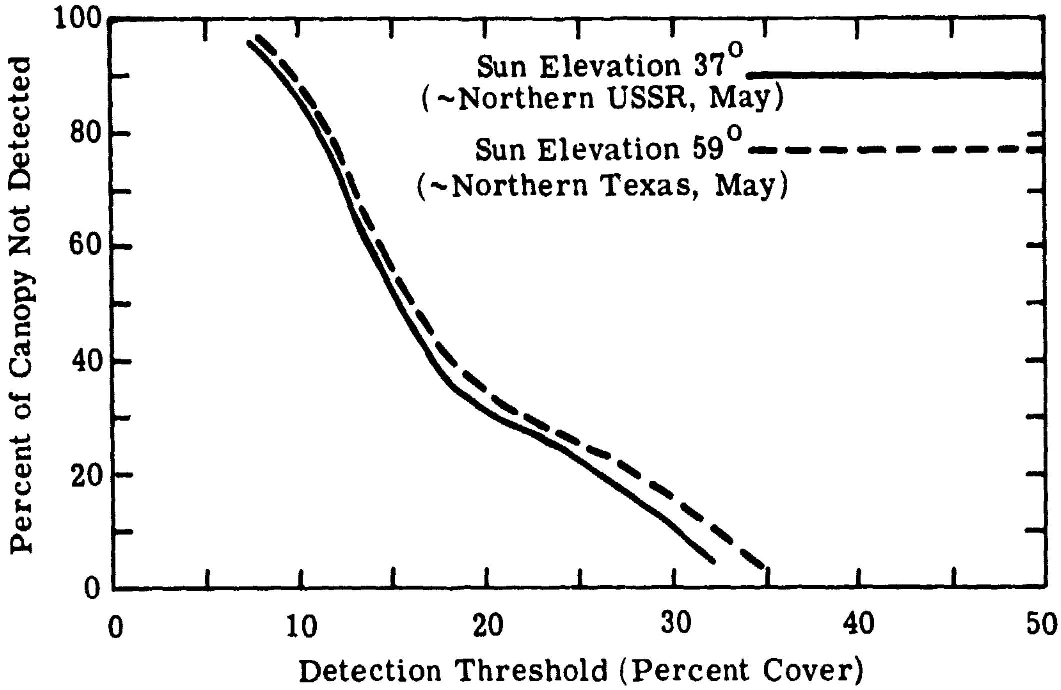

FIGURE 7. COMPARISON OF DETECTION THRESHOLD FOR TWO SOLAR ELEVATIONS USING SIMULATED DATA SET

When the effect of view angle was considered (Figure 8), again only a small difference in TOD was found among the +4°, Nadir, and -4° view angles and the composite given in Figure 6. Even so, the view angle effects could still be important in terms of the interaction with other variables such as haze level and sun angle, especially if low sun angles are considered. These questions should be investigated further.

In contrast to the above tests of sun and view angle, the effect of haze level on TOD is profound. The situation displayed in Figure 9 shows more than a factor of two difference in the threshold between a clear day and an extremely hazy day and a sizeable difference between two, more normal haze levels, showing the effects of noise and contrast reduction due to haze. This is an excellent illustration of the significance of haze and the need to consider its effects on remote sensing problems.

In all, the simulation approach to studying the effect of parameter variation on the detection threshold has begun to give answers, but more complete answers await further efforts.

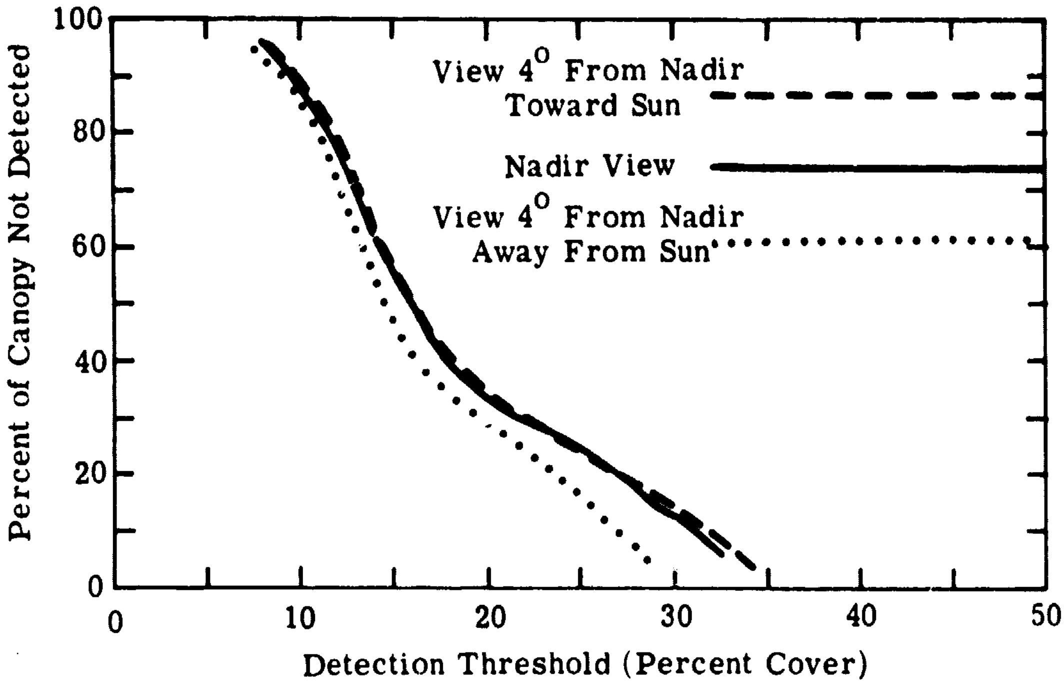

FIGURE 8. COMPARISON OF DETECTION THRESHOLD FOR THREE SENSOR VIEW DIRECTIONS USING SIMULATED DATA SET

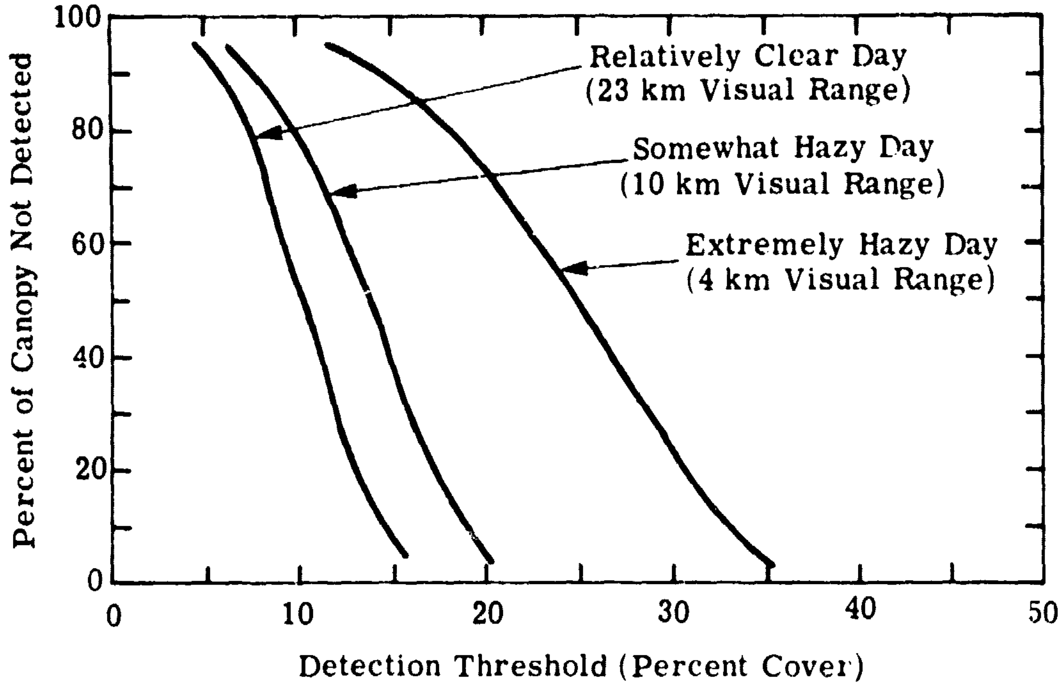

FIGURE 9 . COMPARISON OF DETECTION THREHSOLD FOR THREE HAZE LEVELS USING SIMULATED DATA SET

4
SOME RECOMMENDATIONS FOR FURTHER WORK

The question of threshold of detection is a wider issue than could be fully covered in the investigation described above. We recommend that further efforts be put forth on this topic, and that the following ideas be incorporated into those efforts.

A closer look into sun angle effects should be made. To do this, sensor noise will have to be modeled, so that the variability of low intensity signals can be considered.

Actual field measurements that include low, medium, and high sun angles (and associated ancillary information including solar measurements) should be taken such that the low sun angle behavior of the model can be cross-checked. In order to examine the threshold at low sun angles without the use of modeling, this data set should be sufficiently extensive to represent soil variability and cover the range of canopy densities. The data set should also be consistent in canopy structure and other parameters from one sun angle to another. Actual satellite data should be available for all samples, to incorporate the simultaneous effects of sensor noise, atmosphere, view geometry, and sun angle. Such a data set may be difficult to achieve.

The possible improvement in the detection threshold due to early season techniques such as use of multitemporal recognition should be examined. This may require extending the present methodology described in Section 2 to handle multiple dimensions of information.

Many remote sensing techniques involve the direct interpretation of image produces. It would thus be useful to formulate the detection threshold in terms of these products, using principles of color science.

A more complete analysis should be made of the effect of soil color and brightness on the detection threshold.

Analysis of the detection threshold for crops other than wheat should begin. Furthermore, it would be useful to determine the sensitivity of the detection threshold to canopy structure, since this is directly related to the robustness of remote sensing inventory procedures.

REFERENCES

1. LACIE Field Measurements, Data Acquisition Summary Report, 1975-1976 Crop Year, JSC-11882, NASA, Lyndon B. Johnson Space Center, Houston, Texas, January 1977.

2. Nalepka, R. F., J. E. Colwell, and D. P. Rice, Forecasts of Winter Wheat Yield and Production Using Landsat Data, ERIM 114800-38-F, Environmental Research Institute of Michigan, Ann Arbor, Michigan, December 1977.

3. Suits, G. H., "The Calculation of Directional Reflectance of a Vegetative Canopy," Remote Sensing of the Environment, Vol. 2, 1972, pp. 117-125.

4. Turner, R. E., Radiative Transfer in Real Atmospheres, ERIM 190100-24-T, Environmental Research Institute of Michigan, Ann Arbor, Michigan, July 1974.

5. Malila, W. A., R. C. Cicone, and J. M. Gleason, Wheat Signature Modeling and Analysis for Improved Training Statistics, ERIM 109600-66-F, Environmental Research Institute of Michigan, Ann Arbor, Michigan, May 1976.

6. Condit, H. R., "The Spectral Reflectance of American Soils," Photogrammetric Engineering, Vol. XXXVI, No. 9, September 1970, pp. 955-966.

7. Alrichs, John, Marilyn Hixson and Marvin Bauer, "Analysis of Spectral Data for Physical Understanding," SR&T Quarterly Review, LARS/Purdue University, 12 September 1978.