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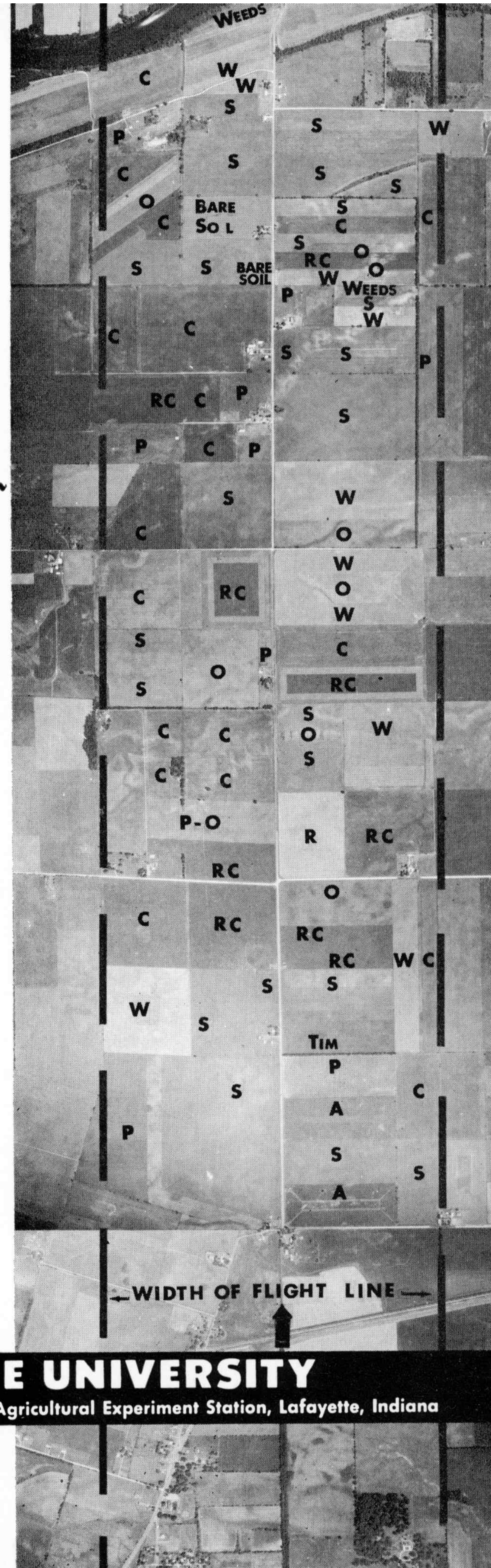
REMOTE MULTISPECTRAL SENSING in Agriculture

This report covers work performed from January through August 1966



Foreword

The agricultural community could make many valuable applications of the ability to detect and identify agricultural features on the Earth's surface over widespread areas in relatively short time intervals. It has long been known that reflected and/or emitted electromagnetic radiation from objects often contains information which characterizes its sources. The recording of such radiation data is referred to in this work as remote sensing. It is of prime importance to the world's future population to determine efficient methods for recording radiation characteristics of important agricultural features over widespread areas through the use of aerospace platforms, and for processing these data for information content in a timely fashion.

The NASA-USDA sponsored research program at Purdue University, whose purpose is to develop remote sensing techniques and to investigate applications of these for the benefit of world agricultural resources, is in accord with the National Aeronautics and Space Act of 1958, which declares that United States space activities shall be devoted to peaceful purposes for the benefit of all mankind.

Usually, reflected and/or emitted radiation is recorded in photographic form; a human interpreter then extracts the desired information content from the imagery. The large quantities of imagery which result from a single mission

PURDUE UNIVERSITY
Agricultural Experiment Station, Lafayette, Indiana

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over extended regions necessitates a high degree of automation in the interpretation of data. Past efforts have concentrated on aiding the human interpreter with automatic processing techniques. Such techniques include distinctive feature enhancement, screening to eliminate frames containing no potential information (such as cloud covered terrain and ocean areas not containing any land features) automatic recognition of important objects on photographs, and interpretation of the information extracted from imagery. Thus far such efforts have resulted in moderate success, and will be continued.

It is, however, the immediate goal of the programs at Purdue to investigate further remote sensing techniques which require little or no human participation in order to reduce collected data to information. Most promising of these is a technique which records the relative amplitude of spectral components of electromagnetic radiation emanating from a source, and applies automatic pattern recognition techniques to reduce automatically the data to the desired information.

Automatic processing is essential if full advantage from the enormous data collection capabilities of future space systems is to be realized. Nevertheless, the outstanding capabilities of the human interpreter cannot be matched for small data loads. Programs to develop enhancements, screening, recognition and interpretation aids for the interpreter are currently being conducted at Weslaco, Texas, the University of California, and elsewhere.

Intensive work at Purdue University was initiated when contract NGR-15-005-028, was awarded through the Office of Contracts Administration on January 7, 1966. USDA contract 12-14-100-8307 (20) was awarded on February 18, 1966. Prior to these dates, Dr. J. Ralph Shay and Dr. Roger Hoffer of the Department of Botany and Plant Pathology were responsible for efforts associated with the remote sensing program at Purdue University. These efforts were comprised of providing support to the program under NASA grant Ns G-715 to the University of Michigan, and an effort to do analysis of collected data for the Economic Research Service of USDA. Various persons from the schools of engineering and agriculture assisted Dr. Shay and Dr. Hoffer from time to time in these programs. Dr. Shay and Dr. J. C. Hancock, Head of the School of Electrical Engineering, began to assemble a working group in February of 1966. R. B. MacDonald came to the program on a full time basis as a technical director of the Laboratory for Agricultural Remote Sensing. Professors R. Holmes and D. Landgrebe of Electrical Engineering, and Dr. Hoffer accepted responsibilities as key principal investigators in the remote sensing porgrams at Purdue. These people were responsible for the staffing, planning, and execution of the remote sensing programs instituted earlier at Purdue.

At the time of this writing a minimum amount of data is available for analysis, and only limited analysis has been accomplished for planning purposes. A vast amount of work remains to be done, the results of which will be published in future reports.

Acknowledgements

The work described in this report has been accomplished by the following Purdue faculty, research, and graduate student staff of the Laboratory for Agricultural Remote Sensing at Purdue University:

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We should also like to recognize the following clerical personnel, Carol Roe, Janet Cooley, and Helene Berg.

All photographic work in this publication is accredited to Jack Halsema.

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CHAPTER I
Introduction and Program Background

Genesis of The NASA-USDA Project

The present NASA-USDA project began in two unrelated activities: one at the National Academy of Sciences, the other at NASA Headquarters. In 1961, the NAS-NRC committee on "Aerial Survey Methods in Agriculture" was formed under the chairmanship of Professor J. Ralph Shay. The purpose of this committee was to formulate plans for future research programs which would develop improved methods of applying aerial survey methods to agricultural problems such as land use and crop distribution censuses, crop yield estimation, species identification, disease detection, etc.

By 1963, the committee had formulated a research program and had received Academy approval of it. A part of the program was a simultaneous multispectral crop sensing plan much like the present NASA program. In 1963, the committee became aware that two divisions of NASA Headquarters, Biosciences and Manned Space Sciences, were beginning to formulate sensing experiments related to the committee plan.

The NASA objectives were to develop techniques for sensing the earth, moon, and other planets in order to obtain and analyze biological and geological information. Discussions were carried out between the NAS-NRC committee and the Bioscience and Manned Space Science divisions of NASA Headquarters, with the result that the remote sensing program was formulated and funded to meet the needs of both organizations.

The U. S. Army, through its Electronics Command, had an interest in the same type of data for military reconnaissance, and agreed to support the program by making available aircraft and sensing equipment already at the University of Michigan under Project MICHIGAN. The Purdue University Agricultural Experiment Station agreed to support the program by making available a number of diverse experimental stations adjacent to Purdue University, providing the records kept at each station, and furnishing some manpower and equipment for making the related ground measurements.

In addition, the Economic Research Service of the U. S. Department of Agriculture made a small, separate grant to Purdue University for added data analysis directed toward their needs. This combination of efforts resulted in the 1964 remote sensing program, carried out under NASA grant NS G-715 to the University of Michigan.

Under this program, five flight missions over the Purdue experimental stations were carried out during the growing season. The resulting data were only partially analyzed when funds were exhausted in November 1964. From that time until February 1966, when the present program reported herein commenced, the only data analysis performed was that done through other research programs at the University of Michigan, and a qualitative analysis of this 1964 multispectral data by one biologist at Purdue University. Partial results of this work are given in Section 3 of this report.

Between 1964 and 1966, the University of Michigan research program developed the capability to obtain data from all 18 wavelength bands including the ultraviolet, through the visible and reflective infrared and into the thermal infrared portion of the spectrum (from 0.32 to 14 microns wavelength) on one tape. They are able to receive and record all these data on electromagnetic tape by using only optical-mechanical scanners. This development eliminates the need for handling data through two entirely different systems—cameras and scanners.

This new capability has created many data handling and analysis problems. However, by changing program objectives and by broadening the scope of the overall remote sensing effort, the data processing program for handling such remote multispectral data is currently far ahead of goals originally anticipated for 1966. The original plan was to measure all 1966 multispectral data by taking densitometer readings from film. However, a process is currently being developed to take all of this multispectral data now on analog electromagnetic tapes and handle it directly through computers to obtain calibrated, digital multispectral signatures from crop and soil areas of interest. This is indeed a significant step forward, and will allow more accurate processing of much larger quantities of data.

Program Objectives

The research efforts reported herein are nearing the end of the first 10 months of an estimated three-year program required to reach initial objectives. This research on remote multispectral sensing in agriculture is directed at establishing methods to determine, by remote means, species, identification, state of maturity, disease conditions, soil types, soil moisture conditions and many other crop and soil parameters.

Objectives of this research program are:

- To determine the degree to which selected major crops of the Corn Belt region, such as corn and soybeans, can be differentiated on the basis of multispectral response signatures at various times during the growing season.
- To determine the amount of variation and to identify the major sources of variation in the mutispectral response signatures of selected soil conditions and major crop species of the Corn Belt region at various times during the growing season.
- To determine and prescribe methods for gathering information from the ground that will allow prediction of multispectral response signatures obtained by remote multispectral sensing techniques.

To achieve these objectives, the research at Purdue University involves three interrelated study areas:

(1) Biophysical studies in the laboratory and field, designed to:

- learn more about natural variation in plant and soil reflectance spectra and the factors which influence these variations.

- determine optimum portions of the spectrum for remote sensing.

- determine feasibility of conducting various experiments with remote sensing systems.

(2) Remote multispectral sensing studies, using aircraft flights over selected agricultural areas near Lafayette, Indiana. In 1966 a DC-3, instrumented and flown by the Institute of Science and Technology, University of Michigan was used. This aircraft can obtain simultaneous data on reflectance and emission characteristics of areas flown-over in up to 18 spectral bands between 0.32 and 14 microns wavelength. Such data are recorded electronically on analog tapes, which can then be processed to produce imagery in each of the 18 spectral bands, or processed directly through computers to yield processed data in whatever form specified. Much work remains to be done, however, before this data handling technique becomes operational.

Data from this phase of the program are being used to determine the feasibility of optical-mechanical scanner system surveys to supplement U. S. Department of Agriculture crop reporting survey systems. Specific research objectives are:

- Determine the degree of reliability with which selected major crops of the Corn Belt region, such as corn, soybeans, wheat, oats, and alfalfa, can be differentiated and identified at various times during the growing season.

- Determine the amount of variation and identify the major sources of such variation in the multispectral response patterns of selected soil conditions and major crop species of the Corn Belt region at various times during the growing season.

- Determine the degree of reliability with which the primary surface coverings of the earth, such as vegetation, soil, water and its various forms of snow and ice, can be differentiated and identified at various times during the growing season.

These objectives require that very detailed ground truth information be gathered on all agricultural fields over which the aircraft obtains multispectral data. Examples of ground truth are crop species, variety, date of planting, soil type, and percentage ground cover. Analysis of the ground truth data collection efforts is directed toward determination of exactly what type of data is necessary to support the initial remote sensing research efforts. The University of Michigan personnel use much of the same ground truth and aircraft scanner data in their analysis of such things as atmospheric attenuation in the various portions of the spectrum, the effects of time of day, sun angle, and direction of overflight upon the multispectral response patterns of various crop types.

(3) The third major study area at Purdue University is data handling and pattern recognition techniques. To study the remote sensing and survey system, enormous amounts of data must be processed and analyzed by extremely specialized techniques. Therefore, data handling and pattern recognition problems become a crucial part of a thorough investigation to determine the feasibility and practical applications of the system. Initial efforts in this phase of the research, using multispectral scanner data obtained at different times during the growing season, will be directed toward the following classification tasks, using various pattern recognition techniques:

- Wheat vs oats
- Wheat vs everything else
- Oats vs everything else
- Bare soil vs vegetation vs water
- Percentage ground cover in a given bare soil/vegetated area
- Corn vs soybeans
- Corn vs everything else
- Soybeans vs everything else
- Alfalfa vs everything else

In conjunction with these efforts, studies will be carried out to determine which spectral bands are the most useful for each task.

CHAPTER II

Current and Potential Test Sites in Indiana

Introduction

The Corn Belt is one of the more economically important regions of the United States, and is representative of other agricultural areas throughout the world. Therefore, NASA has much interest in this region as a test site for programs on Remote Sensing in Agriculture. And, they have designated the vicinity of Lafayette, Indiana, as a primary test site.

Because agricultural crop cover and soil conditions continually change throughout the growing season and from one year to the next, due to climatic variation, frequent and detailed information must be gathered on any agricultural test site. In preparation for future satellite flights, a background of data must be collected at various critical times during several growing seasons, over progressively larger and expanded test sites, so that detailed ground truth information will be available at the time of the first satellite over-flight. Such data are also of utmost importance in current remote sensing efforts from aircraft and ground based instrumentation systems.

Current Test Sites in the Purdue Area

There are currently two general types of test areas in the vicinity of Lafayette, Indiana. One group of test sites involves the agricultural experimental farms owned and operated by Purdue University. The other involves farming areas in the agricultural community which do not include experimental crop varieties, and on which there is no experimental control over such things as planting techniques, size of the fields, date of planting, fertilization, and other cultural practices.

Figure 1 shows the locations of the areas near Lafayette in which multispectral remote sensing over-flights were conducted in 1966. Areas A and C have been the primary test site locations. The Purdue Agronomy Farm is located in Area A, and the Purdue Experimental Livestock Farm is located in Area D.

The Purdue Agronomy Farm has been the site of greatest concentration for remote sensing research. This 480 acre farm contains many of the major field crops of the midwest. These crops include corn, alfalfa, wheat, oats, soybeans, grasses and legumes, as well as limited amounts of sorghum, kenaf, sunflower and safflower which are important in other parts of the world.

The Agronomy Farm has experimental plots on both forest and prairie derived soils, Plate 1 shows the variation in soil types found on the farm. Fundamental studies of crop production, soil fertility, plant breeding, weed control, and plant pathology on different plots provide an area well suited for remote sensing studies, particularly the ground based phases of this research, using the interferometers de-

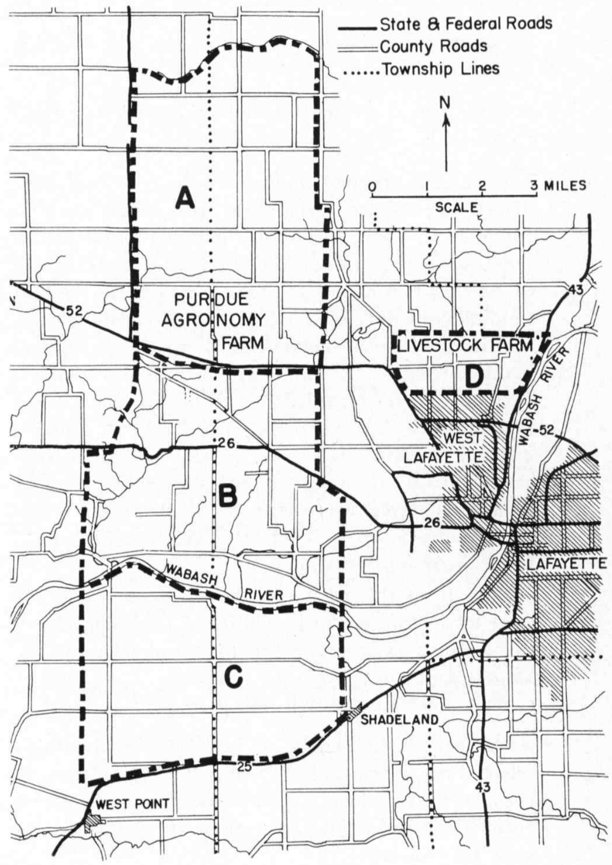


Fig. 1. A portion of Tippecanoe County, Indiana, showing the locations of the 1966 test site areas.

scribed in Chapter 4. An aerial photo of the farm (Figure 2) shows areas of bulk planted crops of various species, as well as smaller plots used for many types of agricultural experiments (See Also Plate 16).

Ground truth data have been obtained on all bulk planted areas, as well as selected smaller experimental plots. The specific measurements and ground truth information obtained include such things as crop species and variety, date of planting, row spacing, fertilization rates, tillage practices, plant height, and an estimate of percentage ground cover at various dates throughout the growing season.

More than 500 feeder cattle, 3,000 hogs, and 300 sheep are kept on the 483 acre Livestock Farm (located in flight Area D on Figure 1). The Livestock Farm is being used in this project to investigate the possibilities of counting animals with thermal infrared scanning techniques. This research is of interest to the Indiana Department of Na-

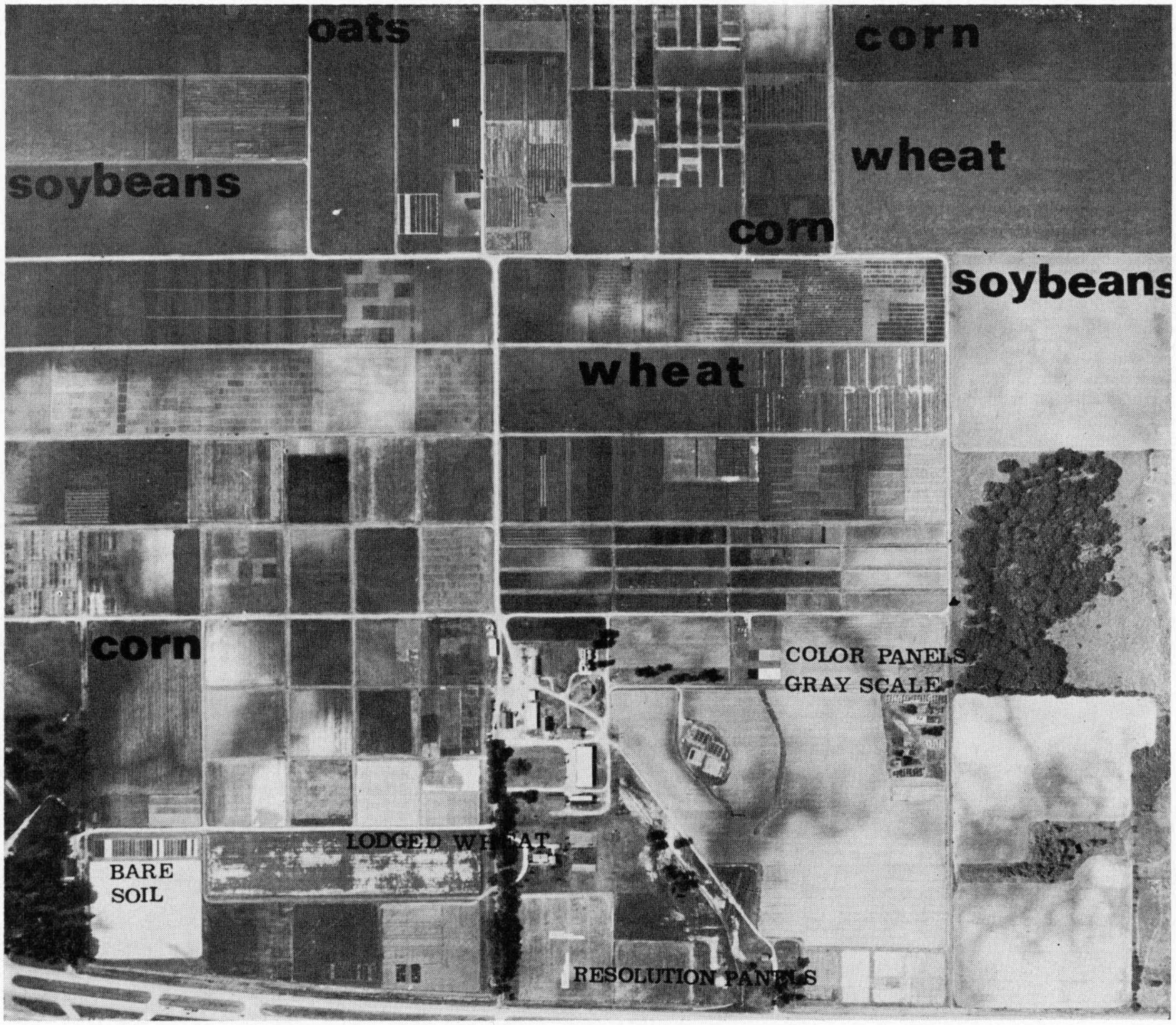


Fig. 2. Aerial photograph of the Purdue Agronomy Farm, taken on June 30, 1966, showing major crop differences as well as color and gray scale panels used for calibration purposes.

tural Resources, who would like to develop improved methods of making deer censuses. They have provided a man to assist with the field work during the 1966 remote sensing flight.

Flight Area A includes the Agronomy Farm and an area north of the farm. The soils in Area A are developed in a parent material of glacial till of the Wisconsin age with a flat till moraine topography. There are a number of different soil types, thus producing much variation in soil color and soil moisture conditions, even within individual fields. A majority of the soils were developed under grassland influence, producing very fertile soils which are intensively farmed. Plate 2 shows an oblique photo of the Agronomy Farm and Area A. The linear array of large fields of various crop types seen in the upper right portion of the photo allows ease in processing the multispectral data obtained along such flight paths.

Area B is located in the general area south of the Agronomy Farm and north of the Wabash River. The soils have the same glacial origin as Area A, but the topography is much more rolling and dissected, properly described as ridge moraine. The developing vegetation was a forest cover. Farming is not as intense and field patterns are very irregular, with many large intermittent woodlots present. Experimental use of this area for remote multispectral sensing has not been as great as in Areas A and C.

Area C, located south of Areas A and B, is separated from Area B by the Wabash River. The soils are derived from outwash materials from the melt waters of the Wisconsin glacier. The soil types are therefore generally more uniform than is the case in Areas A and B. The topography is level to gently undulating, with grass being the original vegetation. Farming practices revolve around very intense grain and hay crops, as well as varying sizes of livestock

Table 1. Acreage figures for the major crops in Tippecanoe County showing trend of acreage shifts (11).

	5 Year Average 1959-1963		1964		1965	
Crop Type	Acreage	Percentage of Total	Acreage	Percentage of Total	Acreage	Percentage of Total
Corn for Grain	91,100	49.6%	91,200	49.2%	93,100	51.1%
Soybeans for Beans	47,200	25.7%	51,400	27.7%	52,200	28.6%
Wheat	21,500	11.7%	23,800	12.9%	18,400	10.1%
All Hay	13,400	7.3%	13,400	7.2%	13,400	7.4%
Oats	10,400	5.7%	5,600	3.0%	5,100	2.8%

enterprises. Table 1 indicates the acreage of the major crop types in Tippecanoe County for the last few years, as well as percentages of the total acreage for the various crop types. This serves to indicate the crop types of major importance in this area.

Plates 3 and 4 are aerial oblique photos of Area C at different times during the growing season showing general crop conditions and field patterns.

Purdue University Sand Farm

The Sand Experimental Farm comprises 40 acres near Culver, Indiana. The soils in this area are uniform sands to loamy sand textures derived from outwash materials deposited by slowly moving melt waters from the Wisconsin Glacier. The topography is level to gently undulating, with occasional sand dunes caused by wind action. The developing vegetation was forest cover. There are two major soil types on the farm.

Since a knowledge of the available soil moisture is important in predicting possible yields during the growing season, research is being conducted to determine the potential use of remote sensing techniques for predicting available soil moisture. Experimental plots were established at the Sand Farm specifically for the remote multispectral sensing program in 1966. These plots include areas of bare soil, soybeans, sorghum, sudangrass, alfalfa and corn. The plots were divided, and half of each plot received supplemental water by sprinkler irrigation during the growing season. The other half received no additional water. Corn was established in two plots, with one plot planted on May 6 and the other on May 18, 1966. This presented an opportunity to study the effect of date of planting and moisture relationships. The configuration of these experimental plots is shown in Figure 3. Plate 5 shows an aerial view of the Sand Farm. A discussion of the ground truth measurements obtained in these experimental plots is given in Chapter 4.

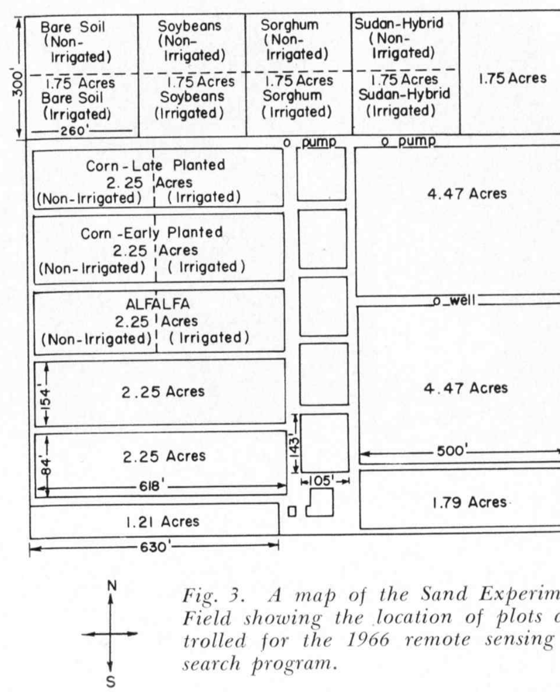


Fig. 3. A map of the Sand Experiment Field showing the location of plots controlled for the 1966 remote sensing research program.

Future Experimental Sites in Indiana

As feasibility investigations concerning the usefulness of remote multispectral sensing continue, preliminary testing will be needed in other geographic locations having different crop and soil conditions. Thus far, work has been carried out only in the vicinity of Lafayette and at the Sand Farm near Culver, Indiana. Average annual temperatures

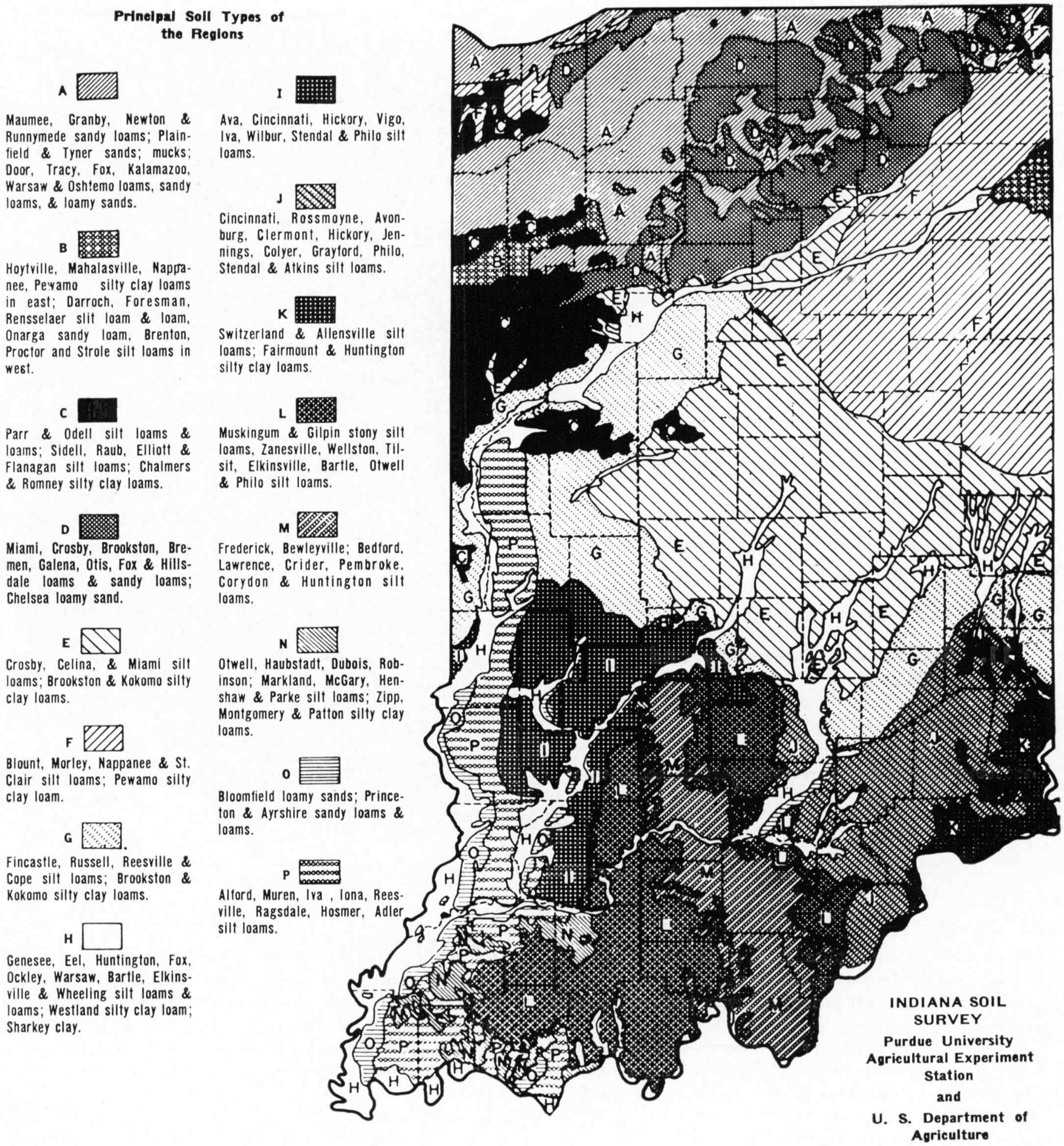


Fig. 4. The general soil regions of Indiana. The major soil types in each soil region are shown on the legend (1).

alone vary 10°F from the southern to the northern part of the state of Indiana. Soils vary even more greatly, with parent materials ranging from glacial till to sandstone, and shale to windblown loess. Figure 4 shows the general soil regions in Indiana. It is noteworthy that the Soil Conservation Service of the U.S. Department of Agriculture has identified and written detailed descriptions of more than 650 different soil types in Indiana. The SCS is currently mapping these soils on aerial photographs in all areas of the state. Preliminary investigations have indicated that remote sensing has possibilities for differentiating between soil types, and delineating and locating soil type boundaries.

1. **Northwest Dairy**
2. **Kankakee Grain and Pasture**
3. **Northeastern Dairy and General**
4. **Western Cash Grain**

5a. **Central Grain and Livestock**

5b. **West Central Grain and Livestock**

6. **Northeastern General**
7. **Southwestern Corn, Wheat and Truck**
8. **South Central General**
9. **Southeastern Central Corn, Wheat and Hogs**
10. **Southeastern General**
11. **Southeastern Dairy, Hay, and Tobacco**

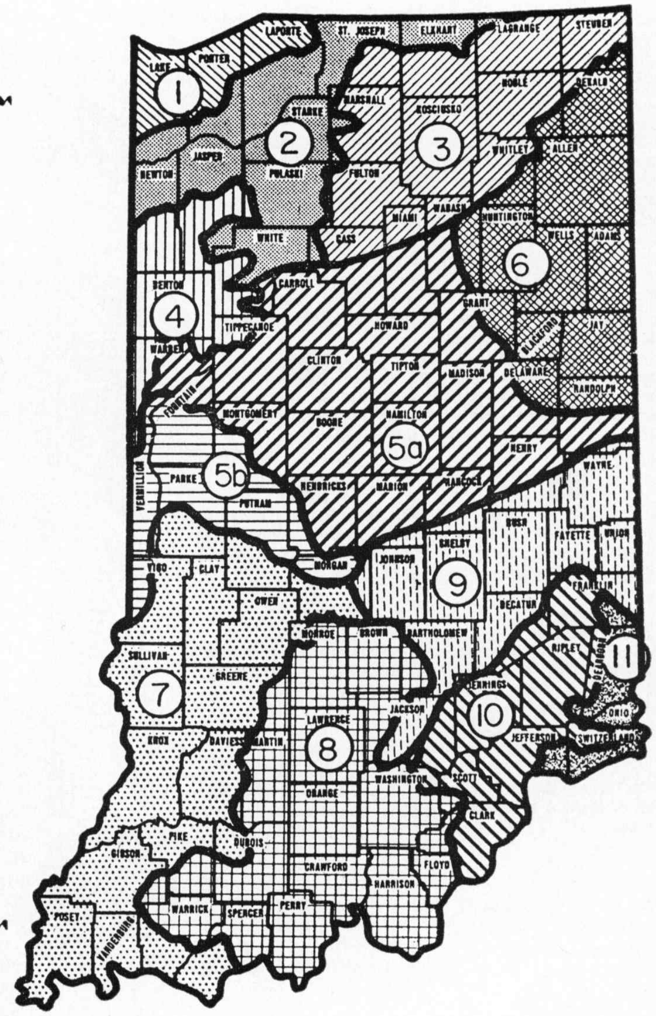


Fig. 5. A map of the general types of farming in Indiana (21).

Further study of this application of remote sensing, as well as soil moisture determinations, is needed, using different geographical areas with various soil types and soil moisture conditions.

Another significant factor in remote sensing research involves the variation in the types of farming across the state. Figure 5 maps the general farming regions in Indiana. These types of farming are representative of the various types found in the midwestern states.

There are a number of additional Purdue Agricultural Experiment Station Farms located in different regions of Indiana, which will be generally available as future detailed test sites. The locations of most of these other experimental farms, as well as the Sand, Livestock and Agronomy Farms, are shown in Figure 6. Programs at these sites would allow investigations of climatological effects, and the effects of different soils on the reflected and emitted radiation from major crop and soil types. The following paragraphs briefly describe the farms, and their current primary research emphasis.

Pinney-Purdue Farm is a 417 acre farm in LaPorte and Porter Counties. Experimental work consisting of variety, cultural and fertility trials is conducted on small grains, soybeans and corn. A livestock herd of 200 red polled cattle is maintained for feeding trials. There are two weather stations on the farm.

The Miller-Purdue Memorial Farm is situated in Grant County with approximately 700 acres available for research activities. In addition to 165 acres of woodland and 200 acres of corn, there are various grazing trials conducted on many important grass and legume species (See Plate 17).

Located on 623 acres in Randolph County is the Herbert Davis Forestry Farm. Purdue's Forestry Department has mapped 125 acres of virgin timber on this farm. Field experiments consist of variety and fertility trials on small grain, soybeans and corn. A large tile drainage experiment is conducted here to study better ways of draining wet lands. A weather station is also maintained at this farm.

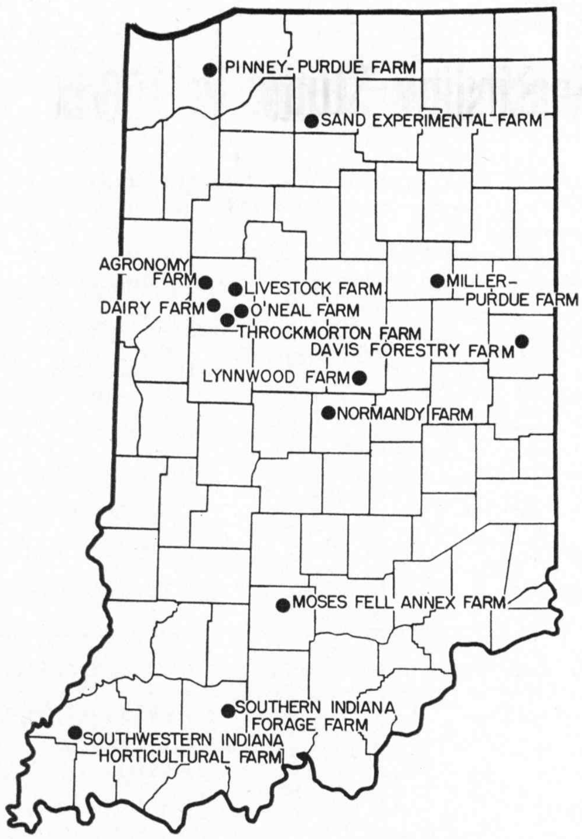


Fig. 6. Locations of the Purdue University Experimental Farms in Indiana. The Agronomy, Livestock and Sand Experimental Farms were the location of the 1966 remote sensing research.

The Lynnwood Farm (623 acres) in Hamilton County and the Normandy Farm (600 acres) in Marion County provide an opportunity for both livestock and cropping experiments. Research with high levels of fertilizer on forage grasses and legumes are conducted on both farms.

The 740 acre Moses Fell Annex Farm is in Lawrence County. Pasture renovation and fertilizer studies are important research activities here. Woodlands cover 175 acres, with an additional 20 acres in orchard. A weather station is located on the farm.

The Southern Indiana Forage Farm is located on 1,016 acres in Dubois County. Research on establishment, production and utilization of forages is conducted. Both dairy and beef herds are utilized in the overall research program.

Horticultural studies are conducted at the 524 acre O'Neal Farm near Lafayette and at the 79 acre Southwestern Indiana Horticultural Farm in Gibson County. Both fruit tree and vegetable studies are conducted on each farm.

The Purdue Dairy Center Farm covers 451 acres near the Lafayette Campus. More than 200 head of cattle representing five major breeds are found on this farm. Grazing and silage feeding research for increased milk production is conducted on this farm.

The 296 acre Throckmorton Farm is also near Lafayette, and is the primary site for research in land use and moisture conservation. Besides 150 head of cattle, more than 1,000 head of hogs are incorporated into the research program.

These Experimental Station farms are located in different soil, climate and farming regions of the state. At these farms controlled conditions, not found in the agricultural community, provide many advantages to remote sensing research. Past climatological records, as well as field cropping histories and records, are available to aid in interpretation of multispectral data.

CHAPTER III
Preliminary Feasibility Study in 1964

Data Generated

Remote Multispectral Data: The program resulting from NASA grant Ns G-715 to the University of Michigan involved five flight missions at intervals throughout the 1964 growing season. These missions were flown over agricultural test sites in the vicinity of Purdue University, Lafayette, Indiana, and each mission included approximately six individual flights distributed throughout the 24-hour day—before dawn, early morning, midday, late afternoon, after sundown, and near midnight. The first mission, June 2-4, 1964, was conducted when alfalfa, wheat, oats and other cereal crops were nearing full growth and maturity. Most other crops were only emerging, and bare, tilled soil was predominant. Mission II, June 24-25, found the winter wheat ripening, the oats mature but not ripe and other crops, primarily corn and soybeans, still in the early stages of growth, with a considerable amount of soil exposed between the rows. By the time of the third mission, July 28-30, the cereal grains had been harvested, corn was starting to tassel, and soybeans had nearly reached full growth. The August 26-27 mission was conducted while corn and soybeans were maturing, and alfalfa or weeds covered the fields of stubble that had not already been plowed in preparation for fall planting. The last mission, September 29 through October 1, 1964, found most corn quite mature and in the process of being harvested, soybeans in various conditions of maturity and harvest, and only alfalfa, sudangrass, some pasture areas, and a few late-maturing varieties of soybeans in a state of green vegetative growth.

Using a combination of K-17 and P-2 cameras, as well as a 9-lens camera and two optical-mechanical scanners, data were obtained in 18 discrete spectral bands, as well as on color and camouflage detection film. The wave-length bands, detectors and film used are shown in Table 2.

From the multispectral data collected, the University of Michigan selected 56 fields representing various crop types, bare soil, and other non-vegetative materials, on which densitometer readings were made on all film obtained. Use of a 9-Lens and other cameras and the capability to reproduce optical mechanical scanner data onto film allowed all data to be reduced to a film format. Five densitometer readings were made on each of the 56 target areas and in all wavelength bands. These data were then normalized to adjust for differences in camera and scanner settings. The University of Michigan carried out several data processing and interpretation programs which have been reported by Miller, 1965. (17)

Leaf Reflectance Data: As part of the support program carried out by Purdue University, reflectance measurements were obtained on plant leaves, using a trailer-mounted Beckman DK-2A spectroreflectometer borrowed from the University of Michigan. Measurements were made on 172 plant samples during the period from September 15 to October 15, 1964, using the spectral range from 0.26μ in the ultraviolet to 2.6μ in the infrared. This range was divided into the following three segments, based upon the energy source and the detector sensitivity:

Wavelength	Energy Source	Detector
0.26-0.36μ	Helium Lamp	Photomultiplier
0.35-0.75μ	Tungsten Lamp	Photomultiplier
0.5-2.6μ	Tungsten Lamp	Lead Sulfide Cell

Table 2. A summary of the wavelength bands and indictated detector and instrument used in the 1964 program

Wavelength Band	Detector	Instrument
microns		
0.32-0.38	Filtered Photomultiplier	Optical-Mechanical Scanner
0.38-0.44	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.41-0.47	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.45-0.52	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.48-0.56	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.55-0.64	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.62-0.68	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.71-0.79	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.85-0.89	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.38-0.89	Filtered Kodak I-N Spectroscopic Film	U-M 9-Lens Camera
0.4-0.7	Kodak Super XX Aerographic Film and Wratten K2* Filter	K-17 Camera (9″ Format)
0.7-0.9	Kodak Infrared Aerographic Film and Wratten 89-B Filter	K-17 Camera (9″ Format)
1.5-1.7	Filtered Indium Antinimide (InSb)	Optical-Mechanical Scanner
2.0-2.6	Filtered Indium Antinimide (InSb)	Optical-Mechanical Scanner
3.0-4.1	Filtered Indium Antinimide (InSb)	Optical-Mechanical Scanner
4.5-5.5	Filtered Indium Antinimide (InSb)	Optical-Mechanical Scanner
1.5-5.5	Unfiltered Indium Antinimide (InSb)	Optical-Mechanical Scanner
8.2-14.0	Filtered Mercury-doped Germanium (Hg: Ge)	Optical-Mechanical Scanner
Color (0.4-0.7)	Anscochrome D 200 Color Film and Color Correction Filter	P-2 Camera (70mm Format)
Infrared Color (0.4-0.9)	Kodak Ektachrome Infrared Aero Film (or Camouflage Detection Film) and Wratten 12 Filter and Special Infrared Color Filter	P-2 Camera (70mm Format)

Materials sampled included corn, soybeans, sorghum, alfalfa, clover, birdsfoot trefoil, bromegrass, timothy, orchardgrass, tall fescue, reedcanary grass and a variety of fruit tree leaves and bark. Of the 172 specimens measured, 103 were leaves of corn, soybeans, sorghum and alfalfa. Corn leaves accounted for 59 of this number. Limits on the maturity of samples and the number of species sampled were defined by the date when the equipment became available, September 15, 1964, and by frost on October 15, which ended the growing season.

Qualitative Analysis of Multispectral Imagery

Photographic prints of all aerial photos and scanner data obtained in 1964 were sent to Purdue University, where a qualitative analysis was carried out under the Purdue University grant from the Economic Research Service. The primary emphasis of this analysis was (1) to determine the type of ground truth data needed in support of remote sensing flights, (2) to determine the feasibility of remote multispectral sensing to differentiate various crop species, and (3) to identify causes of variations in response within a given crop species on multispectral imagery.

Analysis of many pieces of multispectral imagery in many wavelength bands has indicated a high probability of success in being able to differentiate, identify, survey and map such objects as water, vegetation, and bare soil at various times during the year. Also, the capability to differentiate and identify such crop species as wheat and oats, corn and soybeans under certain conditions of crop maturity appears to exist. These conditions occur at specific times of the growing season, depending upon the crop species of interest.

It also appears that a remote multispectral system capable of obtaining imagery when and where desired could aid in soil type mapping, particularly in the determination of soil type boundaries. The usefulness of a remote sensing system for actual determination of a specific soil type appears limited. Dramatic, predictable spectral differences between wet and dry soils and between light and dark-colored (surface color) soils have been found, and additional work on these phenomena is believed to be worthwhile. The statistical reliability of such capabilities as these has yet to be established, however, and further detailed feasibility studies need to be performed before the reliability of remotely sensed data can be determined.

The key to a remote sensing system for crop identification appears to lie in obtaining multispectral data at the proper periods of crop development, and at intervals throughout the growing season. For example, the flight on June 25, 1964, proved very useful for differentiating oats and wheat, but did not allow good differentiation of corn and soybeans. The August 27, 1964, flight proved useful for the latter crop types, but wheat and oats were already harvested. Thus it would appear that no single flight during the growing season will suffice for identification of all crop types of interest.

A further criterion for success in remote multispectral sensing efforts for purposes of crop identification is adequate background and current knowledge of general agricultural conditions in all geographical areas of interest.

There is also much variation in tonal response on multispectral imagery within a given crop species. These differences in response are more marked at certain periods during the growing season and more distinct in some wavelength bands than in others. The primary crop variables within a species appear to be (1) variety, (2) relative maturity at any given date throughout the growing season (as influenced by planting date, soil and the variety), (3) geometry of the crop, involving several factors such as plant height and growth characteristics, population density and planting configuration, lodging, and other crop characteristics, (4) cultural practices, such as tilling of the soil, irrigation, certain fertilization and spray treatments, and harvesting, and (5) soil type and associated characteristics, such as color, texture and moisture content of the surface soil. Numerous variables associated with the taking and developing of the pictures and imagery also have been found to affect tonal response. Some of these variables are (1) past and present weather conditions at the time the photos were taken, (2) time of day, (3) photograph angle, and (4) instrumentation variables, such as film exposure and development, scanner gain setting, lens characteristics and other associated factors.

These variations in tonal response indicate a need to study carefully and thoroughly the causes of such variation, and then to correct instrumentation variables where possible. Placing certain restrictions on multispectral imagery to be obtained would allow one to either eliminate or account for many other variables. Such restrictions might include weather conditions, time of day, and date of flight for various geographical locations. Secondly, the amount of variation in response must be studied in detail by using multispectral data from many crop species. Large quantities of data are necessary to determine the statistical spread of such variation, and how this variation affects the probability of correct classification of multispectral response data.

Analysis of the 1964 multispectral imagery has also shown that in many instances the *detection* of various phenomena can be done with a single wavelength band of imagery, but *identification* of that feature can be achieved only through the use of multispectral imagery. An area of wet, bare soil, surrounded by a lighter toned area of dry soil, would be a good example of this statement. A single wavelength band of imagery in the visible or reflective infrared portion of the spectrum would show the wet soil as an area of darker tone or lower response. Such an area of low response could be interpreted as either a different surface soil color or as an area of wetter soil. However, through comparative analysis using both a reflective wavelength band of imagery *and* a thermal infrared band, one could determine that the area of low response was not dry, darker-colored soil, but was indeed an area of higher soil moisture.

Interpretation of the 1964 remote multispectral imagery has emphasized the need for a system to obtain properly calibrated quantitative data. There is also an absolute necessity for automatic processing and analysis of these data before definitive, statistically reliable results can be obtained. There are far too many wavelengths of imagery, dates of imagery flights, crops and all of the variables inherent within each crop, as well as other variables to be considered to allow successful evaluation of multispectral imagery except through the use of quantitative, automated data handling procedures.

A complete discussion of these conclusions and the data analysis program from which they result (which was carried out under the Economic Research Service grant) is included in Research Bulletin 831, "Interpretation of Remote Multispectral Imagery of Agricultural Crops." Much data used in the following pages has been abstracted from this report, and is presented here to show some of the potentials and problems to be faced in a program of remote multispectral sensing in agriculture.

Figure 7 helps to illustrate the value of sensing the same group of objects or, as in this case, agricultural crops or fields, simultaneously and in several spectral bands. This figure demonstrates the usefulness of *multispectral* sensing, in that each of the special bands of imagery exhibits a different combination of tonal patterns among the fields imaged. It is only through quantitative analysis of all wavelength bands, using carefully calibrated scanner systems, that the individual crop types may be differentiated and perhaps identified. In other words, a statistically reliable pattern recognition capability must be obtained in order to properly classify individual crop types or species.

The use of existing remote multispectral sensing capabilities for the differentiation and identification of agricultural crops depends upon the multi-dimensional analysis of data obtained simultaneously in several spectral bands, using instruments that have limited resolution capabilities at high altitudes. Thus, remote multispectral sensing requires rather unique and highly specialized methods and equipment for proper data handling and analysis. These methods and equipment will be discussed in more detail in Chapter 5 of this report. The following pages based upon a previous paper (9) will help to explain some of the unique features of multispectral data.

Aerial photo interpretation is normally based upon principles of size, shape, pattern, shadow, tone, texture, and association. (16, 19) In remote mutispectral sensing of agricultural crops from high altitudes, many of these principles of photo interpretation no longer apply.

Plate 23 is a photograph of the Salton Sea area in California, taken from Gemini V at an altitude of about 110 nautical miles. (This particular photo has been enlarged from the original photograph). This photograph demonstrates that one obtains no indication of the crop type or condition from size, shape or pattern of agricultural fields. As seen here, shadow and texture become less important with increased altitude and decreased resolution, although texture is still an extremely important factor in radar returns. Association is useful only in a gross geographic sense.

Tone, which varies with wavelength in multispectral imagery, depends upon the spectral reflectance of the object viewed, is, therefore, the primary factor for image interpretation in the remote multispectral sensing research in agriculture. Tone has been defined as "each distinguishable shade variation from black to white." (16) Tone has been a term frequently used in connection with photo interpretation. It represents the relative intensity of photons impinging upon a silver halide plate, in the visible or near-visible portions of the spectrum, as reflected from the objects viewed by the camera.

In remote multispectral sensing one is not confined to the photographic portion of the electromagnetic spectrum. Various types of detectors can be used to sense reflected or emitted energy in the 0.3 to 14μ portion of the spectrum. Radar senses from 0.86 to 3.0 cm wavelengths, and other portions of the spectrum can be viewed with other types of sensors.

Since certain of these sensors do not involve reflected energy, nor do they necessarily produce data in the form of photographic images, reference to "tone" is sometimes misleading. Therefore the term "response" is used in this report to refer to the relative energy received by the sensor, and may or may not be represented by an image. Response is, therefore, a meaningful term whether referring to reflected energy in the 0.3 to about 3μ wavelength portion of the spectrum, or emitted energy in the 3 to 14μ region, or some other portion of the spectrum. Thus, an area that reflects strongly in the visible portion of the spectrum has a high response. An area that is emitting a large amount of energy in the 8 to 14μ region of the spectrum, relative to other objects being sensed, would also have a high response, and an object which has a relatively low reflection or emission would have a low response. In Plate 23, the white area in the lower left portion of the photo would be considered to have a high response.

One phase of the research program at Purdue University involves the identification of crop species and the conditions of health and maturity for several economically important crop types in the Corn Belt region, using multispectral sensors in up to 18 spectral bands. Comparisons of the bands may allow a characteristic multispectral response signature to be determined for each crop type or crop condition studies.

A number of examples have demonstrated the usefulness of multispectral or multiband imagery in differentiating various crop species and conditions. (2, 15, 8) In some instances, these examples have involved crop types or conditions which are quite different, such as mature, golden-brown wheat compared to green oats. Such a difference in the condition of maturity between two species represents an important factor when attempting to differentiate and/or identify a particular crop type, providing that such a difference is characteristic of that crop species at that particular time during the growing season. Figure 8 demonstrates this point. This shows imagery obtained on September 30, 1964, in the 0.4 to 0.7μ and 0.7 to 0.9μ wavelength bands, and also shows an artist's concept in pictorial form of the relative response of these same areas as measured with a filtered radiometer, operating in the 4.5 to 5.5μ wavelength band. (9) Figure 8 is a striking example of the marked differences in response that may be found between various cover types within a given wave-

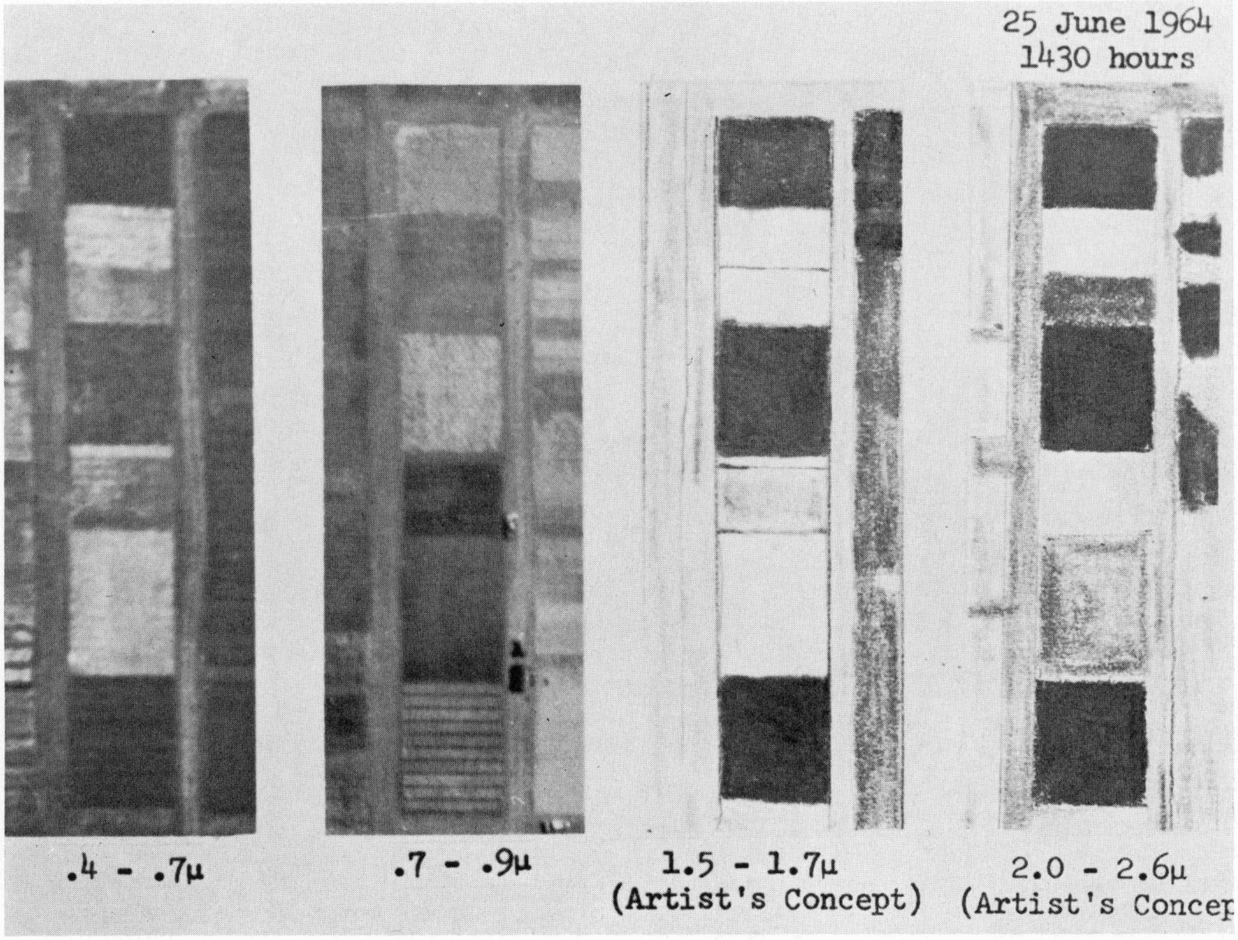


Fig. 7. A multispectral response comparison of different crop types using four wavelength bands of imagery.

length band. Abrupt changes in response for a given crop type, such as alfalfa, are also evident as the different wavelength bands of imagery are compared. As of the date this particular imagery was obtained, the alfalfa had a dense, green vegetative canopy and thus produced a very high response in the 0.7-0.9μ (reflective infrared) wavelength image. This high response is caused by the characteristic high reflectance of healthy vegetation in this portion of the electromagnetic spectrum. The low response of the alfalfa in the 0.4-0.7μ (visible wavelength) band is caused by the green color which is relatively dark as compared to the other cover types viewed, whereas the equally low response in the 4.5-5.5μ (thermal infrared) band is due to cooling effect of the evapotranspiration in the alfalfa—a situation not equaled in the other cover types as of this date. The corn, being dry, brown, and mature at this time of the year, has a response similar to that of the wheat stubble in all three wavelength bands of imagery illustrated. As would be expected, the bare soil has a very high response in the thermal infrared wavelength band, rather low response in the reflective infrared region, and a varied response in the visible wavelengths (the lighter soil being a silt loam and the darker soil being a silty clay loam). Relative responses within each individual wavelength band demonstrated in this example are found in Table 3.

Work so far indicates the potential to differentiate bare soil from vegetation. Such a capability in an operational remote sensing system could significantly supplement the present "Intention to Plant" survey conducted by the Crop Reporting Service of the U. S. Department of Agriculture. This is an annual survey to determine how many acres farmers intend to plant to various crop species. Considering the Corn Belt region of the United States, a remote sensing system capable of identifying bare soil fields and

Table 3. The relative response measured by a densitometer of three different crop covers and two soil types on three different wavelength bands

Item	Wave length bands		
	0.4-0.7μ	0.7-0.9μ	4.5-5.5μ
Corn	75	61	68
Alfalfa	69	72	17
Bare soil, silt loam (Light colored)	87	56	
Bare soil, silty clay loam (dark colored)	70	51	92 (average both types)
Stubble	75	65	not measured

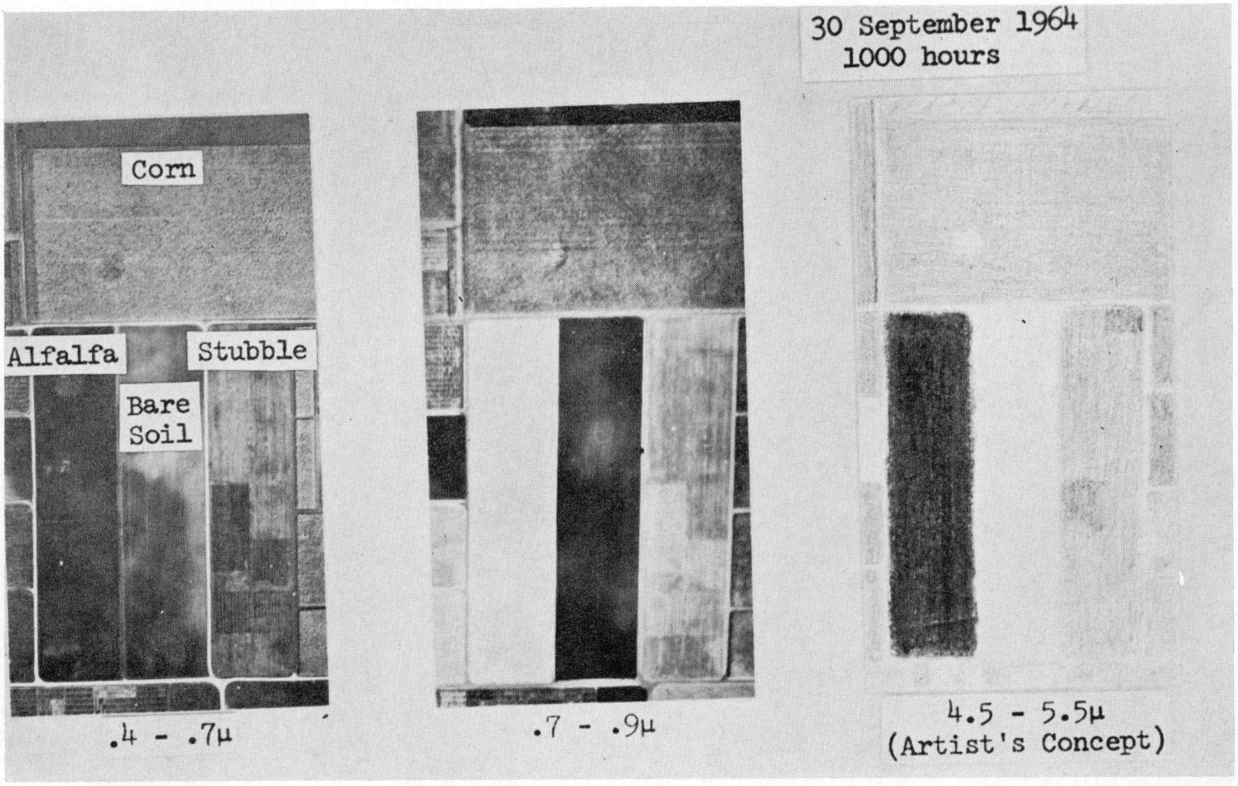


Fig. 8. Multispectral response of corn, alfalfa, stubble, and bare soil on three wavelength bands (September 30, 1964).

determining acreage of such areas could be used in the mid- to late-summer season. The data obtained on bare soil acreage at this time of the year would indicate the probable acreage of winter grain the following year. In similar fashion an early May remote sensing survey which could differentiate areas of bare soil from all vegetated croplands (which would include pasture land, wheat, oats, alfalfa, and other forage areas) would serve to indicate probable areas to be planted to corn or soybeans during the upcoming growing season.

To further illustrate the potential for multispectral differentiation and identification of various crop species or cover types, the following examples are presented:

Figure 9 shows six wavelength bands of imagery obtained from a 9-lens camera and, as observed in Figure 8, distinct differences in response are observed between bare soil, stubble, and healthy, green vegetation (in this case, corn and soybeans), particularly in the reflective infrared wavelength (0.71-0.79μ and 0.85-0.89μ). Note that in many individual wavelength bands, it is virtually impossible to distinguish between two or more of the cover types viewed. It is only through a program of judicious selection of a particular wavelength band to accomplish a specific objective, or through simultaneous comparisons among several wavelength bands, that one can determine differences between various cover types of interest.

The graph in Figure 10 shows qualitative comparisons of several fields of corn and soybeans in thirteen spectral bands. As was seen in Figure 9, there is little if any difference in response between these two crop species as of this date in the 0.38-0.44μ, 0.41-0.47μ, and 0.55-0.64μ wavelength bands, and only a slight difference in the 0.48-0.56μ, 0.71-0.79μ, and 0.85-0.89μ wavelength bands. The primary differences in response are found in the spectral bands between 1.5 and 4.1μ wavelength, which is beyond the photographic portion of the spectrum. This indicates that remote sensing systems operating in wavelengths beyond photographic film capability will sometimes yield information otherwise not available.

As a note of interest, the bare soil in Figure 9 as of July 29, 1964, was planted to winter wheat for the 1965 growing season, which tends to substantiate the previous comments concerning probable future use for fields which are bare soil in mid-summer in the Corn Belt.

Figure 11 graphically compares a light-colored Raub Silt Loam (similar to the far left portion of the bare soil area seen in Figure 9) and soybeans. As in Figures 8 and 9, this graph demonstrates a capability for differentiating bare soil from vegetation, and the previous comments concerning the usefulness of such a capability also apply to this example.

A multispectral response comparison of wheat, oats, alfalfa and bare soil as of June 25, 1964, is illustrated in Figure 12. Although showing only a single field of each crop type, the reversal in relative response between wheat and oats in the 0.62-0.68μ and 0.71-0.79μ wavelength bands was quite typical for imagery obtained during this portion

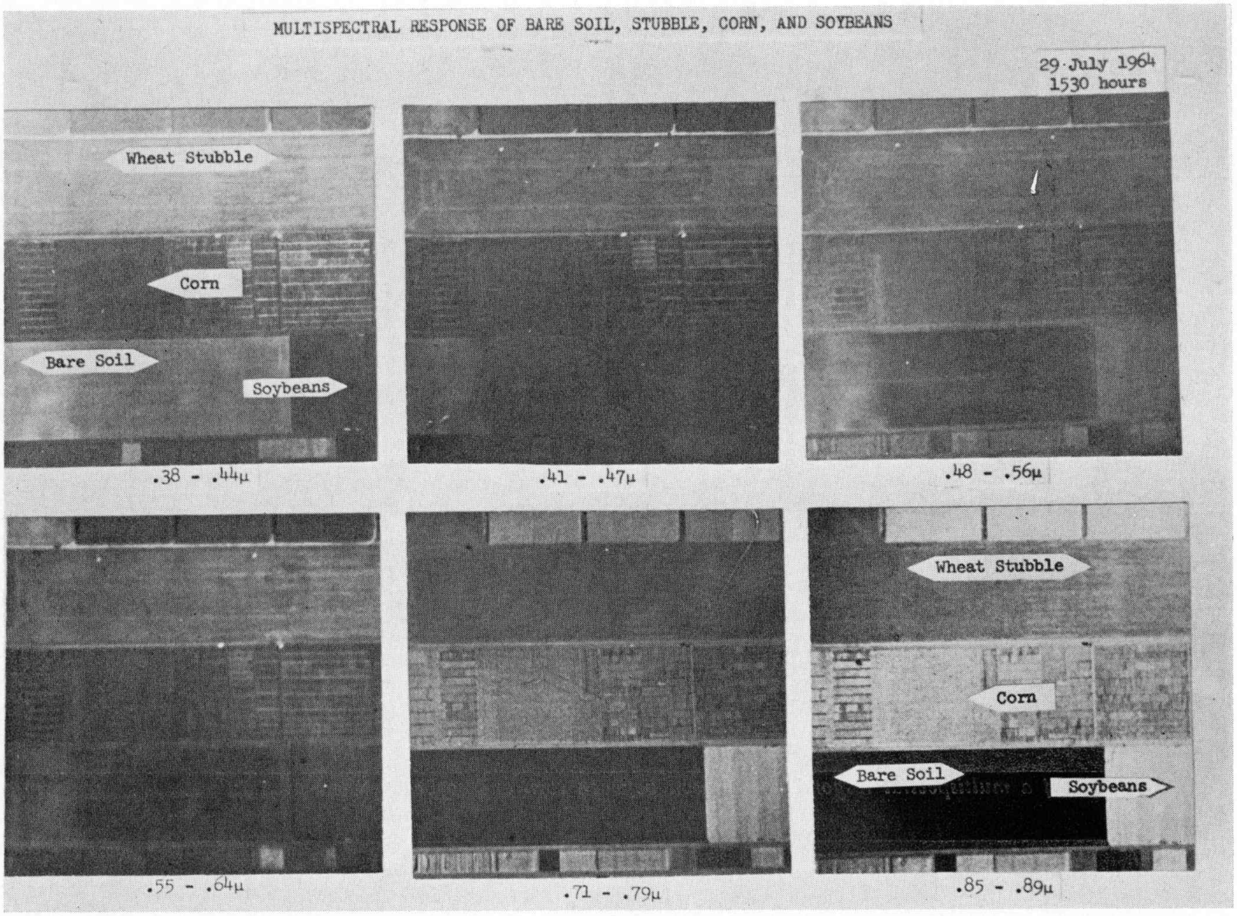


Fig. 9. The comparative response between bare soil, corn, soybeans, and wheat stubble on six wavelength bands of photographic imagery (July 29, 1964).

of the growing season. The reason is that the wheat, which has started to mature, is yellow-brown in color and therefore lighter in tone than the green colored oats in the 0.62-0.68μ (red portion of the visible spectrum) image, but this difference in maturity between these two crop species causes the oats to reflect much more than the wheat in the 0.71-0.79μ (photographic infrared) wavelength band. Note the lack of difference in response in the 0.38-0.44μ wavelength band.

The field of alfalfa in this illustration was not harvested when the imagery was obtained and therefore responded similarly to the oats, although the alfalfa has a slightly higher response in the 0.71-0.79μ wavelength band image. Some alfalfa fields had been cut as of June 25, 1964, and these responded similarly to the wheat field shown. This demonstrates the difficulty of characterizing some crop types during certain portions of the growing season.

The bare soil area is distinct in the visible wavelength bands in this set of imagery, but has a response similar to that of the oats and some of the other crop areas in the infrared photo (0.71-0.79μ). This is a situation opposite to that observed in Figures 8 and 9, where the bare soil appeared much darker than the crop areas. A difference in soil type explains these contrasting situations. These soil types respond quite differently (in relation to vegetation) in the various portions of the spectrum, particularly the photographic infrared. This factor points up the difficulty of using one or two wavelength bands to reliably identify the cover type, particularly under natural situations where wide fluctuations in relative response may occur. Using several wavelength bands allows much more reliability. Even with wide differences in response from a particular cover type (such as bare soil) proper multispectral analysis will allow a correct identification. Another reason for the difference in relative response of bare soil is the different photographic exposure used at different times during the growing season to always obtain maximum contrast. This points up the need for accurate calibration of sensor systems so that such changes can be accounted for accurately and correctly.

A comparison between a single field each of wheat and oats, using three wavelength bands of imagery, is shown in Figure 13. This clearly illustrates the distinct reversal in response found between oats and wheat fields in nearly all of the June 25, 1964, imagery when comparing visible and photographic infrared wavelength imagery. The ripening

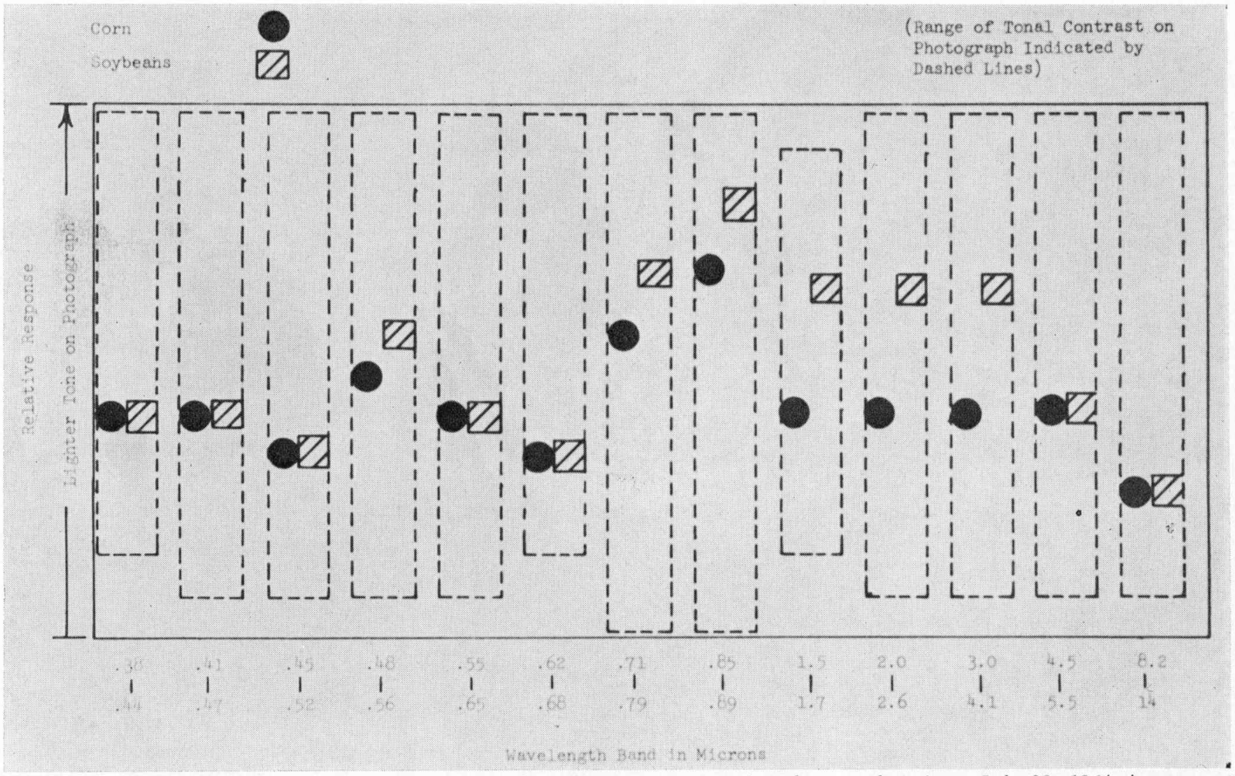


Fig. 10. Graph of a multispectral response comparison between corn and soybeans taken from July 29, 1964, imagery at 1315 hours.

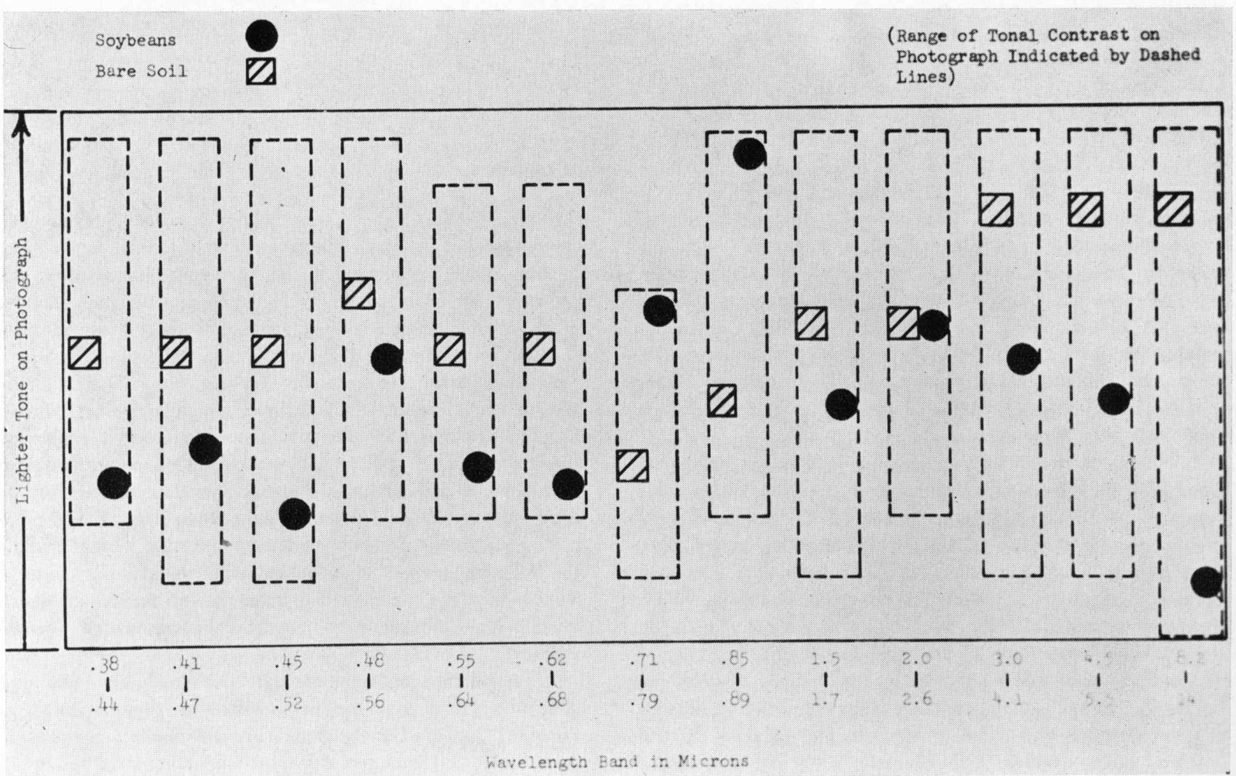


Fig. 11. Graph of a multispectral response comparison between bare soil and soybeans, deduced from imagery obtained at 1530 hours on July 29, 1964.

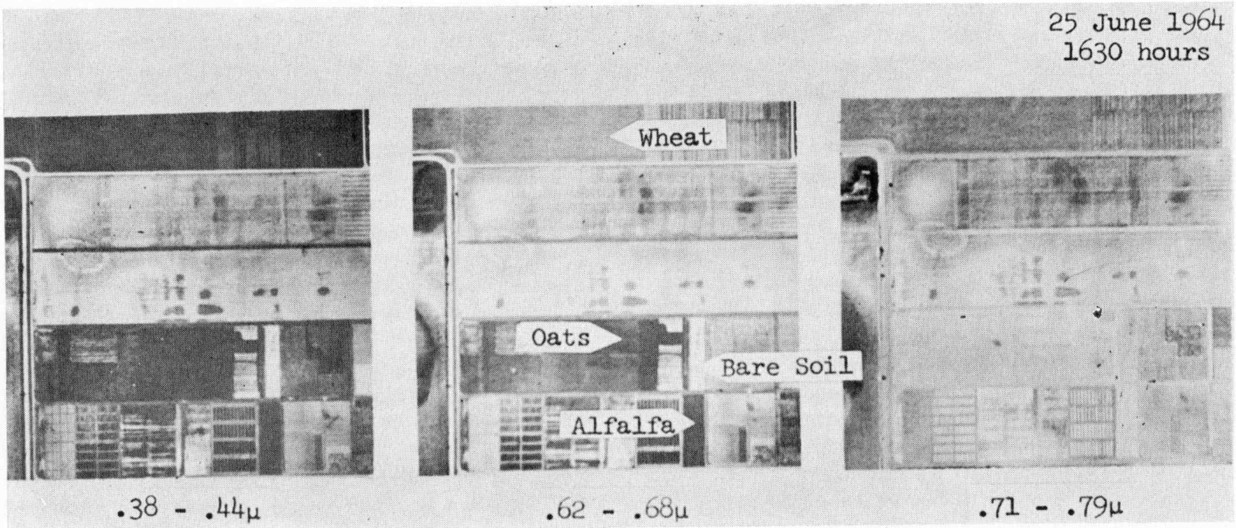


Fig. 12. Multispectral response comparison of wheat, oats, alfalfa, and bare soil on three wavelength bands (June 25, 1964).

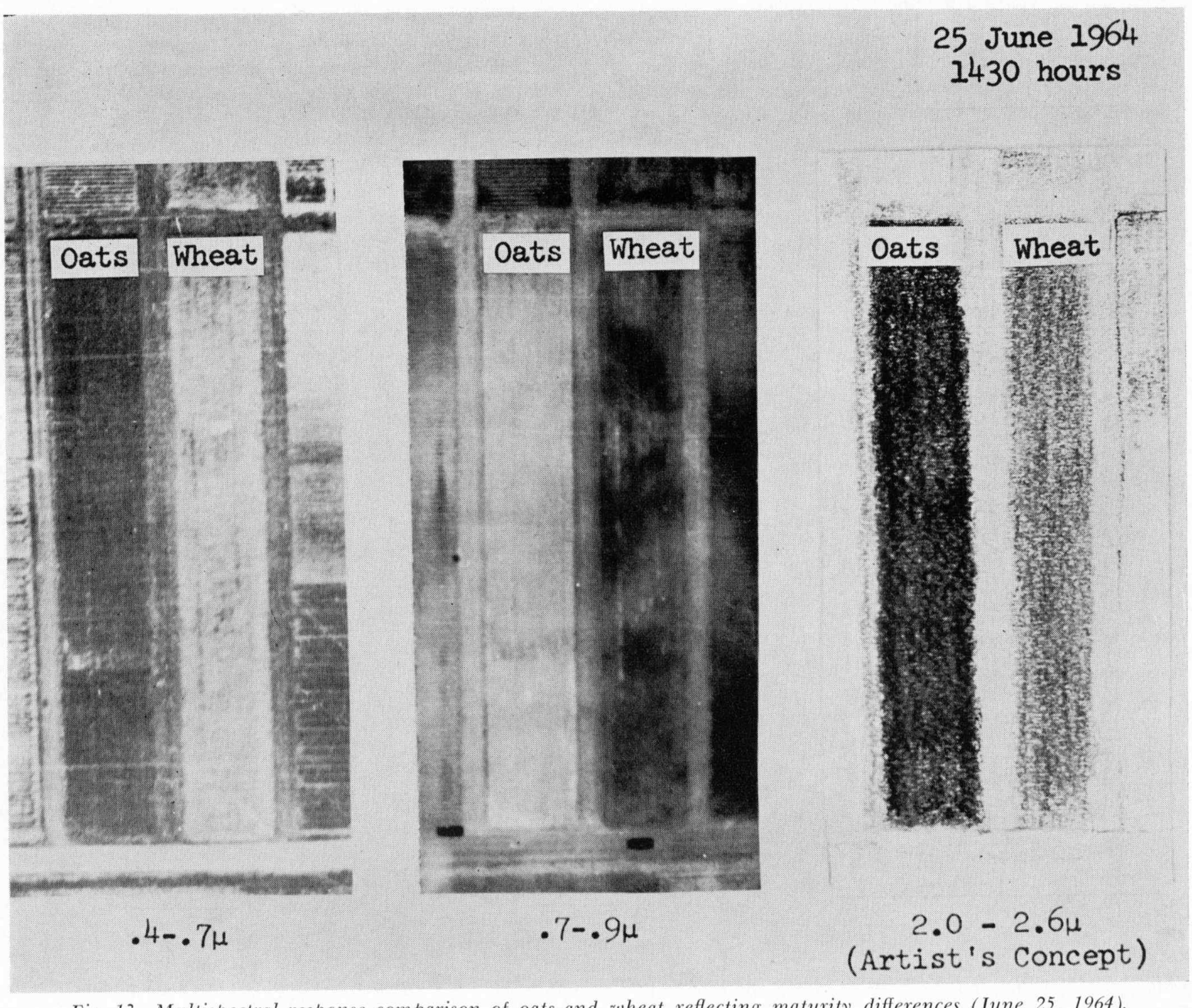


Fig. 13. Multispectral response comparison of oats and wheat reflecting maturity differences (June 25, 1964).

yellowish wheat reflects more than the green oats in the visible (0.4-0.7μ) wavelength band, but less than the oats in the 0.7-0.9μ band. The only wavelength band beyond the photographic portion of the spectrum which indicated a difference between fields of oats and wheat was the 2.0-2.6μ band, where oats were somewhat lower in response than wheat. This may possibly be related to a difference in moisture content. Such a relationship between higher moisture content and lower reflectance has been found in the 2.1-2.3μ wavelength band, using spectroreflectometer data.

The comparison between several fields of oats and wheat in each of twelve wavelength bands is illustrated graphically in Figure 14. This graph demonstrates the marked changes in response found from wavelength band to wavelength band when comparing two crop types having distinct differences in vegetative condition. One may also see the comparison between the pictorial presentation of a few wavelength bands of data, as seen in Figures 12 and 13, and this graphical presentation of many spectral bands.

A comparison between vegetation and an area of bare soil which includes two markedly different soil types is illustrated in Figure 15. The green vegetation shows a typically low response in the ultraviolet and visible wavelengths, but because of the high reflectivity of green, healthy vegetation in the 0.7-1.3μ portion of the spectrum, a very high response in the 0.7-0.9μ image is noted. Evapotranspiration causes the vegetation to be relatively "cool" in the thermal infrared wavelengths, and therefore low in response. The two soil types maintain approximately the same relative response throughout the reflective infrared portion of the spectrum. However, the dark-colored silty clay loam soil absorbs more incoming radiation than the light-colored silt loam soil, and therefore becomes relatively hot in the thermal infrared wavelengths, and has a higher response than the cooler silt loam soil.

An area of moist soil could have been distinguished on this image due to a low response throughout all wavelength bands. The reversal in response between the reflective and thermal infrared portions of the spectrum will occur in areas of uniformly dry, bare soil having different surface color, as seen in Figure 15. A lack of change in relative response for an area of wet soil has been demonstrated on irrigated versus non-irrigated bare soil areas. As previously pointed out, only a *combination* of reflective and thermal wavelength imagery allows one to determine whether the area of low response is moist soil or a different soil type.

Some radar imagery obtained on September 14, 1965, in the K-band is shown in Figure 16. The response of a small number of individual fields on this radar imagery has been compared with ground truth data, and the following relationships between crop cover and response have been found:

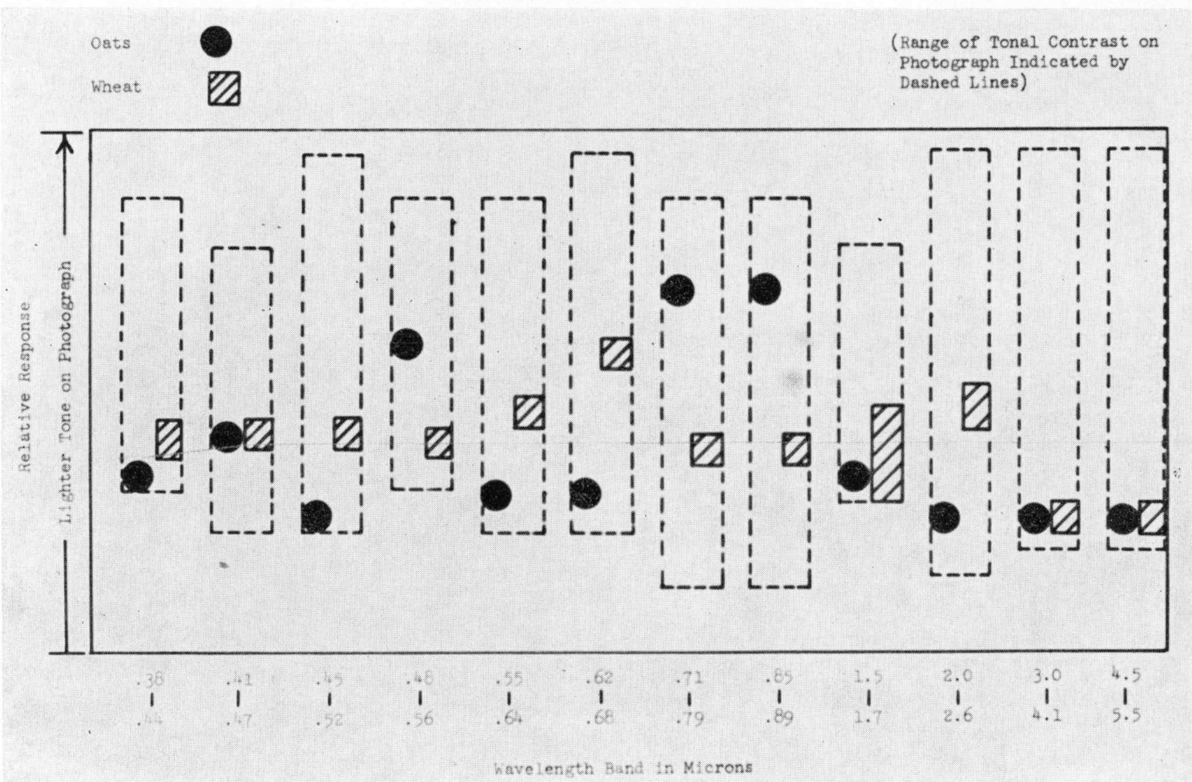


Fig. 14. Graph of a multispectral response comparison between oats and wheat using 12 wavelength bands of imagery (June 25, 1964).

(1) High Response—Corn or soybean fields (which cannot be differentiated)

(2) Medium Response – Stubble fields, pasture and alfalfa fields

(3) Low Response—Bare soil and water

As expected, forested areas showed a much greater texture than did the cultivated cropland areas. Interestingly, radar imagery showed little difference between the corn and soybeans, but on aerial photographs taken both before and after this radar imagery was obtained these two crop types were quite different. Also, analysis of 1964 imagery obtained at approximately the same time of the year showed that dry, mature corn and stubble fields appeared quite similar; but, stubble and alfalfa fields produced very different multispectral response patterns. The radar imagery, however, shows distinct differences between the corn and stubble, but no differences between the stubble and alfalfa. Thus, one finds another example where differentiation of certain crop types is very difficult on the basis of a single wavelength band, but a comparative analysis using more than on band of imagery will allow differentiation. It appears possible that comparative analysis of different wavelength bands of radar imagery or cross-polarizations of a single band of radar imagery may prove that radar is a useful component in a multispectral sensing system.

These examples help to demonstrate the potential for differentiating certain soil conditions and various crop species under a single set of conditions of growth and maturity. However, as pointed out previously, in attempting to specify characteristic multispectral response signatures for a given species, one finds several variables which can markedly affect the response in one or more wavelength bands. Studies to date (2, 8, 9, 10, 17) have indicated that the vegetation and soil variables of primary importance are (1) crop species and variety, (2) relative size and maturity at the time of flight missions, (3) soil type, moisture content, and relative amounts of soil and vegetation observed, and (4) geometric configuration of the crop. Crop or leaf geometry has a marked influence on reflectance of vegetative canopies, particularly in relation to sun angle and view angle.

The particular variety of a crop species can affect response, particularly due to variations in maturity of the different varieties. Some varieties of wheat and corn, for example, mature at a faster rate than other varieties. This

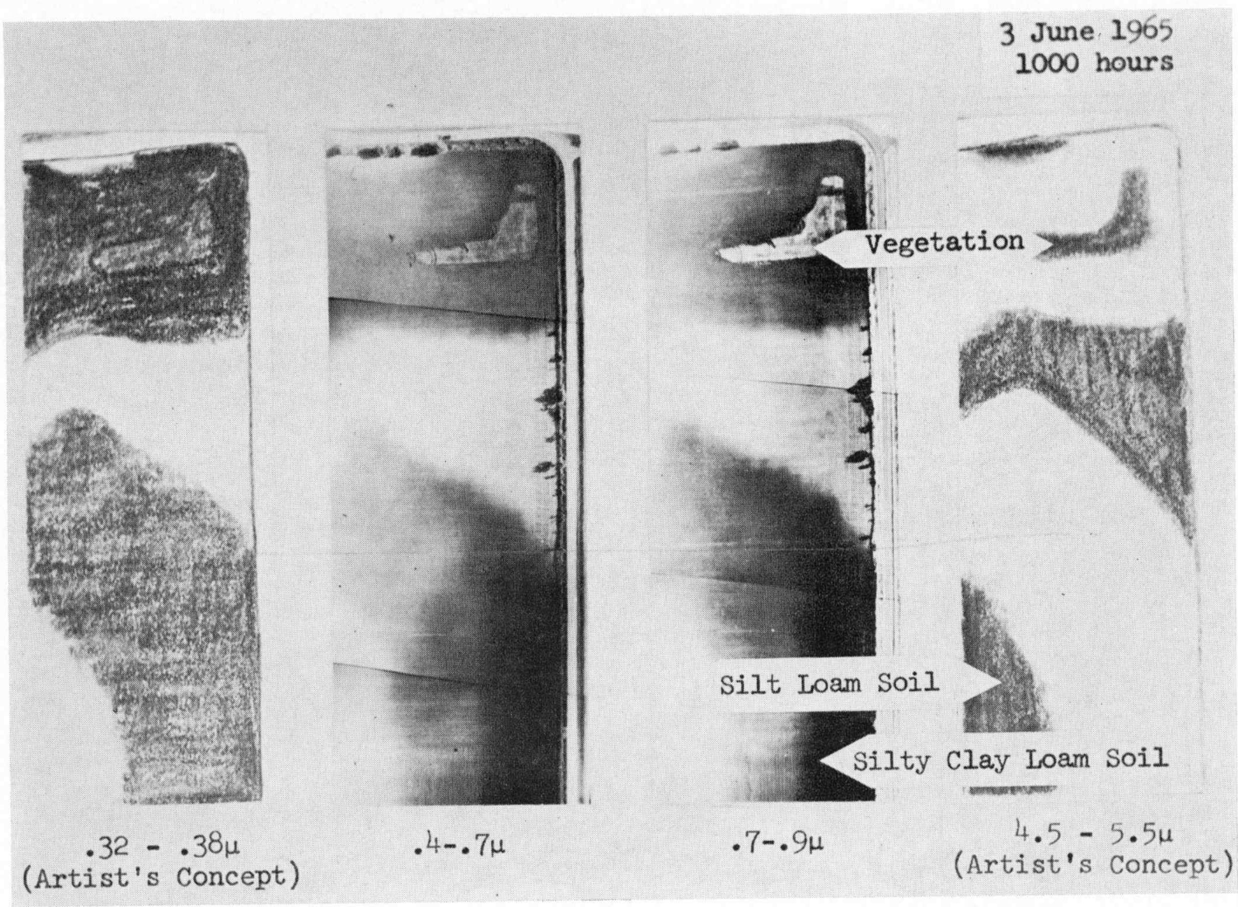


Fig. 15. Multispectral response comparison of two soil types and vegetation (June 3, 1964).

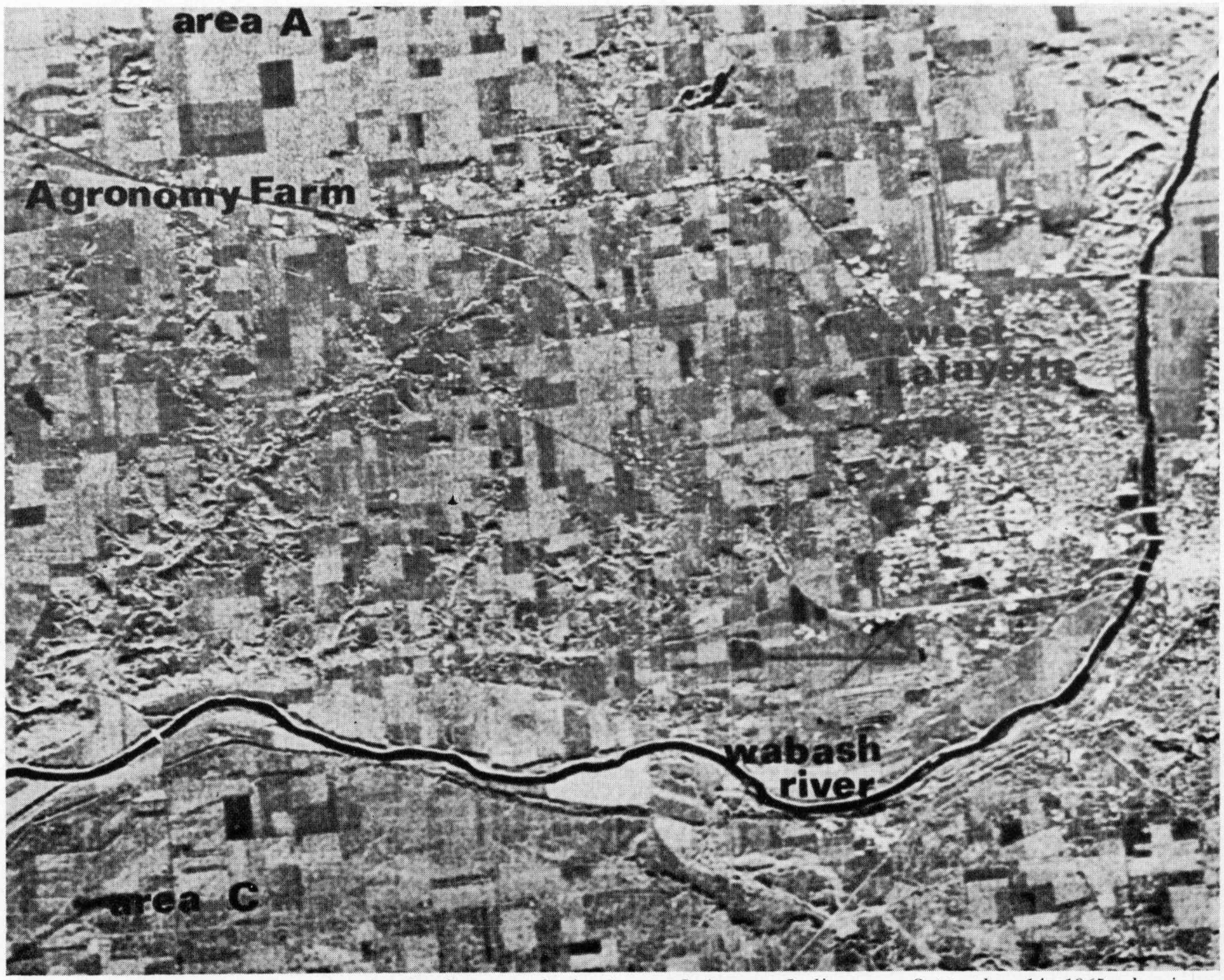


Fig. 16. A photograph of the K-band radar imagery obtained near Lafayette, Indiana, on September 14, 1965, showing a number of distinct tones for different agricultural fields.

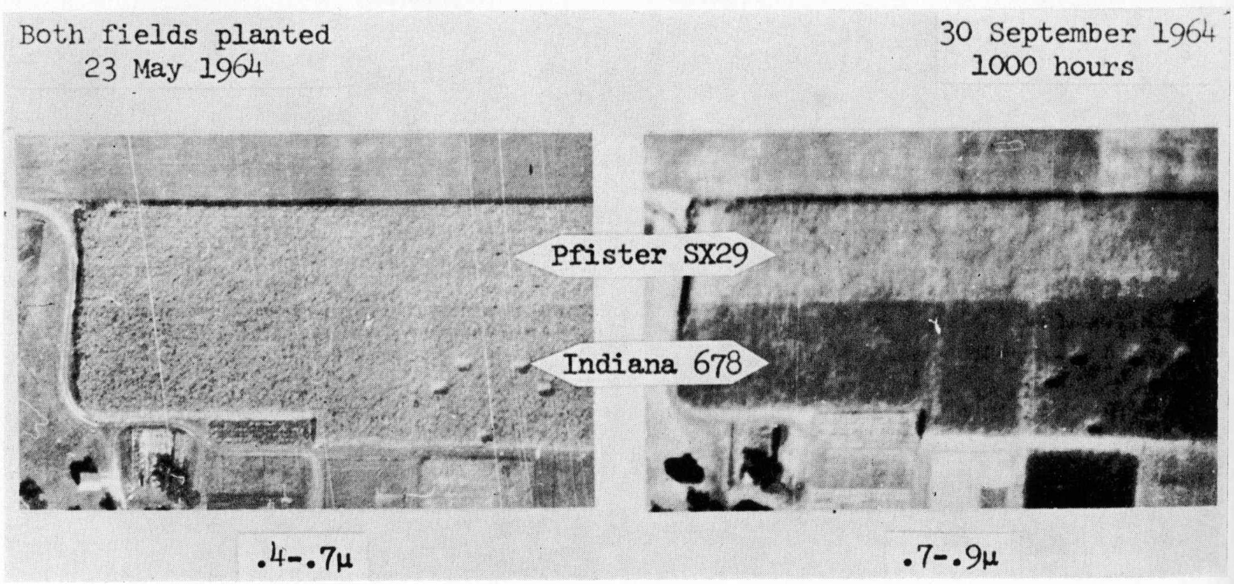


Fig. 17. A comparison within two wavelength bands of two different corn varieties planted on the same day.

becomes particularly critical late in the growing season for the species concerned. Figure 17 shows a field of corn with two different varieties, both planted on the same date. In the visible portion of the spectrum (approximately 0.4 to 0.7μ wavelength), there is little difference in response between the two varieties involved. However, in the photographic infrared portion of the spectrum, the variety Pfister SX29 has a much higher response than does the variety Indiana 678. Since the Pfister SX29 did not mature as fast as the Indiana 678 it has more healthy, green leaves which reflect a greater amount of energy in this portion of the spectrum than the browner, drier, mature leaves of the Indiana 678.

Figure 18 shows variations in response of four winter wheat varieties, all planted on the same date. In this case all four varieties were quite mature when this imagery was obtained, and therefore the response in the 0.7 to 0.9μ wavelength region is low and approximately the same for all of these varieties. However, in the 0.4 to 0.7μ wavelength band, color variations between varieties become evident and produce distinct differences in response, particularly in the case of the Knox 62 variety.

Not only do inherent differences in the rate of maturing of a particular variety cause marked variations in response, but the date of planting of the same variety can cause differences in response. The date of planting is particularly important late in the growing season, when differences in maturity become more evident, and early in the growing season, when variations in the crop height (which are related to date of planting) influence the relative amounts of soil and vegetation sensed remotely. Figure 19 illustrates the effect of date of planting upon two fields of corn late in the growing season. Note that these two fields contain the same variety of corn, but with an eight day difference in planting date. In this case, color differences caused by maturity are so slight that there is little difference in response in the visible portion of the spectrum. However, in the photographic infrared portion of the spectrum, the eight day difference in planting date, 4½ months earlier, caused a distinct variation in response.

As pointed out above, a difference in date of planting will affect response early in the growing season primarily because of a difference in the relative amount of soil being sensed. Figure 20 shows this effect, in an area of relatively low reflecting soil. In the 0.4 to 0.7μ region, no difference in response is observed between either the field of corn or the field of oats. All three fields have a uniform low response. However, in the 0.7 to 0.9μ region, the most recently planted corn field (May 14) does not have as dense a crop canopy, and a greater proportion of the soil is sensed, as compared to the field planted on May 4. The thick green canopy of oats allows relatively little soil to be sensed, and therefore has a higher response than either corn field of the same date. Such a difference in response would probably not be found a few weeks later in the growing season because the corn canopy would have become denser. It is also interesting to note that oats would soon start to mature, and then will have a much lower response than the corn in this 0.7 to 0.9μ wavelength band.

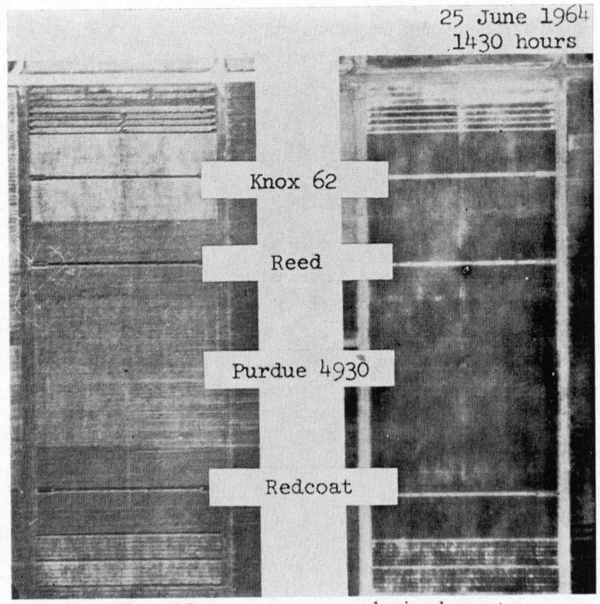


Fig. 18. The different responses obtained on two wavelength bands from four different wheat varieties (June 25, 1964).

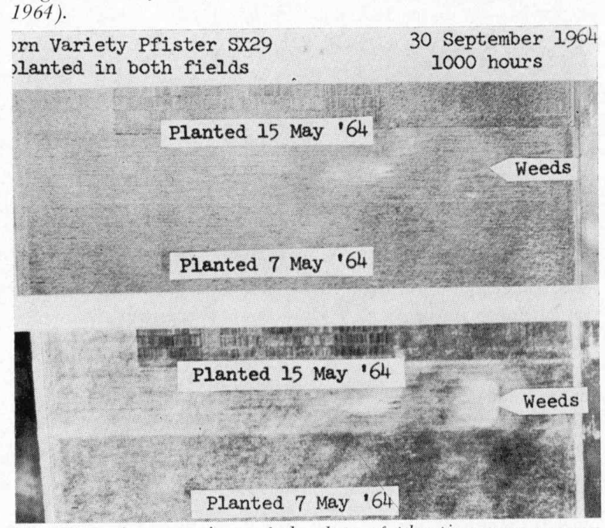


Fig. 19. A comparison of the date of planting corn as seen on two different wavelength bands. Top photo shows .4-.7μ, bottom photo is in .7-.9μ.

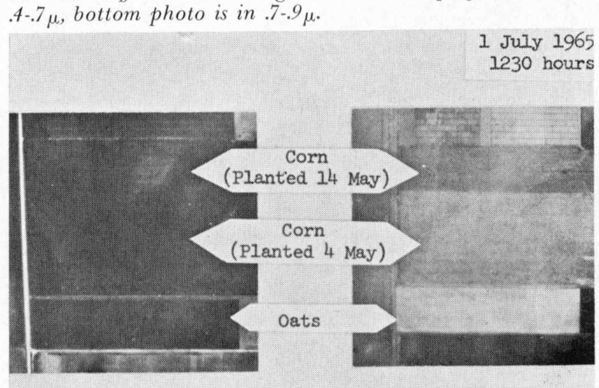


Fig. 20. Oats compared to corn planted at two different dates as seen on two different wavelength bands.

Variations in soil type, however, can cause marked reversals in the situation presented in Figure 20. On a light-colored, highly reflective soil, it has been found that in the 0.7 to 0.9μ wavelength band the highly reflective vegetation will blend with the soil and result in a relatively uniform response despite variations in crop density (8). But in these situations, the light-colored, highly reflective soil will not blend with the relatively low response of the vegetation in the visible portion of the spectrum. Therefore, the thinner the crop canopy being sensed, the higher will be the response. This is just the opposite effect with respect to wavelength band as seen in Figure 20.

The amount and condition of vegetation and soil being sensed remotely may cause major variations and even reversals in response of a given crop species in both the visible and photographic infrared portions of the spectrum. Such variations in response are not only due to species, variety, and date of planting differences as previously shown, but in the case of forage crops, differences between harvested and unharvested, and dates of harvest may cause distinct variations in response, as evidenced by Figure 21. In this situation, the alfalfa that had been cut 20 or more days earlier has grown enough to respond as a dense vegetative canopy. The most recently cut area is largely bare soil and stubble, and therefore has a much higher response in the visible region and a much lower response in the photographic infrared region than the areas that have a good vegetative canopy. The area cut 15 days earlier has not yet had enough re-growth to result in a complete cover, and presents an intermediate response in both wavelength bands.

From some of these comments it becomes apparent that soil type as well as vegetative condition plays an extremely important and variable role when working with multispectral response patterns. If a characteristic, statistically meaningful multispectral response pattern is to be determined for each crop type or species of interest, many of these and similar vegetation and soil variables must be eliminated or accounted for before correct identification can be assured. One important way to eliminate unwanted variations in field crop response is to obtain imagery on a particular crop type only during those portions of the growing season when the crop canopy has reached its maximum. Figure 22 illustrates this point. Using only the visible wavelength region (Plus X film), one sees that on July 1 the soybeans were not yet large enough to allow a complete canopy coverage, even though ground measurements showed them to be 10 to 17 inches tall. Therefore, the difference in soil type in this particular field becomes a major factor in the response, with the areas of relatively light-colored silt loam showing a rather high response. However, after the canopy cover has reached its maximum, the influence of soil type becomes minimal. In this case, the soybeans have a complete canopy cover by September 1, and therefore have a fairly uniform response despite the marked difference in underlying soil type.

Not only have certain vegetative and soil factors been found to cause marked contrasts in response, but multispectral response data obtained by camera have been found to have marked differences in response due to a number of factors involving instrumentation and crop geometry. One

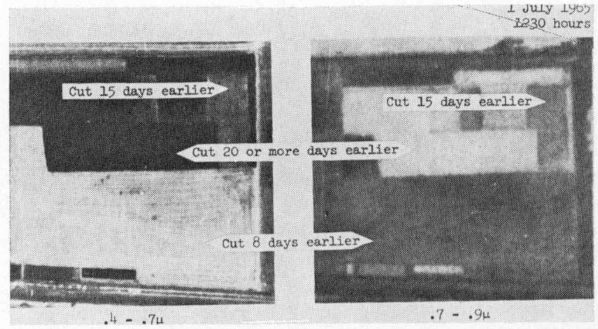


Fig. 21. The variation of the tonal response in two wavelength bands due to density of alfalfa regrowth at different cutting dates.

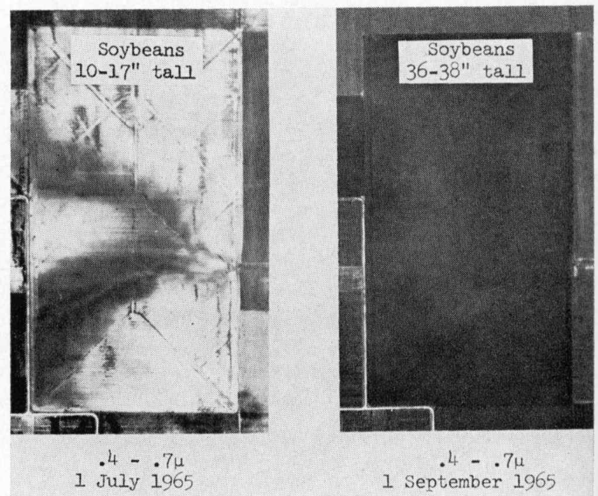


Fig. 22. A comparison of the effect of soil response and vegetation response on a field of soybeans as seen on imagery taken at two different dates.

problem area that has received relatively little attention is differences in backscattering from a vegetative canopy, due to a change in angle of incidence in relation to the area of interest on the ground. About a year ago, Steiner and Haefner (23) wrote a paper on the subject of tonal distortion, and pointed out the importance of consideration of certain angular factors, noting that very little work had been done in the problem area. One factor of primary importance discussed by them was "reflectance characteristics of the terrain." Figure 23 illustrates the problem. In this situation, two Plus X aerial photos were taken from different positions. These photos were obtained by the Institute of Science and Technology, University of Michigan, on one of their 1964 NASA sponsored flight missions to Purdue. The photos were taken on adjacent flight paths no more than 5 minutes apart, and the photo on the left is a portion of photo No. 212 on the roll, the photo on the right is part of photo No. 210, so each was subject to the same development variables. In the case on the left, the response from all wheat fields is relatively low, both immediately below the camera at photo nadir and off to the side toward the sun. Note the difference in response is distinct between the wheat and soybean fields, the latter actually consisting mostly of bare soil at this particular

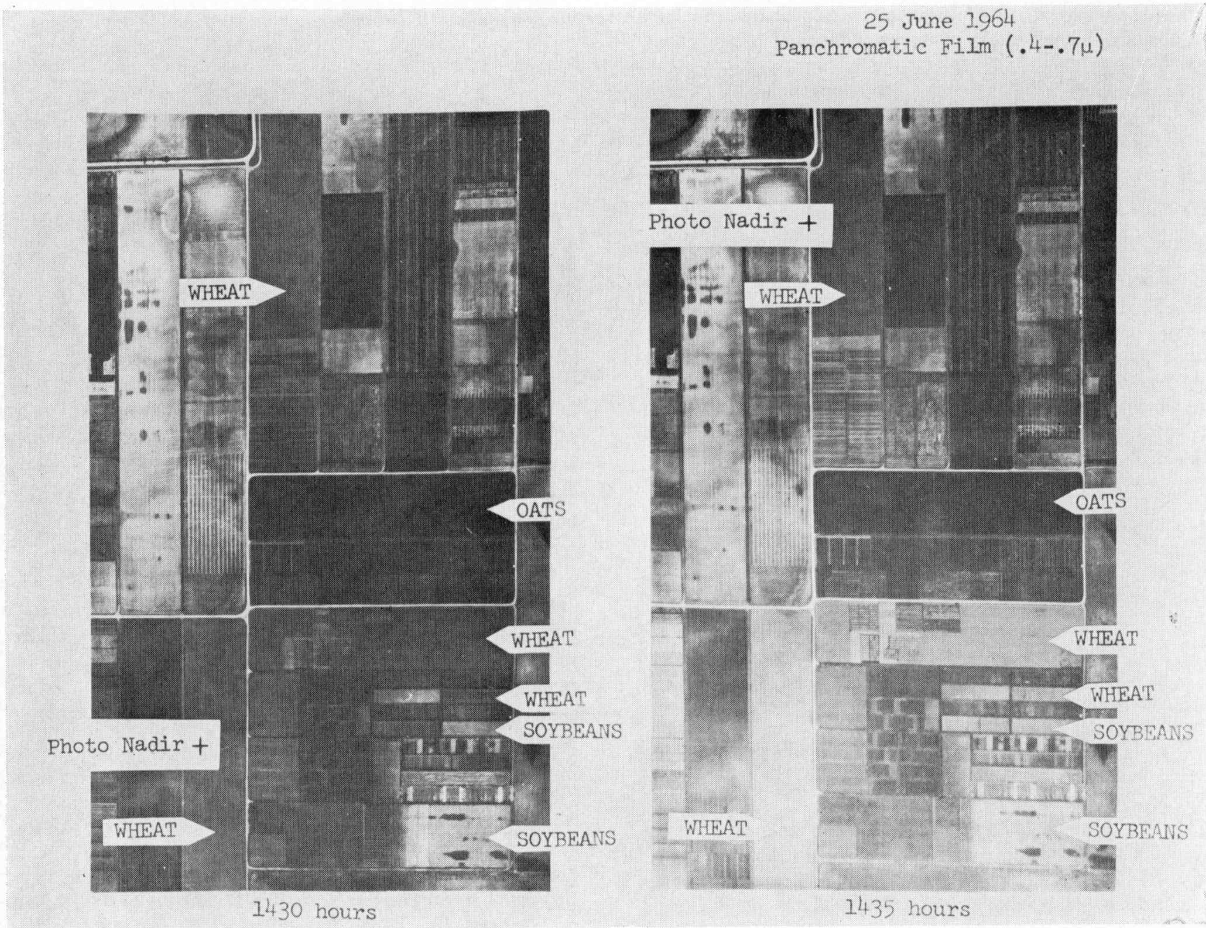


Fig. 23. The effects of angle of incidence and back scattering upon the response of wheat fields shown in two photographs of the same area at approximately the same time.

time in the growing season. In the photo on the right, however, the wheat fields off to the side of the photo away from the sun have a high backscatter, and therefore a high response, and cannot be differentiated on the basis of response from the soybean fields. However, the wheat field at photo nadir still has a relatively low response. Note also that this change in response due to backscattering occurs only to a minor extent in the field of oats in this particular set of imagery. This is probably due to the fact that the oats were green whereas the wheat was a mature golden brown vegetative canopy. The wheat is therefore more likely to demonstrate marked changes in response due to backscatter and specular reflectance. (9)

Quantitative Analysis of 1964 Multispectral Imagery

Using the rather limited amount of data which had been densitometered from the 1964 multispectral imagery by the University of Michigan (as described earlier in this Chapter), the pattern recognition programs described in the following paragraphs (see also Chapter 5) have been performed. Because of the limited amount of data and the lack of calibration on the imagery obtained, the reliability of these densitometer readings are somewhat questionable, except perhaps for relative comparisons. Nevertheless, the following data analysis has been carried out to learn more about the potential of pattern classification when using multispectral data, and to learn more about the relative importance of the various wavelength bands for the various pattern classification tasks, within the limits of data available.

Of the 56 fields on which densitometer data were obtained, there were data on only 5 fields of oats, 4 of wheat, 2-5 alfalfa, 5-6 corn, 6 soybean fields, and 6-11 fields of bare soil. (The numbers of fields of a particular crop species varied from one flight mission to another during the growing season.)

The five densitometer readings on each field were used to estimate feature characteristics, a "feature" being the reflectance in a certain wavelength band. From these limited numbers of densitometer readings, 500 samples

Table 4. A summary of the crop types compared on different wavelength bands by densitometer measurements during 1964

Date of Imagery	Wavelength Bands Used (in μ)	Crop Types Compared
June 4, 1964	.32-.38, .40-.70, .70-.90, 2.0-2.6, 4.5-5.5, 8.0-14	Oats, wheat, alfalfa, silt loam soil, silty clay loam soil
June 25, 1964	.32-.38, .40-.70, .70-.90, 1.5-1.7, 2.0-2.6, 3.0-4.1	Oats, wheat, alfalfa, soybeans, corn
July 29, 1964	.40-.70, .70-.90, 1.5-5.5, 2.0-2.6, 3.0-4.1, 4.5-5.5, 8.0-14	Corn, soybeans, alfalfa, oat stubble, wheat stubble
August 27, 1964	.70-.90, 1.5-1.7, 2.0-2.6, 3.0-4.1, 4.5-5.5, 8.0-14	Corn, soybeans, alfalfa, bare soil
September 29, 1964	.32-.38, .40-.70, .70-.90, 1.5-1.7, 4.5-5.5, 8.0-14	Corn, alfalfa, bare soil

Table 5. Results of statistical pattern recognition using multispectral scanner data obtained at 1100 hours on June 4, 1964 (See Figure 24 for the distribution of relative response within individual wavelength bands)

	Classification of samples				
Sample types	Oats	Wheat	Alfalfa	Silt Loam soil	Silty Clay Loam soil
Oats	500	0	0	0	0
Wheat	0	500	0	0	0
Alfalfa	4	0	496	0	0
Silt Loam Soil	0	0	0	500	0
Silty Clay Loam soil	0	0	0	0	500

(99% correct recognition)

Table 6. Results of statistical pattern recognition using multispectral scanner data obtained at 1430 hours on June 25, 1965 (See Figure 25 for the distribution of relative response within individual wavelength bands)

	Classification of samples				
Sample types	Oats	Wheat	Alfalfa	Soybeans	Corn
Oats	500	0	0	0	0
Wheat	0	500	0	0	0
Alfalfa	0	0	500	0	0
Soybeans	4	0	0	444	52
Corn	0	0	0	0	500

(97% correct recognition)

Table 7. Results of statistical pattern recognition using multispectral scanner data obtained at 1315 hours on July 29, 1964 (See Figure 26 for the distribution of relative response within individual wavelength bands)

	Classification of samples				
Sample types	Corn	Soybeans	Alfalfa	Oat stubble	Wheat stubble
Corn	411	81	1	0	7
Soybeans	0	500	0	0	0
Alfalfa	0	0	500	0	0
Oat Stubble	0	0	0	500	0
Wheat Stubble	0	0	0	0	500

(96% correct recognition)

were generated to simulate a larger quantity of data. The individual features were first assumed to be statistically independent and uniformly distributed within the maximum range of individual densitometer readings for a given wavelength band. As a second trial the features were assumed to have a normal distribution of points within a given wavelength band, and the classification programs were repeated.

Using these techniques, classification tests were carried out with data from all available wavelength bands (except the nine lens camera) for at least one flight from each of the five missions in 1964. The wavelength bands used and crops compared are shown in Table 4.

Results of the classification of 500 samples generated in each class based on the assumed uniform distribution are presented in Tables 5 through 9 for one flight from each of the five missions flown in 1964.

Table 8. Results of statistical pattern recognition using multispectral scanner data obtained at 1055 hours on August 27, 1964 (See Figure 27 for the distribution of relative response within individual wavelength bands)

	Classification of Samples			
Sample types	Corn	Soybeans	Bare Soil	Alfalfa
Corn	500	0	0	0
Soybeans	71	429	0	0
Bare Soil	0	0	483	17
Alfalfa	37	37	0	426

(91% correct recognition)

Table 9. Results of statistical pattern recognition using multispectral scanner data obtained at 1540 hours on September 29, 1964 (see Figure 28 for the distribution of relative response within individual wavelength bands)

	Classification of Samples		
Sample Types	Alfalfa	Corn	Bare Soil
Alfalfa	500	0	0
Corn	187	313	0
Bare Soil	0	0	500

(87% correct recognition)

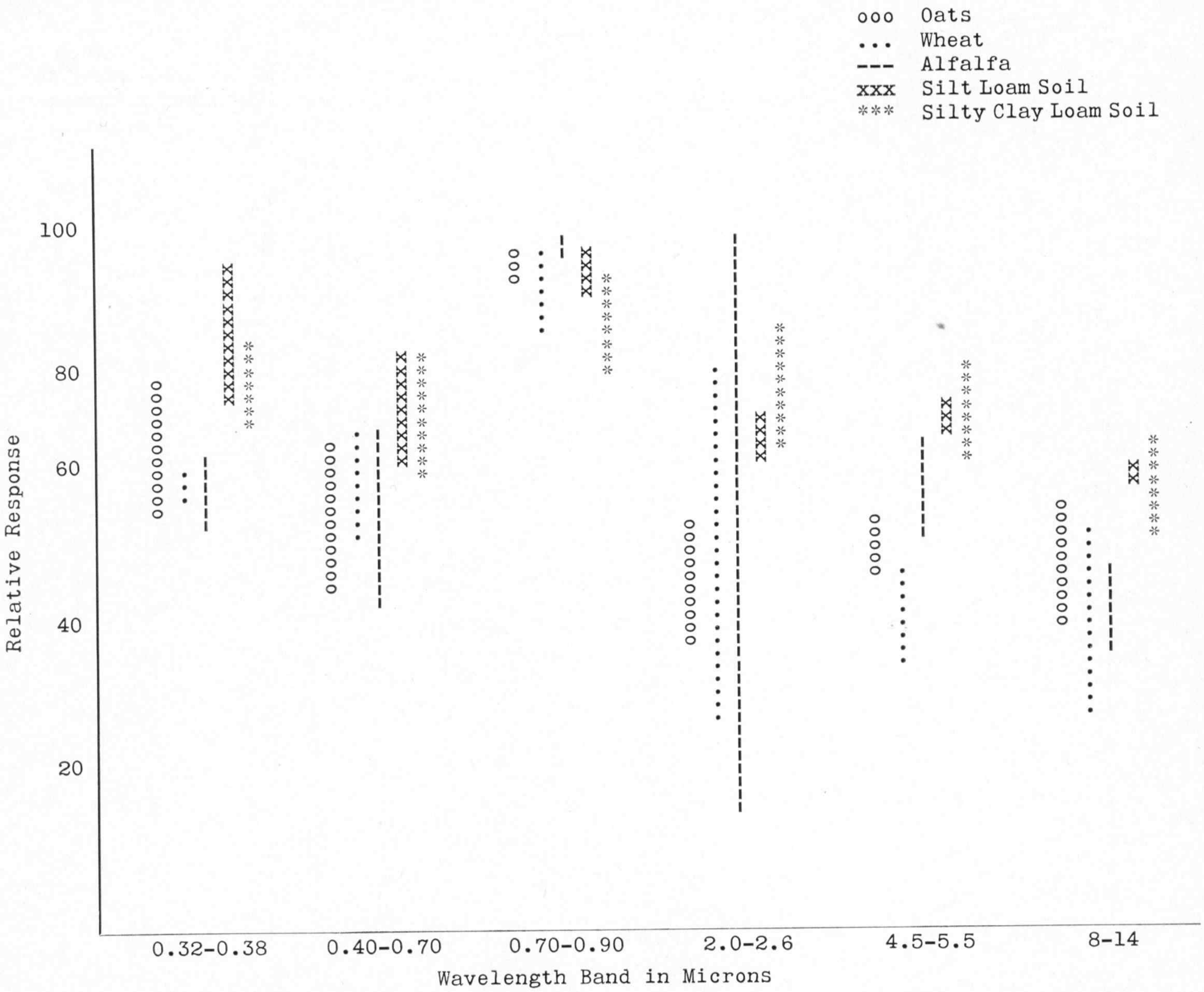


Fig. 24. The distribution of the relative response of three crop covers and two soil types within 6 wavelength bands using data obtained from the flight at 1100 hours on June 4, 1964.

Because of the limited data available, from which 500 samples of each crop or soil type were generated, the results of this analysis are questionable. It is anticipated that a similar analysis, using only original multispectral data from a large number of individual fields within each crop or soil type (no generated samples), would be very likely to have a lower percentage of correct recognition. The important point to note from the results of the data analysis presented above is that there are several situations where crop types have overlapping relative response distributions in all wavelength bands, and the pattern recognition technique still allowed proper classification in a large percentage of the samples. For example, from Figure 24, one observes that the two types of bare soil have overlapping relative response in all wavelength bands, yet through the use of this particular pattern recognition technique, all samples generated from each soil type were correctly identified. In the semi-annual progress report for this research project (10), an example was shown using data obtained on June 3, 1964, in which wheat and oats overlapped in all wavelength bands. In that case, all 500 of the wheat and 494 of the oat fields were correctly classified. Again, as seen in Figure 25, oats and alfalfa and also corn and soybeans overlap in relative response in all wavelength bands, but the table of results for these data indicates a high percentage of correct pattern recognition and classification. The same comment applies to corn and soybeans, corn and alfalfa, and wheat stubble, corn, and soybeans for the July 29, 1964 data shown in Figure 26, and also for corn and soybeans, soybeans and alfalfa, and bare soil and alfalfa in the August 27, 1964 data shown in Figure 27, and for corn and alfalfa in the September 29, 1964 data shown in Figure 28. The results shown in this section are highly questionable *per se* because of the lack of calibration of the original

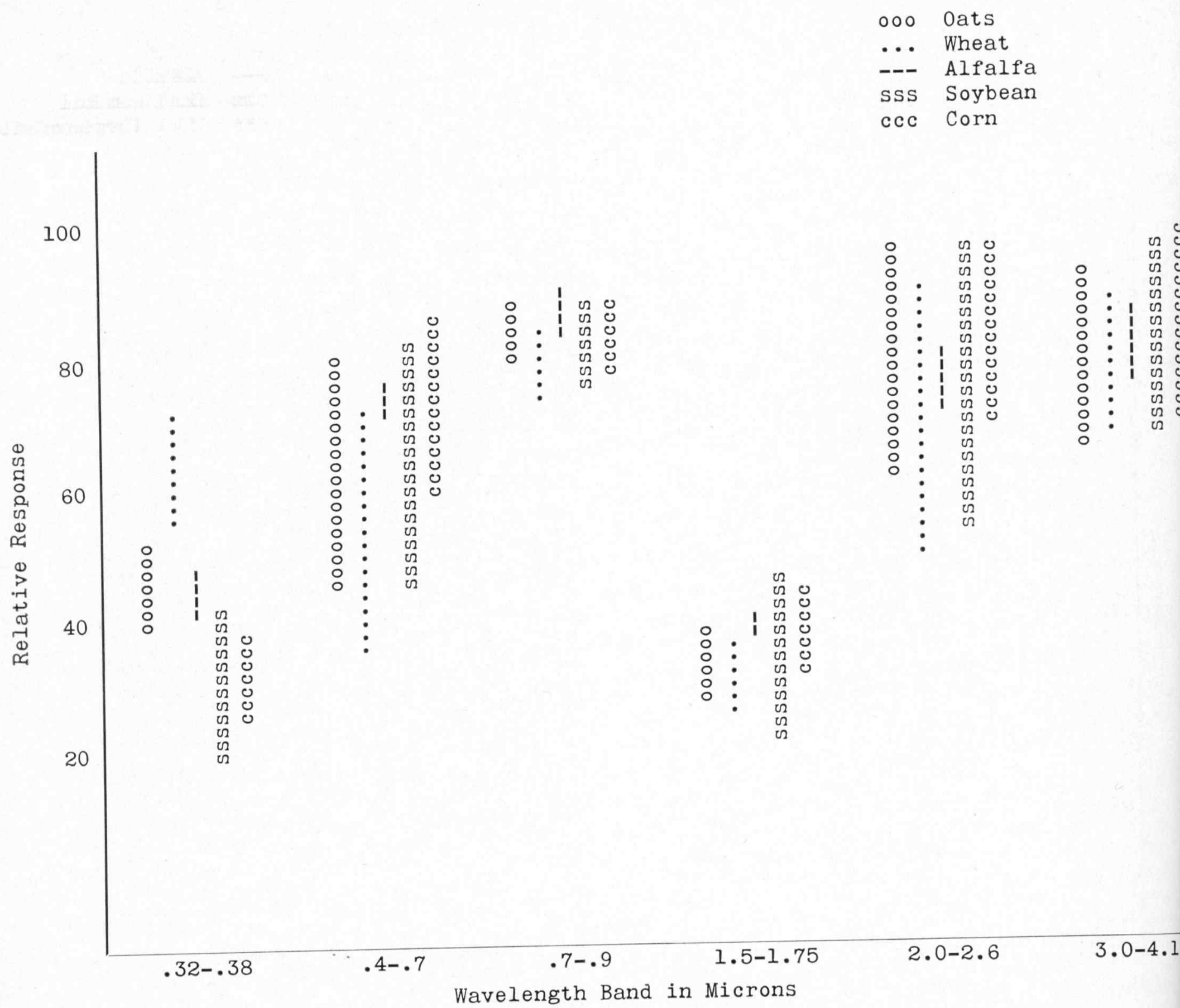


Fig. 25. The distribution of the relative response of 5 different crop covers within 6 wavelength bands using data obtained from a 1430-hour flight on June 25, 1964.

data, and the necessity of generating a large number of samples from a limited amount of data. However, these results do indicate the potential of this multispectral pattern recognition technique and that further study of various types of pattern recognition techniques is warranted. The necessity of more automatic data handling and processing equipment and procedures is also apparent in order to obtain more conclusive results and to allow full exploration into the feasibility of these techniques for an operational remote sensing system.

Quantitative Analysis of 1964 DK-2A Spectroreflectometer Data

As described earlier in this chapter, spectral reflectance curves for 172 leaf samples and other plant materials were obtained on a Beckman DK-2A Spectroreflectometer in late summer 1964. Of the 172 samples obtained there were 15 samples of brown corn leaves, 21 samples of green corn leaves, 8 green sorghum leaves and 12 green soybean leaves. These reflectance curves were analyzed in the portion of the spectrum from 0.5 microns to 2.6 microns. Each sample was considered as an 8 dimensional vector

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \vdots \\ x_8 \end{bmatrix}$$

where

x_1 = Measurement of Percent Reflectance at 0.55μ
x_2 = Measurement of Percent Reflectance at 0.65μ
x_3 = Measurement of Percent Reflectance at 1.05μ
x_4 = Measurement of Percent Reflectance at 1.25μ
x_5 = Measurement of Percent Reflectance at 1.45μ
x_6 = Measurement of Percent Reflectance at 1.70μ
x_7 = Measurement of Percent Reflectance at 1.95μ
x_8 = Measurement of Percent Reflectance at 2.20μ

Each component x_i, $i = 1, \ldots 8$ was a feature for characterizing the sample vector X. Because of the lack of large numbers of samples available, samples were generated

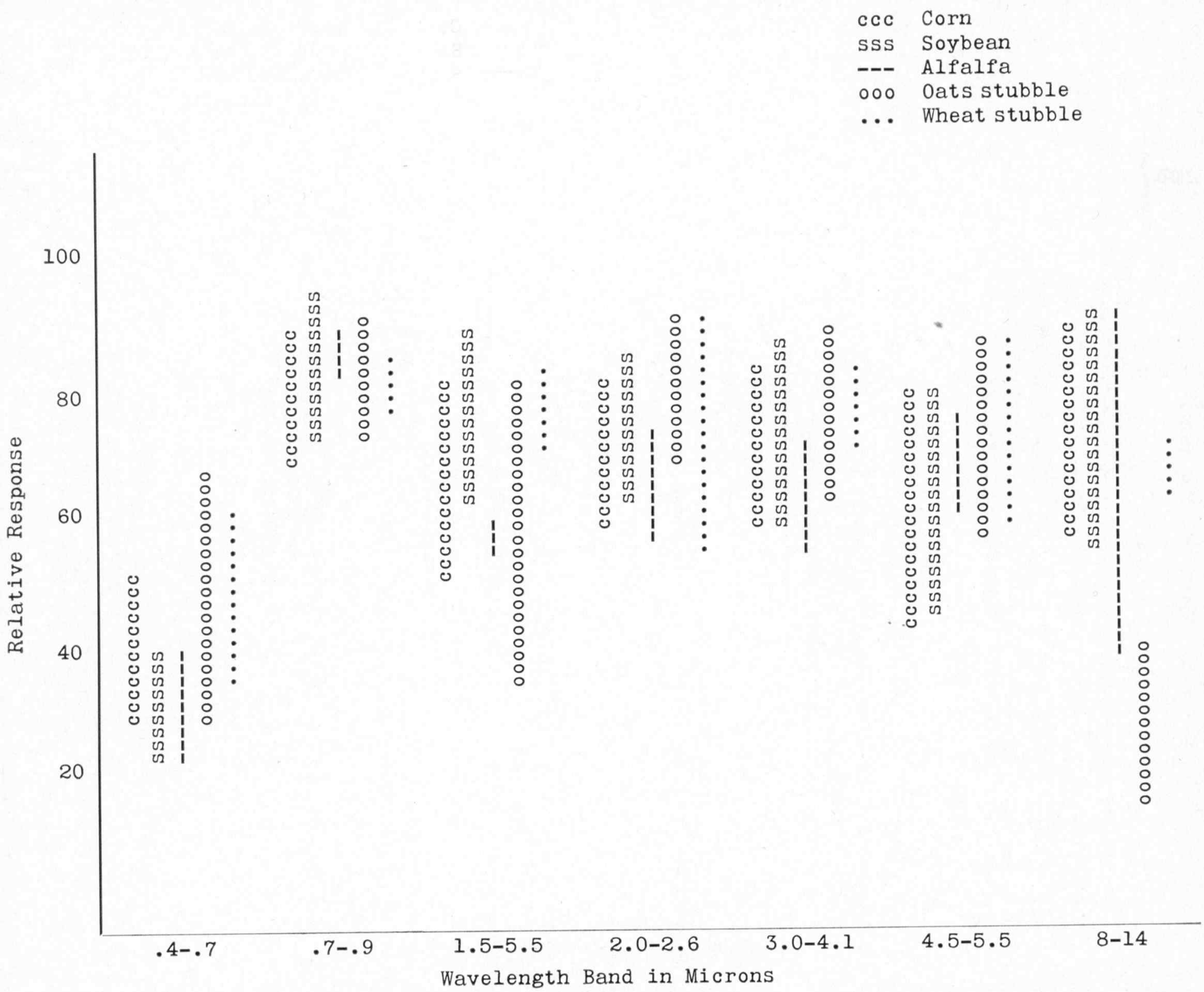


Fig. 26. The distribution of the relative response of 5 different crop covers within 7 wavelength bands using data obtained from a 1315-hour flight on July 29, 1964.

using the characteristics estimated from the available samples. Two types of distributions for the features were assumed, and preliminary classifications were investigated.

Uniform Distribution: The features were assumed to be statistically independent and uniformly distributed over the range estimated by the maximum and the minimum measurements of all available samples in that class. Table 10 and Figure 29 illustrate the feature distributions thus obtained in one such analysis.

For classification purposes, 1,000 random samples were generated from the date available, based on the assumed distribution for the features. The decision procedure used was a simple likelihood ratio test. The generated sample vector X is classified into class k if the conditional probability of X, given X from class k, $P(X|\mu_k)$, is the largest. The results of this analysis are tabulated in Table 11.

Table 10. The estimated feature distribution for brown corn, green corn, green soybeans, and green soybean leaves

Feature	Wavelength	Per cent reflectance measurement of: Brown Corn	Green Corn	Green Sorghum	Green Soybean
X_1	0.55μ	21-35	8-22	12-25	8-18
X_2	0.65μ	33-51	5-17	8-17	4-8
X_3	1.05μ	59-81	64-72	67-74	66-71
X_4	1.25μ	63-82	60-69	67-72	62-70
X_5	1.45μ	60-73	12-25	21-33	20-33
X_6	1.70μ	68-78	32-46	45-51	39-52
X_7	1.95μ	50-66	3-11	8-15	6-15
X_8	2.20μ	56-69	14-25	24-34	21-35

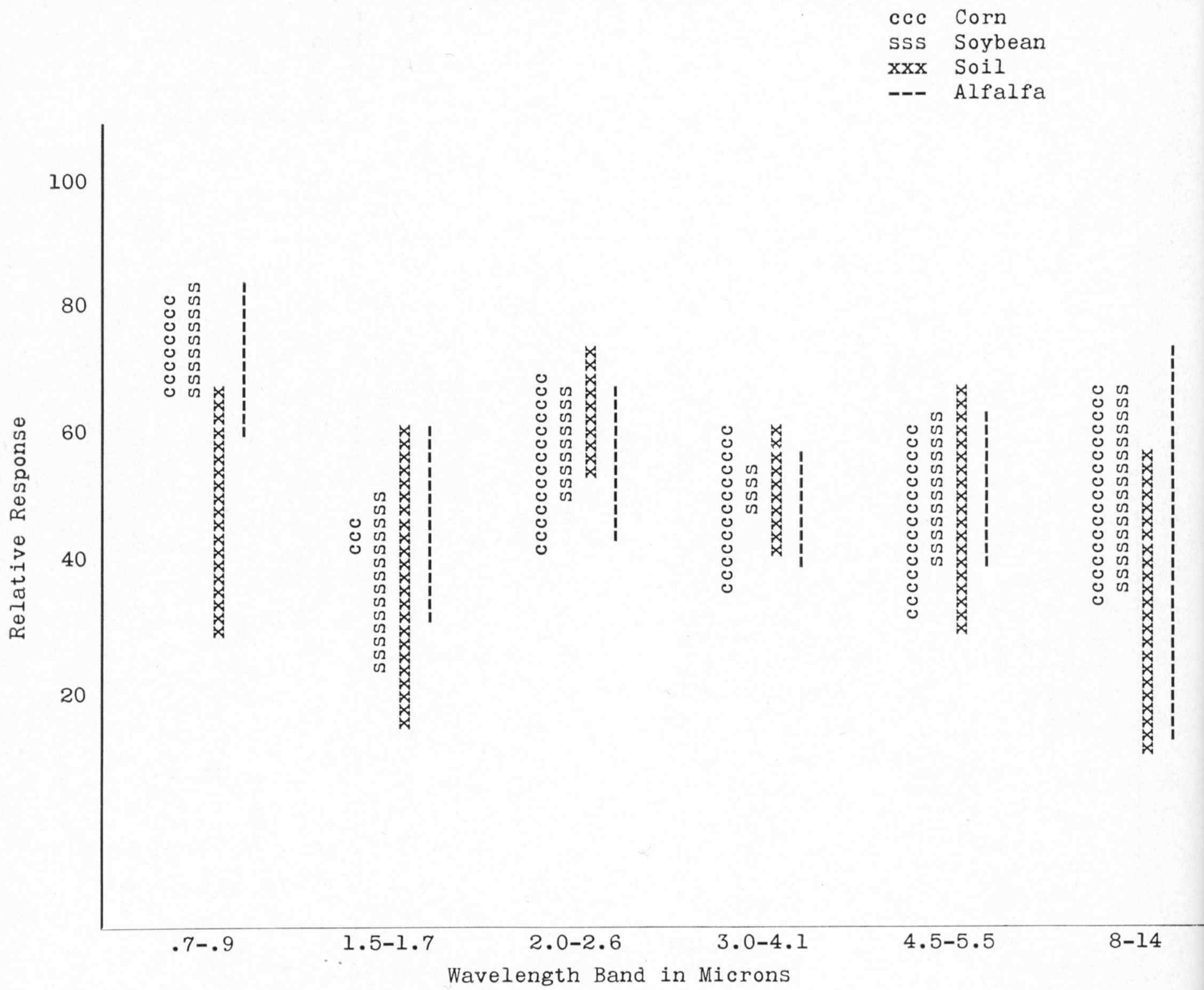


Fig. 27. The distribution of the relative response of three different crop covers and bare soil within 6 wavelength bands obtained from the 1055-hour flight on August 27, 1964.

Table 11. Classification results of 1,000 samples generated from brown corn, green corn, green sorghum and green soybean leaves, based on the assumption of independent, uniform distribution

Using 1,000 samples from:	No. of leaf samples classified as: Brown Corn	Green Corn	Sorghum	Soybean
Brown corn	1000	0	0	0
Green corn	0	996	0	4
Green sorghum	0	0	1000	0
Green soybean	0	0	0	1000
	(99% correct recognition)			

Normal Distribution: Using the same data as in the above analysis, another pattern recognition test was conducted in which the features were assumed statistically independent and normally distributed. The means, $X_1, \ldots, X_8$, and the standard deviations, $\sigma_1, \ldots, \sigma_8$ for each class were estimated from the available samples in that class. Table 12 shows the estimated means and standard deviations for each feature in each class.

A total of 1,000 random samples in each class were then generated from data available, based on the estimated means and standard deviations. The results of the classification of these generated samples are tabulated in Table 13.

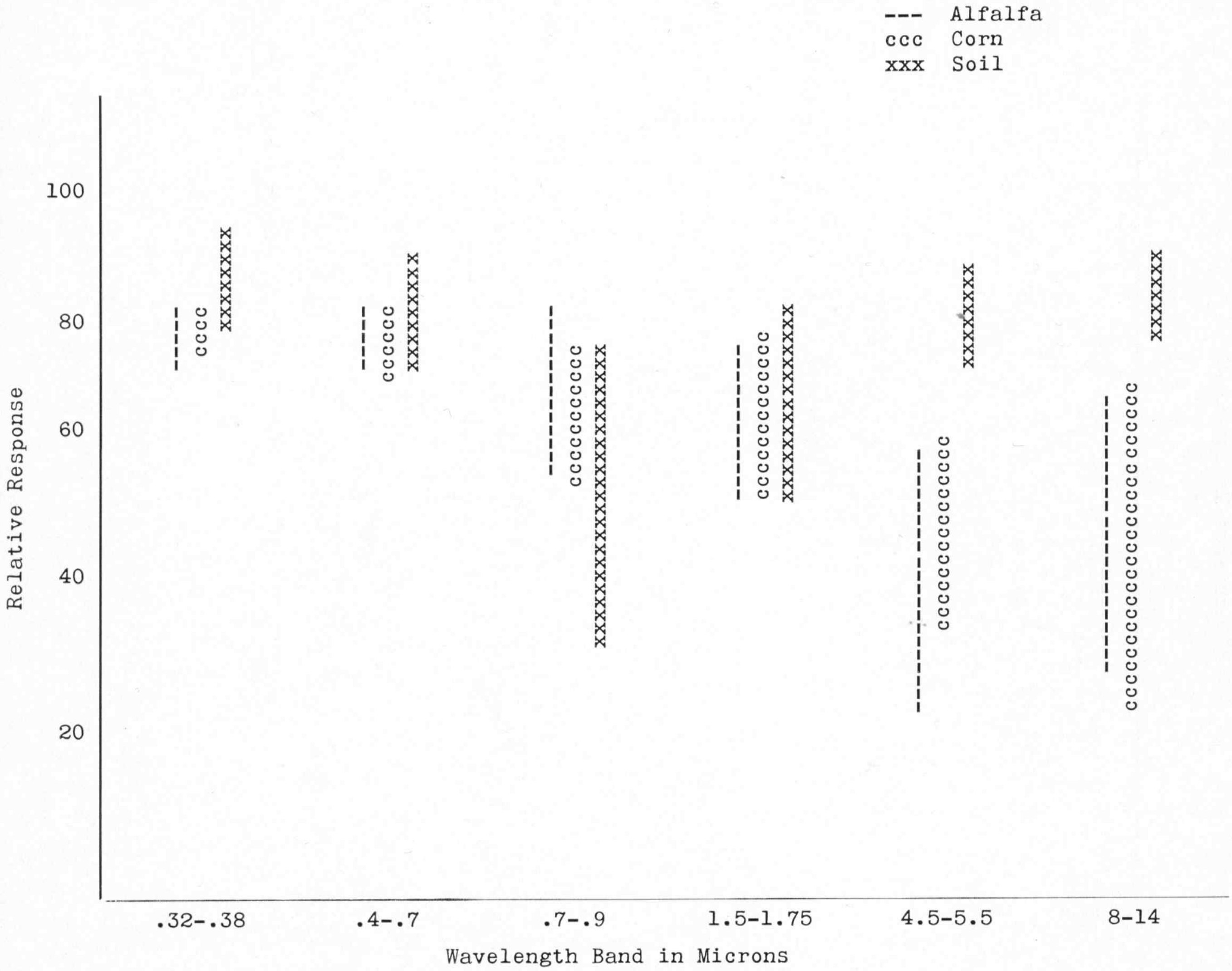


Fig. 28. The distribution of the relative response of alfalfa, corn and soil within 6 wavelength bands obtained from a 1540-hour flight on September 29, 1964.

Table 12. Estimated means and standard deviations for brown corn, green corn, green sorghum and green soybean leaves

Features	Measurement at wavelength	Brown corn Mean,	Dev.	Green corn Mean,	Dev.	Green sorghum Mean,	Dev.	Green soybean Mean,	Dev.
x^1	0.55μ	30.0	3.9	13.9	4.2	15.6	4.3	11.5	2.6
x^2	0.65μ	44.7	5.3	8.4	3.3	10.2	2.7	5.5	1.2
x_3	1.05μ	75.0	5.8	67.7	2.0	70.4	1.8	68.9	1.3
x_4	1.25μ	77.3	4.9	63.8	2.4	68.1	1.7	66.7	2.1
x_5	1.45μ	68.1	2.9	17.1	3.4	25.7	4.6	24.7	4.6
x_6	1.70μ	71.9	2.3	38.6	3.4	47.1	2.2	45.5	4.7
x_7	1.95μ	55.5	4.8	6.1	2.2	10.6	2.6	9.2	2.8
x_8	2.20μ	59.7	3.6	19.1	3.1	27.8	3.4	27.2	4.9

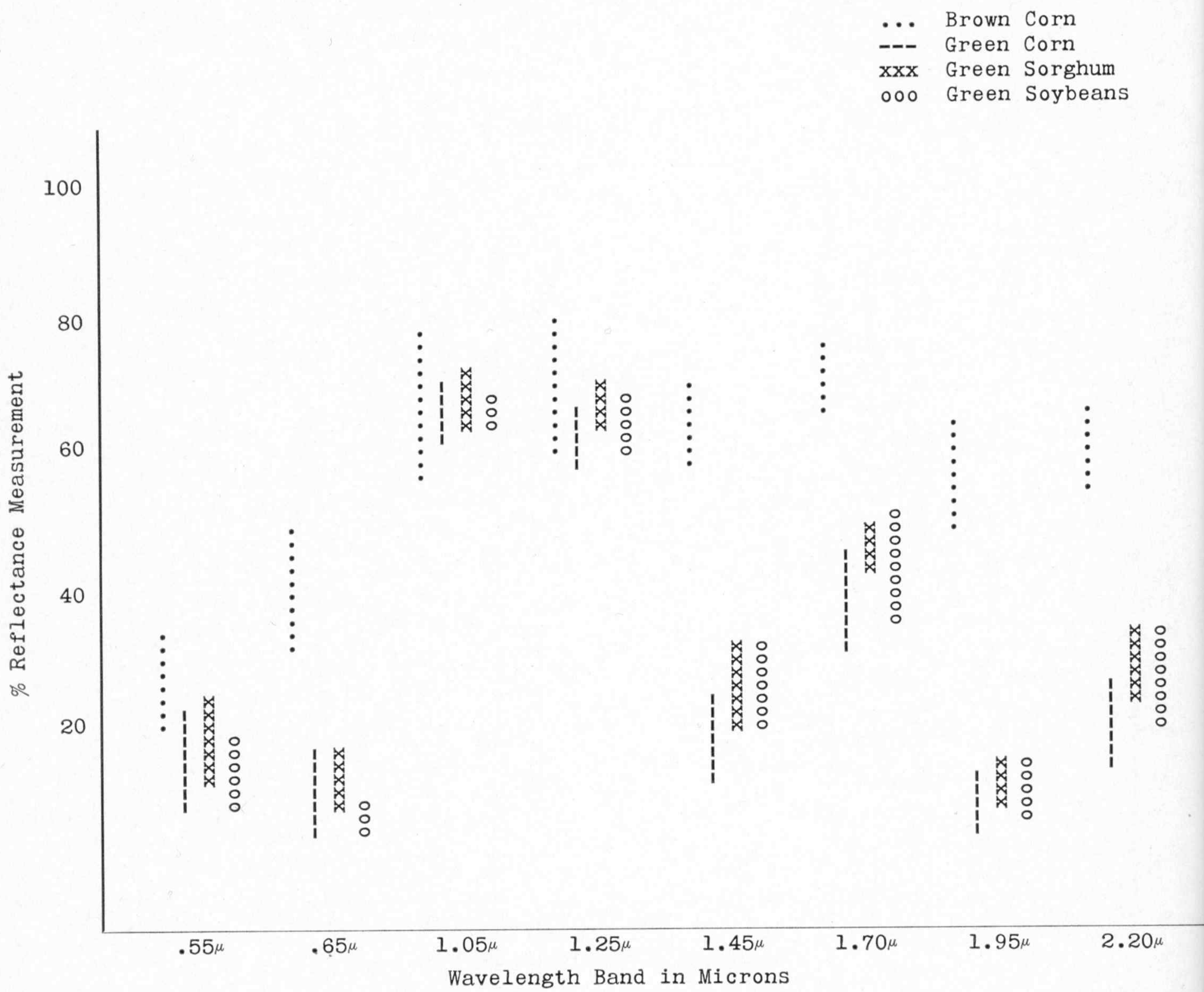


Fig. 29. The feature distribution for brown and green corn compared to green sorghum and green soybeans.

In comparing the results in Table 11 and Table 13, one might reach the erroneous conclusion that uniform distribution is a better method of pattern recognition than normal distribution. Because of the use of generated samples for this particular analysis, the uniform distribution did allow a somewhat better classification because of the limited range for each feature. However, normal distribution may be a much more realistic approach to the true situation.

These limited, preliminary results are not particularly meaningful in identifying wavelength bands of primary importance or in ascertaining the true capability for accurate classification of this type of data. But, they do indicate a potential for using such pattern recognition techniques for further feasibility studies using large quantities of such data.

Table 13. Classification results of 1,000 samples generated from brown corn, green corn, green sorghum and green soybean leaves based on the assumption of indpendent normal distribution

	No. of samples classified into			
Using 1,000 samples from	Brown corn	Green corn	Green sorghum	Green soybean
Brown corn	1,000	0	0	0
Green corn	0	980	3	17
Green sorghum	0	2	937	61
Green soybean	0	9	37	954

(96% correct recognition)

CHAPTER IV
Data Collection

Laboratory Data Collection Programs

Leaf Reflectance and Histology Program: Studying the total reflectance of plant leaves in the 0.5 and 2.6μ wavelength portion of the spectrum is one of the two primary laboratory programs of data collection and analysis. This program required a "Mobile Spectrophotometry Laboratory" owned by the Office of Naval Research, and loaned to Purdue University through the courtesy of Mr. Charles E. Olson, Jr. of the Infrared Laboratory, Institute of Science and Technology, University of Michigan. This laboratory consists of a small house trailer containing a Beckman DK-2A spectroreflectometer coupled to a Datex encoder and IBM digital card punch to record all reflectance data on computer punch cards at 10 mμ intervals, Reflectance measurements are simultaneously recorded in a graphical form by the pen servo-unit. The Beckman DK-2A spectroreflectometer is a ratio-recording instrument, where the energy reflected from the sample is compared to that from a MgO reference standard. The DK-2 may be used to measure either total reflectance or the diffuse reflectance from plant leaves. However, in all work reported here only total reflectance measurements were obtained. This instrument may also be used to obtain transmission spectra of leaves, although only a very limited amount of these data have been obtained to date.

Reflectance samples have been obtained from the Purdue Agronomy Farm, primarily from bulk, non-experimental plantings of corn, soybeans, wheat and oats. Several varieties of each crop species were used, with samples gathered at various conditions of plant maturity. Plants were selected at random from within the field, samples were obtained from various portions of the plants (particularly corn), and reflectance measurements were made on different portions of the leaf. After the reflectance measurement was completed, each sample was weighed, oven-dried at 74°C for at least 48 hours, weighed again, and the moisture content of the fresh leaf thus determined. Approximately 10 per cent of all samples measured were also cross-sectioned and photographed for later analysis to determine possible correlation between changes in leaf histology and reflectance measurements, particularly in the 0.75 to 1.30μ portion of the spectrum.

The procedure for obtaining these leaf cross-sections (13, 14, 22) will be briefly described here.

Immediately after the reflectance curve is run, a section (5 mm^2) is cut from the leaf and placed in the fixative—Formalin-Acetic acid-Alcohol (FAA). Vials containing the samples are then placed in a vacuum for one hour to remove any air and to facilitate the fixation process. After that, water is gradually removed from the tissue by using successively higher concentrations of alcohol. Next, paraffin is introduced into the tissue and following infiltration, the section is embedded in a solid block of paraffin to allow cross-sectioning with the microtome. The tissue is cross-sectioned into 8 and 10μ thick slices on a rotary microtome and mounted on slides. The slides are air dried at room temperature for several days before staining. In this investigation the material is first stained with safranin and then counterstained in fast green. The slides are then examined and photographed with a Zeiss Photomicroscope using Adox KB 14 film. A limited number of color photos have been obtained using Kodachrome II, Type A film. Various magnifications using Phase Contrast have also been tested. A typical corn leaf cross-section with 80.7 per cent moisture content is shown in Plate 6. Plate 7 shows a similar section on a wilted corn leaf with 60.7 per cent moisture content.

Laboratory Instrument Calibration Program: One of the most significant problems in gathering field spectra is the adequate calibration of field spectometers in both wavelength and intensity. In view of this, a calibration facility is being developed, at present concentrating on the portion of the spectrum below 3μ. Mercury, sodium, argon, helium, neon, hydrogen, oxygen, chlorine, and xenon spectral lamps are available, plus a spectral quality carbon arc source for spectographic work. For intensity calibration, a 200 watt NBS quartz-iodine lamp is used, with an NBS traceable absolute irradiance calibration. All these sources may be set up in an optical black cloth enclosure to reduce secondary scatter. A black-body source for thermal IR calibration is on order. A photograph of the calibration area set up for use with the Block interferometers is shown in Figure 30. This laboratory is also used to calibrate field instruments.

Laboratory Leaf Scattering Program: In the winter months, when the field system is not in use on soil studies, a leaf scattering experimental program will be carried out to supplement the DK-2 reflectance program on greenhouse plants. This program will be located physically in the calibration and field check-out facility, which has been designed with this use in mind. Monochromator illumination of in vivo leaf surfaces at various incidence angles is available for forward and back scatter measurements.

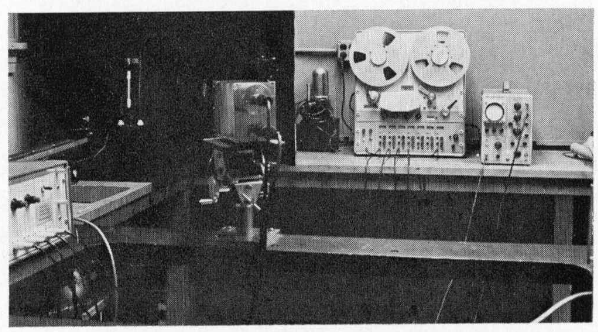


Fig. 30. Laboratory area for instrument calibration and field instrumentation checkout.

Field Data Collection Programs

Field Spectroscopic Data Collection Systems: The field spectroscopic data collection system was described in the semi-annual progress report of May 1, 1966, and the various items of equipment were ordered at that time. The system is shown in Figure 31. The tape recorder, Block interferometers, Eppley pyrheliometer, transceiver gear, PRT-4 radiometer, and rack and bench mounting furnishings for the field van were on hand by August 20, 1966. The pyrheliometer, transceiver gear, and PRT-4 radiometer were used extensively in the field throughout much of the summer, being among the early equipment arrivals. The Block interferometers and the tape recorder have been checked out in the laboratory at the time of this writing and will be used in the field during September, 1966.

Fortunately, it has been possible in this past summer to utilize spectrometer (Perkin-Elmer SG-4) on loan from Marshall Space Flight Center, Huntsville, Alabama, to obtain field data from 0.35 to 4.0μ. This effort was supported through the use of a rented truck and recording equipment already available at Purdue University. The general system layout for this interim data collection is shown in Figure 32.

Since Block interferometers and the Perkin-Elmer SG-4 are the major data collection instruments of present and future systems, they will be described in further detail below. The signal-recorder interface board and associated recording and monitoring equipment are conventional, and result mainly in an analog tape of the field data to be handled in the data processing system discussed elsewhere.

Block Michelson Interferometer Spectrometers: Both the Block 195E (2 to 6.5μ) and the Block 195T (2 to 16μ) are Michelson interferometer instruments. A sketch of a typical interferometer is shown in Figure 33. Assume monochromatic collimated light enters the instrument. Distances *along the path of a typical ray* are defined as follows:

l_1 = length in air from the entrance aperture plane to plate P1.
l_2 = length in air from P1 to M1.
l_3 = length in air, including the gap between P1 and P2 from the surface S to M2.
l_4 = length in air, including the gap between P1 and P2 from the surface S to the exit aperture.
p = length in the plate material, one transmission.

In addition, the magnitude of the wave vector in air is k, that in the plates is k_p, and δ_t is the phase shift associated with transmission through the surface S. Finally, δ_{ri} is the internal phase shift associated with internal reflection from P1 on the surface S, while δ_{re} is the external phase shift associated with external reflection from the air side of the surface S.

The entrance aperture is chosen as reference plane for the incoming irradiance, and a scalar wave of the form

$$\exp\ [i\ (\vec{k}\circ\vec{r}-\omega t)]$$

is considered, with time dependence suppressed in the work to follow.

The wave arriving at the exit aperture from the M1 path will have a phase factor of

$$\exp\left[ik\left(l_1+2l_2+l_4+4\frac{k_p p}{k}\right)+i\left(\delta_{ri}+\delta_t\right)\right]$$

while a wave arriving at the exit aperture from the M2 path will have a phase factor of

$$\exp\left[ik\left(l_1+2l_3+l_4+4\frac{k_p p}{k}\right)+i\left(\delta_{re}+\delta_t\right)\right]$$

From this it is seen that the optical disturbance at the exit aperture could be assumed to arise from two planar sources, one at a distance $l_1+2l_2+l_4+4\frac{k_p p}{k}$ from the exit, the other at a distance $l_1+2l_3+l_4+4\frac{k_p p}{k}$ from the exit, with both sources parallel to the exit plane. It is clear that, save for the k_p/k correction for the optical path length in the plates, these sources are just the images of the entrance aperture reflected through S and M1, and M2 and S, respectively. The phase difference of these two sources would be

$$\delta_{re}-\delta_{ri}$$

The net result of this is that the optical disturbance (E-field magnitude, for example) in the exit aperture may be assumed to come from a simple phased array of two circular parallel sources as shown in Figure 34. At this point it is convenient to define a new coordinate system and a new time reference. Source M1 is in reference phase, while source M2 has a relative phase of $\delta_{re}-\delta_{ri}$. The quantity z_d is the displacement of M2 from its zero retardation position. In Figure 34, definitions of source and field vectors are given. The net optical disturbance at the exit plane may be written as

$$\int K'\frac{\exp[i\vec{k}\cdot(\vec{r}-\vec{r}')]}{|\vec{r}-\vec{r}'|}r'dr'd\phi'+\exp i(\delta_{re}-\delta_{ri})\int K''\frac{\exp[i\vec{k}\cdot(\vec{r}-\vec{r}''+\hat{z}\,2z_d)]}{|\vec{r}-\vec{r}''+\hat{z}\,2z_d|}r''dr''d\phi''$$

First, assume that

$$|\vec{r}-\vec{r}'|\approx|\vec{r}-\vec{r}''+\hat{z}\,2z_d|\approx|\vec{r}|\equiv r$$

next that K′ and K″ are independent of r′, ϕ' and r″, ϕ'' respectively, and finally

$\vec{r}-\vec{r}'$, $\vec{r}-\vec{r}''-\hat{z}\,2z_d$, and $\vec{r}$ are nearly parallel.

Then the disturbance is, approximately,

$$\left\{1+\exp i\ (\delta_{re}-\delta_{ri})+2K z_d\cos\theta\right\}2\int K'\frac{\exp i\vec{k}\cdot(\vec{r}-\vec{r}')}{r}r'dr'd\phi$$

The integral is just a Fraunhofer integral for the circular source, multiplying the bracketed term by a circular aperture diffraction pattern. It is the bracketed term

$$1+\exp i\left[(\delta_{re}-\delta_{ri})+2K z_d\cos\theta\right]$$

which is of most interest. (Henceforth wavenumber, ν, will replace k, $k=2\pi\nu$). This term can be represented as complex vectors, and it is a simple matter of trigonometry to find the intensity of the optical disturbance which is proportional to the square of the magnitude of the resultant vector, i.e.,

$$\text{Intensity disturbance} = A\cos^2\left(\frac{\delta_{re} - \delta_{ri}}{2} + 2\pi\nu Z_d \cos\theta\right)$$

The intensity disturbance is the instrument response at the exit aperture, call it R, and from this interference fringes can be determined. In a properly designed instrument the field of view will be approximately uniformly illuminated, in which case cosθ may be set to unity. The response from an element of the spectrum between ν and $\nu + d\nu$ with intensity $I(\nu)$ is

$$dR(\nu,t) = I(\nu)\tau(\nu)\left[\frac{1}{2} + \frac{1}{2}\cos\left(\delta_{re} - \delta_{ri} + 4\pi\nu Z_d\right)\right] d\nu$$

The phase shift, $\delta_{re} - \delta_{ri}$, may be a function of wave number, ν, call it $\varphi(\nu)$. The overall instrument transmittance is denoted by $\tau(\nu)$. If mirror M2 is driven by a sawtooth waveform from $-L/4$ to $+L/4$ about the zero retardation position in a time T, then

$$Z_d(t) = \frac{L}{2T}t$$

Integrating over all wavenumbers to obtain the overall response yields

$$R(t) = \frac{1}{2}\int_0^\infty I(\nu)\tau(\nu)\,d\nu + \frac{1}{2}\int_0^\infty I(\nu)\tau(\nu)\cos\left[\varphi(\nu) + 2\pi\frac{L\nu}{T}t\right] d\nu.$$

The limits of integration can be as shown, the factor $\tau(\nu)$ providing realistic limits determined by the bounds of the instrument components.

The response is composed of a "constant" part and a time-varying part which is the Fourier transform of $I(\nu)\tau(\nu)\exp i[\varphi(\nu)]$ as can be seen by rewriting the integral above as

$$R(t) = \frac{1}{2}\int_0^\infty I(\nu)\tau(\nu)\,d\nu + \frac{1}{4}\int_{-\infty}^{+\infty} I(\nu)\tau(\nu)\exp i\varphi(\nu)\exp i2\pi\frac{L\nu}{T}t\,d\nu$$

It is most interesting to note that the constant level is a function of the total energy admitted to the instrument. In the reflective portion of the spectrum this is very useful as a means of monitoring rapid fluctuations of solar illuminance while taking spectra.

It is the function of the data analysis group to process the interferogram, taking the inverse transform to yield $I(\nu)\tau(\nu)$ and $\varphi(\nu)$. A recent discussion of this is given by Forman, et al. (6) The Block instruments have been set up in order to fully evaluate them and one trial session was held on the front lawn of the laboratory. Interferograms from the model 195T, the 2.5 to 16μ instrument are shown in Figure 35. The "clock waveform" is a triggered

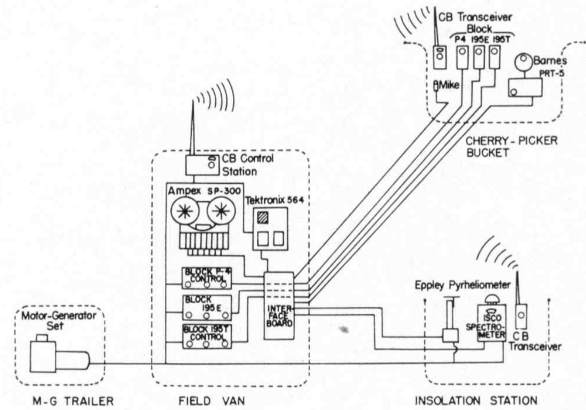


Fig. 31. Diagram of the Block Interferometer system adapted for field instrumentation.

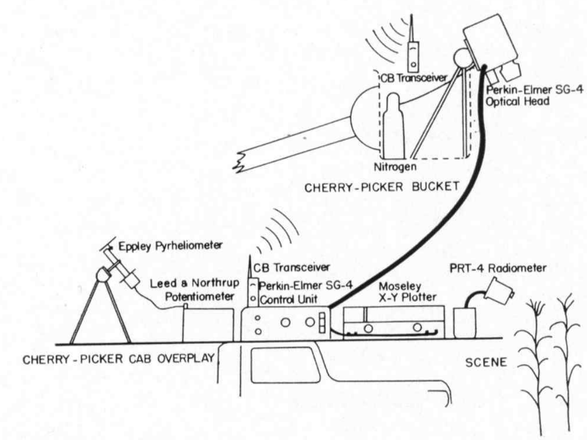


Fig. 32. Diagram of the Perkin-Elmer SG-4 system as used in obtaining data in the field.

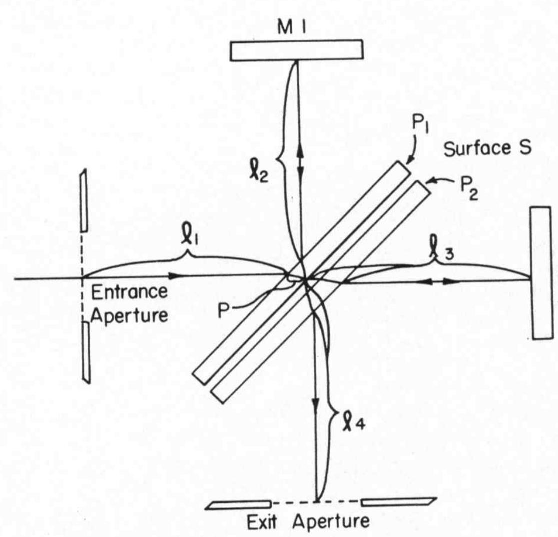


Fig. 33. Diagram of the Michelson interferometer.

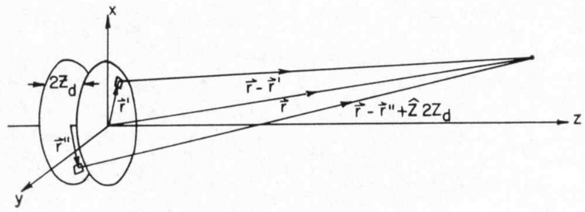
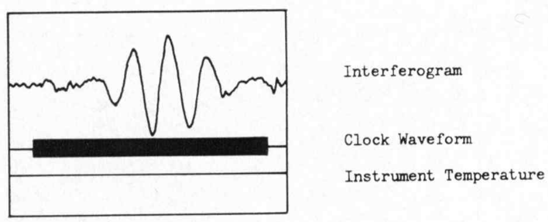
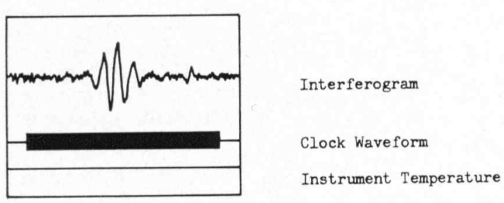


Fig. 34. Diagram showing the equivalent source geometry of the Michelson interferometer.



(a) Blue sky through haze.



(b) Grass in tree shade.

Fig. 35. Block 195T interferometer signals in the 2.5 to 16μ wavelength region under two different natural light conditions. (Instrument temperature: 35°C).

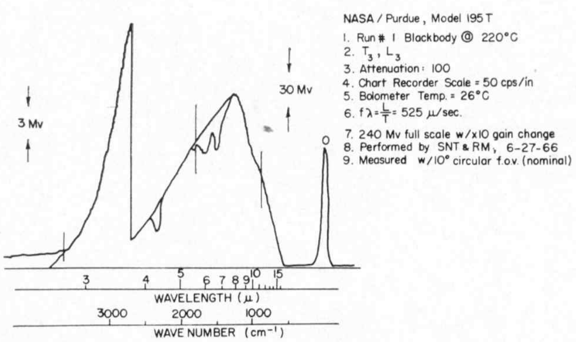


Fig. 36. A calibration sheet of a blackbody at 220°C by the Block 195T interferometer (performed by Block Engineering Inc.).

high-frequency sinusoid, the zero-crossings of which are used to initiate sampling commands for inverse transforming. The third trace is a thermistor instrument temperature signal. In both interferograms shown, the instrument temperature was above the field of view ambient temperature.

In addition, some calibration curves of both the 195T and the 195E interferometers are shown in Figures 36 through 38.

Block Polarization Interferometer: The polarization interferometer is another scheme for achieving a phased array of two equivalent sources. The basic geometry of the device is shown in Figure 39. The entrance polarizer acts on the incoming radiation to yield components of the electric field along both the ordinary and extraordinary axes of the compensator and chip. The bias block axis orientation is at right angles to that of the compensator and chip. If the ordinary and extraordinary indices of refraction are n_o and n_e, k the free-space wave vector, then one component of the incoming radiation results in a disturbance at the detector of

$$\exp\,[ik\,(l_1 + l_2 + d_1 n_o + d_2 n_e)]$$

while the other (perpendicular) component causes a disturbance of

$$\exp\,[ik\,(l_1 + l_2 + d_1 n_e + d_2 n_o)]$$

with the exit polarizer causing interference between these two components. Here, l_1 and l_2 are free space distances in the instrument from entrance to detector.

The net detector signal appears to come, then, from two sources separated by a distance

$$d_1 n_o + d_2 n_e - d_1 n_e - d_2 n_o = (d_1 - d_2)(n_o - n_e)$$

This distance is modulated in the interferometer by moving the compensator in the direction shown, so that

$$d_1 - d_2 = \text{const.} \times t$$

From this point the anaylsis of detector response is similar to that for the Michelson interferometer. Typical interferograms are shown in Figure 40. The detector is a combination silicon photovoltaic detector ($\sim$ 0.35 to 1μ) over a lead sulfide photoconductive detector ($\sim$ 1 to 2.5μ). A calibration curve of the lead sulfide channel is shown in Figure 41.

Perkin-Elmer SG-4 Spectometer: The optical arrangement of the SG-4 spectrometer is shown in Figure 42, not including the reflective fore optics portion. Entrance slits of 0.175 X 10 mm, 0.75 X 10 mm, and 2 X 10 mm are available, while the exit slit is fixed at 2 X 10 mm, though provision exists for installing various slit diaphragms. A 300 line/mm grating blazed for 1.2μ was used in the early part of the growing season, while a 600 line/mm grating blazed for 0.5μ became available in mid-August. With resolution determined by the exit slit, values of 32 mμ and 16 mμ total slit spectral intercept occur with the 300 line/mm and 600 line/mm grating, respectively.

Wavelength calibration is straightforward, using spectral tubes, and compares well with the wavelength-grating angle relation given by Perkin-Elmer. On the other hand, intensity calibration is rendered difficult by the extreme sensitivity of the gain control of the instrument. A stepped-

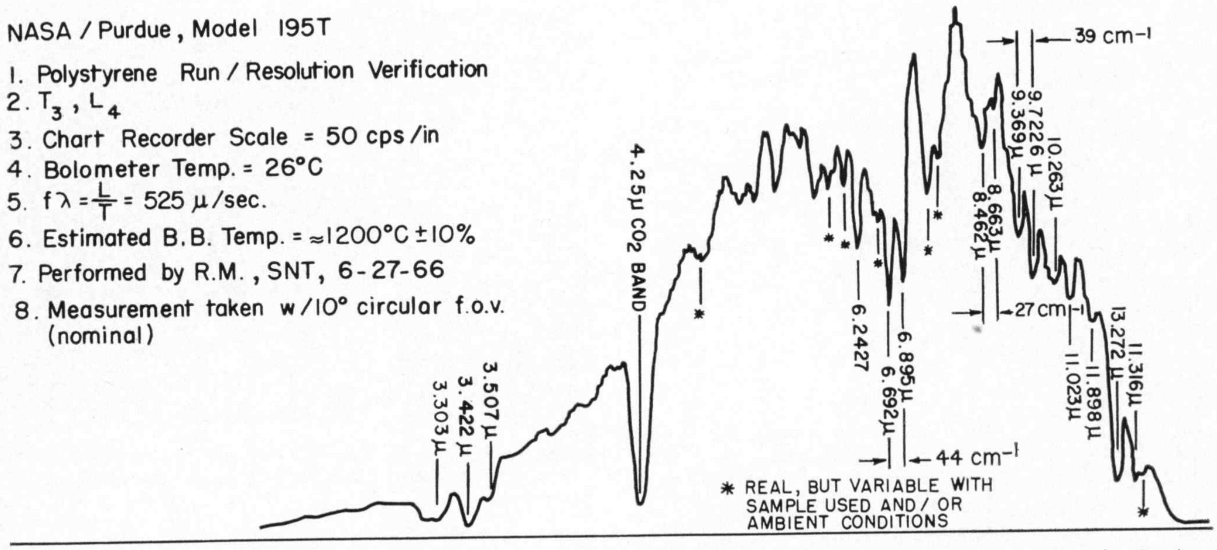


Fig. 37. A calibration sheet of polystyrene by the Block 195T interferometer (performed by Block Engineering Inc.).

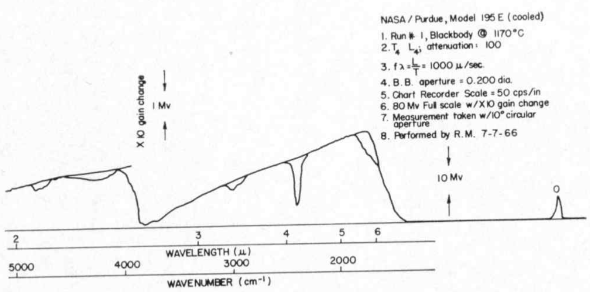


Fig. 38. A calibration sheet of a blackbody at 1170°C by the Block 195E interferomotor (performed by Block Engineering Inc.).

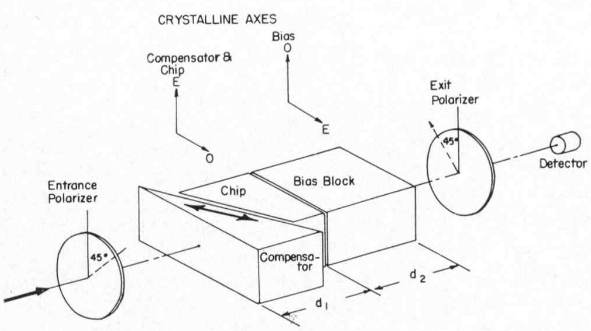


Fig. 39. Diagram of polarization interferometer optics.

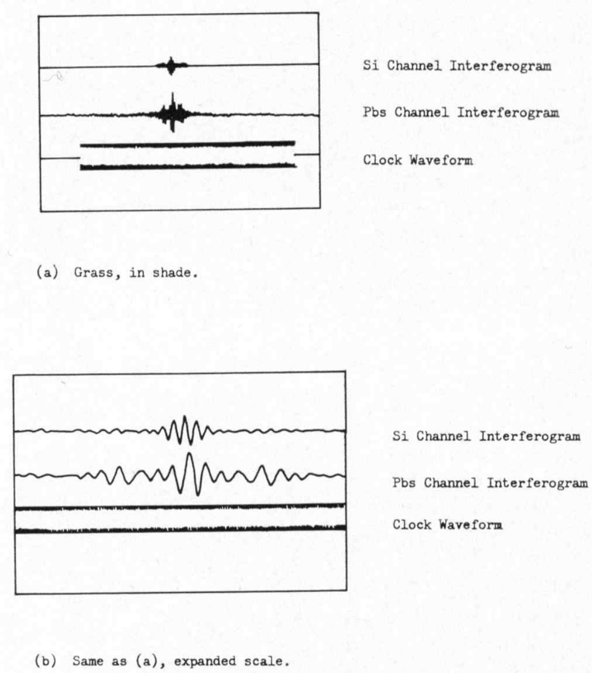


Fig. 40. Block P-4 polarization interferometer signals of shaded grass.

plus-variable attenuator in place of the present gain control would greatly improve gain reset capability. Still, relative instrument response can be measured. Curves of an NBS standard lamp test are shown in Figure 43, and a typical helium wavelength calibration run is shown in Figure 44.

Micrometeorological Equipment: The micrometeorological equipment consists of a system of components designed to sense and record environmental parameters that may contribute to the interpretation of the aerial imagery. The instrumentation system consists of (1) the sensors, (2) signal modules, and (3) a multi-point potentiometric re-

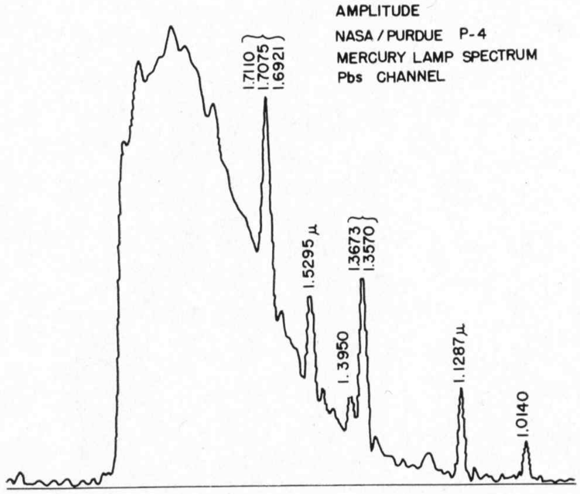


Fig. 41. Calibration sheet of the Block P-4 interferometer using a PbS channel (performed by Block Engineering Inc.).

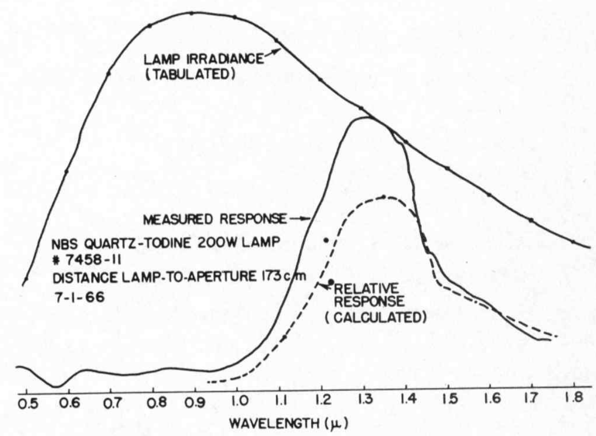


Fig. 43. NBS lamp calibration data on the Perkin-Elmer SG-4 spectrometer. (Vertical scales are all linear relative scales.)

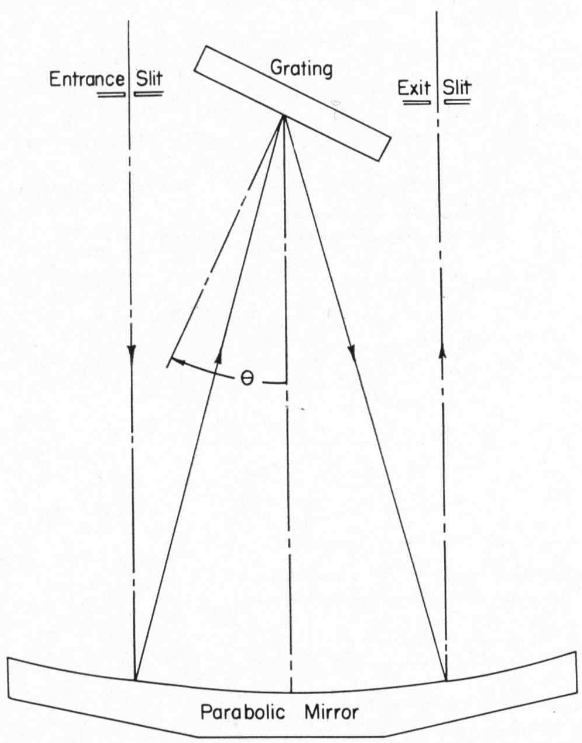


Fig. 42. Diagram of the main optics of Perkin-Elmer SG-4 spectrometer.

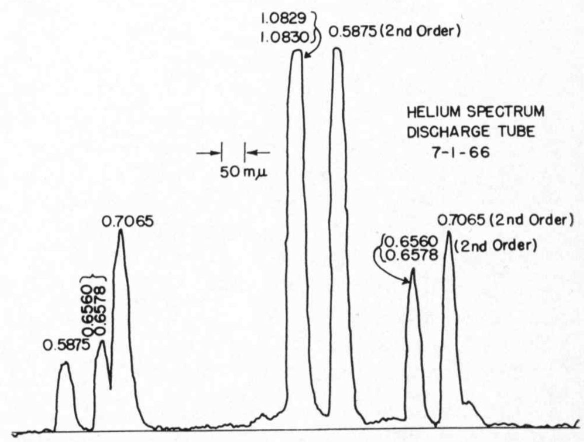


Fig. 44. A typical helium wavelength calibration curve of the Perkin-Elmer SG-4 spectrometer.

corder. The environmental factors measured are (1) radiation, which includes incoming and outgoing solar and long-wave radiation; (2) sensible temperatures; (3) water vapor content of air, (4) wind velocity as the horizontal vector above a vegetative canopy (5) barometric pressure, and (6) soil moisture.

Two instrumentation systems were purchased in 1964 with funds provided by Ns G-715 as part of the sub-contract to Purdue University from the University of Michigan. Each system has a 24-channel Honeywell Multipoint Recorder, a power supply system which can accommodate 24 independent plug-in signal modules, and sensors for measuring the various environmental parameters. The instrumentation system was designed so that any channel could accommodate any signal module, as well as modules which may be developed in the future. Specific reference can be made to spectral discriminating radiation sensing modules, atmospheric gas content modules, or special air movement detectors. Electrical power is supplied by A-C electrical outlets located near the weather station at the Purdue Agronomy Farm.

Within each instrument system the following channels are used for measuring the environmental parameters: Four channels are used for sensing incoming and reflected, or outgoing, radiation. Two channels consist of pyreheliometers which are sensitive over the spectral region of 0.3 to

COLORED PLATES

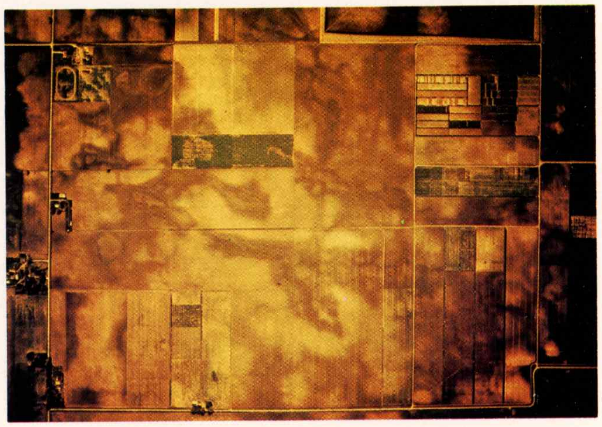


Plate 1. Photo tone variations corresponding to different soil types on the northern portion of the Purdue Agronomy Farm (May 13, 1966).

Plate 2. An oblique aerial view of the Purdue Agronomy Farm and test Area A showing color contrasts of major crops (July 28, 1966).

Plate 3. An oblique aerial view of field patterns in test Area C taken on June 30, 1966. The yellow toned fields in the center of the photograph are mature winter wheat while the bluish colored field is oats.

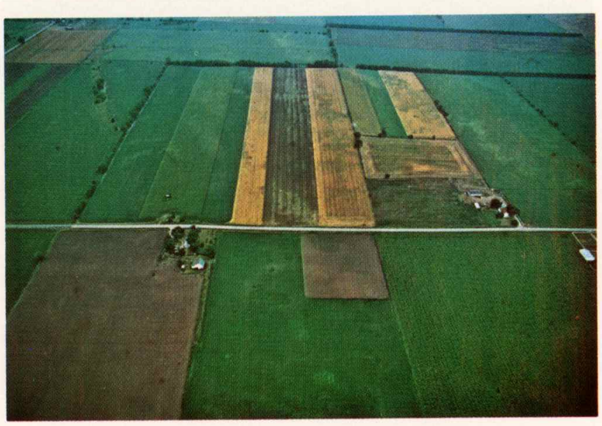


Plate 4. An oblique aerial view on July 27, 1966, of the same general area shown in Plate 3. It is difficult to distinguish between the oats and wheat stubble on this date.

Plate 5. An oblique aerial view of the Sand Experiment Field (July 27, 1966). A key to the specific treatments is given in Figure 3.

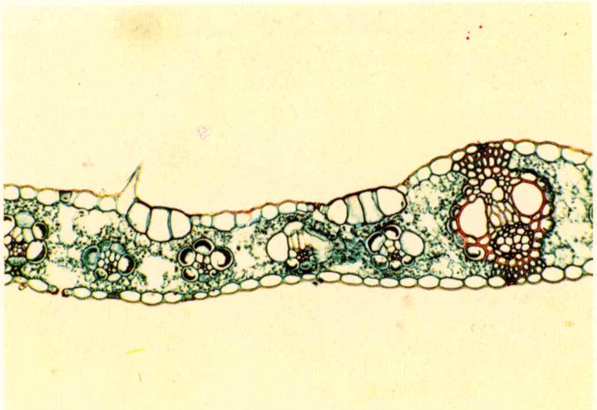


Plate 6. A cross section of the center part of a middle corn leaf with a moisture content of 80.7 percent.

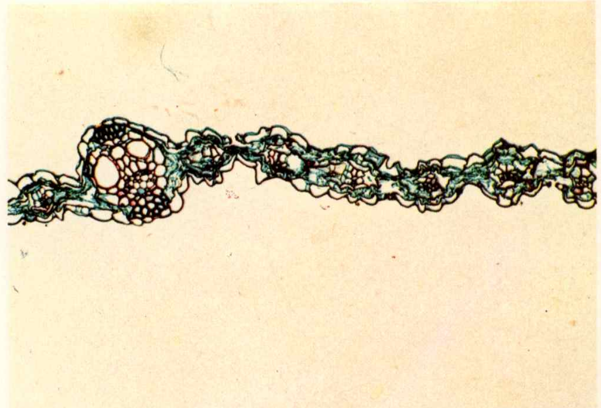


Plate 7. A cross section of the outer tip of a base corn leaf with a moisture content of 60.7 percent.

Plate 8. Micrometeorological equipment set up in a field of oats on Purdue Agronomy Farm.

Plate 9. Vertical photograph of a corn field taken from 50-foot elevation for purposes of estimating percent ground cover (June 27, 1966).

Plate 10. Vertical photograph of a soybean field showing the difficulty of distinguishing between the soybeans and morning glories found between the rows (July 25, 1966).

Plate 11. Vertical photograph of a corn field showing symptoms of severe drought conditions (July 28, 1966).

Plate 12. Vertical photograph of the same area shown in Plate 11 one day later after 1¾ inches of rainfall (July 29, 1966).

Plate 13. An oblique photograph taken for ground truth showing red clover in the foreground. The blue strip above the red clover is oats followed by wheat in the background (June 27, 1966). An oblique aerial view of these same fields may be seen in Plate 3.

Plate 14. Oblique photograph from 50-foot elevation of research plots at the Purdue Agronomy Farm showing soybeans in the lower foreground, wheat variety trials, the gold color at mid-right and oats, the bluish color at mid-left. Note visible differences in the different wheat varieties (June 27, 1966).

Plate 15. An oblique photograph of research plots at the Purdue Agronomy Farm showing alfalfa—lower left, soybeans—large field upper left, non-tasseled corn—dark green upper left, wheat stubble—large field on right, and tasseled corn—upper right (July 29, 1966).

Plate 16. An aerial EKta aero infrared photograph of the Purdue Agronomy Farm showing vegetation contrasts in the fall. The bluish colored areas are plowed fields. Moisture patterns are also evident in several fields.

Plate 17. An aerial EKta aero infrared photograph of the Miller-Purdue Farm showing different grazing intensities on different grass species. Each square area contains several fenced pasture areas with a specified number of grazing cattle.

Plate 18. Aerial oblique photograph of the southwest portion of the Purdue Agronomy Farm showing typical crop colors are the last part of June (June 30, 1966).

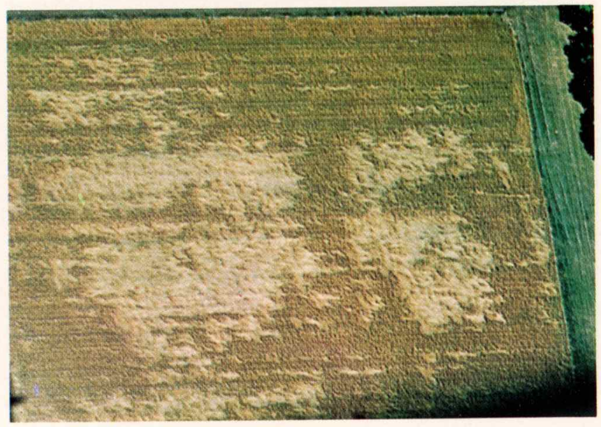


Plate 19. Aerial photograph of a field containing lodged wheat. This field is also visible in Plate 18.

Plate 20. Aerial photograph of the research area on the Purdue Agronomy Farm studied with the SC-4 spectrometer. The yellow truck is the cherry picker and the weather station is located at the lower left. Field crops visible are soybeans, wheat, corn, and oats.

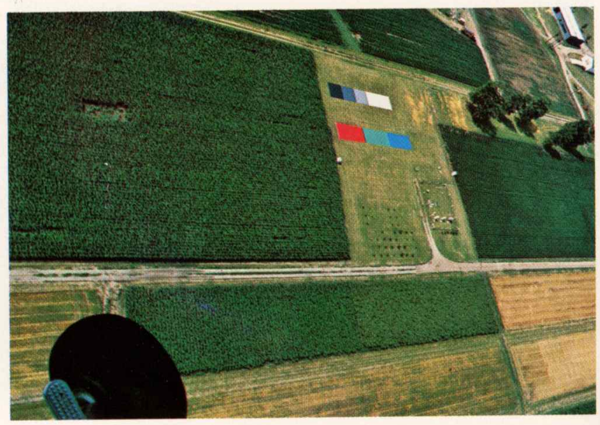


Plate 21. Aerial photograph including the area shown in Plate 20 and the surrounding research plots. The color and gray scale panels used for calibration purposes are located in the center of the photo.

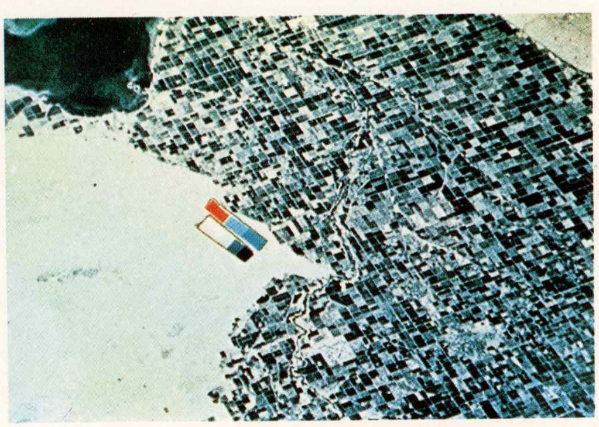


Plate 22. Artist's concept of the proposed Imperial Valley-Salton Sea calibrated test site.

Plate 23. Gemini V photograph of Imperial Valley-Salton Sea region.

about 1.0 micron. One of the pyreheliometers is mounted in an upward orientation, and thereby measured the incoming direct and diffuse solar and sky radiation in the band of spectral sensitivity of the instrument. The other pyreheliometer is mounted in a downward orientation, and thereby measures the outgoing, or reflected, solar radiation.

The other two channels are small hemispherical black bodies acting as radiometers. Thermal transducers sense the black body temperature which can be translated into radiant temperature. The radiometers respond to both solar and thermal radiation over the spectral region of 0.3 to 15 microns. The radiometers are enclosed, and thus are in the general class of non-ventilated total radiometers. Like the pyrheliometers, the total radiometers are mounted in both upward and downward orientation to measure the total incoming and outgoing radiant energy flux, respectively. All the radiometers are mounted above the vegetative canopy.

Six channels are provided for measuring ambient temperatures. Temperature is sensed by means of thermocouples which can be operated in air, soil, or water. Thus, temperature gradients of the air above a crop canopy, within the canopy, and below the canopy, or the soil surface as well as within the soil, can be estimated.

Three channels are provided for measuring the moisture content of the air. The moisture content of the air is sensed by means of a direct relative humidity reading element with maximum sensitivity over the range of 30 to 90 per cent relative humidity. The relative humidity of the air above and within a vegetative canopy can be estimated.

Single channels are provided for measuring soil moisture, barometric pressure, and air movement. Soil moisture is sensed by means of a resistance block which provides a comparative basis for the rate of moisture loss over a given time period. Barometric pressure is sensed by means of a potentiometric pressure transducer and is interpretable as millibars, millimeters, or inches of mercury. Air movement is sensed by a three-cup anemometer mounted above the vegetative canopy. Thus the rate of horizontal flow of air over the vegetation is estimated.

The above described channels do not utilize the 24 channel capacity of the potentiometric recorder. However, as imagery data are related to environmental parameters, the available recorder channels will permit increased emphasis on the most desirable parameters.

Plate 8 shows this equipment set up in the field. Micrometeorological units were located in oats and wheat during the June mission and in corn and soybeans during the July mission.

Ohio State University Radar Unit

Dr. William Peake, Department of Electrical Engineering, Ohio State University, Columbus, Ohio, has used the Purdue Agronomy and Sand Farms for detailed radar studies of various crop types and crop conditions. Some interesting results were obtained in 1965 from studies on alfalfa, wheat, and oats (20), and Dr. Peake conducted studies on corn, soybeans, alfalfa, wheat stubble and bare soil at the Purdue Agronomy Farm and Sand Farm in August, 1966.

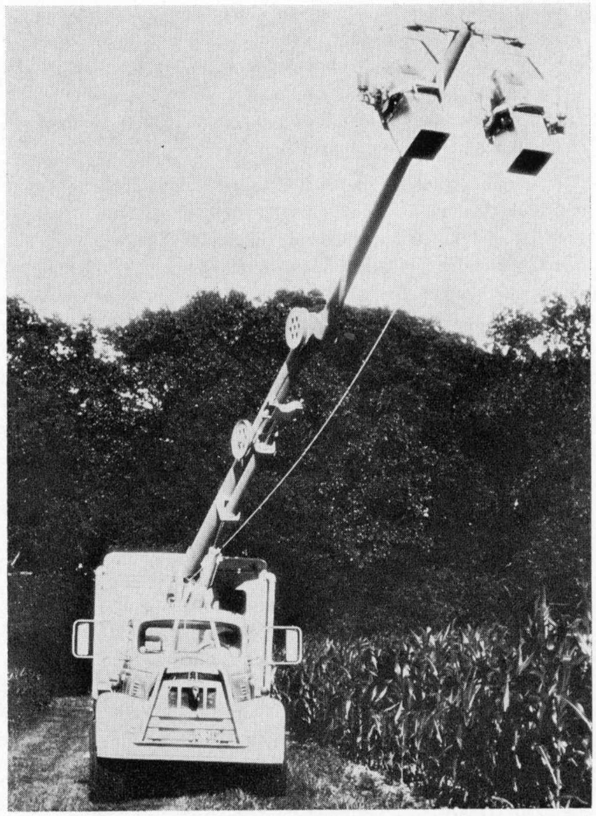


Fig. 45. Radar and passive microwave radiometer truck obtaining data on a field of corn.

The radar system is a side-looking radar with the sensors mounted on a truck boom approximately 20 feet above the ground. The truck moves along the edge of the field for approximately 50-100 feet, sensing a strip of crop area adjacent to the road. Figure 45 shows this procedure. Various angles of incidence from 10° to 80° (in 10° increments) are used, as well as horizontal and vertical polarizations. The radar sensors include the following frequencies: 35 GHz (K $\propto$ Band), 15 GHz (Kμ Band), 10 GHz (X Band), 1.8 GHz (S Band). One passive microwave radiometer sensor (10 GHz frequency) was also used.

Aircraft Data Acquisition

In support of the general program objectives as stated in Chapter 1, the following more specific objectives regarding aircraft data are being pursued at Purdue:

- Comparison of airborne measurements to those measurements taken in the vicinity of targets to determine if models formulated from ground measurements apply in the aircraft situation.
- Development of automatic processing capabilities to analyze large quantities of data collected by airborne systems and to support meaningful orbital experiments.
- Delineation of specifications for operational aircraft remote sensing systems where airborne sensing is most practical.
- Delineation of specifications for meaningful orbital experiments.

Investigations are being conducted to determine the characteristics of suitable remote sensing instrumentation for aerospace systems. Such sensors are to operate in the various atmospheric transmission windows from near ultraviolet wavelengths through the infrared region to some 14 microns and radar wavelengths.

At present a single aperture, optical-mechanical scanner configuration as the principal data source, and a photographic system to supplement the scanner data, has been found desirable in this phase of the research program. A principal reason for choosing this is that the spectrum covered by the optical-mechanical scanner (0.3μ to 14μ) appears to contain the greatest information about agriculture targets. Also, automatic processing of the data from this type of sensor appears to be feasible. The purpose of the photographic coverage is to complement the scanner data and to aid in preliminary investigations in the research situation. While a major effort will be devoted to the use of data from this configuration, the investigation of other data sources will continue.

During the 1966 growing season the major aircraft data source for Purdue was operated by the Willow Run Laboratories at the University of Michigan's Institute of Science and Technology. The configuration of the Michigan data collection system closely resembles the one described above. The one difference is that the Michigan optical-mechanical scanner system has four apertures instead of one aperture. The photographic system in the Michigan plane includes coverage on Panchromatic, Aerographic IR, Color, and Camouflage Detection film. This photographic data gives adequate coverage to supplement the scanner data and to aid the ground truth program.

Four flight missions were planned for the 1966 growing season. A checkout mission in May and data missions in June, July, and September were scheduled. These months were chosen, as in 1964, to observe crops in various stages of growth. Also, as on each 1964 mission, data were obtained in the early morning, midday, late afternoon, and night, at various altitudes. The flight paths were designed to be over all important Corn Belt crops in areas where ground truth could be obtained. These areas include the Purdue Agronomy Farm, the Purdue Sand Farm and privately operated farms in the Purdue area which were not under the supervision of this project.

At this point in the program the occurrence, or reoccurrence in some cases, of special problems of importance to the agricultural remote sensing program stand out. Current consideration of these proplems will speed success of the program in succeeding years. One such item is the availability of the airborne data to the researcher. Late delivery of data impairs mission-to-mission planning. At this writing very little visual data (photographs and scanner strip maps) have been made available for preliminary analysis prior to succeeding missions. If these data were immediately available after its acquisition, or at least prior to succeeding missions, necessary changes in future missions could be made. Thus, mission-to-mission improvements of the data gathered would be possible instead of year-to-year improvements. The inability to make a preliminary analysis also necessitates an attempt at the collection of all possible related data complicating the collection of ground truth. Some ground truth can be obtained after its need is known based on early (one to two weeks) interpretation of airborne data. The difficulties associated with obtaining ground truth two and three months after a mission are obvious.

A second item is the availability of the aircraft to the researcher. As a result of the Viet Nam War and other world military situations, the Project Michigan and Wright Patterson Air Force planes are even now heavily committed to military research programs, and it is conceivable that they could become entirely unavailable to civilian remote sensing programs. Also, the scheduled commitments of these aircraft are such that they cannot be easily changed. As a result of this, bad weather hampers some of the data gathering process. Also, some situations occur during the growing season which are of interest but which do not occur at the time of pre-planned missions. In the future, situations such as a killing frost in late spring or widespread disease should be investigated as they occur.

It is evident that there is now a need for aircraft exclusively responsible for the research needs of the agricultural remote sensing program throughout the country. At this time NASA is providing two test planes for the Natural Resources Program. A survey of this reference will reveal that the proposed sensors aboard the NASA planes do not include the desirable configuration required in the Purdue program. And the number of proposed test sites seems to indicate only limited coverage in any one research area. A better solution may result from present plans of USDA to equip an available plane now being used by the U.S. Forest Service. Since such a plane is under control of USDA, some of the above problems would become nonexistent. However, when taking into account all possible future test sites in Agriculture, such as California, Texas, Florida, Oregon, Indiana, and others, this aircraft also will be overcommitted in the not too distant future.

A single-aperture, optical-mechanical scanner to collect data in various intervals throughout the optical frequency interval (0.3-14 microns) must be a fundamental sensor on the USDA controlled plane. The output of the present four-aperture system leads to unnecessarily expensive data handling. Roughly, the cost of data handling can be multiplied by the number of apertures, making the current system four times as costly as a single-aperture device. In addition the data from a four aperture device is degraded since exact correlation of data from each aperture is impossible.

Ground Truth Data Collection

Introduction: The primary role of ground truth information is to support the analysis of the multispectral data, particularly the data obtained from the aircraft flights. Ground truth as used in this report refers to both the description of crops and the biological, physical, or meteorological factors which may influence the reflective or emissive radiation sensed by remote multispectral equipment of any type. One of the primary problems of the ground truth work is to determine which information is essential to support the program, and which additional data may prove valuable. The ground truth obtained in support of the 1966 flights has been based on past experience gained in the 1964 and 1965 flights, and experiments.

Primary Agricultural Field Data Forms and Field Identification: Separate data forms were kept for each field on the major flight lines in area A and area C, the Agronomy Farm and the Sand Farm. Information on the size of field and soil types could be filled in before going to the field. Some information was obtained by observation, and the remaining was obtained by personal interview with the farmer or researcher in charge. Data are recorded on a format that allows putting all such ground truth information onto computer punch cards. This procedure helps group agricultural fields of similar characteristics for the pattern recognition phase of the research.

To help obtain accurate records on each field in the flight line areas a numbering system was devised so that each field could be identified by a unique number (field designation) on the data form. Figure 46 is an aerial photograph of a part of Area C showing the method used to delineate and label each field of interest. The identifying letter and first set of numbers refer to the flight area and the section in which a particular field is located. The last numbers identify each field within that 640 acre section of land. An example from Figure 46 would be C-32-6, which refers to flight area C, section 32, field 6. This system allows for expansion of flight lines in the future to other areas, in which case the present flight area label could be replaced with a state, county, and township identification.

It would seem that numbering the fields in a section would be a simple task. However, since the farmers do not have fences around individual fields except in certain cases, as for separation of pasture from crop land, individual field boundaries frequently could not be determined until crop vegetation was of sufficient height for identification. Government acreage allotments and crop rotation programs often determine the location and size of corn, wheat, and soybean fields. Such factors may cause the field boundaries to change from year to year, and

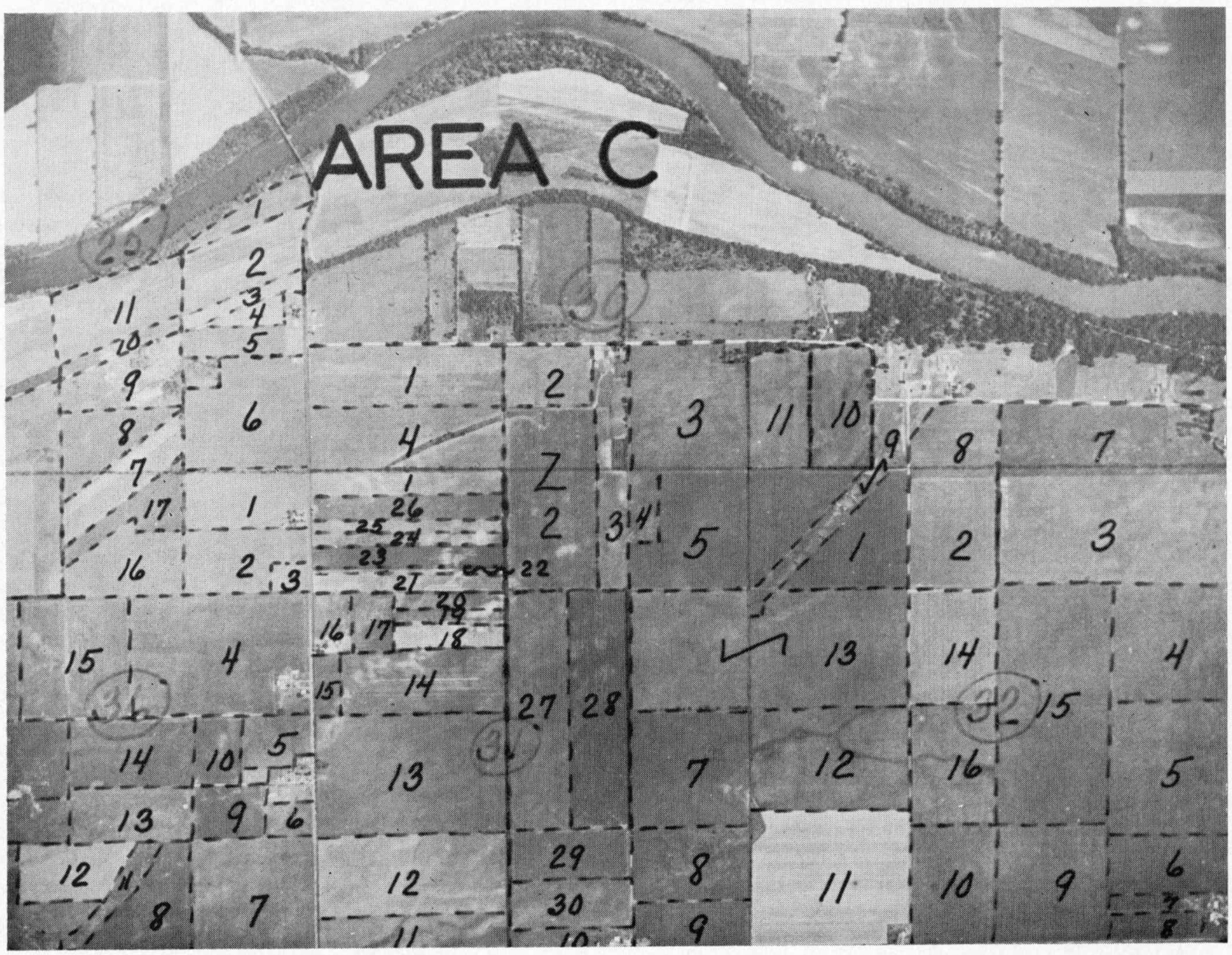


Fig. 46. Annotated aerial photograph (taken at 10,000 ft.) showing field separation and number system used for identifying individual fields in ground truth measurements.

may cause an initial early season series of field boundaries and numbers to be changed during the growing season as crop areas become apparent. As seen in Figure 46, there are often rather irregularly shaped fields and fields with unusual field patterns due to various farming practices. High altitude photographs (10,000 feet) taken in late June or July appear to be satisfactory for proper identication of field boundaries.

Information Recorded: Data recorded at the times of flights for all fields either on the experiment farms or elsewhere included crop species, row width and direction, height of crop, percentage of crop cover, general crop condition, and any special field conditions observed. Such measurements necessarily involve the establishing uniform methods for taking these data, particularly since different people were involved in gathering these data. For example, in measuring crop height for the late July flights which occurred when the corn was tasseling, should one measure to the top of the tassel, (if present) or only to the height of the top leaf? Can techniques be established to allow a more quantitative method for estimating the per cent of ground covered by a crop? For a short crop, one could look down and obtain a qualitative estimate of how much of the soil was hidden from view in several square foot areas. Such qualititative estimates were found to vary greatly from person to person among those obtaining this ground truth. In a taller crop, such as full grown corn, a man on the ground could simply not make a reasonable estimate of per cent of ground cover because the corn plants were taller than the man. In this case, a cherry picker (see Figure 47) proved very useful in that it enabled one to obtain a vertical view of even the tallest crops. The cherry picker also allowed a permanent photographic record of ground cover to be obtained from the various crop types at intervals throughout the growing season. A more quantitative estimate of ground cover of crops such as soybeans is also possible by measuring the row width and the width between the rows, and determining percentage of ground covered (row width as a percentage of the total row width and distance between the rows). Controlled plant population and crop density plots on the Agronomy Farm were carefully photographed so that more reliable methods of estimating such ground truth variables can be developed for future work.

The Agronomy Farm allowed study of many factors known or believed to affect response on multispectral imagery. Plots of different varieties of wheat, oats, soybeans, corn and other crops in close proximity to each other were photographed from both the cherry picker and a small airplane, and were closely observed. Fertility rate studies on several crops resulted in various height and color relationships which are of interest in remote sensing studies. Different planting techniques, such as uniform rows, various row widths and direction, broadcast seeding, evenly spaced plants, and drilled seedings, were also measured and photographed. Other plots used in such studies as turf management, chemical weed control, and disease conditions in oats and wheat were photographed, and appropriate data obtained from the researchers in charge.

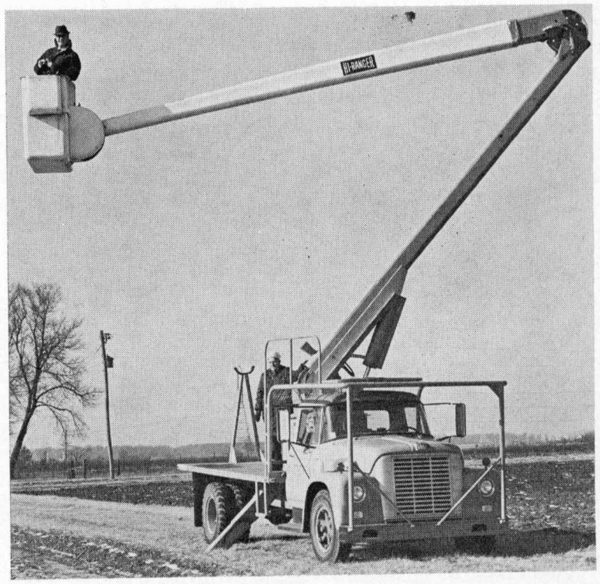


Fig. 47. Mobile elevated platform used extensively for obtaining descriptive and photographic ground truth data as well as spectral signature work.

During the flights, surface moisture measurements were made at the Agronomy and Sand Farms with a Troxler Neutron Surface Probe. Such data were obtained in many fields, especially where differences in soil type occurred. During the July flight, plant samples were taken from selected fields for use in crop moisture determination in conjunction with the surface soil moisture measurements. Samples were also taken for DK-2 spectroreflectometer and moisture determinations. Reflectance measurements were made on numerous varieties of several crop types. This phase of the program, as well as the collection of micrometeorological data, have been described previously in this chapter.

At the Sand Farm 2-inch diameter aluminum tubes were placed in each treatment area to allow measurements of the soil moisture three feet deep. Each week throughout the growing season, the Troxler Neutron Probe was used to obtain soil moisture measurements at 6 inch intervals of depth for all tube locations. These readings, along with surface moisture readings, were also taken at the time of each flight. Height and per cent of ground covered by the crop were taken every week, as well as at the times of flights. Temperature measurements at 5 centimeter depths below the soil surface, at the soil surface, and at 30 centimeter intervals above the surface were taken at the time of all remote sensing overflights. Leaf samples were taken from both irrigated and nonirrigated treatments of each crop for DK-2 spectroreflectometer measurements and moisture content determinations. Color photographs were taken from the ground of crop appearances during flights and throughout the growing season.

During the first week in August, Dr. William Peake, Department of Electrical Engineering, Ohio State University, brought a truck-mounted radar and passive microwave radiometer unit, previously described, to the Purdue Agronomy Farm and Sand Farm for further studies of agricultural crops.

This radar study was supported by ground truth measurements on crop and soil moisture for each of several crop species. Both surface and depth measurements of soil moisture were recorded. As is the usual procedure for crop moisture determinations, plant samples were taken and weighed, dried in an oven at 74°C for 48 hours and then weighed again. From these data, the percentage of moisture content can be obtained. At least four samples were taken from each crop area for this determination.

Photographic Recording of Crop Conditions: In earlier remote sensing work crop conditions were often very difficult to describe accurately, particularly crop maturity, the presence of several plant species (as in pastures), or the presence of nonuniform conditions for numerous other reasons. In such circumstances, photographic records of crop and field conditions are extremely useful. These photos are particularly useful in attempting to explain variations in response found on the remote multispectral imagery, especially since analysis of such imagery is often not completed until months after the imagery was obtained.

Ground truth photographs are taken with four 35 mm cameras. Kodachrome II, Ektachrome Infrared Aero (or camouflage detection film), Plus X (black and white) and black and white infrared film types are used to record the various field scenes of interest. Kodachrome II has been used extensively on this project. Such photographs have been taken from the mobile elevated platform or (cherry picker) see Figure 47, and a small single engine aircraft.

The lift bucket of this cherry picker can be elevated to 55 feet. From this height agricultural fields can be photographed from vertical and oblique angles. Vertical photos from this elevation are an excellent means of permanently recording the ground cover of various crop types at intervals throughout the growing season, as seen in Plates 9, 10, 11, and 12. Particularly note the differences seen in Plates 11 and 12, which show the same portion of a corn field on two successive days. Oblique photos from this altitude are also useful for recording crop conditions, as observed in Plates 13, 14, and 15.

The cherry picker can move between the fields on the narrow roadways at the Purdue Agronomy farm. Thus, vertical shots over fields at the Agronomy farm are relatively easy to obtain. Problems occur in areas such as A and C, where ditches on either side of existing roads keep the cherry picker about 20 feet away from fields of interest. In many instances when the bucket is necessarily extended at 90 degree angles over telephone lines, electric lines, and fences, only end rows can be recorded at vertical angles. End rows of the crops are many times quite different from interior rows, and therefore do not represent conditions throughout the field.

As a result of these difficulties, more complete and representative coverage is obtained from small aircraft. A Cessna 174 is chartered from a local airport to fly over test sites. Oblique and vertical views are achieved by removing the door on the aircraft. This allows the photographer to fly over the very center of large fields to record the crop cover. This enables data to be obtained that could not be gathered either on foot or from the cherry picker. Such photographic coverage has been primarily obtained at 500 and 1,000 foot elevations. Plates 18, 19, 20, and 21 are representative examples of this type of photographic data.

At the conclusion of each ground truth photographic mission, the film is returned to the photographic facilities at the Laboratory for Agricultural Remote Sensing for processing. In the case of both black and white infrared and panchromatic film, the processing is accomplished with a daylight loading tank in a relatively dust-free environment. Water temperature control is set at 68° $\pm$ 0.5° Fahrenheit. Kodachrome II film is sent to a local processing firm which uses automatic processing machines, electronically controlled for temperature and chemical replenishing. The Kodachrome II processing color balance has been reasonably true for existing light conditions. Difficulty has been encountered, however, in obtaining the necessary custom processing for the Ektachrome Infrared film. A capability for processing all camouflage detection film was developed by the Laboratory Photographer. Examples of the film are shown in Plates 16 and 17 of the Purdue Agronomy Farm and the Miller-Purdue Farm, respectively.

Additional Photographic Capabilities: The laboratory dark room is small, being primarily a custom lab. Some of the present capability includes contact printing of negatives as large as 9" x 18", though most of the material received from current flights is no larger than a 9" x 9" format. Each photograph is manually dodged to compensate for any "hot spots" in the center of the film and areas in the corners. After exposure, the print is processed through the standard processing cycle. This 9" x 18" printer is also capable of contact printing narrower film widths.

Other photographic work, such as copying, is done with a 4 x 5 view camera with swings and tilts. This is particularly useful for photographing mosaics of flight areas. Such capability is also useful for the reproduction of line drawings, charts, graphs, and aerial of satellite photos used by the Labortary.

For 35 mm slides, techniques are being developed to better illustrate black and white line drawings as well as increasing color quality for artwork displays, color copy work, and photos obtained in the field showing crop conditions. Color printing and enlargements of areas in the test sites will be needed to analyze or verify computer findings.

Mounting of photographic illustrations, both black and white and color, is accomplished through a dry mount process.

Orders have been placed for an enlarger or a print drier, both of which are necessary for much of the work required by the remote sensing program.

CHAPTER V
Data Handling and Analysis

Introduction

This section of the report describes the work of the data group. This group was established in February 1966 (a) so that the availability of appropriate quantities of data in formats usable by researchers is assured, and (b) to develop suitable equipment so that the data processing capability can grow at a rate commensurate with the rest of the remote sensing program. In addition, this group is engaged in analysis and reduction of data.

It is appropriate to define three terms for use in this report: data handling, data reduction, and data processing. As here used the term data handling refers to the more or less mechanical operations changing data formats. (e.g., analog-to-digital conversion, tape-to-punched card conversion, or data editing) so that they are in a more suitable form for research purposes. The data editing problem discussed below is a prime example of a data handling problem.

The terms data reduction and data analysis (synonymous terms) will be used in this report to refer to any mathematical methodology by which research results are obtained from data. Examples of data analysis techniques are spectral matching and the automatic pattern recognition techniques to be discussed below.

The term data processing will be used whenever reference to the combination of both data handling and data reduction is intended. It is apparent that a successful remote sensing program requires careful attention to the data processing problem, and also that different technical skills (and therefore probably different personnel) are required for data handling research as compared to data reduction research.

There are a number of posssible approaches to the data reduction problem. These include spectral matching techniques, photo interpretive techniques and automatic pattern recognition. Each approach has its advantages, and probably all will be successfully applied to different phases of the agricultural remote sensing problem.

The data group at Purdue has particular competence in the area of automatic pattern recognition and has begun work on developing these techniques for appropriate portions of the agricultural problem. Pattern recognition techniques are particularly suited to problems in which the quantity of data is so large that entirely automatic procedures are required. The next portion of this chapter describes this approach in a non-mathematical, tutorial fashion.

The major portion of time and effort of the data group since February has been devoted to data handling techniques, however. This was done in order that adequate data handling equipment and techniques would be available to all agricultural remote sensing researchers as soon as possible.

Data Reduction

What is Pattern Recognition: It is appropriate to discuss pattern recognition here for at least three reasons. First, it will help establish the terminology to be used in this and subsequent reports. Second, it will give insight into the magnitude and the details of the data handling problem. Third, and most important, it will provide details on this approach to the automatic reduction of data.

Generally, the term pattern recognition (PR) as used in the technical literature refers to the development of techniques and equipment for the automatic recognition of patterns. The emphasis here is on automatic since this field has been developed to handle problems in which the large quantity of data demands the complete reliance upon a machine for classification.

There appear to be similarities between pattern recognition and photo interpretive techniques (PI). As with photo interpretation, pattern recognition requires the development of a key, a set of tests which are to be carried out on a candidate pattern to determine its correct classification. The similarity ends at this point, however, due to the nature of the set of tests in the two cases. For photo interpretation, the tests are usually relatively sophisticated and require human attention. On the other hand, the purpose of pattern recognition is to permit the complete removal of man from the process in order to be able to process data faster.

Some Examples of Pattern Recognition: To further clarify what is meant by the terms pattern and pattern recognition, a number of examples of current and important problems are presented.

Probably the first thing that comes to mind upon hearing the term pattern recognition is the problem of the recognition of various geometrical patterns. Examples of this type of problem are

- Reading of typed, printed, or handwritten text.
- Recognition of a person from his handwriting.
- Distinguishing manmade from natural objects on aerial photographs.

But pattern recognition is by no means limited to these cases, as evidenced by the following examples:

- Recognition of the spoken words from various speakers (e.g. human voice to computer communication).
- Recognition of a speaker regardless of the words spoken.
- Recognition of an environment or situation in which a system is placed (important for adaptive automatic control and learning systems).
- Recognition of the location of faults in complex electronic systems.
- Character or signal transmission-recognition over lines of communication, e.g. communication between computers.
- Target identification of aircraft, submarines, and

missiles, and separation from decoys using radar, sonar, etc.

- Recognition of fields of agricultural crops and their condition and state of growth from aerial observation.

The Pattern Recognition Device: The problem of designing devices which classify patterns requires two main investigations. The first investigation involves the problem often referred to as "feature extraction," i.e. operations on the pattern which determine its significant characteristics. The second investigation involves the decision making device which classifies the pattern on the basis of the comparison of characteristics (both the similarities and differences) with those of a reference set of patterns. We now look at each of these problems in more detail.

Generally, in a pattern recognition problem there are a number of measurable quantities which are used to characterize the patterns. The optimum choice of these quantities (called features) represents the "feature selection" problem mentioned above. This problem, by no means a trivial one, is as yet unsolved and in fact lies as the major stumbling block to the total unification of all the applications of pattern recognition. Often the designer must use his intuition based on some prior experience to choose what seems to be a suitable set of features. On the basis of these features, studies are undertaken to determine the best decision or classifying strategies to employ.

In accordance with this subdivision of the pattern recognition problem into two subproblems, the recognition device is generally designed in two parts. One part is called the *receptor* and the second is the *categorizer*. A simple block diagram is shown in Figure 48.

The input to the receptor is the pattern to be recognized. The receptor, through various sensors, performs the task of measuring the chosen features. The output of the receptor is a vector (called the measurement or feature vector), the components of which denote the various feature measurements.

The categorizer portion of the recognization device is responsible for assigning a given input pattern to a class on the basis of the measurement vector. The designer constructs the categorizer to obtain the "best" possible recognition of the patterns to be classified. The term "best" used here refers to the best performance as indicated by the measure of goodness chosen by the designer. It should be noted that the optimum design of the categorizer in a particular problem is carried out with respect to a given set of features. To obtain the best *overall system,* it is necessary to then optimize overall sets of possible features.

Perhaps the following example will be helpful in visualizing the operation of a pattern recognition device and the function played by its components. Consider the problem of remotely sensing whether a given field contains wheat or corn or alfalfa. Assume we have decided that the percentage reflectance of electromagnetic energy in certain selected regions of the spectrum are the features. This choice of features could have been arrived at, for example, by examining the characteristics of the various crops as they would appear from the air. The receptor portion of

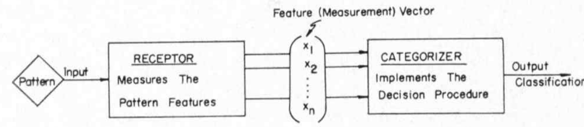


Fig. 48. A block diagram of a typical pattern recognition device.

the pattern recognition device then measures the percentage reflectance in the selected spectral bands.

Let x_1 be the percentage reflectance in band one, x_2 in band two, . . . x_n in band n where n is the total number of features measured.

The ordering of these features form a measurement vector $X = (x_1, x_2 \ldots . x_n)$ and on the basis of this vector the categorizer is then to decide if the field is wheat, corn or alfalfa.

We will examine this example further to introduce the concept of a measurement space or feature space, and then show how some of the common types of decision criteria can be represented in this space.

To represent a feature space easily on the plane of the paper, let us consider the situation in which we only measure two features (i.e. reflectance in two spectral bands). Thus the feature vector contains only two components $X = x_1, x_2$).

The receptor then represents each point on the ground examined (at its input) by two numbers (at its output). To start the process we might examine ten sample points each of wheat, corn and alfalfa, then plot and label the classification of each sample. Figure 49 shows a set of results which might be obtained. These known samples then constitute the reference set of patterns to which are compared the patterns of unknown fields. Obviously, this reference set must be large enough, and carefully selected so that the set is typical of all future patterns to be classified. In practice the selection of this set is crucial and takes great care and judgment. The point labeled U in Figure 49 represents the feature vector of an unknown field whose classification is to be determined.

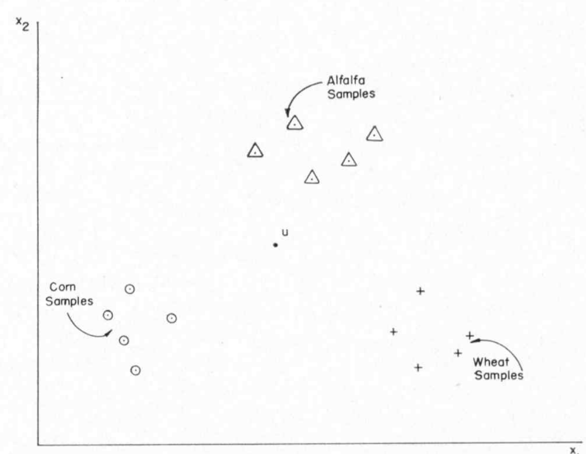


Fig. 49. A hypothetical example of corn, alfalfa, and wheat samples in a two dimensional feature space.

The job of the categorizer begins at this point. That is, to classify the unknown field on the basis of its representation in the chosen feature space. Many methods for making the classification have been proposed and studied in the technical literature. We will mention only a few here to illustrate the approach.

A. **Minimum distance to the means criterion**—According to this approach the mean of each known class is found and represented as a point in the feature space. The pattern is then classified into the class whose mean is closest. This criterion then divides the space into three regions for classification as shown in Figure 50. Then if the feature vector for the unknown field falls in regions A, C, or W, it is classified as alfalfa, corn or wheat, respectively.

B. Minimum distance to the nearest member of a class—According to this criterion the distance from the unknown pattern to each reference pattern for each class is determined and the minimum distance found. The unknown pattern is then classified into the class containing the member nearest it. As before, this decision criterion divides the feature space into decision regions. A graphical representation of this is shown in Figure 51.

In these first two classification schemes the assumption is made that the classes are sufficiently represented (characterized) by the known reference sample patterns. Specifically, in the example being considered it is assumed that the 10 reference samples of each class are sufficient to characterize the various classes. (Usually literally thousands of reference samples are necessary for this purpose.) The justification of this assumption is a problem in its own right. As will be seen, this same assumption is employed in the third method of classification to be discussed, but in a slightly different way.

C. **Statistical pattern recognition** — Assume for the moment that we have three joint probability density functions, one each for the classes wheat, corn, alfalfa. Let each represent the probability that the representation in feature space for a sample of the particular class falls in a given region of the feature space. Therefore, we might have the three density functions shown in Figure 52. For each category of interest, a set of likelihood ratios can be computed. These likelihood ratios express the relative probabilities that a point in question belongs to the category of interest rather than to any of the others. Thus, points in the feature space are assigned to the class for which the probability of occurrence of that point is the largest. Figure 53 shows the decision regions which

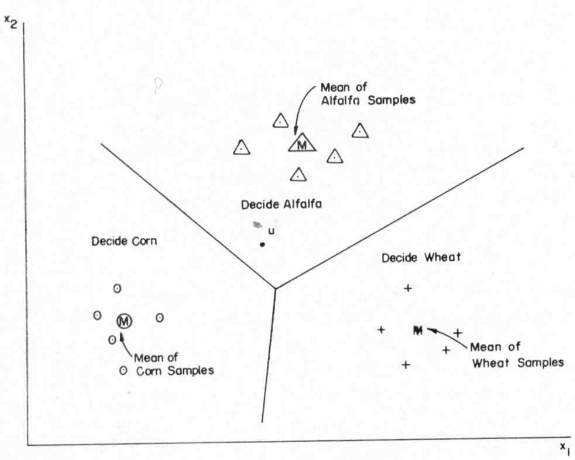


Fig. 50. Decision regions of minimum distance to means criteria.

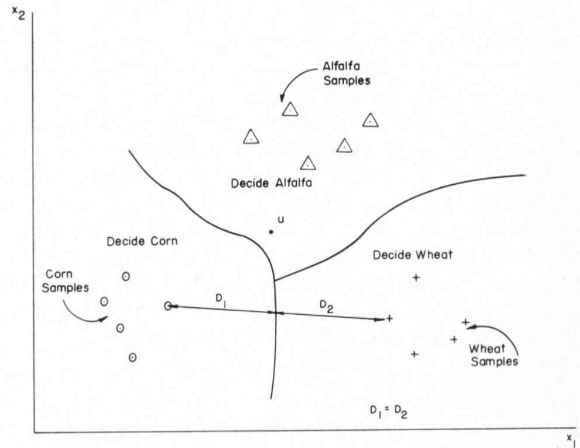


Fig. 51. Decision regions of minimum distance to the nearest class criteria.

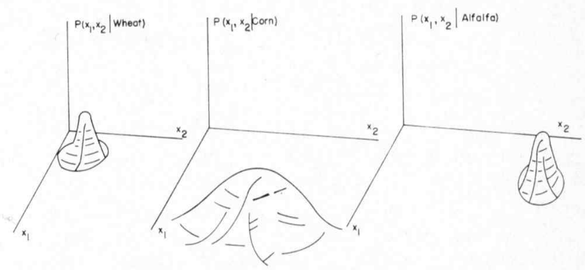


Fig. 52. An example of the probability density functions for wheat, corn, and alfalfa.

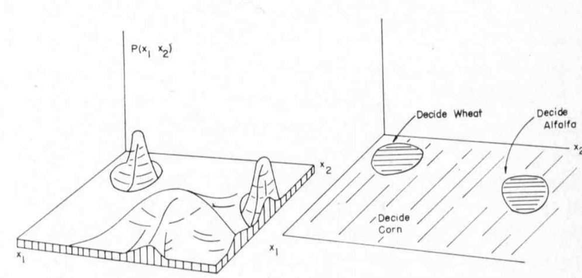


Fig. 53. Density functions and decision regions for a statistical approach.

might be obtained by this approach. It should be noted that most, if not all, optimum statistical decision criterion can be put in the form of a ratio criterion such as this.

We return for a moment to the problem of obtaining the joint distribution functions, and see how it is connected with the basic assumption discussed above. The knowledge of the density functions could come about in one of two ways. (1) The probability densities are actually known, say through some theoretical study. (2) If the probability densities are not known, this knowledge must be gained by taking samples of each class, employing the basic assumption that the number of samples taken are sufficient to characterize the classes. This means that the sample size is large enough to construct the probability densities required.

Using the geometrical interpretation of making classification decisions outlined above, we can summarize the discussion of the operation of the categorizer as follows. The feature space in which events are represented by points is divided into non-overlapping regions, one region corresponding to each of the categories. A classification decision consists of assigning to each candidate pattern the name of the category associated with the region in which the event is located.

Again, in practice, considerable judgment and experimentation are usually required to select the best categorizer approach for a given recognition task. A given categorizer may work well on one problem and not on another. Or two different ones may have the same error rates, but one may make different types (more costly?) of errors and for different reasons.

One final comment about the amount of data required. The agricultural remote sensing problem is one in which recognition tasks must be carried out under a tremendously varied set of conditions. There are atmospheric conditions, soil moisture variation, soil type variations, percent ground cover variation, crop development variations, and many more. If correct recognition is expected in the face of all these variations, then it is only reasonable that data for design of the recognition devices must be available from as many permutations and combinations of the background conditions as possible. This is true with the automatic pattern recognition approach and with any other.

Further, the automatic pattern recognition approach to design was conceived to be used in situations of unpredictable variabilities. It is concluded from this that (1) pattern recognition is an appropriate technique to try on the problem and (2) a very great amount of data for design purposes will be needed.

Data Reduction Work Planned: As soon as quantities of aircraft data become available in digital form, extensive experimentation and research is planned with automatic pattern recognition. It is seen from the previous section that this work must be carried out as two (parallel) investigations: receptor study and categorizer design.

It should be emphasized here again that the categorizer examples discussed above were selected to convey the concept of this approach. They are not necessarily the best choices for this problem nor the ones to be used. Categorizers may be of several different types, for example,

A. Deterministic Techniques (that is minimum distance to the means criterion and minimum distance to the nearest member of a class).
   (1) Linear
   (2) Nonlinear
B. Statistical Techniques (that is statistical pattern recognition).
   (1) Maximum likelihood
   (2) Bayes
C. Sequential Techniques
   (1) Forward
   (2) Backward
   (3) Deferred
D. Stochastic Automata

All of these will receive some consideration.

The receptor studies will be pursued not only with aircraft data but also DK-2 Spectroreflectometer, SG-4 Spectrometer and Block Interferometer data now being gathered. Actually these studies are already under way and some preliminary results appear elsewhere in this report.

The DK-2 data, which is taken in the laboratory under highly controlled circumstances, presents an excellent opportunity to test various receptor approaches and study plant reflectance when the number of parameters not subject to control is a minimum. The SG-4 and Interferometer data gathered in the field presents a situation one step nearer to the aircraft environment.

In addition to and in support of these pattern recognition studies considerable standard statistical analysis is either under way or planned, using all three types of data (laboratory, field and airborne). These include (1) distribution and density function estimation, (2) estimation of such statistics as the means, variances and covariances of the feature vectors and (3) determination of correlation of various spectral bands with various parameters such as moisture content. Again some preliminary results on these studies appear elsewhere in this report. Detailed results will be presented at a later date.

Data Handling

Introduction: As previously stated, the two functions of the data group are to be data handling and data analysis. Of these two, by far the greatest portion of time in the first seven months after the group was formed has been spent on data handling. This is because data analysis research cannot begin until at least a first generation data handling system is operational.

There are at least nine types of data being gathered or to be gathered as follows:

- Aircraft Scanner Data
- Primary Agricultural Field Data (Ground Truth)
- DK-2 Spectroreflectometer
- SG-4 Spectrometer
- Block Interferometer
- Photographic (Ground and Airborne)
- Micrometeorological
- Insolation
- Radar

Consideration has been given to the processing of each of these, including cataloging and storing. By far the most complex data handling problem arises from the aircraft scanner data, and a great deal of time and work has been devoted to it. In particular, the editing of the multispectral scanner data will be seen below to require some type of visual display of digital imagery. This editing capability is the most difficult capability to achieve, and the entire data system is built around the hardware and programming to accomplish it.

The following sections describe the work of the data group in planning and procuring a suitable data system and devising suitable interim measures until the data system is installed.

Planning: The entire data handling task of remote sensing research may be divided into two broad categories: (1) data formating and editing, and (2) computation. Included in the first category is the conversion of data from the form in which they occur at the sensor output to a form useful for analysis and computation. The first category also includes the more difficult airborne scanner data editing operation. For example, it must be possible to select from airborne multichannel scanner data that specific part which comes from a particular wheat field or even a particular part of a particular wheat field.

In the second category is included the many and varied types of computation which the data analysis researchers wish to carry out. Examples of these are various statistical analyses, automatic pattern recognition, and perhaps color reconstitution.

The data group began its work by considering what type of data system would be the most suitable for the many research phases of the agricultural program. The digital approach was chosen as the most desirable for the following reasons:

A. **Flexibility.** It is easy to merge different types of data in digital form; e.g., multichannel scanner imagery and ancillary information. It is also possible to make changes in computational approaches and procedures, changes dictated by research results, without making extensive hardware changes.

B. **Compatibility.** Data stored in digital form, perhaps on digital magnetic tape or punched cards, is more universally compatible among different data systems than, for example, analog magnetic tape. This will be very important for the transferring of data between the various research locations.

C. **Fidelity.** Data in digital form can be processed repeatedly and stored over an extended period of years without deterioriation or loss of information.

D. **Speed.** Rapid access and manipulation is possible with high speed digital systems.

E. **Evolutionary Convenience and Economy.** A digital system can be of modular design. This provides for easy expansion, revision, and modernization.

It was therefore decided to convert raw data immediately to digital form.

A digital system of sufficient capability and flexibility for use in remote sensing was conceived by the data group. This system is divided into two parts. Figure 54 shows the portion of the system required to convert analog tape data to digital form. This system provides a comparatively low-cost, high-speed, off-line digital conversion capability.

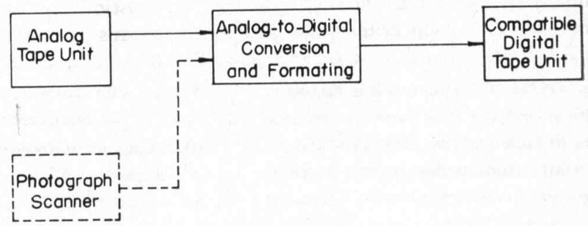


Fig. 54. Block diagram of analog to digital conversion.

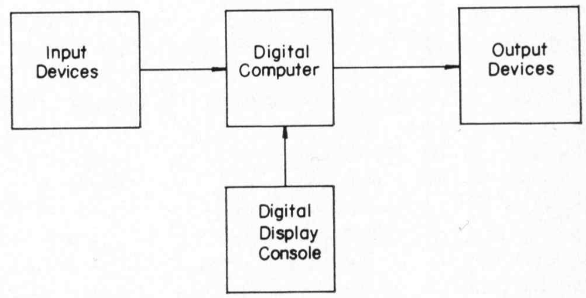


Fig. 55. Block diagram of computation/data editing system.

Figure 55 shows the proposed system required to do the editing-formating and computation mentioned above. The system provides a digital visual display of imagery with light pen capability such that geometrically complex areas of data can be easily selected without requiring a highly trained operator. It also has considerable general purpose digital computational capability.

In operation, raw data in analog tape form would be brought to the system of Figure 54 and converted to digital tape form. Then to edit this data, the digital magnetic tape would be brought to the system of Figure 55, imagery would be read into the system, and displayed. The researcher could then examine the image, identify the region in it of interest, and indicate this region to the computer with the light pen. The data so indicated could then be automatically stored on digital tape for further processing.

From the standpoint of computer time economy, an important feature of the system is that during the time the operator is examining an image on the display, the computer itself is not in any way involved. It could, during this time, be carrying out some entirely unrelated computation, and need only be interrupted briefly for the transfer of data to or from the display on command from the operator. This will be particularly important as the amount of aircraft data gathered increases, since aircraft data editing will occupy a not insignificant portion of time available on the system.

Procurement. In connection with the design of the data system, two investigations were made. In the first, inquiries were made to find out what equipment of this or similar type might already be in operation in this country, perhaps within NASA or a university. The hope was that there might be a system in existence which could be used during crop year 1966 to get data for study.

The results of this study were negative. There appears to be no existing system capable of editing large quantities of multichannel scanner data. If large quantities of data were to be available within 1966 an interim solution to the editing problem would have to be found.

The second investigation involved finding out if a data system was possible, i.e. not beyond the state of the art. The results of this study were positive.

Following these studies considerable work was carried out to detail the specification of this data system, and proposals from industry were received on the system in three parts:

- An analog-to-digital conversion system similar to that in Figure 54.
- A general purpose digital computer (1) to be used for data analysis work (2) to support the interim data editing procedure described below, and (3) perhaps later to be used as shown in Figure 55.
- A digital display as shown in Figure 55.

Orders have been placed with the Raytheon Computer Company for the analog-to-digital conversion system and with IBM for the general purpose computer (3, 4).

The proposals for the digital display have only recently been received.

The Phase I Data System: In the intervening time until the previously described multichannel scanner data editing system is delivered and becomes operational, an interim system, hereafter referred to as the Phase I System, will be placed in operation. This system is divided into four parts:

A. Digitizing process
B. Calibration and Reformating
C. Display process
D. Selection process

A data flow diagram of the total process is shown in Figure 56. Data are collected in the aircraft and on the ground. The aircraft data consist of scanner imagery in electrical form recorded on analog tapes and photographic data. The photography includes strip maps obtained from the scanner data and photographic coverage obtained by camera during the flight.

The ground data or ground truth consists of photographic coverage taken from the ground and written reports of many ground measurements and observations. Spectral data obtained from the Hi-Ranger by SG-4 and/or interferometer will also be available, but they are not used directly in the Phase I System.

The analog tapes obtained from the aircraft will be digitized in bulk form, using facilities at the Marshall Space Flight Center, Huntsville, Alabama, until delivery of the system shown in Figure 54. The bulk digital data will then be calibrated and reformated onto a digital storage data tape in a format more convenient for research purposes. Also during this time identification information,

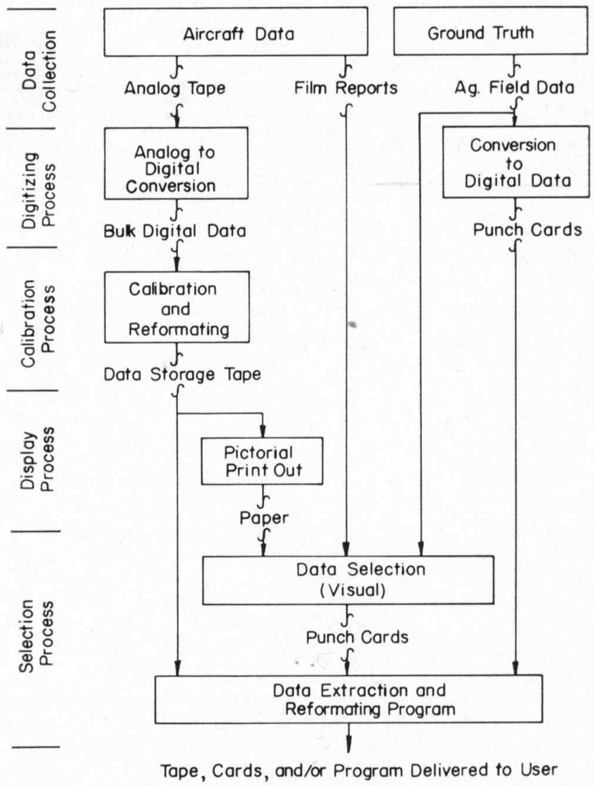


Fig. 56. Phase I data system flow diagram.

obtained from aircraft reports and film, will be added to the data. This information includes such things as the date, altitude, flight line data, and information on the scanner. It is this data tape, the data storage tape, which will be retained and maintained as the permanent data record from the flight.

The next step, the display process, results in a print out of the data in pictorial form which maintains a unique reference to specific data points on the data storage tape. An example of such a print out is shown in Figure 57. By comparing this print out to photographic coverage and ground truth information, the researcher himself can select the data from the specific points on the ground which he wishes to use in his analysis work. He simply specifies the line number and column number of the desired data points. This information is fed back to the computer on punched cards and the desired data are outputed on tape, cards, or in printed form.

Initially, due to some limitations of the Marshall Space Flight Center digitizing equipment, it will be necessary to have print outs of at least six of the 18 channels of imagery available from the University of Michigan scanner. Upon delivery of the analog-to-digital conversion system now on order, this number will be reduced to four, corresponding to the four apertures of the scanner.

Referring again to the Selection Process portion of Figure 56, it is seen that certain ground truth data will be

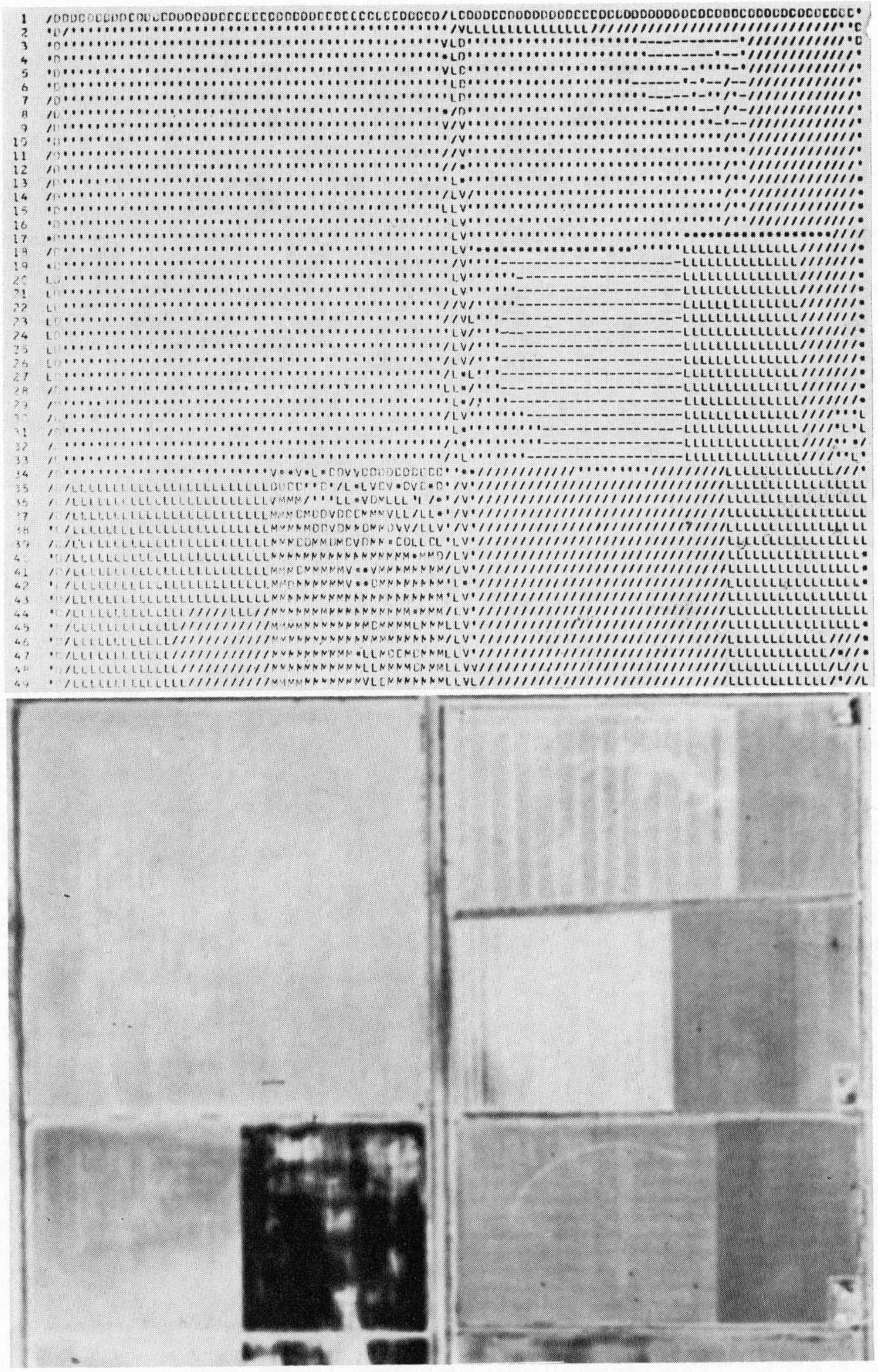


Fig. 57. A comparison of aerial photographs and a computer image print out.

merged with extracted data. The ground truth data are gathered and maintained on special forms. It is portions of these data in punched card form which will be merged with the aircraft data selected by the researcher.

The computer programs for all parts of the Phase I system except the Selection Process have been written and partly debugged using simulated data. Final debugging will proceed as soon as digital data becomes available.

Data Handling Work Planned: Some of the data handling work planned has already been indicated above. The Phase I system must be completed and placed in operation. Staff time will be required for the monitoring of the analog-to-digital conversion system construction. Preparations must be made for the installation of this system and the computer. Users' manuals must be written for the Phase I system so that users at locations other than Purdue can use the system conveniently. And there are many other rather routine tasks which must be accomplished.

It is apparent upon consideration of the work reported above that a great deal of work in data handling research, as distinguished from data handling operational work, is necessary and is highly recommended. The Phase I system is perhaps adequate for the 1966 data and research work. But as the remote sensing program moves forward and semi-operational phases begin, the demand for data handling capability will surely increase. Procurement times alone of a year or more are not uncommon with data systems. If added to this time is time for research to define the system specifications, a most unfortunate delay in progress could develop.

The acquisition of the digital display device will be a long first step in this direction. It is needed now to be able to edit data faster than the print out technique will permit. But it will enable research into many other questions, for example:

- It will be used to study the resolution required for various recognition tasks. The resolution of the display is under computer program control.

- It will be used to study the number of grey levels necessary since this also is under computer program control. Presently, the data contains 256 levels (8 bit data); however, research is planned to establish the circumstances under which fewer than this number is satisfactory.

- It could be used to study color reconstitution using a field sequential approach, adding a whole new dimension to the field of color reconstitution. (For an example of this technique, carried out by NASA and "Life Magazine" technicians in the Propect Surveyor Program, see "Life Magazine," July 1, 1966, p. 3 and p. 62ff.) The versatility and speed of response made possible by the computer driven display permit the researcher to vary the color combinations without changing film parameters. With photography combinations, they are possible only when new film is made available (Example: Camouflage Detection Film). With a computer driven display, new color combinations simulating new film parameters would be available in minutes. And types of color combinations not even feasible with film would become available.

There are many other uses that could be made of such a display device when controlled by computer. Should it later become advisable, the digital display now planned, which is black and white only, could be modified to produce color imagery directly.

There is another area of work necessary. Scanners have several advantages over film for gathering data. Not the least of these are the additional portions of the spectrum which are accessible and the great precision with which the radiation intensity levels can be measured and recorded. However, film has important advantages over scanners also. These include the ease with which photographs can be taken, and the tremendous density with which information can be stored on film.

As the state of film technology advances in the area of grey level intensity stabilization, and as remote sensing research is able to define problems which are entirely in the photographic part of the spectrum and which do not require many levels of grey for proper classification, data gathering by film will become even more important than it is now. In anticipation of this, plans have been made to attach a high speed film scanner to the system of Figure 54 as shown. During the coming year the specification for such a system will be developed.

CHAPTER VI

Field Spectral Data, Perkin-Elmer SG-4

In June, July and August 1966, well over 300 spectral curves were taken in the field at the Purdue Agronomy Farm with the Perkin-Elmer SG-4 system discussed previously. While it is obviously not appropriate to present even a majority of these data in this report, it is within reason to present some typical examples together with a discussion of the general feelings on major features. The following points will indicate the trends:

- In the spectral region from 0.4 to 4.0μ different crop types (corn, wheat, oats, alfalfa, soybeans, grass, shrubs and weeds) do *not have GROSSLY different spectra*. That is to say, there are no readily apparent spectral peaks or depression that will differentiate one green vegetative crop from another. In short, the problem of crop distinction will be a subtle one and, as will be detailed below, will probably have a good deal to do with the visible and near IR regions.

- It is entirely feasible to distinguish between green, turgid vegetation and soil, concrete, and drying, mature vegetation from the strong reflectance of the green vegetation in the 0.7 to 1.3μ region. This, of course, is the principle of CD film and the spectra have simply verified the known results. This also indicates the obvious fact that discrimination of regions by CD film can also be accomplished by spectral scanner instrumentation automatically with simple decision circuitry. Indications have been found that the success of this distinguishing feature depends strongly on the amount of visible soil, whether by CD film or spectrometer.

- It is mandatory for further field spectroscopy to rapidly and continuously monitor the incoming solar spectrum at the scene of view. Though SG-4 spectra were each taken in an interval of 15 seconds, cloud cover could cause significant variations of solar input within 1 or 2 seconds. This variation was obvious when cumulus clouds obscured the sun, but even wispy clouds and near-cloud moisture content had significant effects. Even on a day of crystal clarity by ground observation, the Eppley pyrheliometer showed haze variations. It should be pointed out that the pyrheliometer is not adequate for monitoring rapid fluctuations, having a time constant of 20 seconds. Fast PbS detector instrumentation is being developed now for monitoring in the 1967 growing season.

- In the atmospheric windows beyond 0.9μ the functional form of the spectrum of a crop type in any one of the windows will not vary appreciably from that of another crop type, but the total reflected energy from a window may vary from crop to crop. Since the windows are from 0.4 to 1.0μ wide in this region, this is tantamount to saying that reflectance will be a slowly varying function of wavelength beyond 0.9μ. This further implies that a gross spectral measurement such as that of the four-filter InSb detector in the University of Michigan aircraft is sufficient for this region, and a more finely divided measurement would lead to system complexity without compensating gain of information.

- In the visible region of the spectrum the different hues of green in different crop covers will be indicated by moderately different spectra. Working with a sufficient statistical sample of spectra *per se* will lead to quantitative definition of visible reflectance that is not dependent on physiological observer properties. Unfortunately, the visible grating did not become available till mid-August, so a sufficient number of spectra were not obtained.

- The SG-4 is limited to just beyond 4.0μ by both the detector and the grating. It was just possible, however, to distinguish a pronounced emissive radiation rise beyond 4.0μ in the few curves taken in this region. Specifically, soil, wheat stubble, and the sulfur panel showed rapidly rising spectra at this point, while green vegetation was at a lower apparent temperature. This was found also from PRT-4 measurements on these targets.

- Studies on the variation of spectra with look angle have been inconclusive, and in many cases even inconsistent. Part of the inconsistency might be blamed on the cloud cover insolation variation but not enough to account for curves taken this summer. In some cases the crop cover appears Lambertian, with instrument response being independent of angle. In other cases some wavelengths appear Lambertian while other wavelengths are not while viewing the same scene. More work is necessary for definitive answers on this problem.

- Large scale (2′ x 2′) reflectance panels were tested. A thick (6mm) coating of flowers of sulfur in a matrix of 3M White Velvet enamel provided a workable, reasonably durable field panel. 3M White Velvet on cardboard, $BaSO_4$ slurry on cardboard, and uncoated cardboard were inferior to the sulfur filled panel in these trials.

Examples of these points are illustrated in Figures 58 to 68. The figures are raw data and the reader should consider this point in the relation to the trends discussed above. In all spectra except those marked constant gain, gain setting was varied to achieve a reasonable scale. This was done at the earlier stages of work when spectral relative shape was the topic of interest rather than absolute level. Wavelength scales are nominal, taken from grating angle; actual calibrations are made with spectral lamps, as discussed in Chapter 4.

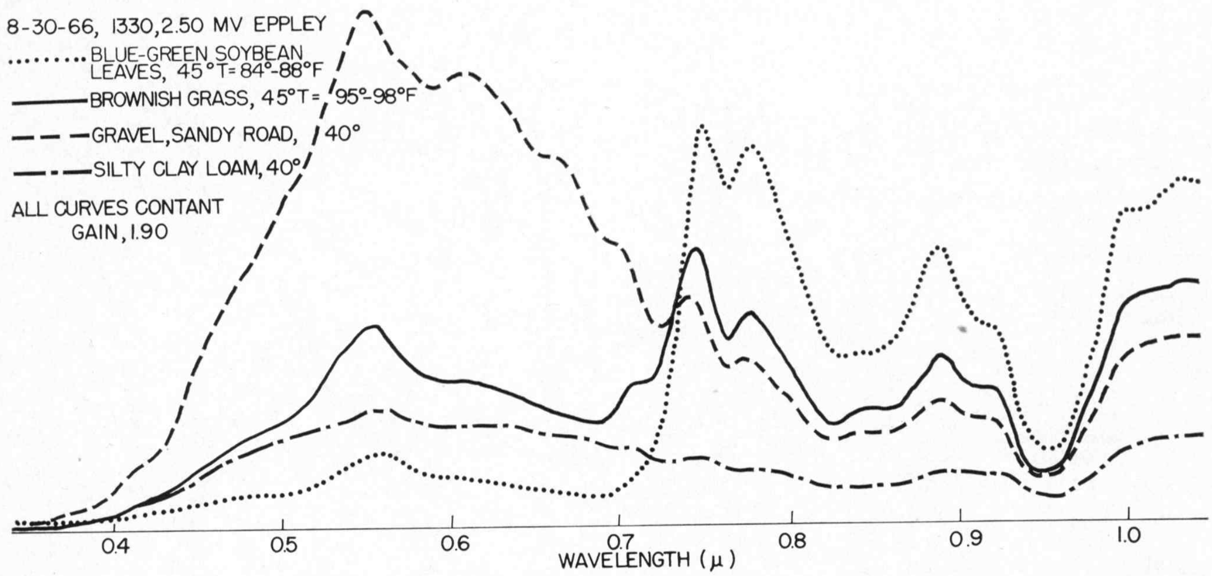


Fig. 58. Spectra of vegetation and soil in the 0.35 to 1.06μ wavelength region.

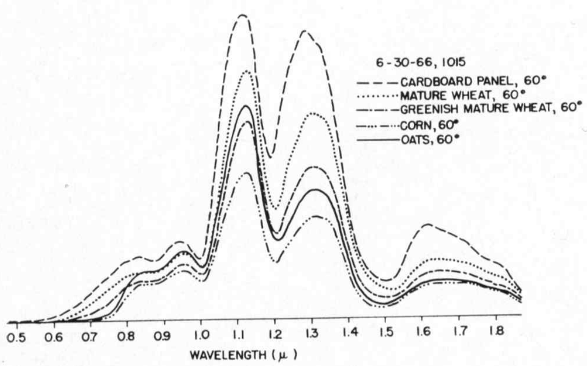


Fig. 59. Spectra of wheat, corn, and oats in the 0.5 to 1.8μ wavelength region.

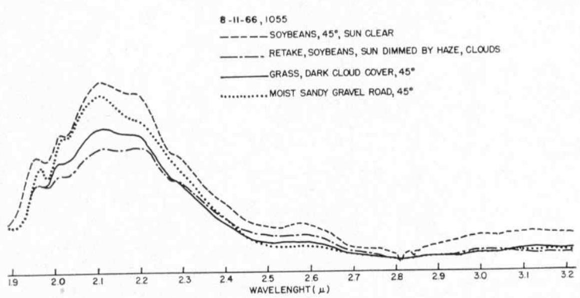


Fig. 60. Spectra of soybeans, grass, and a gravel road in the 1.9 to 3.2μ region.

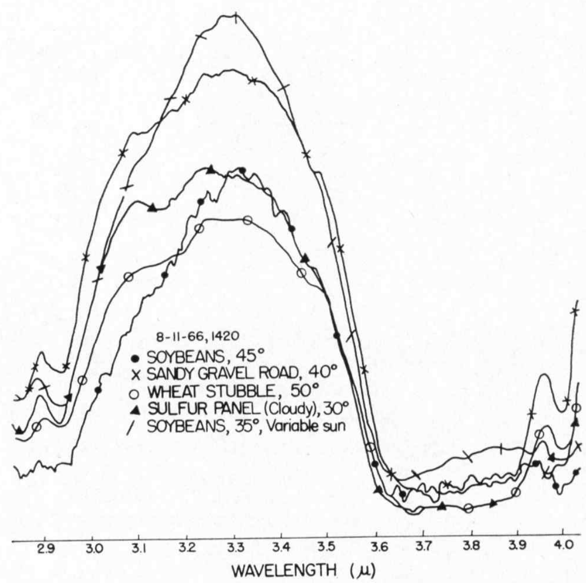


Fig. 61. Spectra of soybeans, wheat stubble, and a gravel road in the 2.9 to 4.05μ region showing strong emissive rise.

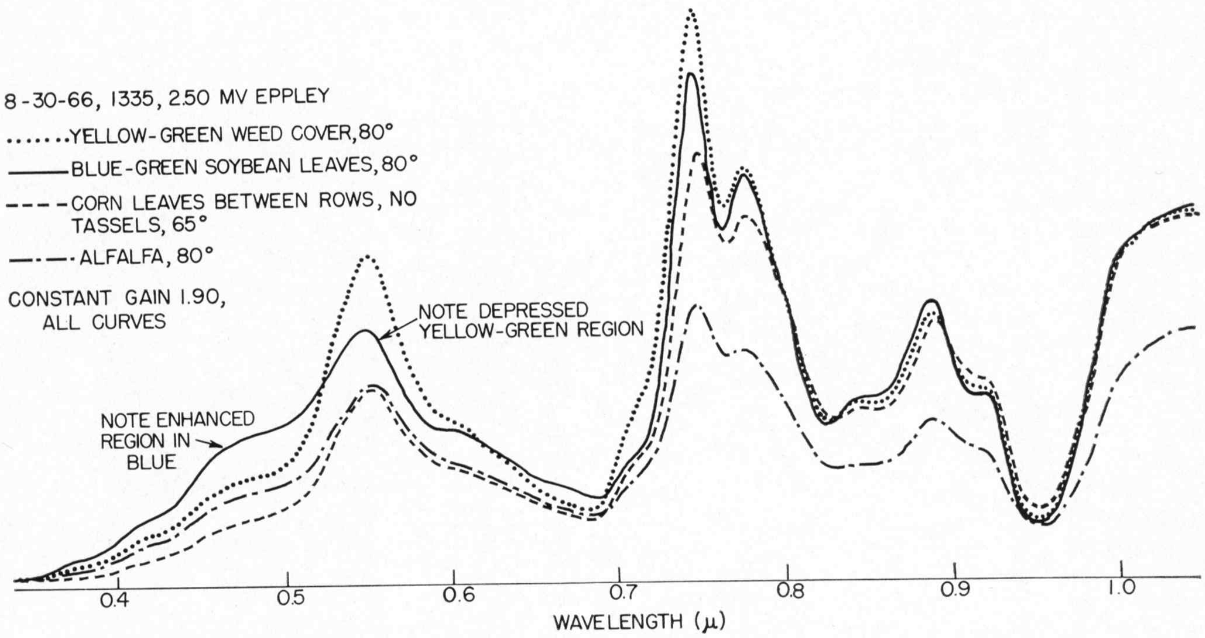


Fig. 62. Spectra of soybeans, corn, alfalfa, and weeds in the visible and near infrared portion (0.4 to 1.0μ).

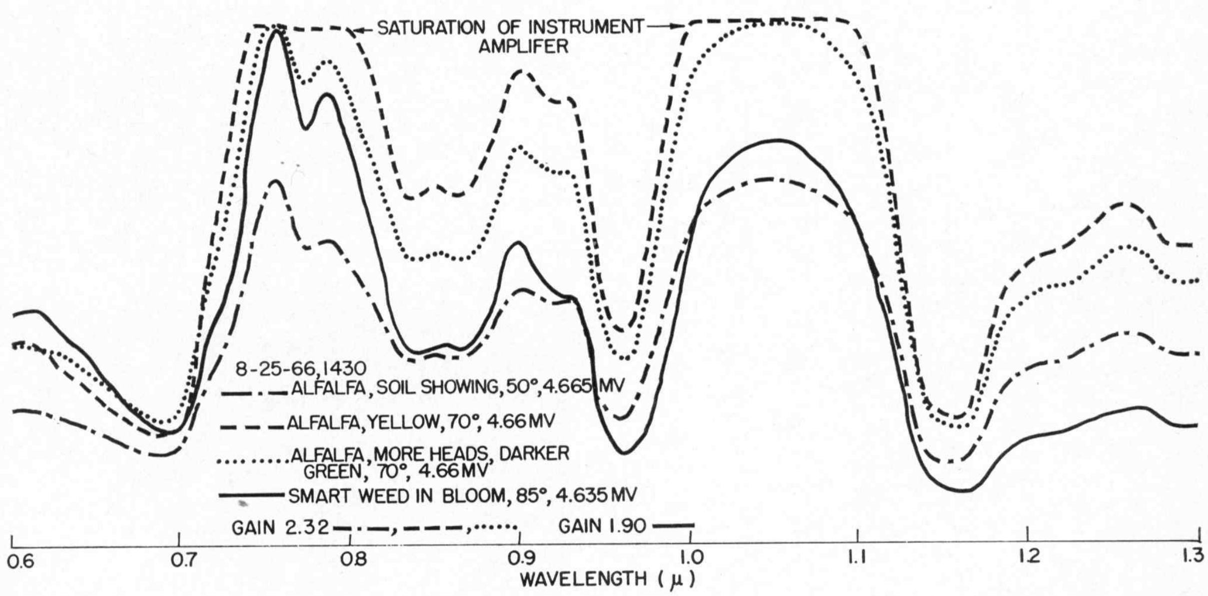


Fig. 63. Spectra of alfalfa and smart weed in the red and near infrared portion (.6 to 1.3μ).

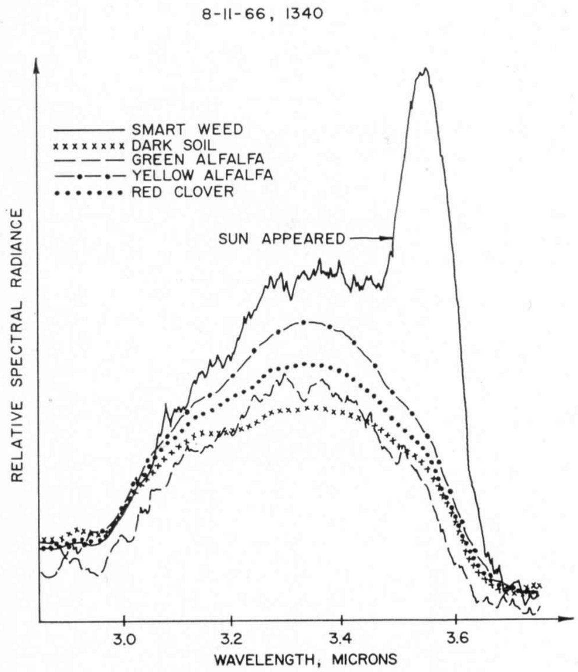


Fig. 64. Spectra of soil, red clover, alfalfa, and smart weed illustrating the solar input variation problem (2.8 to 4.0μ).

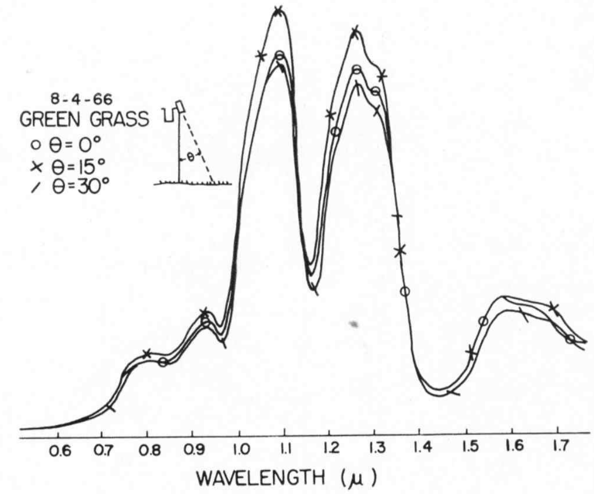


Fig. 66. An angle dependence study on grass.

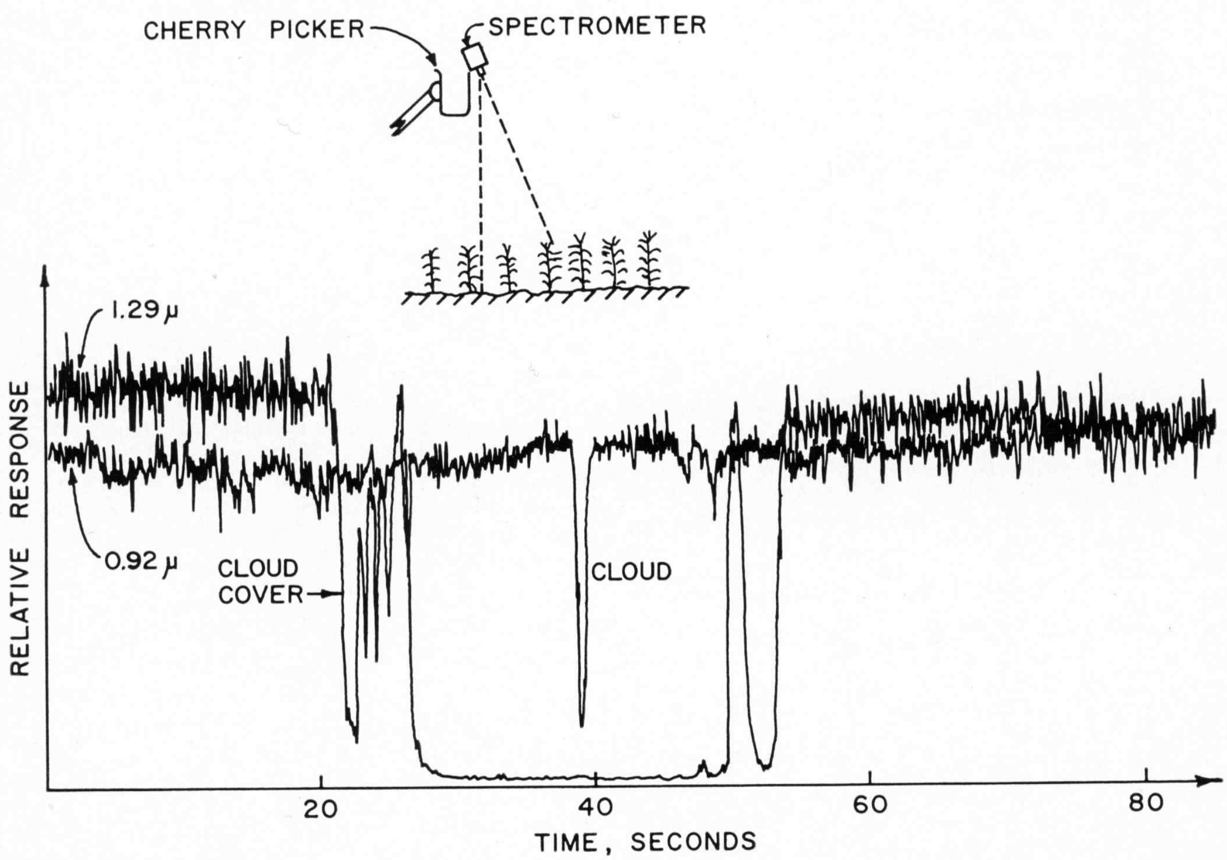


Fig. 65. A consistency plot of a corn field on a cloudy, windy day, viewed for 80 seconds at each of two wavelength bands.

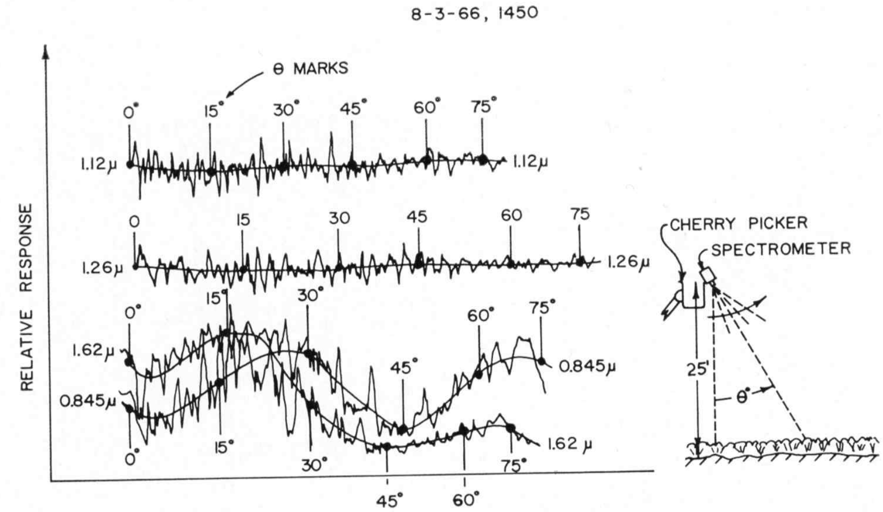


Fig. 67. Angle dependence study on soybeans as panned along the rows at 1.12, 1.26, 1.62, and 0.845μ.

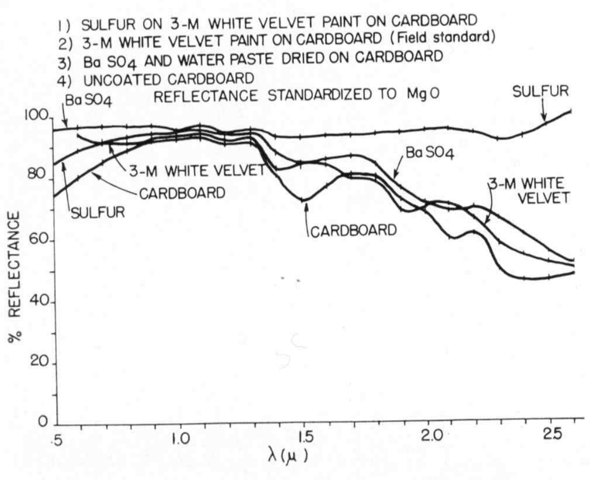


Fig. 68. DK-2 spectrometer reflectance measurements on different field panel designs.

CHAPTER VII

Analysis and Results of DK-2 Spectroreflectometer Data

Introduction

As previously described in Chapter 4, a Beckman DK-2A Spectroreflectometer has been used extensively during 1966 to obtain reflectance data on plant leaves in the portion of the spectrum between 0.5μ in the visible wavelengths and 2.6μ in the infrared region.

These data are being used in two primary analysis efforts: (1) to study variation in leaf reflectance and to determine the primary factors affecting reflectance in various portions of the spectrum; and (2) to use relatively large numbers of reflectance curves from each of several crop species to determine the capability for classification of the leaf samples, based upon the spectral pattern of the reflectance curve.

Gates *et al.* (7) stated: "A relatively small amount of research has been done on the spectral properties of plants and most of that work has concerned itself with the visible and very near infrared portions of the spectrum" (p. 12). In considering the mechanisms of reflectance, transmittance and absorption of leaves, they state: "At wavelengths longer than 1200mμ or 1.2μ water vapor absorption rises very steeply, and in the red and blue regions of the visible spectrum pigment absorption is very strong" (p. 14). "The near-infrared reflectance behavior of the maturing leaf is less easy to understand. It is probable that the near-infrared reflectance is a function of the cell shape and size of intercellular space" (p. 16).

The above statements point out the need to understand more fully the factors affecting reflectance from vegetation, so that we may better predict the conditions under which one would expect to find a change in spectral reflectance; i.e. if a certain disease affects a plant in a known manner, it would be very desirable to be able to predict whether or not one could also expect a change in reflectance that would allow this disease situation to be detected remotely. It is toward this goal of a better understanding of the biological factors which affect reflectance of plant leaves in the 0.5-2.6μ wavelength portion of the spectrum that the following data analysis tasks have been undertaken:

(1) Determination of correlation between moisture content of the leaf and the reflectance measurements in various portions of the spectrum, particularly above 1.3μ wavelength.

(2) Determination of observable relationships between leaf histology and reflectance, particularly in the 0.7 to 1.3μ portion of the infrared spectrum.

(3) Determination of relationships between loss of chlorophyll pigment and changes in reflectance in the infrared portion of the spectrum, and whether such changes in pigmentation are accompanied by changes in moisture content or histology of the leaves.

(4) Determination of correlations between portion of the plant, portion of the leaf, and age of the sample and the reflectance of plant leaf samples in various portions of the spectrum for a given crop species and variety.

To determine the capability for classifying different species of leaf samples, the following data analyses have been started:

(1) Selection of potentially significant spectral bands, both spectral location and width, as a method for dimensionality reduction.

(2) Determination of correlation of reflectance measurements between various selected portions of the spectrum, using leaf samples from a given crop.

(3) Estimation of the distribution of the reflectance measurements in the selected spectral bands.

(4) Selection of a mathematical model for the reflectance measurements and testing the validity of the model.

(5) Application of various decision techniques for classification of crop species and varieties by using the reflectance measurements in the selected bands.

Data Collected

From June 1966 to August 1966, a total of 1,672 reflectance curves were recorded on DK-2A Spectroreflectometer. Table 14 presents the distribution of the numbers of samples from different species and varieties. Data are still being gathered.

Only a portion of the data (281 samples of corn, 276 samples of wheat and 117 samples of oats) were used in the preliminary analyses to be discussed below. Analyses are in process at this writing and new data are being incorporated as they become available.

Definition of Features

For purposes of initial data analysis, nine features were chosen to characterize a reflectance curve of leaf sample. The measurement of each feature is the average of the reflectance measurements over a given wavelength band. The nine bands selected, generally covering peaks and valleys as shown in Figure 69, roughly characterize the outstanding features of a reflectance curve. The nine feature measurements generated from the reflectance curve of a leaf sample are then considered as a vector X for that leaf where

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_9 \end{bmatrix}$$

and

x_1 = the average of reflectance measurements in wavelength band 0.53-0.57μ
x_2 = the average of reflectance measurements in wavelength band 0.62-0.68μ
x_3 = the average of reflectance measurements in wavelength band 0.8-0.9μ
x_4 = the average of reflectance measurements in wavelength band 1.0-1.09μ
x_5 = the average of reflectance measurements in wavelength band 1.2-1.25μ
x_6 = the average of reflectance measurements in wavelength band 1.4-1.49μ
x_7 = the average of reflectance measurements in wavelength band 1.6-1.84μ
x_8 = the average of reflectance measurements in wavelength band 1.9-2.0μ
x_9 = the average of reflectance measurements in wavelength band 2.1-2.3μ

These bands were somewhat arbitrarily selected, and further study is needed to determine a best set of features for optimum classification of leaf samples.

Table 14. The species distribution of samples analyzed by the DK-2 spectroreflectometer

Species	Variety	No. of samples	Total No.
Soybean	Amosoy	88	393
	Harosoy	129	
	Other	176	
Corn	PF SX29	70	559
	PF SX9	159	
	P10 3306 Single Cross	166	
	Other	164	
Oats	Tippecanoe	77	136
	Clintford	59	
Wheat	Vermillion	28	340
	Knox 62	27	
	Riley	37	
	LaPorte	26	
	Monon	67	
	Reed	31	
	Redcoat	24	
	Breeders Wheat	35	
	Breeders Composite	37	
	Other	28	
Clover		15	15
Sorghum		71	71
Miscellaneous		158	158
Final Total			1,672

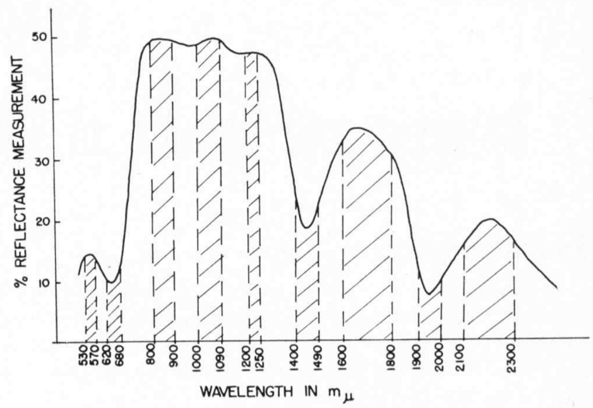


Fig. 69. Selection of wavelength bands for feature measurements.

The Effect of Moisture Content on a Feature Measurement

The moisture contents of the wheat sample gathered during June 1966 cover a range of 5% to 93%, largely due to differences in maturity of the samples. There were 276 samples used to study the effect of moisture content on each feature defined in the previous paragraph. Measurements of each feature were cross-tabulated against the moisture content and the correlation coefficients estimated. Figure 70 shows the cross tabulation plots of x_7 and the percentage moisture content measurement. The estimated correlation coefficients at 5% significance level is tabulated in Table 15.

Correlation Between Features

To apply a statistical decision method for classification, the feature measurements distribution must be known. At this early stage, simplifying assumptions were made, such as statistically independent features and/or normally or uniformly distributed features. It should be noted that any assumptions made at this point have not been justified. With large numbers of samples available, more appropriate assumptions can be made and tested.

Correlation between features was first studied by cross tabulation plots of two features and estimation of the

Table 15. Correlation coefficients between moisture content and wavelength features for wheat.

	x_1 0.53μ 0.57μ	x_2 0.62μ 0.68μ	x_3 0.8μ 0.9μ	x_4 1.0μ 1.9μ	x_5 1.2μ 1.25μ	x_6 1.4μ 1.49μ	x_7 1.6μ 1.8μ	x_8 1.9μ 2.0μ	x_9 2.1μ 2.3μ
Moisture correlation	—0.237 ±0.11	—0.450 ±0.10	—0.328 ±0.09	—0.567 ±0.09	—0.620 ±0.09	—0.667 ±0.09	—0.659 ±0.09	—0.670 ±0.09	—0.665 ±0.09

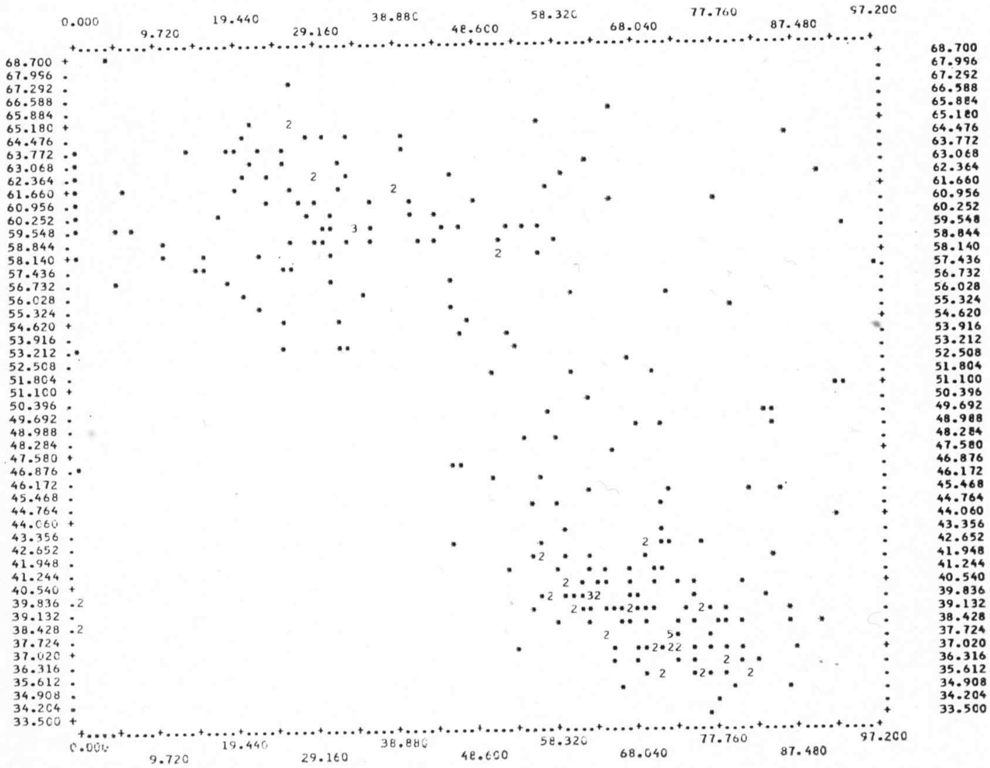


Fig. 70. Cross-tabulation plot of wavelength feature x_7 (1.6μ-1.8μ) and moisture content.

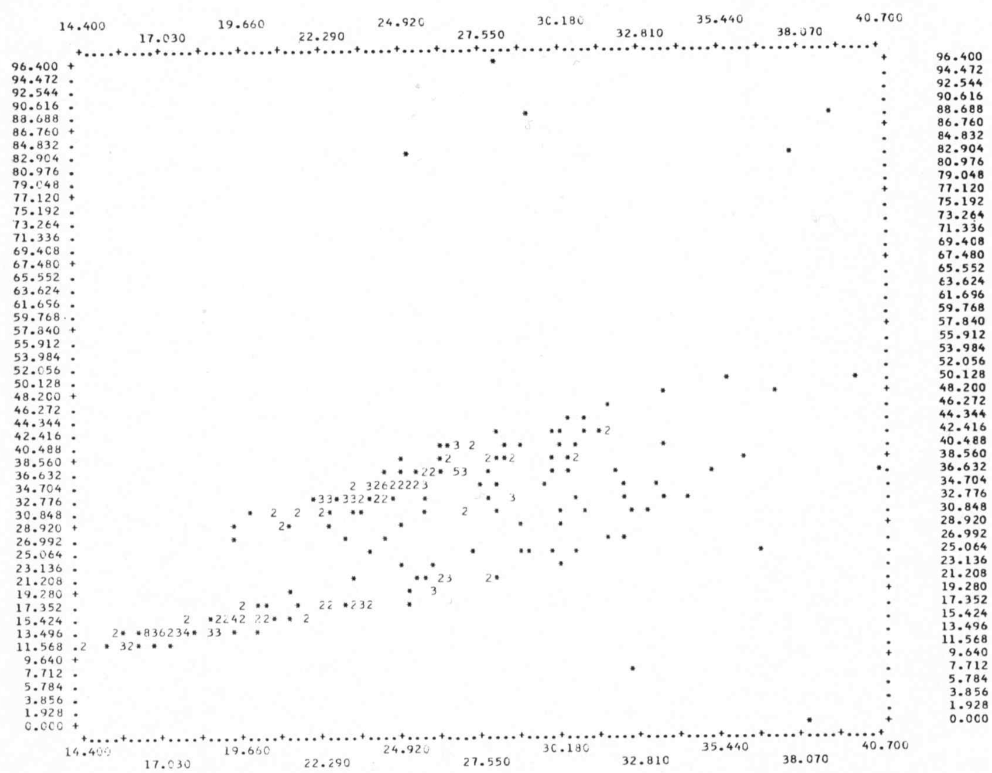


Fig. 71. Cross-tabulation plot of wavelength feature x_1 (0.53μ-0.57μ) and wavelength feature x_2 (0.62μ-0.68μ).

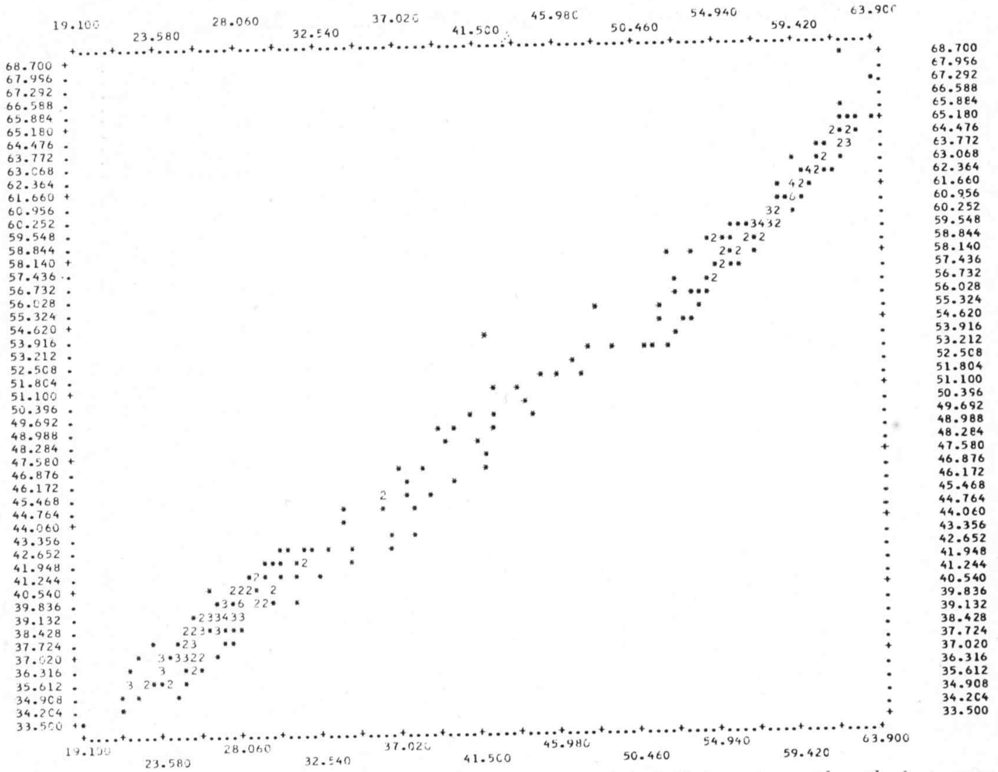


Fig. 72. Cross-tabulation plot of wavelength feature x_6 *(1.4μ-1.49μ) and wavelength feature* x_7 *(1.6μ-1.8μ).*

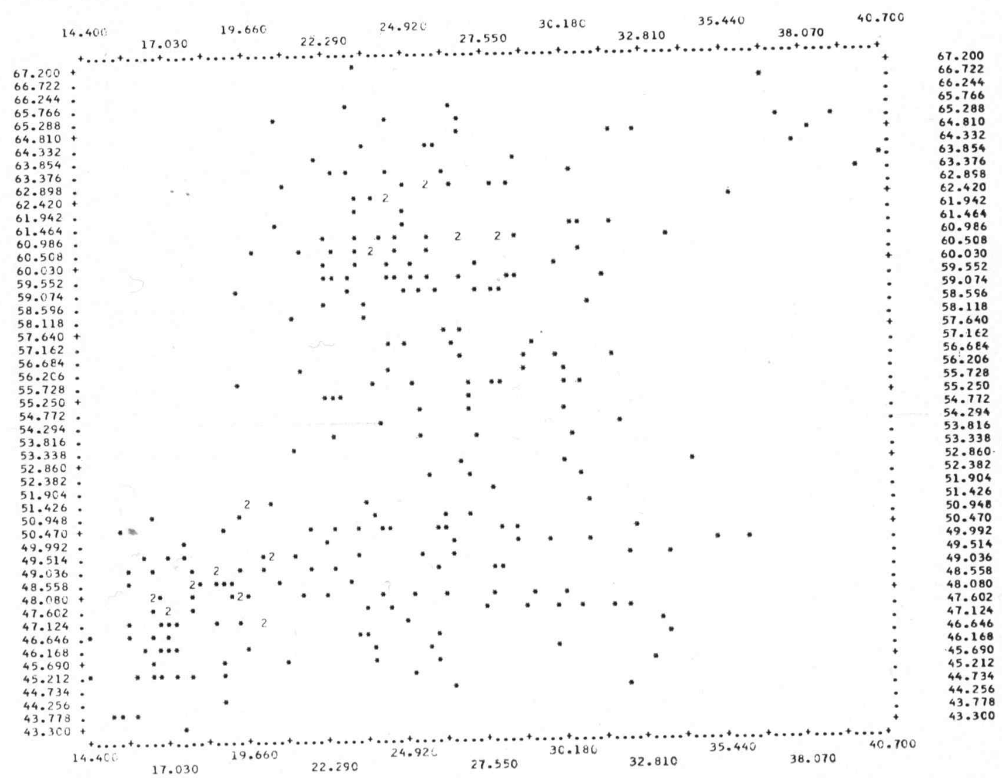


Fig. 73. Cross-tabulation plot of wavelength feature x_1 *(0.53μ-0.57μ) and wavelength feature* x_5 *(1.2μ-1.25μ).*

correlation coefficient to see to what extent the feature measurements are correlated for corn, wheat and oats. The results show high correlation between x_1 and x_2, between x_3, x_4 and x_5, and between x_6, x_7, x_8 and x_9, and relatively little correlation between these subsets. Some examples of high correlation between features are shown by cross tabulation plots of x_1 and x_2 in Figure 71, and of x_6 and x_7 in Figure 72 for the 276 wheat samples used. Figure 71 shows the clustering of two groups. One group primarily constitutes reflectance curves with a peak in the 0.53μ-0.57μ (green) portion and a valley in the 0.62μ-0.68μ (yellow) portion of the spectrum, while the other group is constituted mostly of reflectance curves monotonically increasing in the region from 0.5μ to 0.8μ. They can be separated for further analysis by testing whether $x_1 > x_2$ or $x_1 \leqslant x_2$. Figure 72 shows strong linear correlation between x_6 and x_7 as all points concentrate along a straight line. However, notice the clustering of data at the lower left and upper right. This grouping appears to be related to difference in the moisture content of the leaves sampled. They can be separated by either testing the moisture content measurement or by testing the measurement of one feature such as x_6, x_7, x_8, or x_9. An example of little correlation between features is shown by cross tabulation of x_1 and x_5 in Figure 73.

The correlation coefficients between feature measurements for corn estimated from 281 samples, for wheat estimated from 122 samples, and for oats estimated from 102 samples, are given in Tables 16, 17, and 18, respectively. All the samples used are in the group where $x_1 > x_2$. They are essentially green leaf samples with moisture content above 50%.

Table 16. Correlation coefficients between feature measurements for corn.

		x_1 0.53μ-0.57μ	x_2 0.62μ-0.68μ	x_3 0.8μ-0.9μ	x_4 1.0μ-1.09μ	x_5 1.2μ-1.25μ	x_6 1.4μ-1.49μ	x_7 1.6μ-1.8μ	x_8 1.9μ-2.0μ	x_9 2.1μ-2.3μ
x_1	0.53μ-0.57μ	1.0	.803	— .038	— .066	— .001	.645	.446	.617	.670
x_2	0.62μ-0.68μ	.803	1.0	.150	.130	.202	.776	.631	.774	.783
x_3	0.8μ-0.9μ	— .038	.150	1.0	.995	.983	.129	.606	.138	.093
x_4	1.0μ-1.09μ	.066	.130	.995	1.0	.989	.118	.607	.140	.084
x_5	1.2μ-1.25μ	— .001	.202	.983	.989	1.0	.239	.705	.258	.206
x_6	1.4μ-1.49μ	.645	.776	.129	.118	.239	1.0	.846	.963	.992
x_7	1.6μ-1.8μ	.446	.631	.606	.607	.705	.846	1.0	.826	.829
x_8	1.9μ-2.0μ	.617	.773	.138	.140	.258	.963	.826	1.0	.961
x_9	2.1μ-2.3μ	.670	.783	.093	.084	.206	.992	.829	.961	1.0

Table 17. Correlation coefficinets between feature measurements for wheat.

		x_1 0.53μ-0.57μ	x_2 0.62μ-0.68μ	x_3 0.8μ-0.9μ	x_4 1.0μ-1.09μ	x_5 1.2μ-1.25μ	x_6 1.4μ-1.49μ	x_7 1.6μ-1.8μ	x_8 1.9μ-2.0μ	x_9 2.1μ-2.3μ
x_1	0.53μ-0.57μ	1.0	.957	.197	.283	.326	.350	.390	.433	.425
x_2	0.62μ-0.68μ	.957	1.0	.227	.345	.408	.471	.496	.576	.535
x_3	0.8μ-0.9μ	.197	.227	1.0	.975	.927	.400	.628	.383	.407
x_4	1.0μ-1.09μ	.283	.345	.975	1.0	.980	.526	.735	.535	.536
x_5	1.2μ-1.25μ	.326	.408	.927	.980	1.0	.673	.848	.676	.681
x_6	1.4μ-1.49μ	.350	.471	.400	.526	.673	1.0	.955	.967	.990
x_7	1.6μ-1.8μ	.390	.496	.628	.735	.848	.955	1.0	.924	.960
x_8	1.9μ-2.0μ	.433	.576	.383	.535	.676	.967	.924	1.0	.968
x_9	2.1μ-2.3μ	.425	.535	.407	.536	.681	.990	.960	.968	1.0

Table 18. Correlation coefficients between feature measurements for oats.

		x_1 0.53μ-0.57μ	x_2 0.62μ-0.68μ	x_3 0.8μ-0.9μ	x_4 1.0μ-1.09μ	x_5 1.2μ-1.25μ	x_6 1.4μ-1.49μ	x_7 1.6μ1.8μ	x_8 1.9μ-2.0μ	x_9 2.1μ-2.3μ
x_1	0.53μ-0.57μ	1.0	.957	.219	.218	.182	— .075	.014	— .045	.013
x_2	0.62μ-0.68μ	.957	1.0	.163	.177	.197	.030	.115	.055	.114
x_3	0.8μ-0.9μ	.219	.163	1.0	.989	.804	— .494	— .283	— .537	— .484
x_4	1.0μ-1.09μ	.218	.177	.989	1.0	.864	— .407	— .190	— .444	— .397
x_5	1.2μ-1.25μ	.182	.197	.804	.864	1.0	.091	.321	.029	.101
x_6	1.4μ-1.49μ	— .075	.030	— .494	— .407	.091	1.0	.959	.979	.988
x_7	1.6μ-1.8μ	.014	.115	— .283	— .190	.321	.959	1.0	.911	.967
x_8	1.9μ-2.0μ	— .045	.055	— .537	— .444	.029	.979	.911	1.0	.970
x_9	2.1μ-2.3μ	.013	.114	— .484	— .397	.101	.988	.967	.970	1.0

Preliminary Classification of Corn, Wheat and Oats

A Mathematical Model for the Measurement Vector: Suppose the reflectance curve of a leaf sample, represented by a measurement vector X defined previously, was from one of the three categories—corn (c), wheat (w), or oats (o). Each category is characterized by a probability distribution of the measurement vector X. For preliminary analysis, the form of each probability distribution is assumed to be known, but the parameters of the distribution must be estimated from samples drawn from that category. Let the measurement vector from each category have multivariate, normal distribution with different mean vectors M_i (i = c, w, o) and different covariance matrices V_i (i = c, w, o). Then the density of the measurement vector from the ith category is

$$p_i(x) = \frac{1}{(2\pi)^{\frac{9}{2}}|V_i|^{\frac{1}{2}}} \exp\left[-\tfrac{1}{2}(X-M_i)^T V_i^{-1}(X-M_i) \right],$$

where $|V_i|$ is the determinant and V_i^{-1} is the inverse matrix of the covariance matrix V_i, respectively, and T denotes the transpose operation.

Estimation of the Mean Vector and the Covariance Matrix for Each Category. Since the distribution of the measurement vector is assumed to be normal, the parameters needed to be estimated are the mean vector and covariance matrix for each category. If $X_1, X_2, \ldots, X_{ni}$ constitute a sample from the ith category, then the maximum likelihood estimates of the mean vector M_i and covariance matrix V_i for the ith category are the sample mean

$$M_i = \frac{1}{N_i}\sum_{\alpha=1}^{N_i} X_\alpha = \begin{bmatrix} \frac{1}{N}\sum_{1\alpha=1}^{N_i} X_{1\alpha} \\ \cdot \\ \cdot \\ \cdot \\ \frac{1}{N}\sum_{1\alpha=1}^{N_i} X_{9\alpha} \end{bmatrix} = \begin{bmatrix} m_{11} \\ \cdot \\ \cdot \\ \cdot \\ m_{91} \end{bmatrix}$$

and the sample covariance matrix

$$V_i = \frac{1}{N_i-1}\sum_{\alpha=1}^{N_i} (X_\alpha - M)(X_\alpha - M)^T$$

The estimated mean vectors for category corn from 271 samples, for category wheat from 122 samples, and for category oats 102 samples are as follows, respectively:

$$M_c = \begin{bmatrix} 16.3 \\ 12.2 \\ 46.0 \\ 45.2 \\ 42.7 \\ 19.6 \\ 32.0 \\ 8.7 \\ 18.3 \end{bmatrix}; \quad M_w = \begin{bmatrix} 21.3 \\ 17.0 \\ 50.3 \\ 50.0 \\ 48.2 \\ 26.9 \\ 38.9 \\ 13.6 \\ 25.1 \end{bmatrix}; \quad M_o = \begin{bmatrix} 16.7 \\ 13.6 \\ 52.5 \\ 52.0 \\ 49.1 \\ 21.9 \\ 36.4 \\ 9.7 \\ 20.9 \end{bmatrix}$$

The estimated covariance matrices for each category is given by:

$$V_c = \begin{bmatrix} 14.237 & 10.313 & -.343 & -.716 & 0.034 & 8.688 & 4.462 & 5.618 & 7.917 \\ 10.313 & 8.469 & 1.297 & 1.189 & 1.676 & 7.086 & 4.380 & 4.793 & 6.305 \\ -0.343 & 1.297 & 7.717 & 8.019 & 7.414 & 1.147 & 3.983 & 0.857 & 0.725 \\ -0.716 & 1.189 & 8.019 & 8.407 & 7.789 & 1.109 & 4.169 & 0.912 & 0.695 \\ 0.034 & 1.676 & 7.414 & 7.789 & 7.366 & 2.061 & 4.529 & 1.537 & 1.558 \\ 8.688 & 7.086 & 1.147 & 1.109 & 2.061 & 9.824 & 6.272 & 6.449 & 8.599 \\ 4.462 & 4.380 & 3.983 & 4.169 & 4.529 & 6.272 & 5.577 & 4.186 & 5.411 \\ 5.618 & 4.793 & 0.857 & 0.912 & 1.537 & 6.449 & 4.186 & 4.554 & 5.677 \\ 7.917 & 6.305 & 0.725 & 0.695 & 1.558 & 8.599 & 5.411 & 5.677 & 7.640 \end{bmatrix}$$

$$V_w = \begin{bmatrix} 24.735 & 23.612 & 1.986 & 3.181 & 3.782 & 6.089 & 5.240 & 7.084 & 6.720 \\ 23.612 & 24.617 & 2.283 & 3.871 & 4.722 & 8.193 & 6.646 & 9.404 & 8.446 \\ 1.986 & 2.283 & 4.094 & 4.461 & 4.373 & 2.833 & 3.433 & 2.555 & 2.617 \\ 3.181 & 3.871 & 4.461 & 5.109 & 5.167 & 4.160 & 4.488 & 3.984 & 3.851 \\ 3.783 & 4.722 & 4.373 & 5.167 & 5.438 & 5.495 & 5.343 & 5.188 & 5.049 \\ 6.089 & 8.193 & 2.833 & 4.160 & 5.495 & 12.265 & 9.034 & 11.145 & 11.027 \\ 5.240 & 6.646 & 3.433 & 4.488 & 5.343 & 9.034 & 7.293 & 8.219 & 8.247 \\ 7.084 & 9.404 & 2.555 & 3.984 & 5.188 & 11.145 & 8.219 & 10.841 & 10.136 \\ 6.720 & 8.446 & 2.617 & 3.851 & 5.049 & 11.027 & 8.247 & 10.136 & 10.117 \end{bmatrix}$$

and

$$V_o = \begin{bmatrix} 12.934 & 10.236 & 1.313 & 1.230 & 0.817 & -0.816 & 0.113 & -0.308 & 0.122 \\ 10.236 & 8.844 & 0.805 & 0.826 & 0.732 & 0.268 & 0.757 & 0.310 & 0.903 \\ 1.313 & 0.805 & 2.765 & 2.576 & 1.667 & -2.477 & -1.039 & -1.685 & -2.139 \\ 1.230 & 0.826 & 2.576 & 2.454 & 1.688 & -1.922 & -0.657 & -1.312 & -1.653 \\ 0.817 & 0.732 & 1.667 & 1.688 & 1.555 & 0.344 & 0.884 & 0.068 & 0.335 \\ -0.816 & 0.268 & -2.477 & -1.922 & 0.344 & 9.084 & 6.389 & 5.566 & 7.922 \\ 0.113 & 0.757 & -1.039 & -0.657 & 0.884 & 6.389 & 4.881 & 3.795 & 5.681 \\ -0.308 & 0.310 & -1.685 & -1.312 & 0.068 & 5.566 & 3.795 & 3.556 & 4.863 \\ 0.122 & 0.903 & -2.139 & -1.653 & 0.335 & 7.922 & 5.681 & 4.683 & 7.072 \end{bmatrix}$$

It should be noted that the determinants of the covariance matrices are very small, in the order of 10^{-2} to 10^{-4}, due to high intercorrelation in the subsets (x_1, x_2), (x_3, x_4, x_5), and (x_6, x_7, x_8, x_9) as mentioned previously. Therefore beware of the truncation error which may cause the determinant to go to negative.

Preliminary Classification Result: The likelihood ratio test was used as a decision rule for a preliminary classification trial. Recall from Chapter 5 that for this rule a vector X is classified into the class corn if the conditional probability of X given X from the class corn is the largest. This is equivalent to calculating the three constants

$$L_c(X) = -(X - M_c)^T V_c^{-1} (X - M_c) - \text{Log}_e |V_c|,$$
$$L_w(X) = -(X - M_w)^T V_w^{-1} (X - M_w) - \text{Log}_e |V_w|,$$
$$L_o(X) = -(X - M_o)^T V_o^{-1} (X - M_o) - \text{Log}_e |V_o|,$$

and the decision is made in favor of corn if $L_c(X) > L_w(X)$ and $L_c(X) > L_o(X)$.

The result of classifying 271 samples of corn, 122 samples of wheat, and 102 samples of oats is given in Table 19.

These results seem encouraging, but it must be emphasized that they are preliminary results based upon inadequate quantities of data. Any assumption made at this stage has not been justified. Further studies on choices of mathematical models and decision techniques are in progress.

Table 19. Classifying samples into corn, wheat, and oats from DK-2 data.

Number of samples	No. of samples classified into:			Percent correct classification
	Corn	Wheat	Oats	
271 Corn	266	5	0	98.2%
122 Wheat	4	108	10	88.5%
102 Oats	0	7	95	93.1%

CHAPTER VIII

Future Experimental Systems for Agricultural Remote Sensing

Introduction

Agriculture in its broadest sense may be defined as the science, art and business of planning, producing, marketing and processing the world's supply of food and fiber, and miscellaneous by-products derived from plant and animal sources. The world agricultural enterprise is a vast one comprising some 10 billion acres of arable and tree crop land, meadows, and pastures. It is supported by large research, development, and education programs conducted by government and industry. A great increase in intensity of planning of production activities in agriculture has occurred in the past 3 decades in the U.S. and in other countries. All of these activities and programs may be expected to intensify and expand rapidly in the developing nations as the people of the world become seriously committed to providing an adequate diet for an increased world population.

Intensification of planning requires an increase in the gathering and flow of accurate information. Due to size and global distribution of crop production areas and to marked effects of climatic variations on volume of production, much important world agricultural information is at present unobtainable in accurate form and in timely manner.

The Nature of Agricultural Crops

The extent of world crop production is of great magnitude. World agricultural production can be divided into seven geographic regions. In Figure 74, these regions are outlined and the acreage of arable and tree crop land, permanent meadows, and grain are noted in each region. The grain crops (wheat, rice, corn, millet, sorghum, barley, oats and rye) occupy 1.6 billion acres or more than 70 per cent of the total cultivated areas. Significant acreages of grains are grown in all seven of the geographic regions, ranging from 21 million acres in the Oceania region of Australia and New Zealand to 674 million acres in Asia. Within the seven regions the best and most extensive areas of crop land are in the plains. Plains, however, occupy only about 30 percent of the land. Hilly lands of fairly low altitude (600 to 3,000 feet) are next in importance. Locally, terraces and valleys in mountainous terrain may be farmed intensively to meet the food needs of the native people. The gathering of agricultural data by farmer contact on such extensive and, in some cases, inaccessible acreages is a prodigous undertaking.

Agricultural crop production is also diverse. The principle crops of the world and their acreages are listed in Table 20. About 96 percent of the crop area is occupied by annual crops—those planted and harvested within a year. Exceptions include fruits, sugarcane, beverage crops and rubber—all of which are important export crops. The annual crops are planted at various times of the year depending upon their location in the northern or southern hemisphere. Corn, for example, is planted in May and harvested in November in the Corn Belt of the U.S.A. But in Central Brazil it is the reverse: planted in November and harvested in May. Dates of planting and harvesting of a specific crop within each hemisphere depend upon latitude or elevation. The advance of wheat harvest northward from early June in Texas to late August in the Canadian prairie provinces is a well-known example. However, crop development along a given latitude will generally be at a similar stage at a given time of the

Table 20. Harvested area of principal crops of the world.

Crop	Area	Share of total cultivated area
	million acres	percent
Grains	**1,628**	**71.2**
Wheat	506	22.1
Rice	290	12.7
Corn	261	11.4
Millet and Sorghum	231	10.1
Barley	150	6.6
Oats	114	5.0
Rye	76	3.3
Oilseeds	**164**	**7.2**
Soybeans	52	2.3
Peanuts	36	1.6
Rapeseeds	20	.9
Sunflowers	17	.7
Sesame	12	.5
Copra	12	.5
Castor Beans	3	.1
Palm Kernels	12	.6
Roots and Tubers	**115**	**5.0**
Potatoes	61	2.7
Sweet Potatoes & Yams	36	1.5
Cassava	18	.8
Pulses	**111**	**4.9**
Fibers	**108**	**4.7**
Cotton	82	3.6
Flax	19	.8
Jute	5	.2
Hemp	2	.1
Fruits and Vegetables	**84**	**3.7**
Sugar	**34**	**1.5**
Sugarcane	18	.8
Sugar Beets	16	.7
Beverage Crops	**23**	**1.0**
Coffee	17	.7
Cocoa	4	.2
Tea	2	.1
Tobacco	**9**	**.4**
Rubber	**9.7**	**.4**

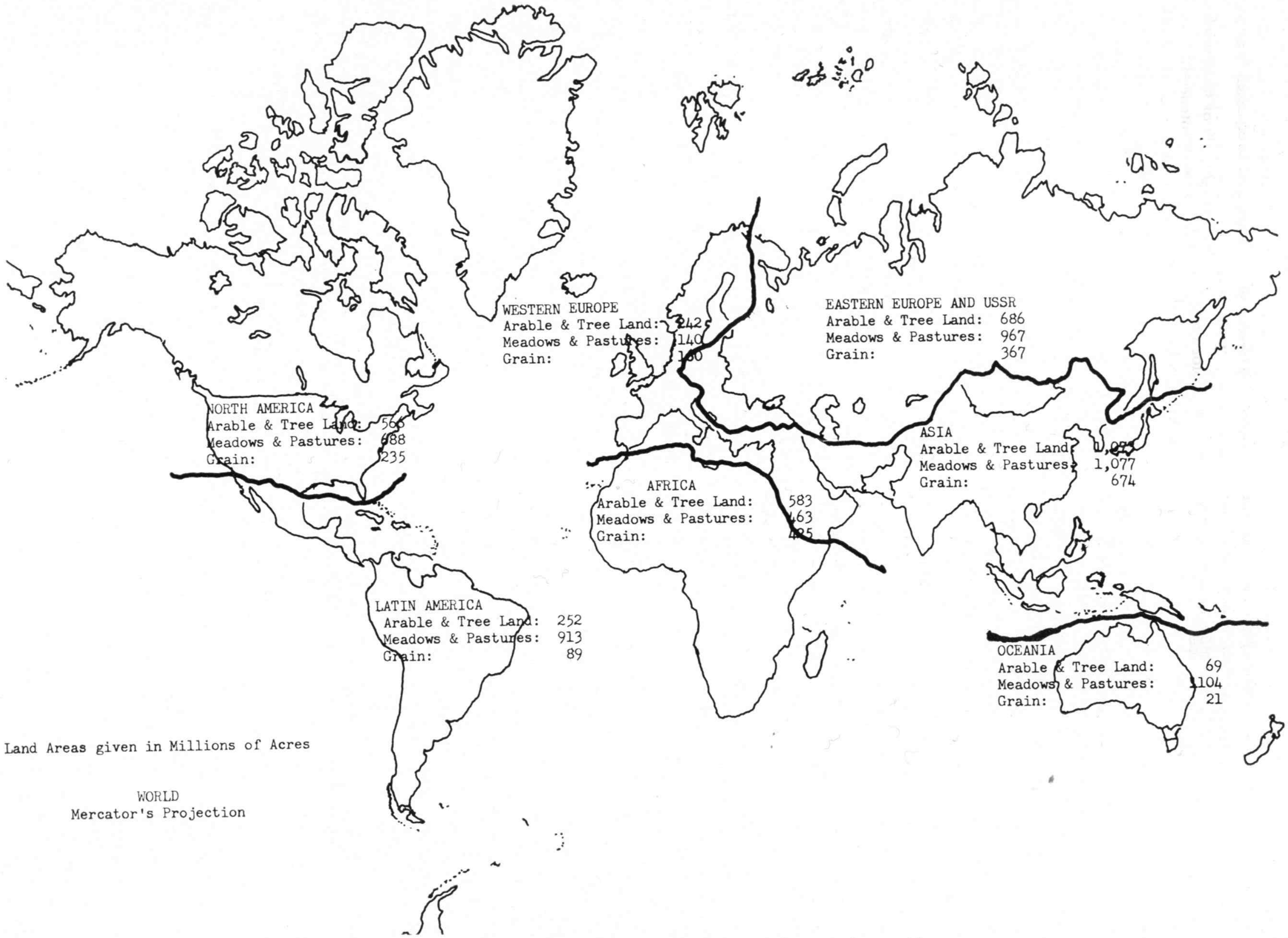


Fig. 74. Seven major agricultural geographic regions of the world.

growing season if elevation is not highly variable. The writer observed this phenomenon in a morning flight from Indianapolis to Washington, D.C. The time was mid-March and in the fields below the only green vegetation was fall-planted cereals—largely wheat. They could be readily differentiated from the brown color of the wooded areas and from all other fields including grasslands and alfalfa meadows.

Agricultural crop production in a given region is variable from year to year. Table 21 presents the variations in yields per acre of wheat, corn, and soybeans for a recent 5-year period on the basis of a single state and the entire U.S. As expected, the ranges for this period of time are smaller for the U.S. than for the single state of Indiana. However, the yield variations emphasize the fact that crop production is primarily a biological system with its operations carried out in open-air environments that are subject to little control by the farmer. As in any biological system, the crop organisms are subject to devastation by climatic extremes—heat, cold, drought, hail, flooding, etc.—and by biological pests such as weeds, insects, fungi, bacteria, viruses and nematodes. Climatic extremes often occur suddenly with little forewarning and damages can be quite extensive. Damage from hail, frosts and floods are well known. However, there are many other subtle climatic effects that are not so obvious. For example, heavy spring rains that delay corn planting in the Corn Belt can result in yield reductions in the fall. Experiments in Ohio and Indiana indicated that delays in planting beyond the week of May 7 of one, two and three weeks, resulted in yield reductions of 2, 7, 14 bushels per acre respectively.

Corn planting is less critical in southern United States. High temperatures and drought can be damaging to all grain crops, especially if these conditions occur at pollinating times.

Insect and disease agents can multiply rapidly when environment is favorable and cause dramatically severe losses. Wheat rusts and leafspots (especially Septoria) diseases may cause yield reduction of 50 percent or more when extended cool wet periods occur after heading.

Table 21. Variation in yields of wheat, corn, and soybeans for Indiana and the United States, 1961-1965.

	Indiana			United States		
Year	**Wheat**	**Corn**	**Soybeans**	**Wheat**	**Corn**	**Soybeans**
	bushels per acre			bushels per acre		
1961	35.0	74.0	28.0	24.0	62.0	25.2
1962	35.5	82.0	28.0	25.1	64.1	24.2
1963	41.0	87.0	27.5	25.3	67.6	24.5
1964	36.5	72.0	23.5	26.3	62.6	22.8
1965	34.0	94.0	28.0	26.9	73.1	24.4
Extremes	34.0- 41.0	72.0- 94.0	23.5- 28.0	24.0- 26.9	62.0- 73.1	22.8- 25.2
Range	7	22	4.5	2.9	11.1	2.4

However, the onset of dry weather during this period stops progress of the disease and further yield reductions do not occur. Even so, foilage destruction may be sufficient to incur yield losses of 15-20 percent over extensive acreages.

Because of these characteristics of world crop production (size, remoteness, diversity, variability and vulnerability), accurate information that is fairly reliable on production during and following the crop season is limited to the crops grown in the more advanced countries. Even there the need is continuously growing for increased accuracy, timeliness, frequency and degree of detail of crop information.

The economic development of African, Asian and South American countries is highly dependent upon improvement in their agriculture. The Advisory Committee on Private Enterprise in Foreign Aid chaired by A. K. Watson (5) states, "The desperate race between population growth and food production in the less developed countries is so well known and documented that we need not labor it here. So critical is this problem that it justifies the greatest attention of USAID. Where industrial feasibility studies are concerned, those which relate to expanding the supply of fertilizer or insecticides, or which relate to the transport and processing of foods will merit an especially high priority." On the magnitude of the task ahead the committee states: "Over the past months as we worked to relate foreign aid and private initiative, we came to believe that no matter how carefully our aid dollars are invested and no matter how wise and energetic USAID's personnel may be, there is still not enough money nor people to accomplish the vast task the U.S. has undertaken. It is only through private resources, our own and those of the developing countries themselves, where the additional resources are potentially adequate to meet the challenge."

In order to attract investment capital into agricultural enterprises in developing countries, rapid information flow must be provided on the progress and results of the program. For example, the development of a soybean industry in western Minas Gerias of Brazil depends upon the simultaneous development and use of phosphorus and calcium fertilizers, improved adapted varieties, and the building of oil extraction plants. The improvement of wheat yields in India is heavily dependent upon availability and use of nitrogen fertilizer. We know from our U.S. experience that major changes in varieties through breeding are required when nitrogen fertilization is increased. Many other important projects or programs involving the coordinated development of new businesses, industries, and expanded crop research will obviously be needed. There will be more programs needed than there will be dollars and trained personnel to carry them out. Priorities will have to be established and these hopefully will be on the basis of the greatest expected return per dollar and man-year invested. Once underway the programs must be carefully monitored. Accurate information on seasonal progress of the crop must be gathered and passed to management so timely corrective measures can be taken to guarantee a stabilized production. In cases of crop failure, accurate diagnosis is required to select and apply effective corrective measures. Multispectral sensing may be a direct and reliable method of gathering essential information on such crop development programs.

Research and development of multispectral remote sensing of crops should proceed with broadened applications. Preliminary studies reported above indicate that multispectral imagery collected over different crop types in the photographic and infra-red regions of the electromagnetic spectrum may show marked differences in tone on the resulting photographs. These studies imply that crop species may be differentiated by their tone response on imagery generated by multispectral cameras and sensors. Advances in equipment which permit either direct recording or energy returns from crops in electronic form on magnetic tape or the conversion of tones on photographs into electronic signals on magnetic tape have made it possible to consider use of computers in analyzing data. If these studies are successful, it will be possible to gather crop data from airborne sensors and process and analyze them in a timely manner.

An important future phase of research is the design, building and operation of a small number of aircraft-borne sensing systems and of data handling systems that can be located for experimental operation in a few production centers of major crops in the United States. Data collection tasks of these experimental systems should be pointed toward gathering some of the types of information now provided in the U.S. by the Statistical Reporting Service. This agency, operating through 43 state field offices, collects agricultural data throughout the U.S. The most common method of gathering data is by voluntary mail samples to 1) regular monthly reporters who receive a general questionnaire each month, 2) direct-mail-individual-farm reporters who receive crop acreage questionnaires in March, June and late fall, 3) random farmers selected by rural mail carriers who receive individual farm questionnaire cards, and 4) special-purpose mail samplings for crops for which an adequate sample cannot be obtained by general-purpose sampling. Periodic reports are issued throughout the year on a rigid schedule.

These types of information collected and released on a given crop that are applicable to gathering by remote sensing include: 1) acreage intended for planting, 2) acreage planted, 3) periodic forecasts during the season of potential production, 4) acreage harvested and 5) total production. Preliminary plans of centers for aircraft remote sensing systems have been carried forward for three locations in the United States. The studies for each center include estimates of numbers of data gathering missions, description of tasks to be performed, and a description of sensing systems and data processing systems. Approximate costs of equipment, supplies and staff have been computed for one of the centers to serve as a guide on economic feasibility.

Proposed U.S. Experimental Aircraft Remote Sensing Centers

Selection of the sites for the remote sensing centers was based upon the U.S. distribution of acreage of the most important food crops—wheat, corn, rice, sorghum and soybeans. The regions selected were the winter wheat region of the Great Plains, the Mississippi Delta, East Texas, Louisiana region, and the central Corn Belt states of Iowa, Illinois, Indiana and Ohio. The major crops and the percentage of total U.S. acreage of that crop available within the region for survey are shown in Table 22.

Survey Missions at each Center: Planting and harvesting schedules and critical crop development periods in each region dictate from 4 to 6 flight missions during the growing season from March through December. The projected dates, purposes, ground conditions and tasks for each mission are described.

Table 22. Millions of acres and percentage of national acreage of important food crops available for remote sensing surveys at three proposed centers.

Area	Corn		Winter Wheat		Soybeans		Rice		Sorghum		Cotton	
	acres	percent	acres	percent	acres	percent	acres	percent	acres	percent	acres	percent
Corn Belt Region (Ohio, Ind., Ill., Ia.)	25.0	44	4.0	11	13.5	48	—	—	—	—	—	—
Great Plains Region (Kans., Nebr., Colo., Okla., Tex.)	7.7	13	20.0	60	1.5	5	—	—	8.5	73	3.2	23
Mississippi Delta Region (E. Tex. and La.)	0.7	1	0.2	1	4.6	16	1.5	83	—	—	7.3	49
Total	33.4	58	24.2	72	19.6	69	1.5	83	8.5	73	10.5	72

Corn Belt Surveys

Mission 1. Mid-March to Mid-April

Primary Purpose: To determine acreage of winter grains and estimate yield on basis of winter survival.

Ground Conditions: The agricultural lands will consist largely of fall-plowed fields; corn or soybean crop debris, dormant grasslands and meadows. Winter grains will be primarily wheat with some winter oats and rye in southern parts of the Corn Belt. Winter grains will be first fields to turn green and will remain greener than grasslands and meadows for four to six weeks in early spring. Spring tillage will begin. Fields intended for oats will generally be lightly tilled, leaving residue of last year's corn crop exposed. Fields intended for corn and soybeans will be plowed and little crop residue exposed. In general, the fields will be wet from frequent spring rains with some ponding in low areas.

Tasks:

1. To differentiate green fields of winter grains from fields
   a) of bare soil, fall plowed
   b) with overwintered corn stubble
   1) On many fields a stalk cutter will have been used after harvest or during winter, and crop debris will be scattered over surface of the fields.
   c) of bare soil spring plowed or disked
   1) More debris will be exposed in disked fields and there will likely be planted oats.
2. To determine density of ground cover of winter grains.
   a) At this stage plants will be short and density of crop will vary within individual fields due to winter killing, soil type, topographic exposure, nutrition, etc.
3. To measure acres of winter grains.

Mission 2. May 1 to 10

Primary Purpose: To determine acreage intended for planting corn and soybeans.

Ground Conditions: Fields of bare soil will predominate and will show soil type and moisture variability as color differences within and among fields. Fall planted grains, established meadows and grasslands will be green. Fields of spring oats will be green if weather permitted early planting. Diseases of wheat may be detectable such as powdery mildew, rusts, **Septoria** spp. etc.

Tasks:

1. To differentiate fields of bare soil from vegetated fields. These will be be predominately intended for corn and soybeans.
2. To differentiate among green fields of wheat, meadow, grass and oats on basis of color and density.
3. To determine acreage of bare fields and of specific crops in vegetated fields.
4. To detect wheat disease infection level.
5. To determine flood or water damage.

Mission 3. June 25 to July 5

Primary Purpose: To determine acreage planted to soybeans and corn, estimate yield from condition of corn, soybeans, wheat and oats.

Ground Conditions: All fields will be vegetated, row crops of corn and soybeans will predominate. Generally corn fields will more fully cover soil in row middles than soybeans. Wheat will be ripening and will be readily differentiable from oats, grass, alfalfa and other uncut meadow crops. Recently cut meadows will be confounded with grasslands.

Areas damaged during excessive June rains will be evident as off-color or bare areas within fields. In wet seasons, weeds may be present in row crop fields.

Tasks:

1. To differentiate fields of corn, soybeans, wheat, oats, meadow and grasslands and measure acreage of each crop.
2. To determine area of cropland damage by flood.
3. To estimate yields of oats and wheat.
4. To detect extent of damage from diseases and insects in wheat and oats.
   a. Diseases of wheat: Leaf rust, Septoria leaf spots.
   b. Insects of wheat and oats: Cereal leaf beetle.
   c. Diseases of oats: Yellow dwarf virus, rusts.
5. To detect and determine acreage of corn and soybean fields with heavy weed population.
   a. Such fields will have green weed cover between rows of corn or soybeans.

Mission 4. July 15 to August 5

Primary Purpose: To determine acreage of wheat and oats harvested; confirm acreages and estimate yields of corn and soybeans.

Ground Conditions: Corn will be tasseling and will be readily identifiable thereafter from all other crops. Wheat and oat fields will have been cut, leaving stubble and straw. These will be readily identifiable. If stubble and straw have been harvested from certain fields, these may be confounded with fields of forages recently cut or with grasslands. If moisture is adequate, some stubble fields may be plowed following harvest.

Vigor and condition of corn and soybeans may be indicated by density of vegetative cover of soil. Area of disease damage due to root rot of soybeans, budblight of soybeans, maize dwarf mosaic of corn and corn leaf blight may be detectable in certain regions. Damages due to flooding, hail or windstorms may be present. Presence of heavy weed infestations in soybeans may be detected.

Tasks:

1. To differentiate fields of corn or soybeans, and wheat or oats from stubble from forages, grass and other crops.
2. To determine acreage of corn, soybeans, and stubble fields.
3. To detect areas of storm, disease and weed damage to corn and soybeans and estimate extent of damage.
4. To differentiate oat stubble from wheat stubble.

Mission 5. August 15 to September 10

Primary Purpose: To confirm acreage of soybeans and estimate yields of corn and soybeans on basis of condition of the crops.

Ground Conditions: If moisture is limiting, stress will develop in corn, soybeans, grasses, and forages and be expressed as yellowing of foliage and defoliation. Low lying areas may have light frosts in September which could be confounded with drought injury. Time and duration of drought and earliness of frost influence yield strongly. Corn leaf blight disease in certain years may reduce density of foliage especially in southern areas of the Corn Belt region. Soybean root rot and budblight may reduce plant size and modify color.

Tasks:

1. To determine condition and vigor of corn and soybeans on basis of crop density and color and estimate yield.
2. To confirm acreage of soybeans.
3. To determine exent and severity of damage to corn by stalk breakage, drought, frost, etc.

Mission 6. September 20 to October 10

Primary Purpose: To determine condition of corn crop and progress of harvest of soybeans.

Ground Conditions: Soybeans will be maturing and harvest will begin. Early harvested fields will be tilled and planted to winter wheat. Corn will be maturing. If year is favorable for stalk rot disease, lodging will be evident at this time. Stalk lodging and breakage reduces yield and increases difficulty of harvest. Alfalfa and other meadow crops and grasslands will be green and growing vigorously if moisture is adequate.

Tasks:

1. To differentiate fields of standing soybeans and harvested soybeans.
2. To determine extent of stalk lodging in maturing corn.
3. To estimate corn yields.

(Soil Moisture from zero to 3-foot depths is a task of all missions)

Dryland Winter Wheat Surveys in Great Plains

Mission 1. July 15 to August 15

Primary Purpose: To determine acreage intended for planting of winter wheat and acreage and condition of sorghum crop.

Ground Conditions: Fields of fallow (bare) soil and of wheat stubble will predominate with row-crop sorghum fields inter-mixed. Extensive areas of grassland occur. Generally moisture is limited in summer so grasslands will be brown and fallowed fields dry on the surface. Sorghum fields may show water stress and be of variable height and density. Occasional fields will be irrigated with water from deep wells.

Tasks:

1. To differentiate fallowed land, wheat stubble and sorghum and determine their acreages.
2. To estimate yield of sorghum on basis of its density and vigor.

Mission 2. October 1 to November 1

Primary Purpose: To determine wheat acreage planted and condition in which crop enters winter.

Ground Conditions: If moisture has been adequate, fall-planted wheat will have grown to cover up to fifty percent of the soil surface. Generally, wheat stubble is left undisturbed until spring so it will catch and hold windswept snow. Sorghum harvest will be in progress.

Tasks:

1. To differentiate wheat from grassland, wheat stubble and sorghum.
2. To determine density of wheat and measure acreage.
3. To estimate acreage of sorghum harvest.

Mission 3. March 20 to April 10

Primary Purpose: To determine condition of wheat crop and soil moisture.

Ground Conditions: Fall-planted wheat will be turning green well before the grasslands, wheat fields in good condition will be readily identifiable although acreage will be confounded with that for winter barley. If moisture has been limiting, density of stand of wheat will be very low and bare soil will predominate in a vertical view.

Task:

1. To determine vigor and density of fall-planted wheat.

Mission 4. May 1 to 15

Primary Purpose: To estimate wheat acreage and yield.

Ground Conditions: Density of wheat stand at this stage should give fair indication of yield potential. Heading occurs during this period and should permit separation of winter wheat and winter barley fields. Frost damage can occur, resulting in partially killed heads that would likely not be detectable unless damage is nearly total. Leaf rust and stem rust diseases build up at this time, but ultimate yield loss is dependent upon continuing favorable weather in June.

Cultivation of last year's wheat stubble begins at this time, initiates the summer fallow program for fields intended for wheat planting in September. Tillage of these fields is devised to maintain the old crop residue near the soil surface to prevent wind erosion. This residue gradually decomposes during summer if rainfall is sufficient.

Estimation of sorghum acreage likely not possible since tillage preparations for sorghum planting will be confounded with summer fallow acreage.

Task:

1. To estimate wheat yield and determine acreage.

Mission 5. June 1 to 10

Primary Purpose: To estimate wheat yield.

Ground Conditions: Headed wheat fields, fallowed fields and grasslands predominate. Planting of sorghum for grain will be nearing completion, but this acreage probably cannot be differentiated from fallowed land.

Damage from hail storms, rust diseases, and drought might be detectable due to reduced density of crop.

Task:

1. To determine yield of wheat and determine extent of damaged areas.

Mission 6. June 25 to July 10

Primary Purpose: To determine yield and acreage harvested in winter wheat and to estimate acreage planted to sorghum.

Ground Conditions: Wheat harvest will be progressing rapidly. Summer fallowed fields, standing or harvested wheat, and row-crop sorghum will predominate. Wheat fields or portions of fields not harvested because of low yield should be detectable. Sorghum plantings in most cases will be detectable and acreage can be determined.

Tasks:

1. To differentiate harvested and standing mature wheat.
2. To determine acreage of row-crop sorghum.

Mississippi Delta-East Texas, Louisiana Surveys

Mission 1. May 1 to 15

Primary Purpose: To determine acreage of cotton and rice planted.

Ground Conditions: Cultivated areas at this time have been planted to cotton and soybeans primarily. Corn is a minor crop. Rice fields in some areas are intermixed with cotton and soybean fields. Rice fields can be identified due to water inundation. Flooding is done for a week or ten days in May, then again for longer intervals throughout the season. Newly planted cotton fields can be distinguished by the general practice of "bedding" for cotton. The rows will be elevated on beds or ridges three to five inches high before planting. Planting and later cultivating levels them out.

Tasks:

1. To differentiate among cultivated fields, those with rows of soil beds three to five inches in height at intervals of three and a half feet. These in general will be cotton.
2. To differentiate flooded or recently flooded cultivated fields. These will be rice fields.
3. To differentiate other vegetated fields, including winter oats and cover crops such as lespedeza.

Mission 2. June 15 to 20

Primary Purpose: To confirm cotton, rice and soybean acreages and estimate yield.

Ground Conditions: Row crops are primarily cotton and soybeans. Cotton at this stage normally will have developed so that middles of rows are covered by a foliage canopy. The rows in soybean fields still will be plainly evident.

Tasks:

1. To differentiate rice, cotton and soybean fields and determine acreage.
2. To estimate yield of cotton, soybeans and rice through determinations of vigor.

Mission 3. August 15 to September 10

Primary Purpose: To estimate yields of cotton, soybeans and rice.

Ground Conditions: Early soybeans, cotton and rice will be maturing. Harvest normally starts about September 10 and continues into December.

Tasks:

1. To estimate yields of cotton from vigor of plants and density of open cotton balls.
2. To estimate soybean yield from vigor of plants.
3. To estimate rice yields.

Mission 4. October 1

Primary Purpose: To estimate cotton and soybean yields.

Ground Conditions: Fields of cotton and soybeans will show a wide range within each corp in amount of foliation, depending upon planting date in the spring. Rice harvest.

Task:

1. To estimate yields of cotton, soybeans, and rice through densities of crop.

General Characteristics of the Proposed System for the Corn Belt

In the specifications listed it has been assumed the aircraft would be equipped with calibrated optical mechanical scanners capable of sensing in up to 18 different spectral regions. Cameras with panchromatic and infrared color (camouflage detection) films will be used for reference information and special studies. The scanner data are to be recorded in analog form on magnetic tape. Selected channels will be processed on board through an analog discrimination device to determine proportions of easily detected areas of crops. Upon return to the center, all chanels of data will be digitized and processed through a digital display-computer system. By pattern recognition techniques the data will be analyzed to yield solutions to the more complex problems of detecting crop species, crop condition, prospective yield, and other objectives delineated in mission descriptions.

Tentative Specifications of Corn Belt Survey Equipment and Operation

Aircraft altitude and speed: 10,000 ft. above ground level; 300 m.p.h.

Percentage of region sampled each mission: 10 percent
Total area sampled per mission: 19,000 square miles
Total area sampled per year (six missions): 114,000 sq. mi.
Flight time per mission: 30 hours
Flight time per day: 4 hours
Number days to complete each mission: 7.5 days
Field of view and width of scanned area: 60°; 2.2 miles

Scanner resolution: 10 milliradians; 100 ft. ground resolution at nadir

Scan rate and time to scan 60° field of view: 60 scan lines/sec. and .003 sec.

Number of spectral channels recorded: 18

Number of samples required to cover 60° scan with 10 milliradiar resolution: 100

Number of samples per scan (18 channels x 100 samples): 1800

Sample rate: 600,000 samples/sec. (1800 in .003 sec.)

Rate of Analog-Digital conversion: 150,000 samples per sec., thus A to D Conversion will require 4 hours for each hour of aircraft data collection.

Table 23. Estimated annual cost of the corn belt survey operation.

A. **Aircraft Operation**	
A/C Operations Cost (Fuel, Maint., Ins., Hangar, Misc.)	$100,000
A/C Depreciation (10% of $400,000)	40,000
Pilot & Co-pilot (Salary & Benefits)	40,000
Sub Total	$180,000
B. **Sensor Equipment & Operation**	
Sensor Operational Cost (Film, tape, Maint., etc.)	
Sensor & Depreciation (Camera, Scanners, Radar, Disp., Processor, etc.)	
Two Technicians	
Sub Total	
C. **Ground Processing & Data Reduction Operation**	
Analog to Digital Conversion (10% of $140,000)	$ 14,000
Digital Display (10% of 300,000)	30,000
Maintenance of the Above Equip. & Supply	16,000
Computer (Rental)	100,000
Sub Total	$160,000
D. Staff for data processing and reduction 15 @ $20,000	$300,000

Proposed Foreign Experimental Aircraft Remote Sensing Center

At an early stage following establishment of the three U.S. experimental centers, it will be desirable to set up similar experimental centers in one or more foreign countries. The purpose is similar to that of the U.S. centers, namely to gain experimental data on accuracy and effectiveness of the remote sensing system under the agriculture conditions of the country.

The Indo-Gangetic plain of India has been selected as a potential region of operation. This is one of the most important agricultural production areas of one of the world's heaviest populated countries. A description of six data gathering missions per year is given below. It is evident that the missions are similar in purpose to those planned in the U.S., but the diversity of crops and the management practices introduce new complex variables such as small field sizes and interplanting of two or more crops. As in the U.S. Great Plains area, soil moisture becomes critical at planting, flowering and maturation times of each crop.

Indo-Gangetic Plain Survey

(Soil moisture in 0 to 3 foot depths and salt damage estimates are tasks of all six missions)

Mission 1. January 15 to February 15

Primary Purpose: To determine planted acreages of wheat, barley and chick pea and assess condition of crops and estimate yields.

Ground Conditions: Cultivated agricultural fields predominate throughout the Plains region. The majority of the agricultural land is still mixed cropping by subsistence farmers with farm sizes of two to five hectares. Wheat, barley, and chick peas will have been planted in October and will be intermixed in plots in the same field. There is a growing tendency to depart from mixed cropping and adopt the culture of a single crop over large acres. However, within these monocultures the management of each small tract is retained by the individual farmer. Management practices such as fertilization and irrigation vary greatly depending upon the resources and efficiency of the individual farmer. Consequently the ultimate plot size required to identify a "management" unit of the crop is still two to five hectares.

At this time, the crop canopies will have developed so they completely cover the soil except in damaged areas.

Tasks:

1. To differentiate fields of barley and wheat from chick pea.
2. To determine vigor and density of wheat and barley. The following diseases will be present:
   - Wheat: stripe rust, foot rots (bare spots)
   - Barley: stripe rust and Helminthosporium spp. (leaf damage)
   - Chick pea: blight, wilt and rust.

Mission 2. March 1 to 30

Primary Purpose: To estimate yields of wheat, barley and chick peas.

Ground Conditions: Wheat and barley heading occurs in early March, with barley one week to ten days ahead of wheat. Chick pea is flowering and these fields are conspicuous with pink flowers during a two-week bloom period.

Tasks:

1. To differentiate wheat and barley acreage on basis of date of heading, and differences in spectral properties after heading.
2. To differentiate chick pea acreage on flowering characteristics and crop density.
3. To determine damage to wheat by leaf rust, **Alternaria,** and possibly by loose smut.
4. To determine damage to chick pea by rust (uromycis) and blight (Ascochyta spp.).

Mission 3. April 1 to 15

Primary Purpose: To estimate wheat, barley, and chickpea (gram) yields and confirm acreage, and to determine acreage of newly planted sugarcane.

Ground Conditions: Wheat and barley are turning yellow with maturity. Barley will mature about one week earlier than wheat. Chickpea is yellowing and losing leaves, exposing brownish colored stems and pods. Harvest of these crops is followed by tillage of fields in preparation of corn, rice, and redgram planting in late May or early June. In some cases, sorghum for forage may be planted and harvested before these crops are planted. Sugarcane planting will have been under way since January. Second-year (rattoon) crops will show heavy regrowth following harvset in winter.

Tasks:

1. To differentiate and measure wheat and barley acreages on basis of maturity dates and spectral properties, and to estimate yields.
2. To differentiate and measure chickpea acreages on basis of maturity characters.
3. To estimate yield of chickpea.
4. To determine vigor of second year (rattoon) sugarcane and estimate acreage of newly planted sugarcane.

Mission 4. August 15 to September 1

Primary Purpose: To determine planted acreage of rice, corn, and red gram.

Ground Conditions: Rice is generally planted in May and June; corn and red gram in June-July. At this time, the rice fields will be flooded. The three crops should be readily identified on basis of flooding (of rice), growth habit and flowering.

Tasks:

1. To assess vigor and condition of corn, red gram, and rice as a basis for yield estimation. Damaging conditions evident at this time are as follows :
   - a. corn: water logging damage, corn borer damage, leaf blight disease of corn (Helminthosporium spp.)
   - b. red gram: Fusarium wilt disease
2. To determine acreage of corn, rice, and red gram.

Mission 5. September 15 to October 1

Primary Purpose: To estimate yields of rice, corn, and red gram.

Ground Conditions: These crops are maturing and yields should be estimable on basis of density of crops as affected by drought, fertility, and other damaging agents as disease, excessive water, insect, salt damage, etc. Harvesting generally peaks in October for corn and red gram. Rice and sugarcane harvest proceeds over a longer period.

Tasks:

1. To confirm acreage and determine vigor and condition of rice, corn, and red gram as a basis of yield estimations.
   - a. stalk rot and root rot damages should be evident on corn
2. To estimate yield of rice and sugarcane on basis of crop densities.
   - a. rice blast (Piricularic Oryzae) and leaf spot (Helminthosporium) damage may be evident at this time.

Mission 6. December 15

Primary Purpose: To determine recently planted acreage, stand and vigor of wheat, barley, and chickpea, monitor progress of rice harvest, and estimate yield of red gram.

Ground Conditions: Wheat, barley and chickpea are planted following harvest of corn, in October. Generally, this is the begnining of the dry season so the establishment of a stand by this period in December is a major requirement for successful crops. Rice harvest begins in October and continues in mid January. Sugarcane and Red gram harvest begins in November-December and continuues through the winter.

Tasks:

1. To differentiate fields of bare soil from areas of vegetation.
2. To differentiate among fields of wheat, barley and chickpea and estimate condition of each crop from
   - a) color
   - b) density
   - c) vigor
3. To estimate acreage of rice harvested.
4. To estimate yield of red gram.

Proposed Satellite Test Site for Early Agricultural Remote Sensing Experiments

Recommended satellite experiments to investigate remote sensing from orbital altitudes for agricultural applications are of a more basic nature than those for aircraft systems. Initially experiments would make use of calibrated test sites, then extended test site regions, and finally global regions with synoptic coverage.

A most desirable test site for early agricultural remote sensing experiments from space is the Salton Sea region in southeastern California. An approximately square area 100 miles on a side bounded on the north by the 34th parallel, on the west by the 116° 40′ meridian, to the east by the Colorado River, and on the south by the Mexican border is proposed. A wide variety of agricultural and hydrological features are found within the region. These include the following:

(1) soils in every stage of moisture capacity;
(2) soils in various degrees of development because of intensive irrigation practices;
(3) saline and alkali conditions important to arid irrigated regions in world;
(4) representative soils of some major soil groups including irrigated and nonirrigated desert;
(5) major world food crops including wheat, corn, millet, sorghum, barley, oats, etc., in close proximity of each other;
(6) crops of major importance at various stages of maturity throughout calendar year;
(7) surface streams, including the Colorado River, New River, Alamo River and various irrigation canals;
(8) the Salton Sea and various spring regions.

"The Imperial Valley is located in the center of Imperial County just north of the Mexican border and south of the Salton Sea. It is the largest and most important agricultural area in the desert region of southeastern California. This valley, reclaimed from the barren domain of sand and wind, has a dependable irrigation water supply from the Colorado River, made possible by the Hoover Dam and the All-American Canal—one of the greatest controlled irrigation projects in the Western Hemisphere. The Imperial Valley forms a depression in the Sonoran Desert (locally referred to as the Colorado Desert), and its elevation ranges from about 35 feet above sea level to 387 feet below sea level at the lowest point. The valley as a whole forms a uniform plain, sloping gently to the north, the surface of which is broken only by the channels of the two intermittent 'wadi-like' local streams (New and Alamo Rivers), and by occasional bodies of dunesand. The principal town in this valley is El Centro. Some of the other towns are Imperial, Holtville, Calexico, Brawley, Calipatria and Niland.

The climate of the Imperial Valley is that of an arid low-altitude desert. The chief characteristics are exceptionally long and hot summers with relatively high temperatures throughout the entire year, many days of intense sunshine, low humidity, and a rapid rate of evaporation. Temperatures of 100°F. (38°C.) or more have been recorded for each of the months from March to October inclusive, and in each of the winter months temperatures have risen to 85°F. (29°C.). A maximum temperature of 118°F (48°C.) has been recorded for both May and June, and 115°F. (46°C.) for July and August, while the absolute minimums for these months are 41°F. (5°C.), 51°F. (11°C.), 57°F. (14°C.) and 60°F. (16°C.), respectively.

Winters are short and mild with a large percentage of warm, sunshiny days. Temperatures slightly lower than the freezing point may be expected occasionally from December to February, inclusive. The rainfall, which usually comes during the winter, is very light. Average annual precipitation at Calexico is only slightly more than 3 inches (76 mm.) and about 2.5 inches (66 mm.) at Brawley. Rain, coming usually at long intervals, is very irregular in occurrence. Hence, the rainfall is entirely unreliable, even as a supplement to irrigation. Thus, rains in the Imperial Valley are seldom beneficial and occasionally can even be detrimental to crops.

Winds of high velocity may blow frequently during March and April, and fairly strong winds and occasional dust storms may be expected at any season. The periods of high winds, however, are of relatively short duration. The drifting of the lighter textured soils, the damage to crops, and the unpleasantness of carrying on farm operations during these storms necessitates extensive use of windbreaks to protect fruits and vegetables in blowsand areas.

As a whole, the climatic conditions in the Imperial Valley, in conjunction with the irrigation water from the Colorado River, are almost ideal for crop production, as the exceptionally long, warm, growing season and mild winters are a distinct advantage to year-round farming. The long growing season and all-year supply of irrigation water easily permit growing two crops on the same land in one year. For example, barley, wheat, or oats may be planted in November and harvested in May or June. Then this land can be prepared, and milo or some other grain sorghum planted in July and harvested in November. Many other combinations of double cropping are also found in common practice.

The soils of the Imperial Valley are composed of highly stratified Colorado River deposits, largely from mixed sedimentary rock materials. These soils vary in texture from loamy sands to clay. The lighter-textured types have usually been re-worked by wind action and have rather low water-holding capacities. The heavier types normally contain considerable salt, often in concentrations detrimental to crops.

All of the soil types which are now being put to agricultural use to any important extent in the Imperial Valley belong to one of the following four soil series: Imperial, Meloland, Holtville, or Rositas. Those of the Meloland and Rositas series are commonly referred to as "soft" soils. This term refers to the sandy texture and the ease with which these soils can be worked into a good condition of tilth. Soft soils usually are sands, sandy loams, and silt loams. Within the Imperial and Holtville series are found all of the fine-textured soils of the valley which are commonly referred to as "hard" soils. This term refers to the firm consistency of the surface soil and the difficulty of working such soil into good tilth. The hard soils are usually clay soils. The term "medium" soils refers to silty clay loams, and clay loams of the Imperial and Holtville series. The common classification of the local soils into "soft," "hard," and "medium" is somewhat misleading, as it refers to the surface soils only and does not take into account the character of the subsoils, which frequently determines the ultimate suitability of soils for given crops.

Drainage and alkali content are two important factors to be considered in connection with the soils of the Imperial Valley. Well-drained soils relatively free of soluble salts or alkali are essential for successful farming. All of the soils of the Imperial Valley naturally contain large quantities of soluble material, because they have never been leached by rain waters. Since the introduction of irrigation, soils are being leached, but soils with dense clay subsoils or substrata horizons are developing conditions of poor drainage. In the Imperial Valley the essentials for successful reclamation of soils are free and adequate drainage and sufficiently prolonged leaching to dissolve and remove salts. Since porous soils are most readily leached, they usually are easiest to reclaim, whereas fine soils are often so dense and impervious that they make reclamation difficult.

Most of the farm land in the Imperial Valley is devoted to field crops, and the field crop most widely grown there is alfalfa. Barley is the next most widely grown field crop, followed by grain sorghum, sugar beets, flaxseed, cotton, wheat, sesbania, safflower, Sudangrass, oats, irrigated pastures, Hubam clover, Bermudagrass (grown for seed) and millet. Relatively small acreages of rice, castor beans, ryegrass, soybeans, dry beans, horse beans, Alta fescuegrass (grown in permanent, irrigated pastures and tolerant of drought and alkali) are also grown.

The Imperial Valley is also an important source of a great many vegetable crops which mature and are marketed at a time when the supplies from other areas are not large. These vegetable crops are grown in the fall, winter and spring. The vegetable crop most widely grown is lettuce. Cantaloupes are next, followed by carrots, watermelons, tomatoes, peas, dry onions, squash and cabbage. Relatively small acreages of broccoli, cucumbers, sweet corn, Honeyball melons, Honeydew melons, Persian melons, asparagus, snap beans, Brussels sprouts, mustard (grown for greens), sweet potatoes, coriander, okra, Casaba melons, spinach, eggplant, lima beans, garlic, chicory (grown for greens), romaine lettuce, table beets and Brenshaw melon are grown.

Fruit acreage in the Imperial Valley is relatively small and unimportant, composed mostly of citrus fruits with some grapes and dates. The fruit crop most widely grown is grapefruit. Cardinal grapes come next, followed by oranges (Valencia and Navel), tangerines, and dates. Relatively small acreages are devoted to pecans, lemons, mixed citrus orchards, fruit tree nurseries and strawberries.

During the winter months large numbers of lambs and cattle are fed here on pasture, crop residues and in feedlots. There has been a considerable increase in winter pasturing and feeding of cattle and lambs. There is some dairying, but this has declined in importance in recent years. The local agricultural experiment station, that is, the University of California Field Station at Meloland, has undertaken livestock investigations to determine the effect of climate, particularly high temperature, on the efficiency of gains of Hereford, Brahman, Hereford x Brahman, and Hereford x Shorthorn crossbred cattle. Valuable information is being obtained on the relative heat tolerance of the cattle breed, as well as on the practical merits of various cooling devices of interest to the livestock producers of this valley. This station is among the foremost in the study of effect of high temperature on the behavior of plants and animals." (18)

The various investigations conducted in the Imperial Valley at the University of California Field Station at Meloland, as well as at the U.S. Department of Agriculture Southwestern Irrigation Field Station at Brawley, have resulted in many contributions to field crop production in this valley and in the adjacent valleys of similar desert climate.

The Salton Sea, Colorado, New and Alamo Rivers, the canals, arid non-irrigated soils, irrigated soils, and lush fields of vegetation cover present areas of highly contrasting tones. Fields are generally of large size and are typically square regions one half mile on a side. The various aforementioned features are of sizes compatible with the lower resolution capabilities of early satellite sensing equipment.

The climate and subsequent atmospheric conditions are rather ideal and offer a favorable environment for early remote sensing experiments. The climate of the low-lying desert basins and ranges is typically arid and is characterized by extreme heat and dryness. Absorption and scattering of energy at optical (visible through 12-14 microns) frequencies by water vapor are greatly reduced in such a condition.

The Salton Sea region is remarkably free of clouds as evidenced in photographs of the area already collected from satellite altitudes. An extremely high probability exists that the region will thus be unobscured by clouds at the time of satellite overflights.

The latitude of the region is such that it can be covered by low inclination orbit launches (about 32 degrees) as well as polar orbiting shots. It is extremely desirable to have black, white and gray reflectance panels, color reflectance panels, and thermal radiation standards located in the area; these could be located adjacent to the Imperial Valley-Salton Sea region. An illustration of such an arrangement is shown in Plate 22. This calibrated test site is ideal for basic testing of sensors for agricultural applications and for isolating interaction of various sensor and phenomenological effects. However, subsequent testing should be conducted with calibrated test sites having environments that are not so ideal and are therefore more typical of regions of major importance to agriculture. For this reason calibrated test sites should be laid out in vari-

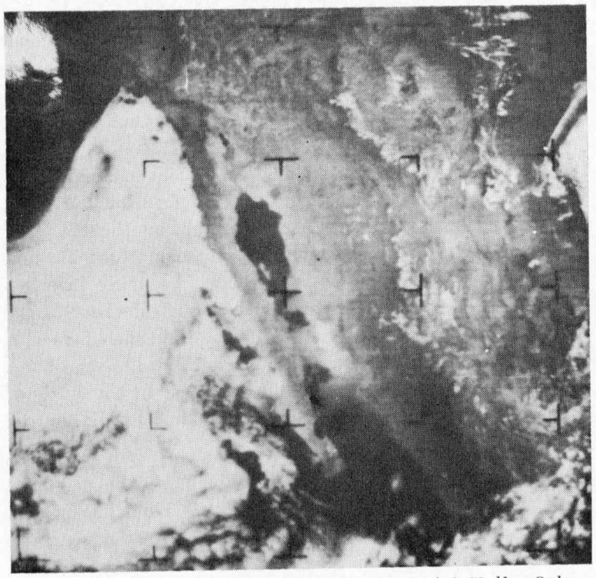


Fig. 75. Nimbus II imagery of the Imperial Valley-Salton Sea region.

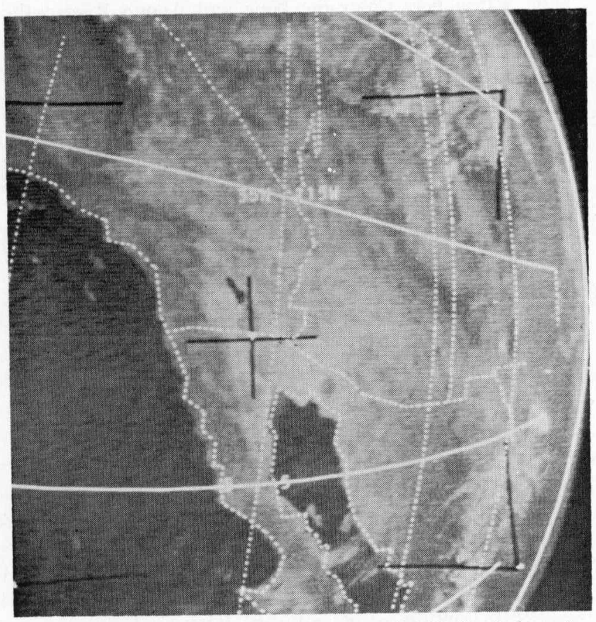


Fig. 76. ESSA I imagery of the Imperial Valley-Salton Sea region.

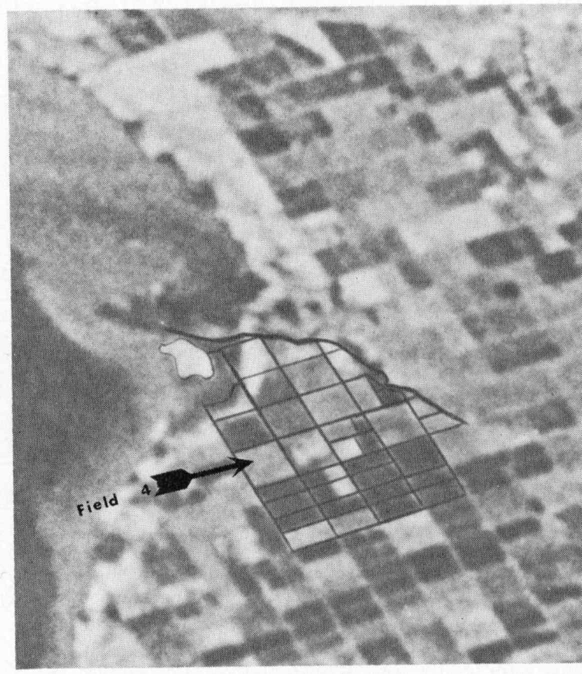


Fig. 77. Enlarged view of the fields located southeast of the Salton Sea.

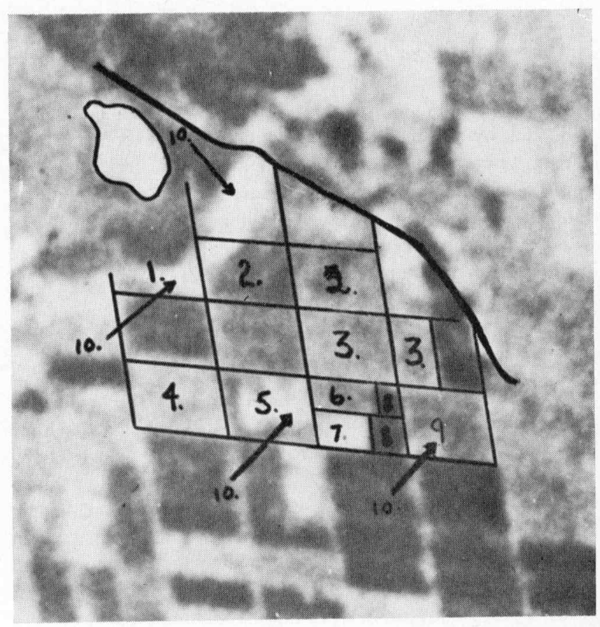


Fig. 78. Annotated enlargement of the photograph taken from Gemini V (Figure 79). 1. Weeds—Federal Geese and Duck Area, 2. Weeds and Barley—State Geese and Duck Area, 3. Sugar Beets, 4. Sorghum, 5. Alfalfa—(poor), 6. Barley, 7. Barley Stubble, 8. Cotton, 9. Bare Soil—(dry), 10. White Area Caused by Salinity.

ous areas set up for previously defined aircraft missions (Corn Belt, Great Plains, Mississippi Delta/East Texas regions). These other sites are already being developed in the vicinity of Purdue University at Lafayette, Indiana, and Weslaco, Texas. At all of the calibrated sites adequate ground truth (crop type, density, soil moisture, soil temperature, etc.) must be determined, and a fair degree of overall control maintained.

The Laboratory for Agricultural Remote Sensing has collected together imagery of the Imperial Valley-Salton Sea region obtained by photographic cameras on Gemini V, Vidicon cameras on Nimbus II, and Vidicon cameras on ESSA I. These are shown in Plate 23 and Figures 75 and 76. The dark tone of the agricultural features in the Imperial Valley to Yuma are clearly observable in all the collected imagery. Remarkable detail exists in the Gemini V photograph. Note the cloud free conditions in the Salton Sea-Imperial Valley areas. An enlarged view of the fields southeast of the Salton Sea is shown in Figure 77. It is interesting to note that the field designated on Figure 78 as number 4 taken on August 22, 1965, contains sorghum and is relatively light in tone, while in Figure 79 taken in June of the same field shows more bare soil and is darker in tone.

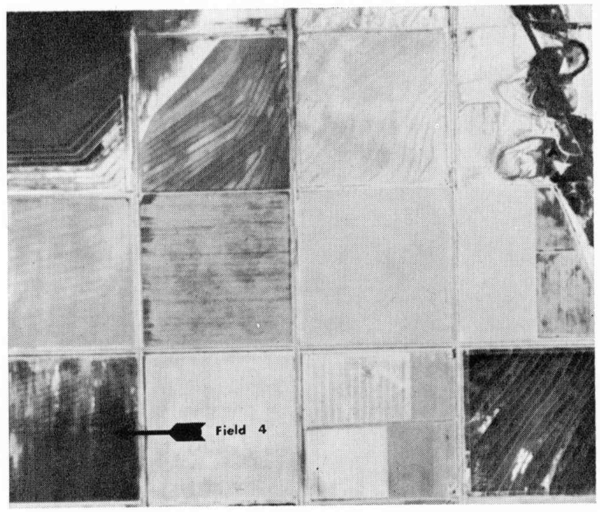


Fig. 79. A high resolution photograph taken from an aircraft of the fields shown in Figure 78.

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