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USE OF ERTS DATA FOR A MULTIDISCIPLINARY ANALYSIS OF MICHIGAN RESOURCES

(E75-10161) THE USE OF ERTS DATA FOR A MULTIDISCIPLINARY ANALYSIS OF MICHIGAN RESOURCES Final Report (Michigan State Univ.) 104 p HC $5.25 CSCL 08F

N75-19785

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G3/43 00161

MICHIGAN STATE UNIVERSITY

1855

Michigan State University
Agricultural Experiment Station
Departments of Botany and Plant Pathology, Crop and Soil Sciences, Forestry, and Geography

1321A

Final Report
Prepared for
Goddard Space Flight Center
Greenbelt, Maryland 20771
November 1974

Environmental Research Institute of Michigan
Infrared and Optics Division

FINAL REPORT

on

THE USE OF ERTS DATA FOR A MULTIDISCIPLINARY ANALYSIS OF MICHIGAN RESOURCES

By

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Under

MSU Office of Research Development, Proposal ORD-1158
NASA ERTS-1 Project 321, Contract NAS-5-21834
MSU Agricultural Experiment Station Journal No. 7091

This project was supported and prepared for the Goddard Space Flight Center, National Aeronautics and Space Administration.

November 1974

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES AND FIGURES FROM APPENDIX A AND APPENDIX B

APPENDIX A

APPENDIX B

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PREFACE

The goal of ERTS Project 321(NAS 5-21834), entitled *Use of ERTS Data for a Multidisciplinary Analysis of Michigan Resources,* was to determine the potential uses of remote sensing data from the ERTS-1 satellite for identification, mapping, and evaluation of (1) forest and related resources, (2) agricultural crops and, (3) soils and landforms. The major specific objectives are as follows:

Task I — Application of ERTS Imagery for Analysis of Forests and Related Natural Resources

Objectives:

1. Assess the utility of manually interpreted (photographic) satellite imagery for evaluating gross characteristics of Michigan's forests, wetlands, and related natural resources on a regional (State of Michigan) scale.
2. Test automated techniques using computer compatible tapes (CCTs) for doing recognition of vegetation type, cover mapping, and area computation using county level test sites.
3. If 1 and/or 2 above produce reasonable success, explore use of ERTS-type sensors for planning, evaluating, and maintaining urban greenbelts.

Task II — Application of ERTS Imagery for Analysis of Agricultural Crops

Objectives:

1. Determine the degree to which agricultural crops in Michigan can be identified by multispectral sensing from ERTS-1.
2. Test the accuracy of multispectral sensing techniques for crop acreage estimation.
3. Provide information for economic studies on the potential for operational space borne crop estimation.

Task III — Application of ERTS Imagery for Analysis of Soils and Landforms

Objectives:

1. Develop and apply techniques for using remote sensor information as a complementary method to traditional aerial photography for identifying and mapping soils and glacial landforms and associated sediments.

The third objectives for Task I and II were not addressed as a result of problems encountered with resolution.

Throughout the report, land area has been variously designated as hectores or acres. The conversion factor for one hectare is 2.47 acres.

SCOPE OF THE INVESTIGATION

ERTS Project 321 is composed of three tasks, each with its own principal investigator at Michigan State University (MSU). Dr. Axel L. Andersen of MSU served as coordinator for Project 321. Dr. Wayne L. Myers was the principal investigator for Task I on the application of ERTS imagery for the analysis of forests and related natural resources. Dr. Gene R. Safir served as principal investigator and Dr. Jon D. Erickson, Environmental

Research Institute of Michigan (ERIM), served as co-investigator, for Task II, which dealt with the application of ERTS imagery for the analysis of agricultural crops; and Task III dealt with the application of ERTS imagery for the analysis of soils and landforms with Dr. Eugene P. Whiteside as principal investigator, and Drs. Harold A. Winters and Delbert L. Mokma as co-investigators. Mr. Richard Rieck assisted Dr. Winters on Task III.

Project 321 was conducted in cooperation with the Environmental Research Institute of Michigan through two subcontracts let by MSU. One of the subcontracts involved data processing and analysis support for all three tasks and the other an investigation on crop acreage estimation techniques primarily in support of task two. The subcontracted research was performed by the Infrared and Optics Division, directed by Mr. Richard R. Legault, under the supervision of Dr. Jon D. Erickson, Head of the Information Systems and Analysis Department and Mr. Richard F. Nalepka. Dr. William A. Malila had major responsibility for the conduct of the investigation, with the assistance of a number of individuals. Mr. James P. Morgenstern performed much of the initial processing and analysis for the Forestry and Agriculture Tasks. Mr. Arthur McCleer participated in the development of the procedure for computer-assisted correlation of ERTS data and Earth coordinate systems. Mr. Ross H. Hieber provided computer programing support and consultation throughout the investigation. Ms. Jane E. Sarno completed the recognition processing and analysis of data from the Agriculture/Forestry test site. Mr. John T. Lewis carried out the mixtures estimation analysis, with assistance from Mr. Jackson P. Livisay. Mr. Thomas W. Wagner performed interpretation and analyses related to the Soils and Landforms Tasks, while computer processing support for it was provided by Mr. James F. Reyer and Mr. William W. Pillars.

It was possible to conduct many of the analyses jointly for Tasks I and II (forests and agricultural crops) because of the similarity of phenology and overlapping test sites. This resulted in reduced costs and more analyses than would otherwise have been possible had the tasks been conducted separately. The results of the investigations from the three tasks are described in separate sections of this report.

CONCLUSIONS

As a result of these investigations the following conclusions were made:

(1) Large forested tracts can be delineated and mapped by manual interpretation of the ERTS transparencies.

(2) Major surface hydrological features such as water bodies, water courses, and permanent wetlands can readily be interpreted because of their distinctive signatures in band 7.

(3) Forest maps with sufficient detail for potential use in regional information systems for general land use planning and for design of forest inventories can be prepared by computer analysis of ERTS-MSS data.

(4) When computer processing techniques were used on ERTS-1 MSS August, 1972 data, field centers of corn, soybeans, trees and bare soil were accurately recognized; senescent vegetation types produced extremely variable signatures and were not satisfactorily recognized; and proportions of corn, soybeans, trees and soil from a 2 x 7-mile area were found to agree well with those obtained through ground truth.

(5) Because there was substantial variability in computer-estimated proportions on a section-by-section basis and because the application of non-local recognition procedures were not as successful as anticipated, caution must be exercised in any generalization of those performance results to other regions.

(6) Mixtures estimation procedures, which estimate the fractional composition of individual pixels, did not give an improvement over standard recognition procedures using August ERTS-MSS data but by using additional or different spectral bands the accuracy should be improved using these techniques.

(7) A computer-assisted technique was developed jointly with another ERTS investigation conducted by ERIM personnel to correctly assign field identifications to training and test pixels. This helped to decrease assignment problems, which resulted in part from the relatively large size of the ERTS resolution elements.

(8) An analysis of soils and landforms performed on August, 1972 and June, 1973 ERTS imagery using level slicing, sum and difference, and ratio processing procedures showed (a) that organic soils in bare fields were distinguishable from mineral soils in bare fields; and (b) well drained, mineral soils were distinguishable from somewhat poorly drained, and poorly drained mineral soils using August ERTS data but could not be separated using the June, 1973 ERTS data.

(9) Identification and mapping of landforms, using ERTS data, was not very satisfactory, however, some success was achieved with RB-57 and C-47 color and color I R photography.

SUMMARY OF RECOMMENDATIONS

The following are suggested modifications for future ERTS-type systems which would enhance their value for meeting the objectives addressed in this project.

First, resolution was a limiting factor for analysis of small tracts and for variability within larger tracts. The degree of improvement needed, however, depends on the size and nature of the target as well as the techniques used for analysis. In order to prepare by manual interpretation a gross forest map of the entire state of Michigan showing stands of 15 hectares and smaller, it is estimated that resolution would need to be improved by at least a factor of two. In order to provide the information on composition and condition of vegetation for practical forest management and agricultural purposes, it is estimated that the improvement in resolution would need to be more nearly on the order of a factor of four. For purposes of computer analysis, improving the resolution by a factor of two would be advantageous.

Second, an increase in the number of spectral bands would also be helpful in discriminating between cover types. This is particularly true for many computer techniques such as the subresolution element analysis. However, it is difficult to make a recommendation as to the ideal number of channels, especially since different bands are involved in discriminating different types of targets. Furthermore, there is an interaction between resolution needed and number of bands available.

Third, shortening the orbital period would reduce the impact of possible cloudy conditions. It is estimated that an orbital period of a week to 10 days might be appropriate.

It should be noted that these recommendations are based primarily on judgment and experience as opposed to simulation studies.

TASK I

APPLICATION OF ERTS IMAGERY FOR ANALYSIS OF FORESTS AND RELATED NATURAL RESOURCES

INTRODUCTION

It is appropriate to begin by reviewing the potential benefits to natural resource managers which may be expected to accrue through remote sensing from satellites such as ERTS. Aerial photography is a well-developed and widely accepted tool in most phases of forestry research, inventory, protection and management. Several textbooks, a multitude of technical articles, and the integrated use of aerial photographs in forestry enterprises all attest to the substantial savings in time and money obtainable through application of photogrammetry and photointerpretation to forestry-related activities. Although these many benefits are currently realized from conventional panchromatic, color, and infrared photographic imagery taken from low to intermediate altitude aircraft, there is considerable potential for improvement that could be realized from advanced sensors operating at satellite altitudes.

Normal aerial photographic missions provide coverage of a rather limited area. This coverage is sufficient for local operations, but natural resource agencies with regional or broader responsibilities are hampered by the heterogeneity of scale, film-filter combination, year, season, and other considerations of the many individual photographic missions which they must employ to obtain information on natural resources over an extensive area. The first benefit to be expected from remote sensing by satellites, then, is that large areas will be covered under uniform conditions during a very short time span.

A second disadvantage of conventional aerial photography is that coverage is usually not available at regular intervals over large areas. Imagery from orbiting space platforms provides a potential means for obtaining synoptic and uniform coverage of extensive areas at regular intervals.

A third limitation of aerial photography is that the usual film types of panchromatic, infrared, conventional color, and false-color with available filters provide a somewhat limited capability for distinguishing cover types, tree species, incipient damage, soil types, mosture conditions, and other parameters of site and stand. The interpreter frequently must resort to texture and other nuances to make a tentative classification. Multispectral scanners, one model of which is included in the payload of the ERTS satellite, offer much greater detail of spectral information on which classifications can be based.

Finally, the time required for human interpretation of aerial photographs imposes limitations on their use. Since the output of the ERTS sensors is telemetered to ground receiving stations, it is ideal for computer processing. Current software for processing this type of data indicates a strong possibility of automated cover mapping, area measurement, and other information processing in which the human interpreter is largely bypassed. Further development of such computerized information processing, storage, and retrieval can provide a major breakthrough for natural resource management.

OBJECTIVES

This task was designed as a three-phase investigation to determine the potential usefulness of remote sensing with ERTS-type satellite sensors for evaluation of Michigan's forests and related natural resources. The original intent was to investigate both return beam vidicon (RBV) and multispectral scanner (MSS) sensors, but work with the RBV system was precluded by its malfunction. Therefore, all conclusions in this report are based on studies conducted with MSS data.

The objective in the first phase was to assess the utility of manually interpreted satellite imagery in hardcopy form for evaluating gross characteristics of Michigan's forests, wetlands, and related natural resources on a regional scale. The entire State of Michigan served as a test site for this phase of the study. Specifically, it was hoped that the imagery would be adequate for preparing a gross forest map for the entire State of Michigan with sufficient detail to serve as a basis for making regional land use decisions.

Phase two of the investigation was a test of automated type recognition, cover mapping, and area computation from the computer compatible tapes (CCT's) produced by the MSS sensor. This work was conducted in the detailed test site (Ingham, Eaton, Ionia, Clinton, and Shiawassee Counties) using the best imagery produced by the MSS sensor.

The proposed third phase of the investigation was dependent on the productivity of the first two phases. Assuming that the above investigations would produce reasonable success in evaluating the composition and condition of more or less extensive forest stands, the application of ERTS-type sensors for evaluation, maintenance, and planning of urban greenbelts was to be explored.

In keeping with the stated philosophy of the overall ERTS program, applications value was emphasized throughout the study. Each phase was pursued to the point where potential or lack thereof for operational applications could be determined. If it became evident that the potential did not exist for an operational application in any given case, that line of inquiry was abandoned in favor of another potential application. Where applications have not proven possible with the current state of the sensor, suggestions are made for improving the sensor to accommodate the application.

In interpreting the results presented here, it should be kept clearly in mind that the conclusions apply specifically to conditions existing in Michigan. In particular, many of the woodlands in Michigan are small tracts on the order of 5 to 10 hectares in size. Furthermore, few areas in Michigan received multiple coverage during the same growing season due to coincidence of cloudy conditions with ERTS overpasses.

COLLECTION OF GROUND TRUTH INFORMATION

"Ground truth" information for the analyses presented in this report came from several sources. The primary source of ground truth information for the forestry work was provided by manual interpretation of aerial photography gathered during underflights with the NASA RB-57 aircraft. Two separate missions were flown with this aircraft in support of the ERTS investigations. The first took place in June, 1972, covering a large part of southern lower Michigan. The second took place in September, 1972, covering the area of the June flight plus an area in northwestern lower Michigan where an outbreak of the red-humped oakworm was in progress. In addition to the RB-57 flights, several missions with the ERIM C-47 aircraft were flown at lower altitude over selected sites to obtain large-scale photography and scanner imagery.

A second source of ground truth was provided through the cooperative efforts of the United States Department of Agriculture, Agricultural Stabilization and Conservation Service (USDA-ASCS). This agency supplied transcripts of their crop certification records on photocopies of enlarged black-and-white airphotos.

The above two sources of ground truth information were supplemented with field visitation and forest maps obtained from other agencies as required.

MAPPING GROSS FOREST CHARACTERISTICS FROM 1:1,000,000 SCALE TRANSPARENCIES

As mentioned in the introduction, the use of conventional aerial photographs has been institutionalized by many agencies concerned with management of natural resources in general and forests in particular. Because of this work with aerial photography, the agencies already have interpretation equipment and personnel. Therefore, it is to be expected that the technology transfer problems for application of ERTS data will be minimized if the hardcopy imagery (transparencies or prints) can be used.

The first phase of the present study was designed to test the applicability of the ERTS bulk and precision transparencies at a scale of 1:1,000,000 to problems of natural resource management. Given that the basic resolution element of the multispectral scanner aboard ERTS is on the order of 57 by 79 meters (or .44 hectares) it was predictable at the outset that resolution would be the main limitation on use. With this in mind, the initial objective was to prepare a forest map of Michigan with sufficient detail to serve as a basis for making regional land use decisions.

Studies of Farm Woodlots and Wetlands in South-Central Michigan

Michigan is characterized by a variety of patterns in land cover and use. Most areas in the southern part of the State are either agricultural or urbanized, with the two types of land use being interwoven with each other. Woodlots and other areas of more or less natural vegetative cover in this region are small, being on the order of 5 to 10 hectares in size. However, many of the critical problems of land use occur in this area, with preservation of forests and wetlands being a key concern for the quality of the environment. Due to the small size of the forested areas, requirements of resolution are greatest in this part of the state. Therefore, the detailed test area (Ingham, Eaton, Ionia, Clinton, and Shiawassee Counties) in the heart of this region was chosen as the starting point for the mapping effort. Another factor which influenced the choice of starting point was the large amount of ground truth information available for this region through underflights, field visits, and USDA-ASCS records.

The first usable imagery obtained over the intensive test area was the August 25th, 1972 frame E-1033-15580. Fig. 1 through 4 are polaroid copies of a portion of this frame covering the vicinity of Lansing, Michigan in the four respective spectral bands. On Fig. 1 through 4, Lake Lansing is circled and numbered 1 to serve as a landmark. Baker Woodlot at the south of the Michigan State University campus is circled and numbered 2 on the band 5 image (.6 to .7 micrometers) only. This is a 32 hectare experimental woodlot that is used extensively by the MSU Forestry Dept. for research and teaching. Fig. 5 is a polaroid copy of an RB-57 photograph showing the area around Baker Woodlot for comparison. Although some detail is lost in the polaroid copies of Fig. 1 through 4, the essential features of the image are preserved. Vegetative features register best in band 5. Band 4 images are hazy and difficult to interpret. Images for bands 6 and 7 are very similar to each other, both showing hydrological and geological features.

Frame E-1033-15580 was taken late in the growing season. Most vegetative canopies were dense and closed, with the exception of some herbaceous species which had become senescent. This phenology produced a low contrast between forests and neighboring vegetation types which made manual interpretation somewhat difficult.

Figure 1. A portion of ERTS frame E-1033-15580, August 25, 1972, showing the area around Lansing, Mich. in spectral band 4 (.5 to .6 micrometers). Lake Lansing is circled and numbered 1 for reference.

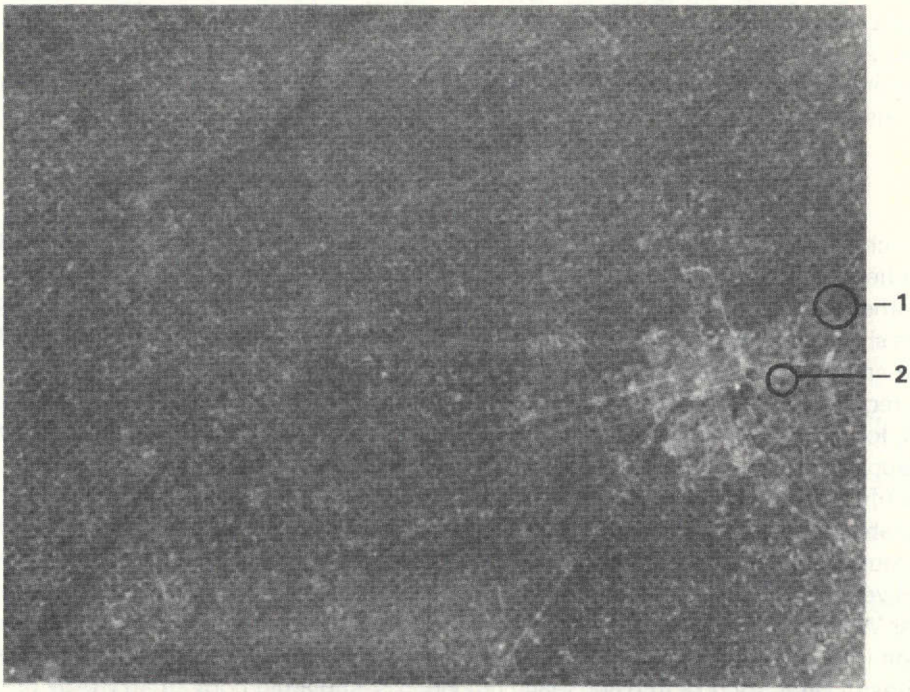

Figure 2. A portion of ERTS FRAME E-1033-15580, August 25, 1972, showing the area around Lansing, Mich. in spectral band 5 (.6 to .7 micrometers). Lake Lansing is circled and numbered 1 for reference. Baker woodlot on the MSU campus is circled and numbered 2.

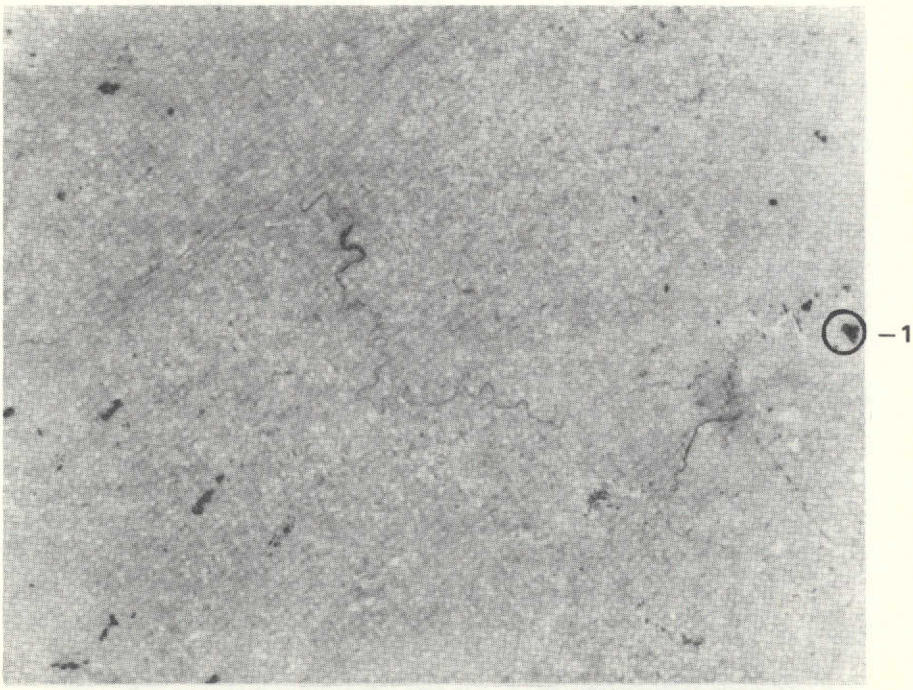

Figure 3. A portion of ERTS frame E-1033-15580, August 25, 1972, showing the area around Lansing, Mich. in spectral band 6 (.7 to .8 micrometers). Lake Lansing is circled and numbered 1 for reference.

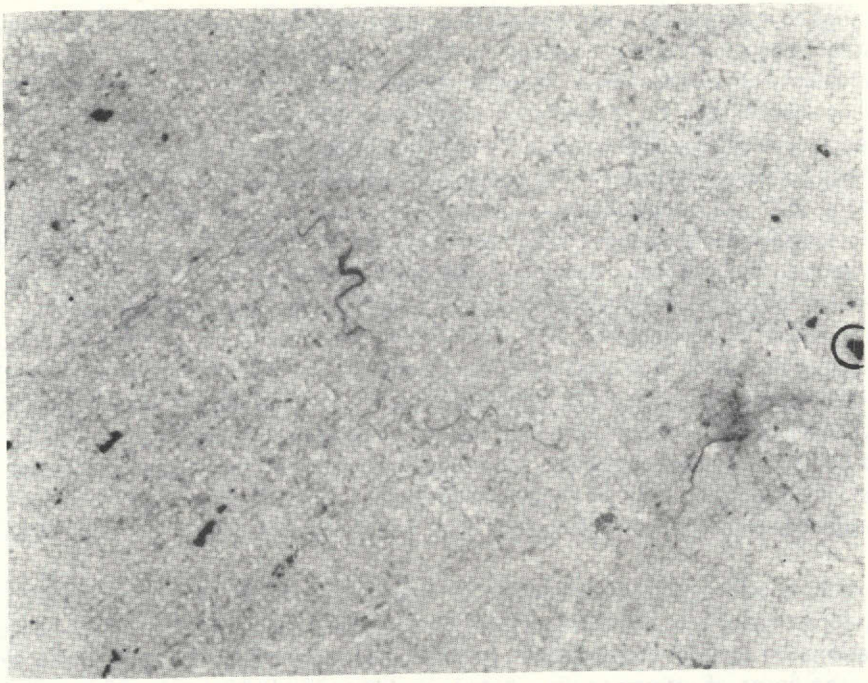

Figure 4. A portion of ERTS frame E-1033-15580, August 25, 1972, showing the area around Lansing, Mich. in spectral band 7 (.8 to 1.1 micrometers). Lake Lansing is circled and numbered 1 for reference.

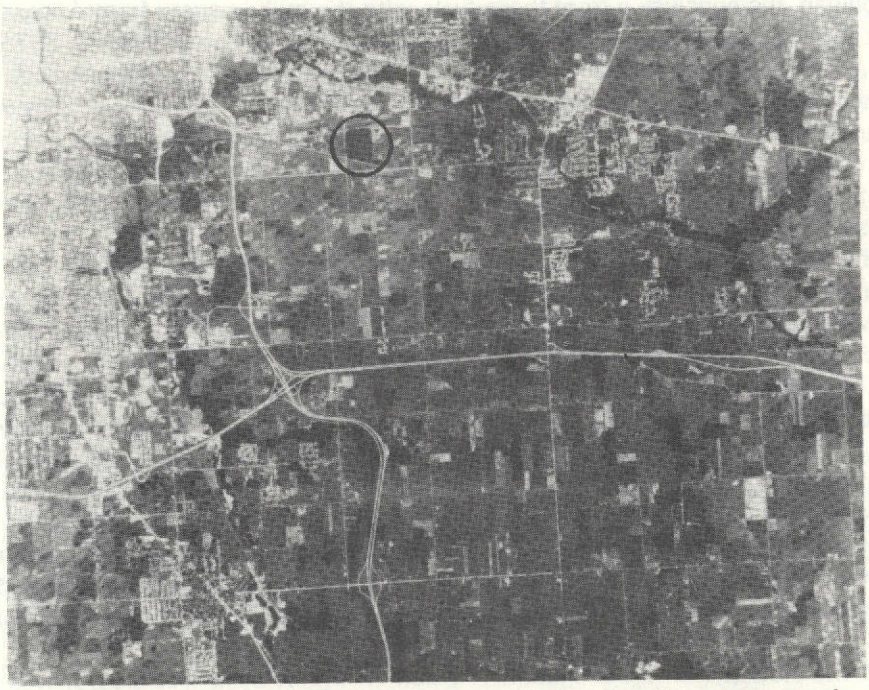

Figure 5. Copy of an RB-57 photograph showing the area around Baker Woodlot on south campus of Michigan State University. Baker Woodlot is circled for reference.

Several approaches to interpreting and mapping from the bulk images were attempted, including: (1) direct delineation of forested areas on an acetate overlay without magnification; (2) direct delineation on an acetate overlay with magnification; (3) delineation of forested areas on 5X and 10X prints made from the bulk transparencies; (4) direct delineation on acetate overlays over diazo composites both with and without magnification; (5) use of a Kargl projector to focus an enlarged image directly on map paper.

The limits of interpretability presented in this section were obtained as follows. First the test mappings were performed, with ground truth or underflight materials being consulted as needed for training. The smaller tracts recognized were then examined with respect to size and any special characteristics. The underflight imagery for selected portions was then examined to determine the sizes and types of tracts that were not recognized. Nonparametric measures (modes and ranges) are used in describing the results of these tests.

Woodlots on the order of 30 hectares and larger could be recognized and mapped quite consistently. Recognition and mapping of woodlots in the size range of about 15 to 30 hectares was somewhat inconsistent. If the tract had a long dimension, such as along watercourses, it was quite easy to recognize and delineate. More compact tracts, especially those with irregular boundaries, were very difficult to interpret. Confusion of small forest stands with brush and native grasses was frequent. Recognition of woodlots in the size range of 5 to 15 hectares was very erratic, and could only be accomplished when the tract was linear or had sharply contrasting types along its boundaries. Recognition and mapping of woodlots less than 5 hectares in size were virtually impossible.

Despite the limitations on manual interpretation of woodlots in Michigan from August ERTS imagery, it should be noted that forest cover was the most readily interpretable of all vegetation types occurring in the area. Therefore, the limitations on manual interpretation of non-forest vegetation are even more severe than those noted. Furthermore, the limits of interpretability noted are for a simple binary breakdown of forest vs. non-forest. In no case was it possible to make separations of species composition within the woodlots from the August imagery. In this regard, it should be noted that the woodlots in the detailed test area contain primarily hardwood species. The few stands of conifers are very small, being only 1 or 2 hectares in size. From the standpoint of manual interpretation, most of the information regarding forest vegetation is contained in band 5 (.6 to .7 micrometers). Band 7 (.8 to 1.1 micrometers) proved useful for separating eutrophic bodies of water from forest cover. In other respects, however, a composite of bands 5 and 7 was less interpretable than band 5 alone because the moisture patterns of band 7 tended to override the vegetational patterns of band 5.

Since woodlots less than 15 hectares in size account for something in the vicinity of half the wooded area in southern lower Michigan, the conclusion from these tests with the bulk imagery from August 1972 was that a map of forests with sufficient detail for land use planning could not be prepared from the ERTS imagery as was originally hoped. Similar tests performed later with precision images (both single band and composite) taken on the same date supported this conclusion. In fact, the bulk imagery was found to have greater clarity than the precision. Since the information requirements for forest management are more stringent than those for general land use planning, manual interpretation of August ERTS imagery produced even less utility in that regard. The ability to differentiate density classes and species composotion would be necessary to make a direct input to the informational needs of the forest manager.

As noted in the introduction, one of the benefits to be anticipated from satellite sensors is synoptic coverage of large areas at regular intervals. ERTS has proven its merit in this regard for areas where fair weather predominates. However, cloudy weather in Michigan during the project period caused problems in this regard. The combination of cloudy conditions with launch midway through the 1972 growing season produced incomplete coverage during the 1972 growing season. Furthermore, few areas of the state received multiple, cloud-free coverage during either the 1972 or 1973 growing season. Since similar conditions can be expected to recur in the future, a shorter orbital interval would be desirable to provide a higher probability of multiple coverage over any given area. A detailed analysis of cloud frequencies has not been conducted, but a judgment or "guesstimate" figure for a desirable orbital frequency would be on the order of one week.

One application to natural resource management that the current ERTS system will accommodate through manual interpretation is the mapping of water bodies, water courses, and permanent wetlands. Water bodies down to a few hectares in size are readily discernible on band 7 imagery, and the linear nature of streamside vegetation is quite apparent on band 5 imagery.

On the basis of the studies with the August ERTS data in the detailed test area, it was determined that resolution was the limiting factor for application of manually interpreted ERTS data to management of forests and related natural resources in Michigan. Therefore it seemed to be the most productive use of project funds to concentrate the investigation on phase two involving computer analysis. In order to determine more fully the limits of application for manual interpretation, however, two other studies were conducted.

The purpose of the first study was to determine what set of phenological conditions would maximize the target (forest) to background contrast and consequently minimize the effects of limited resolution. The incoming imagery was monitored for scene contrast, and it was found that imagery obtained early in the growing season immediately following the expansion of tree leaves was best in this respect. At this time the tree leaves are fully expanded, but the herbaceous vegetation bordering the forest stands has not had an opportunity to grow into a dense cover. This enhancement of contrast is especially marked in the agricultural areas of Michigan where the majority of fields have been tilled and sown, but the new crops have not yet grown into a ground cover.

An area in southern lower Michigan bounded on the west by US-27, on the south by I-94, on the east by US-23, and on the north by the edge of ERTS frame E-1320-15532, June 8, 1973, was selected for mapping of forest vs. non-forest cover. The contrast on this portion of the image was judged to be the best observed. This mapping was performed by direct delineation on an acetate overlay under a magnifier. The resulting map is shown in Fig. 6 at an approximate scale of 1:250,000.

The accuracy of interpretation for this effort was somewhat better than for the study with August data. That is to say, woodlots of about 20 hectares and larger could be interpreted and mapped with fairly good consistency. Interpretation of woodlots in the size range of about 10 to 20 hectares was somewhat inconsistent, with interpretation being erratic for woodlots smaller than 10 hectares. In this case, there was no confusion of woodlots with water bodies, so the mapping was done entirely from band 5 (.6 to .7 micrometers). This level of accuracy is marginal for land use planning, and is still too gross to be of much utility in forest management.

Studies of Forest Stands in Mason County, Michigan

The studies just described have shown that resolution of the ERTS scanner system is a limiting factor for purposes of manual interpretation in agricultural areas of lower Michigan where woodlot sizes are small. However, the more northern areas of Michigan's Lower Peninsula and the Upper Peninsula are characterized by much more extensive forest stands.

One aspect of the work performed under another NASA-sponsored project[1] was the preparation of a forest type map for Mason County, Michigan, including portions of the Manistee National Forest. Since this forest type map is available for comparison and ground truth, Mason County was selected as the location for a test of forest mapping by manual interpretation of ERTS data for more or less extensive forest stands. The forest stands in this area include conifers, so a three-way breakdown of types was used: hardwood, conifer, and non-forest. ERTS frame E-1321-15584, June 9, 1973, was used as a basis for the mapping. The results of this Mason County mapping effort are shown in Fig. 7.

The results of the test in Mason County correlate well with those of the tests in southern lower Michigan. Again, stands of about 30 hectares or larger could be recognized and mapped. Large stands of conifers could be differentiated from large stands of hardwoods. The ability to interpret smaller stands depended on the degree of contrast presented by the bordering types, and could only be done under ideal conditions. Since there were fewer plowed fields in the Mason County area to provide contrast, the accuracy achieved here was somewhat less than that for the area in southern Michigan shown in Fig. 6.

Application of Manually Interpreted ERTS Data for Analysis of Natural Resources in Michigan

The tests of manual interpretation of ERTS imagery conducted under this project indicate that the resolution of the ERTS scanner system is adequate for interpreting and mapping forest stands of about 30 hectares or larger. The ability to interpret smaller stands depends on the contrast between the forest stand and the bordering type. Smaller areas of streamside vegetation with a linear shape are also interpretable. It is

[1]Michigan State University Project for Use of Remote Sensing in Land Use Planning and Policy Formulation. (NASA Grant NGL 23-004-083).

Figure 6. Forest Cover—S.E. Ingham S.W. Livingston, N.E. Jackson, N.W. Washtenaw Cos. Interpreted from ERTS frame E-1320-15532, June 8, 1973.

FOREST COVER – MASON COUNTY, MICHIGAN

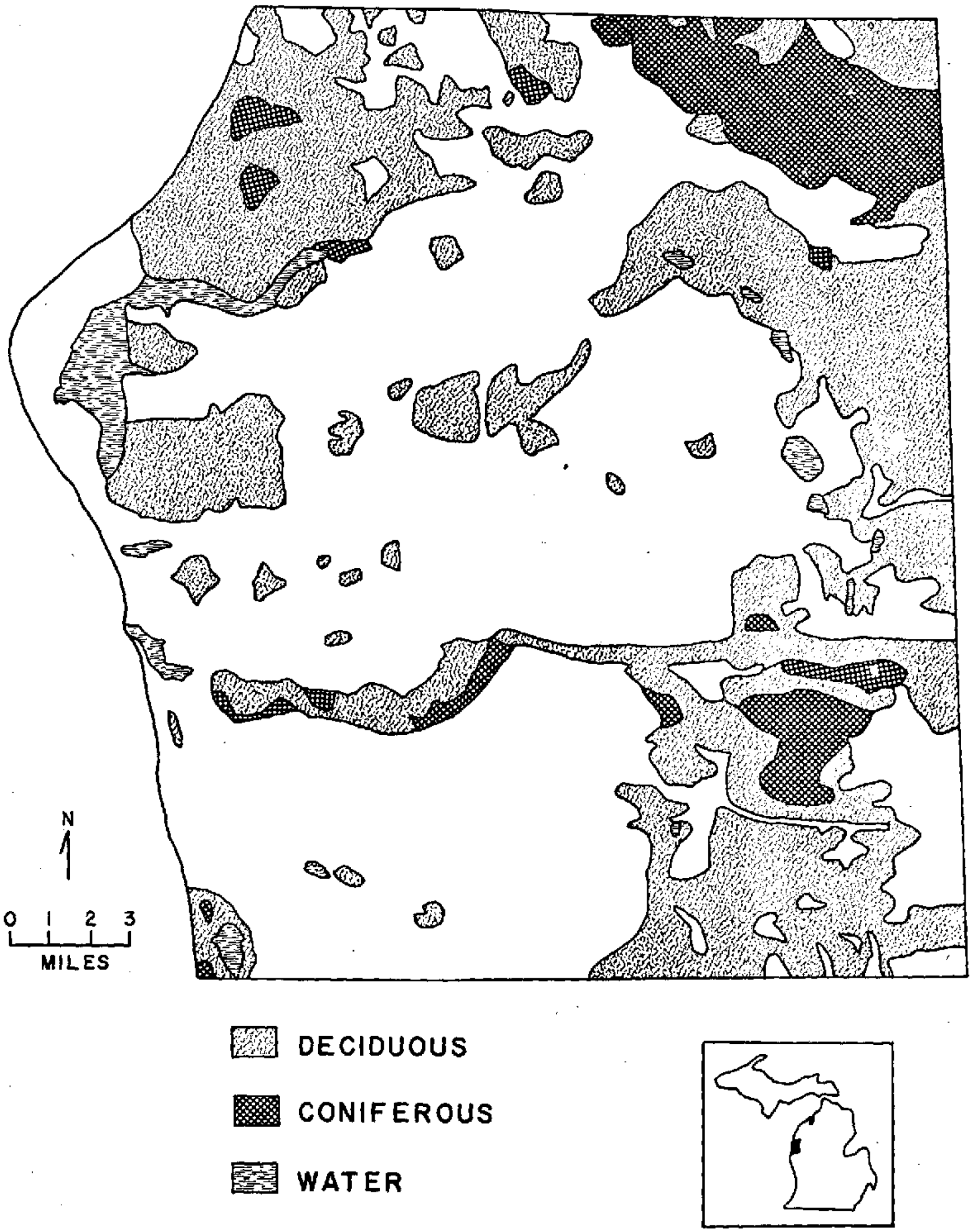

Figure 7. Interpreted from ERTS frame E-1321-15584, June 9, 1973.

frequently possible to locate stands down to about 5 hectares in size if the interpreter has prior knowledge of their existence, but this is quite a different matter than location of stands in unfamiliar terrain. Most of the information for manual interpretation of vegetative cover in Michigan is contained in ERTS band 5 (.6 to .7 micrometers). Band 7 (.8 to 1.1 micrometers) is also useful in cases where there is overlap in band 5 signatures between forests and eutrophic water bodies.

Manual interpretation of major surface hydrological features such as water bodies, watercourses, and large wetlands from ERTS imagery gives good results because of the unique signature of these features in ERTS band 7 (.8 to 1.1 micrometers).

The utility of manually interpreted ERTS information for practical forest management in Michigan is limited by the resolution of the scanner. This is because many of the forest stands in Michigan and type changes within stands are less than 30 hectares in size. For manually interpreted satellite imagery to provide an operational input to the needs of the forester and wildlife manager in Michigan, the resolution would have to be improved over that of ERTS by about a factor of four. As with the suggestions for shortening the orbital interval, the suggested factor of four for improved resolution is based primarily on personal judgment and experience with forestry-related photointerpretation.

STUDIES OF MICHIGAN FORESTS BY COMPUTER ANALYSIS OF ERTS DATA

The telemetered nature and coarse resolution of ERTS data favor computer analysis over manual interpretation. There are several reasons for this. Tone (or spectral signature) is only one of the informational elements that an air-photo interpreter normally relies upon. Size, shape, texture, shadow patterns, and associations of features are equally important clues for identification utilized by the human interpreter. On a microscale (within the forest stand) all of these geometric clues are lost in the .44 hectare resolution of the ERTS scanner system, leaving spectral signature as the primary clue to interpretation. The interpreter must base his classification on tonal differences of the image within a band, coupled with comparisons between the spectral bands. Most human interpreters are not particularly adept at detecting tonal differences corresponding to 2 or 3 counts of the sensor, and comparison between bands is largely limited to the process of color compositing. Likewise, the human interpreter's perception of tonal variations within and between targets is more intuitive than statistical. Consequently, manual interpretations of ERTS images are often more subjective than objective. In contrast, the telemetered data can be coded numerically either before or after transmission to ground receiving stations and formatted in such a way as to be readable directly by conventional digital computers. The full power of statistical analysis in its several varieties can then be brought to bear on the data for purposes of classification.

It should be noted, however, that some of the advantages claimed here for computer analysis are predicated on the electronic nature of the sensor, and would not necessarily be as efficient if the sensor consisted of a lens-film system with direct transport of the film to the ground. With the lens-film sensors, some resolution is lost in the process of numerical encoding for computer analysis. With the electronic-telemetered ERTS data which is recorded on film secondarily, there is little increase in effective resolution obtainable by enlargement of the image. The dots corresponding to resolution elements only become larger dots. In the ERTS systems, the computer compatible tapes contain all the information that exists in the film image.

As a general rule, the less statistical digestion of the data that is required, the less expensive will be the cost of the analysis. A variety of analyses were performed in this project, ranging from simple and relatively inexpensive densitometric or level-slicing techniques to more complex and expensive multivariate methods of pattern recognition.

Simple Densitometric or Level-Slicing Techniques

The simplest and least expensive sort of computer mapping which can be performed with the ERTS data amounts to programing the computer to behave in a manner analogous to a human interpreter. Training sets are selected on the basis of ground truth information which are representative of the target (forests) to be recognized.

Beginning with the channel which contains the most information about the feature (in this case .6 to .7 micrometers) the range of counts covered by the training sets is determined. Resolution elements falling in this range are mapped in the vicinity of the training sets, printing the counts in each of the other channels in turn. This allows each channel to be examined for a window which will contribute to the accuracy of the classification. The result of the training process is a nested series of windows in the various channels, the intersection of which defines the signature of the target to be mapped. A computer run is then made for the entire frame with an appropriate map symbol being printed for those resolution elements which possess the desired signature.

This type of level-slicing analysis was performed for the purpose of mapping woodlots in Ingham and Shiawassee Counties. Both September, 1972 data from ERTS frame E-1033-15580 and June, 1973 data from ERTS frame E-1320-15525 were used to provide a comparison of signatures and results under early and late phenological conditions.

The signature used for the August, 1972 data was channel 5 count range 12-13 intersect channel 7 count range 17-29. Information from channels 4 and 6 did not noticeably enhance the capability for discriminating forested areas. Therefore, the latter two channels were not used in the specification of signature. The use of a window in channel 7 was necessary to eliminate confusion of forested areas with more or less eutrophic water bodies.

The signature used for the June, 1973 data was channel 5 count range 15-17. In this case there was no overlap of channel 5 forest signatures with water signatures, so a window in channel 7 was unnecessary.

A polaroid copy of an RB-57 photograph for an area south of East Lansing, Michigan (including Baker Woodlot) is shown in Fig. 8. The August and June recognition maps for the same area are shown in Fig. 9 and 10 respectively. The light tone on the center strip in the map of Fig. 10 is due to the presence of a worn ribbon on the line printer when this section of the map was run. The areas run were larger than shown, but the remainder is omitted to make the figures a more convenient size.

The close correspondence of the August map (Fig. 9) with forested areas shown on the RB-57 photo is apparent. Virtually all forested areas of two hectares and larger are included, and even some that are smaller. Some brushy areas are included with the forests. The degree of detail obtained on this map is sufficient for many purposes in land use planning, and is what the investigator had originally hoped would be obtainable for the entire state by manual interpretation of the ERTS transparencies. As a review, the phenology in August is such that most forest canopies, even those with fairly sparse stocking are nearly closed. The holes in the more sparse canopies are typically filled with the foliage of underbrush, which appears quite similar to that of the main canopy from ERTS altitudes. Sharp contrast of bordering types is not necessary in the computer analysis because differences of 2 or 3 counts in any given band can be readily determined. However, a conversion factor of .44 hectares per resolution element gives a systematic underestimate of areas on a stand by stand basis. This is attributable to the problem of resolution elements overlapping the border of the stand, in which case the mixed signature is different from the pure forest signature.

The results of the map prepared from the June data (Fig. 10) are less satisfactory from the viewpoint of preparing a forest vs. non-forest map by the simple level-slicing technique. The same factors which operate in the spring phenology to enhance contrast for the human interpreter also work to the detriment of the level-slicing process by introducing variability into the stands. The main canopy is not as fully closed as in late summer, and growth of the underbrush has not yet filled holes in the canopy of sparser stands. Therefore, the level-slicing process is better adapted for use late in the growing season.

When the detail of forest information shown in Fig. 9 is entered into a regional information system, it is operationally useful for assessing environmentally sensitive areas in land use planning, defining forest survey strata and allocating plots therein, for some applications in forest extension work, and might aid forest industries in assessing potential supplies of raw material for new and existing plants. However, there is not sufficient information on stand composition and stocking for direct use in on-the-ground forest management.

Pattern Recognition by Likelihood Ratio Techniques

Although they have the advantage of being less expensive, the level-slicing techniques discussed in the previous section are relatively primitive from a statistical standpoint. Further tests were conducted with pattern recognition by the more sophisticated techniques of cluster analysis and likelihood ratio processing. The purposes of these tests were to locate and map the more densely stocked, commercially operable woodlots; to separate upland hardwood stands from lowland hardwood stands; and to quantify the recognition accuracy.

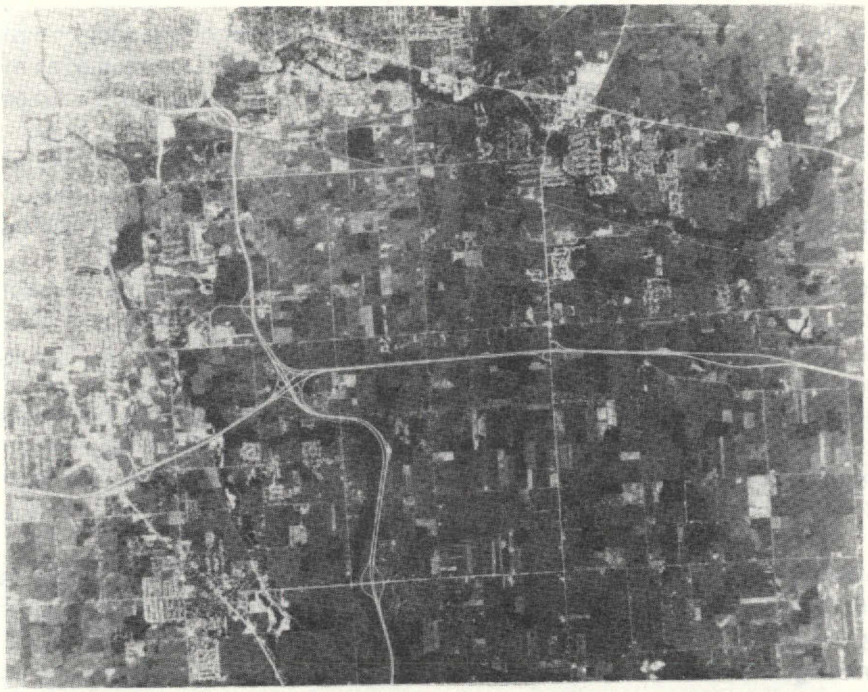

Figure 8. Copy of RB-57 photo showing an area south of East Lansing, Mich., including Baker Woodlot on the MSU campus.

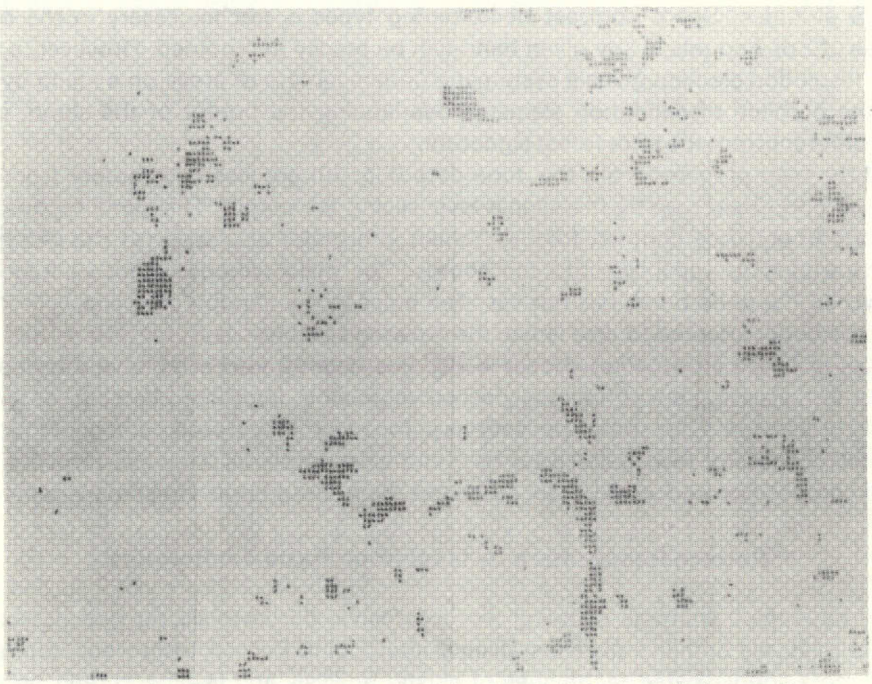

Figure 9. Forest map prepared by level-slicing techniques from ERTS frame E-1033-15580, August 1972.

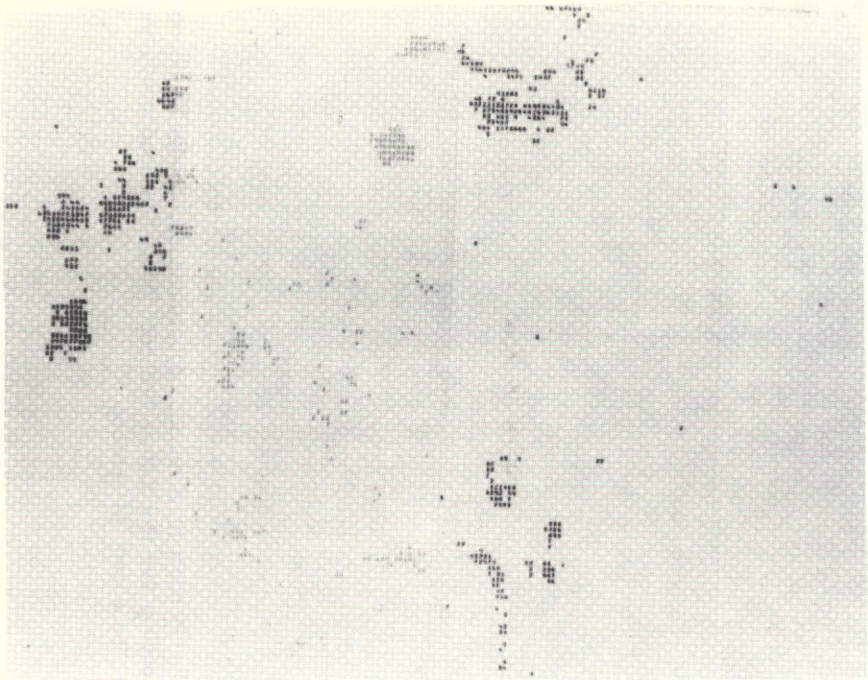

Figure 10. Forest map prepared by level-slicing techniques from ERTS frame E-1320-15525, June 1973.

The first part of this work was conducted in an agricultural area of Eaton Co., Michigan so that work in the forestry task could be combined with similar work in the agriculture task, thereby reducing costs. A polaroid copy of this area from an RB-57 photograph is provided in Fig. 11 for reference. The data from the August 25th, 1972 ERTS frame E-1320-15580 was used for this portion of the analysis. Portions of the analysis described in this section have already been documented in a paper presented at the March, 1973 ERTS Symposium by Safir, Myers, Malila, and Morgenstern (11) (Appendix A). Technical details of the methods used (including measures of accuracy) are presented in the Task II (Agricultural Crops) section of this report, and are not repeated here.

Training sets were selected on the basis of ground truth and underflight information. Forests constituted one of several cover types to be recognized along with selected agricultural crops. Signatures for the cover types were extracted by cluster analysis. Only resolution elements on the interior of training sets were used to extract signatures, in order to avoid the possibility of mixed signatures along the boundaries.

A portion of a recognition map for the Eaton Co. area is shown in Fig. 12. The interior portions of well-stocked woodlots (those which offer possibilities for commercial forest management) were correctly classified with an accuracy of 85%. Less dense stands were usually not recognized by the computer as well-stocked forest. However, the borders of well-stocked stands were also not recognized, with a consequent underestimation of total area for these stands. Attempts at separating out a separate signature by cluster analysis for forest borders were generally unsuccessful, since the resulting signatures were similar to those of certain other cover types such as corn.

The second part of the pattern recognition work was done on the June 1973 ERTS data (frame E-1320-15525) used for the level-slicing analysis described earlier. The purpose of these studies was to separate upland hardwood forest types from lowland hardwood forest types. In addition to signature extraction by cluster analysis with subsequent likelihood ratio processing, sum and difference techniques of classification were also tested. The separation of upland types from lowland types is economically important because the former offer the best opportunities for forest management, whereas the latter tend to be the most environmentally sensitive areas. These analyses were conducted in conjunction with work on the soils task for reasons of economy.

In brief, the tests showed that upland types could be separated from lowland types, but that each of these categories included extensive false recognition of non-forest types.

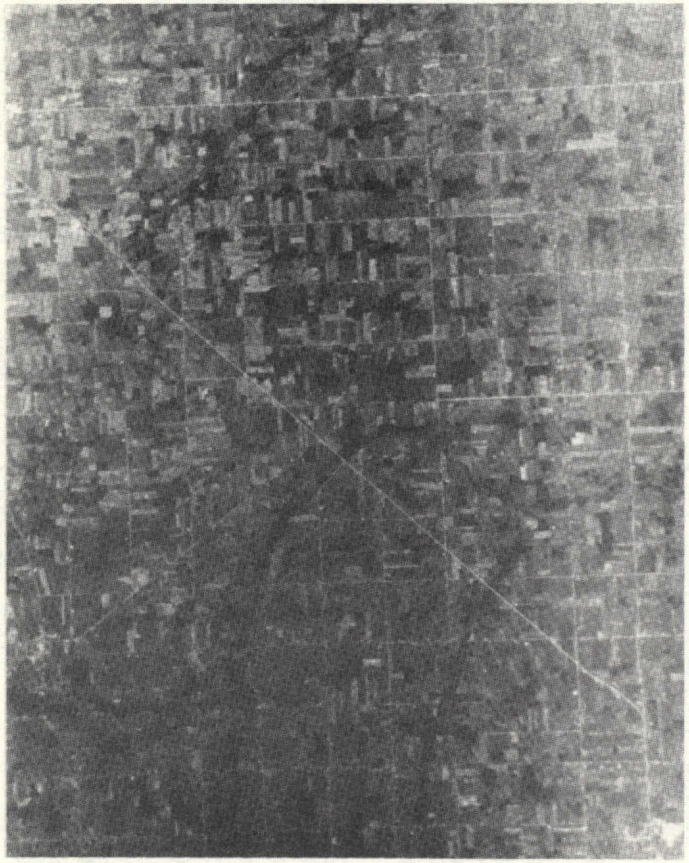

Figure 11. Copy of an RB-57 photograph showing part of the area in Eaton Co. analyzed by likelihood ratio processing.

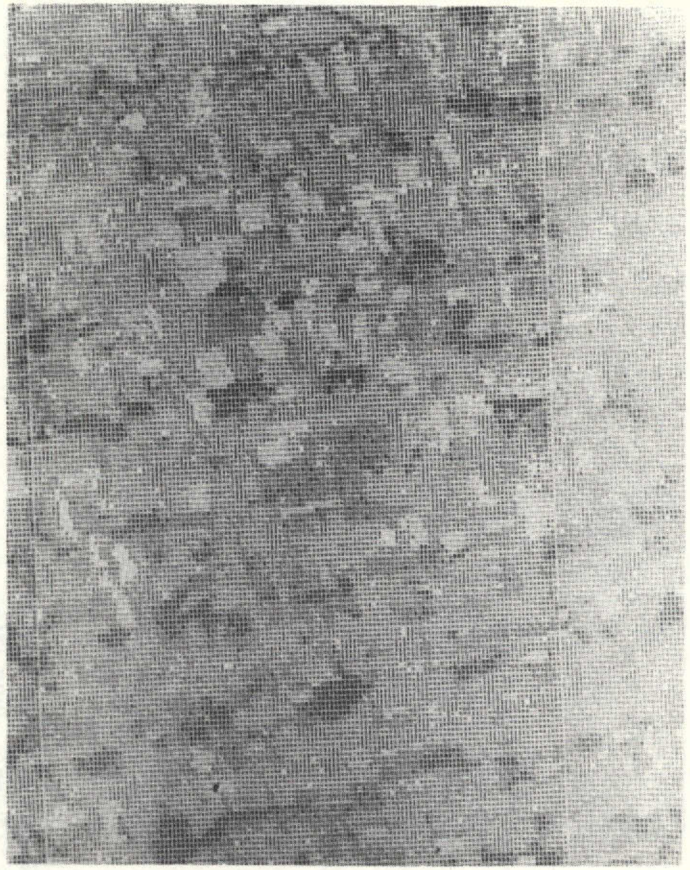

Figure 12. Portion of a recognition map prepared by likelihood ratio processing for the Eaton Co. test area. Forested areas are represented by a dark M symbol.

Application of Computer Processed ERTS Data for Analysis of Forests and Related Natural Resources in Michigan

The studies conducted through computerized analysis of ERTS data were much more successful than those with manual interpretation.

Densitometric or level-slicing methods are adequate for separating and mapping forest vs. non-forest cover types to a degree of detail which is useful for feeding regional information systems designed to be used for general land use planning. The resulting maps can also provide input to the design of forest inventories, and are useful in some degree for forest extension work and studies of raw material supplies for industry.

The attempts at analysis of forest stand structure in combination with other cover types were generally unsuccessful. The results of the tests indicate, however, that the proper approach to this problem should be in two stages. First, level-slicing methods should be used to transfer the data for forested areas to a separate tape, thus eliminating confusion in subsequent analyses with non-forest areas. Several varieties of multivariate statistical analysis could then be applied to the forest data in order to perform secondary separations of low vs. high density stands and upland vs. lowland stands. This might include first-stage separation of forest vs. non-forest areas under late growing season phenology where spectral variation within stands is small, followed by a temporal overlay of early growing season phenology where variation within stands is greater. Unfortunately, project funds for Task II were largely expended on the analyses presented, and there was an insufficient amount remaining for the stage-wise analysis just suggested.

INNOVATIONS IN COMPUTER PROCESSING TECHNIQUES DEVELOPED IN CONJUNCTION WITH THE ERTS STUDIES

Several new techniques of computer processing for ERTS data developed by the subcontractors at ERIM are at least partially attributable to funding under the present contract.

Determining the location on the ERTS tapes of resolution elements corresponding to training sets proved to be a problem at times in the pattern recognition work. This was particularly true in regard to deciding whether a particular resolution element was entirely within the training area or partially overlapped the boundaries. Malila, Heiber, and McCleer (7), (Appendix B) developed a least squares procedure for correlating ERTS MSS data with earth coordinate systems which has proven to be quite workable. The procedure allowed the investigators at MSU to delineate training sets on RB-57 underflight imagery. The photos with training sets delineated were then sent to ERIM where the technique was used to extract the appropriate data from the ERTS tapes for subsequent analysis of signatures.

Another technique which will be very helpful to users of ERTS-type data is one which removes the image skew during computer processing of bulk MSS data. The presence of this skew is quite confusing to the user since it is difficult to associate the skewed shape of tracts with their actual shape on the ground and on vertical airphotos. The technique developed at ERIM removes this skew through an interpolation process and rescales the data so that line printer outputs will correspond with U.S.G.S. maps.

There has also been progress on testing a previously developed technique for subresolution analysis that is directed primarily at recognition of agricultural crops in Task II. With further development, however, the technique may have considerable use for analysis of forests, particularly with respect to the border element problem.

STUDIES OF RED-HUMPED OAKWORM DAMAGE IN THE MANISTEE NATIONAL FOREST

A large-scale outbreak of red-humped oakworm (*Symmerista canicosta,* Notodontidae) in the area of the Manistee National Forest presented a target of opportunity for study from ERTS in the fall of 1972. During such outbreaks, this insect causes widespread and almost complete defoliation of red and black oaks during late September and early October. In the hope that a cloud-free ERTS pass would be obtained during the period of peak defoliation, ground truth information on the insect populations and degree of defoliation was gathered. Also, an extra segment was added to an RB-57 underflight to cover the area in September.

Unfortunately, the area of the defoliation was covered by clouds during the ERTS passes up to the time of leaf fall, so there was no opportunity to study the infestation on ERTS imagery. Detection of transitory phenomena such as this provides another incentive to shorten the orbital period in future satellites. Since the defoliation was so severe and widespread, it is virtually certain that it could have been detected by computer analysis of a temporal overlay.

SUMMARY AND CONCLUSIONS

The results of this study indicate both operational possibilities and needs for improvement in the ERTS systems with respect to use in management of Michigan's forests and related natural resources.

Large forested tracts such as occur in the national forests can be delineated and mapped by manual interpretation of the ERTS transparencies. However, maps with a greater degree of detail are already in existence for these areas. In order to prepare by manual interpretation a gross forest map of the entire state showing stands of 15 hectares and smaller, it is estimated that resolution would need to be improved by at least a factor of two. In order to provide the information on composition and condition of stands needed for practical forest management, it is estimated that the improvement in resolution would need to be more nearly on the order of a factor of four. However, major surface hydrological features such as water bodies, water courses, and permanent wetlands can be interpreted to a greater degree of detail due to their distinctive signature in ERTS band 7 (.8 to 1.1 micrometers).

Computer analysis of ERTS data offers much better possibilities for operational input to management of forests and related natural resources in Michigan than does manual interpretation. With the current state of the sensor and imagery obtained late in the growing season when canopies are dense, forest maps can be prepared by simple densitometric techniques with sufficient detail for use in regional information systems, general land use planning, design of forest inventories, and similar applications. By the use of a two-stage analysis in which forest data is first separated from non-forest data and then subjected to multivariate statistical analysis, it should be possible to detect gross differences in stocking of stands and separate upland from lowland types. Funds for the project were exhausted, however, before this two-stage analysis could be completed. To provide more detail on stand composition and condition of the type needed for practical forest management, it is estimated that resolution of the scanner would need to be improved by at least a factor of two.

Because of cloudy conditions during the project period, multiple coverage during a growing season was less than desired. Shortening the orbital period in future satellites would provide a higher probability of multiple coverage during the same growing season. It is estimated that a one-week orbital interval might be appropriate.

The problems of resolution encountered in the first two phases of this task precluded work on the proposed third phase dealing with planning and maintenance of urban greenbelts.

TASK II

APPLICATION OF ERTS IMAGERY FOR ANALYSIS OF AGRICULTURAL CROPS

INTRODUCTION

A wide variety of crops are grown in Michigan, and acreage estimation of these crops has been conducted by the USDA since its establishment in 1862. During this period techniques have gradually shifted from emphasis on rural carrier surveys to enumerative surveys with a probability basis. Because of the high cost of enumerators and travel and the limited budget, the sample size is limited and the estimate is imprecise. The use of ERTS or other satellite imagery for making timely and precise estimates of crop acreage would permit farmers and other market participants to make better management decisions. These decisions are becoming more important as world wide population rates and costs of food and fibre increase. Although population growth in the U.S. appears to be stabilizing, the pressure for food exports to alleviate shortages abroad and the removal of agricultural lands from production through urbanization create additional domestic food problems.

The objectives of this project were three fold. The first was to determine the degree to which agricultural crops in Michigan can be identified by multispectral sensing from ERTS-1. The second was to test the accuracy of multispectral sensing techniques for crop acreage estimation in Michigan using ERTS-1 imagery. The third was to provide information for economic studies on the potential for operational spaceborne crop estimation. The third objective was not addressed as a result of problems encountered with resolution during efforts relating to objectives 1 and 2.

APPROACH AND METHODS

Michigan test sites in Eaton, Clinton and Ionia counties were selected for investigation of agricultural crops. Supporting aircraft and ground truth data were also collected for use in data analysis.

Digital processing procedures were used exclusively for the ERTS data and a description of these procedures as they pertained to analysis of agricultural crops is presented in this report. Also, as mentioned earlier, much of the computer analysis of forests was conducted in conjunction with the agricultural studies and is presented as part of the Task II report.

Test Site Selection

The main test site selected was in Eaton County Michigan and comprised a 4 by 20 mile strip beginning 2 miles north of Charlotte, Michigan (North-South orientation). This area was selected because it contained a sizeable sample of Michigan's field crops. Also, fields were of variable sizes ranging from 1 acre to well over 100 acres. Fields in these size ranges provided an excellent opportunity to test the resolution limits of the ERTS scanner and enabled us to make generalizations which will apply to many other areas of the world. For testing signature extension, two additional 4-square mile test areas were selected (one in Clinton County and one in Ionia County).

Data Collection

The data collected for this investigation included ERTS-1 MSS data, aircraft multispectral scanner data, aerial photography (both high- and low-altitude), and ground-truth information.

ERTS-1 MSS data for the three dates and frames listed in Table 1 were obtained from NASA's NDPF (NASA Data Processing Facility). All other frames during the 1972 growing season and early 1973 growing season were severely cloud covered. The agricultural test sites were cloud-free on August 25th, 1972, and on June 9th, 1973, with some thin airy clouds present on June 8. A frontal system spanned and variations in visibility readings were reported by airports throughout the frame. Imagery was used for orientation and location of landmarks within digital data on computer-compatible tapes.

TABLE 1. Description of Remote Sensor Data

A. Analyzed ERTS-1 Multispectral Scanner Frames

Frame Number	Date Collected	Test Site Covered
1033-15580	August 25, 1972	Agriculture, Forestry, Soils
1321-15584	June 9, 1973	Agriculture

B. Aircraft Multispectral Scanner Data and Low-Altitude Photography (< 12 Kft)

Date	Test Site Covered
August 25, 1972	Agriculture, Forestry, Soils
June 8, 1972	Agriculture, Forestry, Soils

C. High Altitude Aerial Photography (60 Kft)

Date	Test Site Covered
June 11-12, 1972	Agriculture, Forestry, Soils
September 15, 1972	Agriculture, Forestry, Soils

Airborne multispectral data were collected over the agricultural site (ERIM M-7 scanner) on the day of ERTS-1 passes on August 25, 1972, and June 8, 1973 and were synchronized with the ERTS-1 overpasses.

Low-altitude aerial photography was obtained on each of the multispectral scanner missions, as well as high-altitude photography by the NASA RB-57 aircraft in June and September of 1972.

Several sources of ground truth information were utilized. The first source was provided by the United States Department of Agriculture, Agricultural Stabilization and Conservation Service (USDA-ASCS). This comprised a set of annotated copies of enlarged airphotos showing the nature and location of vegetation types on holdings of farmers who participate in USDA-ASCS programs. Approximately 60% of all fields in the test strip were initially described and located on these air photos. The second source of information was actual field visitation. All fields in the test area were visited and characterized except for a few small fields in the centers of a few sections. Specifically, biological parameters such as plant height, row direction and width, percent ground cover, stage of development, and stress (disease and water) were described. Thirty-five mm photographs were taken of numerous fields with special attention given to fields with unusual characteristics. The third source of information was derived from RB-57 and C-47 photography by photointerpretation. These photographs were very useful in defining the current-year boundaries of fields and in extending field identification information to areas not visited by ground observers and not identified in USDA-ASCS records.

Preparation of Data for Analysis

Before carrying out any analysis of computer-compatible ERTS-1 MSS data, it was necessary to convert from the ERTS tape format to that format used on ERIM computers. This operation did not affect the data values themselves. Processing and analysis then were performed without any additional data preparation for the August 1972 data, except that every sixth line in ERTS Band 6 was found to have erroneous values, leading to the elimination of Band 6 from subsequent processing. Data for the agricultural site from June 9, 1973, were placed in spatial registration with data from the August 25, 1972, frame, again using a nearest-neighbor algorithm which did not change data values.

Location of Training and Test Area Coordinates in ERTS Data

Training and test areas of known identity are required for computer recognition processing and results evaluation. These areas usually are located and designated by investigators on aerial photographs and/or topographic maps. The seemingly simple task of choosing pixels in ERTS-1 MSS data from within these specified ground areas was found to be a difficult assignment. The problem was caused primarily by the relatively large size of the ERTS-1 MSS ground resolution element in comparison with the sizes of fields and other features in the scenes. The fields in the test areas ranged from less than 1 to well over 50 hectares (from one to > 120 acres) with an average size of less than 10 hectares (< 25 acres). (A maximum of 18 pixels could fall wholly within the boundaries of an 8-hectar (20-acre) field, but many fewer are found in practice because ERTS scan lines seldom follow field boundaries exactly and field shapes are varied.)

The fact that section and field boundaries frequently are indistinct on ERTS data displays was another factor which complicated the correlation of ERTS-1 MSS data coordinates and earth coordinates on maps and photographs. Road networks can be distinguished partially and are apparent at some times of year in some areas, but may be very difficult to detect at other times or in other areas.

Pixel mis-assignments resulting from errors in the visual location of fields in ERTS data can cause erroneous training of recognition computers with consequent errors in recognition and evaluation, and potentially incorrect conclusions. Even if the errors are detected before final conclusions are drawn, additional resources are required to correct them.

After experiencing problems of the type discussed above, a solution in the form of a computer-assisted procedure for pixel assignment was developed jointly by this contract and another ERTS-1 investigation at ERIM.[2] The procedure is described in detail by Malila, et al in 1973 (7) and is included as Appendix B, and a brief summary is given in the following paragraphs.

The computer-aided procedure for ERTS pixel assignment relies on an empirical map transformation derived by least squares calculations from a network of control points in and around the area of interest, e.g., the 20x25-km area on a 15′ quadrangle map. These control points can be located either on topographic maps and/or on aerial photographs. Their selection is based on their visibility and the accuracy with which they can be located on ERTS data displays (e.g., digital line printer maps), as well as on the earth reference grid.

A least-squares calculation is made to determine the coefficients of a map transformation from Earth to ERTS coordinates. To date, in portions of ERTS frames, a first-order linear transformation has been found satisfactory, although higher-order transformations can be calculated if needed.

Once the map transformation has been determined, the ERTS data coordinates of hard-to-locate points and vertices of fields can be computed from their Earth coordinates. A companion computer program computes which ERTS pixel centers lie within fields defined by an arbitrary (< 63) number of vertices. There also is a capability to move the polygon sides in or out by specified distances so as to exclude or include pixels that contain boundaries between more than one type of ground cover. Exclusion of such pixels is especially important in training a recognition processor.

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[2] MMC-136, *Image Enhancement and Advanced Information Extraction Techniques,* W.A. Malila and R.F. Nalepka, Co-Principal Investigators.

Signature Extraction and Digital Processing of ERTS Data

Having identified which pixels fell wholly within designated training areas, the next major step in each computer analysis and recognition processing task was the extraction of signal statistics. Both a mean vector and a variance-covariance matrix of signals were extracted from each of these training areas. Plots of these statistics were made and analyzed and other analysis operations applied to help determine which processing procedures to employ.

Recognition Processing

Computers can be programmed to make decisions regarding the class of ground cover represented by each pixel or observation. In multispectral recognition processing, such decisions and class assignments are based on spectral signatures for the classes of interest. A class spectral signature is a composite set of statistics determined from statistics for several individual training fields or plots.

The distribution of signals from each scene class was assumed to be multivariate normal. Three and four channels were used for recognition processing, but bivariate examples are used for the following discussion. Three bivariate normal distributions are represented by ellipsoids of concentration in Fig. 13. The curved decision boundaries of Fig. 13(a) denote a partitioning of the space by a quadratic decision rule, also called a maximum likelihood decision rule. Such a rule was used for some recognition processing for other tasks in this investigation, but for this task a linear approximation to it was utilized. The linear decision rule, illustrated in Fig. 13(b), employs separate (straight) decision lines between each pair of classes; for three channels, the decision lines become decision planes, and, similarly, become hyperplanes in higher dimensional signal spaces. Very little difference in performance has been noted between these quadratic and linear decision rules, so the linear rule is more frequently used because it requires less computer time. Both rules were employed with a no-decision threshold; that is, once a pixel was assigned to a particular class it was tested to see if it was sufficiently likely to have come from that class. In other words, it was determined whether or not the pixel fell within a specified ellipsoid of concentration, which resulted in decision regions analogous to those shown in Fig. 14 for this bivariate example. Points outside these regions were assigned to a null class, because they were considered to be from classes not represented in the signature set utilized.

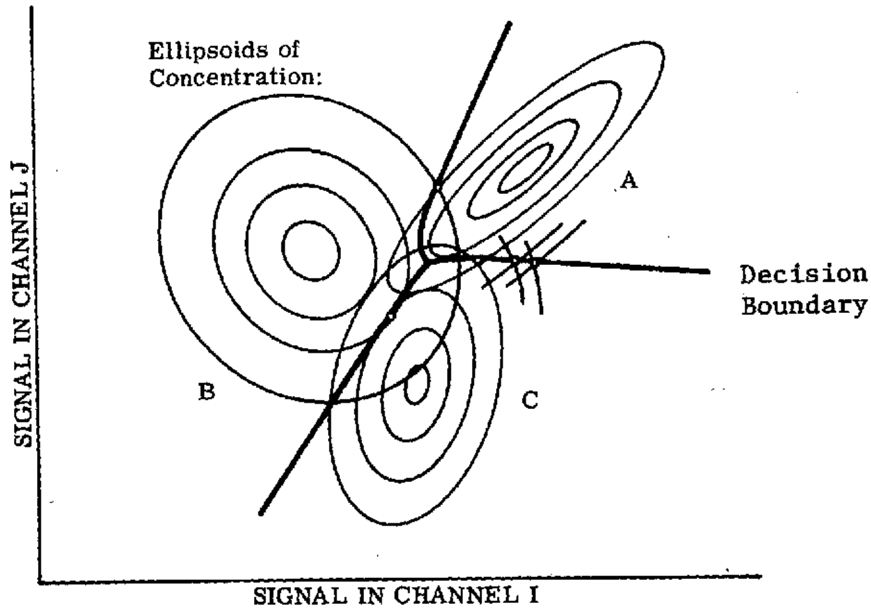
Resulting class assignments were mapped on a line printer and tallied for test and training areas. Also, likelihood maps were produced for specific classes in some instances. On a likelihood map, symbols were assigned to denote which ellipsoid of concentration was nearest to the observation ir, equivalently, the probability that, if rejected, the observation would actually be from the class.

Estimation of Fractional Composition of Individual Pixels (Mixtures Estimation)

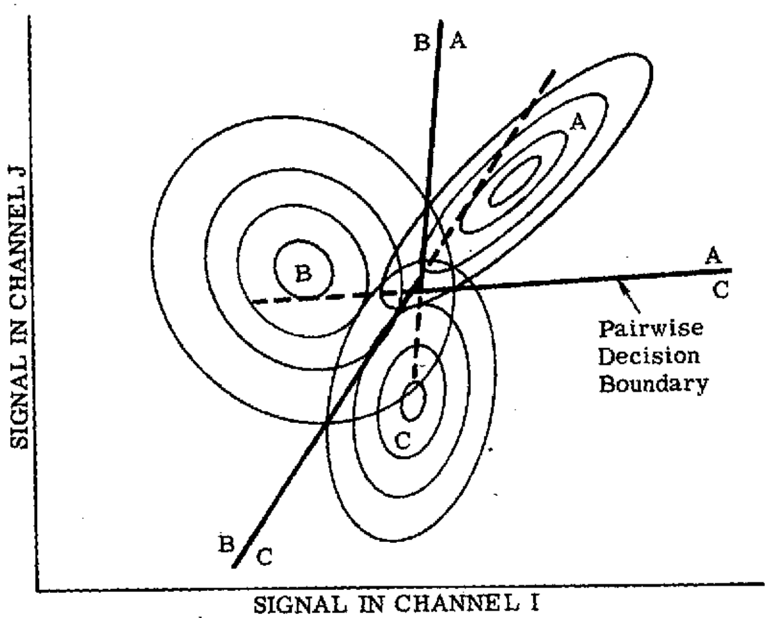
The relatively high frequency in which the ground area represented by an individual ERTS pixel contains a mixture of two or more different materials has been mentioned earlier and is illustrated in Fig. 15. The smaller and more elongated the field shapes, the greater the incidence of mixtures in pixels. Conventional recognition processing makes a class assignment for each whole pixel, based on its observed spectrum. Errors in ground area estimates for any specific ground cover can result when many pixels contain mixtures of ground covers. There may be some compensation in errors of this type, but the spectrum of a mixture might not be close enough to the signature of either (any) of its constituents to be recognized as one of them, resulting in additional errors in area estimates.

A procedure previously developed at ERIM by Horwitz et al. in 1971 (4), by Nalepka and Hyde in 1973 (8), and by Horwitz et al. in 1974 (3), to estimate the fractional composition of individual pixels was applied to three sections of agricultural data. The algorithm requires signatures for pure samples of the various classes and makes a maximum likelihood estimate of the proportions of these classes in each observation (spatial resolution element). To generate a unique estimate, there can be at most one more material class than there are spectral channels. The reason for this limit will be apparent for the two-channel case which will be utilized for the remainder of this discussion.

Three points are necessary and can be sufficient to define a plane. Fig. 16 illustrates the means of three spectral classes (A_1, A_2, and A_3) as they might appear in the space of two signal channels. They can be connected to form a triangle (or signature simplex), and the location of each point within the triangle represents a linear combination of the vertices or, equivalently, the fraction of each material in a resolution element that



(a) Quadratic Decision Rule



(b) Multiple Linear Discriminant Decision Rule

Figure 13. Two types of decision boundaries, illustrated for three bivariate normal classes.

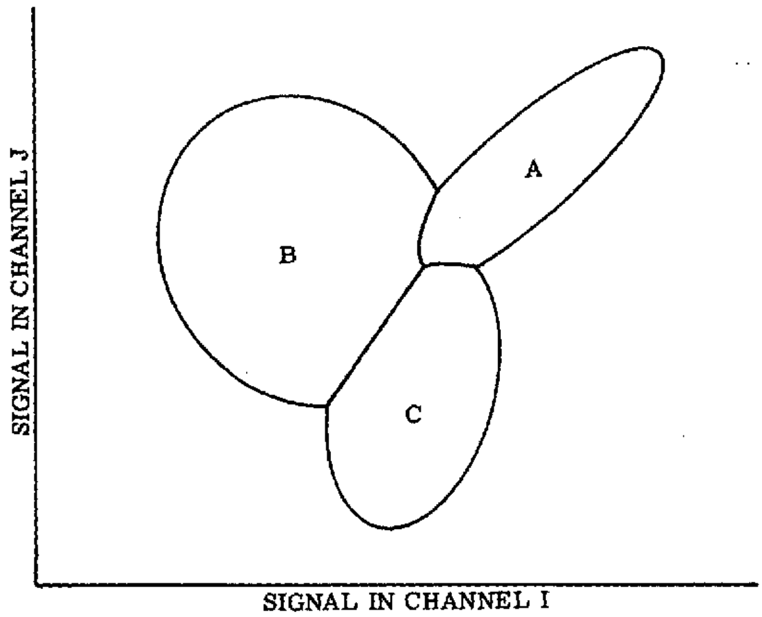


Figure 14. Decision regions for quadratic rule with a no-decision threshold.

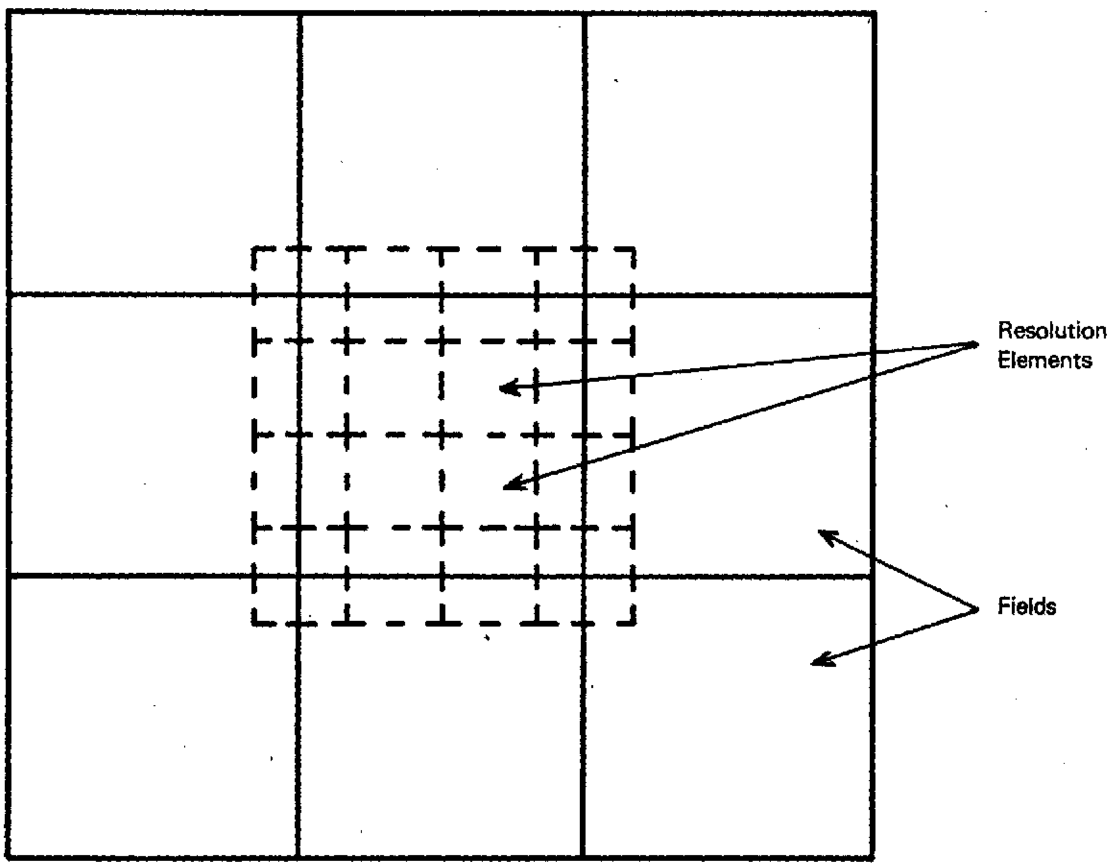


Figure 15. Illustration of the mixtures problem at field boundaries.

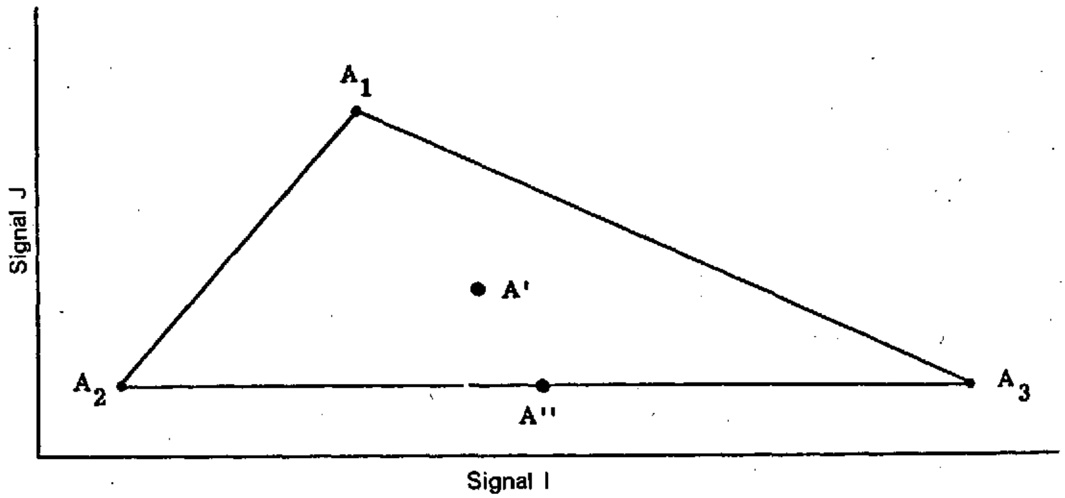


Figure 16. Geometric interpretation of means of signatures of mixtures.

would produce that particular observation vector. Designating these fractions or proportions as (P_1, P_2, P_3), we see the vertex A_1 has a proportion vector (1, 0, 0) and A_2 has a vector (0, 1, 0). A′ is the centroid of the triangle and has a vector (1/3, 1/3, 1/3), while A″, the midpoint of line segment A_2A_3, has a proportion vector (0, 1/2, 1/2). If more than three vertices were present, there would not be a unique combination of proportions for each point in the resulting quadrilateral simplex, and the algorithm would not produce valid estimates. Similarly, if vertex A_1 were to lie along the line A_2A_3 (as at point A″), there again would not be a unique solution since material A_1 would appear to be a combination of materials A_2 and A_3. Because there is a variance-covariance matrix associated with each vertex, problems can result when one vertex is too close to the simplex formed by the others; such a simplex is said to be ill-conditioned. Fig. 17 illustrates the difference between well-conditioned and ill-conditioned simplexes.

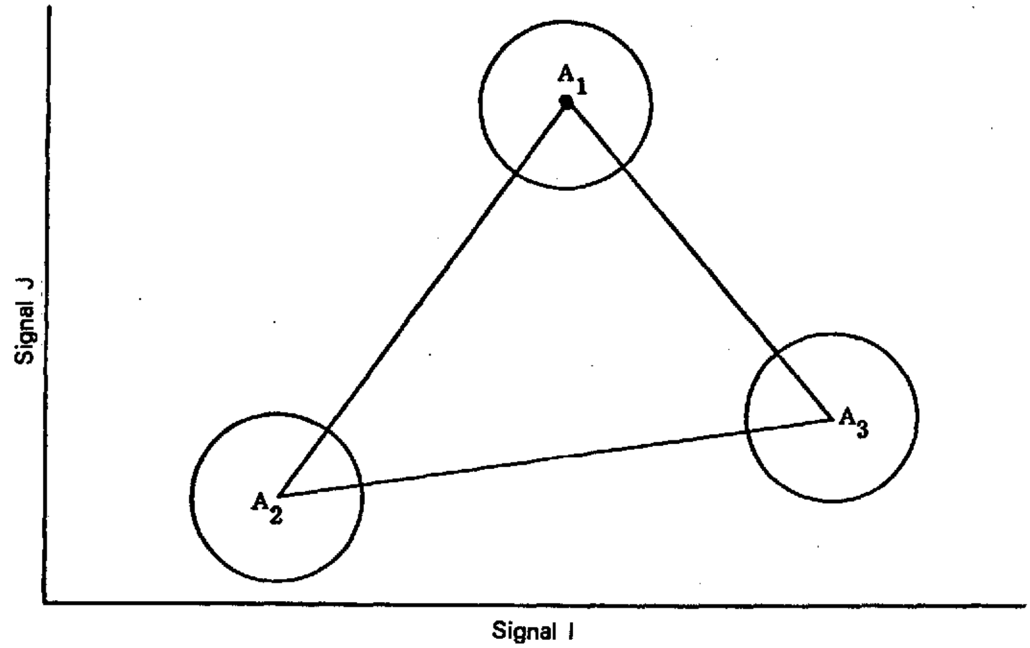
Special procedures are used to estimate proportions for observations which fall outside the signature simplex. Estimations were made only for those observations which lie close enough to the signature simplex to pass an "alien object" test.

Specific Utilization of Procedures

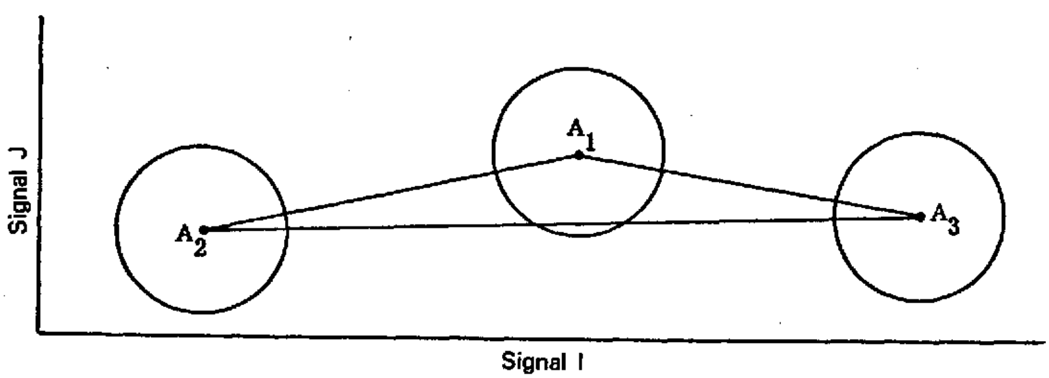
Three aspects of crop recognition were considered for the August 25, 1972, frame: (a) recognition accuracy for field-center pixels in the locale of the training data, (b) accuracy of crop area estimates for full sections where boundary pixels were included along with field-center pixels, and (c) accuracy of recognition (both in field centers and full sections) when signatures were applied to data from counties other than the one used for training.

Pixels were selected from centers of fields for training, with boundary elements being avoided so as to obtain unmixed representations of the various types of ground cover. These signatures were used for recognition with a linear decision rule, and results were evaluated for two sets of test fields. The first test set was made up of the largest identified fields in the test site. Manual procedures were used exclusively to locate pixels in these fields, and some difficulties were encountered in accurately locating even these larger fields. After the computer-assisted pixel assignment procedure was developed, a second test set was defined. This second set consisted of all identified fields within a 2 x 7 mile area from which more than one field-center pixel could be defined. An inset of 3/4 of a resolution element from boundaries was utilized[3] to insure that no mixed-cover elements were included.

[3] The inset was 3/4 of a pixel from line to line but 1.05 pixel along scan lines because data samples are generated at 57-m intervals even though the ground resolution element size is 79 m.



(a) Well-Conditioned Signature Simplex



(b) Ill-Conditioned Signature Simplex

Figure 17. Example Signature Simplexes.

Next, recognition results for pixels belonging to each of the 14 sections (1 mi. sq.) were tallied. The proportion of each major ground cover present was computed section-by-section and compared with the corresponding proportion determined from ground truth information. A grid-count method was used in measuring the areas of fields and sections for the determination of ground truth proportions. These measurements were made on an overlay drawn from enlarged high-altitude aerial photographs of the test area.

The fractional-pixel estimation procedure also was used to compute proportions for three of the sections. This was done to permit a comparison to be made between that procedure and the conventional "whole-pixel" recognition procedure.

An important capability for area surveys with remotely sensed data is that of being able to extend signatures from one area to another. The extent to which signatures from Eaton County could be applied successfully to 4-sq.-mi. test areas in Clinton and Ionia Counties was evaluated empirically.

Limited analyses were performed on June 9, 1973, data over the Eaton County test site. The objective was to determine whether or not winter wheat could be distinguished from other crops and ground covers. As part of the effort, data from this June frame were placed in spatial registration with data from the August, 1972, frame and a multi-temporal analysis was conducted.

RESULTS

The primary analysis effort was applied to the August 25, 1972, frame over the Eaton County test site. Signal statistics, extracted for 58 of the largest fields in the site, were analyzed with a clustering procedure. Based on this analysis and knowledge of the crops present, statistics for 23 of the fields were combined into 12 three-channel recognition signatures which, in turn, were used to represent five major classes of ground cover. These classes were: corn, soybeans, trees, bare soil, and senescent (or senescing) vegetation. The last category included field beans, wheat stubble, alfalfa, and grasses.

Selection of Field-Center Pixels

It was noted earlier that purely manual selections of field-center pixels produced results inferior to selections made with the computer-assisted procedure. Another important factor, both for training and evaluation, is the number of field-center pixels that can be identified in fields of different sizes. Figure 18 summarizes results obtained for 88 fields of differing sizes and shapes in the Eaton County area. Many fewer pixels were selected than would theoretically be possible for the optimum field shape for each size of field. Considering that one ERTS pixel represents 1.1 acres on the ground, the fact that an average of only ten field-center pixels was found for fields of 30 to 50 acres (12 to 20 hectares) in size is notable. As shown in Table 2, there were fields between

TABLE 2. SELECTIONS OF FIELD-CENTER PIXELS

Data Set: ERTS-1 MSS, August 25, 1972, Eaton County, Michigan

Field Size (acres)	No. Fields	Average Number of Points Selected*	Range of Number of Points
0-4.9	7	0.43	0-1
5-9.9	19	2.11	0-9
10-14.9	14	2.50	0-6
15-19.9	12	3.42	1-6
20-29.9	13	7.54	3-13
30-49	5	10.20	8-13
50 and above	10	33.90	17-95

***Note:** Only pixels whose centers fell within an area inset by 3/4 of an ERTS-1 MSS resolution element from the field boundary were selected.

10 and 15 acres (4 and 6 hectares) for which not one field-center pixel could be found, and the average number found for fields of this size was only 2.5. Current-season aerial photography was important to the success of the pixel selection procedure. It was found most convenient to draw overlays, with field boundaries and ground truth annotations, on large-scale enlargements of the photographs.

Conventional Recognition

Recognition results with these signatures are summarized in Table 3 for 76 fields (the above 58 fields and an additional 18 test fields). Recognition accuracies are between 98% and 70% correct for soils and senescent vegetation, respectively, with accuracies in the mid to high 80's for corn, trees, and soybeans.

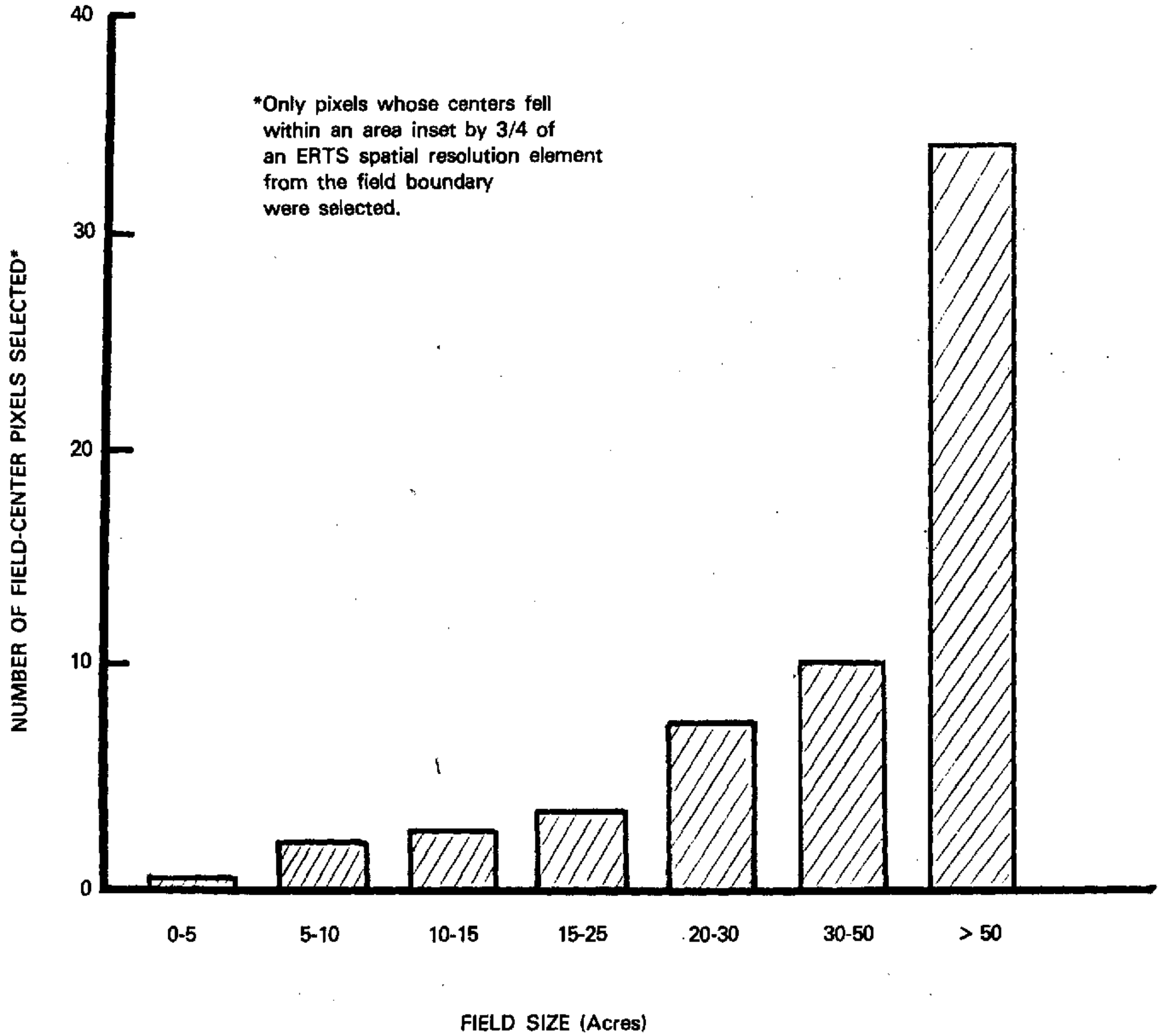


Figure 18. Influence of field size on selection of ERTS field-center pixels.

TABLE 3. INITIAL FIELD-CENTER RECOGNITION RESULTS FOR AGRICULTURE/FORESTRY TEST SITE

Averages Over Plots of Percents of Total Number of Points in Each Plot

Class	No. Plots	No. Points		Soybeans	Trees	Soil	Senescent Vegetation	Not Classed	Percent Correctly Assigned To Class	Percent Correct Excluding Not Classed	Percent Incorrectly Assigned From Other Classes
Corn	21	481	84.3	0.6	9.9	0	5.3	0	84.3	84.3	7.3
Soybeans	10	115	1.0	89.4	2.6	0	4.9	2.1	89.4	91.3	0.5
Trees	12	358	11.0	3.8	84.5	0	0.7	0	84.5	84.7	3.7
Soils	4	56	0	0	0	97.6	0	2.38	97.6	100.0	2.0
Senescent Vegetation	16	306	16.3	6.6	0	6.5	69.7	0.94	69.7	63.1	2.6
TOTALS	76	1416					Average over Five Classes	1.1	83.7	84.7	3.2

Notes:

(1) ERTS Frame 1033-15580, 25 August 1972

(2) Three channels only (ERTS Band 6 excluded because of noise)

(3) No-Decision Threshold with 0.001 Probability of False Rejection

These represent field-center results for large fields scattered throughout the site, many of which were analyzed during training. The numbers are averages of percentages computed separately for each plot analyzed. On the average 3.2% of non-class points were incorrectly assigned to a class.

A more extensive analysis of recognition results with the same signatures was made for all fields in a 2 x 7-mile area for which two or more field-center pixels could be defined. The recognition performance, summarized in Table 4, is similar to that of Table 3, except for a decrease of 10% in corn recognition, an increase of 7% in senescent vegetation recognition, and smaller changes (both up and down) in recognition of the other scene constituents. The overall average recognition performance is the same.

Recognition results also were tallied for each of the 14 full sections in the 2 x 7-mile test area in Eaton County. In full sections, one has pixels that contain boundaries between fields, farmsteads, and other non-field-center materials. It was of interest to see how well crop acreages (or proportions of crops within larger areas) could be estimated with processed multispectral scanner data. Results with the same conventional recognition procedure used for field centers are presented in Table 5. Both ground truth proportions and proportion estimates obtained from recognition results for corn, trees, bare soil, and soybeans are listed in the table. They are given for each section for a composite of the three sections used in the mixtures estimation analysis (Sec. 3.3) and for a composite of all 14 sections. Also listed are two types of RMS errors, per-section errors and per-crop errors. The computation equations are given in footnotes to the table.

The percentage recognition results come very close to the actual percentages according to the ground truth when averaged over 3 and 14 sections. This result is in part due to compensating errors. RMS errors indicate the uncertainty in these sections. On a section-by-section basis, one finds that the four-crop RMS error varies from 1.2 to 12.1%, averaging 4.7%. This error decreases to 1.9 and 1.2% when composite areas of 3 and 14 sections, respectively, are considered. Per-crop RMS errors range from 2 to 8%, with no consistent difference between values for 3 and 14 sections; errors for trees and corn are higher than those for bare soil and soybeans.

An examination of the results section by section shows that the two sections with the highest RMS error are Benton 7 and Chester 12. The main problem in these two sections is that corn recognition is high while tree recognition is low. Previous efforts with ERTS data have noted that boundary pixels around tree areas are frequently recognized as corn. The Thornapple River which flows through these two sections has tree lined and brushy banks, and the linear shape of the river produces many boundary pixels. The other section which has a

TABLE 4. FIELD-CENTER RECOGNITION RESULTS FOR 2x7-MILE AGRICULTURE/FORESTRY TEST AREA

MSU ERTS Eaton County 25 Aug. 72
3 Channel Recognition, .001 Rejection
12 signatures

Averages over Plots of Percents of Total Number of Points in Each Plot

	Nr. Plots	Nr. Point	Corn	Soybeans	Trees	Soil	Sensc. Veg.	POINTS IN CLASS Not Classed	Right (Of all)	Wrong (Of all)	Right (Of Classed)	Wrong (Of Classed)	Ass'd From Other Class
Corn	32	444	75.5	0.3	7.1		16.8	.3	75.5	24.2	75.7	24.3	7.6
Soybeans	7	51		84.9			6.7	8.4	84.9	6.7	93.2	6.8	2.5
Trees	5	75	11.8		88.2			.0	88.2	11.8	88.2	11.8	2.9
Soil	5	36				95.0	5.0	.0	95.0	5.0	95.0	5.0	4.0
Senescent ve.	47	258	9.1	4.5	0.7	7.8	76.8	1.2	76.8	22.1	77.4	22.6	12.4
	96	864					Avg. Over Points	.9	79.9	19.2	80.6	19.4	
							Avg. Over Plots	1.3	70.5	20.2	79.5	20.5	
							Over Class by Point	1.2	85.8	13.1	86.8	13.2	
							Over Class by Plot	2.0	84.1	13.9	85.9	14.1	5.9

TABLE 5. FULL-SECTION RECOGNITION RESULTS FOR 2 x 7-MILE AGRICULTURE/FORESTRY TEST AREA

Crop Proportions (Percent)

SECTION	CORN G.T.	CORN R.R.*	TREES G.T.	TREES R.R.	BARE SOIL G.T.	BARE SOIL R.R.	SOYBEANS G.T.	SOYBEANS R.R.	4-Crop RMS Error**
019	24	19	6	4	5	8	16	14	3.2
030	32	31	8	8	11	8	3	2	1.2
031	20	20	14	9	18	19	1	3	2.7
R24†	12	22	14	9	8	14	15	14	6.4
R25	33	29	0	2	8	6	11	15	3.2
R36	26	23	8	4	10	15	6	7	3.6
C01	18	21	3	6	4	8	6	4	3.1
C12	19	34	21	12	4	4	0	4	9.0
C13†	39	33	18	12	12	10	2	1	4.4
C24	41	32	1	3	12	12	6	4	4.7
B06†	42	38	7	14	4	7	0	5	5.0
B07	20	38	31	15	3	4	0	0	12.1
B18	23	27	10	8	3	10	0	1	4.2
B19	41	38	4	4	3	4	2	2	1.6
									Avg. = 4.7
3-Section† Composite:	31	31	13	12	8	11	5	7	1.9
(Per-Crop RMS Error††)		(7.1)		(6.1)		(4.0)		(3.0)	
14-Section Composite:	28	29	10	8	8	9	5	5	1.2
(Per-Crop RMS Error)		(7.9)		(6.1)		(3.4)		(2.4)	

*G.T. = Ground Truth; R.R. = Recognition Results

**Computed as:

$$E_{RMS} = \sqrt{\frac{1}{4}\sum_{i=1}^{4}(p_i - \hat{p}_i)^2}, \quad p_i = \text{Ground-Truth Proportion}, \quad \hat{p}_i = \text{Recognition Proportion}$$

†Sections utilized for mixtures estimation analysis, Sec. 3.3.3.

††Computes as:

$$E_{RMS/crop} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(p_i - \hat{p}_i)^2}, \quad N = \text{no. of sections}$$

high RMS error is Roxand 24. The same situation exists here. Instead of a river flowing through this section many forest areas are really brush or sparsely forested. An inspection of a recognition map of this section indicated that many of the pixels recognized as corn are in areas which are really brush.

Mixtures Estimation

Mixtures estimation is an alternative to conventional recognition for estimating the proportion of each crop type in a given area. The first step in mixtures estimation is to select a set of field-center or "pure" signatures. It was desired to use the same signatures as used for the previously discussed recognition studies but the limitation of one more signature than the number of channels available posed problems in view of the use of multi-modal signatures (two or more sub-class signatures per class) for recognition. Single signatures were established for each of the five classes by combining sub-class signatures for each of the classes: corn, trees, soybeans, and bare soil, and selecting one, field beans, to represent senescent vegetation.

Still, there were too many signatures for processing, because only three data channels were to be utilized. Various subsets of four signatures were analyzed and three were chosen on the basis of their spectral separations, the acreage of each component, and on their importance as crops. The sets are: (1) corn, beans, soils, and trees; (2) corn, beans, soybeans, and soils; and (3) corn, soybeans, soils, and trees. Spectral separations for the crops of each set are presented in Table 6. The numbers represent a computed distance from each crop to the hyperplane through the three other signatures of that set. The numbers are in units of standard deviation so the smaller the numbers, the less well-conditioned is the simplex formed by the set.

TABLE 6. SPECTRAL SEPARATIONS WITHIN SIGNATURE SETS

Signature Set	Distance* for Indicated Crop				
	Corn	Beans	Soybeans	Soils	Trees
I	.754	1.41		3.21	.808
II	.585	.255	.750	1.06	
III	.746		4.52	4.91	.783

*These numbers represent the distance (in units of standard deviation) from each signature to the hyperplane through the other signatures of that set.

There is a rejection threshold in the mixtures estimation algorithm which excludes from calculations those points which lie too far from the signature simplex. A chi-square (X^2) value is used as the parameter for this threshold, the smaller the X^2 value, the closer the rejection threshold is to the simplex. An analysis was made to determine the effect of different X^2 values on results with the three signature subsets for three test sections (R24, C13, and B06). RMS errors of proportion estimates over the three sections were obtained as follows: Defining the norm-square of the error in a section as—

$$E^2 = \sum_{i=1}^{4} (p_i - \hat{p}_i)^2$$

where, p_i = ground truth proportion for one crop

and $\hat{p}_i$ = estimated proportion for the same crop,

the overall RMS error for a combination of the sections is then:

$$\underset{\text{Combined Sections}}{\text{RMS Error}} = \sqrt{\frac{1}{3} \sum_{j=1}^{3} E_j^2}$$

E_j^2 = norm-square of the error in the j-th section

Because the spectral separation of the signatures in all sets was small, RMS errors were calculated for only chi-square values of one, two, and four. Table 7 shows that the best results were obtained for signature set II with chi-square equal to one, since it is here that the RMS error is a minimum.

TABLE 7. RMS ERRORS OF CROP PROPORTION ESTIMATES

Signature Set	RMS Error over 3 Sections* $X^2 = 1$	$X^2 = 2$	$X^2 = 4$**
I	.215	.205	.241
II	.150	.74	.227
III	.190	.198	.229

I:	Corn	Beans	Trees	Soils
II:	Corn	Beans	Soybeans	Soils
III:	Corn	Soybeans	Trees	Soils

** Roxand 24, Chester 13, Benton 6

**X^2 = Chi-square (Rejection Threshold)

Trees, which comprise 12.5% of the combined sections, were not included in signature set II. The best set which contained trees was set III, also at chi-square equals one. These two sets were chosen for comparison with recognition.

For each crop, the proportions estimated by the mixtures procedure at chi-square equals one were averaged over the three sections. This was done both for the two mixtures sets and for the recognition over the entire three sections (i.e., not just field centers). The RMS error of each crop proportion estimate was calculated as follows:

$$\text{RMS Error per crop} = \sqrt{\frac{1}{3} \sum_{i=1}^{3} (p_i - \hat{p}_i)^2}$$

p_i = Ground truth proportion for a crop in one of the sections

p_i = Estimated proportion for this crop in the same section for chi-square equals one (recognition has only one estimate per crop per section)

i = section designator

The overall error (Eq. 2) measures the discrepancy between the estimated proportion *vector* and the true proportion vector, whereas the per-crop error (Eq. 3) measures the discrepancy for an individual crop.

Figure 19 and Table 8 present results of error calculations for the individual crops. Each average estimated proportion on the figure is a dot with the brackets above and below representing plus or minus the RMS error. The horizontal line marks the ground truth proportion. The chart shows that for this data set recognition is generally more accurate in its predictions than for mixtures. Mixtures set II is substantially more accurate than recognition only on beans, is more accurate on bare soil, does almost as well on corn and is less accurate on soybeans. Mixtures set III has about the same accuracy as recognition for trees, while showing much more error on corn, soybeans and bare soil. In most cases the error spread is smaller for recognition in every example. Only for one crop, namely beans, was recognition much worse than mixtures, but one should not place too much importance on this point because beans represent senescent vegetation, a class with much variability.

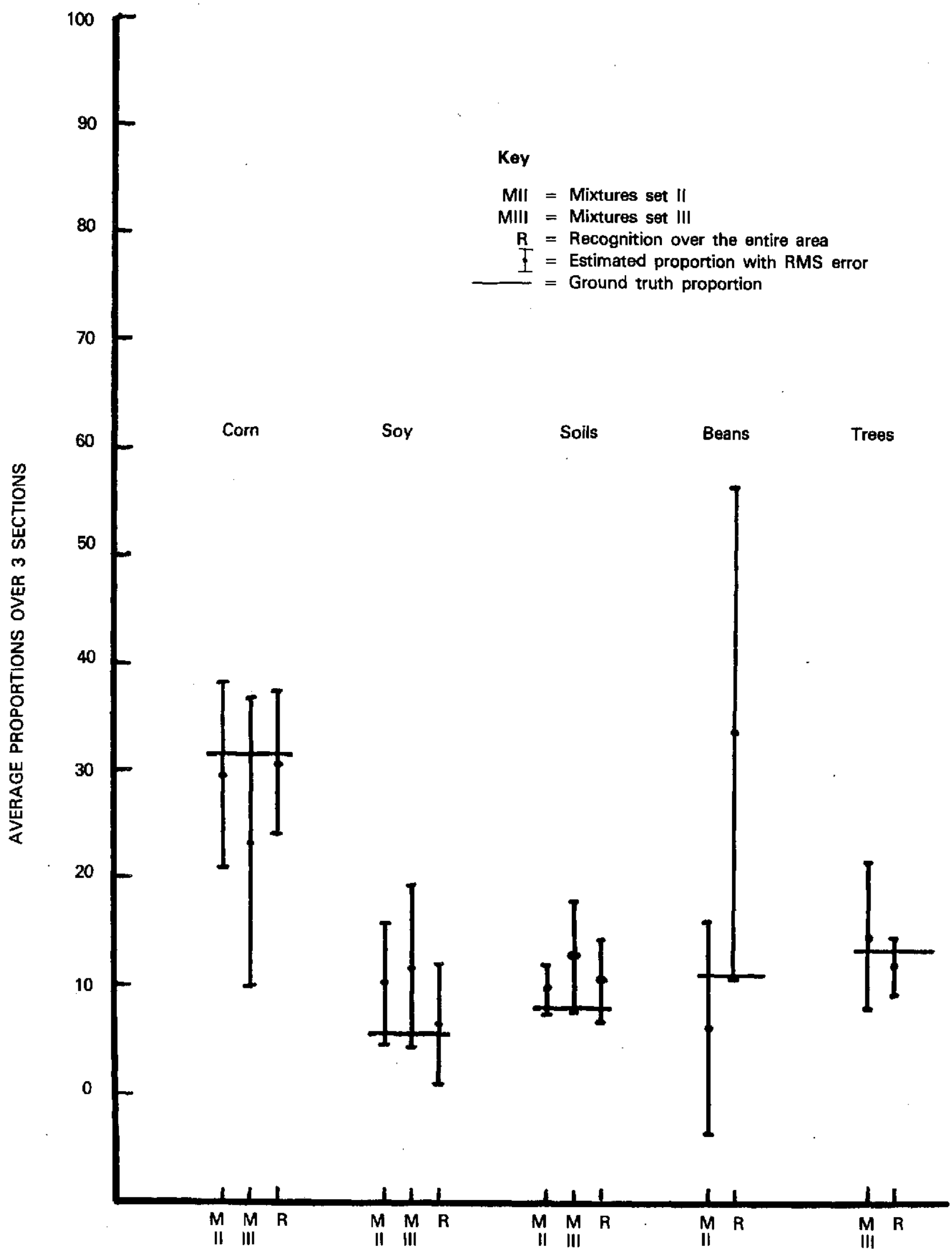


Figure 19. Comparison of methods for estimating crop proportions.

TABLE 8. RMS ERROR OF INDIVIDUAL-CROP PROPORTION ESTIMATES, FOR THREE SECTIONS AND A_2 REJECTION THRESHOLD OF $X = 1$

	Mixtures Proportion Estimate			
	Signature Set II		Signature Set III	
Crop	Estimate	RMS Error	Estimate	RMS Error
Corn	0.296	0.086	0.233	0.134
Field Beans	0.062	0.098		
Soybeans	0.103	0.056	0.119	0.074
Soils	0.097	0.023	0.128	0.050
Trees			0.148	0.068

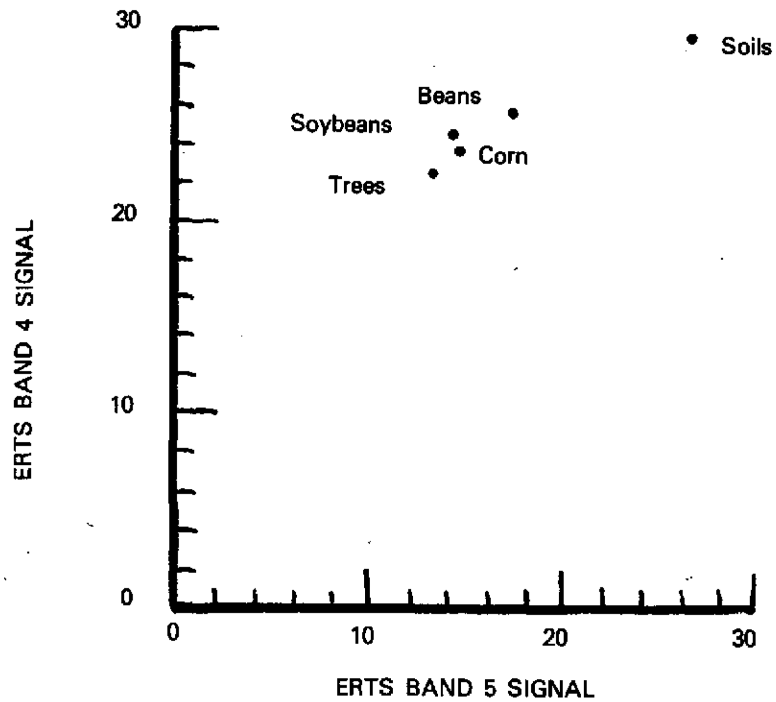
It is apparent that mixtures did do somewhat worse than recognition over the entire three-section area. Some discussion and explanation of these results is in order.

When the signature sets were chosen, even those with maximum separation usually had one member near or less than a distance of one standard deviation from the simplex of others. Some sets had two or more such cases. Past experience has shown us that estimation accuracy is partly a function of signature separation. Small separations usually lead to poor results, as seems to be the case this time. The minimum RMS errors were found at $X^2 = 1$ instead of the more typical $X^2 = 2$ or 3 for past projects. This indicates that the signature sets are ill-conditioned.

Plots of the signature means are presented in Fig. 20. For ERTS Band 4 vs ERTS Band 5 (Part a), the means lie nearly on a straight line. This will cause great difficulty in deciding whether to assign a signal, for example, to a mixture of a pair of signatures or one signature that lies between them. In fact, this graph indicates that all sets comprising four signatures are going to be nearly degenerate. Also, the means for corn and trees are close to each other in all three graphs, which could frequently cause them to be mistaken for each other. Line printer maps generated from mixtures estimation results for the three sections confirm this, as trees are often recognized in corn fields and vice-versa.

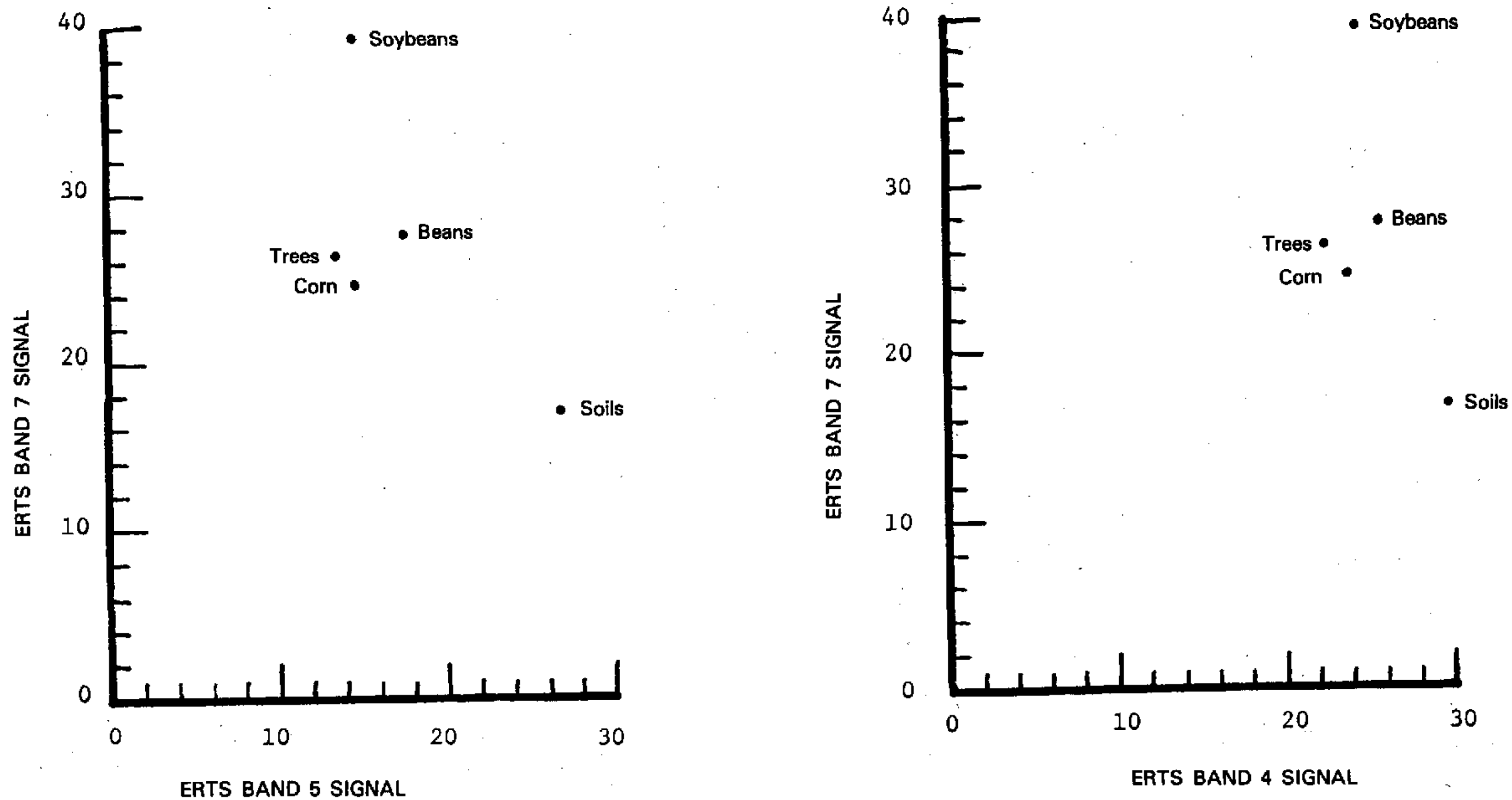
Scatter diagrams of signatures are displayed in Fig. 21. The distributions were found by plotting the mean signals for every field (training and test) used in field-center recognition. Then, an outline was drawn to include every field signal that belonged to the signature class. The class means (determined from a subset of field means) also are plotted to show their relation to the scatter outlines. In these graphs it is more apparent how trees and corn will be confused for each other since the distributions overlap in every case. Furthermore, the graphs (especially Figs. 21 (b) and (c)) show that corn and beans fall inside the simplex of soybeans, trees, and bare soil. This means that either corn or beans could be mistaken for a combination of the other three. If a signature set excluded corn this would relieve most of the overlap problems, although beans would still be inside the simplex. The results might be improved in such a case but, since corn is the major crop in the three sections, this would seem pointless.

The previous arguments, though strong, do not, and were not intended to, completely exonerate the mixtures estimation procedure. However, the fundamental problem is with the ERTS data and basic spectral characteristics. Fig. 20 (a) and 21 (a) show more than just the degeneracy of the signature sets; they show that Band 4 and 5 are highly correlated. This also can be seen in Figs. 20(b) and 20(c)[also 21(b) and 21(c)] which are very similar, the only difference being that the spread along the abscissa is more compact in part (c). Other evidence has shown that Bands 6 and 7 are also quite highly correlated. Consequently, we conclude that ERTS should be treated as a two-channel system as far as mixtures estimation for this particular data set is concerned.



(a) Band 4 vs. Band 5

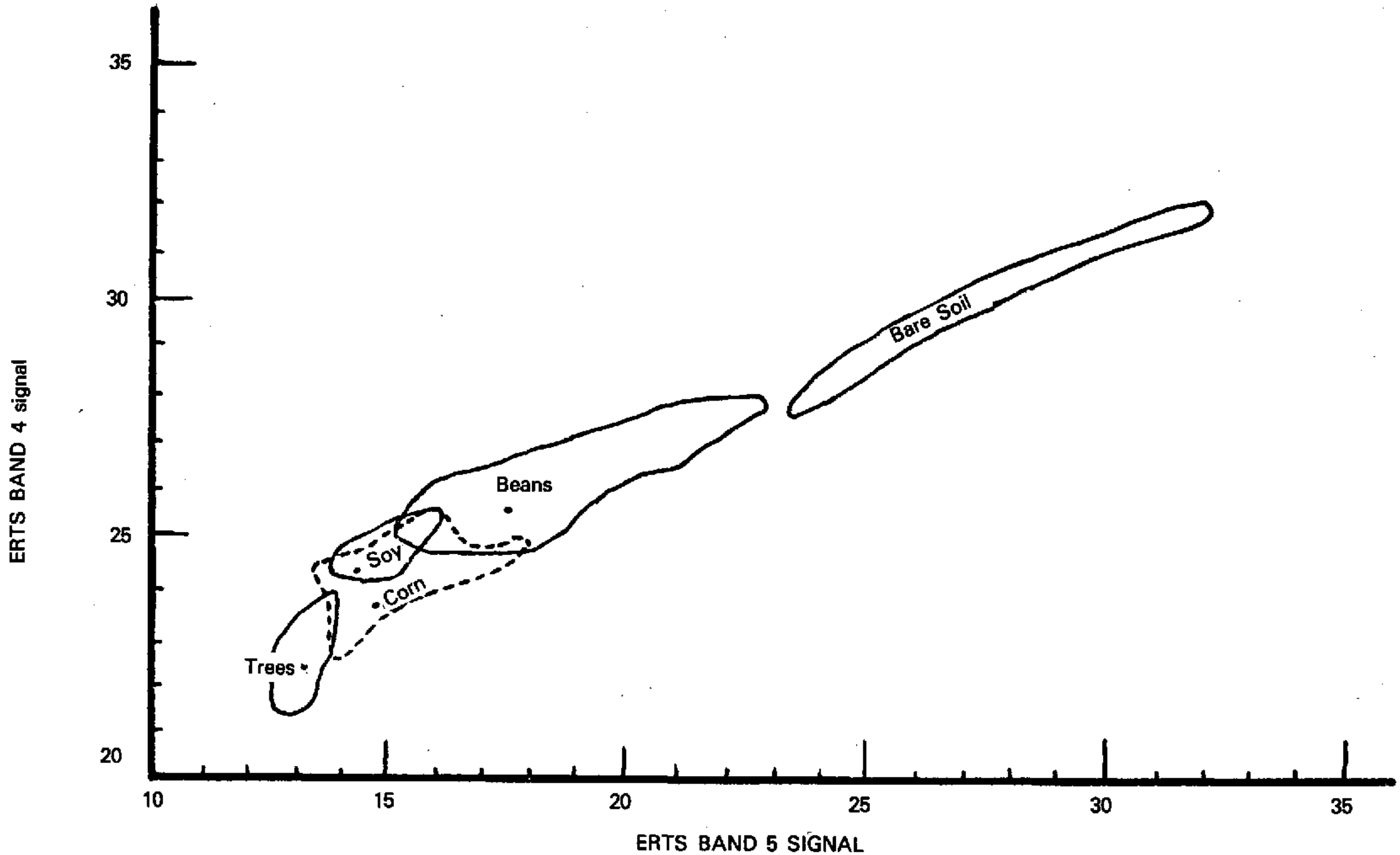
Figure 20. Scatter diagrams of signature means



(b) Band 7 vs. Band 5

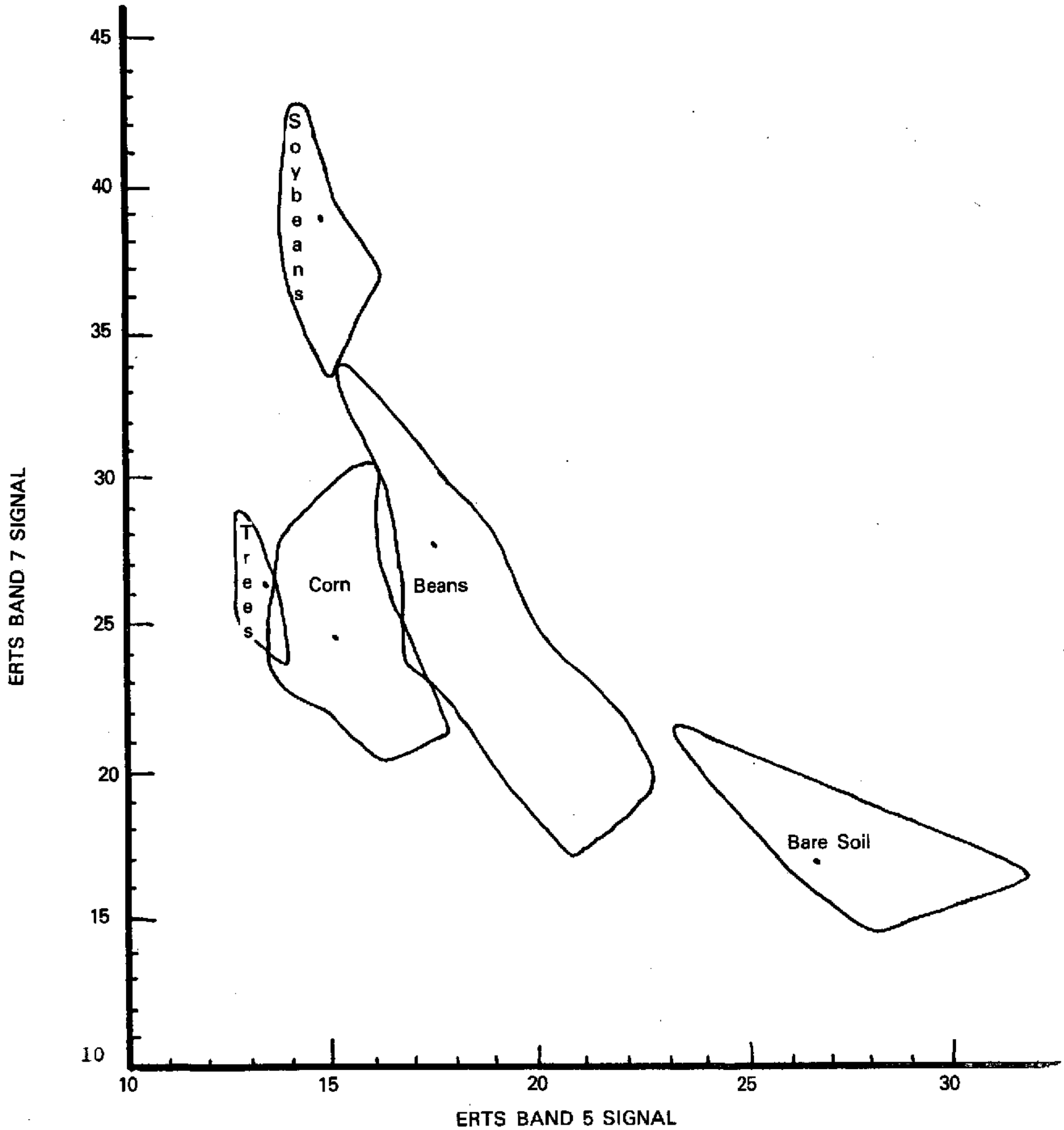
(c) Band 7 vs. Band 4

Figure 20. Scatter diagrams of signature means (concluded).



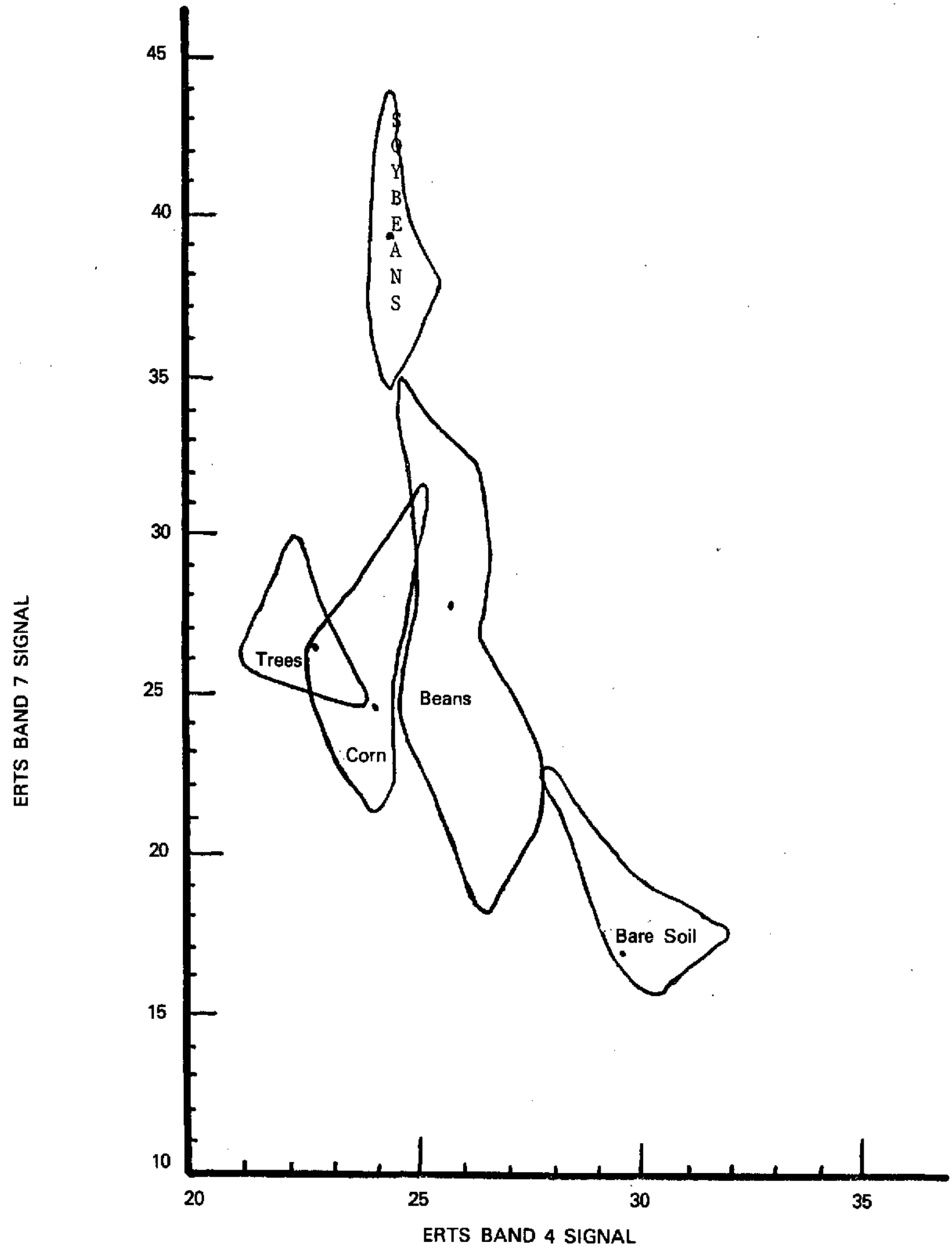
(a) Band 4 vs. Band 5

Figure 21. Scatter diagrams of field means (continued).



(b) Band 7 vs. Band 5

Figure 21. Scatter diagrams of field means (continued).



(c) Band 7 vs. Band 4

Figure 21. Scatter diagrams of field means (concluded).

Non-Local Recognition

For surveys of large areas, it is desirable to be able to apply signatures obtained in one area to other areas. In the discussion that follows, this procedure is called "non-local" recognition.

Signatures from Eaton County were applied to data in Clinton and Ionia Counties. Recognition results are presented in Table 9 for field centers. The notable changes from the results presented earlier in Tables 3 and 4 are the reduced recognition accuracies for corn and trees. A substantial portion of the corn is recognized as senescent vegetation and trees as corn. Furthermore, a substantial increase is observed in the amount of senescent vegetation called bare soil. These trends could all be explained by a shift in the average signals over these counties from averages over Eaton County. The patterns of the various classes on scatter diagrams of Fig. 21 are such that a shift of data values to higher levels would cause trees to move closer to the corn signature, corn to the beans (senescent vegetation) signature, and beans to the bare soil signature. In addition, there were several fields of oats in the senescent vegetation category which, being recently harvested, could have a substantial amount of bare soils visible. These fields were predominantly recognized as bare soil for one or both of the reasons just given.

To illustrate the way recognition results can depend on the method of calculation, Table 10 describes the same recognition results as Table 9, but presents averages over the total number of points (pixels) in each class rather than other percentages for the individual fields. This method of calculation produces higher values for soybeans (+ 9%) and trees (+ 12%) by giving more weight to large fields with better recognition percentages. In other words, the lower averages of Table 9 were produced by small, poorly recognized fields.

Table 11 presents full-section recognition results for Ionia and Clinton Counties. They again reflect the trend observed for field centers.

There are procedures whereby signatures can be extended to non-local areas with better performance than is obtainable by the application of unmodified training signatures when there are changes in environmental conditions. Whether or not these procedures would result in improved performance in the situation described here is a matter that would have to be resolved by additional analysis. However, the apparent systematic shift of signatures in the non-local area is an indication that such techniques might be successful here. Two types of procedures that could be employed are signature-extension preprocessing as reported in 1969 by Kriegler et al. (5), and Nalepka and Morgenstern in 1972 (9); and adaptive processing as reported by Kriegler et al. in 1972 (6), and by Crane in 1974 (2). Both transform signatures and/or data, based on a pre-determined strategy or empirical data analysis in the first case, and on the signal characteristics and actual along-ground-track recognition results in the second case.

Multi-temporal Recognition of Winter Wheat

Signatures were extracted for wheat, pasture and trees in ERTS data over Eaton County on June 9, 1973. Ground-truth information for the 1973 season was available only for wheat, except for areas that remained constant from year to year, like tree stands and permanent pastures. There was essentially complete overlap between the wheat and pasture signatures, both of which were green at this time of year.

A multi-temporal overlay of this June 9 data set with data from the August 25, 1972 frame, was made using a nearest-neighbor algorithm. The objective was to use data from these two time periods to differentiate between wheat and other early-greening ground covers. It was found that some wheat fields were indeed much different from pastures, being bare soil in August when pastures contained mainly senescing vegetation. Unfortunately, the August time frame in Michigan is too early for all eventual winter wheat fields to be in a bare-soil state. For example, wheat frequently follows field beans in the crop rotation, but a majority of field bean fields had not been harvested on August 25th. Bean fields in August also were senescent, making the temporal combination, field beans/wheat, difficult to distinguish from pasture/pasture. A later frame in the Fall, in combination with a Spring frame, should provide a much better capability for winter wheat recognition.

TABLE 9. FIELD-CENTER RESULTS FOR NON-LOCAL RECOGNITION, SAVERAGED OVER PLOTS

Signature Extension — MSU ERTS
Recognition in Ionia and Clinton Counties, Training in Eaton County
Three Channels, No-Decision Threshold for 0.001 Probability of False Rejection

Averages Over Plots of Percents of Total Number of Points in Each Plot
By Classes of Plots and Classes of Signatures

			SIGNATURES					POINTS IN CLASS					
	Nr. Plots	Nr. Point	Corn	Soy Beans	Trees	Bare Soil	Senesc Veg.	Not. Classed	Right (Of all)	Wrong (Of all)	Right (Of Classed)	Wrong (Of Classed)	Ass'd From Other Class
Corn	37	295	57.7		1.4		41.0	.0	57.7	42.3	57.7	42.3	4.9
Soybeans	6	27	8.3	83.3			8.3	.0	83.3	16.7	83.3	16.7	7.8
Trees	7	47	39.1	4.8	43.7		12.4	.0	43.7	56.3	43.7	56.3	.5
Bare Soil	11	53				100.0		.0	100.0	.0	100.0	.0	10.9
Senesc. Veg.	49	258	.7	15.9		22.0	61.4	.0	61.4	38.6	61.4	38.6	27.1
	110	680				Avg. over Points		.0	64.4	35.6	64.4	35.6	
						Avg. over Plots		.0	64.1	35.9	64.1	35.5	
						Over Class by Point		.0	73.8	26.2	73.8	26.2	
						Over Class by Plot		.0	69.2	30.8	69.2	30.8	10.2

TABLE 10. FIELD-CENTER RESULTS FOR NON-LOCAL RECOGNITION, AVERAGED OVER POINTS

Signature Extension — MSU ERTS
Recognition in Ionia and Clinton Counties, Training in Eaton County

Percents of Total Number of Points in Each Class
By Classes of Plots and Classes of Signatures

			SIGNATURES					POINTS IN CLASS					
CLASS	Br. Plots	Nr. Point	Corn	Soy Beans	Trees	Bare Soil	Senesc. Veg.	Not Classed	Right (Of all)	Wrong (Of all)	Right (Of classed)	Wrong (Of classed)	Ass'd From Other Class
Corn	37	295	57.3		.3		42.4	.0	57.3	42.7	57.3	42.7	5.2
Soybeans	6	27	3.7	92.6			3.7	.0	92.6	7.4	92.6	7.4	8.6
Trees	7	47	36.2	2.1	55.3		6.4	.0	55.3	44.7	55.3	44.7	.2
Bare Soil	11	53				100.0		.0	100.0	.0	100.0	.0	5.7
Senesc. Veg.	49	258	.8	21.3		14.0	64.0	.0	64.0	36.0	64.0	36.0	30.6
	110	680					Avg. Over Points	.0	64.4	35.6	64.4	35.6	
							Avg. Over Plots	.0	64.1	35.9	64.1	35.9	
							Over Class by Point	.0	73.8	26.2	73.8	26.2	10.0
							Over Class by Plot	.0	69.2	30.8	69.2	30.8	

TABLE 11. FULL-SECTION RECOGNITION RESULTS FOR NON-LOCAL RECOGNITION IN CLINTON AND IONIA COUNTIES

		CORN		SOYBEANS		TREES		BARE SOIL		SENESC. VEG.	
COUNTY	SECTION	G.T.	R.R.	G.T.	R.R.	G.T.	R.R.	G.T.	R.R.	G.T.	R.R.
Ionia	1	25	17	6	10	3	2	12	19	47	51
	2	24	13	0	5	3	0	20	35	50	46
	11	42	23	0	5	5	1	7	14	43	55
	12	28	17	5	12	6	3	5	15	51	53
Clinton	5	26	10	9	7	5	1	6	26	42	56
	6	32	25	7	7	8	2	14	21	31	45
	7	30	20	7	3	15	0	6	19	36	52
Overall		30	18	5	7	6	2	10	21	43	52

G.T. = Ground Truth
R.R. = Recognition Results

SUMMARY AND CONCLUSIONS

The use of computer processing techniques on ERTS-1 multispectral scanner (MSS) data for recognition of agricultural crops was applied both for field centers and whole sections. Field-center processing permits an evaluation of recognition performance on spatial resolution elements that contain single crops, avoiding those that cross boundaries and contain mixtures of two or more crops. Recognition over larger areas, such as full sections, permits an evaluation of the more practical full-coverage inventory over agricultural areas.

Field-centers of corn, soybeans, trees, and bare soil were accurately recognized with three channels of ERTS data from August 25, 1972, over Eaton County, Michigan. Types of vegetation that were highly variable in appearance at this time were collectively called senescing or senescent vegetation and were less satisfactorily recognized. When field-centers were selected only from the larger fields in the test area, correct recognition percentages averaged 89% for the four classes. Some degradation was observed when results were obtained for all sufficiently large fields in a 2 x 7-mile area. The most notable decrease was for the larger crop, corn, for which 50% more fields were defined with fewer total pixels than in the former case. This is an indication that there might be more spectral variability among smaller fields, of which there were many in the test site, than among larger fields. Additionally, smaller fields have proportionately fewer field-center pixels and more would include or cross their boundaries than they would in large fields.

Recognized proportions of the four classes present in the total 2 x 7-mile area were found to agree very well with ground truthed proportions. (These proportions could easily be converted to acres or hectares and thus be of more general use.) The accuracy of these proportion estimates was greater than would be predicted from the field-center correct recognition percentages because of compensating errors in recognition. There was substantial variability in estimated proportions on a section-by-section basis. Therefore, one should use caution in any generalization of these performance results to other regions.

Mixtures estimation procedures, which estimate the fractional composition of individual pixels, were less accurate than standard recognition procedures in estimating crop proportions in three sections. In theory, one would expect better results for a procedure which would properly recognize boundary pixels, but in practice the spectral separation of the signatures in the ERTS-1 spectral bands was inadequate for this data set. For example, signatures in Band 4 and 5 were highly correlated resulting effectively in only two bands for mixtures estimation, and the procedure can handle at most only one more signature than channels. For this data set, the lack of separability suggests a need for either more or different spectral bands. However, the situation might be different at another time in the growing season.

The timing of ERTS data collection and the establishment of a crop calendar are other important factors for recognition performance, but sufficient cloud-free ERTS data for that test site were not available for the exploration of these topics. Corn and soybeans were distinguishable in late August, but field beans were in a highly variable state. Wheat (winter) had long since been harvested, and its stubble was in a variety of states, one of which included growth of spring seeded clover. There were other times, such as mid-May, when wheat would have been much more distinguishable. Multi-temporal data should be useful but it was found here that the two available data sets spanned two growing seasons and were not at the proper time for reliable identification of wheat, the August data being too early for the planting of wheat for the next year's crop.

For surveys of large areas, it is important to be able to recognize crops in areas distant from those used for training. When Eaton County signatures were applied to areas to the north in Clinton and Ionia Counties, recognition accuracy was significantly degraded. Although signatures were not extracted and analyzed for these northern areas, the observed pattern of recognition errors seems to indicate a systematic shift in data values. It is quite possible that the application of signature-extension techniques would result in improved recognition, because of the apparent systematic shift. In addition, biological differences in crops and differences in soil type or terrain may have hindered recognition.

Aerial photography is important for the analysis and interpretation of ERTS data. High altitude photography, preferably rectified and from the current growing season, furnishes an excellent base map and reference for locating training and test fields, and near-simultaneous photography, preferably from lower altitudes, provides information on current crop conditions. Current-year field boundaries also can be determined from the current-year photography.

ERTS-1 MSS data have characteristics that create different problems than are present in aircraft MSS data. The relatively large spatial resolution size is a major difference. One of the first obstacles in computer analysis of ERTS MSS data is that of locating oneself in the data and correctly assigning field identifications to training and evaluation pixels. A computer-assisted technique was developed (jointly with another ERTS investigation) and was effective in reducing the severity of this problem. The large size of the ERTS resolution element is not nearly as great a problem in areas where fields are mostly over 30 acres in size. However, much of the nation's agricultural production takes place in fields of 30 acres or less, and the proportion is even greater in other countries. Crop type and acreage estimation should be possible with the current ERTS system in areas where most fields are over 30 acres (12 hectares) in size. In these areas, the border element problem is not as severe and differences in the biology of the crop and the terrain would be changing more gradually. The procurement of information on crop conditions and yield from the current ERTS system would be resolution limited, and would be difficult. The exception would be detection of those diseases and physiological stresses which are present in large areas of large fields, such as certain virus diseases of wheat. The monitoring of the intensity of these diseases in large fields would be extremely valuable.

TASK III

APPLICATION OF ERTS IMAGERY FOR ANALYSIS OF SOILS AND LANDFORMS

INTRODUCTION

The current interest in land use and land use planning has increased the need for information on soils, soil conditions and landforms. Where modern, medium intensity soil surveys, published on an aerial photo base, are available they constitute a comprehensive information base for land use planning. The older and more general soils maps also provide much information for general land use planning. In Michigan, modern soil surveys of 24 counties published or to be published on aerial photography as a base, are complete and surveys in eight counties are currently in progress. Older and more general soils maps, many made without the aid of aerial photographs, are available for many of the other 51 counties. Current soil mapping techniques utilize known interrelationships between soils and other observable landscape features such as topography or landforms, vegetation, ages of land surfaces, nature of geologic materials, and climate.

A variety of topographic maps are available for the state but these vary considerably in terms of scale, contour interval and date of compilation and publication. These maps are especially valuable for determining topographic variation, drainage characteristics and certain cultural features and patterns. However, only a few maps have been published for the entire state that show relationships between landforms and surficial geologic materials. All of these maps are generalized and based to a considerable extent upon reconnaissance mapping rather than detailed study. Detailed geologic information does exist for many smaller areas within the state but for most areas such information is lacking.

Both soil and geomorphology mapping techniques and procedures are costly and time consuming. If newer remote sensing techniques are appropriate and applicable to these tasks they might result in major economies and/or result in improved quality and utility of such basic planning information. Remote sensor information may allow automatic recognition of some soils and landforms, but it may also complement traditional black and white aerial photography in mapping soils and landforms or be useful in conjunction with existing soils and landform information for land use planners.

LITERATURE REVIEW

Several researchers have reported on the successful use of ERTS-1 data in delineating soil associations in various states (1, 10, 12, 14, 15). The success was dependent upon a close vegetation-soil relationship. The greatest success has been in areas which have a large moisture deficit for plant growth, resulting in a very close vegetation-soil relationship. In Michigan the moisture deficit is small and a close vegetation-soil relationship does not exist in the present disturbed natural conditions.

A soil association is a group of defined soil units, regularly geographically associated in a definite pattern (13). The soil units could be mapped individually in a more detailed soil survey. Task III of this project attempted to evaluate ERTS-1 data for mapping the individual soil units which are being delineated in current, medium intensity soil surveys.

The assemblage of landforms within Michigan are largely the result of the effects of Pleistocene glaciation and post-glacial modification. Remote sensing techniques including ERTS-1 data and many other types of imagery have been used by many researchers in an effort to determine topographic configuration, surficial sediments, drainage and general water conditions, the magnitude of effect of geomorphic forces, and geologic history. The nature of such studies varies greatly with the scale, quality, and resolution of the imagery. In Task III of this project ERTS-1 data was utilized and compared with other information such as RB-57 and C-47 imagery, topographic maps, soils maps, and general truth findings based on field work.

OBJECTIVES

Michigan State University in cooperation with the Environmental Research Institute of Michigan began in the summer of 1972 to test the utility of ERTS-1 data for mapping soils and landforms. The objective of this project was the development and application of techniques for using remote sensor information as a complementary method to traditional aerial photography for identifying and mapping soils and glacial landforms, and associated sediments.

In general, three characteristics of soils are of primary importance for establishing the limitations of mineral soils for various land uses: average or dominant texture, natural soil drainage, and surface slope. From laboratory and field studies it is known that the first two characteristics influence soil reflectance properties. It was an objective of this study to separate soils of differing natural drainage and texture using ERTS data. Because of the great complexity of soils over small areas in Michigan, it was necessary to evaluate ERTS for this purpose on a pixel by pixel basis.

Differences in natural soil drainage frequently result in near-surface variations of organic matter in mineral soils. As a result more poorly drained soils have darker surfaces than well drained soils and are less subject to erosion (as a result of their generally lower topographic positions and nearly level slopes). Soils of coarse texture usually have higher reflectances than medium or fine-textured soils under natural conditions.

Two, 3 x 20 mile north-south trending tracts were selected for this study in regions with contrasting glacial landforms, sediments and soils.

Test site III, within northwestern Ingham and southeastern Clinton counties, extends through a terrain reportedly consisting of several east-west trending end moraines separated by areas of ground moraine that were formed in association with the Saginaw glacial lobe. In addition, individual landforms such as an esker, several drainage ways, and glacial outwash within a spillway had been mapped in the area. Test site IV, located in Livingston and Washtenaw Counties, traverses a landscape interpreted to be developed, at least in part, within an interlobate area when deposition was taking place from both the Saginaw and the Erie lobes. The result is an especially complex area consisting of interlobate moraine with unusually high relief and considerable variety of topographic forms and associated sediments.

COLLECTION OF GROUND TRUTH INFORMATION

Soil conditions at the time of ERTS-1 overpasses were observed directly in the field and recorded on recent U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service (USDA-ASCS) aerial photography and parially on 35-mm photography. The recent USDA-ASCS aerial photography, RB-57 and C-47 imagery supplemented the direct observations and extended the ground truth to areas not readily accessible.

Modern, medium intensity soil maps, prepared jointly by the U.S. Department of Agriculture, Soil Conservation Service, and the Michigan Agricultural Experiment Station, as part of the National Cooperative Soil Survey, comprise the major portion of soils ground truth information for the two test sites. Areas of individual soil types are commonly too small (less than three acres) or too intimately associated to delineate at the scale of 1:15,840 or of 1:20,000 used in these surveys. The proportions and kinds of these inclusions within major mapping units were determined with use of transects and aerial photographs as they might affect the interpretations of the ERTS-1 data.

Glacial landforms and sediments were mapped in detail at a scale of 1:62,500 at site III and 1:24,000 at site IV. These scales were selected because they were the largest available in association with U.S. Geological Survey topographic maps. All accessible roads were traversed and all apparent exposures of sediments were investigated and meaningful information was recorded. Landform units were recognized and delineated on the basis of topographic form, associated sediments and altitude. Topographic, geologic, drainage and soils maps as well as ERTS-1, RB 57 and C-47 data were used as additional sources of information in determining ground truth.

REMOTE SENSING DATA

Analysis of ERTS data was limited to ERTS-1 frames E-1033-15580 collected on August 25, 1972 and E-1320-15525 collected on June 8, 1973. Frame E-1033-15580 covered Test Site III, but not Test Site IV. On August 25, 1972, vegetation covered 95 percent of the soil in Test Site III, a condition which is not very satisfactory for identifying soils and landforms. Because of inclement weather conditions which occurred on the dates of the ERTS-1 overpasses for the remainder of 1972, Test Site IV was not covered in 1972.

Frame E-1320-15525 (June 8, 1973) covered both test sites. On June 8, 1973 vegetation covered about 81 percent of the soil in Test Site III and 90 percent of the soil in Test Site IV.

RB-57, color and color infrared imagery was collected on June 10 and 11, 1972. This imagery was evaluated for identifying soils and landforms. C-47, black and white infrared, color, color infrared, and multispectral scanner imagery was also evaluated. USDA-ASCS aerial photography (black and white) was evaluated for identifying landforms but not soils because this type of imagery is currently used generally as a base for soil maps.

Processing of ERTS-1 and C-47 Multispectral Scanner Data

The procedures for preparation of the data for analysis, location of training and test sets, and signature extraction were the same as those used in Tasks I and II. Several different processing procedures of differing degrees of complexity were employed in Task III.

Level Slicing

The simplest procedure was to "level slice" the signals in a single channel. That is, the range of signal values was divided into a number of intervals according to the distribution of values from various classes represented in the training data. Distinctive line-printer symbols were assigned to certain intervals to designate specific groups of scene materials. A line printer map then was produced to display, spatially, the designated values in the given spectral channel. (The normal gray-scale line-printer map is a special case of this type of map.) The uniqueness of the classes or groups represented by the symbols depended, of course, upon the inherent separation of their signals, and was evaluated for separating soils and landforms.

Sum and Difference

Rather than level slicing values in an individual channel, one procedure level sliced a linear combination of values from two channels. Weighted sums and differences were utilized in separate mapping operations. A refinement will be discussed later; in it, the weighted sum of two channels was level sliced only when the weighted difference of those same two channels fell between specified limits. The potential advantage of such linear combinations is that greater contrast between (or within) classes might be obtained for certain patterns of spectral signatures. Lines of constant difference have positive slopes on Fig. 22, while lines of constant sum have negative slopes.

Ratios

Another operation that was performed on signals from pairs of channels was that of computing the ratio of their values. Ratioing is a non-linear operation, with lines of different, but constant, ratios radiating like spokes of a wheel from the origin of the ratioed variables, as shown in Fig. 23. Ratios have the property of canceling or minimizing positively correlated variations in the data while emphasizing negatively correlated variations. In other words a ratio will enhance contrasts for a pair of variables (like ERTS Bands 5 and 7) which exhibits negative correlation between various amounts of healthy vegetation cover, while positively correlated multiplicative variations, such as those due to different levels of brightness, will be diminished. Differences,

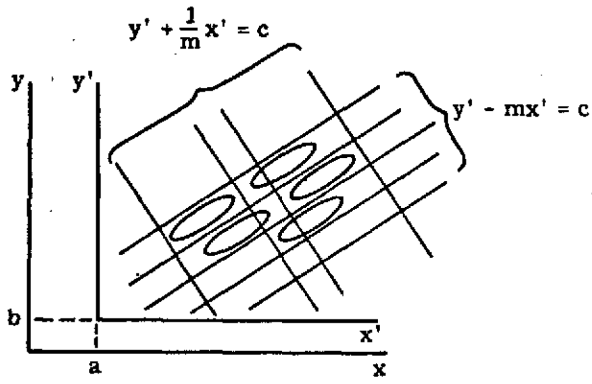


Figure 22. Sum and difference partitioning of signal space.

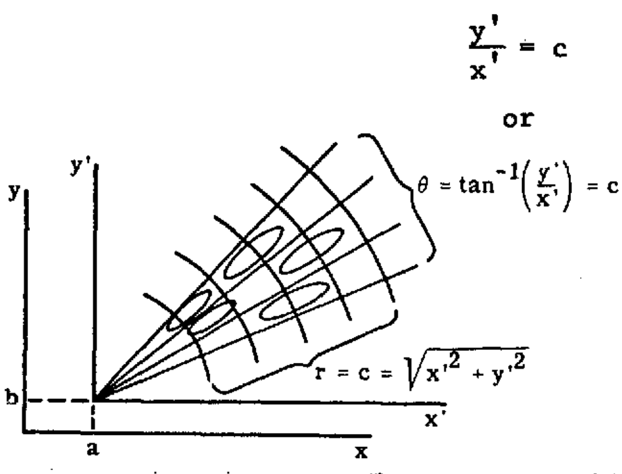


Figure 23. Ratio partitioning of signal space.

discussed in the preceding section, have characteristics similar to those of ratios. Before ratioing, values representative of path radiance were subtracted in each of the channels. Path radiance is extraneous radiation that reaches the sensor after scattering from particles in the atmosphere. Ratioed data were both level-sliced and gray-scale mapped for interpretation and evaluation by discipline investigators.

Recognition Processing

Recognition processing for Task III was similar to that for Tasks I and II.

Analog Processing of Aircraft Multispectral Scanner Data

Aircraft MSS data were processed in analog form to produce ratio images. The aircraft scanner system recorded 12 spectral channels over a greater spectral range than ERTS-1, 0.4 to 11.7 um vs. 0.5 to 1.1 um. Ratio images were formed both for pairs of channels that represent various combinations of ERTS-1, notably a thermal channel.

RESULTS

Soils

Bare, mineral soil areas were identifiable on the ERTS-1 channel 5 (0.6-0.7 um) graymap prepared from the computer compatible tapes (blank areas in Figure 24). The graymaps were also used for locating fields on the recognition maps.

Digital Analysis of Soil Signatures

Average signal levels were obtained for bare soil training sets in each of the four ERTS-1 bands from data collected on August 25, 1972 (Figure 25), and June 8, 1973 (Figure 26). Two characteristics of the soils within the training sets are shown in Table 12.

On August 25, 1972 the somewhat poorly drained soil (1) and the poorly drained soil (2) had signal ranges in the four ERTS bands that were too similar to allow separation (Figure 25). However, these two soils and signal ranges were distinct from the other soils (well-drained and organic) in bands 4 and 5. The signal ranges for mineral soils 1,2,3,4,5, and 6, were similar to band 6 and, particularly, band 7. In other words, ERTS data showed signal differences related to natural soils draininage in bands 4 and 5, but not bands 6 and 7.

Texture differences of well-drained soils do not show consistantly separable signal ranges for these data (Figure 25). The well-drained coarse (soil numbers 3 and 5) and medium (soil numbers 4 and 6) textured soils had overlapping signal ranges in all four bands. The signatures for these soils were obtained from two different areas, 3 and 4 from one area and 5 and 6 from another area approximately 20 miles away. Signal values for each of the two well drained soils from the same area are nearly identical in bands 6 and 7. The coarse-textured soil has a higher average signal value than the respective medium textured soil of the same site in bands 4 and 5.

The two organic soils were distinctly lower in signal values for all ERTS bands (Fig. 25). The signatures from the eight training sets were combined to form four signatures for automatic data classification. The signatures represented: (i) very poorly drained organic soils (Nos. 7 and 8), (ii) somewhat poorly and poorly drained mineral soils (Nos. 1 and 2), (iii) well drained-medium textured soils (Nos. 4 and 6) and (iv) well drained-coarse textured soils (Nos. 3 and 5).

From the June 8, 1973 ERTS data five medium-textured mineral soil and three organic soil signatures were obtained (Fig. 26). Unlike the August 1972 data, the drainage classes of the mineral soils could not be distinctly separated. The average values for the poorly and somewhat poorly drained soils were consistently lower than those of the well-drained soils in all bands, but their average variation substantially overlapped that of the well-drained soils, particularly in bands 4 and 5.

Signatures for the three organic soils were distinct from all mineral soils in all bands and were distinct from each other in bands 6 and 7. It is not currently known in what way these organic soils differed one from the other.

The signatures from these training sets were combined to form four composite signatures representing: (i) well drained mineral soils (A and B), (ii) somewhat poorly-drained mineral soils (C and D), (iii) poorly-drained mineral soils (E) and (iv) very poorly drained organic soils (F, G, and H)—although there was little likelihood of correctly separating the first three categories.

In general, as soils become more poorly drained, the organic matter content increases causing the surface soil to become darker (3). This trend holds for the soils in these training sets.

It is not clear why the poorly and somewhat poorly drained soils appeared to be separable from the well-drained mineral soils on the August 1972 ERTS data and not the June 1973 data but possible reasons may be related to differences in soil moisture (high surface moisture content suppresses soil reflectance differences), cultivation (fresh tillage may emphasize or reduce surface differences related to natural drainage) and vegetation (minor components of stubble or weed vegetation in otherwise bare fields may have relatively great effects on average reflectance).

Recognition Processing

A recognition map was produced with the four composite soil signatures from the August 25, 1972 data. Portions of this map are included in Fig. 27 and 29. The soil maps for the areas in Fig. 27 and 29 are shown in Fig. 28 and 30, respectively. Recognition occurred in all bare soil areas, but considerable misclassification of natural soil drainage classes occurred within those areas. The percent of correct classification was less than the percent agreement (85%-95%) of the natural drainage class of transect observations with the natural drainage class of the soil series in the mapping unit name (Table 13). Because of the skew in the ERTS-1 data the percent of resolution elements correctly classified was difficult to determine as soil patterns are irregular. Some large fields of predominately well drained soils were mostly misclassified as somewhat poorly drained and poorly drained soils (eg. Field A in Fig. 27 and 28). Also, somewhat poorly drained and poorly drained soils were frequently misclassified as well drained soils.

A frequently observed pheonomenon in bare, predominately well drained mineral soil areas was predominantly correct classification of well drained soils in the center of fields and misclassification as somewhat poorly drained and poorly drained soil around the edge of fields (eg. Field B and Fig. 27 and 28). This classification is probably the result of the ERTS-1 resolution elements covering a portion of vegetation in adjacent areas.

Bare, organic soil areas were successfully separated from bare, mineral soil areas (Fig. 29). Some water areas were misclassified as organic soil. No part of bare, organic soil areas was classified as mineral soil, and no part of bare, mineral soil areas was classified as organic soil (Fig. 30). Organic soils are part of the lowland landform unit. Well drained, mineral soils and some somewhat poorly drained and poorly drained, mineral soils occur in the upland landforms.

A recognition map was produced using the four soil signatures from the June 8, 1973 data. A portion of this map is shown in Fig. 31. The soils map of this area is shown in Fig. 32. Recognition occurred in all bare soils areas, but considerable false recognition also occurred. As expected from the digital analysis of the soil signatures, mineral soils could not be separated into (a) well drained soils, (b) somewhat poorly drained soils, and (c) poorly drained soils. Bare, organic soil areas were again successfully separated from bare, mineral soils areas (Fig. 31 and 32). No part of bare, organic soil areas was classified as mineral soil, and no part of bare, mineral soil areas was classified as organic soil. Some vegetated areas were misclassified as organic soil.

Ratio Processing

Ratio processing is a simple image enhancement technique that can be coupled with a choice of ratio values to classify scene elements. While several different ratios can be utilized in the computer decision operation, only a single exploratory ratio transformation was employed for August 25, 1972 i.e.—Band 7/Band 5.

The procedure was initially to subtract a path radiance term from each ERTS-1 band, approximated by a value for the darkest object in the scene in each band. The ranges used were obtained through examination of a histogram of the ratio values for the entire scene. It was hoped that these ratio signal ranges would separate soils of differing drainage classes. An evaluation of the ratio images of bare soil areas indicated results similar to those from the recognition processing except that organic soil areas had greater misclassification. This was essentially an unsupervised classification and determination of *a priori* ratio values for the different soils might have improved the results.

Inter Range		Voltage Range		Symbol
0	14	.0000	14.0000	▓
15	15	15.0000	15.0000	X
16	16	16.0000	16.0000	E
17	17	17.0000	17.0000	I
18	19	18.0000	19.0000	*
20	20	20.0000	20.0000	=
21	22	21.0000	22.0000	.
23	24	23.0000	24.0000	-
25	511	25.0000	511.0000	

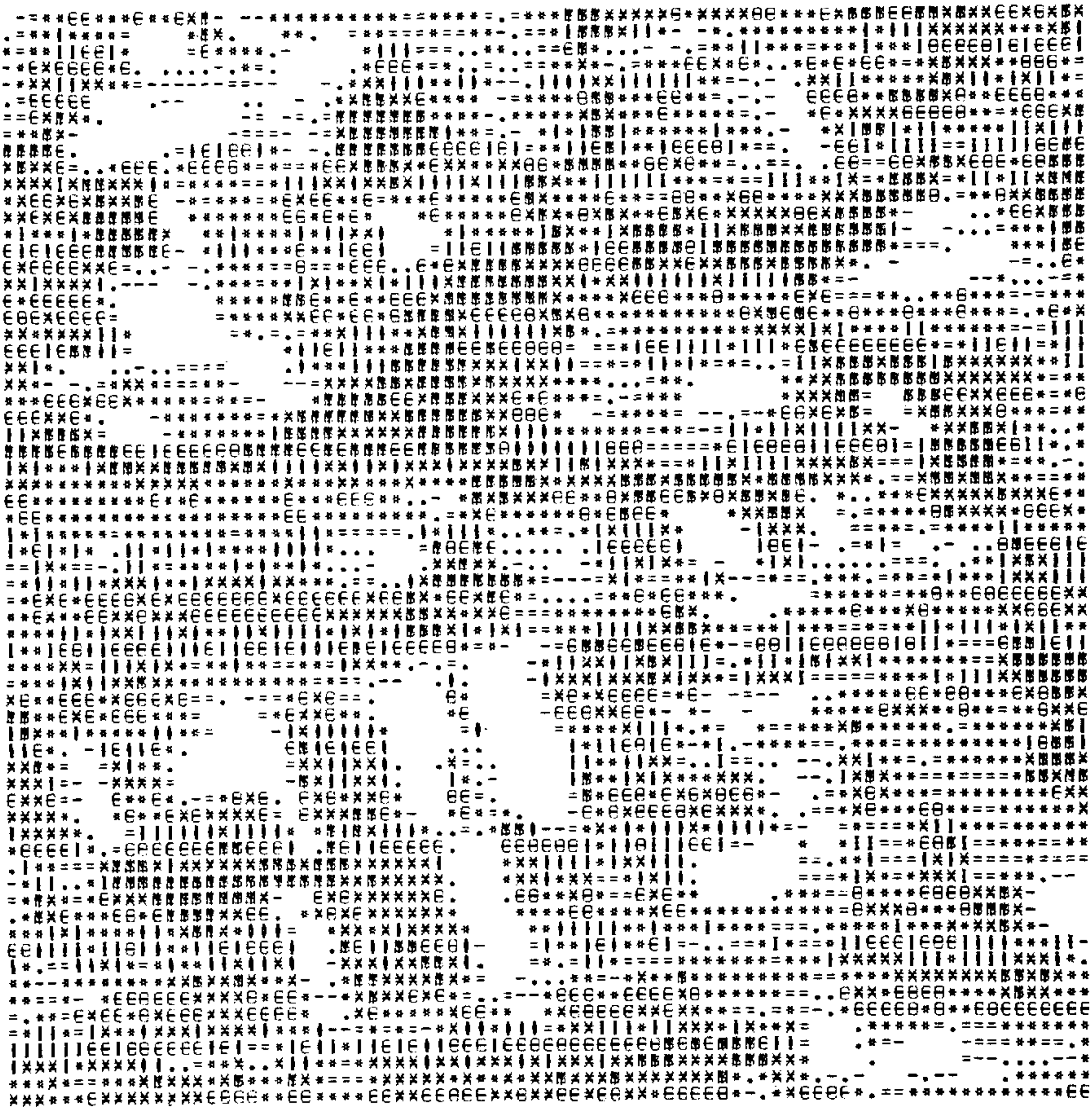


Figure 24. Graymap of band 5 of a portion of Bath and Dewitt Townships in Clinton County, Michigan. Blank areas indicate fields of bare soil on August 25, 1972.

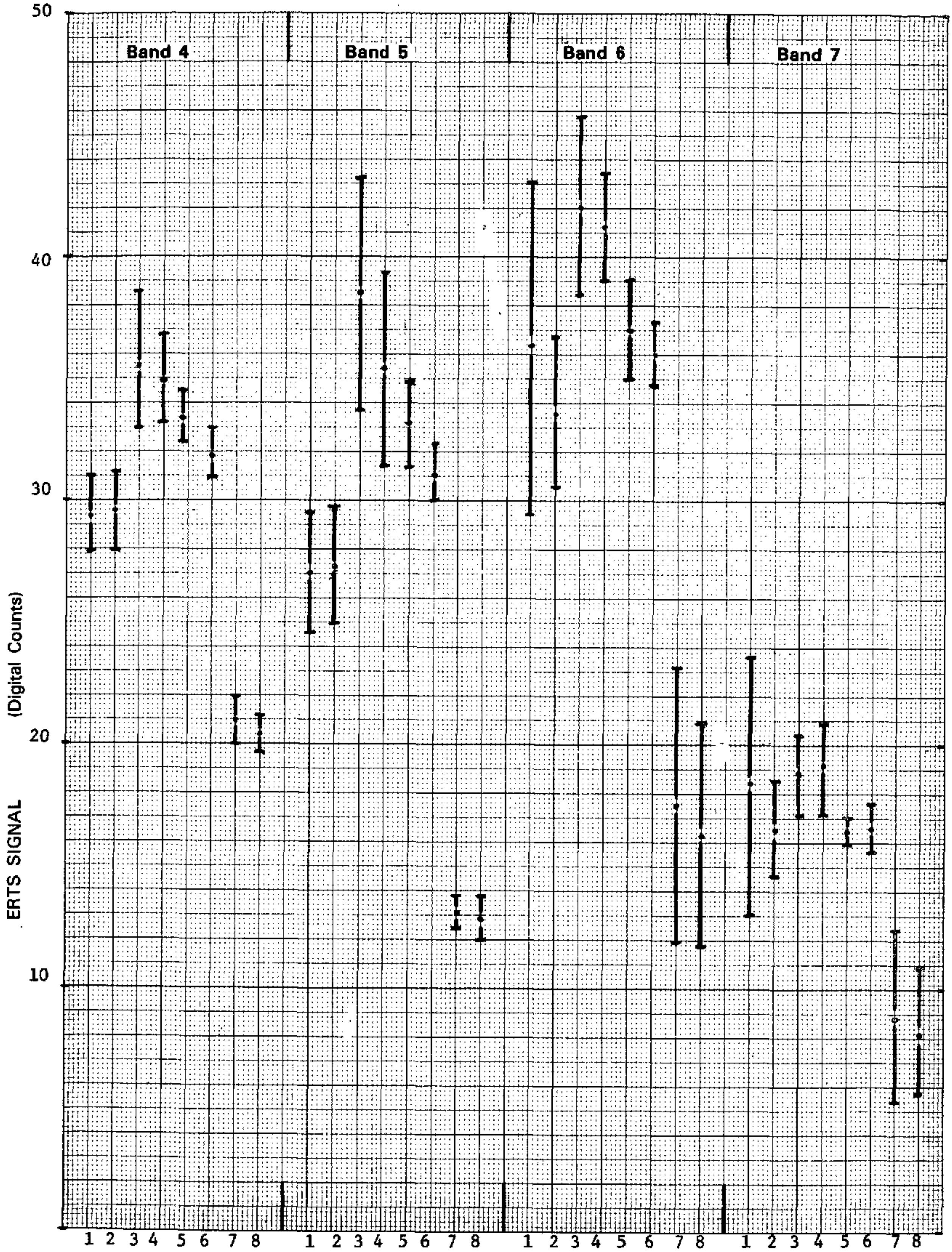


Figure 25. Summary of soil signatures in ERTS-1 bands on August 25, 1972.

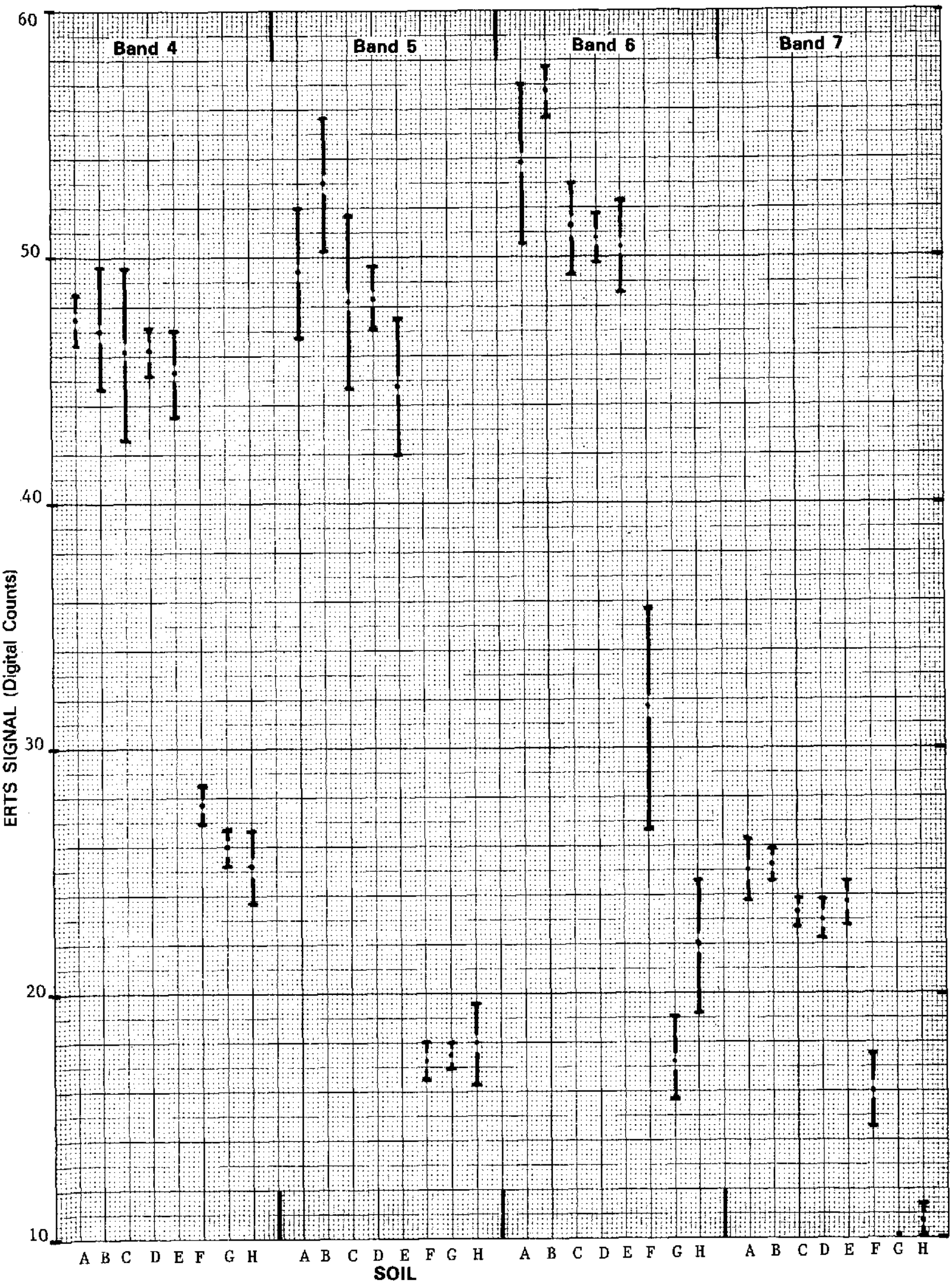


Figure 26. Summary of soil signatures in ERTS-1 bands on June 8, 1973.

TABLE 12. GENERAL DESCRIPTION OF SOILS WITHIN THE SAMPLE AREAS

SELECTED CHARACTERISTICS OF SOIL PROFILES

Soil No.	Soil Series	Natural Drainage	Profile Texture or Composition
August 25, 1972			
1	Conover	Somewhat Poor	Medium Textured
2	Brookston	Poor	Medium Textured
3	Spinks	Well	Coarse Textured
4	Miami	Well	Medium Textured
5	Owosso	Well	Coarse Textured
6	Miami	Well	Medium Textured
7	Houghton	Very Poor	Organic
8	Tawas	Very Poor	Organic
June 8, 1973			
A	Miami	Well	Medium Textured
B	Miami	Well	Medium Textured
C	Conover	Somewhat Poor	Medium Textured
D	Conover	Somewhat Poor	Medium Textured
E	Brookston	Poor	Medium Textured
F	Carlisle	Very Poor	Organic
G	Carlisle	Very Poor	Organic
H	Tawas	Very Poor	Organic

Soil Description	Symbol
Somewhat poorly and poorly drained, mineral soils	-
Well drained, mineral soils	θ
Well drained, mineral soils	#
Very poorly drained, organic soils	[illegible]

Figure 27. Soils recognition map (August 25, 1972) of a portion of Bath and Dewitt Townships in Clinton County, Michigan (same area as in Fig. 24).

Soil Description	Symbol
Well drained, mineral soils	W
Somewhat poorly drained, mineral soils	S
Poorly drained, mineral soils	P
Very poorly drained, organic soils	O

Figure 28. Conventional soils map of same area as in Fig. 24 and 27.

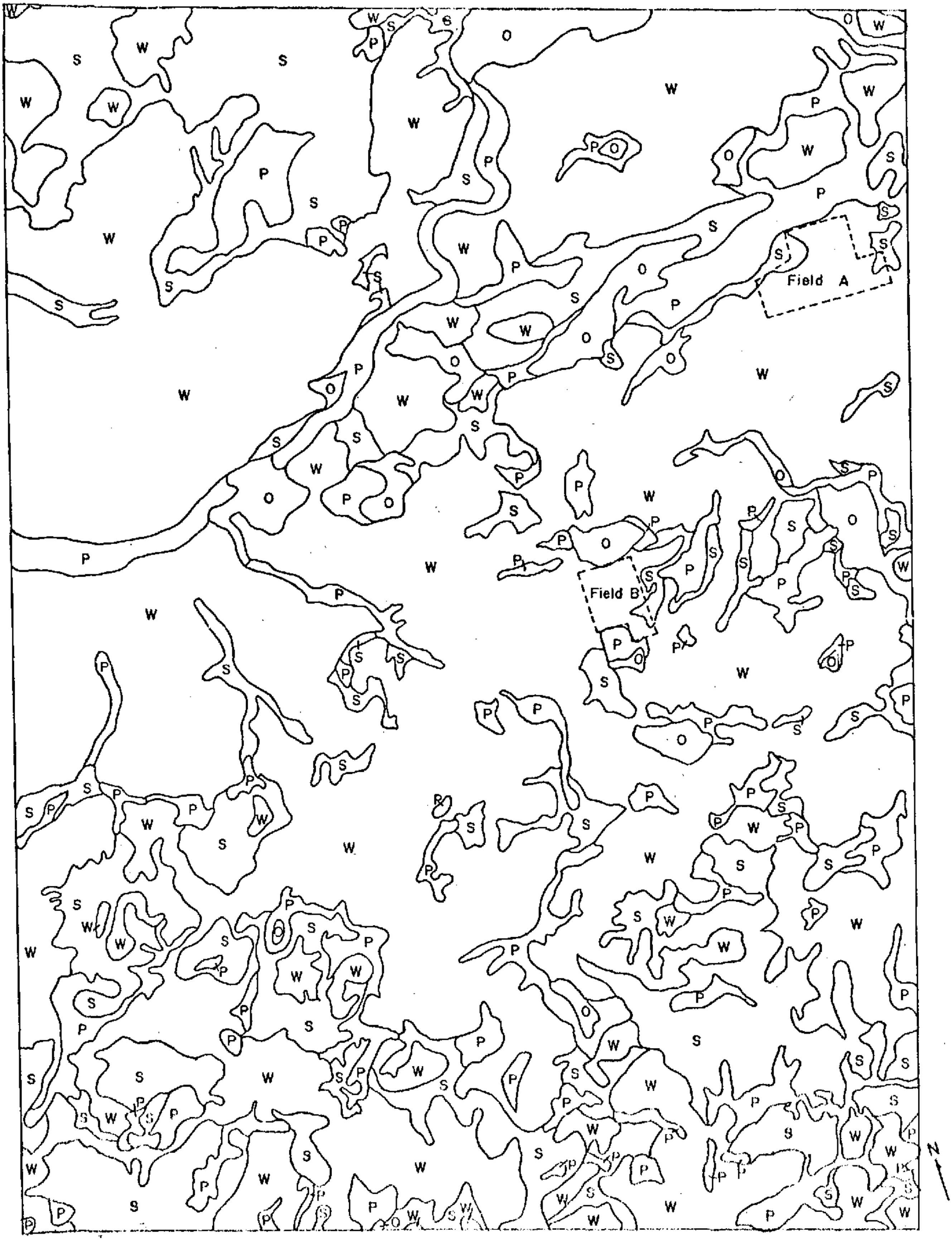


Fig. 28

Soil Description	Symbols
Somewhat poorly and poorly drained, mineral soils	-
Well drained, mineral soils	θ
Well drained, mineral soils	[illegible]
Very poorly drained, organic soils	[illegible]

Figure 29. Soils recognition map (August 25, 1972) of a portion of Bath and Dewitt Townships in Clinton County, Michigan.

TABLE 13. AGREEMENT OF NATURAL DRAINAGE CLASS OF TRANSECT OBSERVATIONS WITH NATURAL DRAINAGE CLASS OF SOIL SERIES IN SOIL MAPPING UNIT NAME

Natural Drainage Class of Soil Series In Mapping Unit Name	Percent Agreement of Transect Observations		
	Test Site III	Test Site IV	Test Sites III and IV
Well Drained	85	95	91
Somewhat Poorly Drained	89	80	86
Poorly Drained	93	80	90

Soil Description	Symbol
Well drained, mineral soils	W
Somewhat poorly drained, mineral soils	S
Poorly drained, mineral soils	P
Very poorly drained, organic soils	O

Figure 30. Conventional soils map of same area as in Fig. 29.

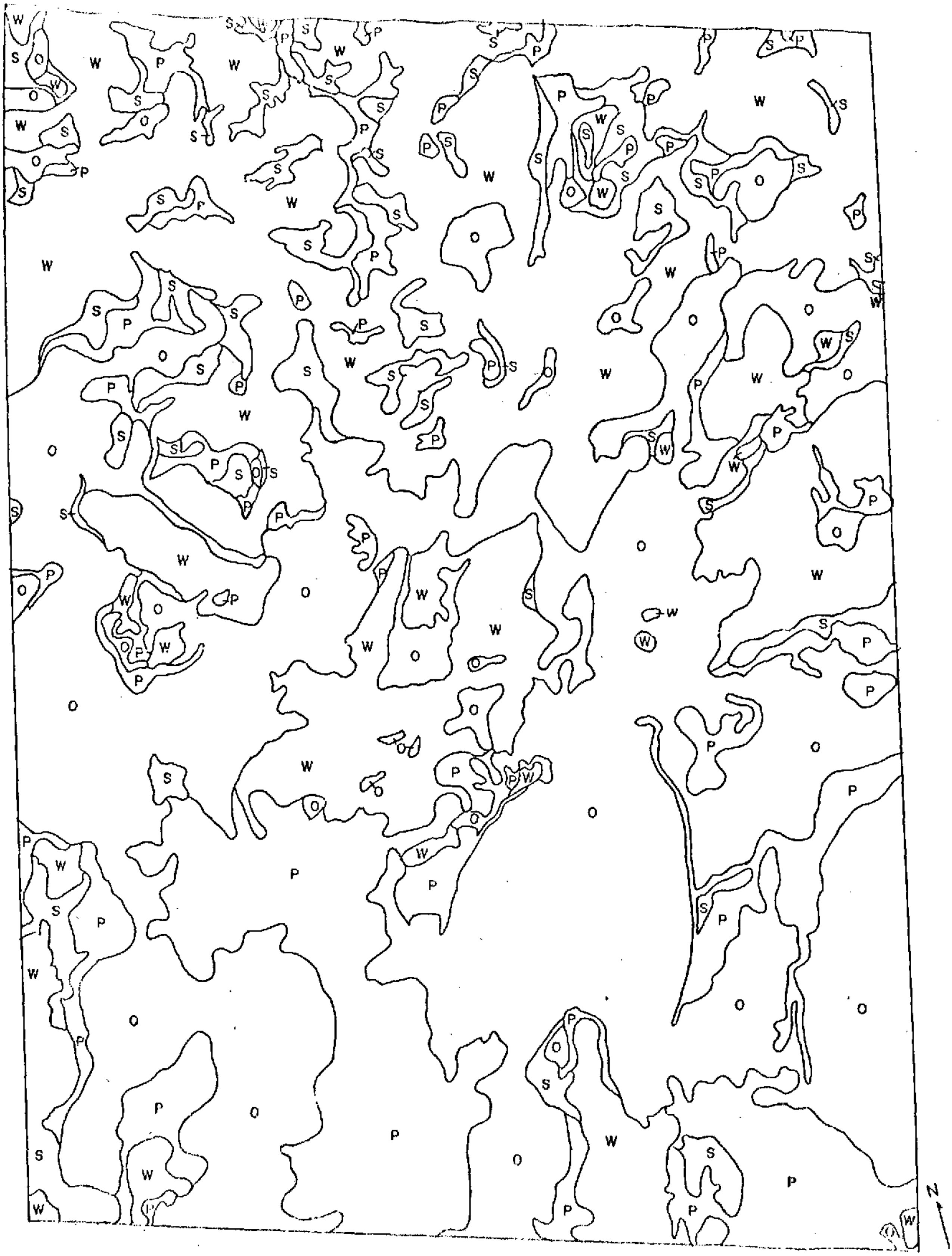


Fig. 30

Insight into ratio processing, as well as other types of processing, can be obtained from scatter diagrams of soil signatures. One-sigma ellipses for signals in ERTS Bands 5 and 7 from individual training fields for June 8, 1973 are shown in Fig. 33. Without subtraction for a path radiance term, different ratio values correspond to radial lines emanating from the origin. Both organic and mineral soils lie close to the same radial line and, therefore, would not easily be separated. However, good separation exists between soils, trees and water. If a path radiance subtraction were to move the origin of the radial lines to a value of 10 along the Band 5 axis, for example, constant-ratio lines would better separate mineral and organic soils but would have difficulty in separating soil and water. Similar results were observed in scatter diagrams for Bands 4 vs 5 and Bands 7 vs 6 because of the high degree of correlation between signals in Bands 4 and 5 and in Bands 6 and 7.

RB-57 and C-47 Imagery

Color photography from RB-57 and C-47 aircraft did not provide more information for soil identification and mapping than black and white photography currently being used as base maps for soil maps. However color infrared photography from RB-57 and C-47 appeared to provide more information for soil identification and mapping than black and white photography, especially in vegetated areas. Because black and white photography was not collected at or about the same time, an accurate comparison could not be made.

Multispectral scanner data collected by the C-47 aircraft was also evaluated for identifying and mapping soils. Video images of 12 individual bands and ratio images were compared to soil maps. Neither the video images nor the ratio images enhanced soil patterns in bare soil areas or in vegetated areas above the patterns on black and white photographs.

Landforms and Remote Sensing Data

Ground truth findings were compared with the following data sources during the course of this study.

No.	Source	Date	Type & No.	Scale (approx.)
1	ERTS black and white transparencies	5/21/73	8 frames	1:1,000,000
2	ERTS black and white transparencies	6/8/73	4 frames	1:1,000,000
3	ERTS color print	8/25/72	1 print	1:1,000,000
4	ERTS digital maps (band 5 & 7)	6/8/73	4 maps	1:24,000
5	RB-57 color transparencies	6/72	10 frames	1:115,000
6	RB-57 color infrared transparencies	6/72	10 frames	1:115,000
7	RB-57 color infrared prints	not given	2 prints	1:30,000
8	C-47 black and white infrared prints	10/19/72	70 prints	1:9,000
9	C-47 color infrared transparency rolls	(8/25/72)	2 rolls	1:35,000
10	C-47 color transparency rolls	(10/19/72)	2 rolls	1:35,000
11	C-47 scanner data strips	not given	6	1:60,000
12	C-47 scanner data strips-ratioed	6/5/73	6	1:60,000
13	C-47 scanner data strips-ratioed	not given	12	1:50,000
14	A.S.C.S. aerial photographs	various	70	1:15,840
15	U.S.G.S. topographic maps	1909 & 1928	2	1:62,500
16	U.S.G.S. topographic maps	1965 & 1968	3	1:24,000
17	Surface formations of the Lower Peninsula (map)	1924	1	1:750,000
18	Surface formations of the Southern Peninsula (map)	1955	1	1:500,000

Soil Description	Symbol
Well drained, mineral soils	W
Somewhat poorly drained, mineral soils	S
Poorly drained, mineral soils	P
Very poorly drained, organic soils	O

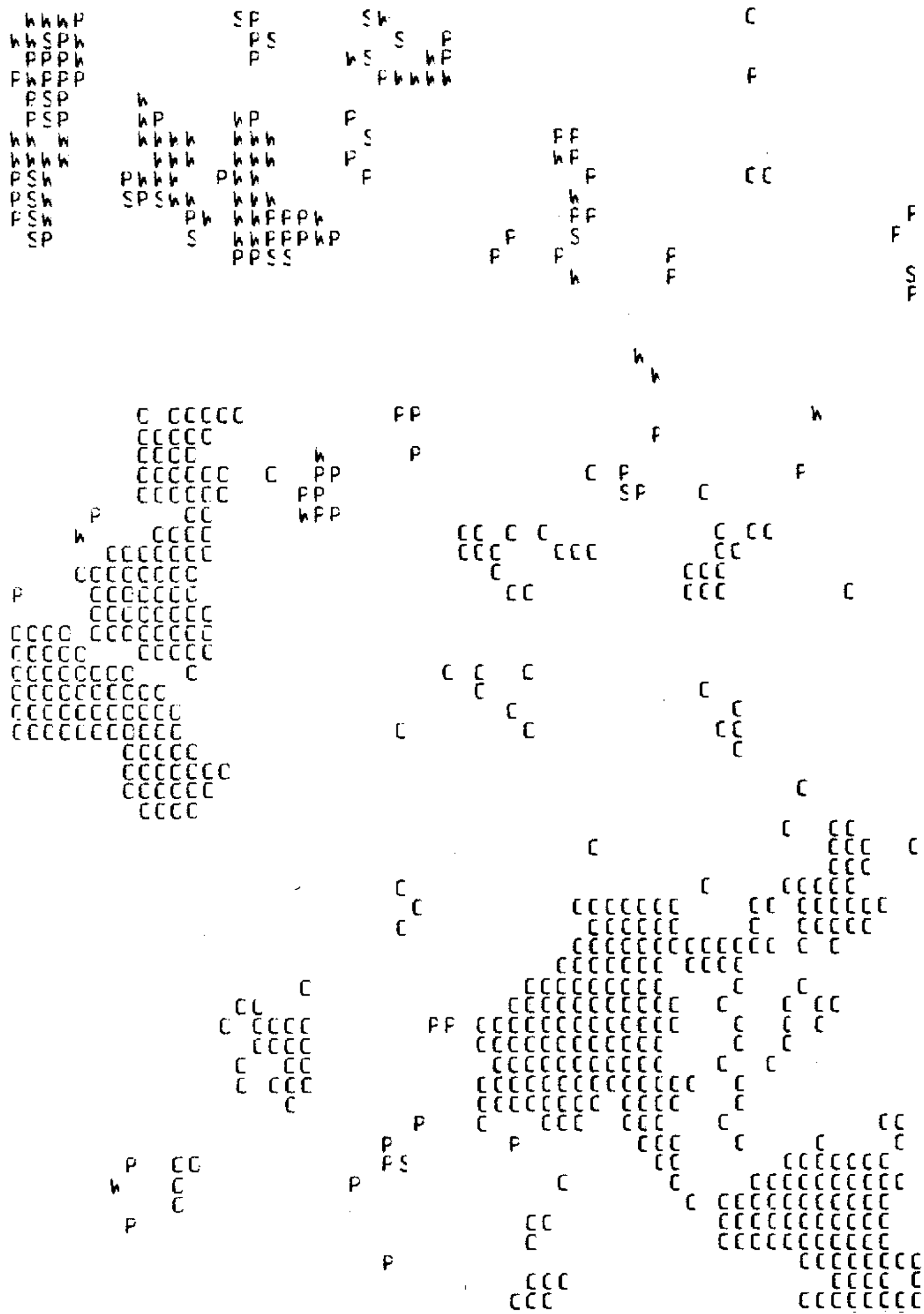


Figure 31. Soils recognition map (June 8, 1973) of a portion of Bath and Dewitt Townships in Clinton County, Michigan.

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Soil Description	Symbol
Well drained, mineral soils	W
Somewhat poorly drained, mineral soils	S
Poorly drained, mineral soils	P
Very poorly drained, organic soils	O

Figure 32. Conventional soils map of same area as in Fig. 31.

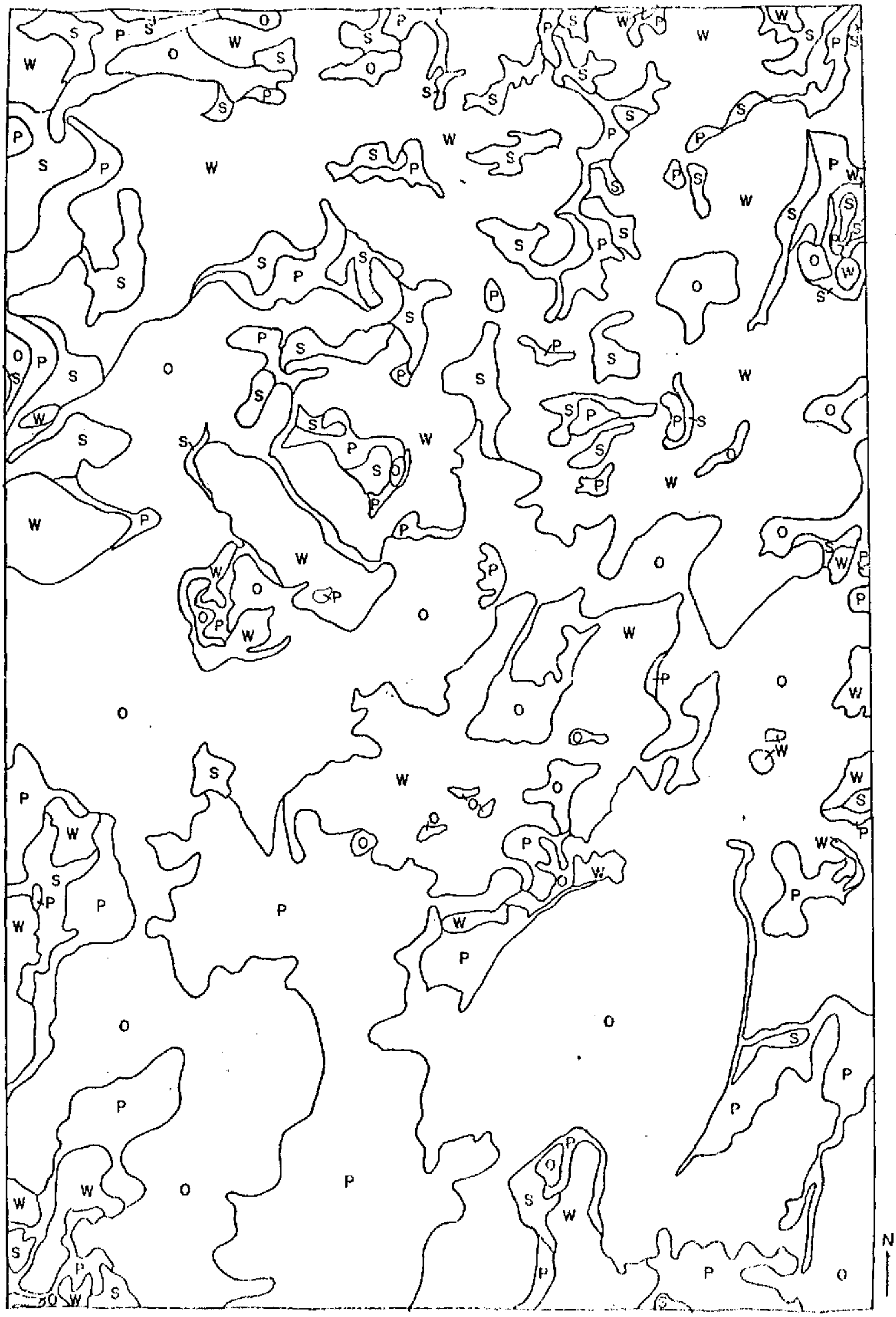

Fig. 32

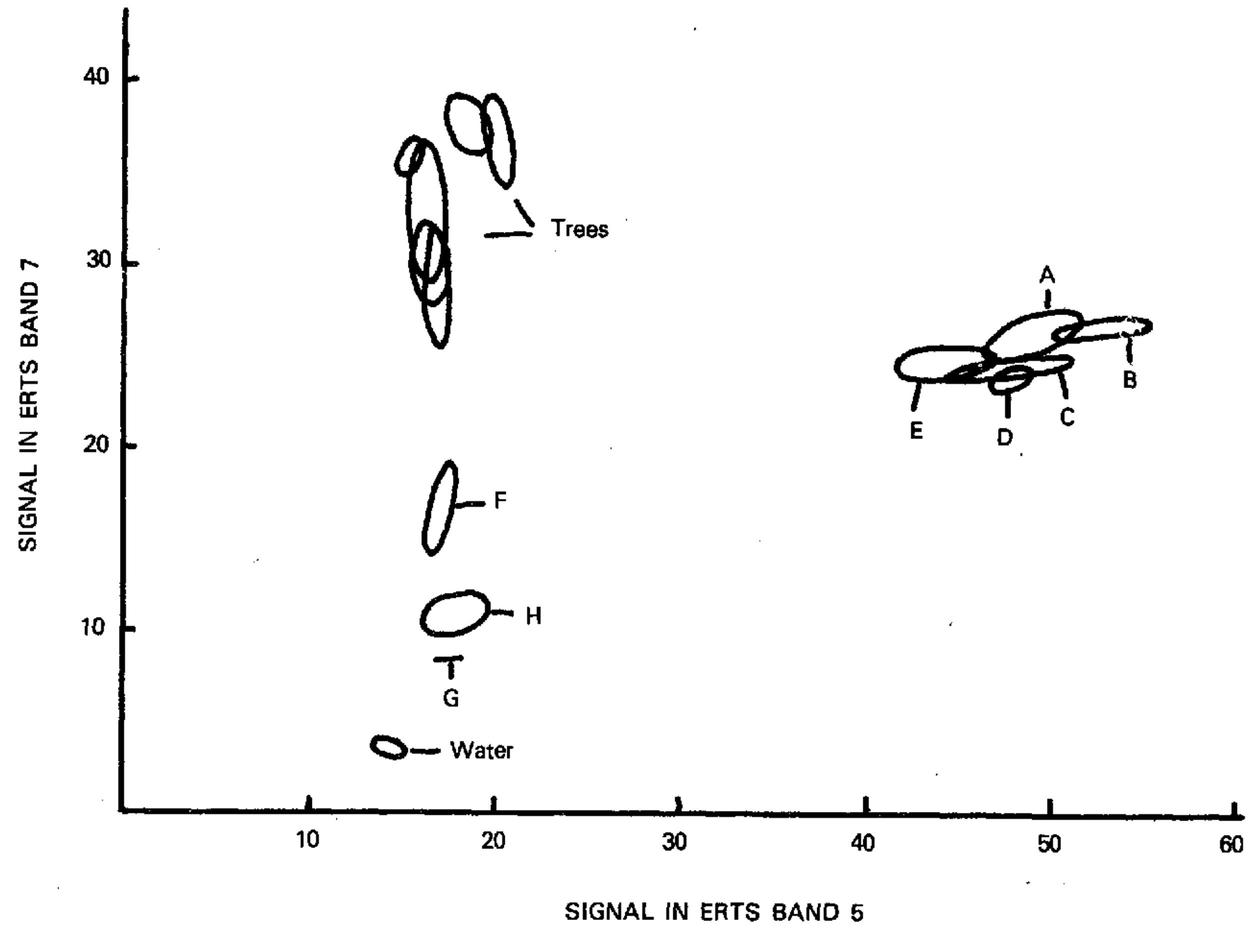

Figure 33. Scatter diagrams of soil signatures on June 8, 1973.

The ERTS black and white transparencies and color print were useful, at least in part, in determining major geographical relationships. Although the quality of the black and white photography varied and the color print showed only Site III features such as rivers, major water filled depressions and some areas of organic soils were apparent. The imagery at a scale of 1:1,000,000, however, is not satisfactory for definitely identifying the nature and extent of a variety or assemblage of glacial landforms. It is interesting to note that certain glacial features may be apparent at this scale because of man's activity. For example, the Mason esker located in the southwest part of site III is apparent in this ERTS-1 imagery because the overlying soil and vegetation had been removed during mining procedures and thus exposed the underlying glacio-fluvial sediments resulting in lighter photo tones. This in combination with dark patterns from lakes that have formed in certain excavations defines the trend of the esker quite accurately.

The ERTS-1 digital maps for bands 5 and 7 for both sites by ERIM at a scale of 1:24,000 are partially revealing regarding certain topographic conditions. For example, extensive low areas that are poorly drained may be easily identified in places. The full assemblage of landforms recognized on the basis of field study is not apparent from the digital print outs. However, with further refining of signatures it may be possible to improve the effectiveness of these maps.

RB-57 color and color infrared transparencies were useful for identifying certain glacial features and sediments even though they are at a relatively small scale of 1:115,000. The color infrared prints, though available only for site III were even more definitive because of their much larger scale of about 1:30,000. Though possibly difficult to delineate exactly it is apparent that photo tones and patterns associated with such features as: (1) well drained uplands underlain by glacial till, (2) lakes and linear drainage lines, (3) low areas of organic soil, (4) linear glacial features such as eskers, and (5) extensive plains of sand and gravel may be identified in this photography.

The C-47 scanner data strips in black and white and the color transparency roles reveal similar data as the RB-57 photography. Six non-ratioed and eighteen ratioed strips were studied but no especially revealing or significant patterns not observed previously were recognized. Possibly certain glacial landforms or sediments could be better recognized by further developing ratio techniques.

The 70 black and white infrared prints of C-47 photography at a scale of 1:9,000 had high resolution and were of fine quality. This photography augmented ground truth signifcantly and was especially helpful because it provided a detailed information base which could be used to evaluate the other remote sensing data.

CONCLUSIONS

Although only five percent of Test Site III had bare soil on August 25, 1972 and 20 percent on June 8, 1973, ERTS-1 data was able to provide some information on soils and landforms. Organic soils in bare fields were distinguished from mineral soils in bare fields. Well drained, mineral soils had different signatures than somewhat poorly drained and poorly drained, mineral soils on August 25, 1972. On June 8, 1973 well drained, somewhat poorly drained, and poorly drained soils had similar signatures and could not be separated. Misclassification occurred along the edges of the bare soil areas as a result of ERTS-1 resolution elements covering both the bare soil and the adjacent vegetated area.

RB-57 and C-47 imagery did not provide significantly greater information for identifying and mapping soils than black and white photography currently being used in soil mapping. Of the various types of imagery, color infrared photography has the greatest potential for identifying and mapping soils.

ERTS-1 imagery was not very satisfactory for identifying and mapping landforms. Some major landforms were identified on RB-57 and C-47 color and color infrared imagery.

A major limitation of ERTS-1 and RB-57 imagery is the small scale. Enlarged 1:30,000 prints of the RB-57 imagery enabled better identification and mapping of soils and landforms than the unenlarged 1:115,000 transparencies.

The repetitive nature of ERTS is advantageous for obtaining information on soils and landforms. Some areas which are vegetated one year or during part of the year may be unvegetated at other times allowing data to be gathered to analyze for soils and landforms. Because many areas of Michigan are permanently covered with vegetation, techniques are needed to trace soil patterns through vegetated areas.

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APPENDIX A

Application of ERTS-1 Data To Analysis of Agricultural Crops and Forests in Michigan

NASA SP-327

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SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM THE EARTH RESOURCES TECHNOLOGY SATELLITE-1

Volume I: Technical Presentations
Section A

The proceedings of a symposium held by
Goddard Space Flight Center
at New Carrollton, Maryland
on March 5-9, 1973

Compiled and Edited by

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and
Margaret A. Becker
Technical Information Division
Goddard Space Flight Center

Scientific and Technical Information Office 1973
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Paper A 21

APPLICATION OF ERTS-1 DATA TO ANALYSIS OF AGRICULTURAL CROPS AND FORESTS IN MICHIGAN

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ABSTRACT

The results reported are based on analysis of ERTS Frame 1033-15580 collected over southwestern Lower Michigan on August 25, 1972. Major agricultural crops such as corn and soybeans were approaching maturity at this data and forest canopies were dense.

Extensive ground truth information was gathered by detailed field study of test strips. This detailed information was supplemented over larger areas by interpretation of RB-57 and C-47 photography and MSS imagery. The U.S.D.A.-A.S.C.S. also cooperated by providing information on crops from their records.

Recognition processing of ERTS-1 MSS data was carried out on a digital computer. Fields and forest stands were selected as training sets and test areas. Aerial imagery was essential for locating the positions of these selected areas on ERTS digital tapes.

The recognition process was successful for each type of vegetation which had a dense green canopy such as forests, corn, and soybeans. Bare soil was also recognizable as a category. However, recognition of species was difficult in senescing or senescent vegetation. Since the accuracy of recognition depends on stage of growth, optimum times for collecting data will vary from one crop to the next.

Accurate computer recognition of crops from satellite data will be useful in operational surveys as the first stage in a multistage sampling process.

Michigan Agricultural Experiment Station, Journal Article 6315

Introduction

Michigan State University (MSU) in cooperation with the Environmental Research Institute of Michigan (ERIM) began a program in the summer of 1972 to test the usefulness of ERTS-1 satellite data for monitoring and managing crops and forests in Michigan. Specifically, the objectives included: (1) verification that major agricultural crops and forest types can be identified from ERTS-1 data; (2) development, application, and testing for accuracy of multispectral techniques for crop and forest acreage estimation in Michigan; (3) correlation of variations in signatures from space with ground truth data.

In addition to the scientists directly involved in analysis of the data, a team of cooperators has been assembled to evaluate the operational utility of the results which emanate from the project. This team includes members of state, federal, and local agricultural and natural resource agencies.

Data analysis to date has been confined to ERTS frame E-1033-15580 (August 25, 1972) as a result of the inclement weather conditions which prevailed throughout most of Michigan's 1972 growing season following the launch of ERTS-1.

Ground Truth Information

Direct field observation and 35-mm photography were the main sources of ground truth information for the analysis of agricultural crops. Specifically, biological parameters such as plant height, row direction and width, percent ground cover, stage of growth, corn tassel color, and disease incidence were estimated and recorded for numerous selected fields in the test area. Since forest cover changes less rapidly than agricultural crops, the primary source of information for forests was photointerpretation of RB-57 and C-47 underflight imagery. The photointerpretive work was supplemented by collection of data on the ground as necessary. The RB-57 and C-47 imagery was also extremely useful for analysis of agricultural crops. In addition to the field and underflight data, cooperators in both the United States Department of Agriculture, Agricultural Stabilization and Conservation Service (U. S. D. A. -A. S. C. S.) and the Forest Service have contributed to the pool of ground truth information. The A. S. C. S. efforts produced a set of annotated copies of enlarged airphotos showing the location and nature of vegetation types on the holdings of landowners who subscribe to A. S. C. S. programs.

M.S.S. Digital Analysis - Methods

Digital tape data for frame 1033-15580, were screened for quality by preliminary processing on the ERIM digital computers. They were found to exhibit the same problem present in a set of tapes for the same frame received by ERIM under another contract. The problem is that reproduced signals from one of six detector elements which generate the MSS data in ERTS band 6 (0.7-0.8 μm) are faulty. Thus, anomalous data are present for band 6 in every sixth line of data; otherwise, the data appear to be satisfactory. This problem complicates signature extraction and data analysis. In particular, recognition processing for the work described here was restricted to three channels.

The primary test sites (in Eaton Co., Michigan) were located within the digital data, and line-printer gray maps were produced for all ERTS bands. The gray maps for ERTS band 5 were used to locate selected training and test plots of known ground cover. The RB-57 and C-47 underflight imagery was essential for correctly locating these plots, which were then designated by line and point number to the computer for extraction of signal statistics. In the selection of training sets, care was taken to avoid boundary points. Fifty-eight plots were designated and ERTS signal statistics were extracted for eight types of ground cover. These statistics were subjected to cluster analysis, and the results were used to select several plots for combination to form recognition signatures. The plots which were not used directly for specifying signatures became "test" sets for evaluating the accuracy of recognition. Eighteen additional test plots were then selected and included in the analysis.

Recognition maps were produced for an intensive test area in Eaton Co., Michigan. Recognition runs were based on the three good ERTS channels using several different sets of parameters. First, twelve recognition signatures were used and maps were produced with different rejection threshold levels. That is, each observation was classified as belonging to one of the recognition signatures and then tested to see if it was unlikely enough to be rejected and categorized as belonging to none of the classes considered. Next, seven recognition signatures were used; the seven recognition signatures included combinations of the pairs of signatures used for several classes in the twelve-signature runs.

MSS Digital Analysis - Results

Recognition results were analyzed for the 76 identified plots. The overall results of the first-look analysis of recognition are summarized

TABLE A-1 SUMMARY OF RECOGNITION RESULTS ON A PLOT-BY-PLOT BASIS FOR 76 PLOTS, ERTS FRAME 1033-15580, 3 CHANNELS (ERTS 6 EXCLUDED), 0.001 PROBABILITY OF REJECTION

A.

Class	No. Plots	No. Points	Average Percentage of Class'Plots Assigned to Listed Recognition Signature: Corn	Soy	Alf	Tree	Senesc Bean	Senesc Grass	Soil
Corn	21	481	84.27	0.55	0.13	9.85	3.85	1.35	0
Soy	10	115	1.00	89.40	2.30	2.59	2.61	0	0
Trees	12	358	11.00	3.80	0	84.50	0.20	0.50	0
Senesc	16	306	16.30	6.55	7.15	0	54.30	8.23	6.53
Soils	4	56	0	0	0	0	0	0	97.62
TOTALS	76	1416							

B.

Summary of Percentages (Averaged Over Plots)

Class	No. Plots	No. Points	Not Clas'd	Correctly Assigned To Class	Incorrect. Assigned To Class	Average Error	Correct Excluding Not Clas'd
Corn	21	481	0	84.27	7.29	11.51	84.27
Soy	10	115	2.10	89.40	.50	6.55	91.31
Trees	12	358	0	84.50	3.66	9.58	84.66
Senesc	19	340	0.94	62.53	2.59	20.03	63.12
Soils	14	122	2.38	97.62	2.00	2.19	100.00
Averaged Over Five Classes			1.08	83.66	0.61	9.97	84.67

in Table 1 for five cover classes (corn, soybeans, trees, senescent vegetation, and soils). As noted earlier, only three ERTS channels were used (4, 5 and 7). The values in Table 1 represent averages of percentages computed separately for each plot analyzed. The overall average percentage of correct classification (for test sets) is over 83%. The average percentage error is 10%, with 16% being Type 1 (i. e., missed classification, including not classified) errors and 4% being Type II (i. e., incorrect classification) errors. If "not classified" points are excluded from the computation, the overall average is nearly 85% correct.

Recognition percentages are high for those vegetation classes that had mature and uniform canopies at the time the data were collected (Aug. 25th). Corn, soybeans, and trees (forest) met this criterion, and were classified accurately. The class of senescent or senescing vegetation included observations from field beans, wheat stubble, and grass. These canopies were characterized by non-uniform distributions of dead and dying vegetation along with patches of more healthy vegetation. For example, field beans had matured and had begun senescing, while soybeans and corn were more vigorous. Also, wheat stubble fields were dry and brown except for some that had been seeded to alfalfa or red clover; the latter fields had patches of green growth among the stubble. The wide variability within these vegetation types at this time of year makes it difficult to classify them accurately. Alfalfa is a crop that is harvested repeatedly at irregular intervals throughout the growing season, and plots of it can appear very different, depending on their conditions at the time of observation. One vigorous alfalfa was included initially and accurately recognized. A lack of test plots, for which the exact condition at the time of the ERTS-1 pass is known, caused us to omit alfalfa as a class from the reported analysis. Bare soil was distinctive and accurately recognized.

Thus, the first-look analysis for computer recognition within boundaries of selected plots shows a good capability for differentiating each type of vegetation that has a dense green canopy, with bare soil also being recognizable as a category. The next step in the analysis of computer recognition is a more critical evaluation of accuracy by cover type for all resolution elements in selected portions of the frame.

Element-by-Element Analysis for Forest Cover

Figure 1 is a portion of the gray map for ERTS band 5 in Chester and Roxand Townships of Eaton County, Michigan with major roads delineated. An RB-57 color infrared photo was used to transfer the locations of the forests to the gray map, and the elements that fall within the forest area are shown by heavy dots in Figure 1. Figure 1 is conservative in that most doubtful border elements were not designated as "forest". Figure 2 is a computer recognition map for the same area. Heavy dots have been superimposed on the elements which were correctly classified as "trees" (forest). The forest elements which were not recognized as such by the computer (Type 1 error) are indicated with a heavy square having a white center. Type II errors (incorrectly classified as "trees") are indicated by triangles. The Type I error for forests on this portion of the frame is approximately 40%. An examination of Figure 2 shows that most of these errors take place in border elements. For the most part, these border elements were classified as corn. The remaining Type I errors are mostly accounted for by areas in which the forest canopy is sparse. The Type II errors are only about 3%.

Since the original "trees" training sets were located in the center of dense woodlots, the misclassification of sparsely stocked areas is not too surprising. An examination of the likelihood for the misclassified elements showed a very low probability of classification under the "trees" signature. Use of separate training sets and subresolution element analysis are being investigated as possible means of improving recognition in sparse forests. The current classification would give a reasonable estimate of the acreage that is suitable for woodlot management, but would give an underestimate for total acreage of forest.

<u>Summary</u>

Computer analysis of ERTS-1 data provided good recognition of vegetation classes that had mature and uniform canopies at the time when the data were collected. Bare soil was also recognized accurately. Classification was extremely difficult for senescent vegetation which was characterized by non-uniform distribution of dead and dying vegetation along with patches of more healthy vegetation. Since the accuracy of classification depends on the stage of growth, optimum times for collecting data will vary from one crop to the next. However, the optimum for recognizing each crop is yet to be determined. This bears further study, especially for field beans since Michigan is the leading producer of this crop in the United States.

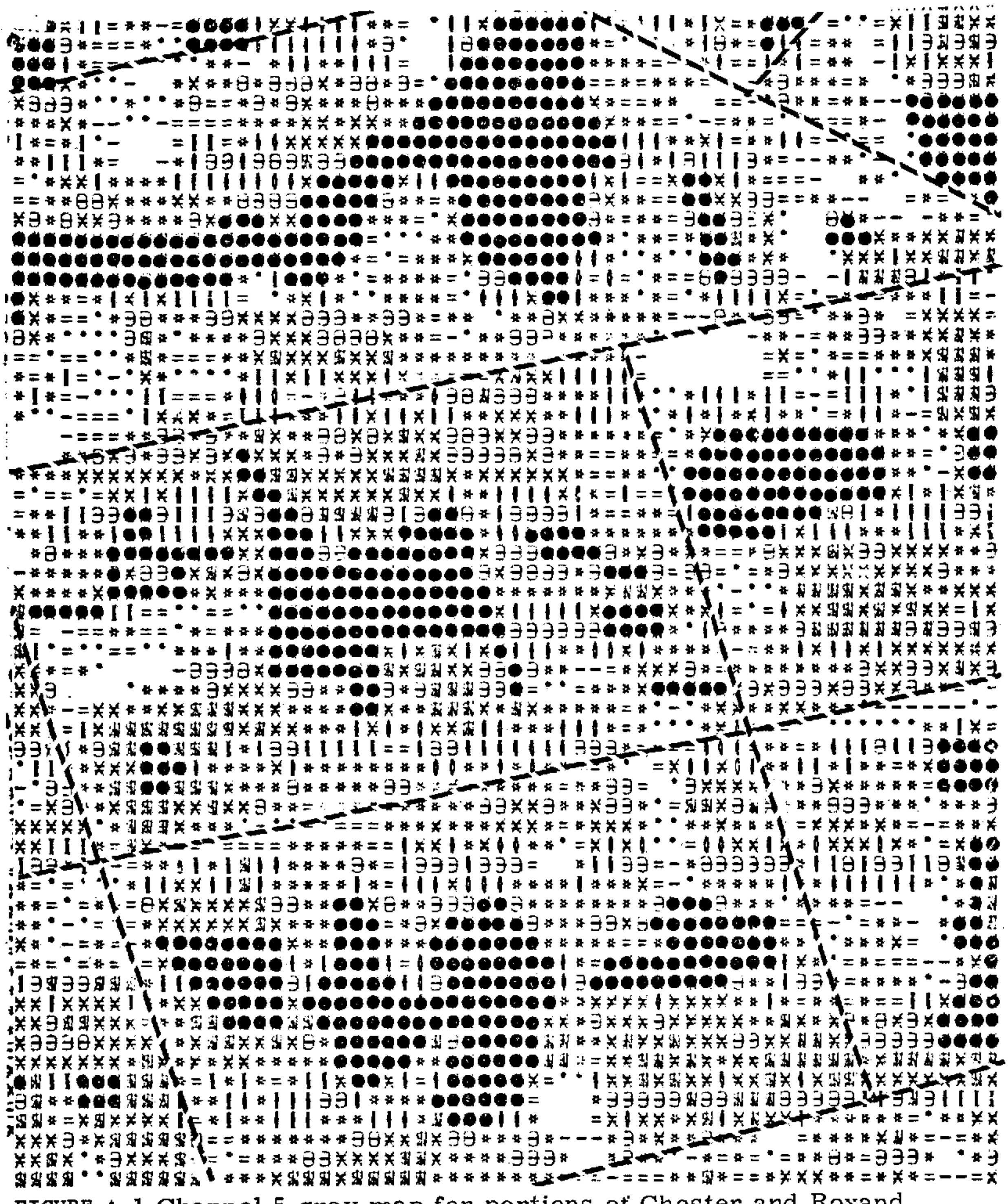

FIGURE A-1 Channel 5 gray map for portions of Chester and Roxand Townships in Eaton County, Michigan showing actual locations of woodlots (●) and roads (←→).

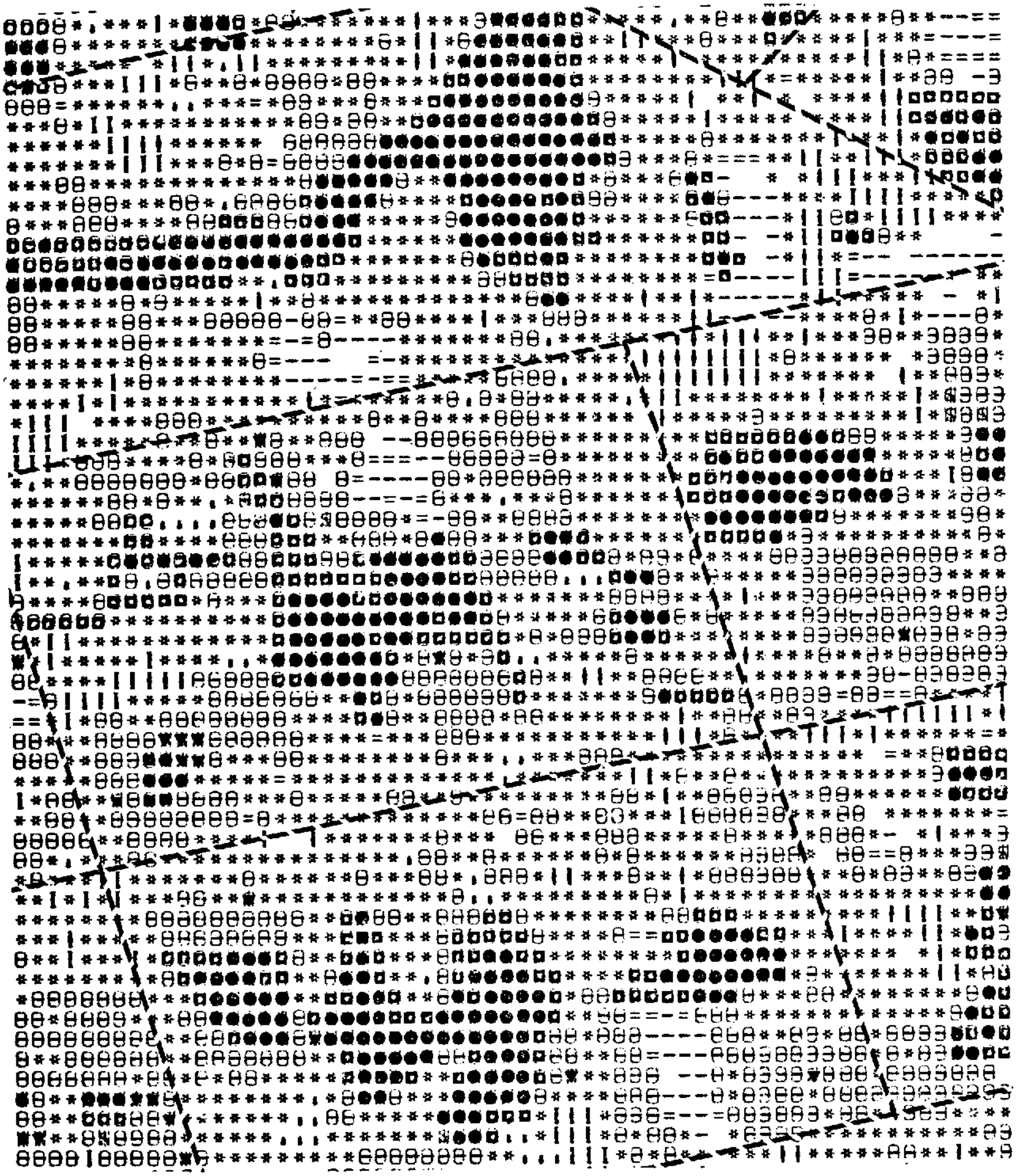

FIGURE A-2 Computer recognition map showing correctly and incorrectly classified elements associated with forest cover; ● indicates correctly classified forest areas, ◘ indicates forest areas misclassified, and ▼ indicates non-forest areas classified as forests.

APPENDIX B

Correlation of ERTS MSS Data and Earth Coordinate Systems

CORRELATION OF ERTS MSS DATA AND EARTH COORDINATE SYSTEMS*

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I. ABSTRACT

Experience has revealed a problem in the analysis and interpretation of ERTS multispectral scanner (MSS) data. The problem is one of accurately correlating ERTS MSS pixels with analysis areas specified on aerial photographs or topographic maps for training recognition computers and/or evaluating recognition results. It is difficult for an analyst to accurately identify which ERTS pixels (picture elements) on a digital image display belong to specific areas and test plots, especially when they are small.

A computer-aided procedure to correlate coordinates from topographic maps and/or aerial photographs with ERTS data coordinates has been developed. In the procedure, a map transformation from Earth coordinates to ERTS scan line and point numbers is calculated using selected ground control points and the method of least squares. The map transformation is then applied to the Earth coordinates of selected areas to obtain the corresponding ERTS point and line numbers. An optional provision allows moving the boundaries of the plots inwards by variable distances (typically $\geq$ half a resolution element) so the selected pixels will not overlap adjacent features.

II. INTRODUCTION

The computer-compatible-tape (CCT) form of ERTS-1 MSS data is well suited to analysis and recognition processing on digital computers. Examples of varied applications were reported by a number of investigators at the Goddard Space Flight Center's "Symposium on Significant Results from ERTS-1 Data" in March, 1973.

It is desirable to evaluate the accuracy of large-area resource surveys made by computer processing of ERTS, or other remote sensor, data. Such evaluations require the checking of recognition results for areas whose identities are known from field observations or other "ground truth" information sources. Even before recognition processing, the training of the classifiers usually involves the use of other areas of known identity that can be located in the remote sensor data.

The location of specific areas and assignment of pixels to individual fields and plots is more of a problem in ERTS data than in airborne scanner data which have finer spatial resolution. For instance, there are less than 600 ERTS pixels per square mile and a maximum of 18*** wholly

*This work was supported under ERIM Contract NAS5-21783 and an ERIM subcontract under Michigan State University Contract NAS5-21834.

**Formerly Willow Run Laboratories of The University of Michigan.

***Even this number is optimistic because the ERTS scan lines do not generally follow field boundaries. Further, as discussed under Section III, the oversampling along ERTS scan lines means that there is overlap between the areas viewed by the scanner for adjacent pixels and thus one must move away from boundaries to eliminate their effects.

within the boundaries of a 20-acre field. Section and field boundaries are frequently indistinct on ERTS data displays; consequently, errors are made in the visual location of fields and the subsequent assignments of pixels. Pixel misassignments potentially can cause errors in classification results and lead to incorrect conclusions. Even if detected, additional resources are required to correct errors.

ERTS images of two types are produced by the National Data Processing Facility at NASA/Goddard — system-corrected images and precision-processed images. They both represent photo maps but with different degrees of accuracy. The system-corrected images are corrected for the major distortions introduced by spacecraft orientation, sensor characteristics, and Earth's rotation. Precision-processed images include additional adjustments based on a number of in-scene ground-control points in each frame.

The bulk digital computer-compatible tape (CCT) data, however, are not corrected for any of these distortions. (Bulk data are preferred to precision CCT data for recognition processing because in the latter, the radiometric accuracy of the data is degraded by re-scanning.) Therefore, when displayed on a line-printer gray-tone map or CRT, substantial distortions are evident in bulk CCT data. Square sections are displayed as parallelograms, and other distortions are present. These distortions increase the difficulty of assigning pixels to specific ground areas, but the major cause of difficulty is the relatively large instantaneous field of view of the MSS scanner.

The problem of correctly assigning ERTS pixels to specific areas is somewhat different from two related problems which are under investigation elsewhere [Refs. 1-6]. Some investigators are studying the cartographic aspects of ERTS data, e.g., image quality and techniques to digitally correct ERTS data to match an Earth coordinate system, using spacecraft attitude information and/or ground control points spread throughout a frame. Others are studying the spatial registration of data from two or more frames that cover the same scene, using ground control points and/or image correlation techniques. The cartographic studies will simplify pixel assignments for areas that are readily identified by their latitude and longitude coordinates, but do not directly address procedures for assigning pixels for areas that are only identifiable on aerial photographs. The spatial registration studies will expedite the transfer of field coordinates from one frame to the next, but again do not consider the problem of initially assigning pixels to fields and test plots.

Techniques for both cartographic correction and spatial registration of ERTS data move data values from their original positions to an overlying grid by nearest-neighbor or interpolation rules. Then, the assignment of pixels to specific fields and test plots can take place; operations on a nearest-neighbor basis increase the uncertainty of true field boundary locations, while interpolation degrades radiometric fidelity. The procedure we have developed warps Earth coordinates to match ERTS coordinates, effectively computing the location of each pixel, and makes pixel assignments without any movement or interpolation of ERTS data.

III. PROCEDURE

The procedure described here for the computer-aided assignment of ERTS pixels relies on an empirical map transformation derived by least squares calculations from a local network of control points in and around the area of interest, e.g., a 20 x 25-km area on a 15' quadrangle map. These control points can be located on topographic maps and/or on aerial photographs. Differing scales can be handled, and the locations of control points and analysis areas on the maps and/or photographs can be obtained on a relative basis.

The empirical transformation produces rotations to account for the non-polar orbit of ERTS and the difference in orientation between Earth and ERTS-data coordinates, and also corrects for effects of the Earth's rotation and other sources of distortion and error, in a least-squares manner. The distortions in ERTS imagery are discussed in the Appendix and, for purposes of illustration only, two transformation matrices are computed: (1) a theoretical transformation that considers the major effects in ERTS data and (2) a similar transformation obtained by scaling the corresponding empirical Earth-to-ERTS coordinate transformation. Good, but not exact, agreement is shown between the two transformation matrices.

As noted earlier, we developed our computer-aided procedure because it is often difficult to distinguish "by eye" the corners of sections, fields, and plots of interest on digital displays of ERTS data, and more difficult to locate them accurately. Lack of contrast between materials and any banding or striping in the ERTS data can complicate matters. On the other hand, there generally are some road intersections and other features in the scene around and within the areas of interest that can be distinguished readily in digital displays.

In our procedure, we typically select fifteen to twenty distinguishable points as control points and estimate their ERTS line and point numbers as well as possible by inspection. Earth coordinates for the same points are determined* from a topographic map or an aerial photograph. A least-squares fit of Earth to ERTS coordinates reduces the error in the estimated location of each control point and produces a map transformation:

$$\begin{bmatrix} P \\ L \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

where P and L are the ERTS data coordinates for points along scan lines and for scan lines, respectively,

$\{a_{ij}\}$ are the empirical transformation coefficients,

X and Y are the Earth coordinates to be transformed,

and b_1 and b_2 are the offset parameters to account for different origins.

(A polynomial transformation has been computed but, thusfar, we have found that terms of higher than first order are not significant.)

The above transformation then is used to transfer Earth coordinates of other points, fields, or plots in the vicinity to their corresponding ERTS coordinates. For several purposes, it has been found convenient to place pixel designation information in a fifth channel added to ERTS data.

A companion computer program allows us to define each training or test area by a polygon with an arbitrary number (≤ 63) of vertices and to compute which ERTS pixel centers lie within the polygon. Further, there is a capability to move the polygon sides in or out by specified distances so as to include or exclude pixels whose signal values include effects of boundaries between scene features, for example, to avoid training on pixels that represent more than one material. An illustration of the effect of this procedure is presented in Figure 1. A section (1 mile square) in actual ERTS data was arbitrarily divided into 16 40-acre "fields". Part(a) of Figure 1 displays as blanks the pixels selected for these fields when the acceptance polygon was inset by one-half a resolution element on all sides.** An average of 22 pixels was selected for each 40-acre field. For Part(b), the inset was increased to three-quarters of a resolution element, and the smaller number of acceptable pixels (an average of 16) in each field is apparent. Parts(c) and (d) show the further reduction in the average number of acceptable pixels to 12 and 5 when the inset is increased to 1 and 1.5 resolution elements, respectively. Figure 2 presents other sets of "fields" delineated by the 0.5 resolution element criterion; field sizes of 640, 160, 80, and 10 acres are shown.

As noted above, the inset of one-half a resolution element is the theoretical minimum needed to exclude pixels whose radiometric signals contain boundary effects. A greater inset probably should be used in practice because of possible errors in the location of the control points in both the ERTS and Earth coordinates and in the location of test plot vertices in the maps or photographs. There also are known displacements inherent in the ERTS data which we presently do not explicitly take into account, e.g., the multiplexer delay in the spacecraft which introduces a displacement between the six scan lines in each mirror sweep.

IV. APPLICATION

A relatively large number of training and test fields were identified manually for use in recognition processing of ERTS-1 data for an agricultural problem, before the computer-aided

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*Digitization is facilitated by the use of an x-y digitizing machine.

**Note that the inset must be greater than one-half a pixel dimension along the scan line since the actual resolution element size is 79 x 79 m even though the sampling rate along the scan lines gives an effective pixel width of approximately 57 m.

procedure was developed. Errors in the assignment of pixels to a few fields were identified during the course of the processing. One particular example is presented here.

Section roads were not always clearly discernible and were not present along all sides of every section, so several section lines were placed on line printer maps by simple interpolation between more distinct roads. The section in question is located on a boundary between two townships and happens to be less than one mile long in the N-S direction. Partly because of the smaller size, the lower section boundary was initially placed below the true boundary. Figure 3a presents the original manual assignment of pixels for four fields; the correct section lines are shown on the line printer map (of ERTS Band 5) and the actual field boundaries, as obtained from an aerial photograph, are mapped on the right. Fields 21, 22, and 23 were originally mis-assigned by the analyst. After poor agreement was observed between recognition results and the assigned crop types, these field delineations were checked and revised manually.

After the computer-aided pixel assignment procedure was developed, it was used to assign pixels to these same fields with a 0.5 resolution element inset. The resulting pixel assignments are presented in Figure 3b. Note the apparent good agreement between the selected pixels and the field boundaries, for example, around the notch in the upper right-hand corner of Field 21 and middle of Field 22. In this example, a USGS topographical map served as the standard coordinate reference for several road intersections that were readily identified in the ERTS data. The derived transformation then was applied to the standard coordinates of the section corners to locate them accurately within the ERTS data. Field vertices were determined relative to these section corners in an aerial photograph taken at the time of the ERTS pass. These relative locations of field vertices then were transformed to ERTS coordinates and pixels were selected.

It is difficult to make a quantitative assessment of the accuracy of our procedure, because of the lack of an absolute knowledge of pixel locations. One attempt is presented and discussed below, using Gull Lake, in Kalamazoo and Barry Counties, Michigan, as imaged in Frame 1033-15580.

A lake was selected because there generally is a large contrast between land and water in ERTS Band 7, so that the accuracy of boundary locations can be assessed. Gull Lake is one of the largest in the area, has some distinctive shoreline features and an island, and is in a region for which topographic maps were on hand. Since the topographic maps are several years old, it is important that the water level in Gull Lake is regulated so as to maintain a fixed level.

Our goals were (1) to select only those pixels that were completely within the lake and (2) to determine whether map-based coordinates of the shoreline features could be accurately placed in the ERTS data. The results discussed below show that a good job was done in selecting only water pixels and that shoreline features were accurately placed around the lake.

Eighteen control points were selected from a 6 x 20 mile area with Gull Lake roughly at the center. None of the control points were on the Gull Lake shoreline and few were near it because of indistinct roads in the immediate vicinity. Latitude and longitude for these points were extracted from three different USGS maps of two different scales. Approximately 90 points along the shoreline of Gull Lake on the USGS map also were digitized for transformation to ERTS coordinates. An inset of +0.5 resolution elements was used along the major shoreline and -0.5 along the shoreline of the island at the South end of the lake. The negative inset, or outset, was necessary to exclude island shoreline points from the water, because the island was the area outlined.

The line printer map in Figure 4 presents the results of the Gull Lake analysis. Five gray levels are displayed, three for values determined by the procedure to be within the lake and two for those outside. The choice of symbols within each of these two groups was determined by the value of the signal in ERTS Band 7. Observation showed that open water points were all at levels of 5 or less, while the surrounding land was generally at levels of 12 or greater; intermediate values were found along the shoreline. For points determined to be within the lake by the procedure, the predominant darkest symbol (M over $) corresponds to the 1554 points with values ≤ 5, the intermediate symbol (X over =) corresponds to the 18 points with values of 6 or 7, and the lightest symbol (*) corresponds to points with values ≥ 8. Only 9 points with values ≥ 8 were said to be within the lake, and the highest of these values was 9. Since land values generally are ≥ 12, the lighter pixels included at most only partial land observations. Further some of them might even have been caused by the presence of weeds near the shore; current aerial photography is not available to check for the presence of weeds. In summary, <1% of the lake points, or <3% of the shoreline points, seem to have been misclassified as being open water.

On the other side of the computer shoreline, 93 points with values ≤ 5 were placed (symbol θ). These points correspond to open water values that were excluded from Gull Lake. This result was not unexpected since the shoreline is irregular and was approximated by a multi-sided polygon.

All shoreline undulations on the map were not followed exactly and vertices were chosen to exclude all land from the polygon, leaving some water areas on the outside. Vertices around the island were all placed in the water.

Upon comparing the ERTS data of Figure 4 to the USGS map on the right-hand side, one can see that the inlets and peninsulas around the lake are accurately positioned by the procedure. The average accuracy of positioning is clearly better than one pixel, but we have not quantitatively determined how much better. The results encourage use of the procedure for processing of ERTS data.

V. CONCLUSIONS

A computer-aided procedure has been developed which provides increased accuracy and consistency over manual techniques for assigning ERTS pixels to specific ground areas. It is flexible in that it permits the use of USGS topographic maps or aerial photographs or a combination of the two, in assigning pixels.

The delineation of specific fields and plots for training recognition computers and evaluating results is an important problem that has not been addressed directly by other investigators concerned with either the cartographic aspects of ERTS data or spatial registration of data sets collected at different times. The assignment of pixels before any spatial adjustment of the pixels is made minimizes errors in such assignments. The accuracy of the procedure remains to be established quantitatively, but the examples given indicate that an average accuracy substantially better than one pixel is achievable.

APPENDIX. GEOMETRIC CHARACTERISTICS OF ERTS DATA

This appendix discusses the geometric characteristics of ERTS-1 data so as to give the reader a better understanding of the empirical transformation described in Section III. The major geometric differences between Earth coordinates and the ERTS data coordinates can be described by the product of several linear transformation matrices, one for each of the major differences, which transforms Earth coordinates to ERTS coordinates. One theoretical transformation is computed below for ERTS-1 orbit parameters at a specific location and compared to a corresponding matrix obtained empirically for one of the examples presented in Section IV. In addition, some typical values for errors introduced by satellite motions are computed for a local area within an ERTS frame.

The assumption made throughout is that the Earth's surface in a local area of up to $\sim 20 \times 20$ km size can be considered to be a plane surface on which meridians are parallel to each other and perpendicular to lines of constant latitude. Such an assumption is commonly made for localized plane land surveys [7].

A.1. THEORETICAL TRANSFORMATIONS

The major geometric characteristics of ERTS-1 data are (1) its non-polar orbit, (2) the different orientation of its data coordinates from those of common Earth coordinates, and (3) the distortion caused by the Earth's rotation.

Because the plane of the ERTS-1 orbit is inclined slightly ($\sim 9^{\circ}$) from that of a perfect polar orbit, the satellite crosses meridians of longitude with increasing frequency as it approaches the poles. Also, the angle at which it crosses these meridians increases at the higher latitudes. Following Kratky [8], we define the nominal track of the satellite to represent the ERTS-1 location when the Earth's rotation effect is neglected. Correspondingly, there is a nominal heading of the satellite relative to the local meridian of longitude:

$$H_s = \sin^{-1}\left[\frac{\sin \varepsilon}{\cos \phi}\right] = \sin^{-1}\left[\frac{0.1583933}{\cos \phi}\right] \qquad (1)$$

where H_s = nominal satellite heading, measured clockwise from South,

ε = polar inclination of the orbit (9.114° for ERTS-1 [9]),

and ϕ = latitude of the satellite.

The Earth's rotation causes both the actual sub-satellite track to deviate from the nominal track and the actual heading to deviate from the nominal heading. Kratky (op. cit.) approximates the deviation in heading as follows:

$$H_e \doteq \tan^{-1}\left[\left(\frac{\omega_e}{\omega_s}\right)\cos\varepsilon\,\sin\rho\right] \tag{2}$$

where ω_e = angular velocity of the Earth,

ω_s = angular velocity of the satellite (ω_e/ω_s = 0.071713 for ERTS-1),

and ρ = orbital travel angle as measured southward from the vertex of the orbit ($\rho = \pi/2$ at equator).

or, since $\sin\rho = \dfrac{\sin\lambda_s}{\cos\phi} = \dfrac{\tan\varepsilon}{\tan H_s}$

$$H_e \doteq \tan^{-1}\left[\left(\frac{\omega_e}{\omega_s}\right)\cos\varepsilon\left(\frac{\sin\lambda_s}{\cos\phi}\right)\right] = \tan^{-1}\left[\left(\frac{\omega_e}{\omega_s}\right)\frac{\sin\varepsilon}{\tan H_s}\right] \tag{3}$$

where λ_s, the nominal longitude of the satellite, can be computed from the actual longitude, λ, and latitude, ϕ, by the following relationship:

$$\lambda_s = \lambda - \left(\frac{\omega_e}{\omega_s}\right)\cos^{-1}\left[\frac{\sin\phi}{\sin\varepsilon}\right] \tag{4}$$

The Earth's rotation causes a shift along lines of constant latitude, converting squares to acute parallelograms (with tops rotated counter-clockwise by the angle, H_e) in uncorrected ERTS data.

The geometric relationships between Earth coordinates and ERTS data coordinates in a localized area can be represented by the product of several transformation matrices:

$$\begin{bmatrix} P - P_o \\ L - L_o \end{bmatrix} = M_5 \cdot M_4 \cdot M_3 \cdot M_2 \cdot M_1 \begin{bmatrix} \lambda - \lambda_o \\ \phi - \phi_o \end{bmatrix} \tag{5}$$

where P is the point count coordinate along scan lines,

L is the scan line count coordinate along the satellite track,

P_o and L_o are the ERTS data coordinates of the reference point,

$M_1, \ldots, M_5$ are transformation matrices,

λ is longitude, measured positive to the West,

ϕ is latitude, measured positive to the North,

and λ_o and ϕ_o are the Earth coordinates of the reference point.

A representation of the major effects is given by the following transformation matrices for specific effects:

$$\begin{bmatrix} P - P_o \\ L - L_o \end{bmatrix} = \underbrace{\begin{bmatrix} \frac{1}{P_{scl}} & 0 \\ 0 & \frac{1}{L_{scl}} \end{bmatrix}}_{M_5} \underbrace{\begin{bmatrix} 1 & \tan H_e \\ 0 & \frac{1}{\cos H_e} \end{bmatrix}}_{M_4} \underbrace{\begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}}_{M_3} \underbrace{\begin{bmatrix} \cos H_s & \sin H_s \\ -\sin H_s & \cos H_s \end{bmatrix}}_{M_2} \underbrace{\begin{bmatrix} \lambda_{scl} & 0 \\ 0 & \phi_{scl} \end{bmatrix}}_{M_1} \begin{bmatrix} \lambda - \lambda_o \\ \phi - \phi_o \end{bmatrix} \tag{6}$$

M_1 converts minutes of latitude and longitude to a standard unit of length, like meters, for the given latitude.

M_2 rotates the Earth coordinate axes by an angle, H_s, so the ϕ' axis is parallel to the satellite track (assuming no Earth rotation at this point).

M_3 rotates the axes by an additional 180^o so the positive directions of the transformed λ and ϕ axes correspond to the positive directions of the P and L axes, respectively.

M_4 accounts for the distortion caused by the Earth's rotation.

M_5 converts length measurements from standard units to ERTS pixel units, e.g., P_{scl} = # standard units/pixel width.

If we multiply the three middle matrices of Equation (6), they reduce to:

$$(M_4M_3M_2)_{\text{Theoretical}} = \begin{bmatrix} -\cos H_s + \tan H_e \sin H_s & -(\sin H_s + \tan H_e \cos H_s) \\ \frac{\sin H_s}{\cos H_e} & -\frac{\cos H_s}{\cos H_e} \end{bmatrix} \tag{7}$$

A corresponding relationship can be computed from an empirical transformation, since the empirical matrix, M, can equal:

$$M = M_5M_4M_3M_2M_1 \tag{8}$$

Pre- and post-multiplying by inverses,

$$M_5^{-1}MM_1^{-1} = M_4M_3M_2 \tag{9}$$

Thus, the empirical version of $M_4M_3M_2$ is:

$$(M_4M_3M_2)_{\text{Empirical}} = \begin{bmatrix} P_{scl} & 0 \\ 0 & L_{scl} \end{bmatrix} \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} \frac{1}{\lambda_{scl}} & 0 \\ 0 & \frac{1}{\phi_{scl}} \end{bmatrix} \tag{10}$$

$$= \begin{bmatrix} \left(\frac{P_{scl}}{\lambda_{scl}}\right) m_{11} & \left(\frac{P_{scl}}{\phi_{scl}}\right) m_{12} \\ \left(\frac{L_{scl}}{\lambda_{scl}}\right) m_{21} & \left(\frac{L_{scl}}{\phi_{scl}}\right) m_{22} \end{bmatrix} \tag{11}$$

A.2. COMPARISON OF THEORETICAL AND EMPIRICAL TRANSFORMATIONS

It is of interest to compare an empirical transformation matrix obtained from one of the examples discussed in Section IV and the corresponding theoretical matrix for effects of non-polar orbit and Earth's rotation.

Assume:

$$\phi = 42.4^{\circ}$$

$$\varepsilon = 9.114$$

$$\omega_e/\omega_s = 0.071713$$

Then:

$$H_s = 12.39^{\circ}$$

$$H_e = 2.94^{\circ}$$

and the matrix of Equation (7) becomes:

$$\begin{bmatrix} -0.9656 & -0.2650 \\ 0.2149 & -0.9780 \end{bmatrix} \tag{12}$$

The corresponding empirical transformation matrix, scaled as in Equation (11), is:

$$\begin{bmatrix} -0.9628 & -0.2682 \\ 0.2101 & -0.9712 \end{bmatrix} \tag{13}$$

It can be seen that the two matrices are in good agreement, but are not exactly the same. There are several possible reasons for the small differences present. They include:

(1) Spacecraft motions, such as yaw, pitch, and roll, and other sources of error are not included in the theoretical transformation.

(2) Nominal orbit parameters were used for the theoretical transformation.

(3) There are residual errors in the locations of the control points in ERTS data, although the use of least-squares techniques minimizes them.

(4) The factors used to scale the empirical matrix depend on an assignment of dimensions to the pixels, and the exact dimensions depend on the MSS mirror scan velocity (a non-constant function) and the sampling rate, among other factors. A 57 x 79 m pixel size was used here.

A.3. COMPUTATION OF TYPICAL ERRORS

The actual heading of the spacecraft ground track, neglecting satellite perturbations, is the sum of the nominal heading and the deviation due to Earth's rotation:

$$H = H_s + H_e \tag{14}$$

It can be seen from Equations (1) and (6) that H_s decreases with decreasing latitude while H_e increases. Therefore, the two effects tend to cancel and minimize the change in heading across a portion of an ERTS frame.

Across a typical 15' quadrant topographic map (~20 x 25 km) the net change in heading is small and results in a displacement that is small in comparison to an ERTS pixel size. The heading is a function of only latitude for a spherical Earth. In passing from 42°45'N to 42°30'N latitude, the change in actual ERTS-1 headings is calculated to be:

$$\Delta H = H_{42^{\circ}30'} - H_{42^{\circ}45'} = -0.0384^{\circ} = -2.3'$$

where $H_{42^o 30'} = 12.3092 + 2.9557 = 15.2649^o$

and $H_{42^o 45'} = 12.3587 + 2.9445 = 15.3032^o$

For an area 20 km wide, this amounts to a total differential displacement of 13 m due to heading change. Therefore, it is a good assumption that the spacecraft flies along a straight line over a local area ~20 km wide.

Spacecraft motions also introduce additional variations during a pass over the same size area, ~20 km x 25 km. If we consider differential angles of 0.13×10^{-3} rad for yaw, 0.20×10^{-3} rad for pitch, and 0.11×10^{-3} rad for roll, the corresponding differential displacements would be ~3 m for yaw, 180 m for pitch, and 100 m for roll. Differential yaw and pitch affect the spacing of data primarily along the flight line, whereas roll affects it primarily along the scan line. Effects of such spacecraft motions are not included in the theoretical transformation described earlier, but are included in the empirical procedure used for pixel assignments which averages over them in a least-squares sense.

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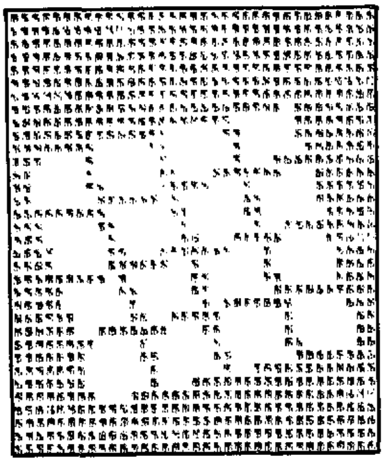
ACKNOWLEDGEMENT

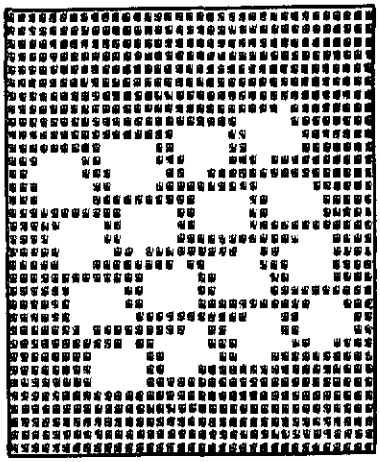
The authors wish to acknowledge helpful discussions and suggestions by their colleagues, M. M. Spencer, H. M. Horwitz, and R. J. Kauth.

Note Added in Publication: R. Kauth has pointed out that Equation (7) can be reduced to:

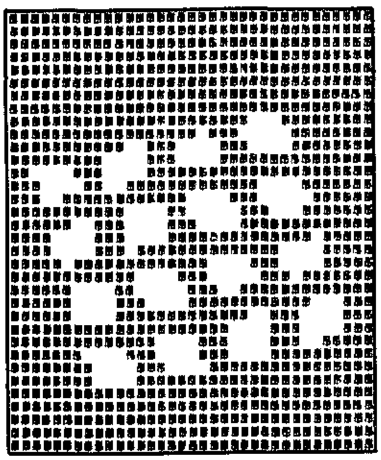
$$(M_4 M_3 M_2)_{\text{Theoretical}} = \frac{1}{\cos H_e} \begin{bmatrix} -\cos H & -\sin H \\ \sin H_s & -\cos H_s \end{bmatrix} \qquad (7')$$



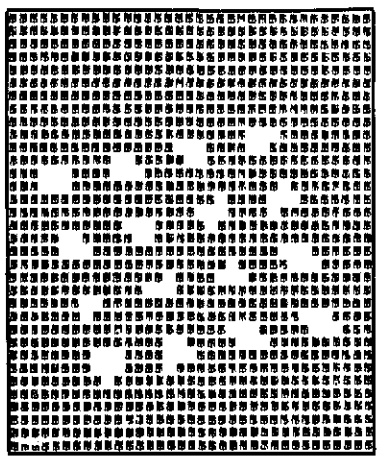
Part (a) 0.5 INSET



Part (b) 0.75 INSET



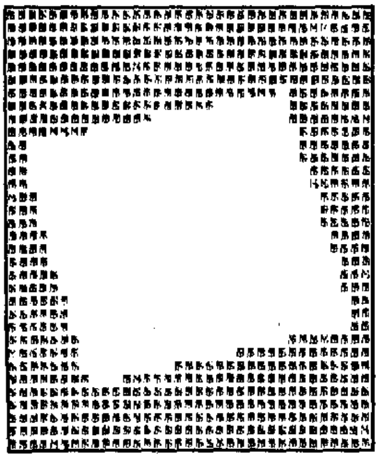
Part (c) 1.0 INSET



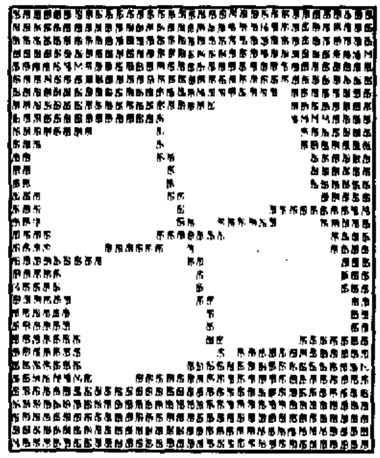
Part (d) 1.5 INSET

EFFECT OF INSET PARAMETER ON PIXEL SELECTION FOR 40-ACRE FIELDS
(Inset Parameter is Measured in MSS Resolution Elements)

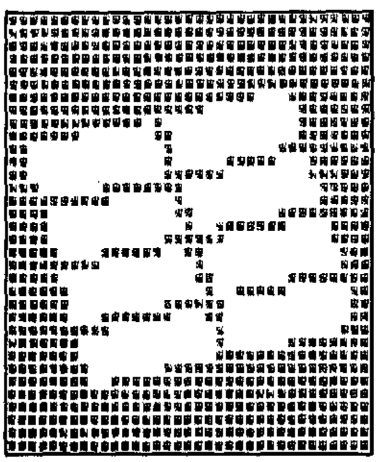
Figure B-1



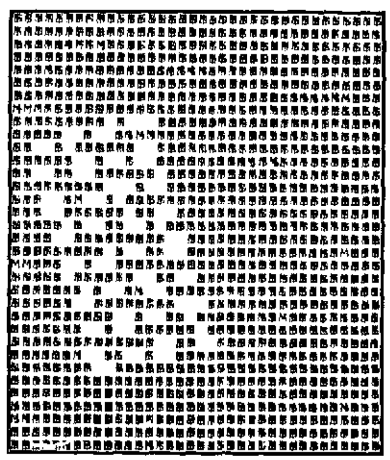
640 ACRE FIELD



160 ACRE FIELDS



80 ACRE FIELDS

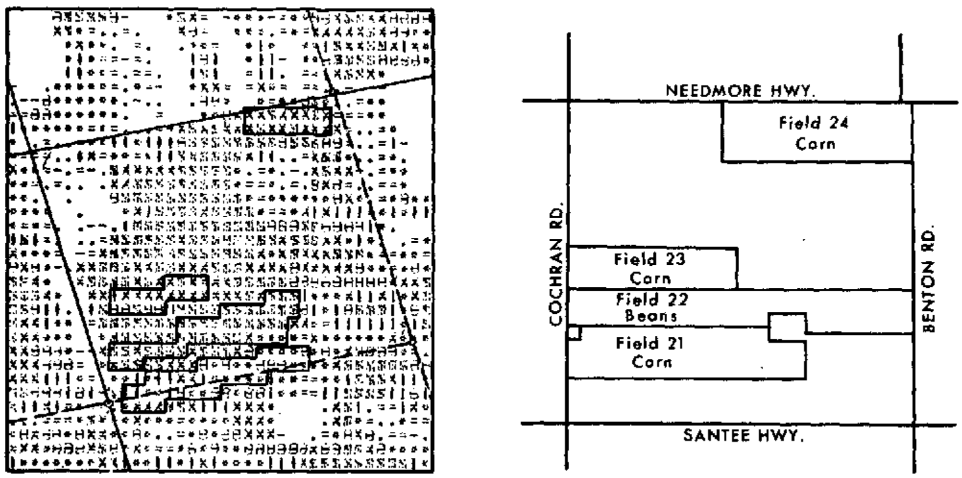


10 ACRE FIELDS

EFFECT OF FIELD SIZE ON PIXEL SELECTION FOR 0.5-RESOLUTION-ELEMENT INSET

ERIM

Figure B-2

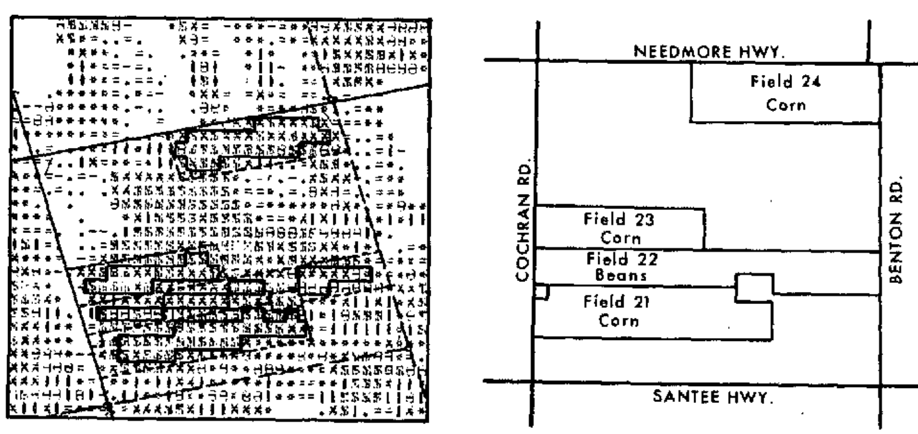


ORIGINAL MANUAL ASSIGNMENT

MAP OF FIELD BOUNDARIES

EXAMPLE OF FIELD LOCATION IN ERTS DATA

Figure B-3a



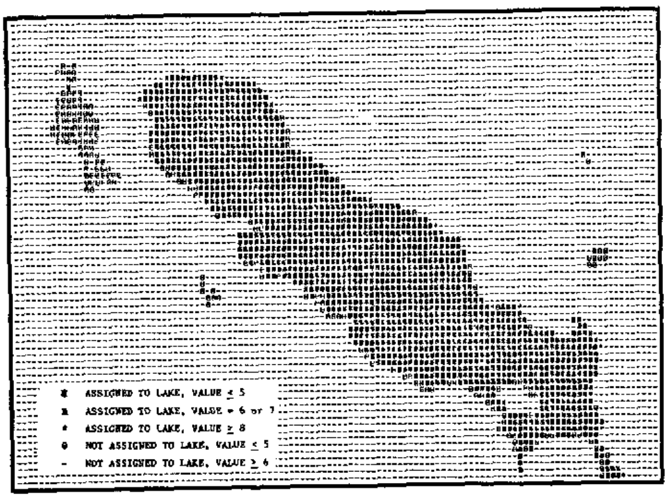
COMPUTER-AIDED ASSIGNMENT

MAP OF FIELD BOUNDARIES

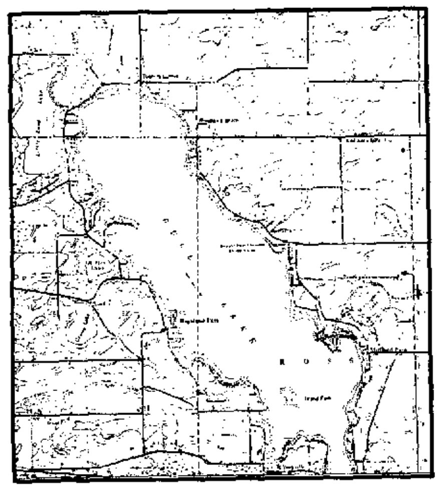
EXAMPLE OF FIELD LOCATION IN ERTS DATA

Figure B-3b

ERIM



ERTS PIXEL ASSIGNMENT



MAP OF GULL LAKE

RESULTS OF COMPUTED-AIDED ASSIGNMENT OF ERTS PIXELS TO OPEN WATER IN GULL LAKE

Figure B-4

ERIM