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Final Report

INVESTIGATIONS OF SPECTRAL SEPARABILITY OF SMALL GRAINS, EARLY SEASON WHEAT DETECTION, AND MULTICROP INVENTORY PLANNING

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16. Abstract

Results of three separate investigations related to the Large Area Crop Inventory Experiment (LACIE) are reported.

First, the potential for spectral separation of Spring wheat from other small grains using Landsat data was investigated. This key technical issue relates to possible alternatives to the primary LACIE procedure for estimating Spring wheat acreage. Landsat data from seven 5x6-segments having crop type information for the 1975-76 season were analyzed. Within segment field-center classification accuracies for Spring wheat vs. barley tended to be best (80% range) in mid-July when crop color changes were in progress. Corresponding wheat proportion (acreage) estimates were less accurate than total small grain estimates. When corrections were made for differences in atmospheric haze, data from several segments could be aggregated and results that approached within-segment accuracies were obtained for selected dates. LACIE field measurement spectral reflectance data provided information on both wheat development patterns and the importance of various agronomic factors on wheat reflectance, the most important being availability of soil moisture. It is recommended that data from additional seasons and locations be analyzed to verify and extend the results obtained in this study.

The second study investigated the early season detection threshold for Winter wheat in Landsat data. Early season estimates tend to be low and unreliable because the rate at which green vegetation develops in wheat fields is variable. Reflectance of developing wheat fields were simulated, through reflectance modeling, as a function of several canopy parameters. Field-measured spectra from a Kansas site during 1975-76 also were analyzed. Intrinsic dimensionality of Landsat inband values agreed with previous experience with Landsat, i.e., most signal variability was represented within two components. Transformations of the data were performed and examined. The green-component development of wheat fields was analyzed as a function of date throughout the season. A selected threshold was not crossed by all fields till mid-April. Comparisons of these reflectance data with actual Landsat data were initiated and were shown to be consistent. It is recommended that the analysis be extended to other sites and seasons and that predictive growth models be developed and used to predict crop reflectances.

The third study assisted in planning for the continued development and application of agricultural remote sensing technology, beyond the single crop focus of present LACIE activities. A preliminary approach and plan, developed and presented to NASA personnel in February 1977, is described herein. A phased approach was recommended. In advance of, and to be modified by, detailed definition studies, we presented preliminary suggestions. We recommended first priority to be given to inventory of corn (maize) production, beginning in the U.S. Corn Belt, including soybeans as a major companion and confusion crop, and extending to other regions based on production and import/export criteria. As second priority, we recommended soil resource inventories, concentrating on soil erosion problems. Next in the suggested priority ranking was rice, the major subsistence food crop of the world,

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PREFACE

This document reports processing and analysis efforts on one task of a comprehensive and continuing program of research in multispectral remote sensing of the environment. The research is being carried out for NASA's Lyndon B. Johnson Space Center, Houston, Texas, by the Environmental Research Institute of Michigan (ERIM). The basic objective of this program is to develop remote sensing as a practical tool for obtaining extensive environmental information quickly and economically.

The specific focus of the work reported herein was the problem of agricultural crop inventory using Landsat multispectral scanner data. Two critical technical issues of the Large Area Crop Inventory Experiment (LACIE) were addressed -- spectral separability of spring wheat from other small grains and early season detection of winter wheat. In addition, consideration was given to a possible expansion of the LACIE effort to include other crops, in addition to wheat.

The research covered in this report was performed under Contract NAS9-14988 during the period 15 May 1976 to 14 November 1977. Mr. I. Dale Browne (SF3) of the Earth Observations Division served as the NASA Contract Technical Monitor and M. C. Trichel (SF3) as the Task 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, Head of the Multispectral Analysis Section served as Principal Investigator and Dr. William A. Malila as Task Leader.

A number of other ERIM staff members also participated in discussions of the multicrop inventory problem (Sec. 5) and made useful suggestions, many of which have been incorporated in this report; apologizing for not acknowledging all participants by name, we do wish to note that inputs by Dr. Thomas Wagner were especially helpful and pertinent. J. Gleason played a major role in the reflectance model calculations and analysis of Sec. 4 and in field measurement data analysis of Sec. 3. In Sec. 4, use was made of a Landsat data set prepared by D. Rice on another contract and one by P. Lambeck and J. Hemdal on Task 2 of this contract. Landsat analysis in Sec. 3 was supported by H. Wagner and F. Sadowski. R. Cicone made key contributions and S. Lindner provided assistance in several aspects of the work. Typing support was provided by D. Dickerson, E. Hugg, and M. Warren.

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1
SUMMARY

Results of three separate investigations related to the Large Area Crop Inventory Experiment (LACIE) are reported. The first two involve key technical issues which have arisen and require additional research and development, while the third considers the possible expansion of large-area agricultural inventory techniques to crops other than wheat.

Spectral Separability of Spring Wheat from Other Small Grains

The first study investigated the spectral separability of Spring wheat from other small grains, as a possible alternative to the primary LACIE procedure which uses historical planting ratios to obtain indirect Spring wheat acreage estimates from direct estimates of total small grain acreage. Spectral separability was studied in multitemporal Landsat data extracted from seven operational LACIE segments for which ground truth had been obtained for accuracy assessment purposes during the 1975-76 growing season. Both field-center classification accuracy and proportion estimation accuracy were examined within the individual segments.

The levels of accuracy achieved varied throughout the season, tending to be best in mid-July, following heading and while Spring wheat was in the process of turning color. Accuracies in the 80% range were achieved on field-center pixels of Spring wheat and barley. Corresponding wheat proportion (acreage) estimates were found to be less accurate than total small grain estimates, with underestimates being the predominant type of error. Use of multiple dates improved accuracy.

Separability also was investigated for aggregated Spring wheat and barley segments. It was found that correction for atmospheric haze (and sun angle) differences between acquisitions could substantially improve multisegment performance, approaching that achieved in individual segments. The improvement was noted only for those times of year where the inherent within-segment accuracy was sufficient (>70%).

The above test results were based on ground-truth labeling of signatures so that the question of Analyst Interpreter (AI) identification accuracy was not addressed in the analysis. Also, the effects of small field sizes, prevalent in many Spring wheat areas, was minimized by selecting segments with larger fields, wherever possible, for this initial study.

In addition to Landsat data analysis, LACIE field measurement spectral reflectance data and ground observation data acquired for 1974-75 at a North Dakota test site were analyzed. These data provided basic supporting information on crop characteristics and the factors that influence spectral response. Barley was found to develop and ripen at a slightly faster rate than Spring wheat. The effects of several agronomic factors on reflectance were examined, with soil moisture availability (i.e., whether the field was cropped or fallow the previous year) being the most significant, followed by nitrogen fertilizer application, planting date, and variety; seeding rate appeared to have little effect in the available data. It was concluded that green development patterns alone might not be sufficient to reliably separate Spring wheat from other small grains. Crop spectral brightness and ancillary data may also be required.

It is recommended that the spectral separability of Spring wheat from other small grains be further investigated using Landsat data from additional seasons and other locations to verify and extend the results obtained in this study. Also, additional analysis should be conducted of 1974-75 LACIE field measurement data and subsequently acquired data, to gain a more complete understanding of agronomic effects on reflectances and sensor signals and of the potential of Landsat and Thematic Mapper bands for discriminating Spring wheat from other small grains.

Early Season Detection Threshold of Winter Wheat

The second study investigated the early season detection threshold for Winter wheat in Landsat data. Early season estimates tend to be low and unreliable because the green development of wheat vegetation over bare soil is variable and depends on many factors. The approach taken included simulation of the reflectance of wheat fields as a function of development stage and relevant canopy parameters. Field measurement spectral reflectance measurements made at a Kansas test site during the 1975-76 season were examined as well. Finally, limited analyses of Landsat data were made, beginning with comparisons between Landsat data and field-measured reflectances.

The intrinsic dimensionality of Landsat inband reflectances from both simulated and field-measured data was found to be such that the vast majority of variance was contained in the plane of the first two principal components. The Tasselled-Cap transformation with its green and soil brightness directions does an acceptable job of describing this plane of variability and providing useful variables for analysis and processing. A polar-coordinate green-angle/brightness-radius transformation may provide an even greater decoupling of soil and vegetation density effects, but further analysis is required for a full assessment. Greening-up characteristics of reflectance were quantified for 21 wheat fields in the Kansas site showing that, for the season analyzed, a reasonable green threshold was not crossed by all productive wheat fields until mid-April. Green-component patterns in Landsat data from the same site and three others were examined; the trends observed were consistent with the reflectance data.

It is recommended that early season detection analysis be extended to both other field measurement data sets and other Landsat data acquired over LACIE intensive test sites and blind sites throughout the Winter wheat region in the same and other seasons. Also, it is recommended that predictive growth models be developed and used to predict crop reflectances in segments as a function of acquisition date and ancillary variables.

Multicrop Research and Development Planning

The third study assisted in planning for the continued development and application of agricultural remote sensing technology beyond the single crop focus of LACIE. A "strawman" approach and plan was developed and presented to Johnson Space Center personnel in February 1977. Agricultural statistics and information were gathered from a variety of sources and examined, in light of remote sensing and applications experience of ERIM personnel. It was recommended that a phased approach be taken to any multicrop expansion or adaptation of LACIE technology, beginning with development of overall program objectives and criteria, and detailed definition studies of specific candidate objectives, crops, and regions.

As an initial suggestion, subject to verification or change after detailed studies, we made several recommendations. We recommended that first priority be given to the inventory of corn (maize) production, beginning in the U.S. Corn Belt, including soybeans as a major companion and confusion crop, and extending to other regions of the world based on production and import/export criteria. As resources permit, lower priority subjects would be phased in after appropriate pilot studies. As second priority, we recommended soil resource inventories, concentrating on soil erosion problems. Next, in the suggested priority ranking was rice, the major subsistence food crop of the world, followed by the key U.S. imports, sugar and coffee.

2
INTRODUCTION

This report describes the results of three separate investigations related to the Large Area Crop Inventory Experiment (LACIE). The objective of LACIE is to develop, test, and demonstrate techniques for the inventory of wheat on a world-wide scale, using remotely sensed data acquired by the Landsat multispectral scanner (MSS) [1]. During the course of the experiment, a number of key technical issues have arisen which require additional research and development. Among these issues are two which were addressed and are reported here, namely the spectral separability of Spring wheat from other small grains and the early season detection threshold for Winter wheat. The third investigation considered the possible expansion of large-area agricultural inventory techniques to crops in addition to wheat.

Spring wheat and other Spring planted small grains (e.g., barley, rye, oats) have rather similar crop calendars and spectral characteristics which make it difficult to distinguish between these crops. The initial and primary LACIE procedure for estimating Spring wheat production was to detect the total area planted to all small grains and use historical data (ratios of Spring wheat to total small grain acreage) to estimate Spring wheat acreage. The objective of the study reported in Section 3 was to investigate the extent to which Spring wheat is spectrally separable from other small grains, so that an alternative might be developed to the previously described procedure for estimating Spring wheat acreage.

Early season estimates, related to the second investigation, are desirable for agricultural management and associated decision making. Perhaps the most unique characteristic of Winter wheat is its temporal cycle of Fall planting with initial emergence and growth (and the appearance of greening up from space) occuring in late Fall and more complete maturation and greening in the Spring, after a dormant period. The rate at which wheat fields green up is a complex quantity dependent on a number of agronomic and meteorological factors. Early season estimates based on detecting green development in wheat fields tend to underestimate the area planted to wheat, due to varied and low levels of green development in fields throughout the region being inventoried. The objective of the effort reported in Section 4, was to investigate both the threshold of detectability of emergent wheat from space using the Landsat MSS and the factors which affect the threshold.

With the progress in agricultural inventory by remote sensing that has been demonstrated by LACIE, it is appropriate to consider both future expansion of the technology to other crops, in addition to wheat, and the development of operational systems. The objective of the activity described in Section 5 was to help establish a sound basis for an analytical design and assessment of an operational multicrop inventory system through recommendation of a research and development plan.

3
SPECTRAL SEPARABILITY OF SPRING WHEAT FROM OTHER SMALL GRAINS

The observed reflectance spectrum from a crop depends upon its stage of development, the spectral properties of its component parts, and the color of the underlying soil, among other factors. The stage of development at any given date, in turn, depends on planting date, species characteristics, and other agronomic factors, as well as on local weather conditions and climate. The question at hand was to determine whether or not, in the presence of these differences, spectral differentiation with Landsat MSS data was possible between Spring wheat and the other small grains.

3.1 APPROACH

The approach taken to assess spectral separability of the small grains was to analyze Landsat data acquired from a number of geographically distributed sites in North Dakota during the 1975-76 season. These sites were 5x6-mile LACIE segments ("Blind" Sites) for which ground observations of crop identification on a field-by-field basis had been acquired for test and evaluation purposes. Additional studies examined both agricultural statistics produced by the U.S. Department of Agriculture (USDA) and detailed spectral and agronomic measurements made as part of the LACIE Field Measurements Program (for the 1974-75 season at the Williams County, N.D., site).

The general analysis approach is indicated in Table 1, for both the ground-based and space-based (Landsat) data sets. Specific details of the procedures followed are presented in Section 3.2 for the analyses of ground-based data and in Section 3.3 for the analysis of Landsat data.

Prime emphasis was placed on the Blind Site Landsat data, with the expectation that they would be more representative of the variability to be encountered in the operational context. The field measurement data provide needed supporting and basic information on crop characteristics, in more detail and under more controlled and better defined conditions, to help our understanding of the sources of variability.

TABLE 1. APPROACH FOR ASSESSING SPECTRAL SEPARABILITY OF SPRING WHEAT FROM OTHER SMALL GRAINS

- Data Sets -- Space: Landsat Data from 1975-76 North Dakota LACIE Blind Sites
  -- Ground: Field Measurement Data (1974-75) From North Dakota and USDA Statistics

- Analysis of Landsat Data
  - Extract and examine Landsat spectral signatures for individual fields
  - Perform analyses for individual LACIE segments (blind sites)
    - •• Analyze small-grain-field spectral separability
    - •• Estimate wheat proportions
  - Conduct multisegment analyses
    - •• Correct for haze and sun-angle differences
    - •• Compute separability and wheat proportions

- Analyses of Ground-Based Data and Field Measurements
  - Analyze cropping practices
  - Extract crop development patterns (spectrum vs. calendar)
  - Compare small grain spectra
  - Analyze effects of agronomic factors on wheat reflectance

3.2 ANALYSES OF GROUND-BASED DATA AND FIELD MEASUREMENTS

Analyses were conducted both of agricultural statistics compiled by the USDA and of field spectral measurements of Spring wheat and other small grains made by the LACIE field measurements team.

3.2.1 CROPPING PRACTICES

Agricultural statistics, compiled from USDA sources for Spring wheat and other small grains, are presented in Table 2. Note that North Dakota, the state selected for our analysis, is the leading U.S. state in Spring wheat production. The major other small Spring grains are oats and barley and, to a much lesser extent, rye. For the U.S. as a whole, oats production is roughly twice that of barley but in N. Dakota 50% more barley than oats is produced. Also in Canada, barley production is substantially greater than oats production. Thus, in terms of quantity, we expect barley to be the major competing small grain in our analysis. The last items on the table show that the ratio

TABLE 2. SUMMARY OF HISTORICAL CROP STATISTICS (Based on USDA Sources)

- MAJOR SPRING WHEAT PRODUCING STATES:

NORTH DAKOTA	52%	OF 1976 U.S. PRODUCTION
MINNESOTA	17%	
SOUTH DAKOTA	12%	
MONTANA	9%	

- MAJOR SMALL GRAIN CROPS:

SPRING WHEAT	43%	OF 1976 U.S. PRODUCTION
OATS	34%	
BARLEY	18%	
RYE	5%	

- MAJOR OTHER SMALL GRAINS BY STATE (% OF STATE'S 1976 PRODUCTION)

NORTH DAKOTA	- BARLEY = 14%, OATS = 9%	CANADA (1973)
MINNESOTA	- OATS = 32%, BARLEY = 12%	27% BARLEY
SOUTH DAKOTA	- OATS = 42%, BARLEY = 10%	13% OATS
MONTANA	- BARLEY = 37%	58% S. WHEAT

- RATIO OF SPRING WHEAT TO TOTAL SMALL GRAINS (EXCLUDING WINTER WHEAT)

	U.S.	N.D.	S.D.	MONT.
1974	.386	.726	.407	.588
1975	.385	.730	.410	.548
1976	.429	.763	.454	.630

	CANADA
1971	.491
1972	.455
1973	.584

of production of Spring wheat to that of total small grains (excluding Winter wheat) varies significantly from year to year. This variability is the reason that spectral discrimination of these crops is of interest.

Additional distinctions are made between varieties of Spring wheat, with hard red varieties accounting for three quarters of the annual production and durum wheat varieties the remaining quarter (nationwide for 1976). (Durum wheat is used in making spaghetti and macaroni, while hard red wheat is used for bread.)

In much of North Dakota, strip-fallow planting practices are followed to conserve soil moisture and reduce wind erosion. In these, long narrow strips of crops are planted, separated by fallow strip fields. Grain crops then are planted after a year of fallow (and therefore increased water storage) in areas where moisture is scarce.

At harvest time, the grain frequently is "swathed", i.e., cut and placed in windrows, to allow heads to dry and harden before it is combined (harvested).

3.2.2 CROP DEVELOPMENT DIFFERENCES

Crop development information obtained from the USDA[2] for North Dakota was examined for year-to-year differences. Figure 1 presents a state-wide comparison of hard red Spring wheat development at the "turning to ripe or beyond" stage for the years 1975-76. Note that wheat development for 1975 was average or slightly behind average in the early portion of this stage. The 1976 crop ripened the earliest of the 11 years averaged, and the 1977 crop was slightly earlier than that of 1976.

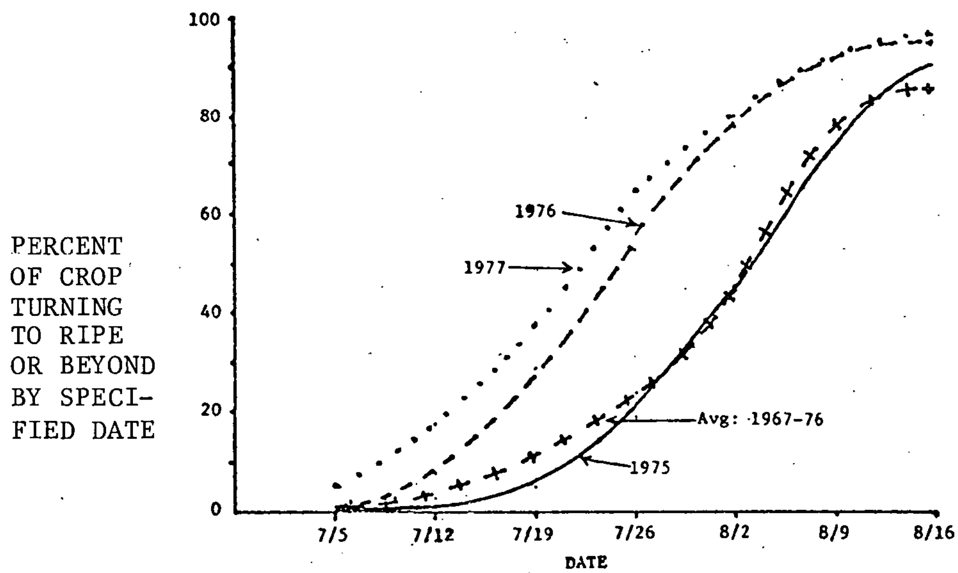

FIGURE 1. YEAR-TO-YEAR DIFFERENCES IN (HARD RED) SPRING WHEAT DEVELOPMENT (North Dakota Statewide Values)

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There also are differences in the development rates of the various small grains, as shown in Figure 2 for crop years 1975-76 and 1976-77.

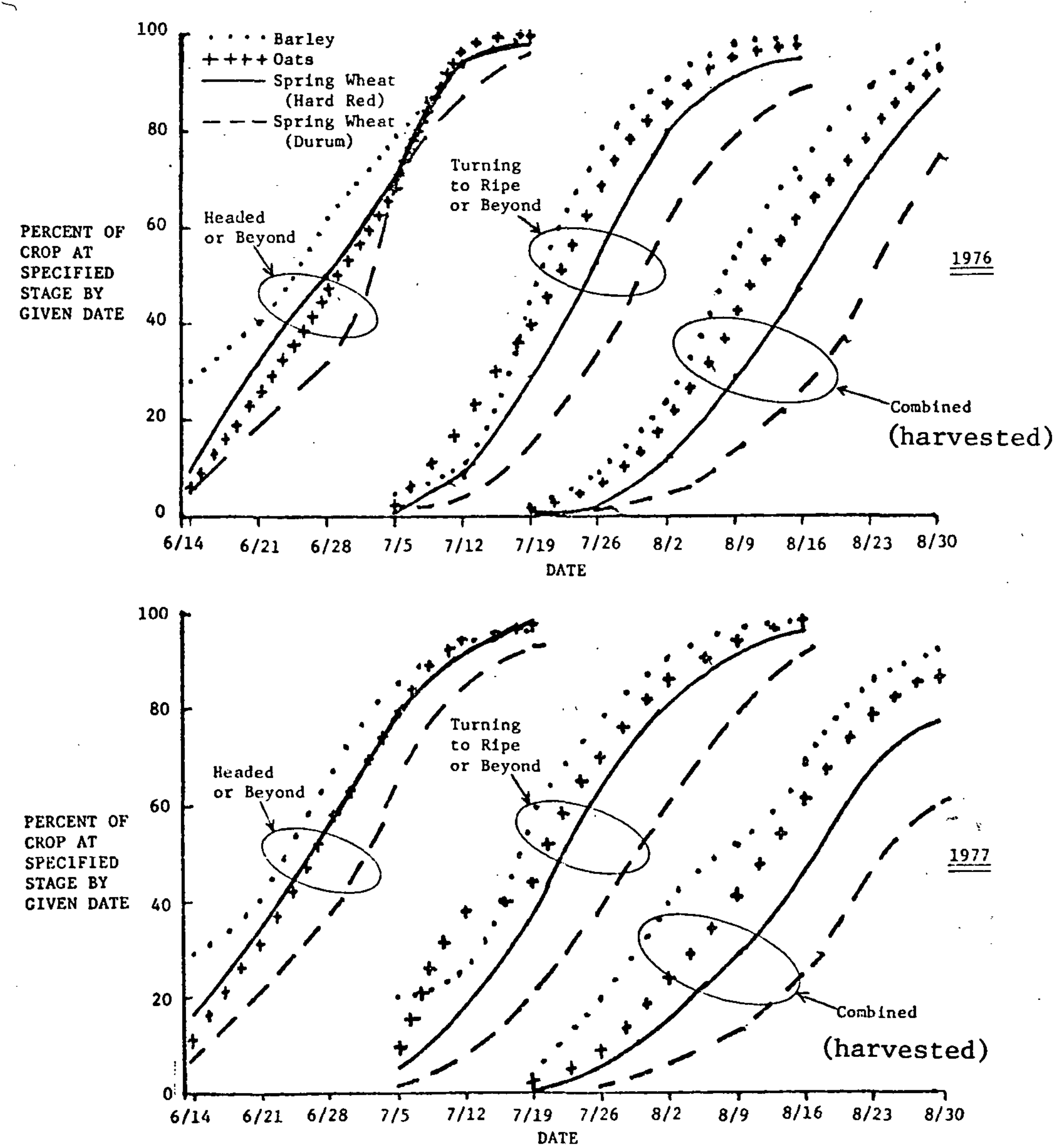


FIGURE 2. NORTH DAKOTA STATE-WIDE SMALL-GRAIN DEVELOPMENT PATTERNS

Comparisons are made for three development stages -- headed or beyond, turning to ripe or beyond, and combined (harvested). At the best 1975-76 date for discrimination, i.e., mid-July, the crops were in various degrees of turning to ripe. Barley and oats were more advanced than the two variety classes of spring wheat which were at the beginning stages of turning. Also note that durum wheat lags the hard red spring wheat, both in turning to ripe and in being harvested (combined). The 1976-77 pattern is similar, but the hard red spring wheat turned more on schedule with barley and oats than with durum wheat; this could adversely affect their separability.

3.2.3 SPECTRAL CHARACTERISTICS FROM FIELD MEASUREMENTS

Two sets of field measurements of crop reflectance spectra were acquired at the Williams County, North Dakota, site by the LACIE Field Measurements Team during the 1974-75 crop season [3]. The first set of data was acquired from farmers' fields across the 5x6-mi intensive test site by JSC (Johnson Space Center) team members, using the helicopter-borne FSS (S-191H Field Spectrometer System) instrument. The second set of data was acquired from test plots on an agricultural experiment station by LARS (Purdue University/Laboratory for Applications of Remote Sensing) team members, using their truck-mounted Exotech Model 20C spectrometer system. Both data sets were acquired periodically throughout the growing season on a schedule related to the Landsat overpass cycle.

To produce a reduced data set for analysis, we computed effective reflectance values within the four Landsat spectral bands by multiplying each spectrum by the Landsat relative spectral response functions and integrating over wavelength. Figure 3 presents an example detailed spectral plot of reflectance; the "plus" signs on the extrapolated curve indicate actual data values from the field measurement data tape, and the squares above the dashed vertical lines denote the computed Landsat in-band reflectance values. Note how the Band 4 and 5 values fall off the actual band-center reflectance values, due to the spectral width and placement of the bands.

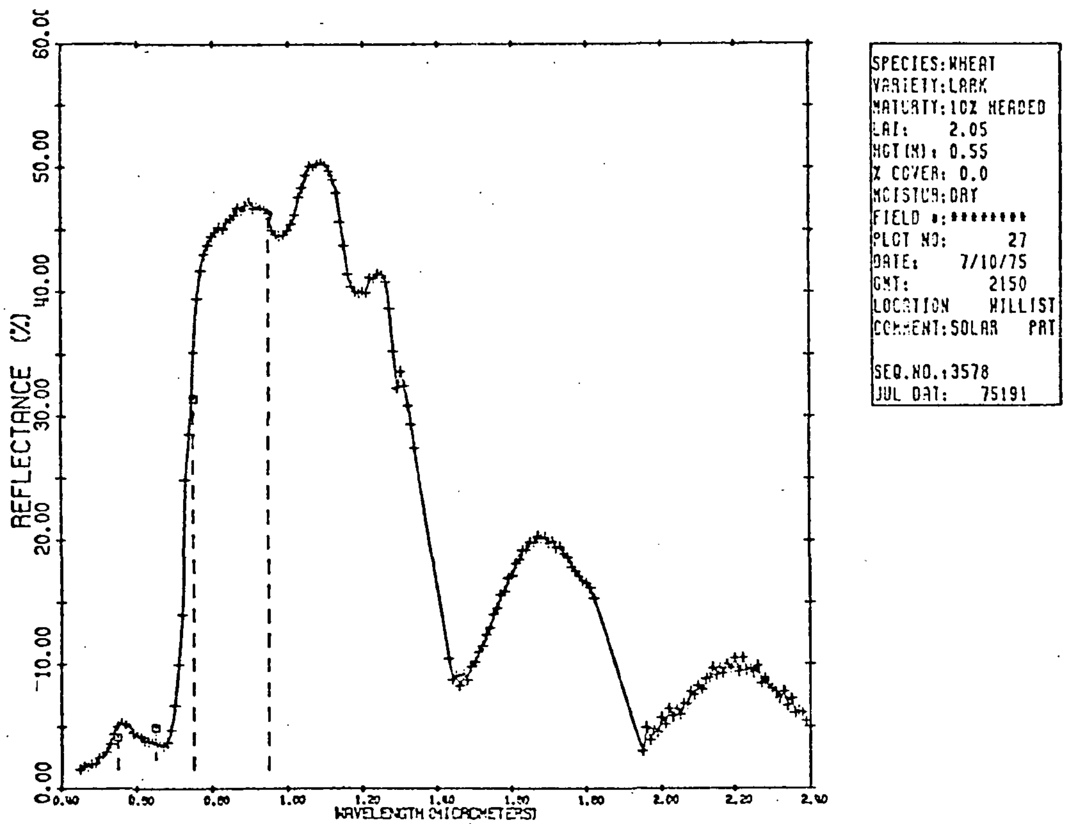


FIGURE 3. EXAMPLE CROP SPECTRUM WITH LANDSAT REFLECTANCES

Another analysis version of the data values was produced to be similar to Landsat data on which the Tasselled-Cap transformation had been applied [4]. The transformation we applied produced two major reflectance components (linear combinations of the inband reflectance values) which describe the majority of variance in the four bands. The first is the "brightness" component which was defined to be in the direction of changing bare soil brightness. The second was made perpendicular to the first in the direction of reflectance from healthy green vegetation, and is the "green" component.

3.2.3.1 DEVELOPMENT PATTERNS OF SPRING WHEAT SPECTRA

The spectral patterns of wheat and other small grain reflectances were determined and examined through the growing season. Figure 4 presents the average green component of reflectance as a function of wheat

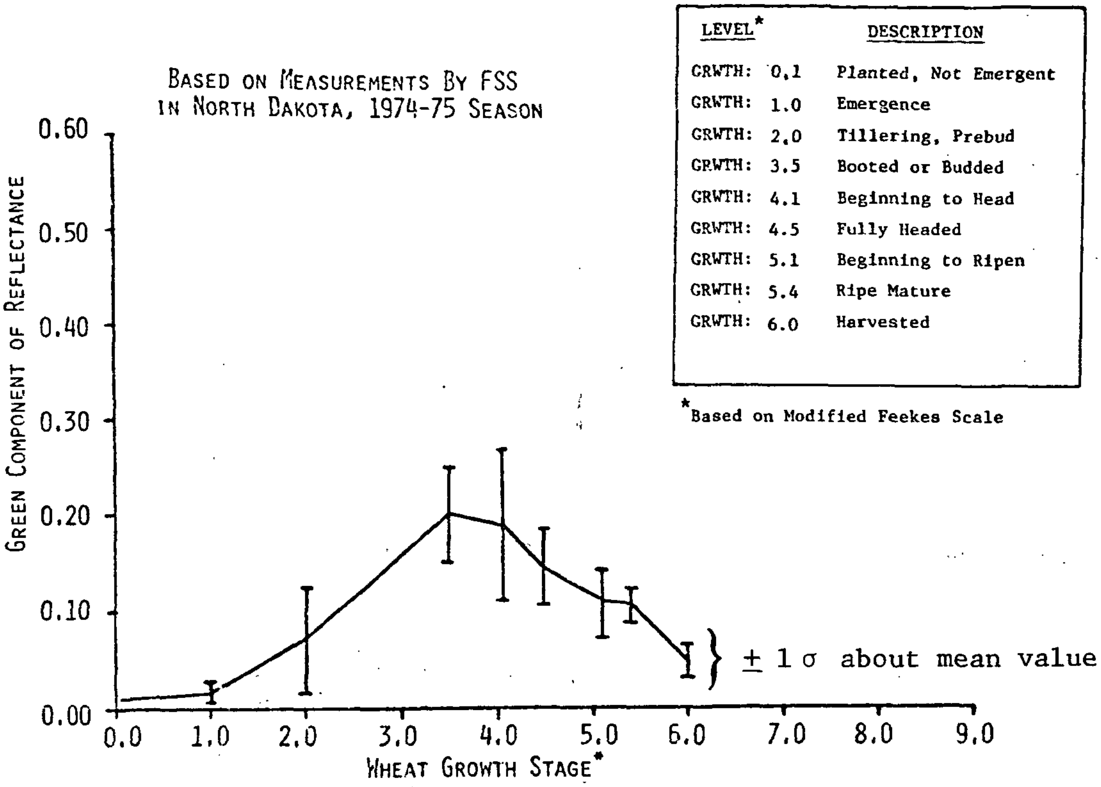


FIGURE 4. GROWTH-STAGE DEPENDENCE OF SPRING WHEAT REFLECTANCE ('LANDSAT' GREEN COMPONENT)

growth stage for the fields measured by the helicopter-borne FSS instrument; the extent of each bar denotes $\pm 1\sigma$. Note that maximum greening occurs at the time of booting and heading. The crop calendars of individual fields varied so that, at any given calendar date, not all wheat fields were at the same stage of growth.

Figure 5 displays the green calendar pattern of these same fields as a function of Julian date. The number of observations on each date is also indicated on the figure. Note that the maximum greening occurred on about Day 190 in 1975.

On the agricultural experiment station, similar patterns of green development were measured for wheat. Figure 6 presents the time track of the average green component for wheat under a variety of experiment conditions.

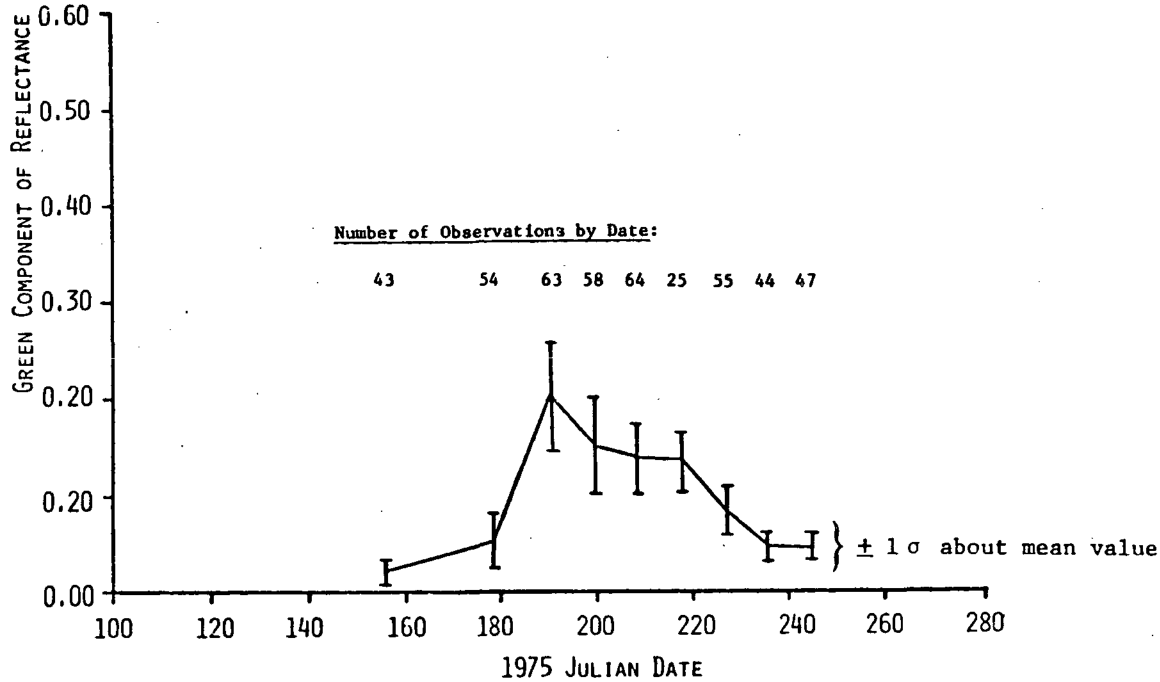


FIGURE 5. TIME DEPENDENCE OF SPRING WHEAT REFLECTANCE ('LANDSAT' GREEN COMPONENT) NORTH DAKOTA; 1975; HELICOPTERBORNE SPECTROMETER (FSS) DATA

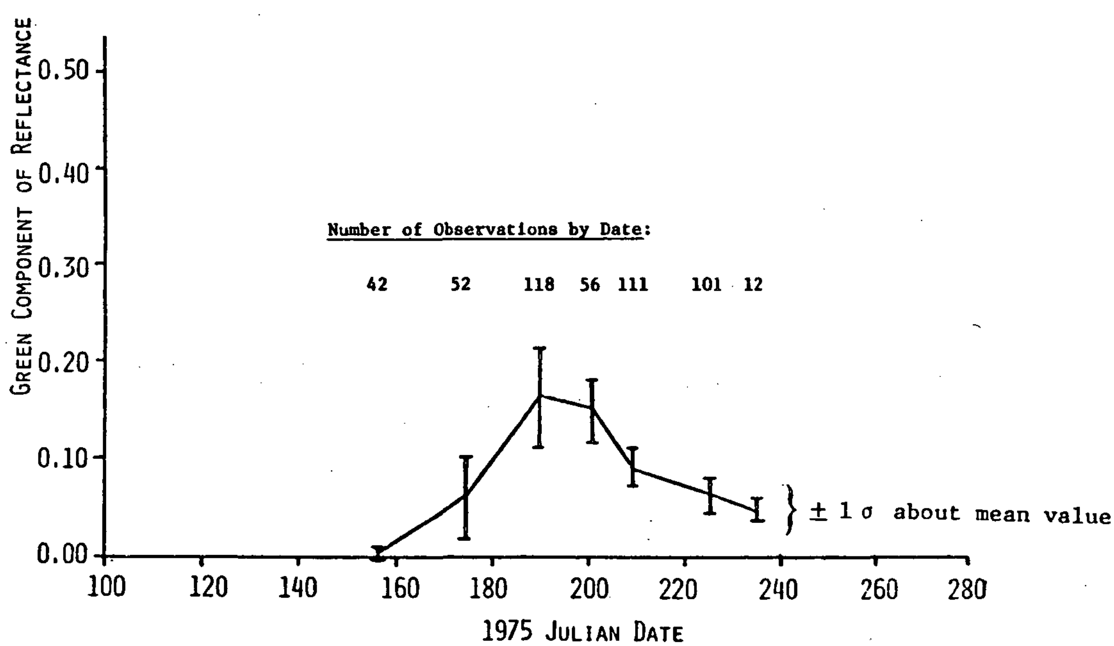


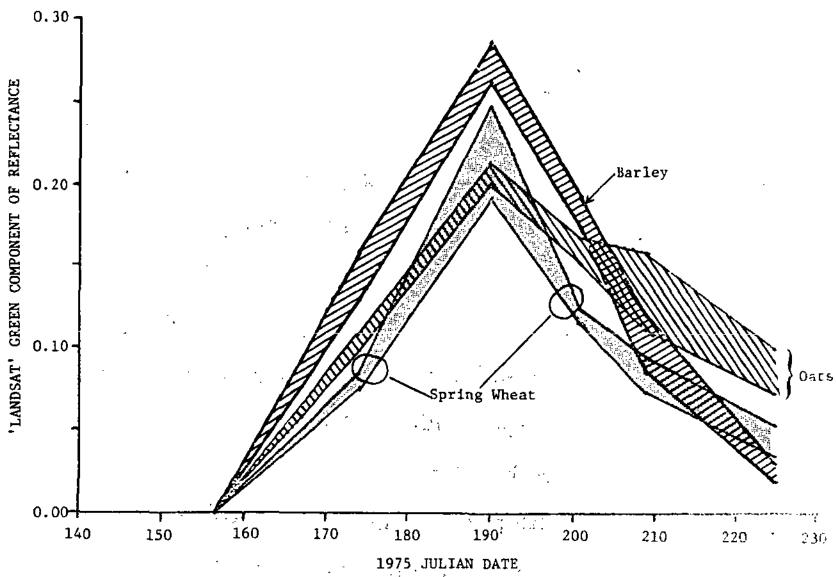
FIGURE 6. TIME DEPENDENCE OF SPRING WHEAT REFLECTANCE ('LANDSAT' GREEN COMPONENT) NORTH DAKOTA: 1975; MODEL 20C TRUCK SPECTROMETER DATA

3.2.3.2 COMPARISON OF SMALL GRAIN DEVELOPMENT PATTERNS

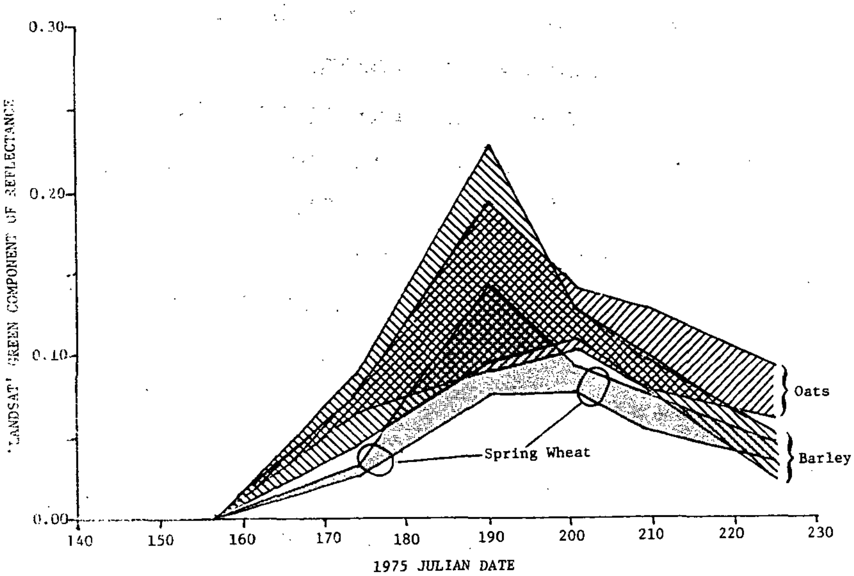
A few test plots of other small grains (barley, oats, durum wheat) also were measured at the agricultural experiment station, in addition to plots of the standard hard red Spring wheat. An examination of these spectra showed similar green development patterns and substantial overlap when data were lumped from plots that had been fallow and non-fallow in the preceding year (see Sec. 3.2.4). However, greater distinctions were noted among the small grains when only one moisture treatment was considered; see Figure 7. Barley tended to green up sooner than Spring wheat and attain higher green levels, while oats tended to green earlier and maintain a higher green component than wheat after the maximum was attained. Durum Spring wheat was similar to the hard red Spring wheat. Barley also tended to be slightly brighter than wheat after heading and while turning color.

3.2.4 EFFECTS OF AGRONOMIC TREATMENTS ON WHEAT REFLECTANCE

The test plots on the agricultural experiment station were established to determine the effects of a number of agronomic treatments on wheat response. The four main treatment factors, listed with their levels in Table 3, are soil moisture, nitrogen, planting date, and wheat variety. As an initial indicator analysis, simple one-way multivariate analyses of variance were performed on these data averaged over the entire season. The treatment factors are listed in order of significance, with soil moisture availability being the most significant. Specific significance levels are not presented because their interpretation is complicated by unbalanced numbers of observations on the various dates and the fact that the effects in some bands change sign as one progresses through the season. A more complete and complex analysis of variance is called for. To give the reader some appreciation for the nature of the treatment effects on reflectance, the last four columns of Table 3 indicate the direction and relative magnitude of reflectance change on 1975 Julian Day 190 in each Landsat band, when the treatment level was changed as indicated in Column 2.



(a) Moisture Treatment: Fallow in Preceding Year



(b) Moisture Treatment: Wheat in Preceding Year

FIGURE 7. COMPARISON OF GREEN DEVELOPMENT PATTERNS OF SMALL GRAINS
(North Dakota Truck Spectrometer Measurements)
($\pm 1\sigma$ about mean of 2-8 measurements)

TABLE 3. AGRONOMIC TREATMENT EFFECTS ON SPRING WHEAT REFLECTANCES IN LANDSAT BANDS (RESULTS OF SIMPLE ONE-WAY ANALYSIS OF VARIANCE)
(Data averaged over all dates)

Factor or Treatment	Levels	Rank Order of Factor's Significance	Effects* on Reflectance in Landsat Band on 1975 Day 190: 4	5	6	7
SOIL MOISTURE	↓ WHEAT PRECEDING YR FALLOW PRECEDING YR	1	--	--	+	++
NITROGEN	↓ NONE 25 LBS/ACRE	2	-	-	+	+
PLANTING DATE	↓ MAY 20 MAY 30	3	+	+	0	0
VARIETY	↓ ELLAR OLAF (SEMI-DWARF)	4	+	0	+	+

*PLUS (MINUS) DENOTES AN INCREASE (DECREASE) IN REFLECTANCE VALUE WHEN TREATMENT LEVEL WAS CHANGED IN DIRECTION OF ARROW IN COLUMN 2. ZERO DENOTES MINIMAL CHANGE.

A decreased moisture supply, caused by planting wheat for a second year in succession on the same plot, both decreased the magnitude of green development from that of wheat planted in fallow ground and delayed the date of maximum greening. A similar delay in maximum greening was observed when the planting date was delayed by ten days, but the difference in maximum green levels was not as pronounced as in the case of reduced available soil moisture.

In another experiment, three different seeding rates were employed -- 30, 60, and 90 lbs/acre. The initial indication of our analysis was that the effect of seeding rate on reflectance was insignificant.

3.3 ANALYSIS OF LANDSAT DATA FROM NORTH DAKOTA BLIND SITES

For the needs of LACIE, our primary analysis of the spectral separability of Spring wheat from other small grains was based on Landsat data from representative sites. The LACIE blind sites in North Dakota were selected. Following analysis of individual sites, a multisite analysis was conducted. As noted earlier, North Dakota is the major producing state for spring wheat while the next most common small grain produced there is barley, followed by oats.

3.3.1 DESCRIPTION OF DATA SET AND ITS PREPARATION

Seven of the eighteen 1975-76 blind sites were selected for analysis. Their locations are indicated on Figure 8. They are mostly in the eastern half of the state. These sites were selected on the basis of: (a) frequent Landsat coverage to permit examination of acquisition-date effects, (b) relatively large field size to reduce the confounding of wheat/small grain separability by small field problems, and (c) sufficient wheat and other grain proportions to permit a meaningful analysis.

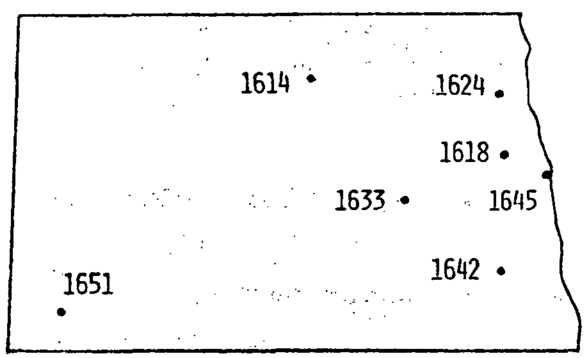


FIGURE 8. LOCATIONS OF NORTH DAKOTA BLIND SITES ANALYZED

Four acquisition dates were analyzed for each site, as indicated in Table 4.

The approach taken to extract crop spectral statistics was to first perform spectral/spatial clustering (blobbing) on the multitemporal data [5]. This technique uses both spectral and spatial data channels to cluster pixels into cells or "blobs" having relatively homogeneous spectral characteristics. The blob patterns compare well with field patterns observed in Landsat data. Each blob can be thought of as being a field. Next, boundary pixels were stripped away from the blob perimeters to

TABLE 4. SEGMENTS AND 1976 DATES ANALYZED

	1976 JULIAN DATES USED			
SEGMENT	1	2	3	4
1614	129	183	201	219
1618	163	199	235	253
1624	128	146	236	254
1633	129	147	201	237
1642	163	182	200	236
1645	146	164	181	235
1651	149	204	221	240

isolate field-center pixels, and mean vectors were computed from these field-center pixels. All stripped blobs of five or more pixels were labeled by comparison to aerial photographs and ground truth overlays. A majority of blobs were of a single crop type, although multiclass blobs (blobs containing pixels from different crops) were more common within sites with small fields. The numbers of blobs produced and percentages of blobs stripped away, i.e., eliminated in the stripping process, are indicated in Table 5. Note that the number of blobs per segment varied from 477 to 1143 and that roughly half of the blobs were stripped away, except for Segment 1624 which had the largest average field size and only 22% of its blobs eliminated.

TABLE 5. RESULTS OF BLOBBING

	NUMBER OF BLOBS		
1975-76 SEGMENT	BEFORE STRIPPING	NON-NULL AFTER STRIPPING	PERCENT STRIPPED AWAY
1614	794	348	56%
1618	1143	509	55%
1624	477	370	22%
1633	712	382	46%
1642	675	397	41%
1645	790	436	45%
1651	734	354	52%

3.3.2 INDIVIDUAL SEGMENT ANALYSIS

Two criteria were examined to assess the spectral separability of spring wheat from other small grains in the individual segments selected. First, the spectral separability of field mean signatures was examined and, then, Spring wheat proportions within entire segments were computed and compared to ground truth values.

3.3.2.1 ANALYSIS OF FIELD-CENTER SIGNATURE MEANS AND THEIR SEPARABILITY

Signatures extracted from wheat and barley field centers were analyzed. First, scatter diagrams were produced to display the dispersions and relative locations of the crop signature means for each acquisition date. For example, Figures 9(a) and (b) display 112 wheat and 54 barley means, respectively, in Landsat Band 6 vs. Band 5 for Segment 1618 on 1976 Julian Day 199, the best available single date for separating Spring wheat from barley in that segment. The average correct probability of classifying these wheat and barley means using a two-class linear discriminant function was 86%. (The analysis procedure used a pooled variance/covariance matrix to represent the two distributions in computing the discrimination function.) Values obtained are presented graphically in Figure 10, as a function of acquisition date, for Segment 1618 and the other four segments with sufficient barley for meaningful analysis. The accuracies range from 54 to 95% correct. The use of multiple acquisition dates improved separability slightly in all but two segments for which there was no change from the best single date.

3.3.2.2 WHEAT AND SMALL GRAIN PROPORTION ESTIMATES FOR SEGMENTS

To place the wheat vs. other small grain analysis more directly in the LACIE context, proportions were estimated separately for Spring wheat and for total small grains (including Spring wheat), for each of the seven blind-site segments analyzed. The results presented in Table 6 were obtained using either all four dates or the best single date for each segment. The total small grain proportion was quite accurately estimated with all four dates, but the proportion of Spring wheat

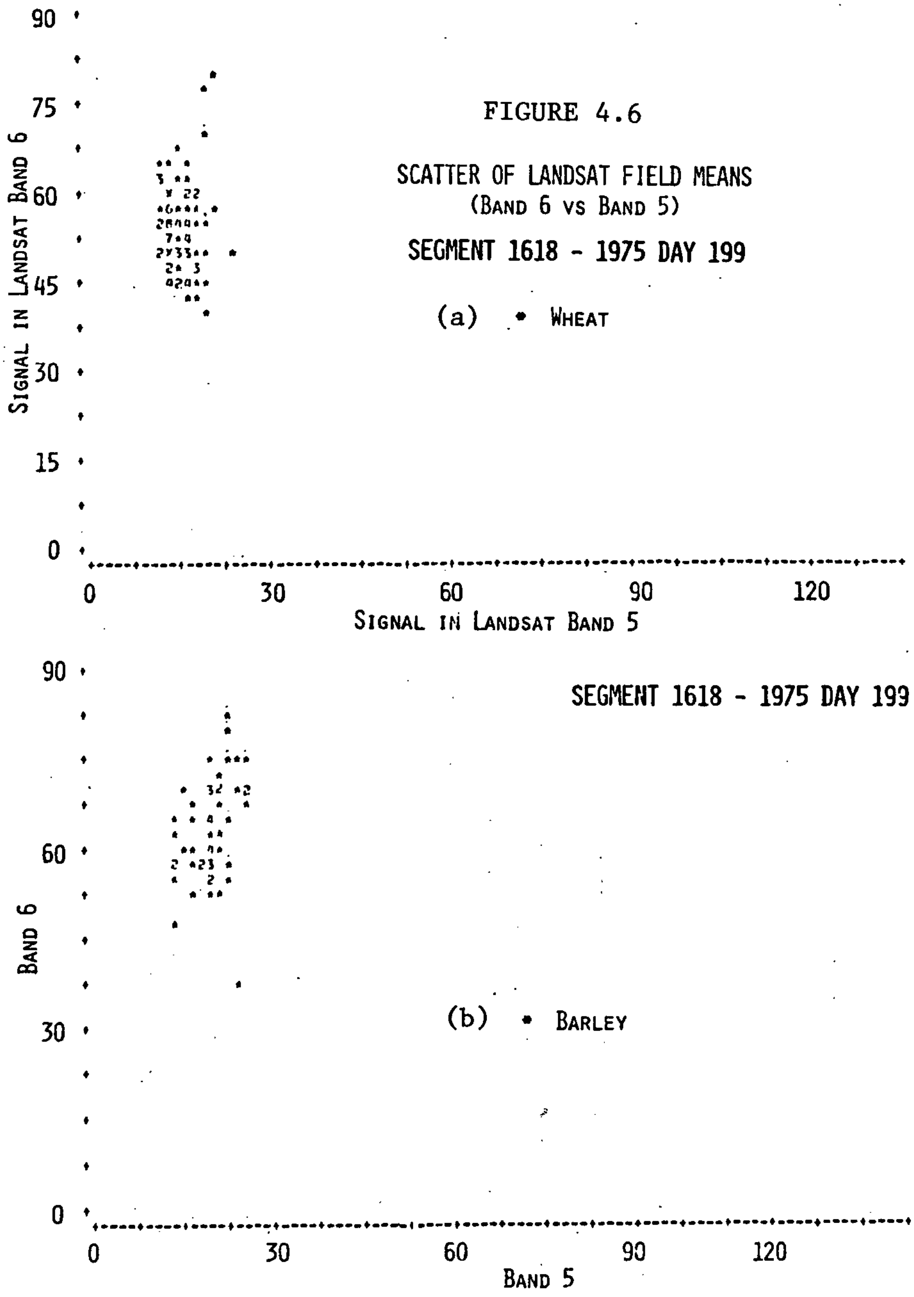


FIGURE 9. SCATTER OF LANDSAT FIELD MEANS (Band 6 vs Band 5)

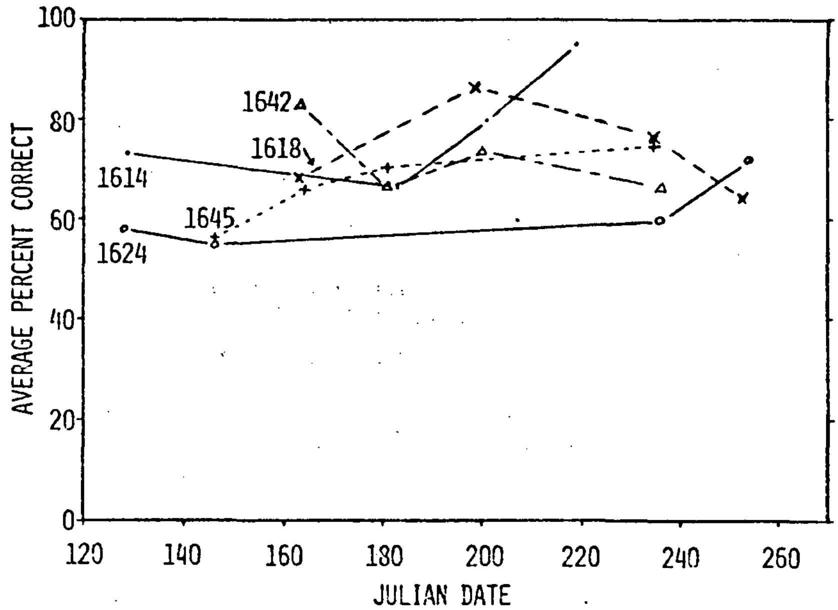


FIGURE 10. RESULTS OF TWO-CLASS DISCRIMINANT ANALYSIS ON FIELD-CENTER (STRIPPED-BLOB) MEAN VECTORS
(Spring Wheat Vs. Barley For 1975-76 North Dakota Blind Sites)

TABLE 6. SEGMENT PROPORTION ESTIMATES BASED ON MULTICLASS DISCRIMINANT ANALYSIS OF BLOBS IN 1975-76 NORTH DAKOTA BLIND SITES

			PROPORTION ESTIMATE ($\hat{P}$) USING:				
		GROUND TRUTH	FOUR DATES		BEST SINGLE DATE		
SEGMENT	CLASS*	PROPORTION (%)	$\hat{P}$(%)	Δ^+	$\hat{P}$(%)	Δ	DATE**
1633	SW	37.5	34.9	-2.6	31.5	-6.0	201
	SMG	40.1	44.0	+3.9	43.8	+3.7	
1614	SW	27.0	29.8	+2.8	25.3	-1.7	201
	SMG	42.8	42.0	-0.8	47.6	+4.8	
1651	SW	20.9	17.9	-3.0	17.1	-3.8	149
	SMG	27.9	27.2	-0.7	32.4	+4.5	
1642	SW	39.2	42.6	+3.4	26.6	-16.0	163
	SMG	57.6	58.1	+0.5	49.1	-9.0	
1618	SW	40.2	34.5	-5.7	31.3	-8.9	199
	SMG	63.5	61.6	-1.9	56.5	-7.0	
1645	SW	48.3	41.1	-7.2	35.6	-12.7	181
	SMG	66.5	67.4	+0.9	66.2	-0.3	
1624	SW	41.8	26.1	-15.7	21.9	-19.9	236
	SMG	53.5	51.8	-1.7	35.5	-18.0	

*SW = SPRING WHEAT
SMG = SMALL GRAINS (INCLUDING SPRING WHEAT)

**BEST FOR WHEAT PROPORTION
+ Δ = ESTIMATE MINUS GROUND TRUTH

was usually underestimated. The underestimates were greatest for Segments 1645 and 1624 for which an acquisition on or near 1976 Julian Date 200 was not available. This same mid-July acquisition date was most frequently selected as the best of the four individual dates available for the other segments, using the accuracy of the Spring wheat proportion estimate as the criterion. (Wheat in mid to late July would mostly be headed and turning color, although the LACIE biowindows differed by as much as ten days among the seven segments analyzed; barley tends to mature slightly ahead of wheat). The single-date wheat proportion estimate was less accurate than the four-date estimate in all but one instance for which the reason is not understood. Estimates were also made using all combinations of three acquisition dates for each segment. The best combination usually produced an estimate close to that of the four dates. In four of five possibilities, the mid-July date was included in the best combination.

Table 7 compares estimated ratios of Spring wheat to total small grain (including wheat) with ground truth ratios for the segments. The results are variable, with the remote sensing estimates tending to have smaller ratios than ground truth.

TABLE 7. WHEAT/SMALL-GRAIN RATIOS FOR NORTH DAKOTA BLIND SITES (1975-76)

SEGMENT	GROUND TRUTH	RATIO BASED ON LINEAR DISCRIMINANT PROPORTION ESTIMATES USING: ALL FOUR DAYS	BEST SINGLE DAY
1633	0.94	0.79	0.72
1614	0.63	0.71	0.53
1651	0.75	0.66	0.53
1642	0.68	0.73	0.54
1618	0.63	0.56	0.55
1645	0.73	0.61	0.54
1624	0.78	0.50	0.62

The above proportion estimates were produced by classifying the segment blobs with multiclass linear discriminant functions and aggregating the number of pixels in blobs assigned to each class. Every blob was assigned to a single class. Blobs that were large enough to have pixels remaining after stripping were classified on the basis of their stripped-blob signal means, but the pre-stripping numbers of pixels were used in the aggregation. Blobs that had been stripped away were classified on the basis of their mean signals before stripping.

3.3.3 MULTISEGMENT ANALYSIS

This section reports a multisegment analysis of the Landsat separability of Spring wheat from other small grains. The approach followed is given in Table 8.

TABLE 8. APPROACH FOR MULTISEGMENT ANALYSIS OF SPRING WHEAT VS. OTHER SMALL GRAINS

- Screen LACIE Segment Data (Using ERIM Screen Algorithm) To:
    - Flag: bad data, clouds, cloud shadows, and water pixels
    - Compute haze diagnostic features
- Perform Atmospheric Haze (ERIM XSTAR Algorithm) and Sun Angle Corrections and Tasselled-Cap Transformation
- Analyze Corrected Field Means
    - By Landsat cycle
    - By Spring wheat crop calendar
    - Correlation with ancillary data
    - Compute separability from other small grains
- Compute Segment Proportions

The same seven North Dakota 1975-76 LACIE Blind Sites were screened, to flag and exclude data that were inappropriate for computing haze diagnostic features. A cosine correction for sun zenith angle was then applied to field (blob) mean signature data, followed by an XSTAR haze correction procedure. (The ERIM screening and haze correction procedures used are described in Reference 6). The objective of the correction procedures was to compensate for differences in observation conditions between the sites so they could be pooled for analysis and discrimination studies. Tasselled-cap green and brightness components then were computed for analysis.

Acquisitions were grouped by Landsat cycle, i.e., data were pooled from all acquisitions within each five-day period during which Landsat-2 coverage traversed the state of North Dakota. (The cycles are spaced at 18-day intervals.) Eight Landsat cycles contain the data set analyzed here, with from two to six segments acquired in each cycle. Figure 11 presents example comparisons of the spectral scatter of multisegment wheat field means both before and after correction. The top two charts are plots of green vs. brightness for Landsat Cycle 4. A narrowing of the dispersion pattern is evident after the correction. A similar effect was found for barley fields, but they overlapped the wheat fields substantially in this Landsat Cycle 4 time period (mean Julian day = 182; spring wheat heading).

The second pair of diagrams in Figure 11 displays green vs. brightness for five segments during Landsat Cycle 5 (mean Julian day = 201; Spring wheat in soft dough). Again, a compression of the patterns is observed in corrected data. Barley fields tended to be slightly brighter than wheat at this time (as noted previously).

Quantitative assessments of the relative separability of multi-segment Spring wheat and barley were made as a function of Landsat cycle. A two-class linear discriminant rule based on pooled covariance

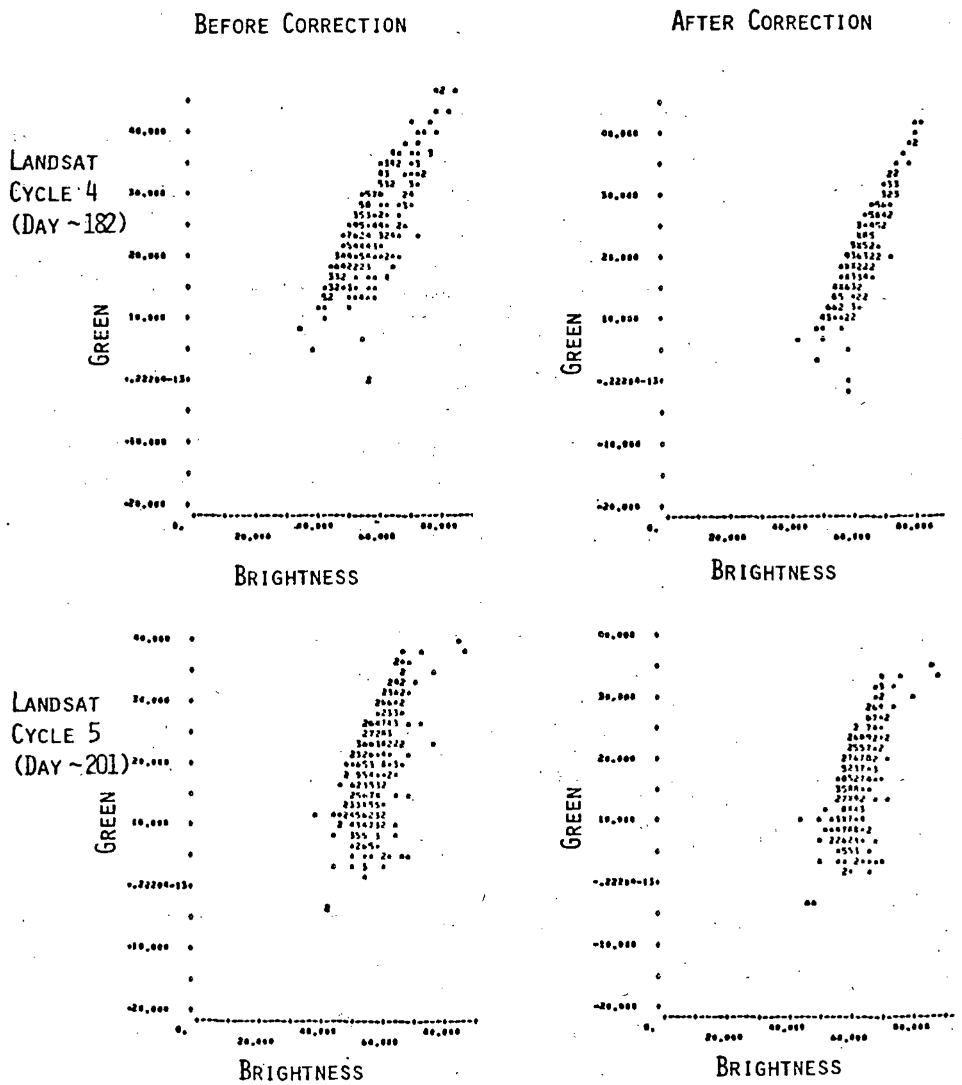


FIGURE 11. COMPARISON OF SPRING WHEAT SIGNATURE DISTRIBUTIONS
(Selected North Dakota 1975-76 LACIE Blind Sites)

matrices was employed. The results are presented in Table 9. Percent-correct figures were obtained separately for Spring wheat and barley and these were averaged to obtain the values shown. Three multisegment results are shown--before correction, after correction, and within-segment (i.e., a grouping of within-segment results presented in

TABLE 9. RESULT OF TWO-CLASS (SPRING WHEAT VS. BARLEY) SEPARABILITY ANALYSIS FOR MULTIPLES SEGMENTS GROUPED BY LANDSAT CYCLE (Linear discriminant rule based on pooled covariance)

Landsat Cycle (Avg. Jul. Day)	Number of Segments	Average Percent Correct: Before Correction	After Correction	Within Segment	Number of Fields: Wheat	Barley	Approx. Spring Wheat Development Stage
129	3	58.4	62.3	62.3**	280	42	PLANTING-EMERGENCE
147	4	60.5	58.2	55.2**	410	66	EMERGENCE-JOINTING
163	3	58.1	61.3	69.7	360	104	JOINTING
182	3	59.4	57.7	69.1	305	65	HEADING
201	5	74.9	82.1	81.5***	391	86	SOFT DOUGH
220	2	82.1*	93.0*	95.0*	35	17	RIPE-HARVESTED
236	6	64.9	70.2	71.2****	609	133	HARVESTED
254	2	61.2	62.2	67.3	228	79	HARVESTED

*Note small number of cases; only one segment for local training case.

**Two segments for local training case.

***Three segments for local training case.

****Four segments for local training case.

Section 3.3.2). The corrections provided a substantial improvement over uncorrected data in those three instances where the local, within-segment, results indicated reasonable separability, i.e., >70%. Otherwise, the corrections did not have a substantial effect.

3.4 SPRING WHEAT VS OTHER SMALL GRAINS: CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were drawn from our investigation of the spectral separability of spring wheat from other small grains.

3.4.1 CONCLUSIONS

Based on the analysis and results presented, we observed and/or concluded that:

1. Both similarities and differences were observed among reflectance development patterns of Spring wheat and other small grains in the small sample of fields measured during the 1974-75 seasons:
   a. Green development reached a maximum for all fields on 1975 Julian Day 190 (booting and early heading for wheat).
   b. Barley tended to green up sooner than Spring wheat, attain higher levels of the green reflectance component, and be brighter than wheat after heading.
   c. Oats tended to green earlier and maintain a higher green component level than wheat, after its maximum was attained.
2. Agronomic factors produced affects on season-average wheat reflectances that were significant in simple one-way Analysis of Variance.
   a. The most significant factor was moisture availability (i.e., whether the field was fallow or cropped the preceding year), followed by nitrogen fertilizer application, planting date, and variety.
   b. Reduced moisture decreased green development at all acquisition dates and delayed the date of maximum green development.
   c. A delayed planting date correspondingly delayed the date at which maximum green development was attained.
   d. The effect of seeding rate differences appeared to be insignificant.
3. While crop development patterns are the key to multispectral discrimination, green development patterns alone may not provide sufficient criteria for adequately distinguishing Spring wheat from other small grains, e.g., crop brightness and ancillary data may be required as well, and perhaps different sensor spectral responses.

The following indicators were obtained, but need further study and verification in an expanded Landsat data set:

4. The within-segment separability of Spring wheat and other small grain (barley) field means using Landsat data varied as a function of acquisition date in 1975-76 data.
   a. A tendency appeared for greater separability in mid-July, when wheat was likely fully headed and beginning to turn color.
   b. Use of multiple dates improved separability, but the available selection of dates limited improvements for some segments.
5. Wheat and total small grain proportion estimates for segments also varied as a function of acquisition date:
   a. Total small grain proportion estimates were quite accurate with multiple (three or four) acquisition dates, but usually were degraded appreciably by use of a single date.
   b. Spring wheat proportion estimates were much less accurate than total small grain estimates.
   c. The best individual acquisition date or combination of dates for wheat proportion estimates tended to be or include a mid-July acquisition (~1976 Day 200).
6. Multisegment separability of Spring wheat from barley was substantially improved by haze and sun-angle corrections of Landsat acquisitions, in the three instances where their inherent within segment separability was sufficient (>70%).
7. The resultant multisegment accuracies approximated those obtained with local, within-segment training, in those three instances.
8. The test results produced and described here were based on ground-truth labeling of blob signatures; thus, the question of AI identification accuracy was not addressed in the analysis. Also, the effects of small fields were minimized by selecting segments having larger fields, wherever possible.

3.4.2 RECOMMENDATIONS

It is recommended that:

1. The separability of Spring wheat from other small grains should be further investigated using Landsat data from additional seasons and other locations.
2. More complete analysis of the 1974-75 LACIE Field Measurement data be conducted, as well as analysis of 1975-76 and 1976-77 data, to gain a more complete understanding of agronomic treatment effects on reflectances and Landsat signals and of the potential of Landsat and Thematic Mapper bands for discriminating Spring wheat from other small grains.

4

EARLY SEASON DETECTION THRESHOLD FOR WINTER WHEAT

Present early season estimates of winter wheat area from Landsat depend on detecting the green development of the wheat vegetation. Because the green development rate is variable and depends on many factors, early season estimates tend to be low and unreliable. These factors include planting date, crop rotation, irrigation and fertilization practice, possible over-winter grazing by cattle, wheat variety, and local weather and climate. The objective of the study reported here was to investigate the threshold of wheat detectability.

4.1 APPROACH

A three-step approach was taken to investigate the threshold of wheat detectability. As indicated in Table 10, these steps utilized three different types of data: simulated wheat canopy reflectances, field measurements of wheat canopy spectral reflectance, and actual Landsat MSS data.

TABLE 10. INVESTIGATION OF EARLY SEASON ESTIMATION: APPROACH

- Simulate Reflectance of Wheat Fields as Function of Development Stage
- Analyze Field Measurement Spectromter Data and Associated Ground Observations
    - Compute inband reflectance values and green and brightness components
    - Edit and identify valid wheat field spectral histories
    - Analyze green component threshold
- Correlate Landsat Data With Field Measurement and Simulation Data

In the first step, the reflectance of wheat fields was simulated as a function of development stage. The bidirectional canopy reflectance model developed by Dr. G. Suits of ERIM, [7] was employed in a parametric simulation of the reflectances of developing wheat canopies. The following factors were varied in the simulation:

1. Green Leaf Area Index (GLAI)
2. Soil Brightness Level
3. Canopy Structure (i.e., effective leaf orientation or V/H ratio)
4. Sun Zenith Angle.

Each computed reflectance spectrum was converted to a vector of Landsat-band equivalent reflectances by multiplying the spectrum by the relative response functions of Landsat and integrating over wavelength. Then, a transformation similar to the Tasselled-Cap transformation of Landsat data [4] was applied to produce green and brightness components of these inband reflectances for each spectrum. The brightness reflectance component was aligned with the direction of bare soil variation, while the green reflectance component was made perpendicular to it in the plane of principal variation, toward the direction of healthy green vegetation.* We also computed a polar coordinate transformation in the plane of principal variation, consisting of a radial distance from the origin and a "green angle" of rotation from the soil line, toward green vegetation values. The resultant calculations then were examined to determine the relative importance and effects of the various factors.

In the second step, field measurement data acquired in the Finney County, Kansas, LACIE "supersite" during the 1975-76 growing season by the LACIE Field Measurement Team were analyzed [3]. Spectral reflectance data acquired by the helicopter-borne FSS (Field Spectrometer System) on ten dates were analyzed; truck spectrometer data were not analyzed, due to resource constraints. Landsat-band reflectances and green and brightness reflectance components were computed from each

*The brightness axis of the Landsat Tasselled-Cap coordinates does not exactly align with the line of bare soil brightness.

analyzed spectrum, in the manner described previously. Each analyzed spectrum represented the average of five to 30 or more spectra measured for a single field. These reflectance values were examined in several ways. The dimensionality of the inband values was computed through principal component analysis, temporal patterns of reflectance from individual fields were compared, and histograms of green reflectance components from wheat fields were computed as a function of acquisition date.

In the third step, we began an examination of Landsat data. Correlations between Landsat values and reflectances measured by The FSS were made. We also computed histograms of Tasselled-Cap green components from wheat fields in four LACIE intensive test sites, including the Finney, Kansas, site and examined wheat field detectability.

4.2 ANALYSIS OF SIMULATED REFLECTANCES OF DEVELOPING WHEAT FIELDS

Through simulation modeling, the reflectances of Winter wheat fields under varied conditions and stages of growth were calculated. The model results and their subsequent analysis are described in the sections that follow.

4.2.1 EFFECTS OF MAJOR FACTORS ON WHEAT REFLECTANCE

The parameters for simulations of vegetation canopy reflectance describe the density of vegetation and its structure, the soil reflectance, and the viewing and illumination geometry. The specific factors and levels used in our simulation of developing Winter wheat canopy reflectances are presented in Table 11. They span a broad range of values that should encompass most conditions encountered. Spectral characteristics used for wheat leaves and stems were the same as used for the emergent stage in our prior simulations of wheat reflectance throughout a growing season [8].

TABLE 11. FACTORS IN PARAMETRIC SIMULATION OF WINTER WHEAT REFLECTANCE

Factor	Number of Levels	Levels and Description
Green Leaf Area Index (GLAI)	9	From bare soil (0) to extremely dense (26) (0, 0.10, 0.52, 1.04, 2.08, 3.12, 4.16, 5.2, 26.0)
Soil Brightness	3	Dark, Medium, Light (Mean ± 1 sigma of Condit's Data [9])
Canopy Structure (V/H)	6	Ratio of vertical to horizontal leaf cross-sections (0.25. 0.5, 1, 2, 3, 4)
Sun Zenith Angle	3	(40° and 61°): Kansas in Apr and Nov at time of Landsat Pass (80°): Northern Latitude Extremes
View Angle	1	Nadir

Figures 12, 13, and 14 indicate the effects of the four factors of interest in this study on the simulated Landsat, inband, emergent wheat canopy reflectances (Band 7 vs. 5). Figure 12 illustrates the effect of GLAI for 6 different V/H ratios, a soil of mean brightness level and a 61° sun zenith angle. The effect of increasing GLAI is clearly evident from this figure as is the significance of the V/H ratio of the wheat canopy. LACIE Field Measurement data for the 1975 growing season has indicated that actual emergent wheat canopy GLAI's fall within an approximate range of 2 to 4.) Although a GLAI of 26.00 is totally unrealistic, these points serve the useful purpose of indicating an "asymptotic" reflectance for an extremely dense canopy. Increasing GLAI from 2.08 to 26.00 results in no significant change in Band 5 reflectance and a relatively small change in Band 7 reflectance.

Figure 13 illustrates the effects of soil brightness on emergent wheat canopy reflectance. This figure represents reflectances for two

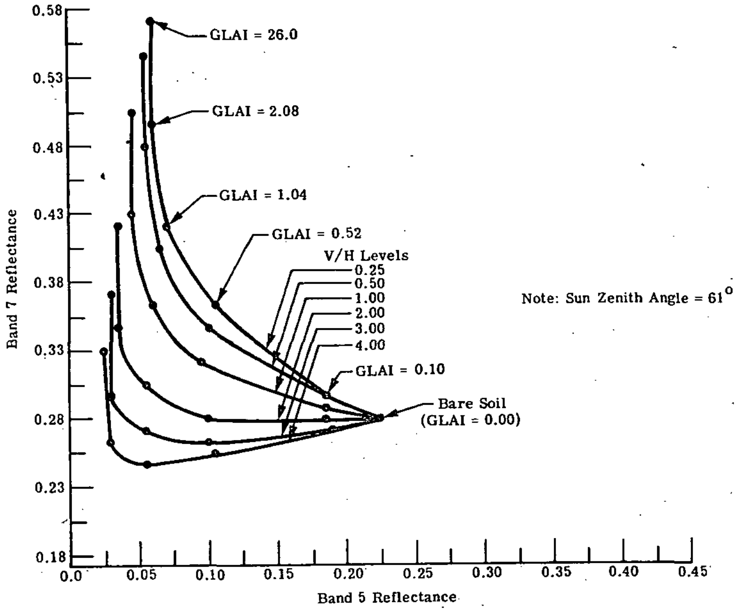


FIGURE 12. EFFECTS OF GREEN LEAF AREA INDEX (GLAI) ON SIMULATED LANDSAT INBAND REFLECTANCE (BAND 7 VERSUS 5) OF EMERGENT WHEAT CANOPIES WITH FIXED V/H RATIO AND MEAN SOIL BRIGHTNESS

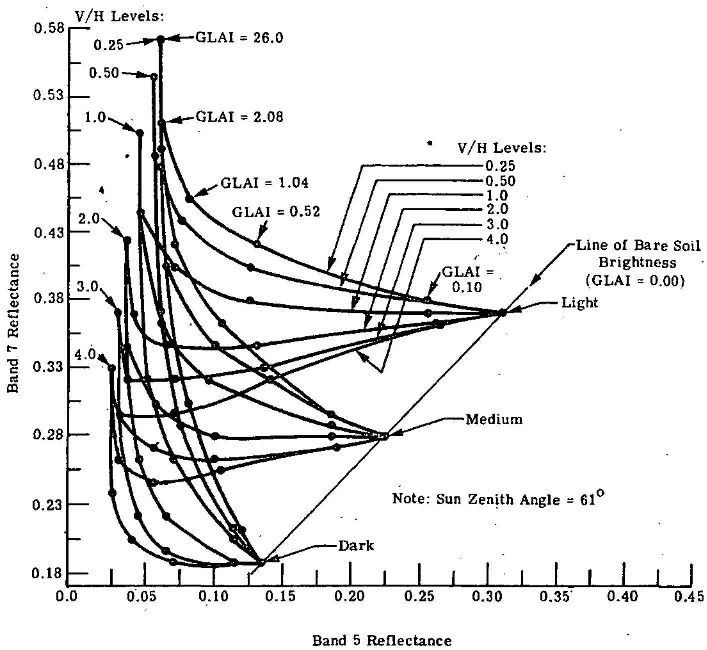


FIGURE 13. EFFECTS OF SOIL BRIGHTNESS AND GLAI ON SIMULATED LANDSAT INBAND REFLECTANCE (BAND 7 VERSUS 5) OF EMERGENT WHEAT CANOPIES WITH FIXED V/H RATIOS

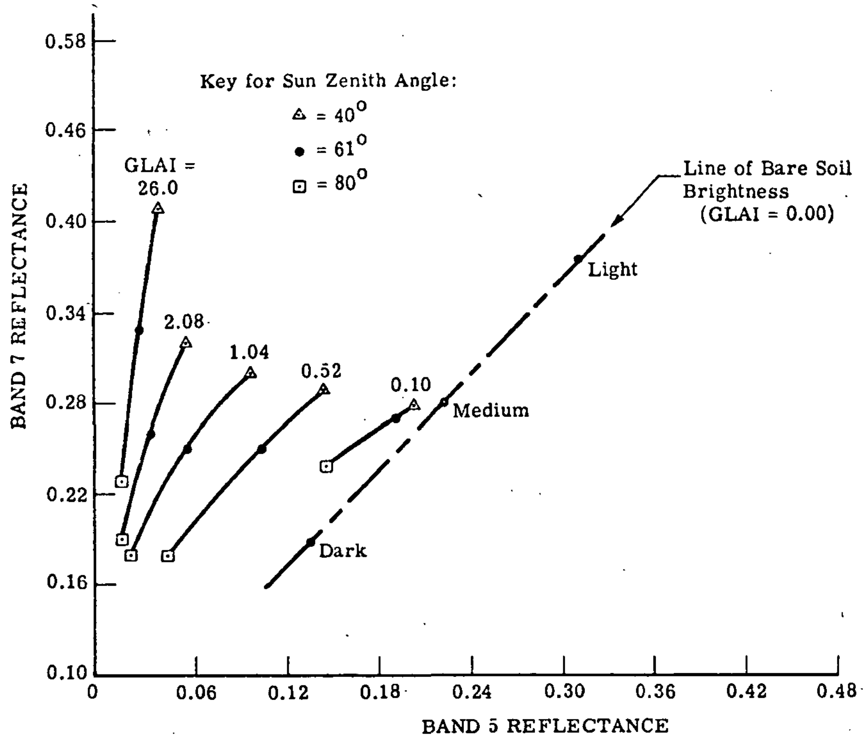


FIGURE 14. EFFECTS OF SUN ANGLE ON SIMULATED LANDSAT INBAND REFLECTANCES OF EMERGENT WHEAT CANOPIES WITH VARIOUS GREEN LEAF AREA INDEXES (GLAI), V/H = 4, AND MEDIUM SOIL BRIGHTNESS

additional soil brightness levels not illustrated in Figure 12, i.e., light and dark soil. Note that as one would expect, soil brightness has its greatest effect on canopy reflectance for low GLAI's and has a decreasing effect as GLAI increases. For the very dense canopies, soil brightness has no effect -- the reflectance there being determined by the V/H ratio.

Figure 14 illustrates the effects of sun zenith angle for various GLAI's, a V/H ratio of 4.0, and the medium soil brightness. The sun zenith angles, differentiated by the symbols listed in the key, are 40°, 61° and 80° (this latter angle is indicative of conditions at a far Northern latitude, e.g., Canada and USSR). This figure illustrates that overall reflectance of the canopy decreases (toward the origin) as sun zenith angle increases. This decrease is attributable to increasing shadows within the canopy.

4.2.2 PREDICTORS OF INBAND REFLECTANCES

Three other useful parameters of an observed canopy, which can be determined from the leaf area index, the V/H ratio, and the sun and view angles are:

1. Percent canopy vegetation viewed
2. Percent illuminated soil viewed
3. Percent shadowed soil viewed.

One would expect the observed inband reflectance values to depend on these variables, in combination with the soil and vegetation reflectances. We carried out a regression analysis to determine the relationships between Band 5 and Band 7 reflectances and these variables.

Band 5 reflectance (ρ_5) was well predicted by linear equations of the form:

$$\rho_5 = K_1 (1 - P_{ISV}) + K_2 P_{ISV}$$

where

P_{ISV} is the percent illuminated soil viewed

and

K_1 and K_2 are regression constants.

K_1 was found to be essentially the reflectance of an extremely dense canopy -- hence, it depends on the V/H of that canopy. K_2, on the other hand, was found to be essentially the reflectance of the bare soil in the particular canopy. Shadowed soil is dark, like vegetation, in Band 5.

The situation was somewhat different, however, for Band 7. Due to the high transmittance of leaves in this wavelength interval, a third term was needed:

$$\rho_7 = K_1 P_{VV} + K_2 P_{ISV} + K_3 P_{SSV}$$

where

P_{VV} is the percent vegetation viewed,

P_{SSV} is the percent shadowed soil viewed,

and

P_{ISV} again is the percent illuminated soil viewed.

K_1 again was essentially the reflectance of an extremely dense canopy and a function of its V/H value. K_2 again was correlated with soil reflectance, but also had a small dependence on V/H. K_3 exhibited a dependence on both soil reflectance and V/H.

4.2.3 INTRINSIC DIMENSIONALITY

Figure 15 presents the same set of simulated data values presented in Figure 13 but in a coordinate system which lies within a plane containing the first two principal components of the four-channel simulated Landsat reflectances. Approximately 99% of the variance of the data occurs within this plane and, thus, this figure gives an essentially complete view of the data. (This trend is significant in that a similar trend has been observed in actual Landsat data, tending to verify the reliability of the simulated data.) Each of the two components illustrated are different linear combinations of the four band reflectances; the first component depends predominantly on Band 6 and 7 reflectances and the second component depends predominantly on Bands 4 and 5. The location of the bare soil line within this plane is also indicated. The brightness and green components of the Tasselled-Cap transformation define an essentially corresponding plane in Landsat signal space.

4.2.4 TASSELLED-CAP TRANSFORMATION

A transformation similar to the Tasselled-Cap transformation of Landsat data was applied to the data, as described earlier in Section 4.1. Figure 16 is a diagram of the transformed version of the data

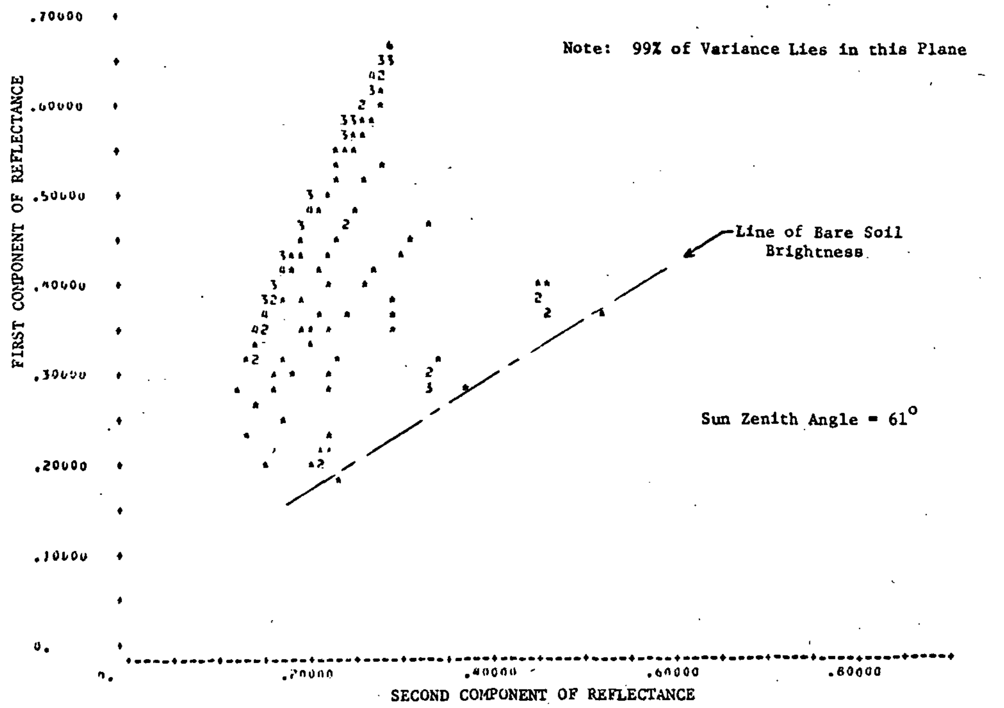


FIGURE 15. SCATTER OF SIMULATED REFLECTANCE VALUES IN PRINCIPAL COMPONENT PLANE

in Figure 13. On these two figures, points of constant V/H and soil brightness are connected.

In Figure 17, on the other hand, points of constant GLAI and V/H are connected. The radial nature of soil effects, is striking. This led to our definition of a polar coordinate description of the data, as discussed in Section 4.2.5.

4.2.5 GREEN-ANGLE/BRIGHTNESS-RADIUS TRANSFORMATION

The simulated reflectance values in Figures 16 and 17 show that soil effects are not limited to the brightness component. When a moderate amount of vegetation is present, the radial nature of a change in soil reflectance causes a change in the green reflectance component as well.

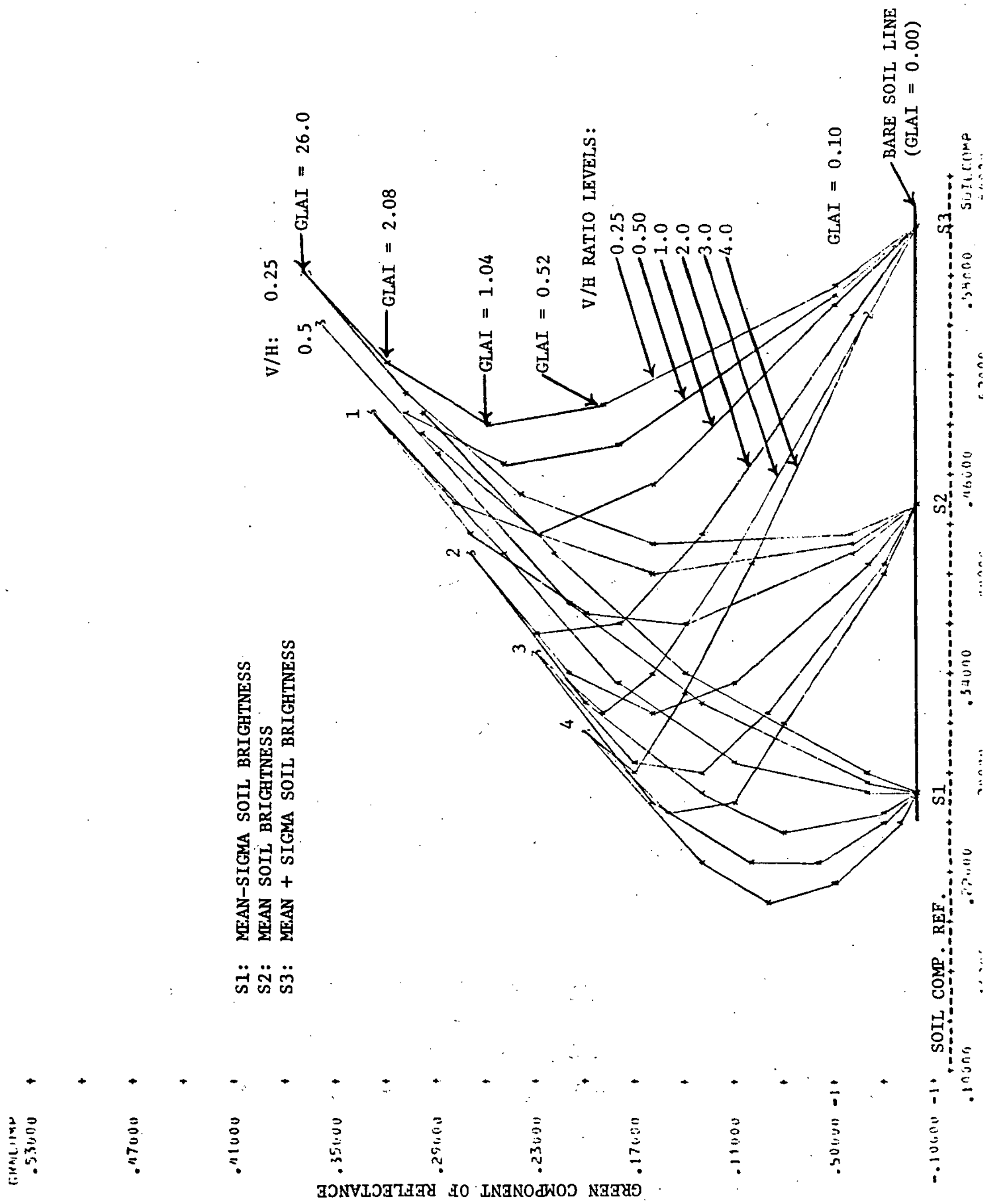


FIGURE 16. TASSELLED-CAP TRANSFORMATION OF SIMULATED WHEAT REFLECTANCES, ILLUSTRATING GLAI EFFECTS

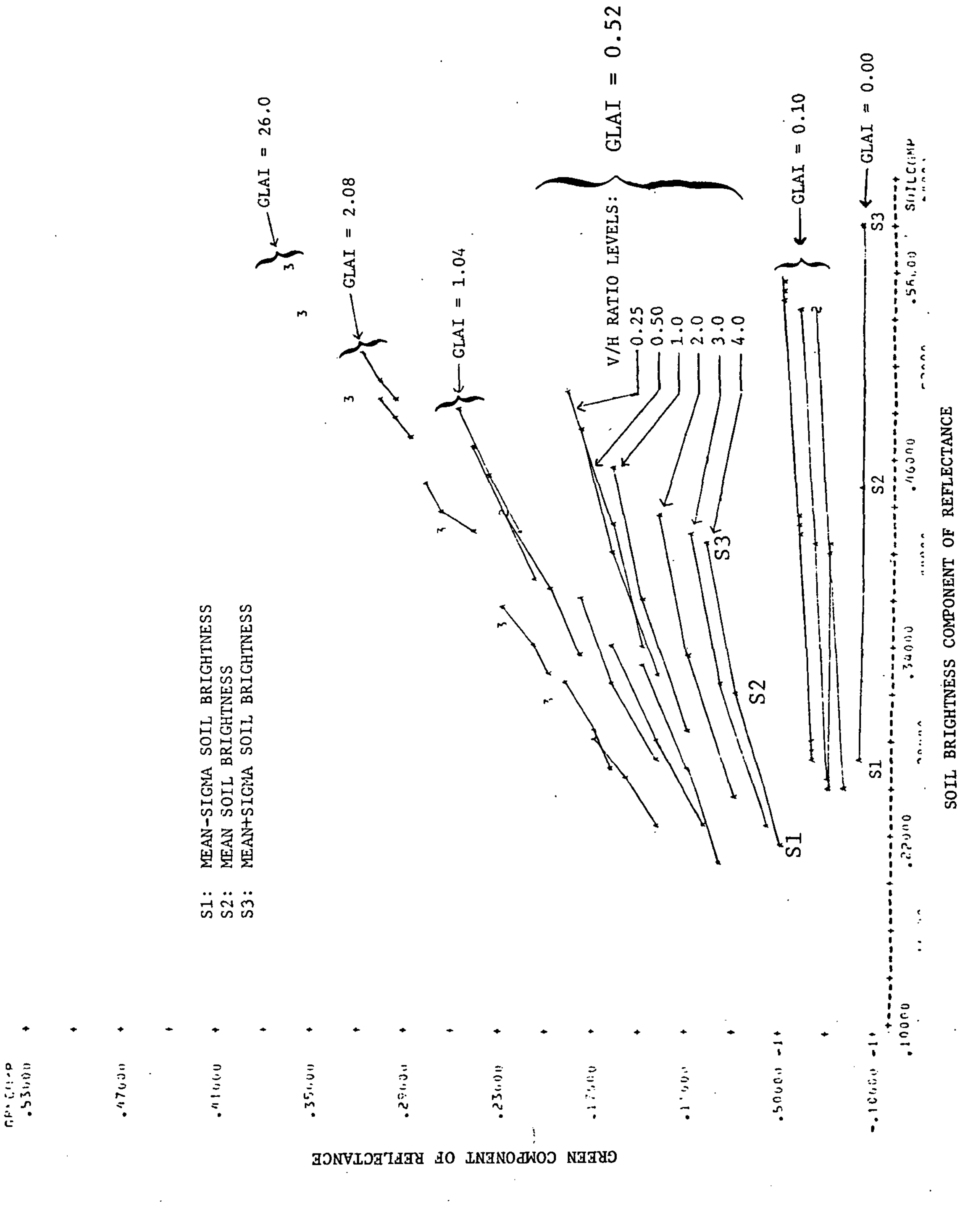


FIGURE 17. TASSELLED-CAP TRANSFORMATION OF SIMULATED WHEAT REFLECTANCES, ILLUSTRATING SOIL BRIGHTNESS EFFECTS

A polar-coordinate transformation of these data would produce an angular component that should be very independent of soil brightness effects. Measured counter clockwise from the line of bare soils, this "green angle" would be a good indicator of the level of green vegetation present. It is relatively insensitive to V/H differences.

The polar radial component would more truly be a brightness measure than the rectangular brightness coordinate because it measures distance from the origin, independent of angle. Use of the term "brightness-radius" should help to differentiate it from the rectangular brightness component.

For the foregoing reasons, the polar green-angle/brightness radius transformation of data is set forth as a useful method of extracting independent indicators of vegetation canopy state from reflectance and Landsat data. One potential problem for its application is the reliable location of the zero-reflectance point in Landsat signal coordinates. Haze correction and sun-angle correction procedures should help reduce the magnitude of the problem.

4.2.6 COMPARISON WITH MEASURED REFLECTANCES

A scatter diagram of the simulated reflectance values for developing wheat canopies is presented on the left half of Figure 18, for Band 7 vs. Band 5 reflectances. The general shape of the pattern of values is similar to that observed in cluster plots of actual Landsat data. It also is very similar to empirical measurements of wheat field reflectance shown on the right half of Figure 18; these measurements were made in Finney County, Kansas, with a Landsat-band radiometer during the 1974-75 season by Texas A&M University, as part of the LACIE Field measurement program. The bare soil brightness line is carried over from the simulated data, to facilitate comparison.

4.3 ANALYSIS OF FIELD-MEASURED REFLECTANCES OF DEVELOPING WHEAT FIELDS

The LACIE Field Measurements Program provided measurements of Winter wheat and other fields in Kansas for use in this investigation.

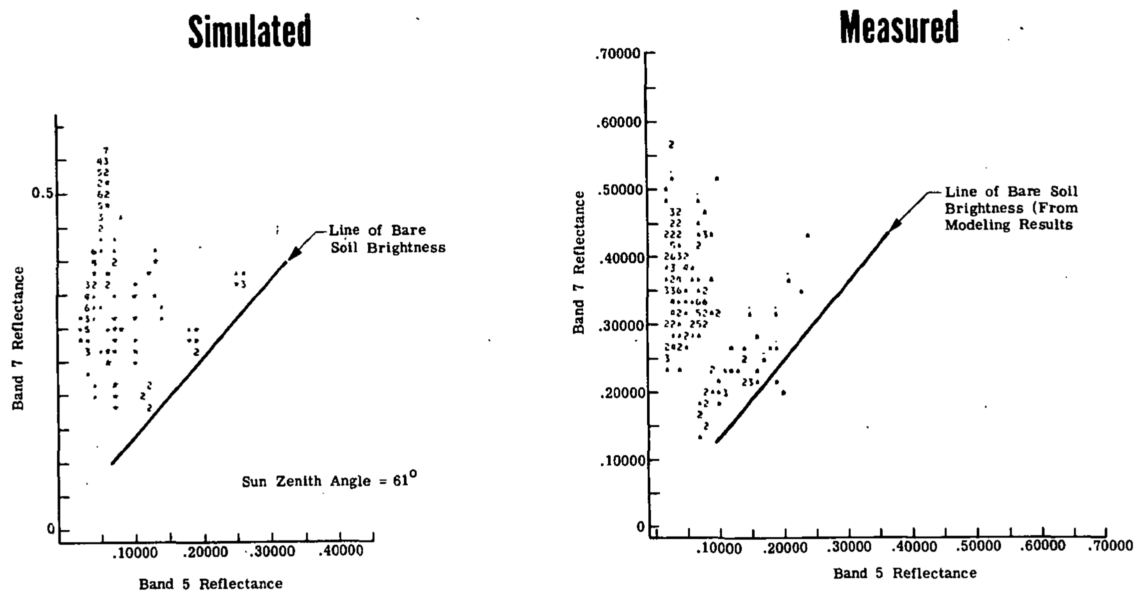


FIGURE 18. COMPARISON OF SIMULATED AND EMPIRICAL REFLECTANCE DATA

Several different analyses are presented, following a description of the data set.

4.3.1 DESCRIPTION OF FSS DATA SET ANALYZED

The FSS (Field Spectrometer System) is a helicopter-borne spectrometer which has been deployed in the Finney County, Kansas, LACIE "supersite" during the 1974-75, 1975-76, and 1976-77 growing seasons [3]. We have analyzed the 1975-76 data set and present results of that analysis in this report. Data were acquired by the FSS on ten dates throughout the 1975-76 season, as indicated in Table 12. Reflectances of a total of 68 fields were measured, along with the ancillary parameters indicated in the table. These were converted to Landsat-band values and into Tasselled-Cap components, using the procedures previously described.

TABLE 12. 1975-76 KANSAS FSS DATA SET

• Acquisitions:

Calendar Date	Julian Date
9-16-75	75258
10-3-75	75275
10-21-75	75293
11-11-75	75315
3-18-76	76078
3-31-76	76091
4-18-76	76109
5-6-76	76127
6-12-76	76164
6-30-76	76182

• Number of Fields: - Total = 68
  - Harvestable Wheat = 21

• Other Parameters Measured
  - Growth stage
  - Percent ground cover (5 intervals)
  - Stand quality
  - Surface moisture
  - Planting and harvest dates
  - Irrigation and fertilization practice
  - Crop species and variety

A scatter diagram displaying the distribution of the entire data set in green vs. brightness reflectance coordinates is presented in Figure 19. Note that groups of points are circled. Most of these were excluded from the analysis because we found that they all occurred during one data collection pass for which unusually low calibration

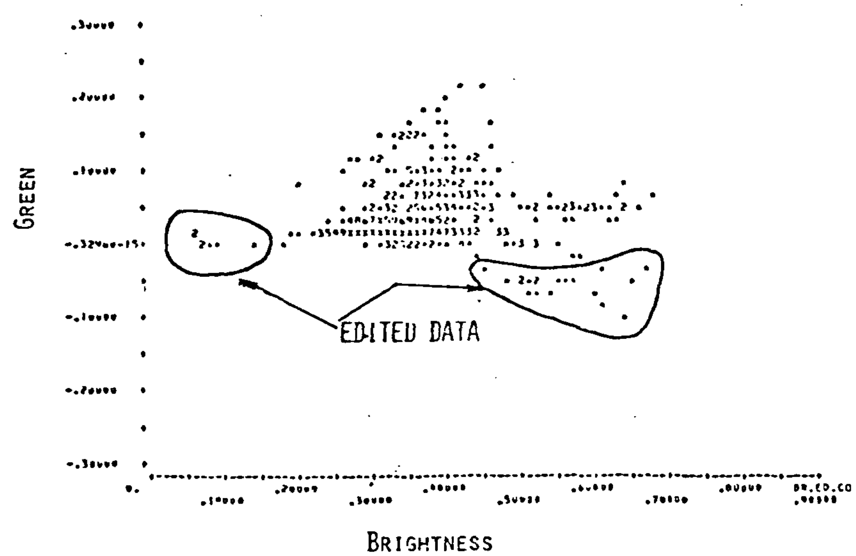


FIGURE 19. DISTRIBUTION OF 'LANDSAT' GREEN AND BRIGHTNESS COMPONENTS OF REFLECTANCE FOR ENTIRE FSS DATA SET (1975-76 Finney Country, Kansas)

panel readings were obtained; others had strong indications of cloud shadow problems. Several "wheat" fields were excluded because their crops failed and they were plowed, in total or major part, and planted to another crop. A total of 21 harvestable wheat fields remained for analysis.

A principal components analysis was performed on the set of FSS data and 98% of the variance was found to be in the plane of the two major components.

4.3.2 SEASONAL VARIATIONS IN MEASURED WINTER WHEAT REFLECTANCES

The next three figures describe the seasonal variations in the spectral reflectance characteristics of the winter wheat fields throughout the 1975-76 growing season. Figure 20 displays scatter diagrams of the green and brightness reflectance components versus Julian date. The greening up characteristic is readily apparent.

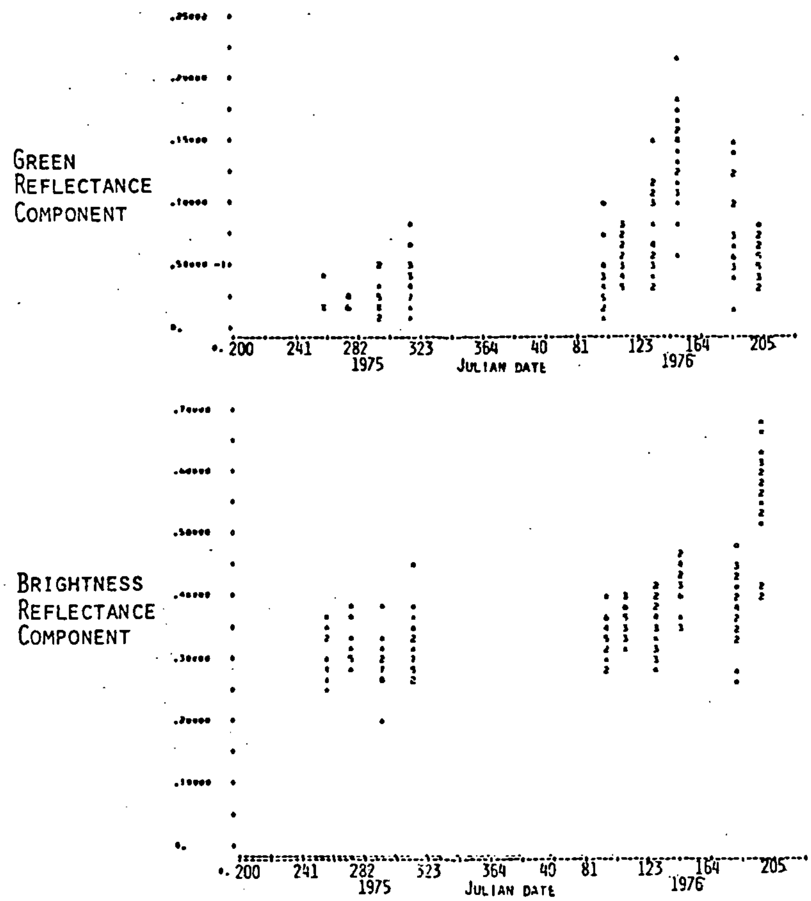


FIGURE 20. CHARACTERISTICS OF WINTER WHEAT SIGNATURES
(Components of 'Landsat' Reflectance in Finney ITS)

Four individual wheat fields were selected to illustrate differences among the fields present in the scene. Two irrigated and two dryland Winter wheat fields were chosen; in each pair, one was planted at the normal time and one later in the Fall. Figure 21 presents the green reflectance component vs. acquisition date for these four fields, while Figure 22 displays the time tracks of their signatures in the green-brightness plane of Landsat-band reflectance. Note the absence of Fall green development in the late-planted fields and the appreciable Fall greening up of the normal-date irrigated field.

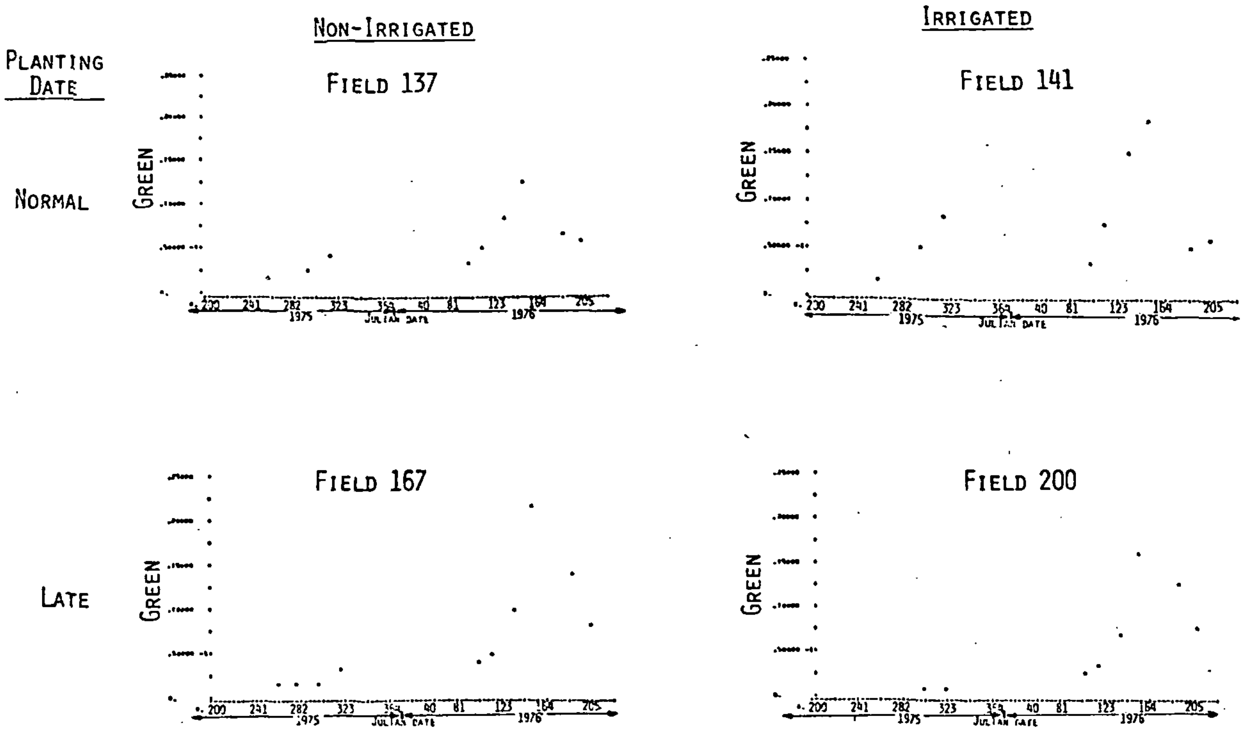
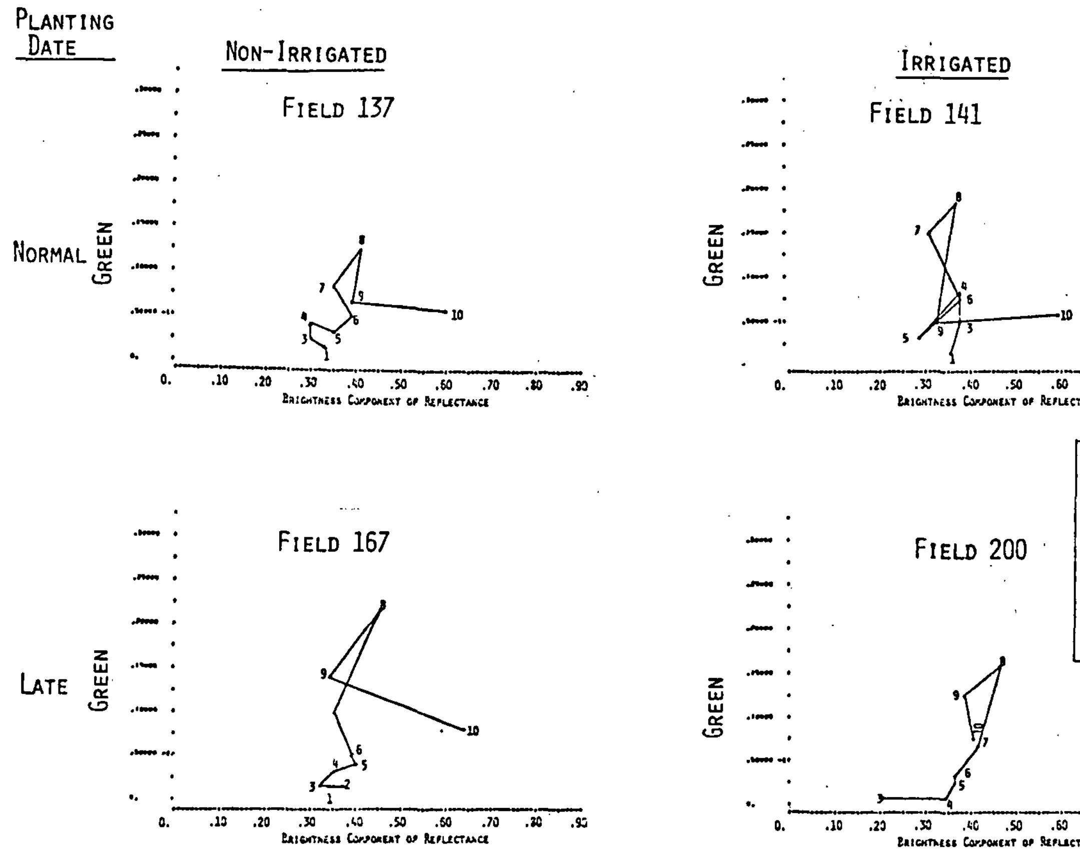


FIGURE 21. CHARACTERISTICS OF SELECTED WINTER WHEAT FIELDS (Green Component of 'Landsat' Reflectances)

4.3.3 THRESHOLDING ON THE GREEN COMPONENT

The actual numbers of late and early planted fields and irrigated and non-irrigated fields will vary from site to site, as will other factors which determine development rates. Yet, it is of interest to determine both how the collection of wheat fields in the Finney County site developed in 1975-76 and how well they would have been detected by a decision rule which called them wheat if their green component exceeded a given threshold by a given date.

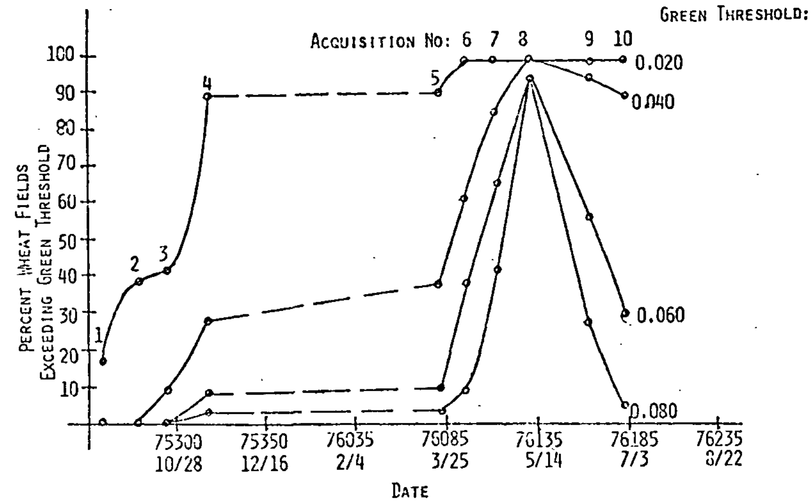
Therefore, to provide a quantification of the greening up characteristics of this group of fields, histograms were computed to describe the percentage of fields exceeding a given green threshold value, as a function of acquisition date. Figure 23 displays these



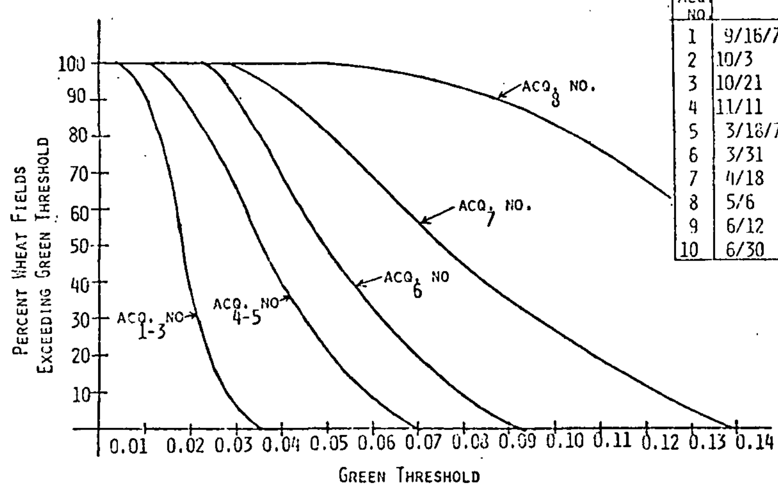
ACQ. NO.	DATE
1	9/16/75
2	10/3
3	10/21
4	11/11
5	3/18/76
6	3/31
7	4/18
8	5/6
9	6/12
10	6/30

ACQ. NO.	NOMINAL DEVELOPMENT
5	TILLERING, PREBUD
6	TILLERING, PREBUD
7	TILLERING, PREBUD
8	BOOTED OR BUDDED
9	BEGIN TO RIPEN
10	RIPE TO HARVESTED

FIGURE 22. SPECTRAL REFLECTANCE TRACKS OF SELECTED WHEAT FIELDS



(a) As a Function of Acquisition Date



ACQ. NO.	DATE	JULIAN
1	9/16/75	258
2	10/3	275
3	10/21	293
4	11/11	315
5	3/18/76	078
6	3/31	091
7	4/18	109
8	5/6	127
9	6/12	164
10	6/30	182

(b) As a Function of Green Threshold

FIGURE 23. THRESHOLDING OF GREEN REFLECTANCE COMPONENT OF WINTER WHEAT (Finney County, Kansas, 1975-76 FSS)

results in two manners, Part (a) with fixed threshold levels and varied dates, and Part (b) with fixed dates and varied thresholds. The green development in late Fall (November 11, 1975) was about the same as that for the first Spring mission (March 18, 1976). Note that nominal development steps at each of the dates are given in Figure 22.

To help interpret and apply the charts in Figure 23, we assumed a two-count uncorrelated rms noise level in each Landsat band and computed the equivalent green-component reflectance variation to be 0.018. This value should account for some within-field variation, in addition to system noise. If one were to have set a threshold of 0.06, 95% of the 21 wheat fields would have been detected on the eighth acquisition (May 6, 1976), 63% of them on the seventh acquisition (April 18), and only 38% on the sixth (March 31). For a lower threshold of 0.04, the corresponding percentages would have been 100% for the eighth acquisition, 86% for the seventh, and 62% for the sixth; even 28 to 38% of the two next earliest acquisitions -- Number 4 (November 11) and Number 5 (March 18) -- would have been detected, respectively.

The other fields in this rather limited data set were also tested for the green threshold crossing, with good exclusion of them. For the threshold of 0.06, only one other field (2.5%) exceeded the threshold on the eighth acquisition and none for earlier ones (5, 6, or 7). For the 0.04 threshold, the values were 10% on eighth, 2.5% on seventh, and none on 5 or 6.

In Section 4.3.4, we make initial comparisons of these observations with available Landsat data. Beyond that, a larger data base with other seasons of reflectance measurements (both FSS and truck-mounted) should be analyzed as well as more extensive Landsat coverage of varied locations (e.g., LACIE Intensive Test Site (ITS) and Blind Site Data sets).

4.3.4 RELATIONSHIPS BETWEEN MEASURED REFLECTANCES AND ACTUAL LANDSAT VALUES

Landsat signature data for three dates over the Finney County ITS, extracted for use on another contract [10], were matched to a subset of the fields in the FSS data set. These signature values, having been extracted from full frame data, have a slightly different calibration from LACIE Landsat-2 data. Figure 24 presents our preliminary correlation of these Landsat signatures with the corresponding inband reflectance values obtained from FSS data. R^2 values ranging from 0.69 to 0.77 were obtained. The regression lines shown were computed with reflectance as the independent variable. The intercepts for Bands 6 and 7 are greater than one would expect for path radiance. Regressions with Landsat values as the independent variables have lower y intercepts. Perhaps an orthogonal regression line or the line bisecting the two normal regression lines would be more appropriate, since both variables include random measurement errors. A greater range of measured reflectance values would also be beneficial for Bands 6 and 7.

Later, Landsat data prepared under Task 2 of this contract [6] became available, including two additional dates for the Finney ITS and data from three other ITS's: Randall County, Texas; Saline County, Kansas; and Whitman County, Washington. These data had been haze and sun-angle corrected using the XSTAR algorithm. We computed the Tasselled-Cap Transformation in both Cartesian and polar-coordinate form.

The Tasselled-Cap green and brightness components of the Finney Landsat data were regressed on the corresponding green and brightness components of reflectance from FSS data. The results are presented in Figure 25 for the green components and Figure 26 for the brightness components. Note that the R^2 value is 0.89 for green and only 0.54 for brightness; individual channels were in the 0.70-0.80 range. This result confirms that more of the data variability is in the brightness direction and suggests that the greeness component is a more stable variable for analysis and classification purposes.

In Figure 20 we presented data on the development of the green component of wheat reflectance throughout the 1975-76 season in Finney County, Kansas. Figure 27 presents analogous green components of Landsat data from the Finney ITS, as well as data from the other three ITS's.

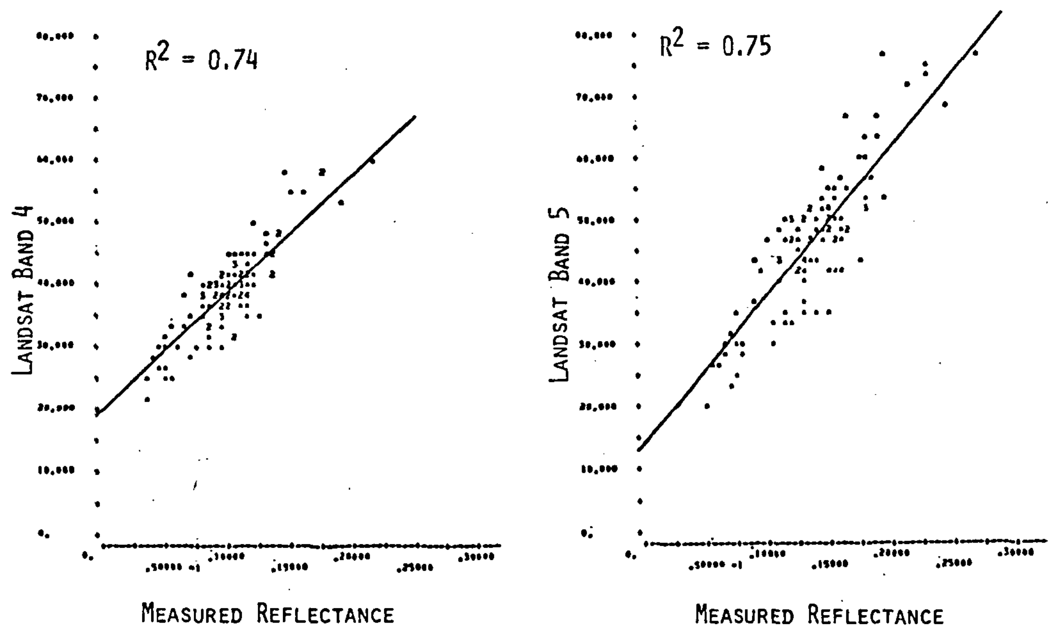


FIGURE 24(a). PRELIMINARY RESULTS RELATING FIELD MEASUREMENT REFLECTANCES TO LANDSAT DATA (Bands 4 and 5)

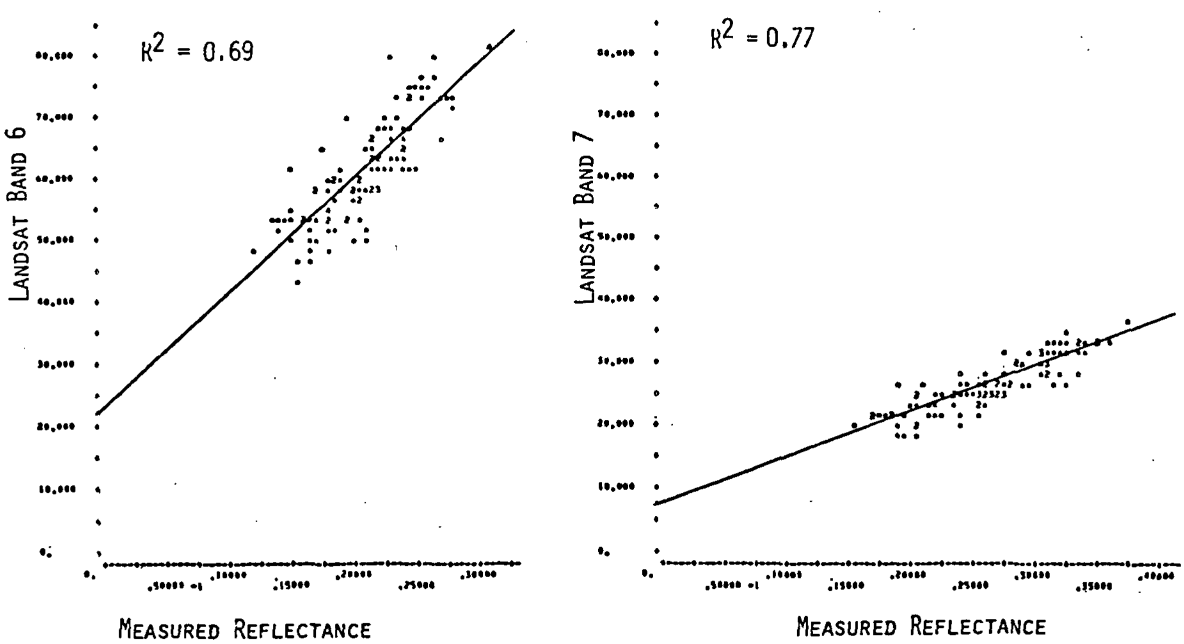


FIGURE 24(b). PRELIMINARY RESULTS RELATING FIELD MEASUREMENT REFLECTANCES TO LANDSAT DATA (Bands 6 and 7)

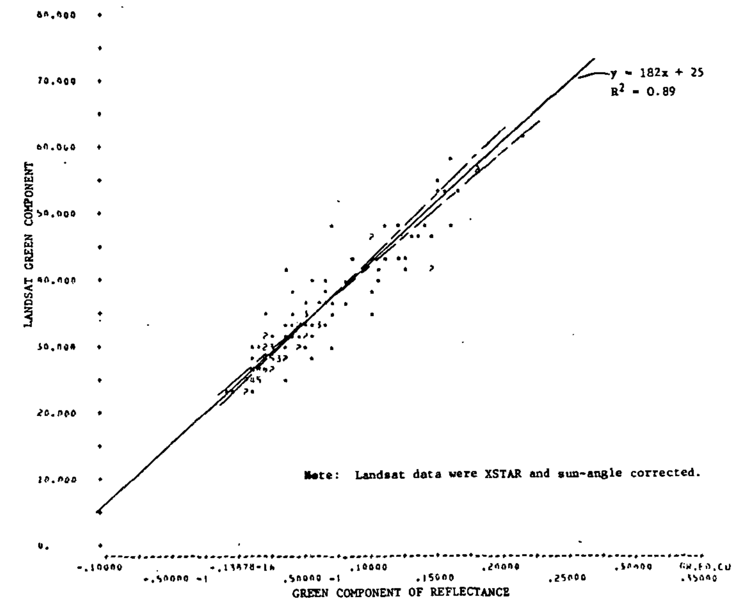


FIGURE 25. RELATIONSHIP BETWEEN GREEN COMPONENTS LANDSAT DATA AND FIELD-MEASURED INBAND REFLECTANCES OF WINTER WHEAT; FINNEY, KANSAS ITS, 1975-76 SEASON

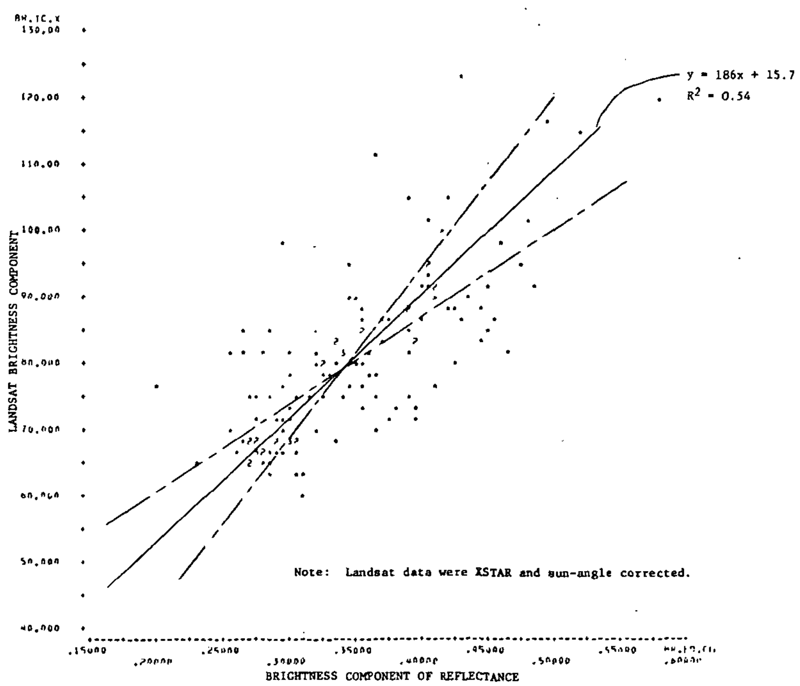


FIGURE 26. RELATIONSHIP BETWEEN BRIGHTNESS COMPONENTS OF LANDSAT DATA AND FIELD-MEASURED INBAND REFLECTANCES OF WINTER WHEAT; FINNEY, KANSAS ITS, 1975-76 SEASON

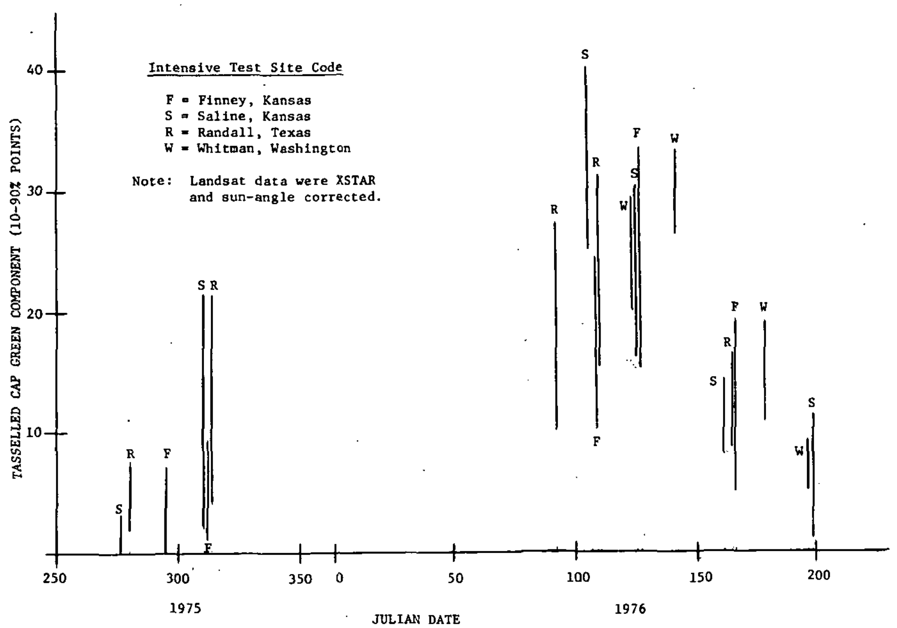


FIGURE 27. SEASONAL LANDSAT GREEN COMPONENT PATTERNS FOR WINTER WHEAT IN FOUR LACIE INTENSIVE TEST SITES

Each vertical line represents the range of values spanned by the wheat field signatures, less the top and bottom 10% of the fields. The pattern for Finney is similar to that observed in Figure 20 for reflectance data. The trends for the other ITS's are similar, but the following differences are noted. Saline and Randall green up sooner. Saline reaches a higher peak of greening, while the other three segments are somewhat comparable to each other. These differences are likely related to differences in crop calendars and growing conditions in these sites.

4.3.5 RELATIONSHIPS BETWEEN REFLECTANCES AND AGRONOMIC FACTORS

The relationship between the green component of measured reflectance and the observed percent ground cover for the wheat fields was analyzed. The ground cover observations were coded in to one of five equal intervals, e.g., 41-60%, and we used the center of each interval as the "true" numerical value, 50% for the example. A scatter plot of the data values for Acquisitions 5 through 8 is presented in Figure 28,

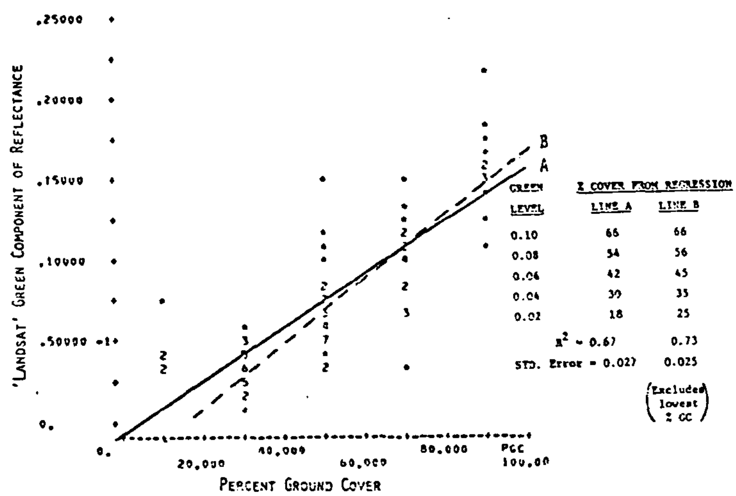


FIGURE 28. RELATIONSHIP BETWEEN GREEN REFLECTANCE COMPONENT AND PERCENT GROUND COVER
(1975-76 FSS Wheat Fields, Spring Acquistions)

along with regression lines computed using percent ground cover as the independent variable. Note that a green reflectance threshold of 0.04 corresponds to roughly 30-35% ground cover and one of 0.06 corresponds to roughly 40-45% ground cover. These are very preliminary results based on the coarse gradations of ground cover. Further comparisons should be made with simulation results and different regression relationships should be examined, in light of those comparisons, before definite conclusions are drawn.

The simulation results provide another source of information to assist in the interpretation of Landsat signals from wheat as it develops. The relationships presented earlier in Figures 12 and 13 illustrate the relative effects of the variables which describe the structure of the canopy.

One additional set of relationships may assist in the interpretation of the results of Section 4.2 and other data. Figure 29 presents a graph displaying percent ground cover as a function of leaf area index (LAI) and average leaf orientation, as measured by the ratio of vertical to

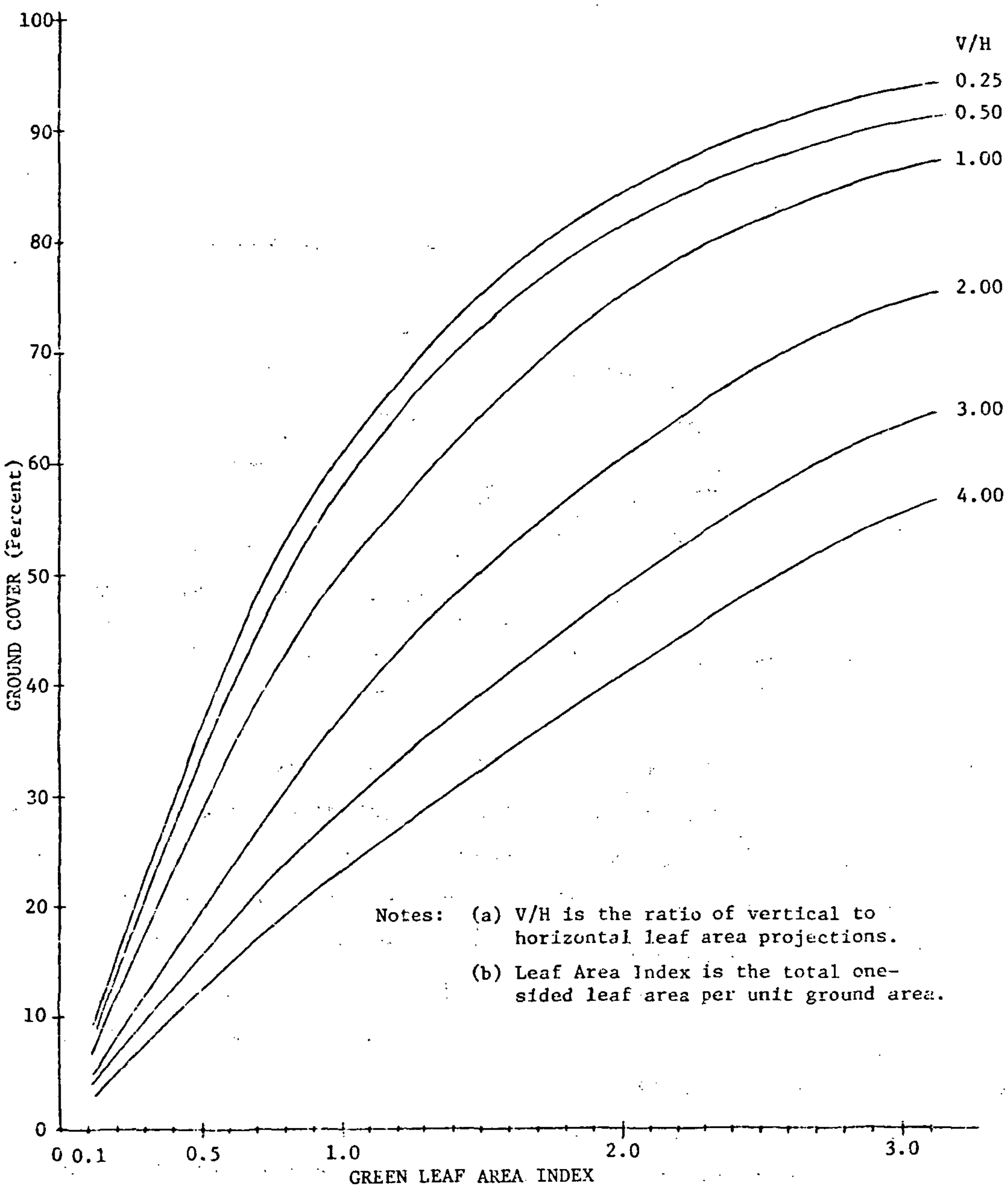


FIGURE 29. RELATIONSHIP BETWEEN PERCENT GROUND COVER AND LEAF AREA INDEX FOR VARIOUS GREEN WHEAT CANOPY STRUCTURES (V/H Ratios)

horizontal projections of cross-sectional area (V/H). The specific growth patterns of wheat fields, in terms of V/H (and LAI) as a function of time, remain a major source of uncertainty in interpreting and applying these simulation results.

4.4 CONCLUSIONS AND RECOMMENDATIONS FOR EARLY SEASON DETECTION

On the basis of the analyses conducted, the following conclusions were drawn and recommendations are made.

4.5.1 CONCLUSIONS

1. The intrinsic dimensionality of Landsat inband reflectances from both simulated and field-measured data is such that the vast majority of variance is contained in the plane of the first two principal components -- essentially the Tasselled-Cap plane of Landsat data.

2. The relative importance of the major factors affecting the reflectance of developing winter wheat fields has been quantified. Initially, soil color is most important, but the leaf orientation gains in importance as the leaf area index increases.

3. The Tasselled-Cap transformation is useful in interpreting and analyzing Landsat data. A polar-coordinate green-angle/brightness-radius transformation may provide an even greater ability to decouple soil and green vegetation density effects, but further analysis is required before full assessment can be made.

4. Greening-up characteristics have been quantified for those Winter wheat fields whose reflectances were measured by the FSS during the 1975-76 season in Finney County, Kansas. Initial comparisons have been made to relate the measured reflectance data to actual Landsat signals.

5. Consistent single-pass detection of the winter-wheat greening-up phenomenon will depend on the planting date and development rate of the wheat fields in a given area. The rate for Finney County fields in Kansas in 1976 indicated missed fields prior to mid April. Year-to-year differences in development patterns should be analyzed.

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4.5.2 RECOMMENDATIONS

1. The early season detection analysis should be extended to the other field-measured reflectance and Landsat data sets, to cover additional seasons and sites.
2. Wheat crop calendar and growth models should be utilized to predict conditions in segments as a function of acquisition date and ancillary conditions,

5
MULTICROP AGRICULTURAL INVENTORY DEVELOPMENT PLANNING

In contrast to the detailed analysis of current and specific LACIE technical issues discussed in Sections 3 and 4, the third topic of this investigation was more general and had a longer range outlook. The objective of this third subtask was to assist in planning for the continued development and application of the agricultural remote sensing technology that has been developed under LACIE and related activities. This planning should take into account and/or help establish what is technically feasible, what is relevant to identified user(s), what resources are required, and how to make most effective use of LACIE system components.

The material in this section was presented to Johnson Space Center (JSC) personnel in a quarterly review session during the week of 28 Feb 77. It was prepared* as an initial "strawman" plan to facilitate discussion and plan development by the Earth Observations Division.

Remote sensing technology provides a new source of information of potential value for Earth resource applications. Its value may be enhanced through combination with other types of information. However, the effective value of any type of information can be judged only in the frame of reference of its users. Information that is not accepted by a given user as being relevant, reliable, and/or in a suitable form is of marginal value, even though its potential value may be great.

The Large Area Crop Inventory Experiment (LACIE) is a joint project of NASA, USDA, and NOAA. Its objective is to demonstrate the feasibility of annual wheat acreage, yield, and production estimates on a worldwide basis using satellite-borne multispectral scanner data. The design of the LACIE system and its information outputs has been strongly influenced by the "user" needs of USDA. The advanced wheat inventory

*See preface for acknowledgements.

system, PAYES (Production, Acreage, and Yield Estimation System), defined for procurement by the USDA, is based on LACIE experience and is even more closely tailored to specific USDA information needs.

The general outline of our proposed development plan was as follows:

1. Develop future program objective (Jan - Jul 77)
2. Conduct definition studies for major candidate objectives (May 77 - May 78)
3. Develop detailed multicrop experiment implementation plan (Apr 78 - Oct 78)
4. Implement multicrop inventory experiment (Oct 78 - Oct 81, or longer)
5. Design and implement multicrop inventory system (Apr 80 - Dec 82, or longer).

Table 13 is an expansion of Item 1. and lists the topics which are discussed in detail in this report.

TABLE 13. EXPANSION OF PLAN OUTLINE

1. Develop Future Program Objectives
   - 1.1 Identify potential beneficiaries and users
   - 1.2 Identify functional types of information required
   - 1.3 Identify general program criteria
   - 1.4 Identify candidate objectives, crops, and regions
   - 1.5 Prioritize candidates

5.1 DEVELOP FUTURE PROGRAM OBJECTIVES

The interrelationships of information value with user needs and judgments have already been noted. At this point in the planning, it is appropriate to take a broad viewpoint in considering both the potential users of agricultural inventory information derived from remotely sensed data and the possible types and functional forms of that information.

5.1.1 IDENTIFY POTENTIAL BENEFICIARIES AND USERS

The potential beneficiaries of improved agricultural inventory information may or may not be direct users of it and may or may not pay for its acquisition, either directly or indirectly. These potential beneficiaries range from the individual consumer or farmer to the entire world and mankind as we know it. Intermediate levels include organizations such as businesses, local governments and populations, national governments and populations, industrial consortiums, and groups of nations. In most cases, direct use of such information would be made only by larger organizations, such as government agencies. The costs of the information would be borne directly by some or all of these organizations and indirectly by groups of taxpayers and consumers.

The use and applications of the acquired information will depend on the sponsoring organizations and their objectives relative to the interests of their constituencies. In other words, political and profit criteria will enter in, as well as humanitarian and long-range worldwide criteria.

Table 14 identifies potential users of improved agricultural inventory information.

5.1.2 IDENTIFY FUNCTIONAL TYPES OF INFORMATION REQUIRED

Agricultural crops comprise a renewable resource that is essential to human life and well being. The quantity and quality of agricultural production vary substantially from year to year, depending primarily on local and global climatic and weather conditions. At different geographic locations, the availability and quality of the resources needed for production also affect the relative levels of production which are attained.

The long-term trends evident in agricultural production depend on management decisions, such as the amount and type of land to place

TABLE 14. POTENTIAL USERS OF IMPROVED AGRICULTURAL SURVEY INFORMATION

1. Individuals
   - Farmers
   - Consumers
2. Organizations
   - Agribusiness (Producers, Import/Export, Equipment, Supplies, Transportation, etc.)
   - State and Local Governments and Agencies
3. U.S. Government Agencies
   - Department of Agriculture
     - Agricultural Stabilization and Conservation Service
     - Statistical Reporting Service
     - Foreign Agricultural Service
     - Soil Conservation Service
     - Economic Research Service
     - Forest Service
   - Department of Interior
     - Bureau of Land Management
   - Agency for International Development
4. Individual Foreign Nations
5. United Nations
   - Food and Agriculture Organization
   - Industry Cooperative Programme

under cultivation, and on available technology and farming practices which affect crop yields, such as irrigation, fertilization, crop and variety selection, weed and moisture control, and cropping practice. The long-term availability and cost of necessary resources also are potential limiting factors.

Table 15 lists what, in our view, are the major potential agricultural inventory and monitoring functions that could benefit from inputs derived from remotely sensed data.

5.1.3 IDENTIFY GENERAL PROGRAM CRITERIA

Several different types of criteria can be identified for use in defining and prioritizing the long-range objectives of the large-area agricultural resource inventory program. Several criteria relating to economic value, technical feasibility, and implementation factors, as well as crop and region selection criteria, are presented in Table 16. These and others must be weighted by the requirements and priorities of major users of the inventory information, as final decisions are made.

TABLE 15. POTENTIAL INVENTORY FUNCTIONS

- Monitor Renewable Crop Resources
  - Estimate Area, Yield, and Production
  - Detect Episodic Condition Changes and Predict Effects
    - Weather- or Climate-Related Stresses (major source of variability)
    - Disease, Pests
    - Effects on production for management, distribution, and marketing decisions
- Monitor Use and Status of Basic Resources
  - Land (erosion rate and potential, suitability for agriculture)
  - Water (irrigation, quality)

TABLE 16. GENERAL PROGRAM CRITERIA

- Economic value to user(s)
    - Market or import/export value
    - Improvements over currently available information
- Technical feasibility
    - Data availability and suitability
    - Confusion classes
    - Spectral/temporal separability
    - Spatial separability (e.g., field sizes and adjacency)
- Implementation factors
    - LACIE and/or PAYES compatibility and/or experience
    - Cost vs benefit analyses
    - Growth potential
    - Spatial and temporal sampling requirements
    - Timeliness requirements
    - Implementation schedule
- Crop vs. Regional Emphasis
- Crop Selection Criteria
    - Year-to-year production variability
    - Economic and/or social value
    - Agricultural system and practices
    - Confusion crops
    - Crop calendar and crop inventory cycle(s)
    - Availability and accuracy or yield models
    - LACIE experience
- Region Selection Criteria
    - Economic and/or social value
    - Complexity index
    - Agricultural system and practices
    - Cloud cover and other environmental variables
    - Availability of Landsat data
    - Availability of ground truth
    - Topography, soils, and other site variables
    - LACIE experience

5.1.4 IDENTIFY CANDIDATE OBJECTIVES, CROPS, AND REGIONS

Candidate objectives are those which would accomplish the inventory functions listed in Table 15. Candidate crops for inventory are listed in Table 17. Although supporting statistical data have not been included, the three major world food crops are rice, wheat, and corn (maize). Candidate regions include the major continents and any associated island areas, and subdivisions of the same, based principally on climate and available soil and water resources.

TABLE 17. CANDIDATE CROPS

Cereal Grains	Legumes	Tubers	Other
Rice	Soybeans	Potato	Sugar Cane++
Wheat	Mungbeans	Sweet Potato	Coffee+
Maize (Corn)	Peas	Cassava	Tea+
Sorghum		Taro	Cocoa+
Millet			Fruits+
Barley			Nuts+
Oats			Tobacco
Rye			Cotton+
			Rubber+
			Jute

Note: The three major food crops are: Rice, Wheat, Corn (Maize)

Note: Plants are annuals unless otherwise indicated:
+Perennial
++Biannual

5.1.5 PRIORITIZE CANDIDATES

Although not incorporating direct inputs from potential users, we have used our experience and collective judgement to provide the prioritization of candidates that is indicated in Table 18.

TABLE 18. RECOMMENDED MULTICROP PRIORITIES

1. Corn (Maize) - Worldwide
2. Soil Resource Inventory - Regional Initially
3. Rice - Regional
4. Sugar Cane and/or Coffee - Regional

With wheat already being inventoried, it becomes a choice between the other two major world food crops for addition to the inventory list. Our choice of corn as first priority instead of rice was based on a number of considerations, including those listed in Table 19.

TABLE 19. ADVANTAGES OF INVENTORYING CORN INSTEAD OF RICE

- Greater export volume and value
- Greater USA share of market
- Larger field sizes and less scene complexity
- Single crop cycle per year rather than two or three
- Clouds may be less of a problem
- Production of maize is expanding throughout world, especially where standard of living is substantial or increasing

DISADVANTAGES

- More people depend on rice for subsistence
- Corn requires more fertilizer

The rationale for including soil resource inventory with such a high priority (ahead of rice) is presented in Table 20.

TABLE 20. RATIONALE FOR SOIL RESOURCE INVENTORY AND MONITORING

- Agricultural productivity depends on soil
- Soil is a non-renewable resource
- Soil erosion is a serious problem
    - Even on prime land in U.S.
    - Especially on marginal land
    - Very serious in rest of world, e.g., S. America and Africa
- Landsat can provide information on ground cover
    - Ground cover at times of hard rains and dry winds is critical
    - Landsat estimates could be coupled with meteorological data (and terrain data) to estimate erosion

Finally, the choice of sugar cane and coffee is based on their ranking as the major U.S. imported agricultural commodities, as shown in Table 21.

TABLE 21. 1974 U.S. IMPORTS OF AGRICULTURAL COMMODITIES

Sugar	$2,256 Million U.S. Dollars
Coffee	1,504
Fruits & Nuts	628
Vegetables	387
Cocoa	316
Tea	79

5.2 ADDITIONAL CONSIDERATIONS

Having established a first priority, a number of additional considerations remain.

5.2.1 AREAS TO BE INVENTORIED

We have recommended that initial inventories be conducted within the U.S. Corn Belt. Table 22 identifies the six largest producing states which contribute about 2/3 of the total U.S. production. Three

TABLE 22. LEADING PRODUCING STATES IN 1974

Corn		Soybeans
Iowa	948 million bu.	Illinois
Illinois	831	Iowa
Indiana	388	Indiana
Nebraska	381	Missouri
Minnesota	360	
Ohio	266	
	3174 $\left(\frac{2}{3}\right)$	
Total USA =	4651	

NUMBER OF STATES IN WHICH LEADING CROP, IN 1974 VALUE, WAS:

Corn	- 13
Soybeans	- 5
Wheat	- 5
Hay	- 8

of these states also are the top three producers of soybeans. On this basis, we recommend that sites be established as discussed in Table 23.

TABLE 23. SITE RECOMMENDATIONS

- Establish LACIE Intensive Test Sites in Corn Belt Region
  - Iowa
  - Illinois
  - Nebraska
  - Indiana
  - Minnesota
  - Ohio

  (Indiana, Minnesota:) Evaluate suitability of current ITS's for corn and soybeans
- Establish super sites for intensive field measurements
- Establish LACIE sample segments within these states plus Missouri

  Stratified sampling based on LACIE experience

When foreign areas are included for the inventory of corn, choices should be based on production, import, and export criteria. Table 24 identifies the principle countries for producing and exporting maize.

TABLE 24. MAIZE PRODUCTION STATISTICS

PRINCIPAL PRODUCERS OF MAIZE

	Percent		Percent
USA	46.0	France	3.4
China	8.0	Argentina	3.2
Brazil	4.8	Yugoslavia	2.6
USSR	4.2	Rumania	2.2
Mexico	3.9	Thailand	
South Africa	3.5	Others	

PRINCIPAL EXPORTERS OF MAIZE (73/74)

	Million Metric Tons
USA	35.1
Argentina	5.1
France	4.4
Thailand	2.0

TOTAL WORLD PRODUCTION = 310.8 Million Metric Tons

5.2.2 TECHNICAL ISSUES AND DATA REQUIREMENTS

A variety of technical issues require further definition before the recommended additional large-area inventory functions can be undertaken. A number of these are listed in Table 25.

TABLE 25. ISSUES REQUIRING FURTHER DEFINITION

- Important Confusion Crops
- Crop Characteristics Relating to Identification
- Temporal Sampling Strategy
- Spatial Sampling Strategy
- Effects and Severity of Cloud Cover
- Status of Yield Models
- System Performance Criteria
- Timing Requirements for Estimates
- Classifier Training Requirements

In order to effectively resolve many of these issues, it is important to have a well-defined and documented set of data. See Table 26. More detail would be obtained in domestic areas while lesser detail would be likely in foreign areas. We also recommend that preliminary studies be made in foreign areas, in advance of the major emphasis there.

TABLE 26. DATA REQUIREMENTS

- Field Measurement Data For Corn and Soybeans
  - Crop canopy structure and component spectral properties as function of crop calendar and ancillary variables
  - In situ spectrometer measurements
  - Aircraft multispectral scanner measurements and photography
  - Intensive test site types of data (e.g., periodic observations and field yields)
  - Blind Site types of inventory information
- Site-Specific Data
  - Soils and topographic data
  - Historical crop, meteorological, and land use data
  - Crop calendar estimates
- Landsat Data
  - Multitemporal CCT data from sample segments (5 x 6 mi, or other)
  - Full frame imagery and CCT's
  - Image products for segments (such as those produced in LACIE)

5.3 MULTICROP SUMMARY AND RECOMMENDATIONS

We have developed a proposed outline for the continued development and expansion of large-area agricultural inventory techniques. A phased approach is recommended, as summarized in Table 27. It would begin with corn (maize) in the U.S. Corn Belt region and include soybeans as a companion crop of major interest. Foreign areas would be added in stages, according to production and import/export criteria. Following this the other objectives would be phased in, as resources permit, beginning with soil resource inventories emphasizing soil erosion problems; pilot studies should be initiated well in advance of major phase-in efforts.
An effective field measurement program to acquire additional data is deemed to be very important to the technical success of this project.

TABLE 27. RECOMMENDED PHASED DEVELOPMENT APPROACH TO MULTICROP INVENTORY
(To be confirmed or modified by detailed program definition studies)

- Begin With Corn in the U.S. Corn Belt Region
    - Include soybeans as a crop of interest
        - Experience has shown it to be an important confusion crop (Corn Blight Watch and CITARS)
        - It is of major economic importance in its own right
    - Develop capabilities to accurately model and predict corn (and soybean) growth, reflectance, and yield
    - Conduct preliminary studies in foreign areas to determine important confusion crops and potential technical problems
- Add Corn (Maize) in Foreign Countries, Based On Production, Import, and Export Criteria
- Phase in the Lower Priority Objectives, As Resources Permit
    - Begin with pilot studies
    - Expand to desired levels
    - Give next priority to soil resource inventory (erosion potential), followed by inventory of rice, and then sugar and coffee

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