ECONOMIC EVALUATION OF CROP ACREAGE ESTIMATION BY MULTISPECTRAL REMOTE SENSING

(E77-10010) ECONOMIC EVALUATION OF CROP ACREAGE ESTIMATION BY MULTISPECTRAL REMOTE SENSING (Michigan State Univ.) 138 p HC A07/MF A01 CSCL 02C

N77-10593

Unclas
G3/43 00010

by

Lester V. Manderscheid

Wayne Myers

Gene Safir

Douglas Ilhardt

of Michigan State University

and

J. Morgenstern

J. Sarno

R. Nalepka

of Environmental Research Institute of Michigan

Report to NASA on Contract NAS 9-13332

1976

ECONOMIC EVALUATION OF CROP

ACREAGE ESTIMATION

by

MULTISPECTRAL REMOTE SENSING

This work was performed under contract NAS 9-13332 between Michigan State University and the National Aeronautics and Space Administration and a subcontract between the University and the Environmental Research Institute of Michigan. Further support was provided by the Michigan Agricultural Experiment Station under project number 3136.

University personnel are assigned to academic departments as follows:

Lester V. Manderscheid	Agricultural Economics
Wayne Myers	Forestry
Gene Safir	Botany and Plant Pathology
Douglas Ilhardt	Graduate Assistant, Forestry

TABLE OF CONTENTS

LIST OF FIGURES

C-1

LIST OF TABLES

SUMMARY

This report analyzes data obtained as part of the Skylab program, specifically the earth resources component of that program. Data was obtained over the Michigna test area on June 12, 1973; August 5, 1973 and September 18, 1973. Sensor imagery from the S-190A, S-190B and S-192 was utilized in the study and compared with ground truth obtained by the PI.

The statement of work for Contract NAS9-13332 provided:

> "The PI shall apply the identified information extraction techniques to the Skylab and aircraft data for crop discrimination, mensuration and analysis results for cost effectiveness and accuracy using ground truth and the agriculture statistical reporting service as a data base. The efforts are to include specifically:
>
> 2.1.3.1 The PI shall by photointerpretation analyze EREP imagery to construct basic land use and crop maps.
>
> 2.1.3.2 The PI will investigate digital techniques to discriminate crops and characteristic signatures which indicate crop health and vigor.
>
> 2.1.3.3 The PI shall differentiate crops within a resolution cell by appropriate digital analysis techniques.
>
> 2.1.3.4 The PI shall compare his crop discrimination, mensuration and predicted yields with the agriculture statistical reporting service for accuracy.
>
> 2.1.3.5 The PI shall make a cost effectiveness study to determine the feasibility of using remote sensing for crop inventories and mensurations.

This report leads to the following general conclusions which are more fully developed in the text of the report. Analytical techniques and the rationale leading to the con-

clusions are also in the report text.

Photointerpretation of S-190A and S-190B imagery showed significantly better resolution with the S-190B system. A small tendency to underestimate acreage was observed. This averaged 6 percent and varied with field size. Fields of less than 10 acres were estimated as larger than actual. As long as fields are greater than 5 acres in size the resolution of the S-190B system is adequate.

The S-190B system had adequate resolution for acreage measurement but the color film did not provide adequate contrast to allow detailed classification of ground cover from imagery of a single date. In total 78 percent of the fields were correctly classified but with 56 percent correct for the major crop, corn. Part of this difficulty can be attributed to the existence of dual signatures for corn on this date.

Acreage measurement is more critical to this study. Use of S-190A imagery in the June 12, 1973 imagery resulted in 91 to 95 percent accuracy in estimating acreage of bare soil, forest, grass, forage, grain, etc. categories after a ratio correction of 25 percent for underestimation was applied.

Analysis of S-192 was conducted by a subcontractor, E.R.I.M. These data had been acquired on August 5, 1973 at 15:02 GMT. The crop recognition accuracy which was achieved during this investigation was shown to be related to the amount of data available for training the computer. Accuracy increased as 10, 20 and then 40 sections were made available for extracting training statistics via a supervised clustering approach. Even with 40 sections available for training, however, the average absolute accuracy of roughly 70 percent for 5 classes was somewhat disappointing. These relatively low values were attributed to:

1) the data were gathered at a non-optimum time in early August when corn, and other crops were quite variable in their state of maturity,
2) the atmospheric conditions over the test site were fairly hazy thereby reducing available contrast,
3) the data gathered by the S-192 had significant deficiencies with regard to signal-to-noise ratio in some bands, the dynamic range covered by the signals, and channel-to-channel spatial registration.

Attempts to discriminate for health and vigor using S-190A, S-190B and S-192 imagery all proved unsuccessful. This finding is consistent with the difficulty in obtaining accurate acreage estimation which is, of course, much easier.

A mixtures classifier was applied in an attempt to increase the accuracy of crop classification of pixels in the S-192 data. The error rate was slightly larger using the mixtures classifier than it was with the linear classifier. Surprisingly, only 18 percent of the pixels were classified as mixtures. Given the field and pixel sizes many more mixtures had been expected.

The statistical Reporting Service (SRS) of the U.S.D.A. currently publishes estimates of crop acreage for the U.S. and major producing states. Their probability based surveys cover about 150 commodities including crops, fruits, nuts, livestock and poultry. Their accuracy in crop acreage estimation is a function of the total expenditures for the survey as well as the proportion of the acreage in that crop. At current cost levels their estimates of national aggregates are more accurate than those obtained from the Skylab data set. Therefore, the SRS estimates are more accurate than would be obtained from a national sample using Skylab <u>if</u> the accuracy found in this study is representative of an operational system. Obviously, improved technology, more frequent data collection, use of crop calendars, etc. would change this comparison.

The report text contains information on costs of both the current SRS system and the classification costs of processing the Skylab data. While lack of data restrict the quality of this analysis, it is clear that the Skylab system was not as cost-effective as the SRS system as both operated in 1973.

Introduction

This report contains the result of a study entitled "Economic Evaluation of Crop Acreage Estimation by Multispectral Remote Sensing" under a contract between the National Aeronautics and Space Administration (NASA) and Michigan State University (MSU). In turn MSU subcontracted with the Environmental Research Institute of Michigan (ERIM) for the computer analysis of S-192, multispectral scanner data.

The statement of work on the contract, NAS9-13332 provided:

> "The PI shall apply the identified information extraction techniques to the Skylab and aircraft data for crop discrimination, mensuration and analysis results for cost effectiveness and accuracy using ground truth and the agriculture statistical reporting service as a data base. The efforts are to include specifically:
>
> 2.1.3.1 The PI shall by photointerpretation analyze EREP imagery to construct basic land use and crop maps.
>
> 2.1.3.2 The PI will investigate digital techniques to discriminate crops and characteristic signatures which indicate crop health and vigor.
>
> 2.1.3.3 The PI shall differentiate crops within a resoultion cell by appropriate digital analysis techniques.
>
> 2.1.3.4 The PI shall compare his crop discrimination, mensuration and predicted yields with the agriculture statistical reporting service for accuracy.
>
> 2.1.3.5 The PI shall make a cost effectiveness study to determine the feasibility of using remote sensing for crop inventories and mensurations."

Skylab overflights obtained information over Michigan on June 12, 1973, August 5, 1973 and September 18, 1973. Only the August 5, 1973 pass occurred in good weather with all sensors obtaining usable information.

Sensors utilized to provide data for this study included The S-190A and S-190B cameras as well as the S-192 multispectral scanner. Aircraft underflights provided additional data. Ground truth was compiled from the U.S.D.A. Agricultural Stabilization and Conservation Service offices, field visits, and aerial photography.

The Statistical Reporting Service of the U.S.D.A. provided information on the current system of acreage estimation.

This report contains analyses of the Skylab data and a comparison of the interpreted Skylab data with ground truth. These results are then utilized to compare current acreage estimation procedures with potential procedures using Skylab technology.

Skylab Intensive Test Site

The whole of Michigan's Lower Peninsula served as a test site in the sense that all available Skylab imagery over Michigan was examined for quality, interpretability, and major features of interest; if not directly by personnel on the present project, then by other units across the MSU campus to whom the imagery was made available according to their special interests in the respective areas. However, the major thrust of effort with regard to ground truth and analysis of field crops in this project was concentrated in a test strip of approximately 90 square miles located in eastern Ingham County Michigan (Figure 1). This test strip is centrally located

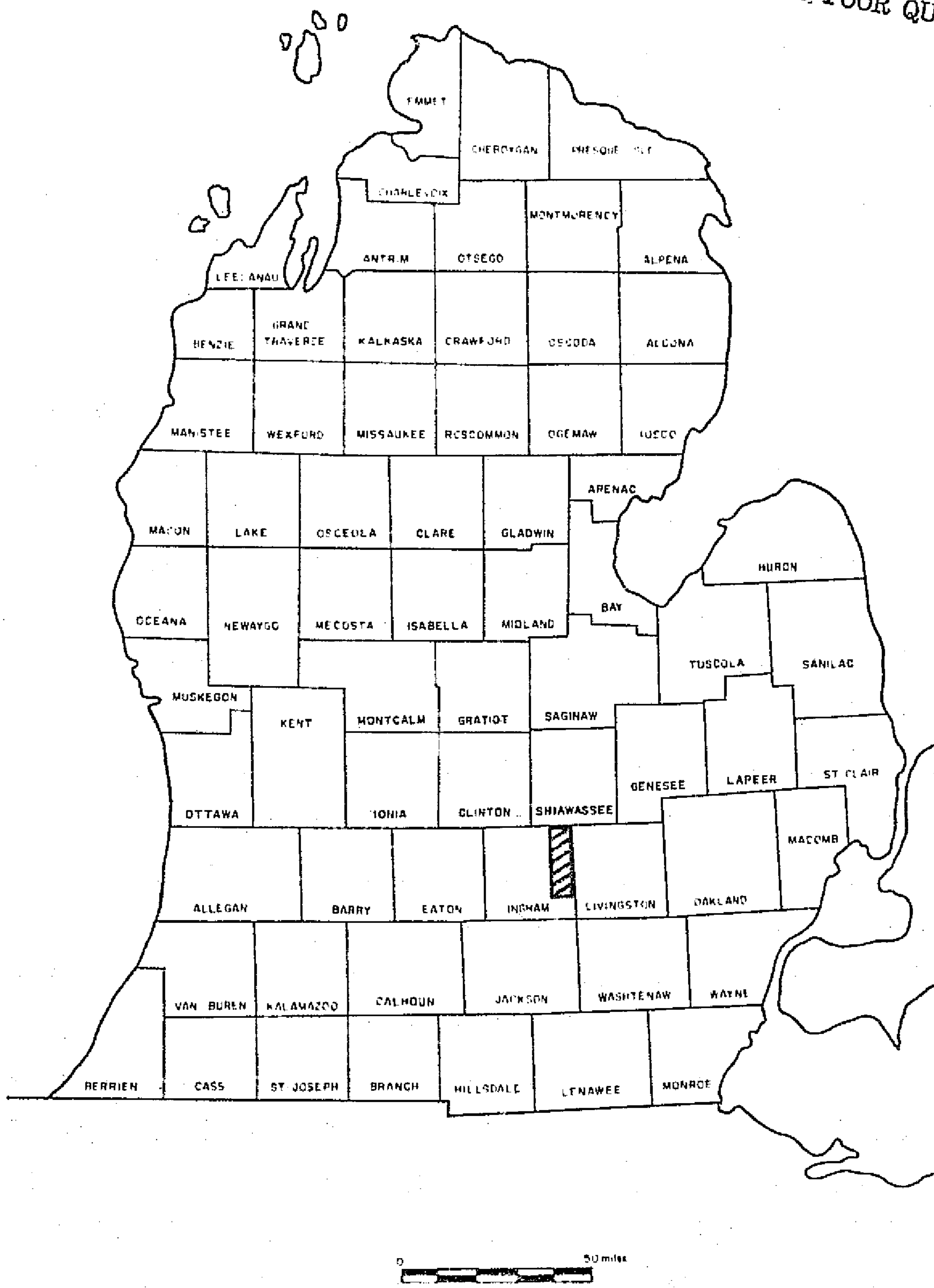
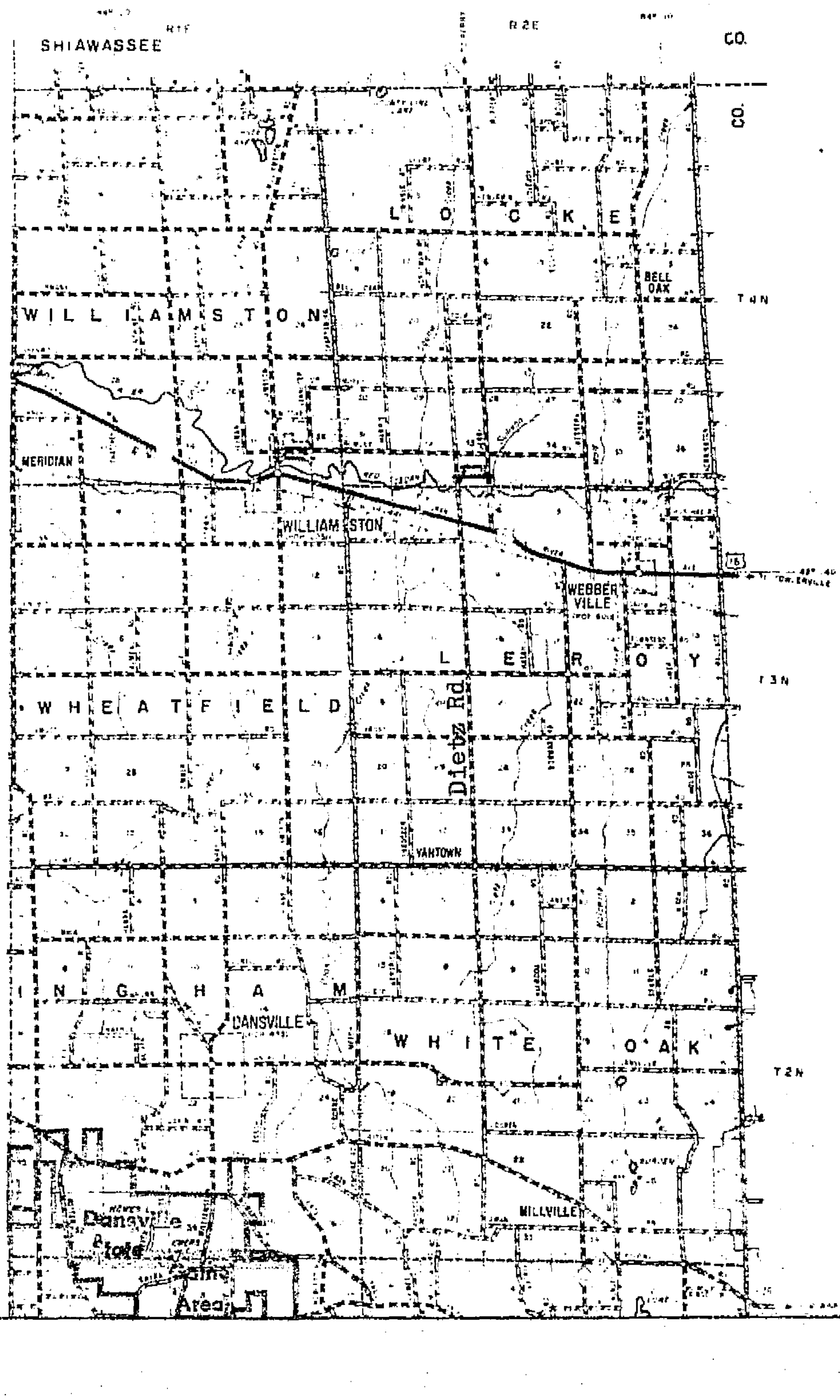


Figure 1. Location of the Skylab intensive test area within the State of Michigan

between the MSU and ERIM laboratories, which helped to keep travel costs to a minimum for both institutions. The test strip runs 18 miles along Dietz Road, extending three miles east of Dietz Road and two miles west (see portion of Ingham County map in Figure 2). Most of Locke (T4N, R2E), Leroy (T3N, R2E), and White Oak (T2N, R2E) Townships are included in the test strip. The test strip includes the variety of crop types and field sizes needed for purposes of the study. Figures 3a and 3b are reproductions of RB-57 airphotos covering the northern and southern portions of the test strip, respectively.

The test strip is about 99% rural, the town of Webberville being an exception. A major interstate highway (I-96) crosses the test area just south of Webberville. The area is characterized by intensive agriculture including corn, beans, small grains, forage crops, lettuce and cooking onions. In addition, the strip contains a few swampy areas and farm woodlots or bushy areas which are also present on most sections. It is representative of much of mid-Michigan agricultural land. A breakdown of the ground truth data for the test area by field size is given in Table 1, and by major crop types in Table 2. Small farmsteads, fence lines, secondary roads, etc. are excluded from the tabulations in Tables 1 and 2. Table 3 combines the previous Tables to provide data on crop acreages and number of fields by field size.



ORIGINAL PAGE IS OF POOR QUALITY

Figure 2. Portion of Ingham County map showing location of Skylab intensive test area.

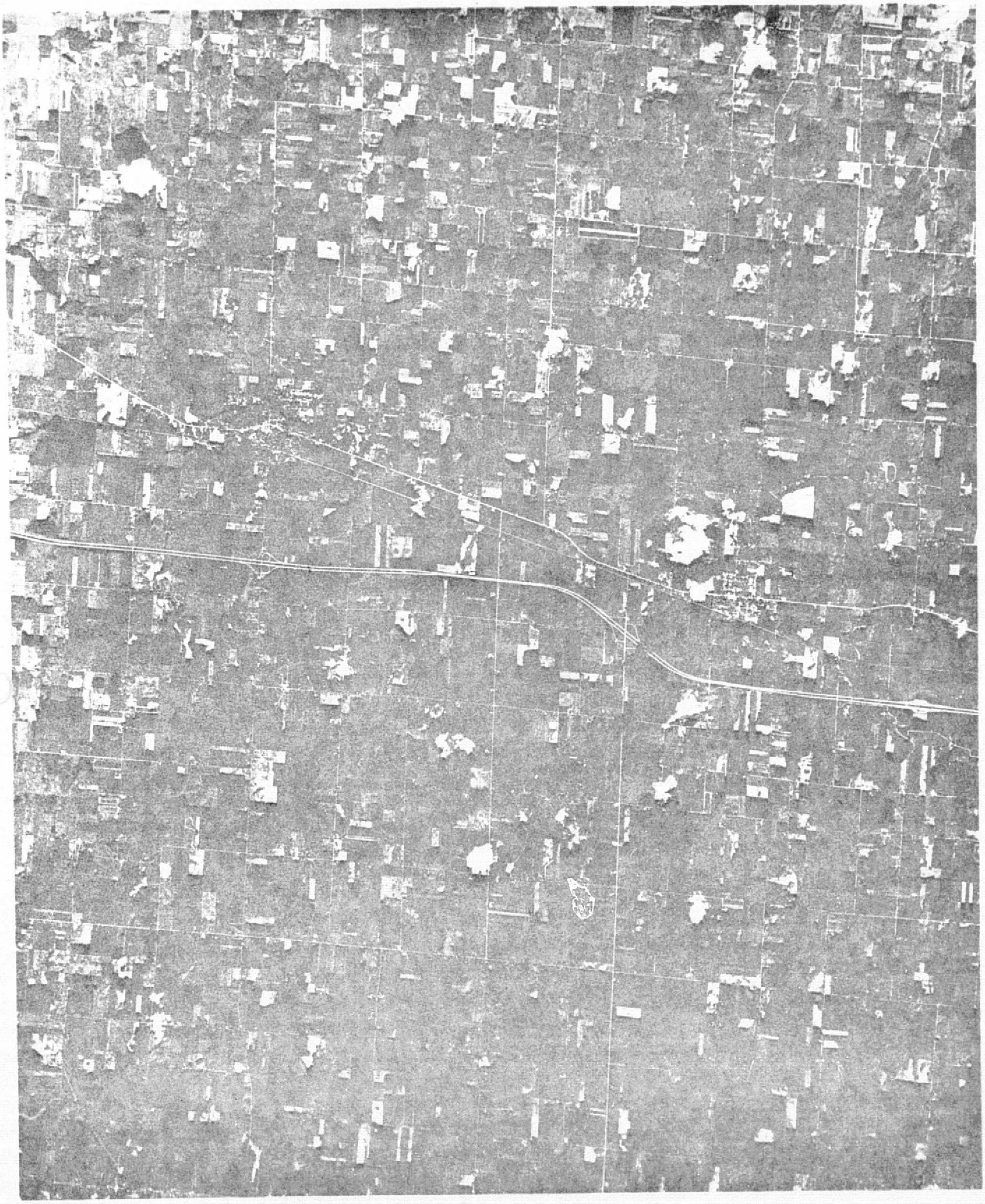


Figure 3a. Reproduction of RB-57 airphoto covering northern portion of Skylab intensive test area.

Figure 3b. Reproduction of RB-57 airphoto covering southern portion of Skylab intensive test area.

Table 1. Breakdown of ground truth information for Skylab intensive test area by field size.

Field size (acres)	No. of fields	% of fields	Total acres	% of acres
0 - 5	367	13.67	1194.8	2.20
5+ - 10	625	23.28	4673.6	8.59
10+ - 20	811	30.21	11950.6	21.96
20+ - 30	417	15.53	10199.9	18.74
30+ - 40	173	6.44	6033.2	11.09
40+ - 50	96	3.58	4239.4	7.79
50+ - 60	66	2.46	3599.9	6.61
60+ - 70	41	1.53	2647.6	4.86
70+ - 80	33	1.23	2434.2	4.47
80+ - 90	13	.48	1108.4	2.04
90+ - 100	3	.11	285.0	.52
100+ - 120	14	.52	1504.5	2.76
120+ - 140	8	.30	1035.6	1.90
140+ - 160	5	.19	735.5	1.35
160+ - 180	6	.22	1000.9	1.84
180+ - 200	2	.07	386.2	.71
200+ - 250	1	.04	241.9	.44
250+ - 300	2	.07	528.3	97
300+	2	.07	630.3	1.16
Totals	2685	100.00	54429.8	100.00

Table 2. Breakdown of ground truth information for Skylab intensive test area by major crop type.

Crop type	No. fields	% fields	Total acres	% acres
Corn	661	24.62	16,508.9	30.33
Beans	137	5.10	2,633.2	4.84
Forage crops	656	24.43	12,710.7	23.35
Truck crops	6	.22	182.0	.33
Stubble/grain	226	8.42	3,765.9	6.92
Bare soil	311	11.58	3,963.5	7.28
Weeds	201	7.49	4,084.7	7.51
Woods/brush	434	16.17	9,891.4	18.17
Wetland	10	.37	105.0	.19
Other	43	1.60	584.5	1.08
Total	2,685	100.00	54,429.8	100.00

Table 3. Distribution of major crop types by field size in the Ingham County intensive test area. F = number of fields. A = total acres.

Field size (acres)	Corn	Beans	Forage crops	Truck crops	Stubble/ grains	Bare soil	Weeds	Woods/ Brush	Wet- land	Other
0 - 5	37F 130.9A	7F 23.7A	73F 263.5A	1F 2.3A	19F 67.6A	82F 267.4A	28F 95.5A	96F 264.0A	4F 12.8A	20F 67.1A
5+ - 10	112F 870.6A	30F 230.2A	168F 1240.6A	0F 0.0A	65F 488.7A	86F 647.2A	53F 386.2A	96F 703.7A	4F 29.2A	11F 77.2A
10+ - 20	208F 3154.3A	55F 816.1A	219F 3166.0A	0F 0.0A	84F 1273.8A	93F 1324.3A	53F 788.2A	94F 1356.9A	1F 13.3A	4F 57.7A
20+ - 30	139F 3450.6A	[illegible]0F 704.5A	99F 2419.4A	2F 45.0A	27F 655.7A	27F 654.2A	29F 681.7A	62F 1501.4A	0F 0.0A	4F 67.4A
30+ - 40	62F 2145.6A	9F 328.9A	30F 1032.1A	1F 36.8A	17F 592.7A	12F 426.9A	15F 499.6A	27F 970.6A	0F 0.0A	0F 0.0A
40+ - 50	35F 1545.2A	2F 93.3A	27F 1196.1A	1F 43.2A	9F 383.0A	2F 90.8A	5F 216.0A	12F 536.3A	1F 49.7A	2F 85.8A
50+ - 60	29F 1576.8A	1F 57.0A	11F 595.2A	1F 54.7A	3F 154.9A	6F 331.1A	4F 219.7A	10F 558.6A	0F 0.0A	1F 51.9A
60+ - 70	13F 856.0A	2F 129.0A	10F 642.5A	0F 0.0A	1F 60.8A	1F 65.0A	5F 318.6A	9F 575.7A	0F 0.0A	0F 0.0A
70+ - 80	12F 899.7A	2F 144.5A	5F 370.2A	0F 0.0A	0F 0.0A	1F 72.5A	4F 300.6A	9F 646.7A	0F 0.0A	0F 0.0A
80+ - 90	4F 337.4A	0F 0.0A	4F 336.8A	0F 0.0A	1F 88.7A	1F 84.1A	2F 172.5A	1F 88.9A	0F 0.0A	0F 0.0A
90+ - 100	1F 90.5A	0F 0.0A	0F 0.0A	0F 0.0A	0F 0.0A	0F 0.0A	0F 0.0A	2F 194.5A	0F 0.0A	0F 0.0A
100+ - 160	6F 725.9A	1F 106.0A	7F 829.1A	0F 0.0A	0F 0.0A	0F 0.0A	2F 245.2A	10F 1202.0A	0F 0.0A	1F 157.4A
160+	3F 415.4A	0F 0.0A	3F 619.2A	0F 0.0A	0F 0.0A	0F 0.0A	1F 160.9A	6F 1282.1A	0F 0.0A	0F 0.0A

Ground Truth Information

Three basic sources of information were utilized in assembling "ground truth" data. The first was USDA, ASCS field certification records for Ingham County. The second was field visitation by technicians employed by MSU for the study. The third source of information was photointerpretation of underflight imagery by technicians employed for the project. All of this ground truth information was obtained during the 1973 growing season.

The first set of ground truth information to become available was provided through the cooperation of the Agricultural Stabilization and Conservation Service (USDA, ASCS). During the spring of 1973, this agency conducted an annual certification of acreages planted to crops and acreage set-aside from production under the Federal wheat and feed grain programs. This certification was recorded in the form of annotations on enlarged photocopies of black and white airphotos. The approximate scale of these photocopies was 1:7, 920 or 8 inches to the mile. At this scale, each section was covered conveniently by a single page in a loose-leaf notebook. It should be noted in passing that ASCS no longer conducts this type of certification program. These certification records did not constitute a complete ground truth base because data was collected only for owners participating in the Federal programs. Since the black and white airphotos annotated for certification were several years old, they could not be used for extracting current crop information in areas not covered by certification. Nevertheless, the old airphotos were useful for developing a field numbering system since field pattern is relatively stable over time. The field numbering system was structured as follows:

Township identifier - 1 digit

Section number - 2 digits

Field number within section - 3 digits

Subdivision of field - 1 decimal digit

The field numbers were recorded directly on the ASCS photocopies and kept in a loose-leaf notebook.

During August of 1973 a program of field visitation by the project technicians was undertaken to fill gaps in the certification records. Most fields within the test area that were accessible from roads or without violation of trespass laws were visited. For each field the crop species or dominant natural vegetation was recorded and any unusual conditions noted. Extensive use of ground-level photography was made during these field visits.

The combination of ASCS certification records and on-site observation of accessible fields still left gaps in the interior of sections. Acreage figures were available for fields covered in the ASCS records, but actual acreage measurement on the ground for other fields during field visitation would have been prohibitively time consuming. Thus, another source of information was needed for identifying crops in the interior of sections and for acreage measurement. Photointerpretive analysis of underflight imagery flown with the NASA U-2 and ERIM C-47 aircraft was used to obtain this information. The U-2 Skylab support flight took place on August 11, 1973 and provided complete stereo coverage of the test area at a nominal scale of 1:130,000 on CIR film. The C-47 imagery was collected during a simultaneous underflight of the August 5, 1973 Skylab pass. The C-47 sensor complement included several cameras loaded with different film types and the ERIM multispectral scanner. Imagery was collected at several flying heights. Only a portion of the test area was included in the C-47 mission since its primary purpose was to provide information on atmospheric and ground conditions for use in computer analysis of S-192 scanner data.

The C-47 imagery became available for use in the vault at ERIM laboratories before the U-2 imagery was received. Therefore, 70mm CIR imagery from this mission was used for crop identification to fill gaps in ground truth for the limited area covered. Crop identification for the remainder of the area was completed later upon receipt of the U-2 imagery. Acreages were scaled either from the ASCS black and white photocopies or from the U-2 imagery. Several methods of scaling acreages were used depending on the preference of the interpreter. Methods of area measurement included transparent dot grid, planimeter, and ocular grid on the Bausch and Lomb Zoom 240 stereoscope. Rolatape measurements were taken in the field to determine precisely the scale of airphotos used for acreage measurement.

Ground truth information from these various sources was assembled first in notebook form and subsequently on punched cards. As the analysis proceeded, it also became evident that time woul be saved by having the ground truth in map form. Accordingly, 5X enlargements were made of the U-2 photos covering the test area, and maps were prepared in the form of overlays on acetate.

Generalized breakdowns of the test area by field size and major crop types were given previously in Tables 1, 2, and 3. A more detailed breakdown of the ground truth information by township is contained in Tables 4,5, 6 , and 7. The percentage of fields belonging to each ground cover class does not differ significantly between townships. However, the percentage of the total acreage is significantly different for corn and grass. Corn covers 35.8 percent of Leroy Township but only 26.0 percent of Locke while grass ranges from 21.1 percent in Leroy to 31.9 percent in Locke Township. The major ground cover classes, in order of decreasing importance according to the percent found in the test site, are listed below:

Corn	30.3%
Grass	25.5%
Woods	16.8%
Stubble	9.4%
Bare Soil	7.2%

Table 4. Ground truth for Locke Township, Ingham County, Michigan. Given in acres and numbers of fields.

Section	Corn #	Corn Acre	Soybean #	Soybean Acre	Trees #	Trees Acre	Grass #	Grass Acre	Stubble #	Stubble Acre	Bare Soil #	Bare Soil Acre	Alfalfa #	Alfalfa Acre	Other #	Other Acre	Total #	Total Acre	Symbol Other
2	8	170.5	3	42.2	6	177.7	17	206.5	1	7.0	4	21.1	1	11.1			40	636.1	
3	9	192.0	2	32.8	4	108.3	15	297.9	4	65.5	3	24.0	4	58.5	2	19.9	43	798.9	X,θ
4	8	136.3	4	78.4	11	141.4	10	261.3	4	59.8	3	66.1			3	42.7	43	786.0	X,θ
5	8	259.6	1	23.4	4	272.0	3	72.6	4	58.6	5	92.4					25	778.6	
6	14	253.9	1	18.8	4	71.4	7	96.7	10	123.4	3	31.0			2	10.6	41	605.8	X,W
7	5	60.7			1	59.7	10	259.4	4	49.1	5	53.3	1	18.1	1	5.8	27	506.1	Y
8	11	231.1	4	37.4	6	204.2	3	28.1	9	106.4	5	28.7					38	635.9	
9	11	249.3	2	62.6	3	63.1	9	137.7	2	13.4	2	34.6			2	35.7	31	616.4	?
10	4	91.3	1	25.1	6	145.0	14	270.8	4	95.9			1	17.0	1	7.0	31	642.1	θ
11	5	62.7			8	101.3	11	409.5	2	11.8	3	43.9			2	10.5	31	639.7	H,Y
14					3	139.2	17	366.8	3	121.7							23	627.7	
15	1	52.0			1	101.2	6	432.5	1	76.1							9	661.8	
16	9	186.7	4	81.8	2	38.6	7	237.3	1	13.5	4	41.7					27	599.6	
17	16	187.8	1	26.9	5	124.6	15	183.7	3	34.6	4	28.2	1	19.9	1	12.3	46	618.0	N
18	10	[illegible]	4	45.5	7	117.5	8	57.3	4	52.3	5	45.6	1	29.8	1	7.6	40	486.6	N
19	3	46.7			6	99.5	15	218.9	6	52.6	4	18.8	1	20.5	1	12.8	36	469.8	θ
20	8	176.8			1	94.8	13	185.4	9	120.8	6	51.6	2	35.7			39	615.1	
21	3	54.6			4	61.4	5	302.5	2	41.6	2	137.5			1	18.8	17	616.2	H
22	3	192.5			7	143.4	5	320.2									15	656.1	
23	11	352.9	3	46.2	5	66.8	3	55.0	2	84.3	1	49.2					25	634.4	
26	9	[illegible]			4	68.5	3	72.5	2	68.0	1	25.1	3	124.6	2	17.0	24	642.6	X
27	6	135.0	1	8.2	6	65.5	13	336.2	2	74.9	2	18.1			1	5.3	31	643.2	W
28	11	227.6	1	32.2	3	31.6	7	91.3	7	132.3	7	137.8	1	8.2			37	657.0	
29	11	191.1			9	110.1	11	199.1	3	25.1	6	92.6					40	618.0	
30	7	129.5	1	36.9	4	107.1	5	70.8	2	10.5	5	70.2	1	15.8	1	4.7	26	445.5	X
31	7	76.8	5	55.6	6	74.3	2	167.3	5	33.9	3	24.6	1	10.0	2	21.0	31	463.5	H,θ
32	8	149.1	1	8.2	5	203.7	5	74.3	5	95.4	5	45.6			3	55.0	32	631.3	2N,
33	8	266.1	2	23.4	3	35.8	8	163.2	3	86.6	2	27.0			1	17.0	27	619.1	θ
34	6	269.0	1	13.5	5	53.8	6	99.4	2	73.7	3	122.4					23	631.8	
35	3	123.4			7	114.6	10	264.5	5	85.6	3	26.9			2	14.1	30	629.1	2H
TOTAL	223	4840.7	42	699.1	146	3196.1	263	5938.7	111	1874.4	96	1358.0	18	369.2	29	317.8	928	18594.0	
AVE.	7.4	161.4	1.4	23.3	4.7	106.5	8.8	198.9	3.7	62.5	3.2	45.3	.6	12.3	1.0	10.6	30.9	619.8	

Locke: Section = 30

ORIGINAL PAGE IS OF POOR QUALITY

Table 5. Ground truth for Leroy Township, Ingham County, Michigan. Given in acres and numbers of fields.

ection	Corn #	Corn Acre	Soybean #	Soybean Acre	Trees #	Trees Acre	Grass #	Grass Acre	Stubble #	Stubble Acre	Bare Soil #	Bare Soil Acre	Alfalfa #	Alfalfa Acre	Other #	Other Acre	Total #	Total Acre	Symbol Other
2	1	41.6			5	193.1	6	269.1	2	22.8	4	13.5			1	8.2	19	548.3	Y
3	3	105.4	1	14.0	4	83.7	3	148.6	4	104.8	2	65.5	2	29.2			19	551.2	
4	4	50.9	1	71.3	4	180.4	4	180.1	3	14.6	2	11.1	3	41.0	1	8.8	22	558.2	Y
5	8	203.0			3	160.4	4	52.9	3	104.7	2	19.3					20	540.3	
6	7	205.2	1	6.5	3	45.7	4	66.7	1	18.8	2	35.7			2	21.7	20	400.3	X
7	7	97.2	3	69.7	3	33.9	4	67.4	6	114.7	3	32.1			3	62.6	29	477.6	2N,X
8	7	278.6			4	104.1	7	159.6	1	21.6	3	50.4			3	29.9	25	644.2	2X,Y
9	8	300.7	3	33.3	5	84.2	1	14.0	4	73.7	1	27.5			3	109.4	25	642.8	X,Y,θ
10	9	217.1			4	32.8	4	96.5	5	65.4	8	97.1	5	96.5	1	42.1	36	647.5	X
11	5	82.5			4	51.0	9	226.7	5	51.0	3	23.9	2	48.0	1	157.4	29	640.5	X
14	6	136.1			8	80.0	12	280.5			8	81.1	2	10.3	3	38.0	39	626.0	2X,θ
15	8	231.0			3	62.8	7	159.6	4	35.8	5	27.0	4	61.2	2	47.1	33	624.5	2X
16	7	373.4	2	31.7	5	69.6	4	62.8	4	70.3	1	10.3					23	618.1	
17	10	355.8	1	11.5	2	32.9	12	159.2	2	23.1					2	61.5	29	644.0	θ
18	6	54.6	2	17.8	6	54.1	5	207.1	4	73.1	5	35.2	2	19.5			30	461.4	
19	9	152.8	3	42.7	2	75.4	8	108.2	2	62.8	2	12.6	1	19.6	1	24.2	28	498.3	N
20	5	364.7			5	42.3	7	64.3	4	86.4	3	25.3	4	36.3	2	30.0	30	649.3	θ,X
21	3	269.1			1	194.8	3	53.7	2	73.2	1	25.4			2	28.8	12	645.0	2θ
22	6	200.4	2	59.3	4	98.5	5	133.8	3	78.9			1	69.1			21	640.0	
23	8	256.3			3	70.8	11	155.0	4	60.5	3	91.7	1	10.3			30	644.6	
26	6	300.0	1	14.9	3	189.5	8	84.2			6	59.7					24	648.3	
27	7	212.3	3	26.4	3	16.2	12	148.2	2	39.7	7	95.4	4	72.7	1	20.1	39	631.0	N
28	12	221.8	2	57.6	6	127.3	8	141.1	2	20.1	7	54.2	2	20.8			39	642.9	
29	12	230.1	4	91.4	3	55.9	9	170.4	2	25.3	3	63.3			1	9.8	34	646.2	θ
30	11	201.6	1	14.4	2	41.9	7	127.8	5	51.6	7	64.3	3	20.1	1	10.3	37	532.2	θ
31	5	183.8	1	23.6	3	99.6	5	72.1	2	22.6	4	89.9	1	36.8	1	19.0	22	547.4	D
32	9	243.8	2	23.1	3	51.9	6	95.7	4	87.4	1	2.9			5	148.2	30	653.0	N,2θ
33	11	239.6	6	72.6	3	103.6	6	60.7	8	102.1	3	17.2	2	8.6	2	16.1	41	620.5	N,X
34																			Clouds
35	8	374.2	1	17.3	3	87.0	4	79.7	1	11.5	4	47.3	1	29.3			22	646.3	
TOTAL	203	6183.8	40	699.1	107	2523.4	185	3645.7	89	1516.5	100	1178.9	40	629.3	38	893.2	807	17269.9	
AVE.	7.2	213.2	1.4	24.1	3.4	87.0	6.4	125.7	3.1	52.3	3.4	40.7	1.4	21.7	1.3	30.8	27.8	595.5	

Leroy: Section = 29

Table 5. Ground truth for Leroy Township, Ingham County, Michigan. Given in acres and numbers of fields.

Section	Corn #	Corn Acre	Soybean #	Soybean Acre	Trees #	Trees Acre	Grass #	Grass Acre	Stubble #	Stubble Acre	Bare Soil #	Bare Soil Acre	Alfalfa #	Alfalfa Acre	Other #	Other Acre	Total #	Total Acre	Symbol Other
2	1	41.6			5	193.1	6	269.1	2	22.8	4	13.5			1	8.2	19	548.3	Y
3	3	105.4	1	14.0	4	83.7	3	148.6	4	104.8	2	65.5	2	29.2			19	551.2	
4	4	50.9	1	71.3	4	180.4	4	180.1	3	14.6	2	11.1	3	41.0	1	8.8	22	558.2	Y
5	8	203.0			3	160.4	4	52.9	3	104.7	2	19.3					20	540.3	
6	7	205.2	1	6.5	3	45.7	4	66.7	1	18.8	2	35.7			2	21.7	20	400.3	X
7	7	97.2	3	69.7	3	33.9	4	67.4	6	114.7	3	32.1			3	62.6	29	477.6	2N,X
8	7	278.6			4	104.1	7	159.6	1	21.6	3	50.4			3	29.9	25	644.2	2X,Y
9	8	300.7	3	33.3	5	84.2	1	14.0	4	73.7	1	27.5			3	109.4	25	642.8	X,Y,θ
10	9	217.1			4	32.8	4	96.5	5	65.4	8	97.1	5	96.5	1	42.1	36	647.5	X
11	5	82.5			4	51.0	9	226.7	5	51.0	3	23.9	2	48.0	1	157.4	29	640.5	X
14	6	136.1			8	80.0	12	280.5			8	81.1	2	10.3	3	38.0	39	626.0	2X,θ
15	8	231.0			3	62.8	7	159.6	4	35.8	5	27.0	4	61.2	2	47.1	33	624.5	2X
16	7	373.4	2	31.7	5	69.6	4	62.8	4	70.3	1	10.3					23	618.1	
17	10	355.8	1	11.5	2	32.9	12	159.2	2	23.1					2	61.5	29	644.0	θ
18	6	54.6	2	17.8	6	54.1	5	207.1	4	73.1	5	35.2	2	19.5			30	461.4	
19	9	152.8	3	42.7	2	75.4	8	108.2	2	62.8	2	12.6	1	19.6	1	24.2	28	498.3	N
20	5	364.7			5	42.3	7	64.3	4	86.4	3	25.3	4	36.3	2	30.0	30	649.3	θ,X
21	3	269.1			1	194.8	3	53.7	2	73.2	1	25.4			2	28.8	12	645.0	2θ
22	6	200.4	2	59.3	4	98.5	5	133.8	3	78.9			1	69.1			21	640.0	
23	8	256.3			3	70.8	11	155.0	4	60.5	3	91.7	1	10.3			30	644.6	
26	6	300.0	1	14.9	3	189.5	8	84.2			6	59.7					24	648.3	
27	7	212.3	3	26.4	3	16.2	12	148.2	2	39.7	7	95.4	4	72.7	1	20.1	39	631.0	N
28	12	221.8	2	57.6	6	127.3	8	141.1	2	20.1	7	54.2	2	20.8			39	642.9	
29	12	230.1	4	91.4	3	55.9	9	170.4	2	25.3	3	63.3			1	9.8	34	646.2	θ
30	11	201.8	1	14.4	2	41.9	7	127.8	5	51.6	7	64.3	3	20.1	1	10.3	37	532.2	θ
31	5	183.8	1	23.6	3	99.6	5	72.1	2	22.6	4	89.9	1	36.8	1	19.0	22	547.4	D
32	9	243.8	2	23.1	3	51.9	6	95.7	4	87.4	1	2.9			5	148.2	30	653.0	N,2θ
33	11	239.6	6	72.6	3	103.6	6	60.7	8	102.1	3	17.2	2	8.6	2	16.1	41	620.5	N,X
34																			Clouds
35	8	374.2	1	17.3	3	87.0	4	79.7	1	11.5	4	47.3	1	29.3			22	646.3	
TOTAL	208	6183.8	40	699.1	107	2523.4	185	3645.7	89	1516.5	100	1178.9	40	629.3	38	893.2	807	17269.9	
AVE.	7.2	213.2	1.4	24.1	3.4	87.0	6.4	125.7	3.1	52.3	3.4	40.7	1.4	21.7	1.3	30.8	27.8	595.5	

Leroy: Section = 29

Table 6. Ground truth for White Oak Towhship, Ingham County, Michigan. Given acres and numbers of fields.

tion	Corn #	Corn Acre	Soybean #	Soybean Acre	Trees #	Trees Acre	Grass #	Grass Acre	Stubble #	Stubble Acre	Bare Soil #	Bare Soil Acre	Alfalfa #	Alfalfa Acre	Other #	Other Acre	Total #	Total Acre	Symbol Other
2	9	205.1			6	38.0	12	350.0	2	29.9	6	49.5	2	66.8			37	739.3	
3	14	319.9	1	38.6	3	110.0	11	118.8			8	99.7	1	5.7	1	4.1	39	696.8	X
4	7	208.6	2	19.7	9	99.7	8	160.7	5	146.1	4	32.2	1	17.3	1	8.7	37	693.0	N
5	5	103.1	4	100.2	2	120.9	10	137.1	10	125.3					1	106.0	32	692.6	N
6	18	222.1	5	59.3	4	69.7	3	21.7	7	86.6	9	119.6	1	21.9	1	6.9	48	607.8	θ
7	6	139.4	1	26.5	4	189.4	3	45.0	3	39.7	5	35.2	2	81.9	1	19.7	25	576.8	θ
8	5	178.0	2	27.0	6	94.3	6	214.8	1	28.8	3	21.2			5	79.0	28	643.1	H,4N
9	8	293.3	2	47.8	6	73.0	4	42.9	2	38.0	5	94.0			3	57.1	30	646.1	X,2H
0	7	235.5			5	141.1	5	88.0	1	11.5	4	32.1	3	109.3	3	10.8	28	628.3	3X
1	2	72.6			4	292.8	5	224.6			2	61.7	1	7.5			14	659.2	
4	3	91.0			6	156.0	12	337.7	2	36.8	1	25.4					24	646.9	
5	9	267.5			4	69.1	3	65.6	1	88.7	6	119.8	1	4.1	2	13.9	26	628.7	θ,X
6	12	307.5	3	18.9	8	89.4	9	172.3	1	19.0	3	28.2					36	635.3	
7	8	159.5	2	43.2	5	150.5	5	55.4	6	62.1	9	74.8			6	91.0	41	636.5	?,5H
8	11	247.3			9	99.7	5	74.3	4	76.7	3	55.9	1	11.0	2	22.4	35	587.3	θ,X
9	8	201.3	1	39.8	4	76.5	3	45.4	4	128.9	1	29.3	1	45.5	1	2.9	23	569.6	X
0	8	207.3	2	89.2	6	100.2	9	168.7	4	28.3	2	6.8			3	42.0	34	642.5	N,X,J
1	7	192.4	2	24.7	9	80.7	6	236.8	4	36.3					2	70.9	30	641.8	N,θ
2	12	233.4	2	71.9	5	30.5	7	78.3	6	121.6	5	100.7	1	7.5			38	643.9	
3	2	29.5			2	90.5	8	196.8	2	30.5	3	88.8			8	196.4	25	632.5	Y,I,5F
6	2	62.7	1	7.5	4	347.9	9	192.8	1	16.2	1	1.8			2	11.0	20	639.9	2Y
7	11	149.9	2	29.9	6	130.5	12	161.9	8	83.5	8	59.3	1	8.7	4	12.1	52	635.8	θ,3X
8	5	110.0	1	26.5	7	137.7	4	176.8	6	93.2	6	71.2	3	36.0			32	651.4	
9	4	277.7			1	46.1	6	206.8	4	39.1	2	35.2	1	12.6	2	31.1	20	648.6	H,X
0	8	153.3			7	107.7	12	127.7	5	59.3	5	47.1	2	32.8	5	58.5	44	586.4	3H,2X
1																			Cloud
2	12	242.5			3	52.4	6	131.0	4	39.1	4	23.7	7	127.8	1	4.1	37	620.6	X
3	9	139.2	1	15.5	9	135.4	7	143.3	7	82.8	3	37.4	1	4.6	5	76.0	42	634.2	?,W,X,
4	11	199.5			9	142.3	11	157.7	10	99.1	3	13.3	1	4.6	3	21.9	48	638.4	θ,2X
5	7	184.3	1	6.9	7	146.2	7	141.6	4	72.6			4	72.5	1	11.5	31	635.6	J
OTAL	230	5433.4	35	693.1	160	3418.2	208	4274.5	114	1719.7	111	1363.9	35	678.1	63	958.0	956	18538.9	
VE.	7.9	187.4	1.2	23.9	5.5	117.9	7.2	147.4	3.9	59.3	3.8	47.0	1.2	23.4	2.2	33.0	33.0	639.3	

White Oak: Section = 29

Table 7. Percentage of totals of acreages and number of fields for various ground cover classes for each of the three townships and for the entire test site.

	LOCKE			LEROY			WHITE OAK			TOTALS		
	% of total fields	% of total acreage	average acreage	% of total acreage	% of total acreage	average acreage	% of total acreage	% of total acreage	average acreage	% of total acreage	% of total acreage	average acreage
Corn	24.0	26.0	21.7	25.8	35.8	29.7	24.0	29.3	23.6	24.6	30.3	24.9
Soybean	4.5	3.8	16.6	5.0	4.0	17.5	3.7	3.7	19.8	4.3	3.8	17.8
Tree	15.7	17.2	21.9	13.3	14.6	23.6	16.7	18.4	21.4	15.3	16.8	22.1
Grass	28.3	31.9	22.6	22.9	21.1	19.7	21.8	23.1	20.6	24.4	25.5	21.1
Stubble	12.0	10.1	16.9	11.0	8.8	17.0	11.9	9.3	15.1	11.7	9.4	16.3
Bare soil	10.3	7.3	14.1	12.4	6.8	11.8	11.6	7.4	12.3	11.4	7.2	12.7
Alfalfa	1.9	2.0	20.5	5.0	3.6	15.7	3.7	3.7	19.4	3.5	3.1	18.0
Other	3.1	1.7	11.0	4.7	5.2	23.5	6.6	5.2	15.2	4.8	4.0	16.7
Total			21.4			20.0			19.4			20.2

All other ground covers represent less than 5 percent of the total acreage of the area. This analysis is confounded by ambiguity concerning the definition of a field. A farmer usually refers to a unit of land as a field when it is all included within one fenced area with no natural barriers to cultivating the entire area in continous passes. For purposes of the detailed analysis above we defined fields with reference to the traditional definition plus requiring a single cover crop. Thus, if a field contained 50 percent of one crop and 50 percent of another, it was treated as if it were two separate fields. If dually listed as a woods-pasture or weeds and brush, it was placed under the category first mentioned. However, a weedy field crop was labeled by the crop, e.g. weedy soybeans were called soybeans. Since fields with dual crop identification were arbitrarily classified by the first designation, there may be a slight bias in the results. This bias is likely to be important only for the grass and trees categories where the dual listing occured most often.

Supplemental ground truth information was also collected in Eaton County, Michigan in an area previously used for ERTS studies. This area was situated along an extension of the Skylab flight path, and it was felt that additional data on wheat might be garnered for the photointerpretive studies of Skylab imagery as well as for possible use in subresolution element analysis. The Eaton County information was collected in June, 1973 on a 4 by 5 mile strip having McConnell Road as the southern boundary and Cochran Road as the north-south bisector. Information on fields in this area came from field visits and photointerpretive analysis of aircraft imagery. Additional information on all wheat and plowed fields was also obtained for a 5 by 2 mile strip immediately to the north of this area. Unfortunately, little Skylab imagery was obtained for this area while the bare soil and growing wheat conditions prevailed.

Collection of ground truth information occupied most of the 1973 field season, and acreage determinations extended into the summer of 1974. However, the effort was required because the ground truth information served as the basis for both the photointerpretive analysis of Skylab imagery at MSU and the computer analysis of S-192 scanner data at ERIM.

Description of Photographic Imagery

This section contains a description of photographic imagery collected in support of the project by both Skylab and aircraft cameras. Aircraft imagery is treated first, then Skylab imagery.

The first photographic mission was flown with the ERIM C-47 aircraft on August 5, 1973. This flight took place simultaneously with a Skylab pass over the Ingham County test area, and was intended primarily to provide supporting data for computer analysis of S-192 MSS data. However, it was also used to fill gaps in ground truth. The sensor complement for this mission included three cameras and the ERIM multispectural scanner. The P220 camera (70mm format) was loaded with CIR film. The KB-8 camera (70mm format) was loaded with conventional color film. The K-19 camera (9 inch format) was loaded with black and white film. The latter camera is used primarily to provide a navigational record of the mission. This mission included passes at several altitudes over the test area, but included coverage only for the central portion of the test strip.

The second support mission was flown with a NASA U-2 aircraft on August 11, 1973. The photographic product of this mission was 9-inch CIR imagery at a nominal scale of 1:130,000. Full stereo coverage in five flight lines of Eaton, Ingham, Livingston, Oakland, and Macomb Counties was included, as well as partial coverage of Kalamazoo, Calhoun, Jackson, Washtenaw, Wayne, Kent, Clinton, Shiawassee, Genessee, Lapeer, and St. Clair counties. The 9-inch transparencies from this mission served as the primary reference for photointerpretive studies in this project.

Aircraft imagery flown in previous years to support other projects such as ERTS and land use studies was also available for use in the Skylab work. Details of this imagery will not be discussed here except to note that the various dates of photography, scales, film types, and formats collectively covered most of southern Michigan.

The Skylab satellite made data collection passes over southern lower Michigan on three dates during 1973. Because of cloud cover on September 18 only the first two provided usable imagery for the Ingham County test area. Table 8 contains a summary of imagery by date and sensor.

Table 8. Summary of Skylab photographic coverage for southern lower Michigan.

Date	Mission	Sensor	Rolls
June 12, 1973	SL-2	S-190A	13 to 18
August 5, 1973	SL-3	S-190A	19 to 24
August 5, 1973	SL-3	S-190B	83
Sept. 18, 1973	SL-3	S-190A*	43 to 48
Sept. 18, 1973	SL-3	S-190B*	88

* Ingham County test area covered by clouds.

Skylab 2 passed over the Ingham County test area on June 12, 1973 (Figure 4). Because encroaching clouds indicated uncertain weather conditions for this pass, only the S-190A sensor system was operated. Despite the occurrence of widespread clouds over southern Michigan on that date, the Ingham County test area happened to be clear at the moment of coverage and usable imagery was obtained. The S-190A system consisted of six cameras with 70 mm format and 6-inch focal length. These cameras were loaded with different film/filter combinations to give multiband imagery. Film types included panatomic-X aerial black and white, infrared aerographic black and white,

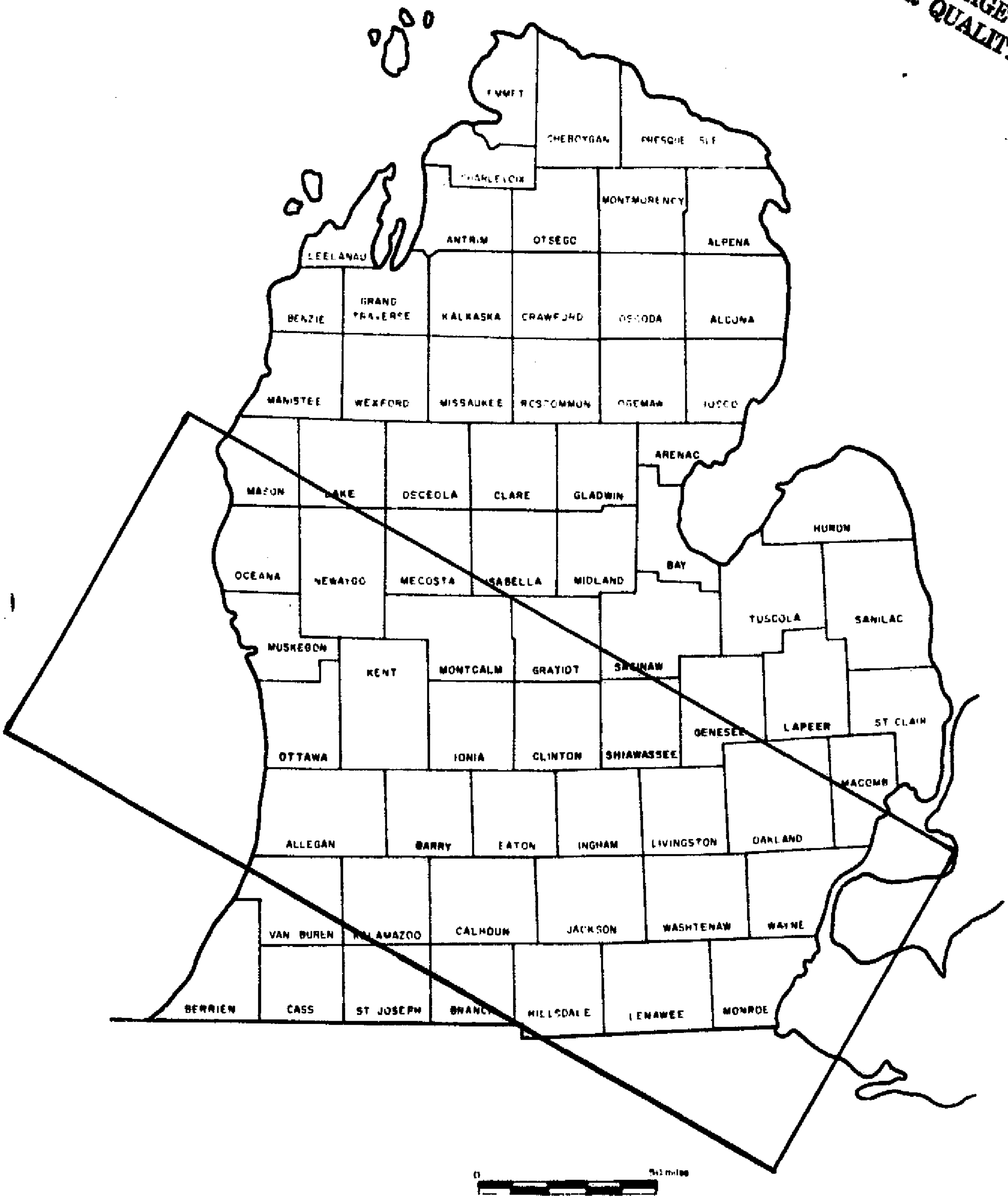


Figure 4. S-190A coverage obtained on June 12, 1973 during the SL-2 mission. Heavily clouded over much of the area.

infrared aerochrome color, and high resolution aerial color. The combination of 6-inch focal length and 270 mile orbital altitude produced imagery with a scale of 1:3,000,000.

The prime Skylab pass for this project took place on August 5, 1973 during the SL-3 mission. Weather conditons were excellent and both the S-190A and S-190B camera systems were operative. The S-190A coverage is shown diagrammatically in Figure 5, and the S-190B coverage is shown in Figure 6. The S-190B camera had an 18-inch focal length (scale 1:1,000,000) and was loaded with high resoultion aerial color film (SO-242). This pass was accompanied by a simultaneous C-47 underflight, and followed the next week by a U-2 support mission. Both of these aircraft missions were described at the beginning of this section.

On September 18, 1973 SL-3 again passed over southern Michigan with both the S-190A and S-190B camera systems in operation. Coverage for S-190A on this pass is shown in Figure 7, and for S-190B in Figure 8. On this pass, however, only Saginaw and Huron Counties were free of clouds. As a consequence, imagery over the Ingham County test area was not usable.

Description of Multispectral Scanner Data

On August 5, 1973 the Skylab multispectral scanner, S-192 was operated over the Michigan test site at approximately 10:02 EST or 15:02 GMT. Atmospheric conditions were variable and hazy. This date provided the only usable S-192 data because of poor weather conditions at the time of the scheduled June and Septem-

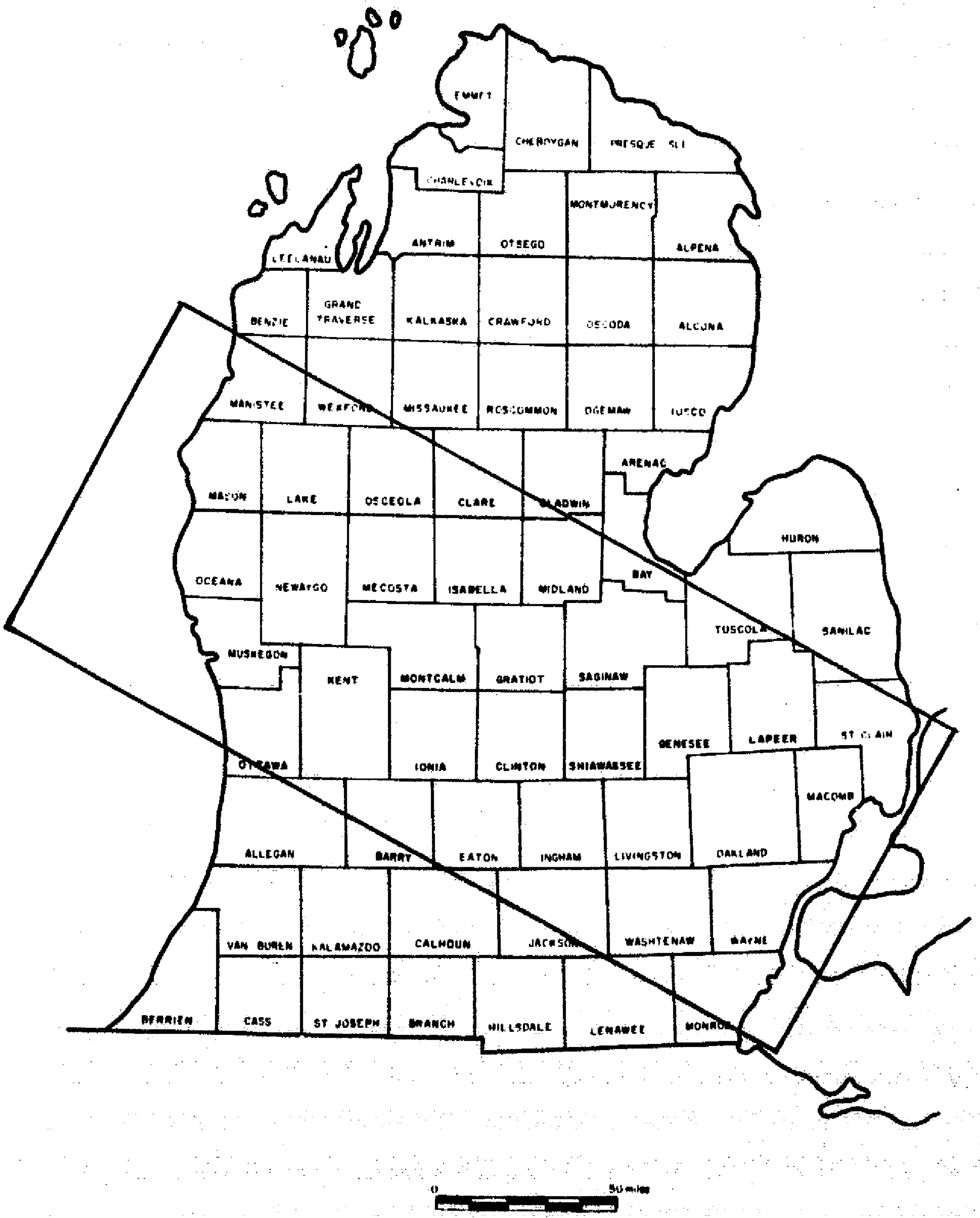


Figure 5. S-190A coverage obtained on August 5, 1973 during the SL-3 mission. Weather conditions mostly clear.

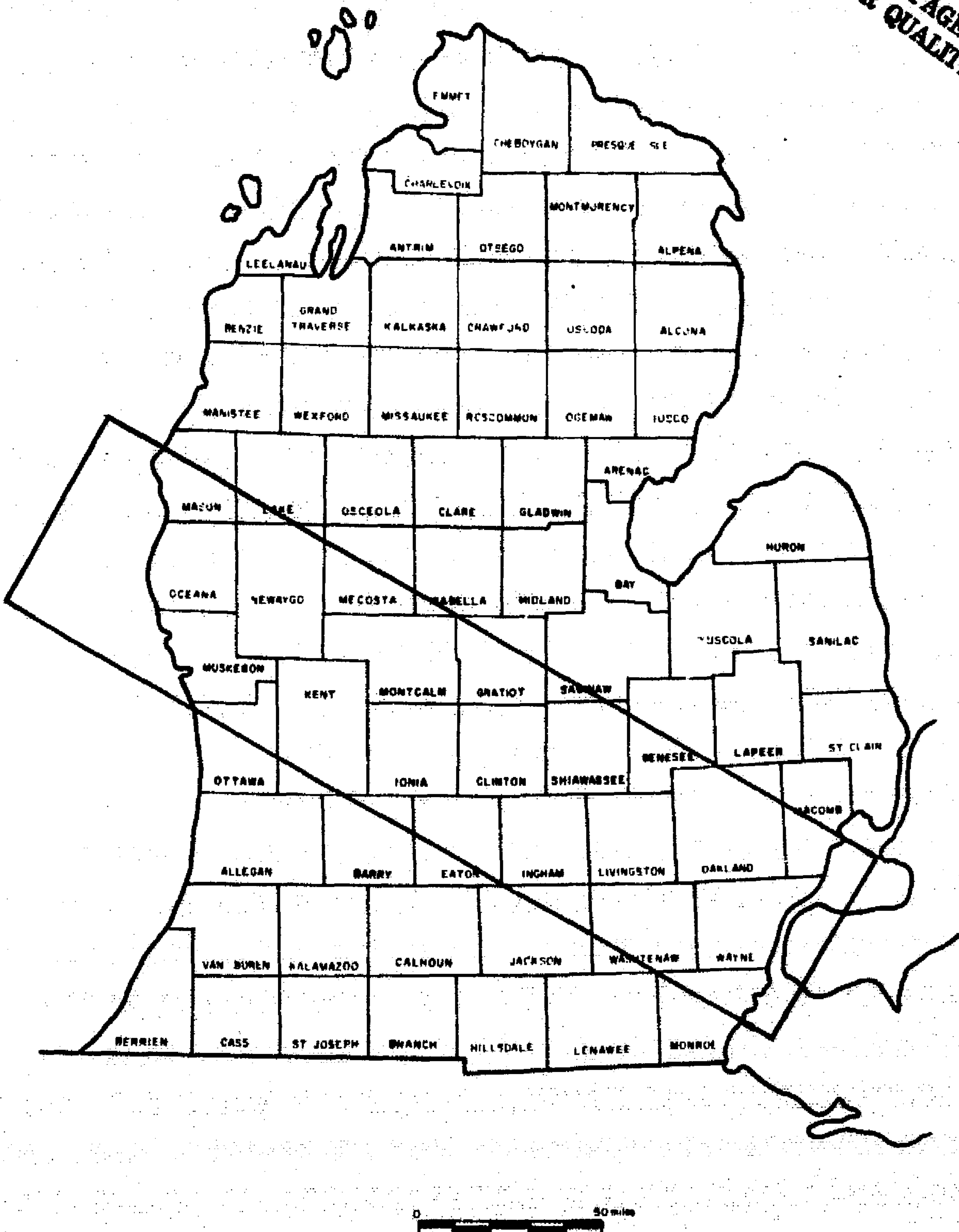


Figure 6. S-190B coverage obtained on August 5, 1973 during the SL-3 mission. Weather conditions mostly clear.

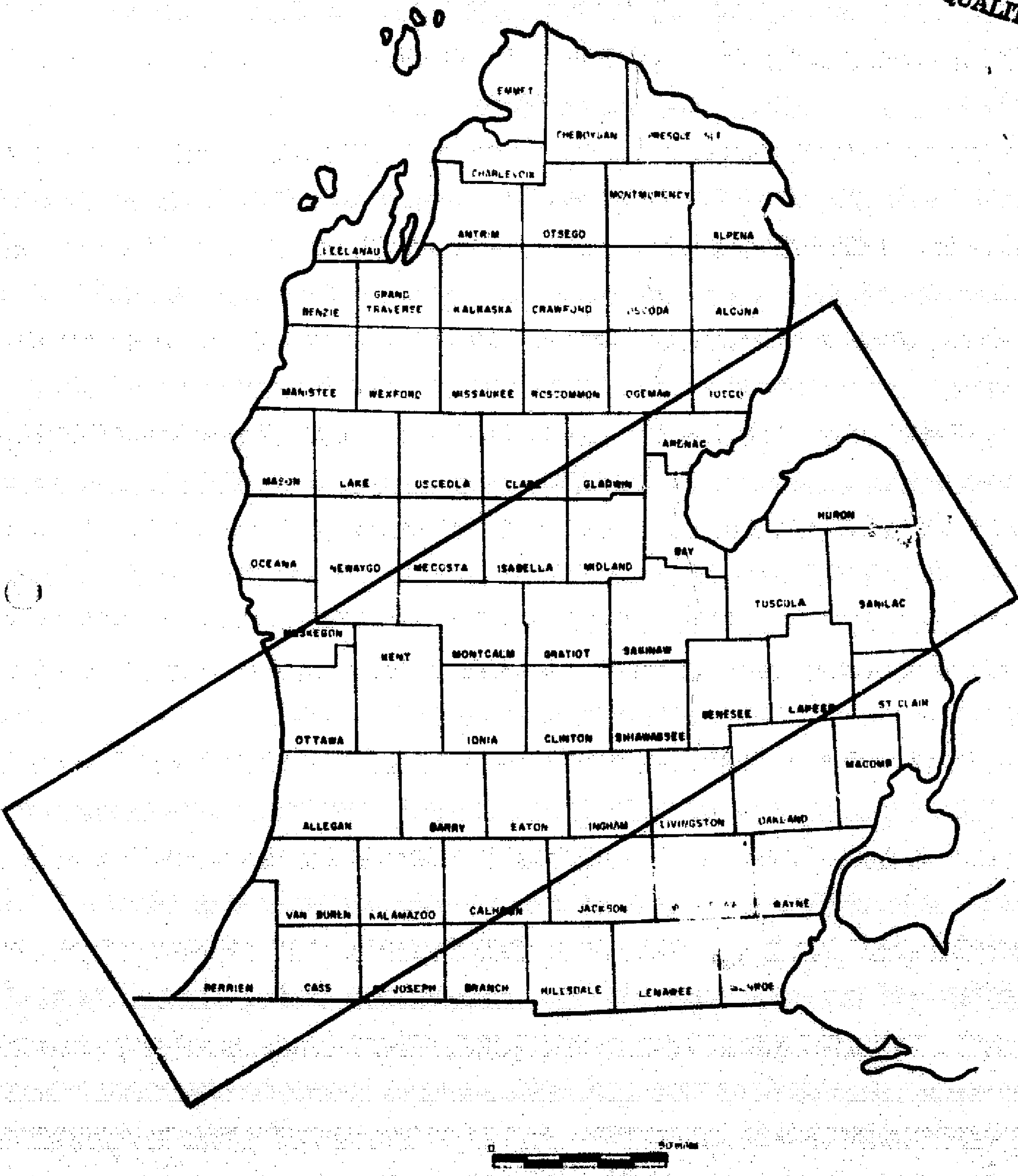


Figure 7. S-190A coverage obtained on September 18, 1973 during the SL-3 mission. Only cloud-free sections are in thumb area.

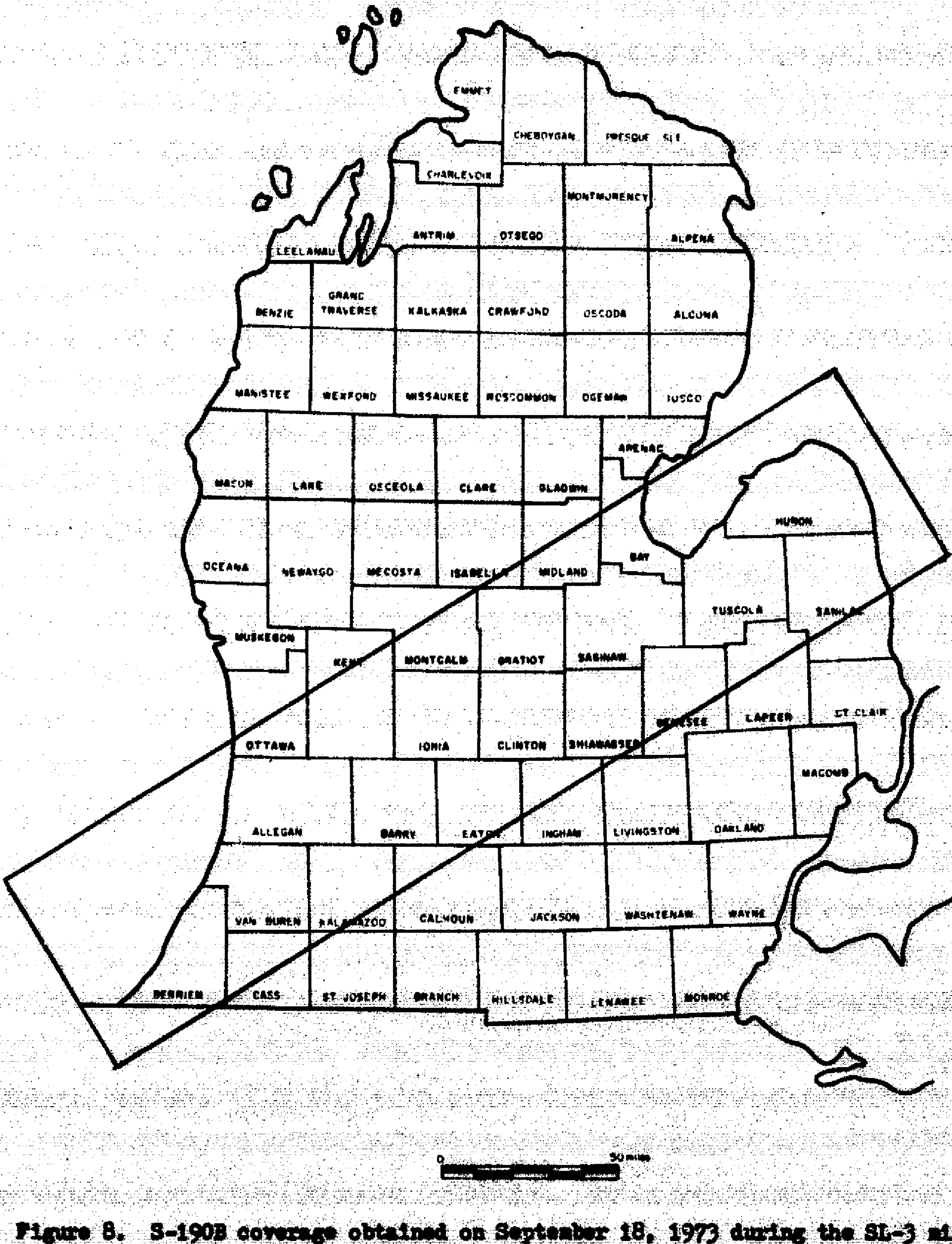


Figure 8. S-190B coverage obtained on September 18, 1973 during the SL-3 mission. Only cloud-free sections are in thumb area.

ber passes.

The data quality is described more fully in Appendix II of the ERIM subcontractors report.[1/] Because misregistration in the scan-line straightened data is much larger than for conic data, the analysis used conic data. The effect of misregistration in the corrected conic data is believed to be minimal. The data had a limited signal range, especially in relation to system noise. The range: noise ratio varied from 1.9 on detector 2 (SDO 18) to 6.0 on detector 8 (SDO 19). Most values were between 2.9 and 5.0 with only dectors 2, 4, and 11 above 5.0. This limited range reduced the probability of correct crop classification.

Photointerpretation Procedures

The primary instrument used for interpretation of Skylab imagery in this project was a Bausch & Lomb Zoom 240 stereoscope mounted on a Richards light table (Figure 9). This unit provides 30X zoom magnification in stereo mode, or 15X zoom when used as binocular macroscope. Light intensity is adjustable, and scanning capability is provided through slow motion cranks on both the X and Y axes. Auxillary equipment included rhomboids for stereo viewing of 70mm imagery and oculars for distance and area determination.

This unit was very convenient for the interpretive work, but is also quite expensive to pruchase. Cost of equipment is

1/ Report No. ERIM 104600-44-F of The Environmental Research Institute of Michigan, Ann Arbor, Michigan, August 1975.

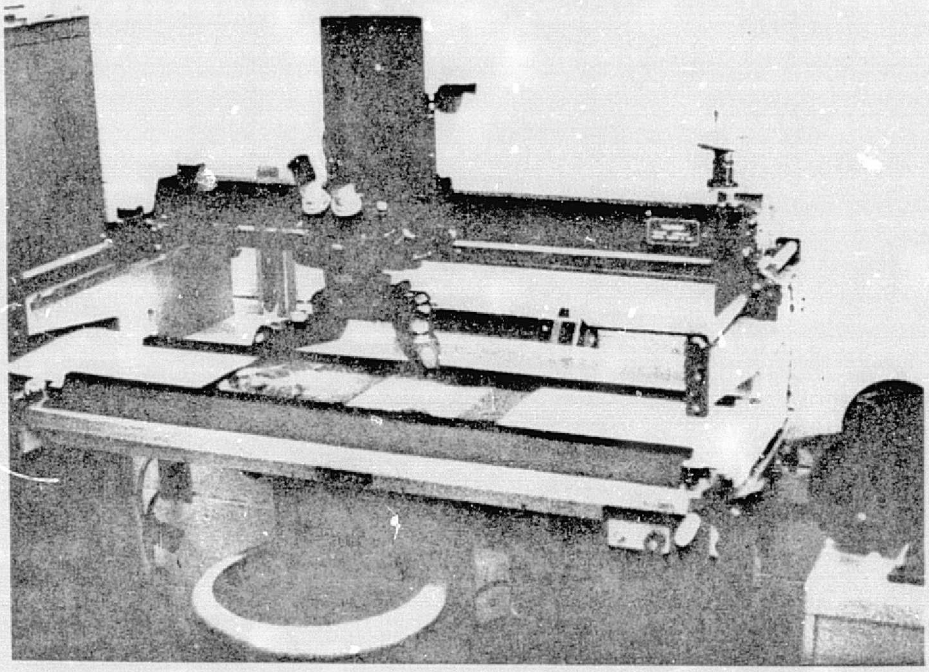


Figure 9. Bausch & Lomb Zoom 240 stereoscope mounted on a Richards light table.

one factor that must be considered when widespread application of Skylab-type imagery is contemplated. Therefore, some discussion regarding a minimal configuration of interpretive equipment is in order. Given the small scale and orbital altitudes, stereo viewing adds little to the interpretive process and is scarcely worth the time required to orient the stereopair properly. In practice, the Bausch & Lomb unit was usually used in the binocular macroscope mode during routine interpretation. Likewise, the adjustable intensity of the light table and the slow motion scan are more in the category of conveniences than necessities. Experiments with interpretation of projected images on rear projection screens showed this approach to be much less satisfactory than direct viewing of the transparencies with transmitted light. Thus, a minimal set of equipment for effective interpretation would be a zoom macroscope with oculars used over a portable light table. It might also be noted that the tendency of the transparencies to curl necessitates the use of a glass hold-down plate or a cardboard frame to keep the imagery flat.

The usual clues which the photointerpreter uses to make identifications include tone, texture, pattern, size, shape, shadow, location, and association of features. As scales become smaller, with consequent loss of resolution, the geometric clues such as size, shape, and shadow fade until they are lost except for their contribution to tone, texture, and pattern. Likewise, textures become more uniform, and therefore less useful, at smaller scales. By any criteria one might choose, the

the S-190A and S-190B contact scales of approximately 1:3,000,000 and 1:1,000,000, respectively, must be classed as very small scale. Thus, the interpreter is forced to rely primarily on tonal or color signature in identifying cover types, with some aid from texture in the case of forested areas and pattern in certain other instances. Very small scales also make annotation and mapping on overlays extremely difficult.

The importance of resolution cannot be overemphasized. Although small scales can be enlarged either optically or photographically, little is to be gained by enlargement if no further ability to discriminate between objects is obtained. ERTS transparencies and S-190B photos, for example, are both distributed to users at a scale of approximately 1:1,000,000. ERTS can be profitably enlarged by a factor of five to produce a working scale of about 1:200,000. At this enlarged scale, main roads can usually be distinguished and sometimes secondary roads, but field boundaries are indistinct. In contrast, S-190B imagery will stand at least 15X enlargement by photographic means and more than 20X by optical means. Thus, working scales ranging from 1:50,000 to 1:100,000 can be readily obtained. Individual fields are easily delineated on such enlargements. This ability to delineate and measure acreage on individual fields effectively increases the degrees of freedom for statistical estimates. For this reason alone the added resolution is worthwhile, even if lack of variation in tone between cover types limits the ability to classify crop species. Classification accuracy can be improved by temporal overlays keyed to a crop calendar, but accuracy of acreage measurement cannot.

Interpreters on this project faced several variables such as differences in scale and resolution between S-190A and S-190B imagery, differences in film types, and in crop phenology. In view of this, the first step in assessing a set of imagery was always a first-look examination for purposes of orientation and general determination of image quality, cloud cover, etc. The second step was to formulate a set of categories that were consistently separable and to develop a key to the tonal signatures of the categories. The procedure for doing this was first to select a training set of large and distinct fields on the basis of ground truth information. These fields were then located on the imagery and their tonal signatures noted. The signatures for these training fields were then compared across cover types to arrive at a set of categories for which the probabiltiy of discrimination was relatively good. The third step was to run a test of these tentative categories to see if they could be recognized consistently on the imagery. In this phase, large and distinct fields were selected from the Skylab imagery, interpreted, and compared with the corresponding ground truth data. This phase might result either in acceptance of the tentative categories, or in some refinement of the categories. Next came the operational phase of interpretation in which a block of 3000 - 5000 acres was selected. The cover types in this block were classified according to the predetermined categories and acreages measured with the ocular grid. Cover classification and acreage were recorded on a field-by-field basis for S-190B imagery, but this was not possible for S-190A imagery because of the lack of resolution. The only reference to ground truth during operational interpretation was for tonal signatures that had not been previously encountered, and for field numbers in the case of S-190B imagery. General notes regarding time involved and any particular problems encountered were maintained during the interpretation of this large block. Time study data, per se, was not collected during this phase. Results of interpretation for the block served as the basis for analysis of accuracy and assessing utility of the imagery for agricultural surveys. A separate time study for interpretation of S-190B imagery was conducted later.

Most of the interpretation was performed by a technician with a Bachelors degree in forestry and a background in agriculture and use of airphotos. It was felt that a Bachelors degree is some agriculturally oriented field and prior experience with airphotos might be typical of interpreters employed for operational work in agricultural surveys, whereas a Ph.D. with experience in remote sensing research would be atypical.

Analysis of S-190A Imagery

The S-190A sensor system is a multiband photographic camera equipped to provide imagery in six spectral regions. The specifications of the six high precision lenses are: 6-inch focal length with matched distortion and focal length: f/2.8; 21.2^{o}

FOV. The shutter assemblies are a rotary-intralens type providing for variable aperture settings from f/2.8 to f/16 in ½ -stop increments and shutter speeds of 2.5, 5, and 10 milliseconds with 0.4 millisecond synchronization. Intervalometer settings are adjustable from 2 to 20 seconds in 2 second increments. Imagery is provided in 70mm format. The combination of orbital altitude and field of view gives ground coverage over a square approximately 100 statute miles on a side in each frame, with contact scale of 1:3,000,000.

Four of the six camera stations were loaded with black & white film/filter combinations to cover four adjacent spectral bands of 0.1 micrometer each as follows:

Bandwidth (micrometers)	Film	Filter	Camera position
0.5 to 0.6	Panatomic-X aerial B&W, type SO-022	AA	6
0.6 to 0.7	Same as above	BB	5
0.7 to 0.8	IR aerographic B&W, type EK 2424	CC	1
0.8 to 0.9	Same as above	DD	2

Camera position (station) 3 carried aerochrome IR color film (type SO-127) with EE filter to give a CIR image in the spectral range 0.5 to 0.88 micrometers. Camera position 4 carried high-resolution aerial color film (type SO-356) with FF filter to give a conventional color image in the spectral range 0.4 to 0.7 micrometers. Other filter combinations were available for testing, but were not used for the present study.

The first S-190A imagery over the Ingham County test area was acquired on June 12, 1973 during the SL-2 mission. Although much of the region was clouded on that date, the test area happened to be free of clouds. Phenological conditions in southern Michigan on June 12, 1973 were as follows:

Forests: Most species in full leaf;

Grasses: Green and from several inches to over a foot in height, although some areas still showed dead material from the previous season over the current year's green growth;

Small grains: Heading, mostly green;

Row crops: Many fields tilled, some of which were planted, but few of which had any emergent green growth above 3 inches in height. Some fields not yet tilled.

This set of phenological conditions is relatively favorable for interpretation of forests and related natural vegetation. Conditions also favor interpretation of grasses as a group, but separation of species is difficult because many appear similar in early and middle stages of development. Likewise, separation of small grains from grasses would be expected to be difficult. Fields destined for cultivation of row crops would appear as bare soil if tilled, or possibly grass or small grain tilled. Therefore, different species of row crops are not detectable at this date.

As expected, the first-look analysis indicated that the general detectability of features varied by film type. On the two panatomic-X films covering the spectral range 0.5 to 0.7 micrometers, main roads showed well and boundaries between contrasting types were relatively distinct. Water bodies, however, were difficult to see. The B&W IR bands covering the spectral range of 0.7 to 0.9 micrometers were complementary to the previous bands since water bodies were easily distinguishable while roads and type boundaries were indistinct. The characteristics of the conventional color image were similar to the black and white images covering the same spectral range, except that the color tones produced more variability in signatures between cover types.

There was considerable variation in quality, however, between the duplicate bands of this film. Two of the duplicate bands were quite dark and difficult to interpret. The lighter duplicates were much easier to interpret . The broad band CIR imagery was best with respect to variety of features registered. On this latter type of imagery main roads showed fairly well, water bodies registered clearly, and boundaries between contrasting types were relatively distinct. However, resolution was generally poorer on the CIR imagery than for the conventional color. As with the conventional color, quality of reproduction was quite variable for CIR.

In general, this S-190A imagery was satisfactory for interpreting gross characteristics on a regional scale. However, the resolution was not sharp enough to allow consistant interpretation or measurement on a field-by-field basis. Field boundaries could not be delineated unless a field was surrounded by other fields that would produce a sharp contrast on the film. Under ideal conditions, such as with bare soil in adjacent fields, a field as small as one acre could be delineated; but this was strictly the exception rather than the rule. A general idea of location was possible because the major roads and freeways could be seen. However, most section-mile roads could not be seen, and one could not tell where the different sections began or ended. This lack of resolution created a problem in locating specific areas on the imagery for quantitative tests.

Since first-look interpretive efforts substantiated the general separability to be expected from phenological conditions on June 12th, only three categories were used:

1) bare soil
2) forest/brush
3) Grass, forage crops, small grains, etc.

Signatures on the conventional color film were brown for soil, green for crops/grasses, and a darker green for forests. Color categories on the CIR film were white for soil, red for vegetation, and black for wet areas. Different shades of red were not detectable for the different crops. Futhermore, crops and forests looked essentially the same shade of red on the CIR except that lowland hardwoods had a tinge of black. There was some confusion between forests and wetlands on the CIR as will be explained later.

The difficulty in locating specific areas on the June 12th S-190A imagery has already been mentioned. Such location was essential, however, in order to conduct quantitative tests of interpretive accuracy. The difficulty was resolved by using distinctively shaped woodlots situated at the corners of an 8-section rectangle in Leroy Township to establish a block of area which could be compared with ground truth. Cover types were identified in the three categories and acreages measured from both the color and CIR S-190A imagery. The results of these tests are summarized in Table 9.

In all cases except the forest category as interpreted from CIR, there was a consistent underestimation of approximately 25 percent. Upon further investigation of the anomaly involving forests on CIR, it was discovered that the technician was actually using a signature produced by seasonally wet areas instead of forests. The confusion arose because many of the forests in the area are lowland hardwoods. On the whole, the color film was judged to be more easily interpretable for most categories than CIR due to somewhat better resolution in the color film. The reason for the consistent bias toward underestimation was not fully determined, but it is suspected to have arisen from the difficulty in delineating type boundaries. Given this consistent bias, however, the use of a ratio correction factor seems appropriate. If the ratio correction of 1.25 is applied to the interpretations from the color film, the results are as shown in Table 10. Therefore,

Table 9. Results of photo-interpreting S-190A imagery taken on June 12, 1973 for eight sections in Leroy Township, Ingham County, Michigan.

Category	Color IR (acres)	Color (acres)	Ground truth (acres)	Color IR % error	Color % error
Bare soil	1,112	1,039	1,422	-22%	-27%
Forest	1,265	654	858	+47%	-24%
Grass, forage, grain, etc.	1,539	1,529	2,002	-23%	-24%
Totals	3,916	3,222	4,282	-9%	-25%

Table 10. Results of photo-interpretive tests on eight sections in Leroy Township, Ingham County, Michigan using color film from S-190A (June 12, 1973) and a ratio correction factor of 1.25 .

Category	Estimated acres	Ground truth acres	% accuracy
Bare soil	1,299	1,422	91%
Forest	816	858	95%
Grass, forage Grain, etc.	1,911	2,002	95%

these tests of three categories as interpreted from the June 12, 1973 S-190A color film indicate approximate accurcies of 75 percent before ratio correction and over 90 percent after ratio correction. In practice, the development and use of a ratio estimator of this type would imply some sort of double sampling system for developing the correction factor. The second phase of the sampling could be based on aircraft imagery, ground imagery, or some combination of the two. Due to the inabiltiy to distinguish individual fields or even sections consistently, standard errors are not available to support the results presented in Tables 9 and 10.

A second set of S-190A imagery over the Ingham County test area resulted from a Skylab pass on August 5, 1973. Weather conditions over most of southern Michigan on this date were good, and general phenological conditions were as follows:

Forests: all species in full leaf with closed canopy;

Grasses: most species starting to senesce;

Small grains: mature, senescent - with some already harvested;

Row crops: in late stages of growth with nearly complete ground cover, and part of corn in tassle.

The results of the first-look analysis for the August 5th S-190A imagery were similar to those for the June 12th imagery with respect to detectability of features on the several types of film. Variability in either exposure or processing for the S-190A imagery was again evident. In this case, the conventional color film was very dark. Bare soil could be distinguished fairly readily even on the darkened imagery, but the ability to make other distinctions such as between forested areas and crops was seriously impaired. Larger roads were recognizable, but with difficulty. Because of this poor quality, the color images from the August 5th pass were not used in quantitative tests. The CIR film for the August 5th pass was of better quality than that for June 12th. However, there was again a rapid decay in clarity with magnification and location was difficult because of inability to distinguish section-mile roads. As with the June 12th imagery, individual fields could not be distinguished consistently which meant that comparisons with ground truth data were limited to a large-area basis.

There were three distinct shades of red on the August 5th CIR imagery: dark red, a dull red, and a bright red. The dark red was a hardwood forest signature. It was initially thought that the bright red would correspond with a specific crop. However, this did not prove to be the case. For example, this shade of red represented such diverse cover types as alfalfa field, grassy area, and weed-filled soybean field. The dull shade of red also included a variety of crop types. Therefore, the bright and dull shades of red were pooled into a category that included crops, grasses, and miscellaneous types.

Acreage estimation was again done on the same block of eight sections in Leroy Township used for the tests with June 12th imagery. In this case, it was felt that the shifts in phenological conditions and color signatures between June 12th and August 5th were sufficiently large that the tests would be essentially independent despite use of the same area. The same three categories were used as for the June 12th imagery. The results of this test are presented in Table 11. It should be noted that the total acreages from ground truth are slightly different in Table 9 and Table 11, even though the same area is used for both tests. In the case of the tests on June 12th imagery presented in Table 9, the early phenological conditions and lack of an underflight early in the growing season made it necessary to rely on the ASCS certification records in conjunction with a June field visit for ground truth. For the August data presented in Table 7, however, the U-2 under-

Table 11. Results of photointerpreting S-190A imagery taken on August 5, 1973 for eight sections in Leroy Township, Ingham County, Michigan.

Category	Acres from S-190A CIR imagery	Acres from ground truth	Percent accuracy
Bare soil	432	557.5	77%
Forest	955	889.7	93%
Grass, forage, crops, etc.	3028	3219.2	94%
Overall	4415	4666.4	95%

flight from August 11, 1973 was used for scaling acreages and was supplemented as needed by the August field visit. The differences in source of "ground truth" account for the discrepancies in total acreage. Since the chances for uncontrolled recording errors and variation in scale of enlarged photocopies are greater, the ASCS certification records are less reliable than the U-2 underflight.

Overall accuracies for the forest and generalized crop categories in the August 5th test are 93 percent and 94 percent, respectively. Ratio correction was not necessary in this case. A probable explanation for the lack of negative bias in these categories for the August 5th test comes from the interpreter's prior experience with S-190B imagery. It is suspected that the knowledge of negative bias in the first effort made him more conscious of the need for interpolation in drawing boundaries between adjacent types in the second test. This variability of the interpreter's performance with experience again underscores the need for a double-sampling approach if low resolution imagery such as that from the S-190A is to be used in practical crop surveys. The final point relates to the underestimation of the bare soil category in the August 5th test giving an accuracy of only 77 percent. Interpreter bias is not a likely explanation in this case since the bare soil signature was quite distinctive. The amount of bare soil present on August 5th was relatively small and plowing of two or three large fields (in preparation for planting of wheat) during the week between the August 5th Skylab pass and the August 12th U-2 flight could account for the discrepancy.

Skylab 3 again passed over Michigan on September 18, 1973. Clouds obscured the Ingham County test area on that date, however, preventing further analysis of S-190A imagery. Examination of the imagery over cloud-free areas, however, revealed that the quality of the September imagery was considerably better than that of either the June or August sets. Section-mile roads were generally evident on both the conventional color and CIR filmstrips. This would simplify location of fields and probably would allow calculation of standard errors based on the section as a unit of observation.

In summary, the quality of S-190A imagery was highly variable between passes, between film/filter combinations in the same pass, and between duplicates of the same filmstrip. Since resolution was marginal for purposes of crop acreage estimation, utility varied directly with quality of the imagery. An assessment based on the average quality of color and CIR images is that a three-way breakdown of bare soil, forests, and "other" cover types can be accomplished with about 90 percent accuracy if double-sampling is used for developing ratio correction factors. However, the inability to accomplish a consistent breakdown of estimates by section or smaller units prevents calculation of standard errors for classifications made from the imagery. Furthermore, interpretation is a rather slow process because of difficulty in locating specific points in reference to maps or aircraft imagery. Separation of crop types could not be accomplished using imagery from a single date. Inability to distinguish individual fields would make development of temporal overlays of imagery from multiple dates difficult.

Analysis of S-190B Imagery

In addition to the S-190A multiband camera system, the Skylab EREP package also included the S-190B earth terrain camera. Salient features of the S-190B camera are f/4 lens with focal length of 18 inches, intervalometer settings from 0 to 25 frames per minute, shutter speeds of 5.7 and 10 milliseconds, and compensation for forward motion through programmed camera rotation from 0 to 25 milliradians/second. Film format is 5 inches with a 4.5 inch square image. This format with the 270 statute mile orbital altitude gives ground coverage of a square approximately 68 statute miles on a side at a contact scale of approximately 1:1,000,000. For purposes of the present project, the S-190B camera was loaded with SO-242 high-resolution aerial color film sensitive to wavelengths in the .4 - .7 micrometer region of the spectrum.

The S-190B camera system was operated over the Ingham County test area on August 5, 1973 and September 18, 1973. Since the test area was covered by clouds on September 18, analyses could be performed only on the August 5th imagery. A comparison of the S-190A and the S-190B imagery clearly shows that substantially better resolution was obtained with the S-190B system. Section-mile roads and most field boundaries are readily visible on the S-190B imagery when viewed under the magnification afforded by the Bausch & Lomb Zoom 240 equipment. Thus, measurement and comparison with ground truth can be performed on a field-by-field basis, including calculation of standard errors.

Phenological conditions existing on August 5, 1973 for the southern Michigan area have already been described in connection with analysis of S-190A imagery and will not be repeated here. Sections 2 - 8 of Locke Township in the Ingham County test area were used for the quantitative tests of photointerpretation with the S-190B imagery.

Two aspects of photointerpretive analysis for crop acreage assessment must be considered. The first is accuracy of acreage measurement. Area measurements from the Skylab imagery were performed under 15X magnification with an ocular grid on which the lines are spaced 0.25 mm apart. Given good equipment such as this, accuracy of acreage measurement is primarily a function of resolution and field size. The results of the quantitative tests on S-190B imagery with respect to accuracy of acreage measurement are summarized in Table 12. The figures contained in the columns of Table 12 labeled "no. of fields", "total acreage from ground truth", and "total acreage from S-190B" are self-evident. "Aggregate % error" is calculated as:

$$\text{Agg. \% error} = \frac{\text{Total acr. from S190B - Total acr. from ground truth}}{\text{Total acreage from ground truth}}$$

"Average signed error (acres)" is calculated as:

$$\text{Avr. signed error (A)} = \frac{\Sigma\ |\text{measured field size - actual field size}|}{\text{number of fields}}$$

"Average unsigned error (acres)" is calculated as:

$$\text{Avr. unsigned error (A)} = \frac{\Sigma\ |\text{measured field size - actual field size}|}{\text{number of fields}}$$

"Average % error" is calculated as:

$$\text{Avr. \% error} = \frac{100 \times \Sigma \left|\dfrac{\text{measured field size - actual field size}}{\text{actual field size}}\right|}{\text{number of fields}}$$

For calculation of "Std. Dev. of error (A)", the formula is:

$$\text{Std. Dev.} = \frac{\Sigma X^2 - (\Sigma X)^2 / n}{n - 1}$$

where

X = measured field size - actual field size

and

n = number of fields

The same formula applies for Std. Dev. of % error except that

$$X = \frac{100 \times (\text{measured field size - actual field size})}{\text{actual field size}}$$

There is a slight tendency toward underestimation as reflected in the overall aggregate percentage error of -6%. Only in the case of fields less than ten acres was there a tendency to overestimate acreage from the S-190B imagery. This small tendency toward underestimation can be attributed to limits of resolution along the field boundary, and should not constitute a limitation for use of the imagery in acreage assessment since a correction for bias could be obtained

Table 12. Results of tests on accuracy of acreage measurement from S-190B imagery taken on August 5, 1973 based on analysis of 7 sections in Locke Township, Ingham County, Michigan.

Field size (acres)	No. of fields	Total A. Gr. Truth	Total A. S-190B	Agg. % error	Avr signed error (A)	Avr unsign error (A)	Avr % error	Std. Dev. error (A)	Std. Dev. % error
0 - 10	45	295.1	300.0	1.66	.11	1.6	28.98	2.13	26.73
10+ - 20	64	962.0	952.5	-.99	-.15	2.9	19.50	3.79	15.27
20+ - 30	30	721.1	690.4	-4.26	-1.02	2.6	10.74	3.42	9.44
30+ - 40	16	549.7	460.0	-16.32	-5.61	5.8	16.74	5.10	13.86
40+ - 50	5	222.0	200.3	-9.77	-4.34	6.0	13.26	7.77	13.11
50+ - 60	2	101.9	69.6	-31.70	-16.15	16.2	31.63	5.02	9.37
60+ - 70	1	60.7	60.5	-.33	-.20	.2	.33	----	----
70+ - 80	5	367.3	331.1	-9.86	-7.24	7.2	9.94	4.62	6.68
80+ - 90	---	-----	-----	----	----	---	----	----	----
90+ - 100	1	91.9	75.6	-17.74	-16.30	16.3	17.74	----	----
100+	1	209.2	196.6	-6.02	-12.60	12.6	6.00	----	----
Overall	170	3580.9	3336.6	-6.82	-1.44	3.28	19.68	4.7	18.92

through a relatively small sample of fields. Although the smaller base for the percentage gives an inflated percentage error for individual fields less than 20 acres, there is no noticeable decline in ability to measure actual acreage as fields become smaller within the usual range of field sizes. Since a rather small percentage of the total crop is produced in fields less than 5 acres, the resolution obtained with S-190B is judged to be adequate for purposes of crop acreage assessment for major field crops. Further improvements in resolution would, however, be useful when working with minor crops such as vegetables which are often grown on small plots.

Besides measuring acreage of fields, one must be able to identify crop type from the imagery in order to do crop acreage assessment. The S-190B imagery has less utility in this regard than for acreage measurement per se.

The self-training procedure for the interpreter, as described earlier, involved the following steps:

1) Selection of training fields from ground truth;
2) Location of training fields on the imagery and description of their color signatures;
3) Correlation of signature with crop type and development of tentative categories for interpretation;
4) A test from imagery to ground truth to verify the suitability of categories.

The results of this training procedure as applied to the

August 5th S-190B imagery showed that bare soil had a distinctive signature that was whitish in tone. Forested areas were easily recognized by virtue of a very dark green color and rough texture. Senescent vegetation such as uncut oats and wheat had a light brown color which could be quite readily detected. The stubble of cut hay and small grains had a large contribution of soil to its signature along with a sparse cover of vegetation which combined to give a very light green tone. Mature corn which was well-tasselled gave a brownish-green signature. However, no other categories were consistently separable since all other crops along with corn which had not yet tasselled had a medium green tone.

Classification results for the operational test over 7 sections in Locke Township are presented in Table 13. In this table, fields are grouped into five categories according to ground truth information. The combined "stubble and senescent vegetation" category includes all small grains along with some recently cut fields of hay. All crops with the exception of small grains, stubble fields, and corn are included in the "other" category along with such miscellaneous types as nonforested wetlands and farmsteads.

Sixteen of the 18 bare soil fields were correctly classified for an accuracy of 89 percent. The other two bare soil fields were misclassified as stubble, probably due to the invasion of sparse weeds which darkened the signature.

The fact that 15 of the 45 corn fields were not recog-

Table 13. Classification results for August 5, 1973 S-190B imagery based on interpretation of 7 sections in Locke Township, Ingham County, Michigan.

Category from ground truth	No. of fields	Total acres	Correctly classed # fields	Correctly classed % fields	No. of fields wrongly classified as -- Soil	Corn	Br/woods	Stub/senesc	Other
Bare soil	18	252.3	16	89%	0	0	0	2	0
Corn	45	1100.1	25	56%	0	0	0	0	20
Brush/woods	17	399.4	17	100%	0	0	0	0	0
Stubble/senescent	20	315.1	12	60%	0	3	0	0	5
Other	70	1514.0	63	90%	1	2	0	4	0
Overall	170	3580.9	133	78%	1	5	0	6	25

nized as corn is due to the presence of dual signatures for this crop as mentioned earlier. The tasselled corn was classified correctly due to the distinctive brownish-green signature, while the fields of corn which had not yet tasselled were classified in the "other" category.

Twelve of the twenty "stubble and senescent vegetation" (uncut small grain being the main type of senescent vegetation at that date) fields were classified correctly for an accuracy of only 60 percent. Lack of accuracy in this category is not too surprising due to the variable nature of the targets. Grass and low weeds below the level of the cutter bar may contribute a green cast to the signature, which accounts for the five fields misclassified as belonging to the "other" category. Also, the presence of wheat or oat straw on such low weeds can give a cast similar to that of tasselled corn, which accounts for the three fields classified as belonging to the "corn" category.

There are a variety of possible reasons for errors of classification in the "other" category which will not be discussed here.

Difficulty in discriminating crop types on the basis of color signature alone from conventional color imagery is not surprising. Several support missions were flown for ERTS investigations at MSU with the RB-57 high-altitude aircraft. These missions included simultaneous coverage with both conventional color and CIR imagery at a scale of approximately 1:120,000. The signatures of cover types on the conventional color imagery were quite washed-out and exhibited little contrast between cover types in comparison to the CIR imagery. With the RB-57 imagery, however, texture provides more supplemental clues to identification than is the case with S-190B imagery from Skylab.

An overall assessment of the S-190B imagery for purposes of crop acreage assessment is that resolution is adequate for acreage measurement, but the natural color film does not provide enough contrast in signatures between cover types to allow detailed classification from imagery obtained on a single date. Since the tests did show quite distinctive signatures for bare soil and senescent vegetation, temporal overlays are a good possibility for obtaining more detailed classifications. Winter wheat, for example, is green in late fall, green in spring, and becomes senescent in mid-summer. Fields devoted to other small grains would be bare soil during the planting season, green during the early growing season, and senescent in mid-summer. Corn and beans would both show a pattern of transition from bare soil to green from spring to summer, but corn could be distinguished at the tassel stage. Since cloud-free S-190B imagery over the Ingham County test area was only obtained for one date, there was no opportunity to pursue the question of temporal overlays in this project.

Another means to obtain better detail of classification is through development of CIR film with a resolution equivalent to that of the SO-242 high-resolution aerial color film. CIR film gives more variation in signatures between crop types and is less affected by atmospheric haze than conventional color film.

Since time required to interpret the S-190B imagery influences both cost of surveys and speed with which the results become available, this aspect must also be considered. After the interpretations discussed previously had been completed, the interpreter performed a time study for which the results are summarized in Table 14.

Table 14. Results of time study for interpretation (including acreage measurement) of S-190B imagery.

Field size (acres)	No. of fields	Avr. interpretation time per field (sec.)	Std. Dev. (sec.)
0 - 20	72	58.4	33.4
20+ - 40	21	67.4	29.2
40+ - 60	5	80.8	51.1
60+	5	87.2	37.0
overall	103	62.7	34.1

Time required for interpretation of a field increases somewhat with its size as expected, but this increase is not linear. In fact, other variables such as shape of field and contrast along the borders are as important as field size in determining time required for interpretation. Therefore, the overall time of 63 seconds/field with standard deviation of 34 seconds provides a reasonable figure for cost calculations. Using the average field size in the test area of about 20 acres (Table 1), there are approximately 32 fields per standard section (640 acres). Thus, the expected time required to interpret a section is approximately 34 minutes; and about 20 hours would be required per township. It should be noted that these figures apply only to thoroughly trained and experienced interpreters. The actual time required in an operational setting would probably be somewhat longer because the interpreter would become progressively more tired if he/she interpreted for a full eight hour day instead of for the partial day spent on photo-interpretation in this study.

Development of Signatures Multispectral Scanner Data

Signature extraction was performed on field center pixels to obtain pure signals. Field center pixels contained no boundary areas and exclude mixtures except for those classes, i.e. urban areas, that contain a more uniform, defined mixture. Each spectral signature consists of a mean vector and a covariance matrix calculated from selected SDOs. The procedure employed to extract the recognition signature is described in this appendix.

The test area included 90 sections which was divided into two portions, the northern portion containing 40 sections and the southern 50. The northern 40 sections were used as the training site. One objective was to study the relationship between recognition accuracy and the amount of information used for training. Therefore, three sets of recognition signatures were formed using 10, 20, and all 40 sections for training. To select the 10 and 20 section subsets used, all 40 sections were numbered and ranked according to a random number table. Table 15 gives the resulting rankings. The first 10 and 20 sections were used to form the 10 and 20 section signature sets.

Table 15. Ranking of 40 northern sections used to select 10 and 20 section subsets.

RANK	SECTION	RANK	SECTION	RANK	SECTION	RANK	SECTION
1	Locke 11	11	Locke 7	21	Leroy 10	31	Locke 18
2	Leroy 5	12	Locke 22	22	Locke 16	32	Locke 2
3	Locke 20	13	Locke 15	23	Locke 30	33	Locke 23
4	Leroy 6	14	Leroy 3	24	Leroy 2	34	Locke 17
5	Locke 29	15	Locke 6	25	Locke 21	35	Locke 3
6	Leroy 4	16	Locke 32	26	Locke 4	36	Locke 10
7	Leroy 11	17	Locke 34	27	Locke 9	37	Locke 5
8	Locke 35	18	Locke 31	28	Locke 14	38	Locke 26
9	Leroy 9	19	Locke 8	29	Locke 27	39	Locke 28
10	Locke 19	20	Locke 33	30	Leroy 7	40	Leroy 8

Signature extraction was completed by the use of a clustering algorithm implemented at ERIM.[1/] For the Skylab

1/ Horowitz, H.M., Lewis, J.T., Pentland, A.P. "Estimating Proportions of Objects from Multispectral Scanner Data," Report No. 109600-13-F, Environmental Research Institute of Michigan, May 1975.

S-192 data, a supervised form of clustering was used which clustered field center pixels of each class or subclass independently. Thus, several distinct signatures were produced for each class and no signature was contaminated with pixels from other classes. Trees and brush were differentiated and clustered as separate subclasses. Also, the various forage subclasses were clustered as six different subclasses: grass, pasture, weeds, clover, stubble, and alfalfa.

Clustering was performed on 12 of the SDOs, selecting one SDO from each detector. SDO 18 had many large anomalies which served to confuse the results and was omitted. The SDOs used for clustering were: 2, 4, 6, 8, 10, 12, 14, 17, 19, 20, 21, 22. The clustering procedure created 24 signatures for the 40 section set, 19 for the 20 section set and 13 for the 10 section set. The distribution of the signatures is given in Table 16.

Since the cost of classifying is highly dependent upon the number of signatures and the number of bands of SDOs, the next step was to reduce the number of signatures. The three urban signatures were discarded because the urban area represented only a small portion of the scene, was located in part of one section and because the main interest was in discriminating among the agricultural ground covers.

An expected performance matrix was generated for the linear rule classifier for the remaining signatures, and signatures were combined when they appeared redundant. Much

Table 16. Number of cluster signatures created for each ground cover class of designation for the 40, 20, and 10 section training

SIGNATURE LABEL	40 SECTION	20 SECTION	10 SECTION
CORN	4	4	4
BARE SOIL	1	2	1
STUBBLE	1	2	1
ALFALFA	1		
TREES	2	2	
BRUSH	1	2	2
SOYBEAN	1		
GRASS	4	2	2
PASTURE	4	3	2
WEED	1	2	1
CLOVER	1		
URBAN	3		
TOTAL	24	19	13

of the redundancy was due to the fact that some ground cover classes were represented by more than one designation or label, and thus two cluster signatures were formed for what represented only one spectral class. Examination of the signatures indicated that the weed signature was highly correlated with one of the grass signatures, and a pasture signature was highly correlated with another grass signature. Some signatures were completely discarded if the expected performance matrix indicated that pixels forming that particular cluster signature would be recognized by other signatures from the same ground cover class. This was true of the clover signature, a pasture signature, and the stubble signature given that stubble is spectrally similar to grass and should be recognized by signatures from that class. The final signature set consisted of 15 signatures including 4 corn, 2 tree, 1 brush, 1 alfalfa, 1 soybean, 1 bare soil, and 5 grass.

Although the cost of classifying is dependent upon the number of signatures, the reduction in number accomplished by the procedure described above could not be accomplished in an expedient manner when required. Therefore, the original cluster signatures were used as the final signatures for the 20 and 10 section training. Thus, though fewer clusters signatures were formed for the 20 and 10 section training set, the final 20 section signature set had more signatures than the final 40 section set.

To further reduce the cost of the classifier, the number of signal bands were reduced. The tradeoff involved here is that the fewer number of channels used the lower the cost of processing, while increased accuracy comes from using a greater number of channels. First, the channels were ranked according to a criterion based on the average pairwise probability of misclassification. The best band was selected, then the band which with the one chosen is best, etc. We calculated the theoretical probability of misclassification (POM) as a function of the number of channels in the decision rule and chose the best n channels where the decrease in POM between using n and n + 1 channels became less than 0.005. This analysis indicated that SDOs 6, 19, and 20 provided little aid in discriminating between major ground cover types in this data set so they were excluded from further study. The SDOs used for each training set are given in Table 17.

Table 17. SDOs used for the 40, 20, and 10 section recognition signatures.

Training Set	SDOs	Total No. of SDOs
40 Section	2, 8, 10, 12, 17, 19, 20	7
20 Section	2, 8, 10, 12, 14, 17, 19, 20	8
10 Section	2, 10, 12, 14, 17, 19	6

Root mean square (RMS) errors were calculated to evaluate the performance of proportion estimation in both the northern and southern portions of the test site. Since recognition results were calculated section-by-section and then aggregated by class for the test area under consideration, RMS errors were calculated in two ways. One way is by recognition class aggregated over the test area; this is a measure of overall performance. The second was section-by-section for an individual class.

RMS errors were calculated as follows:

$$\text{ERMS} = \frac{1}{N} \sum_{i=1}^{N} (p_i - \hat{p}_i)^2$$

where

p_i = ground truth proportion for one recognition class for the test area (or for one section)

$\hat{p}_i$ = estimated proportion for the same recognition class for the test area (or the same section)

N = number of recognition classes (or number of sections) considered.

When N represents recognition classes, there usually is no qualifying decription added to "RMS error" in the main body of text. When N represents sections, the RMS error is identified as "section-by-section RMS error."

Recognition Results of Applying Signatures to S-192 Data

The results are developed as two subsets. One is for the northern area where the data was used to obtain the signatures. The other is for the remaining or southern area which is contiguous with the northern area. Recognition results for the northern 40 sections will be referred to as local recognition, regardless of the number of sections used for training, since the signatures are based on information from the area even if not from every section. In all cases, the ERIM linear decision rule[1/] was used with a threshold corresponding to an infinitesimal probability of false rejection of signals from

1/ Crane, R., W. Richardson, R. Hieber, and W.A. Malila, "A Study of Techniques for Processing Multispectral Scanner Data," Report No. 31650-155-T, Environmental Research Institute of Michigan, January 1973.

the assumed multivariate normal distributions. As discussed in the preceding section, a number of recognition signatures were obtained for each recognition class through the use of a supervised clustering procedure.

To obtain pure signals for various ground cover classes, field center pixels were defined so as to contain no boundary elements and in general exclude mixtures except for certain classes which contain more uniform, defined mixtures, i.e. urban areas. Results are first reported for recognition of only field center pixels since discrimination of ground covers will be optimum if the signals are from pure ground cover classes, instead of composites of several ground cover types. Results for recognition of whole areas, including boundary pixels, are reported later.

Tables 18 - 20 present performance matrices obtained for field center pixels using 40, 20, and 10 sections for training. Each matrix indicates both the number of pixels in each ground truth class and how these pixels were apportioned among the various recognition classes by the decision algorithm. At the bottom of each table are the percentage of total pixels recognized by each recognition signature and the percentage of field center pixels belonging to each signature class according to the ground truth. The major ground truth classes are corn and grass, each with a third or more of the field center pixels. The recognition class "forage" included grass, alfalfa, and/or stubble signatures.

Table 18. Performance matrix for classification of field center pixels from north 40 sections using 40 sections for training.

Percent of field center pixels assigned to recognition class:

Ground truth class	No. Pixel	Corn	Forage	Tree/Brush	Bare soil	Soybean	Unclassified
Corn	344	73.0	6.4	18.1	0.3	1.7	0.6
Forage	474	8.9	81.4	3.8	3.6	1.7	0.6
(Grass 398)		(7.3)	(83.7)	(4.6)	(2.5)	(1.3)	(0.8)
(Alfalfa 23)		(21.7)	(69.5)	(0.0)	(0.0)	(8.7)	(0.0)
(Stubble 53)		(15.1)	(69.8)	(0.0)	(13.2)	(1.9)	(0.0)
Tree/Brush	92	26.1	17.4	51.1	0.0	0.0	5.4
(Trees 24)		(4.2)	(20.8)	(75.0)	(0.0)	(0.0)	(0.0)
(Brush 68)		(33.8)	(16.2)	(42.6)	(0.0)	(0.0)	(7.4)
Bare soil	38	13.2	7.9	0.0	79.0	0.0	0.0
Soybean	19	31.6	10.6	0.0	0.0	57.9	0.0
Urban	69	58.0	30.4	0.0	11.6	0.0	0.0
Total	1036	35.5	43.4	12.3	5.4	2.4	1.0
Excluding urban	967	33.9	44.4	13.1	5.0	2.6	1.0
Ground truth (%)		33.2	45.8	8.9	3.7	1.8	6.7
Excluding urban		35.6	49.0	9.5	3.9	2.0	0.0

RMS error in proportion estimation (%) = 3.12
2.57 (Excluding urban)

Overall percent correct classification of pixels = 70.0%
75.0% (Excluding urban)

Table 19. Performance matrix for classification of field center pixels from north 40 sections using 20 sections for training.

Percent of field center pixels assigned to recognition class:

Ground truth class	No. pixels	Corn	Forage	Tree/Brush	Bare soil	Unclassified
Corn	344	83.7	10.8	3.4	0.9	1.2
Forage	474	8.6	86.3	1.7	1.5	1.9
(Grass 398)		(7.5)	(88.5)	(2.0)	(0.5)	(1.5)
(Alfalfa 23)		(34.8)	(60.9)	(0.0)	(0.0)	(4.4)
(Stubble 53)		(5.7)	(81.2)	(0.0)	(9.4)	(3.8)
Tree/Brush	92	35.9	14.1	45.7	0.0	4.3
(Trees 24)		(25.0)	(12.5)	(62.5)	(0.0)	(0.0)
(Brush 68)		(39.7)	(14.7)	(39.7)	(0.0)	(5.9)
Bare soil	38	0.0	5.3	0.0	86.8	7.9
Soybean	19	84.2	5.3	10.5	0.0	0.0
Urban	69	44.9	31.9	0.0	14.5	8.7
Total	1036	39.5	46.7	6.2	5.1	2.5
Excluding urban	967	39.1	47.8	6.6	4.4	2.1
Ground truth (%)		33.2	45.8	8.9	3.7	8.5
Excluding urban		35.6	49.0	9.5	3.9	2.0

RMS error in proportion estimation (%) = 4.14
2.11 (Excluding urban)

Overall percent correct classification of pixels = 75.1%
79.8% (Excluding urban)

Table 20. Performance matrix for classification of field center pixels from north 40 sections using 10 sections for training.

Percent of field center pixels assigned to recognition class:

Ground truth class	No. pixels	Corn	Forage	Tree/Brush	Bare soil	Unclassified
Corn	344	82.9	10.8	2.9	1.2	2.3
Forage	474	16.0	78.3	2.3	1.5	1.9
(Grass 398)		(15.3)	(80.7)	(1.8)	(0.5)	(1.8)
(Alfalfa 23)		(43.5)	(47.8)	(4.4)	(0.0)	(4.4)
(Stubble 53)		(9.4)	(73.6)	(5.7)	(9.4)	(1.9)
Tree/Brush	92	64.1	10.9	16.3	0.0	8.7
(Trees 24)		(83.3)	(12.5)	(0.0)	(0.0)	(4.2)
(Brush 68)		(57.4)	(10.3)	(22.1)	(0.0)	(10.3)
Bare soil	38	0.0	52.6	0.0	47.4	0.0
Soybean	19	79.0	21.1	0.0	0.0	0.0
Urban	69	15.9	62.3	0.0	14.5	7.3
Total	1036	43.1	46.8	3.5	3.8	2.9
Excluding urban	967	45.0	45.7	3.7	3.0	2.6
Ground truth (%)		33.2	45.8	8.9	3.7	8.5
Excluding urban		35.6	49.0	9.5	3.9	2.0

RMS error in proportion estimation (%) = 5.65
5.18 (Excluding urban)

Overall percent correct classification of pixels = 67.0%
71.3% (Excluding urban)

Examination of Table 18 reveals that correct recognition with 40 training sections ranges from 83.7 percent for grass to 42.6 percent for brush, with 73.0 percent for corn and an overall average of 70.0 percent. The urban class did not have a specific recognition signature and was recognized by forage, bare soil and corn signatures. Bare soil and grass would be expected in an urban scene, but the corn detections must represent mixture pixels, such as mixtures of trees or shrubs and grass. Many of the pixels recognized as bare soil probably represent concrete and buildings. Since exclusion of urban areas is a common procedure in agricultural applications, the totals in Table 18 exclude the urban pixels. The performance matrix indicates that 69.8 percent of the stubble pixels were recognized as forage, with most of the remainder split between bare soil and corn. That some stubble would be recognized as bare soil is not surprising since newly mowed stubble would contain much exposed soil. Many missed detections of brush were due to the corn signature, with as many brush pixels being incorrectly assigned to corn as were correctly recognized as tree/brush. Corn missed detections tended to be assigned to tree/brush signatures with some pixels misclassified as grass. Missed detections for the remaining ground cover classes were largely due to the corn and forage signatures.

Ground truth and recognition percentages have been calculated for two cases. First, urban areas were included and considered to belong to the unclassified category and then the percentages were recalculated excluding the urban areas and urban pixels. A comparison of the recognition and ground truth percentages for the different ground truth classes shows close agreement for all but urban (unclassified), even for tree/brush which had only 42.6 percent correct recognition of brush field center pixels. The root mean square (RMS) error in overall proportion estimates in only 2.6 percent, excluding urban areas. Thus, compensating errors produced accurate estimates of the signature-class proportions of field center pixels. Proportion estimates for whole areas, including boundary as well as field center pixels, are discussed below.

When 20 sections were used for training, the signatures were not formed in the same manner as for the 40 section training. This was explained in the preceding section as was the fact that a different number of S-192 channels was used for recognition. Although different numbers and types of signatures were obtained, a constant set of recognition classes was maintained except for soybeans which did not have enough field center pixels in either the 20 or 10 sections to form a signature. Also, there were not enough pixels for a specific alfalfa signature for the "forage" recognition class in any but the 40 section case.

Table 19 is the performance matrix for recognition over the northern 40 sections using the 20 section signatures. Correct recognition ranges from 88.5 percent for grass to

39.7 percent for brush, with 83.7 percent for corn, 86.8 percent for bare soil, and an overall average of 75.1 percent. Bare soil recognition accuracy improved substantially, with none of the bare soil being misclassified as corn as compared to 13.2 percent with the 40 section training. However, tree recognition accuracy reduced by 13 percentage points. For the 40 section training, forage signatures were responsible for many of the missed tree detections (20.8 percent), but with the 20 section training, corn was responsible for twice as many missed detections as forage, 25 percent versus 12.5 percent. Although the percent of brush correctly recognized is the same as for the 40 section training, the number of pixels misclassified as corn increased. On the other hand, corn recognition accuracy improved by 10 percent. As a result, the percentage of field center corn pixels was overestimated by 4 to 6 percent.

Since there were no signatures for soybeans or urban, these two ground covers could not be correctly recognized. Urban pixels were classified much like they were with the 40 section signature, while 84.2 percent of the soybeans were recognized as the corn signatures.

As with the 40 section training signature set, there is a fairly close agreement between total recognition and ground truth percentages for the various recognition classes. The estimation is especially close when the urban pixels are omitted from the calculations.

When 10 sections were used for training, there also were insufficient field center pixels for a specific signature for dense tree stands. Table 20 gives the performance matrix for the classification of the northern 40 sections with the 10 section signature set. Correct recognition ranges from 82.9 percent for corn to 22.1 percent for brush and 0.0 percent for trees, with an average of 65.3 percent. Brush recognition accuracy is greatly reduced compared to either the 40 or 20 section results. Two and a half times as many brush pixels were misclassified as corn as were correctly recognized as brush. Bare soil recognition accuracy decreased greatly, to 47.4 percent, with more pixels being recognized as forage than as bare soil. Grass was 80.7 percent recognized with 15 percent being misclassified as corn. Corn recognition also was high. Stubble was not as well recognized (73.6 percent) as it was with the 20 section training set; most missed detections were due to the bare soil (9.4 percent) and corn (9.4 percent) signatures. A majority of urban pixels were recognized by forage signatures.

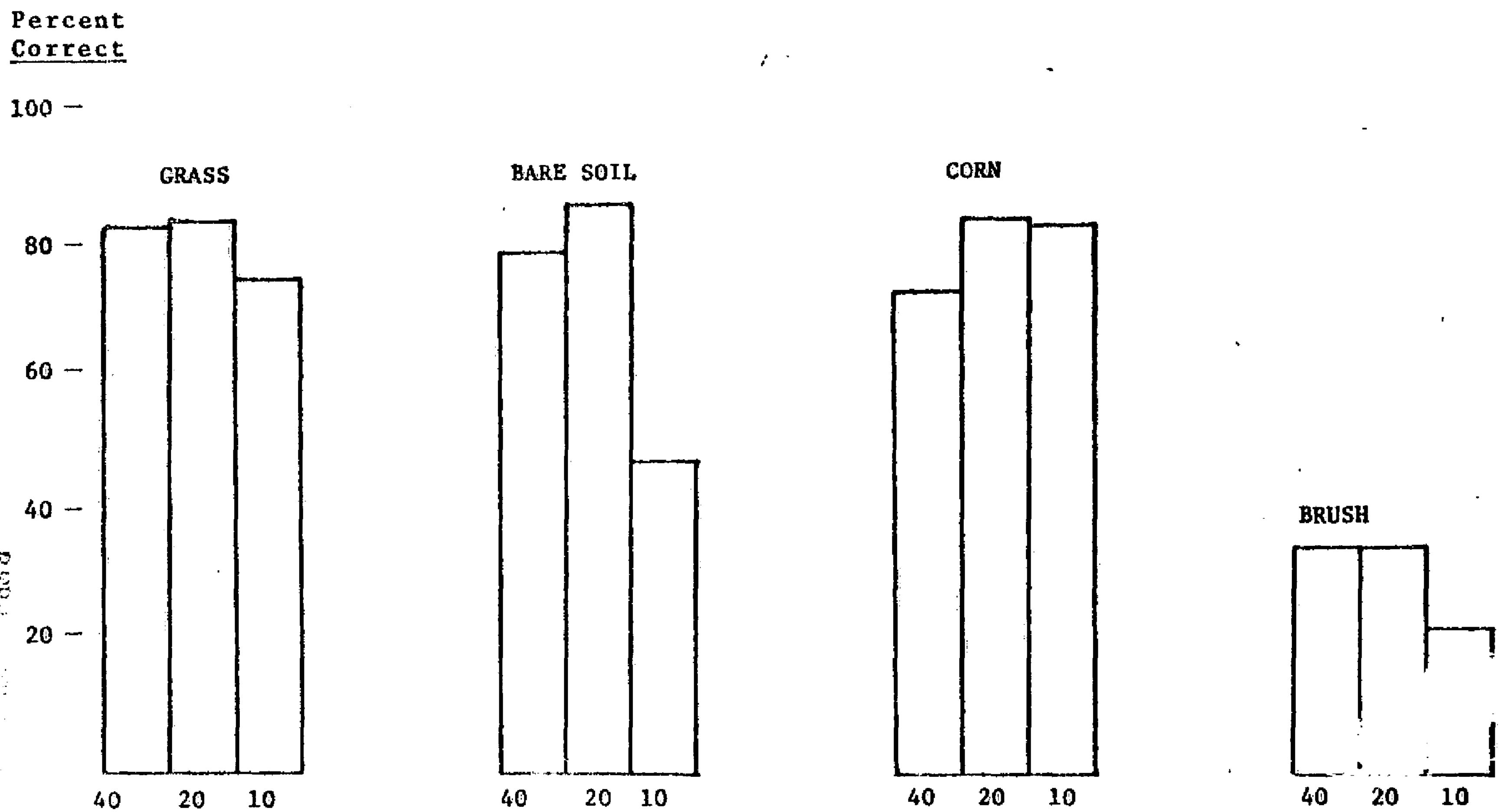
An examination of the recognition and ground truth percentages for the ground truth classes shows that the corn estimates is high by approximately 10 percentage points for these 10 section signatures. The tree/brush estimate is less than half the amount of trees and brush present according to the ground truth, and the RMS error of the estimates is greater than for the other signature sets.

Figure 10 gives the percentage of correct recognition for the four ground truth classes which had specific subclass signatures in all three signature sets. The 20 section results are slightly better than the 40 section results for all classes. It would be expected that the 20 section training set should give reduced recognition results since there was less information available for training. However, different training procedures were used and some of the original 40 section signatures extracted by clustering were omitted and others were combined for the final signature set. All of the original 20 section cluster signatures were used for classification, so in this respect the 20 section set contained more information than the 40 section signature set. Also, one additional channel was used for recognition with the 20 section signatures. The 10 section training procedure was the same as for 20 sections, and the 10 section results are always poorer when compared to the 20 section results. In the cases of bare soil and brush, the decrease is large.

Table 21 gives the root mean square (RMS) error for the percentage estimation of field center pixels over all sections using signatures bases on 40, 20, and 10 sections. Errors were calculated both with and without the urban pixels. The RMS errors show that when all signature classes are considered the RMS error in field center proportion estimates increases with a decrease in the number of sections used for training.

Although field center pixel recognition results indicate

Figure 10. Comparison of correct recognition over field center pixels for four ground cover classes using 40, 20 and 10 sections for training.



Signature class and number of sections used for training.

Table 21. RMS errors in proportion estimation of field-center pixels over the northern 40 sections.

# TRAINING SECTIONS	40	20	10
RMSE (%) With Urban	3.11	4.36	5.65
RMSE (%) Without Urban	2.57	2.11	5.18

the upper limit of recognition performance, the accuracy of acreage estimates provides a better measure of the usefulness for the prupose of crop acreage estimation. Acreage estimates can be calculated by tallying the recognition results for all pixels, section-by-section, over all 40 sections. When all pixels are tallied, boundary pixels and other pixels which are mixtures are included in the tabulations. The results are evaluated here by calculating the root mean square (RMS) error for each section and for each signature class. An overall RMS error by class also was calculated.

Table 22 displays the aggregated recognition results over all pixels in the 40 section test site. The proportion estimates (expressed as percentages) of the six ground cover classes are compared to the ground truth proportions, and overall RMS errors are presented. The RMS error is seen to be inversely proportional to the number of sections used for training comparing Table 22 to Tables 18, 19, and 20 makes it clear that the error in estimating the proportions of all pixels in the test site is considerably higher than the error in estimating the proportions of the field center pixels.

Table 22. Percentages of 6 ground cover classes and recognition percentages over 40 northern sections using signatures from 40, 20, and 10 sections.

Ground Cover	Ground Truth	Training Data 40 Section	20 Section	10 Section
Corn	26.5	36.8	41.2	46.4
Tree/Brush	17.2	14.3	7.4	2.7
Forage	42.4	40.5	43.7	42.5
Bare Soil	7 2	5.4	4.0	4.8
Soybean	3.7	2.4	0.0	0.0
Other	3.1	0.4	3.7	3.7
RMS Error		4.661	6.352	10.103

Another observation that can be made about the data of Table 22 is that the proportion of corn was overestimated in each instance and got progressively worse as less training was used. On the other hand, the proportion of forage (the other major ground cover class) was accurately estimated and was not dependent on the training set used. Trees and brush were always underestimated and became more so as less data were used for training.

Table 23 gives the RMS errors calculated over sections for each of five ground cover classes. Here as in Table 22, the RMS error increases as the number of sections used for training decreases. This trend is also found within each ground cover class, with two exceptions. First, the RMS error for the bare soil class is slightly larger for the 20 section training set than for 10 sections. Second, the RMS error for "other" decreases slightly as the number of training sections decreases.

Table 23. Section-by-section RMS error calculated per ground cover class for 40, 20, and 10 section training sets.

Training Set	Corn	Tree/Brush	Bare Soil	Forage	Other
40 Sec.	13.776	7.418	4.363	9.679	8.492
20 Sec.	17.198	11.918	5.262	10.542	7.942
10 Sec.	23.108	16.927	4.927	11.976	7.604

Since it is very costly in time and resources to collect ground truth and accurately identify fields for training, it is desirable that training signatures from one area be applicable to adjacent areas. Such use of signatures for recognition in areas other than where they are formed is termed nonlocal recognition. Forty-eight [1/] sections from the southern portion of the test area were used to test the accuracy of nonlocal recognition using unadjusted signatures from the nothern portion. A tenfold increase in the number of tree pixels is the major compositional difference between the south and the north portions. In addition, field beans are present in the south but not in the north, while urban areas are missing from the south.

Table 24 gives the performance matrix obtained for field center pixels from the southern portion of the test area using the 40 section signatures from the northern portion. Recognition accuracy ranges from 76.1 percent for corn to 0.0 percent for field beans (a crop not present in the training area), with an overall 63 percent correct classification of the field center pixels. A total of 23.9 percent of the forage, 67.9 percent of field beans, and 31.5 percent of trees and brush were misclassified as corn. Trees were 55.8 percent correctly recognized, while soybeans tended to be recognized as forage. Most missed detections of bare soil were misclassified as forage (30.2 percent).

The root mean square (RMS) error for nonlocal proportion estimation of field center pixels from the southern portion

---

1/ Two other sections in the southern portion are not useable because they are completely cloud-covered on the U-2 acquired imagery which were used to generate the field identifications in this area.

Table 24. Performance matrix for classification of field center pixels from south 48 sections using signatures from north 40 sections.

Percent of field center pixels assigned to recognition class:

Ground truth class	No. pixels	Corn	Forage	Tree/Brush	Bare soil	Soybean	Unclassified
Corn	549	76.1	8.0	14.0	0.0	1.8	0.0
Forage	355	23.9	68.7	2.0	3.9	29.0	0.0
(Grass 264)		(21.6)	(74.3)	(2.7)	(0.0)	(1.5)	(0.0)
(Alfalfa 20)		(80.0)	(20.0)	(0.0)	(0.0)	(0.0)	(0.0)
(Stubble 71)		(16.9)	(62.0)	(0.0)	(19.7)	(1.4)	(0.0)
Tree/Brush	308	31.5	12.3	51.9	0.0	2.6	1.6
(Tree 269)		(32.7)	(8.6)	(55.8)	(0.0)	(1.1)	(1.9)
(Brush 39)		(23.1)	(38.5)	(25.6)	(0.0)	(12.8)	(0.0)
Bare soil	43	4.7	30.2	2.3	62.8	0.0	0.0
Soybean	52	15.4	65.4	0.0	0.0	19.2	0.0
Field bean	56	67.9	28.6	3.6	0.0	0.0	0.0
Total	1363	47.5	28.6	18.1	3.0	2.4	0.4
Ground truth (%)		40.3	26.0	22.6	3.2	3.8	4.1

RMS error in proportion estimation (%) = 3.97

Overall percent correct classification of pixels = 63.0%

of the test site is 3.97 percent, 1.3 times larger than the error for local recognition in the north. Comparison of the ground truth percentages to the total field center recognition percentages (Table 24) shows the largest error was an overestimation of corn pixels, with underestimates of trees/brush and field beans (unclassified).

The signature set formed using all 40 sections in the northern portion of the test site also was used to estimate proportions of the ground cover classes over the entire southern portion of the test site, including nonfield-center pixels. In Table 25, the proportion estimates are compared to the ground truth proportions, and with results obtained locally in the north. The RMS error is considerably higher for the nonlocal recognition. Examination of the estimates for each ground cover class show that the major discrepancy in the south 48 sections is an even larger overestimate for corn that was obtained for the north 40 sections. Proportions for most other ground covers were underestimated.

Table 26 displays the section-by-section RMS error for each ground cover class for the recognition over both the northern and southern portions of the data. As is expected, the errors are higher in the southern portion of most ground cover classes; the only exception is tree/brush. The largest differences in errors for the two areas are for corn and bare soil.

Results for proportional area estimation over the entire

Table 25. Ground truth proportions and recognition estimates for local (north 40) and non-local (south 48) recognition over large areas.

	North 40 sections		South 48 sections	
Ground cover class	Ground truth	Recognition results	Ground truth	Recognition results
Corn	26.5	36.8	33.3	48.0
Trees/Brush	17.2	14.3	16.5	13.3
Forage	47.4	40.5	35.5	30.9
Bare soil	7.2	5.4	7.2	3.3
Soybeans	3.7	2.4	4.0	4.4
Other	3.1	0.4	4.7	0.0
RMS error	4.661		6.891	

northern portion of the test site showed that the RMS error of proportion estimates did increase substantially as lesser amounts of data were used for training. This was true both for errors in the estimated overall proportions in the test site and on a section-by-section basis within each crop type. The major overall error was an overestimate of the proportion of corn in the test site. The overestimate became larger as less training data was used, with the proportion of trees and brush being underestimated correspondingly. The section-by-section RMS errors for these two classes follow the same pattern.

Table 26. Section-by-section RMS error (in percent) for proportion estimation of north and south portions of test site (40 section signatures).

Site	Corn	Tree/Brush	Soybeans	Bare Soil	Forage	Other
N	13.776	7.288	4.983	4.363	9.679	5.901
S	17.000	7.225	5.649	7.374	10.953	7.798

Interpretation of results for the classification of field-center pixels with the same test area is confounded by the fact that slightly different training procedures were with 40 sections than with 20 and 10 and that different numbers of S-192 spectral channels were used in the three cases. The overall correct percentage for 40 training sections is greater than that for 10 sections, but less than that for 20 sections. However, the relative ranking of percentages is directly related to both the number of channels used and the number of recognition signatures used. Thus, the results obtained do not by themselves lead to a clearcut conclusion about the effects that the amount of data used for training might have on field-center classification performance, although one would expect, in general, that results would improve as the amount of training data was increased.

Some discussion of the observed recognition results and possible reasons for them is in order. Corn was represented by two major and two minor clusters in each training set. There were enough corn pixels available so that the major clusters, at least, remained relatively constant from set to set. The observed differences in corn recognition then are more directly related to the other signatures that were developed. Trees and brush were the major competing signatures and captured 18 percent of field-center corn pixels in the 40 section case. This reduced to 3.4 percent in the 20 section case. The major difference in brush signatures was that a single large cluster overlapping the two major corn clusters was found in the 40 section case and two smaller clusters found for 20 sections.

An examination of signature plots showed that the 40 section brush cluster substantially overlapped the major corn clusters. Evidently, the corn/brush decision boundaries were shifted sufficiently, when the brush was represented by two clusters (20 section training), to cause a substantial increase in corn classification and decrease in brush classification.

Another result of the smaller number of pixels available for training was that clusters contained fewer pixels and consequently were not as representative of ground cover classes in the test site. The extreme case was trees for which there were insufficient training pixels to form a recognition signature in the 10 section case.

In conclusion, the crop recognition accuracy which was achieved during this investigation was shown to be related to the amount of data available for training the computer. Accuracy increased as 10, 20, and the 40 sections were made available for extracting training statistics via a supervised clustering approach. Even with 40 sections available for training, however, the average absolute accuracy of roughly 70 percent for 5 classes was somewhat disappointing. These relatively low values were attributed to the facts that:

1) the data were gathered at a non-optimum time in early August when corn, and other crops were quite variable in their state of maturity,
2) the atmospheric conditions over the test site were were fairly hazy thereby reducing available contract and,
3) the data gathered by the S-192 had some signifi-

cant dificiencies with regard to signal-to-noise ratio in some bands, the dynamic range covered by the signals, and channel-to-channel spatial registration.

In order to more fully address the question of crop survey accuracy attainable with multispectral scanners and automatic processing systems, additional studies should be undertaken using data gathered with other sensors at other times and at other locations.

Mixtures Processing to Improve Estimates from S-192 Data

When a spatial resolution element overlaps the boundary between two or more ground classes, the radiation detected is a mixture from the classes involved. The spatial resolution of the Skylab S-192 scanner is such, compared to the size of the fields or areas of the ground cover classes, that the frequency of mixture pixels is expected to be fairly large. The use of conventional multispectral processing techniques on mixture pixels will likely result in an increased probability of improper classification.

Conventional processing techniques rely on compensating errors to cancel the effects of misclassifications or on some fixed bias in the estimate which is measurable to produce accurate proportion estimates. The results reported above indicate that the errors do not always compensate.

ERIM has developed special processing techniques 1/ to handle such situations. These techniques recognize that pixels may contain mixtures of different ground covers and estimate the proportions of each class present in a pixel.

The mixture algorithm first determines the most probable single signature for a pixel and the attendant chi-square value 2/ Next, the proportions of the most probable pair of classes and an associated chi-square value are calculated for the pixel. The pixel may be further analyzed as a mixture of three or four classes. For reasons of processing time and computer space requirements, consideration here was limited to either pure or two-class mixture pixels. This is not an unrealistic restriction when one considers that in an agricultural area like the current data set, most mixture pixels will occur at

---

1/ Horwitz, H.M., J.T. Lewis, and A.P. Pentland, "Estimating Proportions of Objects from Multispectral Scanner Data," Report No. 109600-13-F, Environmental Research Institute of Michigan, Ann Arbor, May 1975.

Malila, W.A. and R.F. Nalepka, "Atmospheric Effects in ERTS-1 Data and Advanced Information Extraction Techniques," Symposium on Significant Results Obtained from ERTS, Vol. 1, Goddard Space Flight Center, Greenbelt, Maryland, 1973.

Horwitz, H.M., R.F. Nalepka, P.D. Hyde, and J.P. Morgenstern, "Estimating Proportions of Objects Within a Single Resolution Element of a Multispectral Scanner," Seventh International Symposium on Remote Sensing of the Environment, May 1971.

2/ The chi-square value is a measure of the likelihood that the pixel is a member of the signature distribution being considered.

field boundaries such that the vast majority of mixture pixels will be mixtures of two ground classes.

Next, these chi-square values are compared to the values set for two parameters of the mixtures algorithm. If the chi-square for the winning pure case is less than X_1^2, the pixel is considered to be pure. If it is not pure according to this test, the chi-square value for the two-class mixture case is less than X_2^2, the pixel is determined to be the mixture indicated. Otherwise, the pixel is condidered to be "alien", i.e., from a class or classes not included in the signature set. Currently X_1^2 and X_2^2 are chosen empirically to minimize the error of the proportion estimate over some training area of known proportion.

One factor affecting the performance of the mixtures processor is the geometrical configuration of the signatures used to define the ground cover classes. The signatures can be defined as hyperellipses in an n-dimensional orthogonal space where n is the number of data bands or SDOs. A simplex is the hypervolume defined by the m signature means. Pure pixels are those located near signature means, while mixture pixels are located between signatures. Further, if for a given set of signatures, a simplex they define is not convex, e.g., one signature being a linear combination of two signatures, then the simplex is said to be degenerate. For such a simplex a nonunique answer is mathematically possible and such simplexes should not be used for processing.

The initial step in implementing the mixtures classifier is to define a signature set. It is important that the signatures used be sufficiently distant, one from the other, so that the simplex formed by the set of signatures will not be degenerate because the algorithm breaks down in that circumstance. To keep the signatures far apart and to conserve processing time which increases as m(m + 1)/2 (for m signatures), the size of the signature set is kept as small as possible.

The signature set for the forty section training consisted of 15 signatures with the following distribution:

Corn	4 signatures
Trees	2 signatures
Brush	1 signature
Grasses, weeds, etc.	5 signatures
Bare soil	1 signature
Soybeans	1 signature
Alfalfa	1 signature

Since soybeans and alfalfa are very minor ground covers in the test site, they were excluded from this study. An analysis of the tree and brush signatures showed the two tree signatures to be very disparate, but the brush was similar spectrally to one of the tree signatures with an overlapping of some 75 percent. The brush signature, representing primarily areas of scrub forest, was, therefore, combined with the tree signature. The bare soil signature was included in the mixture set since bare soil is a ground cover of interest and its signature is distinct from other ground covers. The two corn signatures which were based on most of the corn pixels were found to be very different. Since corn is a major cover, both of these signatures were used.

The grasses were represented by 5 diverse signatures. Since combining several signatures into one resultant signature with a large spread would have decreased the inter-signature distances in the simplex, we endeavored to choose just one signature. An examination of 2-dimensional scatter plots of all the signatures indicated that one grass signature seemed to be more toward the exterior of the total signature set than any of the other grass signatures. That cluster probably represents the grass subclass which had the highest percentage ground cover and thus the lushest condition of the grass object class. This grass signature was selected to represent grass with the hope that pixels from pasture or weed fields would be called a mixture of grass and bare soil.

The signature set described above was applied to a small 550 pixel section of the data. Subsequent analysis showed that very little of the data was being classified as grass and the error rate was substantial. The initial choice of a grass signature was apparently a poor one. Accordingly, a different grass signature was selected, this one being from the grass cluster with the greatest number of grass pixels.

The test data were again processed through the mixtures classifier. The results were somewhat better, but the total error in the proportion estimation for the test data was still slightly inferior to the error rate achieved using the conventional linear classifier. It was further noted that the chi-square thresholds chosen, which minimized the total error of the proportion estimate, resulted in 73 percent of the pixels being counted as "pure" and only 18 percent of the pixels being assessed as mixtures. Many more mixture pixels had been anticipated.

One explanation for these results is that the conventional classification had been done using 15 signatures - the mixtures approach used only six. It seems that it would be necessary to further pack the signature simplex with other grass signatures to increase the grass classification rate. Such a procedure would increase the grass classification and the accuracy of overall classification but it would further decrease the number of pixels processed as mixtures.

Another reason why few pixels were called mixture pixels probably is the poor signal range of the data. Not only are the signature means relatively close together, but also the individual distributions are very broad. Pixels which are mixtures of separate classes may be very near the center of another distribution and may be classified as being from that distribution. Figure 11 illustrates the point showing 2-dimensional ellipses which represent a boundary for a chi-square value of one for each of the distributions pictured. The

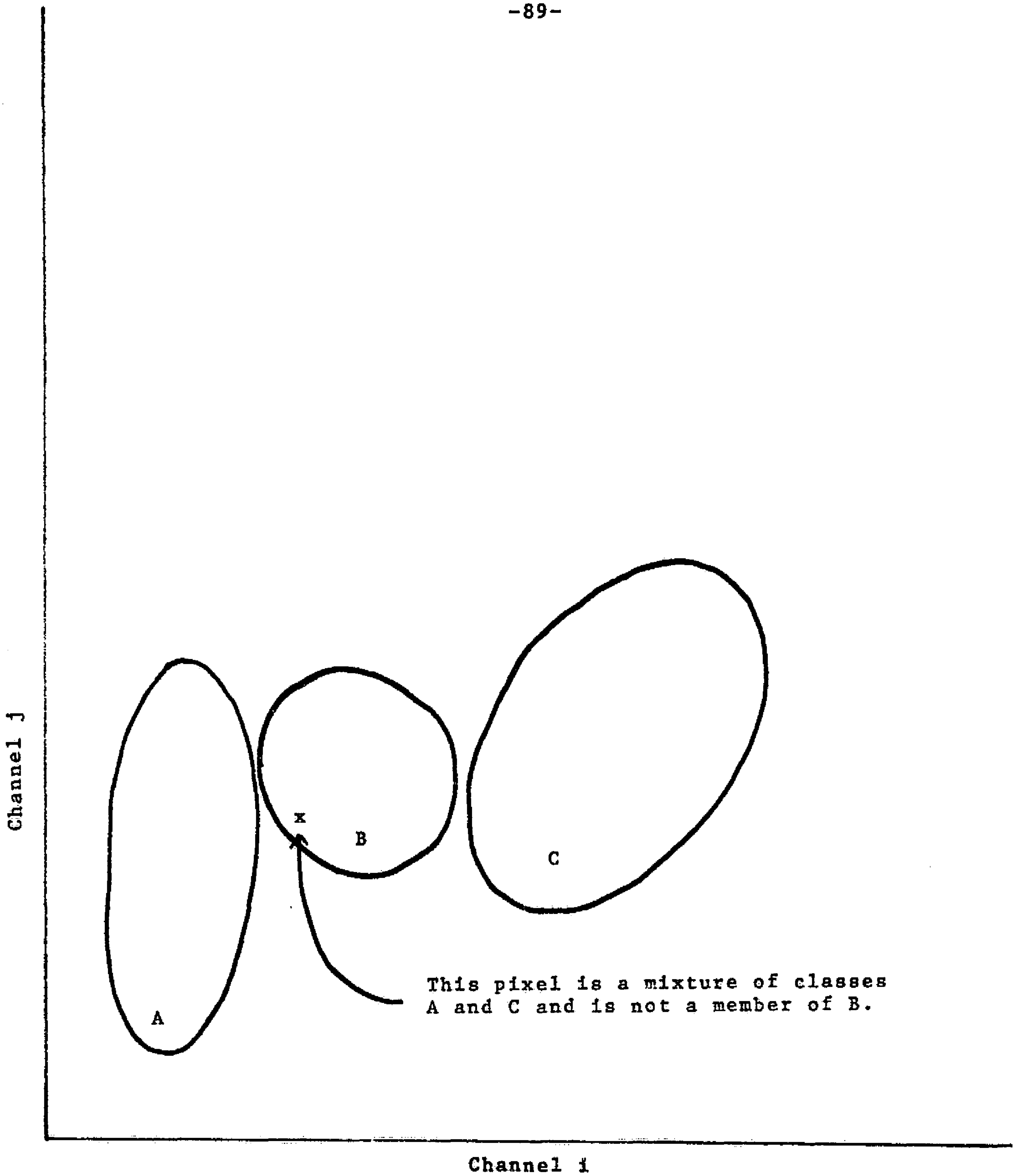


Figure 11. Illustration of a mixture pixel in a three signature simplex.

pixel illustrated is a mixture of Classes A and C but will be classified as being a pure pixel of Class B. Because of these results, no further mixtures processing was performed on the agricultural test site data.

S-192 Maps

Figures 12 and 13 are color maps prepared from the S-192 data. These maps are coded as follows:

Green	Corn
Red and orange	Forage
Blue	Trees and brush
White	Bare soil
Black	unclassified

Figure 12 represents the northern 40 sections which contained the training set. Figure 13 is for the southern 40 sections.

The odd, non-rectangular shapes are the result of having scan-line straightened the results prior to the generation of maps. The computer program did not allow for the yaw of Skylab or the effects of the earth's rotation beneath the spacecraft.

Vigor and Yield Estimation

The statement of work for the contract indicated the investigators would attempt to estimate crop yield or vigor from Skylab data. Given that the relevant data for such estimates are available for only the August 5, 1973 pass, corn is the only feasible crop for such a study. Wheat had al-

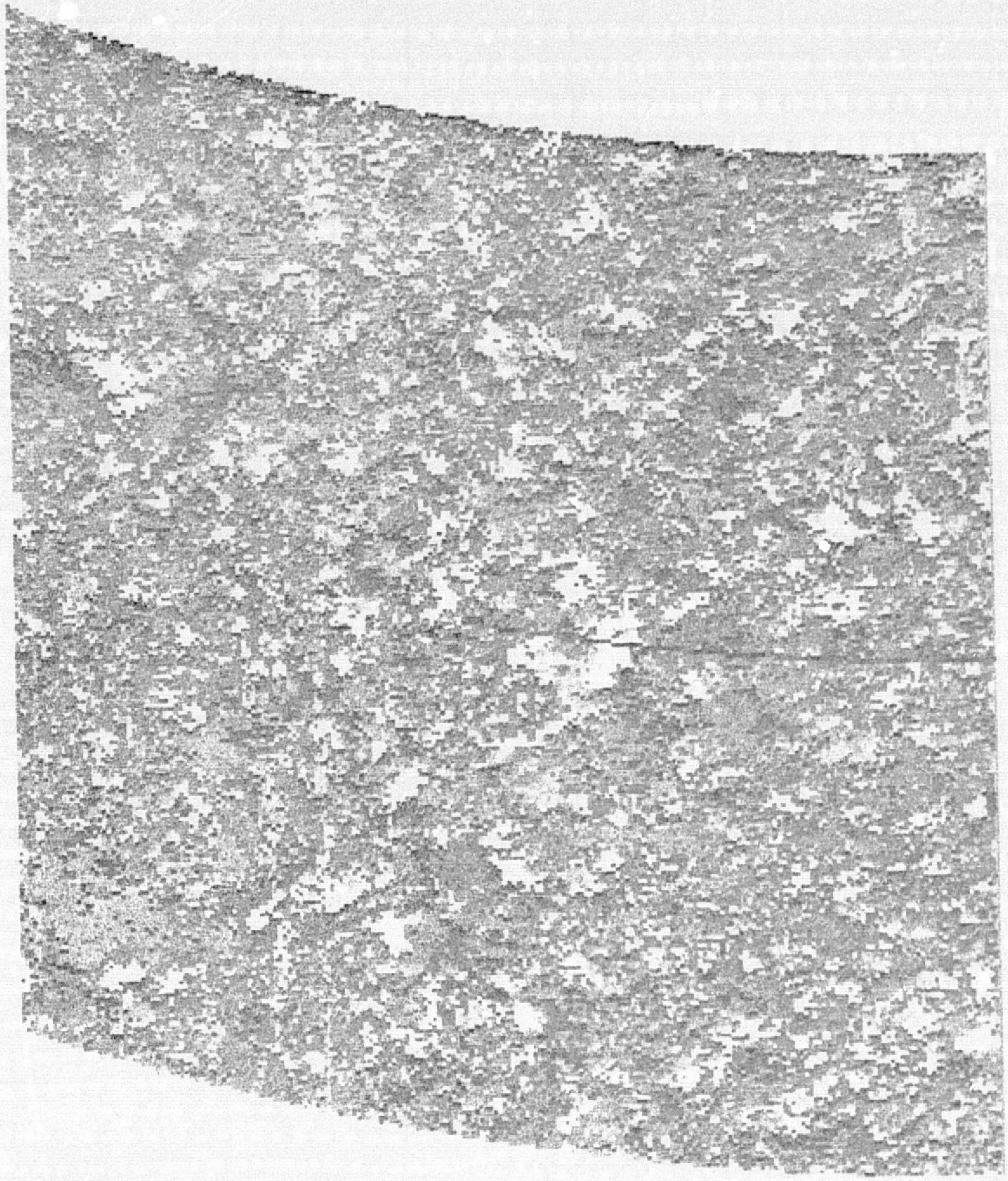


Fig. 12. Color Map of Northern Section of Test Area (color code on p. 93)

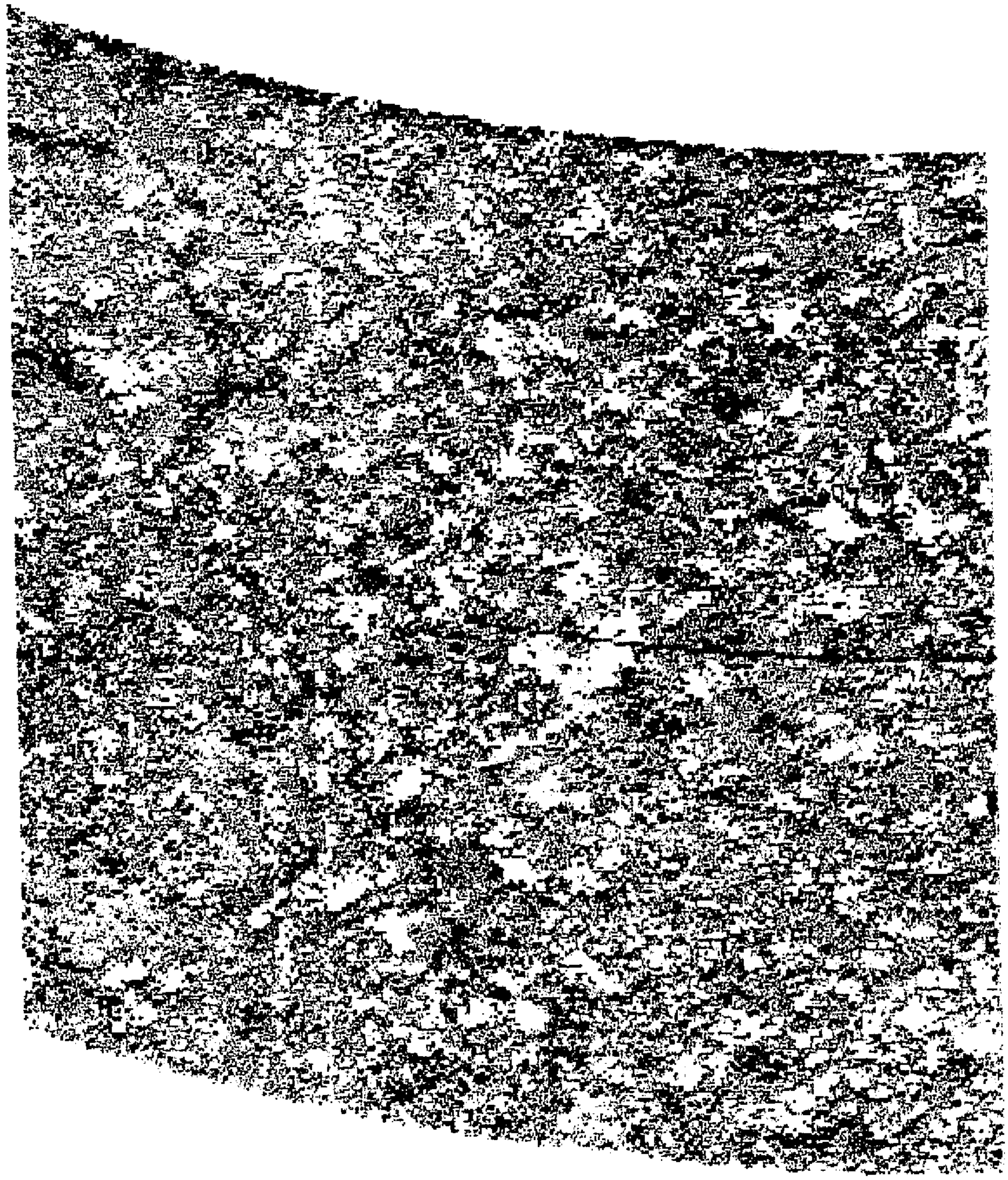


Fig. 12. Color Map of Northern Section of Test Area (color code on p. 93)

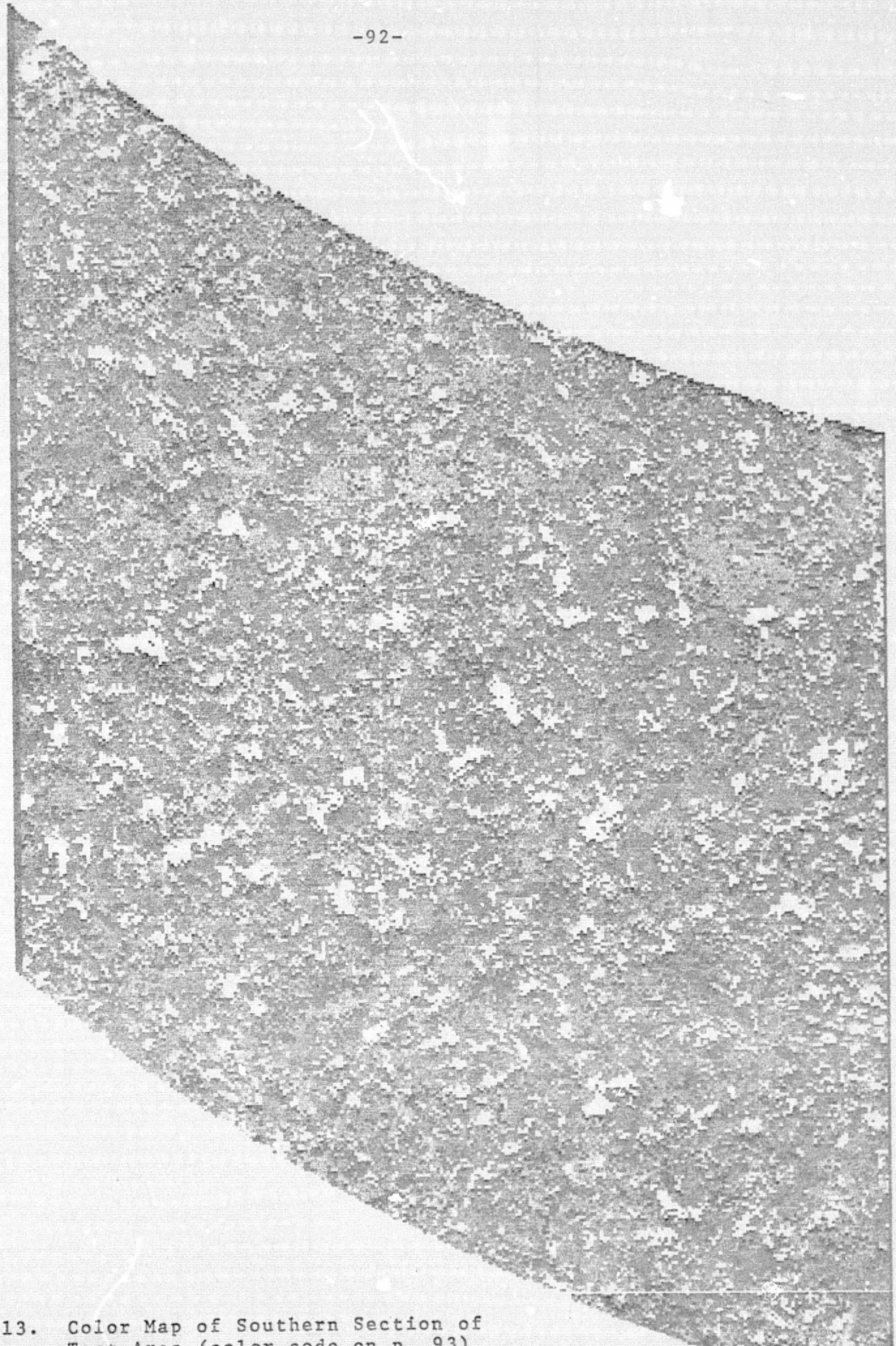


Fig. 13. Color Map of Southern Section of Test Area (color code on p. 93)

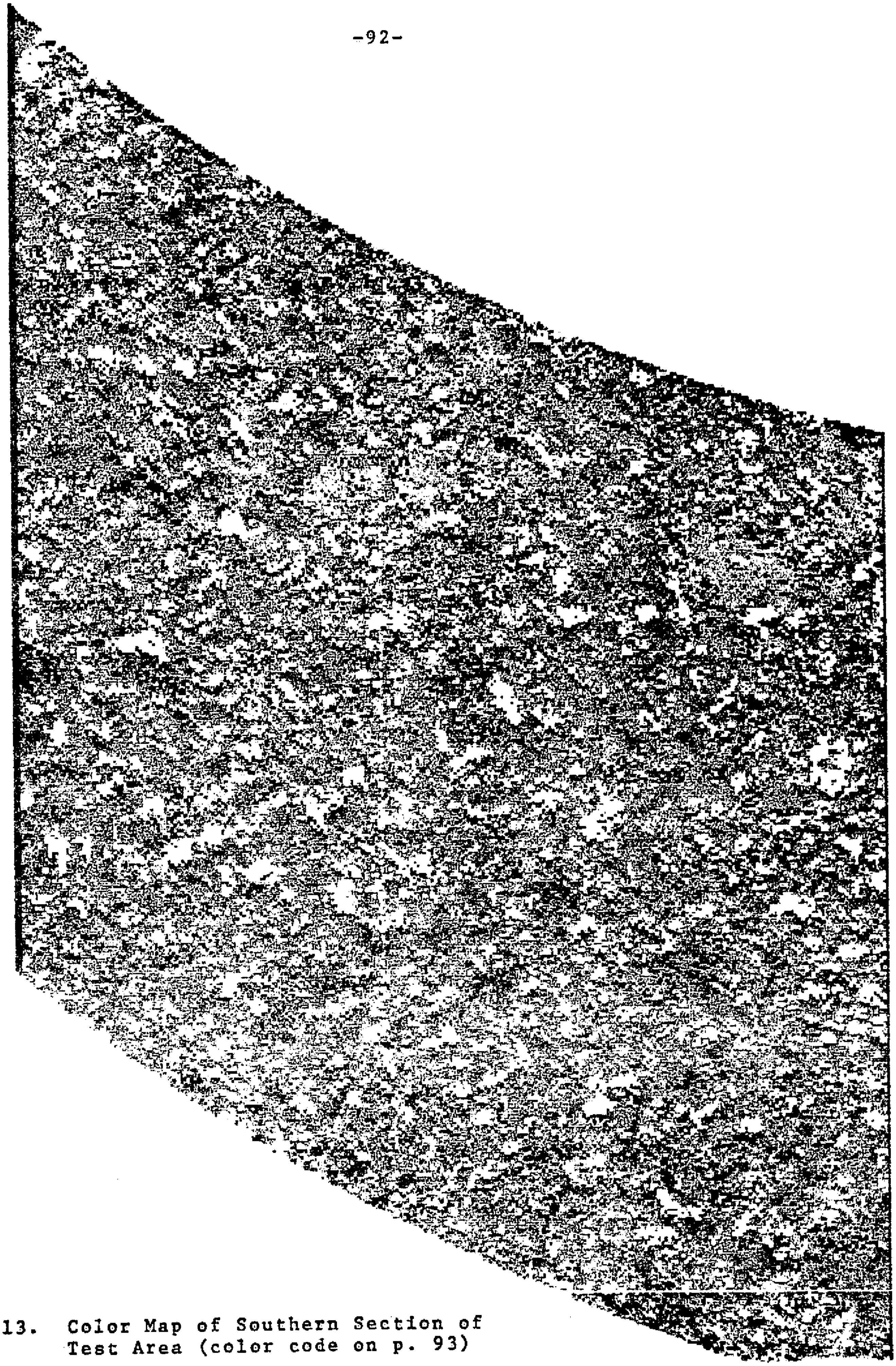
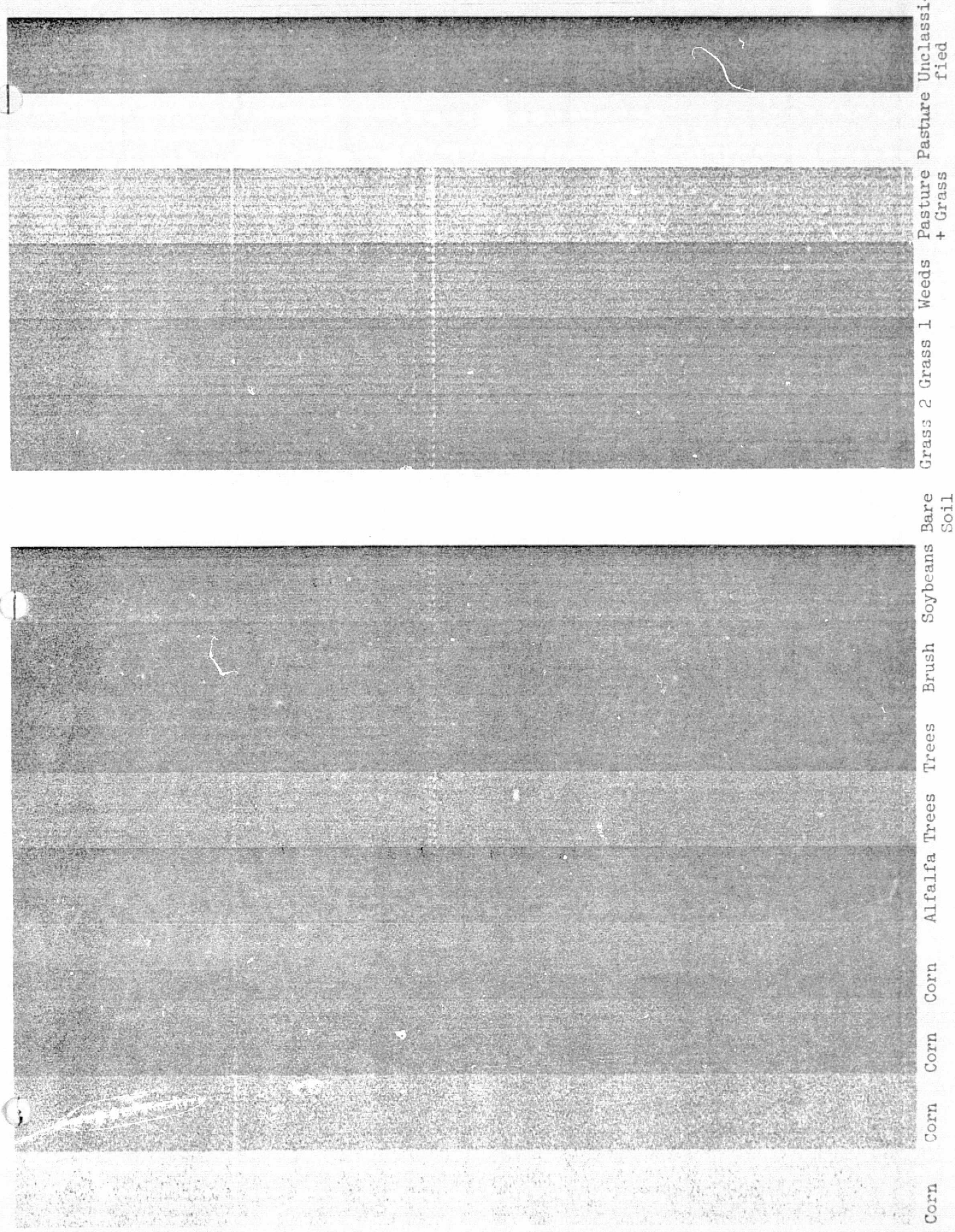
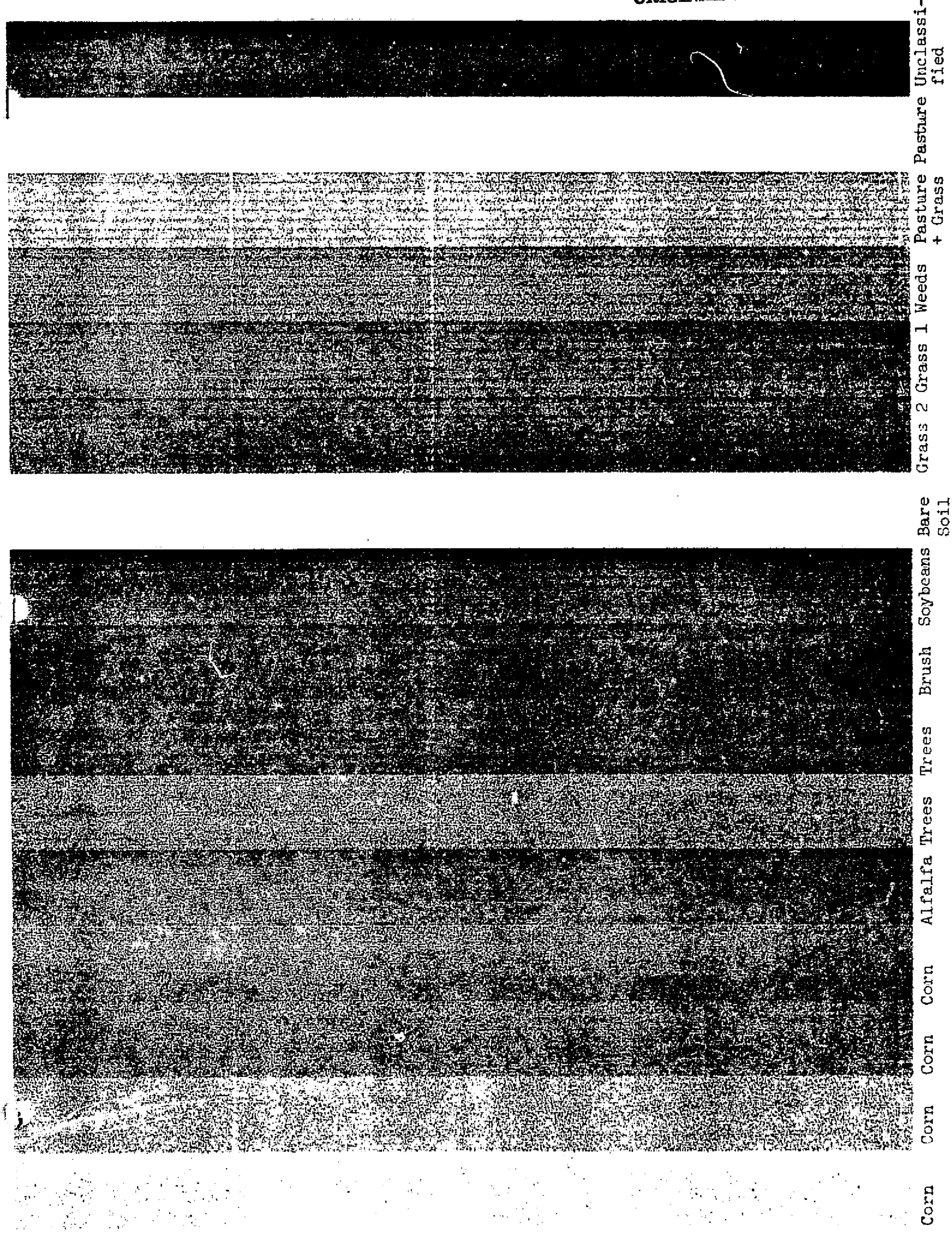


Fig. 13. Color Map of Southern Section of Test Area (color code on p. 93)


Corn
Corn
Corn
Corn
Alfalfa
Trees
Trees
Brush
Soybeans
Bare Soil
Grass 2
Grass 1
Weeds
Pasture + Grass
Pasture
Unclassified


Unclassified
Pasture
Pasture + Grass
Weeds
Grass 1
Grass 2
Bare Soil
Soybeans
Brush
Trees
Trees
Alfalfa
Corn
Corn
Corn
Corn

ready been harvested. The acreage of soybeans was relatively small and grasses are in themselves so heterogeneous as to be inappropriate.

However, as pointed out previously corn was in two distinct states on this date. Some of it was tasselled and some was not. These disparate states produced distinct signatures. Further complicating the situation were those fields that were partially tasselled.

After carefully considering the poor signal quality of S-192 data, the resolution of the S-190B imagery, and the results of acreage estimation reported above, it was clear that further attempts to discriminate for vigor would be fruitless. Determination of vigor requires good resolution in photographic imagery or a large signal range in S-192 data and, in addition, variation in vigor in ground truth. Such variations are more likely to occur over large test sites or among scattered sites. Technicians collecting ground truth for this study found similarity of vigor to be the rule rather than the exception. Therefore, future studies investigating vigor might choose test sites so as to provide good contrast in vigor rather than to be representative of typical field size and cropping patterns. It is also the author's opinion that vigor can not be translated into yield estimates until better agronomic models are available to relate the canopy to yield.

Resource Requirements for Multispectral Automated Crop Surveys

An important factor to be considered when judging the utility of machine processed multispectral scanner data for agricultural applications is the amount of resources required to extract the necessary information. The resources required, which include computer and personnel time as well as their costs, are discussed in this section. The multispectral data set upon which the estimates of necessary resources are based was collected by the S-192 multispectral scanner aboard the Skylab space station during an early August overflight of the southeast Michigan test site. The test site comprised 90 contiguous sections (each being approximately 640 acres) in Ingham County, Michigan.

The primary question addressed in this section is how many resources are needed to carry out automated multispectral crop surveys. The secondary task was to examine costs and processing results as a function of the amount of training information used in that survey. To satisfy these needs, the training of the computer and classification of the data were carried out over the northern 40 sections of the test site with data from: (1) 40 sections, (2) 20 sections, and (3) 10 sections being used for training and with the full 40 sections being used for classification and evaluation in each case. In addition, the 50 sections in the southern part of the test site were classified using the statistics generated by training on the northern 40 sections. Classification results were discussed previously.

The overall processing flow is explained below. Briefly, there were five stages for each test case:

1) supervised clustering for generating signatures,
2) selection of optimum band subsets,
3) classification,
4) evaluation of results for field center pixels, and
5) evaluation of proportion estimation (from classification counts.)

Outside of possible needs for data reformatting, data quality assessment, and location of training fields, the first step in the machine processing of multispectral scanner data is training, i.e., the generation of signatures for the computer which define the statistical characteristics of the ground classes of interest as seen in the data. There are many available means by which the signatures may be determined. The supervised clustering method used here was judged by us to be appropriate for this investigation.

When large numbers of spectral bands are available, the next step generally entails the selection of subsets of these bands which, based on the training data characteristics, will not result in a serious loss of classification accuracy. This step is employed to reduce the overall resource requirements since the use of additional spectral bands increases the computer time necessary to classify the data. Clearly, then, a simple discrimination problem with optimized high quality data will require fewer resources than a more difficult problem with lower quality data.

Following the selection of optimum spectral band subsets, the data are classified and the necessary information is extracted. While it isn't required for an operational survey system, for this investigation the results achieved during classification were fully evaluated and compared with ground observations. The evaluation was accomplished on both the classification accuracy of field center pixels (i.e., pixels clearly inside field boundaries each of which contains information on only one class) and the overall acreage or proportion estimation accuracy.

Computer processing for this investigation was carried out at ERIM using an IBM 7094 Multispectral Processing System. (The processing system includes both hardware and software). The computer time reported below is given in terms of 7094 execution time - care has been taken to eliminate the time spent in spinning the data tapes.[1/]

Table 27 documents the 7094 CPU time to accomplish each of the five stages discussed above. Here we see that the CPU time required to establish training signatures via supervised clustering is between 1.5 and 5 minutes, and the time is clearly and directly related to the amount of data being

---

1/ The 7094, being a second generation computer, is tape oriented. All third and later generation machines - IBM 360, IBM 370, AMDAHL, Univac, etc., are disc oriented, multiprogramming machines which means that input/output (I/O) time is much faster and the user does not pay for the central processing unit (CPU) while performing I/O. Thus, the times reported are comparable to times involved on other machines.

Following the selection of optimum spectral band subsets, the data are classified and the necessary information is extracted. While it isn't required for an operational survey system, for this investigation the results achieved during classification were fully evaluated and compared with ground observations. The evaluation was accomplished on both the classification accuracy of field center pixels (i.e., pixels clearly inside field boundaries each of which contains information on only one class) and the overall acreage or proportion estimation accuracy.

Computer processing for this investigation was carried out at ERIM using an IBM 7094 Multispectral Processing System. (The processing system includes both hardware and software). The computer time reported below is given in terms of 7094 execution time - care has been taken to eliminate the time spent in spinning the data tapes.[1/]

Table 27 documents the 7094 CPU time to accomplish each of the five stages discussed above. Here we see that the CPU time required to establish training signatures via supervised clustering is between 1.5 and 5 minutes, and the time is clearly and directly related to the amount of data being

---

1/ The 7094, being a second generation computer, is tape oriented. All third and later generation machines - IBM 360, IBM 370, AMDAHL, Univac, etc., are disc oriented, multiprogramming machines which means that input/output (I/O) time is much faster and the user does not pay for the central processing unit (CPU) while performing I/O. Thus, the times reported are comparable to times involved on other machines.

Table 27. Data processing machine times in terms of 7094 CPU time with varying amounts of data used for training.

Step processing procedure	North 40 section processing No. of sections used for training 40 Sections	20 Sections	10 Sections	South 50 section processing
1. Supervised Clustering	4'49.7"	2'37.1"	1'28.8"	---
2. Selection of Optimal Signal Bands	5'54.3"	5'39.4"	2'37.3"	---
3. Classification of Data	6'50.1"	10'6.9"	5'38.7"	8'25.0"
4. Evaluation of Classification for Field Center Pixels	56.2"	50.2"	49.7"	1'10.0"
5. Evaluation of Classification of Full Sections	56.9"	56.8"	56.9"	1'11.2"

clustered. The situation for items 2 and 3 is not so straightforward. For the selection of optimum bands, the necessary time did not increase uniformly as the number of sections available for training increased. This was at least partially becuase the number of signatures which resulted from the 10, 20, and 40 sections did not increase uniformly with the addition of sections. A slightly different situation applies for the necessary classification time. Here the same amount of data was processed, however, as a result of the previous steps, the number of signatures, and spectral bands used for classifying the data were fewer when training on 40 sections than when training on 20 sections. The significant fact here is that it took between 6 and 10 minutes CPU time to process S-192 data covering 40 sections on the ground. The evaluation steps took roughly a minute each. For larger data sets one can estimate classification times by using the fact that the 40 section classification in column one used the same signatures and spectral bands as the 50 section classification in the last column. In both cases roughly 1.5 to 2 minutes were required per 10 sections.

As previously stated, all computer times provided in Table 27 were specified as the time required to execute the jobs on the ERIM 7094 Multispectral Processing System after adjustment to substantially exclude I/O time, thus, estimating CPU time to allow a more direct comparison between the 7094 and other machines. In the remainder of this subsection we attempt to provide the information necessary to translate the execution time for these jobs to an equivalent time on other common computer systems.

The only way to rigorously compare computation rates for various computers is by carefully controlled benchmark testing. Unfortunately, such controlled tests were not possible. What was done instead was to gather basic timing information on other computer systems. The basic information gathered includes: cycle time, execution for an integer add, and execution time for an integer multiplication. These quantities give a general impression of relative processing times. However, a very accurate calculation of relative processing times is not possible because of the different hardware peculiarities introduced on various machines to increase the speed with which several instructions may be sequentially executed. Also, differences in computer word size and differences in machine code generated for similar FORTRAN programs will contribute to differences in processing rates between machines as well. Table 28 lists the basic timing information for the computer systems considered. The entries in Table 29 are rough estimates of relative processing times for the same computer systems.

Table 28. Computational characteristics for some computers* (all times given in nanoseconds)

Computer	Cycle time	Integer add instruction	Integer Multiply Instruction
IBM 7094	2,200	4,400	15,400
IBM 360/67	750	1,400	4,800
IBM 370/145	608	2,100	20,100
IBM 370/168	80	160	400
AMDAHL 470/V6	32	64	256
CDC 6500	1,000	600	5,500

* All numbers in this table came from IBM, AMDAHL, and CDC publications describing the CPUs in question.

A new special purpose multichannel data processing system not included in Table 29 is in the final stages of development and testing at ERIM. This system, the MIDAS (Multivariate

Table 29. Relative processing times of selected computer systems.

Computer	Installation	Operating system	Relative processing time
IBM 7094	ERIM	UMES	34.0+
IBM 360/67 (Duplex)	Univ. of Mich.	UMMPS/MTS	9.0*
IBM 370/145	---	---	30.0+
IBM 370/168	Univ. of Mich.	UMMPS/MTS	1.5*
AMDAHL 470/V6	Univ. of Mich.	UMMPS/MTS	1.0
CDC 6500	MSU	SCOPE	15.0+

* From preliminary benchmark tests performed at the University of Michigan, Ann Arbor, Michigan.

\+ Approximate values.

Interactive Digital Analysis System) is expected to process data orders much faster than existing general purpose computer systems. For example, if provided in high density form, a 7.2×10^6 pixel data set (a LANDSAT MSS frame) could be classified in about 40 seconds on MIDAS.

Multispectral remote sensing data connot be processed by the mere existence of a suitable computer processing system. A human as data analyst or parameter coder is necessary to set up individual computer jobs and interpret results.

In a routine processing situation, the data flow is well defined as is the manner in which decisions regarding the processing of data are made. Therefore, the jobs for the personnel involved in processing the data are primarily "housekeeping" chores such as the management of the multispectral data and ancillary data, and the coding of parameters for and subsequent running of individual computer jobs.

In performing this study, we estimated those personnel resources which would be required once a routine had been established. Therefore, the data analyst time in Table 30 is thought to be a good estimate of the time requirement for an operational system similar to the present ERIM processing system on the IBM 7094. Of course it is entirely possible to design an operational system to be more fully automated, combining several steps (e.g signature extraction and optimum band selection) and automating "housekeeping" chores, etc., so that personnel time requirements for some future system could be sharply reduced from those given in Table 30.

The times in Table 30, within limits, are not a function of the amount of data in a data set, but are only a function of parameter selection and job set up. Thus, processing 900 sections as a unit would require essentially the same personnel time as processing 90 sections.

In summary, the personnel time required for processing multispectral data is highly variable, depending upon the system design and the amount of active analyst intervention allowed. Also, the personnel time involved is not primarily a function of the size of the data set.

Thus far we have described the necessary resources to

Table 30. Personnel time required to prepare computer jobs for each step.

		No. of sections used for training			
Step	Processing procedure	40 Sections	20 Sections	10 Sections	South 50 sections processing
1.	Supervised clustering	30 min.	23 min.	19 min.	---
2.	Selection of optimal signal bands for training signatures	10 min.	10 min.	10 min.	---
3.	Classification of data by training signatures	10 min.	10 min.	10 min.	10 min.
4.	Evaluation of classification for field center pixels	20 min.	20 min.	20 min.	20 min.
5.	Evaluation of classificaiton of full sections	20 min.	20 min.	20 min.	20 min.

perform training, classification, and post-classification assessment. There are, however, additional costs involved. The first is the acquisition and assimilation of the ground truth information. The second is in the area of data preparation.

The ground information used for this study was acquired by MSU personnel. The costs of ground truth acquisition is about directly proportional to the amount of training data necessary. That is, it would cost about half as much to acquire ground truth for 20 sections as it would for 40 sections. Detailed records on ground truth costs were not compiled.

For this study, a semiautomated technique was used to locate the scan line and scan point coordinates of the ground truthed fields and areas of interest. The stages in this process and attendant costs are given in Table 31. The entries in the table are for the full 90 sections; times for processing fewer sections are directly proportional, except for basic setup costs.

Table 31. Times associated with assimilation of ground truth information for 90 sections.

Step	Task	Machine	Machine	Personnel time
1.	Acquisition of large scale photography	Photographic laboratory		4 hours
2.	Annotation of photography	---	---	48 hours
3.	Digitization of coordinates	X-Y digitizer	15 hours	15 hours
4.	Regression for transformation	7094	0.05 hours.	3 hours
5.	Transform digitized coordinates to data coordinates	7094	0.3 hours	1 hour

Data manipulation occurs between receipt of the data tapes and the training procedure. Included are such operations as reformatting or copying a subset of the delivered data tapes, or entering the data into a disc file data base. Also included is the checking of data quality via graymaps and histograms. Again it may be that, for an operational system, some of these steps may be ignored. In any event, the costs involved in any of these steps are related to the total amount of data processed and to the total amount of data used for training. The steps included in this category could take up to a full days time.

Conclusion

Using the existing ERIM IBM 7094 Processing System, which has not been optimized for handling multispectral scanner data in an operational mode, the end-to-end time, to prepare the data, train the computer, and classify a large data set requiring the application of no special processing techniques would be three to five days. By optimizing this system or utilizing other existing computer systems one might be able to reduce the elapsed time. Elapsed time is important because of the need for timely estimates of crop acreage and/or vigor in any operational system.

While other existing systems can compute faster than the IBM 7094, they may or may not be more economical. Per minute costs to use these systems are not the same. The faster machines are usually more costly. So while, on the basis of speed alone, one system may be significantly better than another, the processing costs may be similar.

It is obvious that people are still a major resource requirement, even for so-called automated crop surveys. Systems, such as ERIM's MIDAS, which are designed to take into account the special characteristics of multispectral data and the special needs of people by providing interactive displays and data manipulation capabilities will certainly make future automated multispectral crop surveys more effective from the standpoint of both cost and time. Special processing techniques such as signature extension algorithms[1] are being developed which should reduce overall costs even more.

Cost and Accuracy of SRS Procedures

Current crop acreage estimates for the United States are produced by the Statistical Reporting Service (SRS) of the U. S. Department of Agriculture. These procedures are discussed in the U.S.D.A. Miscellaneous Publication 1308 [2] and earlier versions thereof. Basically, acreage estimation is a result of a probability sampling procedure using an area frame or a multiple-frame involving both an area frame and a list frame. This procedure is an evolution from the non-probability procedures previously used.

Information was compiled on the cost-error relationships for SRS methods. Based on 1967 costs these relationships are depicted in Table 32. These data were calculated based on SRS and other information.

On the basis of 1973 costs of a national probability survey, a total probability survey costs $6.80 million while a survey of crop acreage only using a total probability survey

---

1/ Henderson, R. G., G. S. Thomas, and R. F. Nalepka, "Methods of Extending Signatures and Training Without Ground Information," Report No. 109600-16-F, Environmental Research Institute of Michigan, Ann Arbor, May 1975.

2/ SRS, U.S.D.A.,"Scope and Methods of the Statistical Reporting Service,"U. S. D. A. Miscellaneous Publication 1308, U.S. Government Printing Office, 1975.

would cost $2.74 million. In other words, crop acreage estimation accounted for 40 percent of the cost. We therefore used 40 percent of all item survey costs to calculate the 1967 data for crop acreage costs shown in Table 32.

Table 32. Cost - Error, Relationships for SRS Methods. (data are costs in millions of 1967 dollars).

Error levels (percent)	Total probability sample survey		Crop acreage survey	
	Area sample	Multiple frame sample	Area sample	Multiple frame sample
0.0	62.00	44.20	24.80	17.68
0.5	17.10	13.00	6.84	5.20
1.0	7.90	7.60	3.16	3.04
1.5	5.80	5.60	2.32	2.24
2.0	4.13	4.13	1.65	1.65
2.5	3.76	3.76	1.50	1.50
3.0	3.40	3.40	1.36	1.36
3.5	2.90	2.90	1.16	1.16
4.0	2.40	2.40	0.96	0.96
4.5	2.15	2.15	0.86	0.86
5.0	2.10	2.10	0.84	0.84
5.5	2.00	2.00	0.80	0.80
6.0	1.90	1.90	0.76	0.76

Inflation and other cost changes raised costs by an average of 9.3 percent per annum between 1967 and 1973. This means the cost index with a base of 1967 was 165.1 in 1973. Extrapolating the 1967 figures accordingly by increases of 65.1 percent yields the data shown in Table 33.

In Table 34 the data have been rearranged to relate error levels to cost levels. These data relate to national error levels for major crops. Table 35 converts these to

Table 33. Error-Cost level relationships (Data are costs in millions of 1973 dollars).

Error levels (percent)	Total probability sample survey		Crop acreage survey	
	Area sample	Multiple frame sample	Area sample	Multiple frame sample
0.0	102.30	72.93	41.17	29.17
0.5	29.54	22.46	11.35	8.98
1.0	12.54	12.06	5.25	4.82
1.5	9.57	9.24	3.85	3.70
2.0	6.80	6.80	2.74	2.74
2.5	6.20	6.20	2.48	2.48
3.0	5.61	5.61	2.24	2.24
3.5	4.79	4.79	1.92	1.92
4.0	3.96	3.96	1.58	1.58
4.5	3.55	3.55	1.42	1.42
5.0	3.47	3.47	1.39	1.39
5.5	3.30	3.30	1.32	1.32
6.0	3.14	3.14	1.26	1.26

Table 34. Crop acreage estimation: Cost- Error relationships

Costs (Millions 1973 dollars)	Errors (percent)
1.26	6.0
1.32	5.5
1.39	5.0
1.42	4.5
1.58	4.0
1.92	3.5
2.24	3.0
2.48	2.5
2.74	2.0
3.70	1.5
4.82	1.0
8.98	0.5
29.17	0.0

Table 35. Specified levels of typical sampling errors in major U.S. farm commodities.

	Percent						
	Survey Cost (million dollars)						
Area sample	3.40	3.76	4.13	5.80	7.90	17.10	62.00
Multiple frame sample	3.40	3.76	4.13	5.60	7.60	13.00	44.20
Typical sampling error in major commodities[a]	3.0	2.5	2.0	1.5	1.0	0.5	0.0
Individual commodities sampling error.[b]	(percent)						
Wheat	3.2	2.6	2.1	1.6	1.1	0.7	0.2
Rye	9.0	7.5	5.9	4.5	3.0	2.0	0.6
Rice	15.8	12.6	9.9	7.8	5.5	3.5	0.8
Corn	2.1	1.8	1.4	1.1	0.8	0.5	0.0
Oats	3.1	2.6	2.1	1.7	1.2	0.7	0.2
Barley	5.4	4.5	3.5	2.7	1.9	1.3	0.5
Potatoes	18.5	15.5	12.6	9.5	6.6	4.2	1.0
Soybeans	3.4	2.8	2.2	1.7	1.2	0.8	0.3
Peanuts	9.5	8.0	6.3	5.0	3.6	2.2	0.8
Tobacco	5.1	4.3	3.4	2.6	1.8	1.2	0.5
Cotton	4.8	4.0	3.1	2.4	1.7	1.1	0.4
Cattle	2.3	1.9	1.3	1.0	0.7	0.5	0.0
Hogs	4.4	3.8	2.9	2.2	1.6	1.0	0.4
Sheep & Lambs	13.1	11.0	8.9	6.8	4.5	3.0	0.7
Poultry	9.2	7.8	6.2	4.8	3.3	2.0	0.5
Eggs	9.2	7.5	5.8	4.5	3.1	1.9	0.6
Milk	5.4	4.5	3.5	2.7	1.9	1.3	0.4

[a]Major commodities refer to items that are produced on most farms in the United States.

[b]Sampling errors in the production characteristics of individual items corresponding to the specified levels of typical sampling error in major U.S. farm commodities.

Source: Y. Hayami and W. Peterson, "Social Returns to Public Information Services," American Economic Review, LXII No. 1, March 1972.

Table 36. Sampling errors for crop acreages by region, 1973.

Crop	N.E.	N. Cent.	South	West	U.S.
			Percent Sampling Error		
Corn	4.0	1.6	3.1	7.3	1.3
Soybeans	12.7	2.2	4.3	-	2.0
Rice	-	-	12.1	14.7	10.4
Sorghum Grain. . . .	21.6	4.6	5.3	9.2	3.4
Wheat, Winter. . . .	6.2	3.6	4.7	3.4	2.2
Wheat, Spring. . . .	-	4.5	-	9.6	4.1
Oats	6.2	2.4	6.1	12.2	2.1
Barley	9.0	5.0	10.4	4.9	3.2
Cotton	-	15.0	3.4	7.0	3.0
Potatoes	11.9	20.2	33.5	12.0	9.1
Sugar Beets.	-	14.9	-	8.2	7.3

Source: Information provided by SRS, USDA.

error levels for specific crops. Clearly the sampling error increases for crops produced on fewer farms.

Table 36 relates specified sampling errors at the national level the corresponding sampling errors at regional levels. This table shows the actual sampling errors in 1973 and demonstrates that regional errors are larger than national errors and that regional errors are increased when the crop is less important in that region. It also illustrates the differences among crops even at the national level.

The proportion of total costs attributed to crop surveys was 40 percent. This figure covers total crop survey costs including yield and acreage estimation. We have not estimated the marginal cost of crop surveys done for acreage estimation only. However, it is likely that deleting only the acreage estimation from SRS activities would effect only a small savings. In order to provide information about livestock production, the enumerative surveys would need to be continued. Only a few questions would be deleted. There would, however, be a possible savings as a result of redesigning the sample to reduce costs while obtaining the same accuracy with respect to livestock production. No specific dollar amount was estimated but we believe that it would be relatively small.

Criteria for Crop Acreage Estimation by Remote Sensing

A feasible crop acreage estimation procedure using remote sensing data of the type produced by Skylab must meet at least three criteria:

1) Timeliness

2) Secrecy until public release

3) Cost-error relationship better than for SRS

There could be some trade-off between these since a more timely survey is of greater value and therefore worth additional expenditure.

Currently, SRS produces the acreage estimates for corn[1/] on approximately July 10 (exact date depends on the day of the week on which the 10th occurs.) The basis for that estimate is survey data collected in late June with, essentially, a July/cut-off for new information. Similarily, production estimates are released on the 10th of succeeding months based on information compiled essentially as of the first of the month. Current SRS procedures involve use of the postal service to deliver state information to Washington D.C. for compilation. If sufficient value were attached to speed, the information could be transferred by other means (courier, telegraph, telephone, etc.). Since this is not done, there is an implicit judgment that the higher cost of transmitting by other means (or the increased risk of security leaks providing inside trading information) are larger than the value.

Thus, a satellite-based system would need to provide comparable timeliness or significant cost saving. The first requisite is returning the data, or imagery, to earth soon

---

1/ Corn is used as an example because it was the major crop in the test area.

after the observations are made. Radio transmission may provide a quick return to earth. The analysis of S-192 data in this study indicates a 3 to 5 day processing cycle after the data is received. Thus, multispectral scanner techniques with computer processing can provide the timeliness needed. Photointerpretation time would be a function of the number of technicians available to work on the project when imagery is received. Generally, timeliness is more likely to be a probelem in a system based on photographic systems because the poor quality of telemetric transmission products requires actual landing of the film package before processing begins.

Security is a problem in acreage estimation because "leaks" provide valuable information to persons trading in the commodity markets, both the current cash and the futures market.1/ Because of this any satellite based system must have security checks built in to avoid premature leaks. This does not appear to be a significant problem with satellite based systems provided the designers of the analytical system are aware of the potential problem and include safeguards to prevent such leaks from occuring.

1/ In the current SRS system the state reports are kept under guard and unopened until the day the report is released. Once the state reports are opened all operations take place in a guarded room with locked window shades, no telephones, closed sewer system, etc. to insure security.

Cost is the final criterion of importance. It should be clear to the reader that because the Skylab system does not provide yield estimates, it is not competitive in cost with current SRS procedures. Resource requirements for processing S-192 data are specified in a previous section. In addition one would need to specify:

1) Cost of S-192 data acquisition
2) Cost of ground truth
3) Sample design

Estimates of the costs of S-192 data acquisition were not available even though requested from NASA. Unavailability of such data is understandable because of the difficulty of allocating joint costs over a large number of projects.

The cost of ground truth is related to a number of variables. In an operational system one could probably contract with farmers to provide information at low cost. In other words, a set of fields would be identified in a variety of locations to be used for training sets. For a small fee many farmers would contract to provide the information if maps of fields were provided. The total cost would involve some initial overhead in establishing locations for training set fields, identifying the farmers, creating the maps, and establishing initial contracts. Operational costs are likely, however, to be quite small.

Sample design is a major problem. Some comments on this are offered in a following section. We have not, however, attempted a definitive sampling design because of the cost involved.

Thus, total costs of an operational system have not been developed to compare with SRS costs. It is clear, however, that a system for acreage estimation in the U.S. at the present time requires refinement beyond that demonstrated in the Skylab system.

Comparison of Remote Sensing Systems for Crop Survey Purposes

The several investigators for the present project have collectively been involved with studies covering most of the unclassified remote sensing systems (except radar) as they pertain to crop surveys. It is of interest to draw some comparisons between these systems with respect to utility for crop survey work.

The first major distinction to be made with respect to sensor systems is between photographic cameras and multispectral scanners. Photographic camera systems typically produce high geometric detail with the primary product (film or print) being most readily adaptable to analysis by human interpreters. Film and print products are not adaptable to telemetry without secondary scanning which involves major loss of geometric information. Multispectral scanner systems produce high spectral detail with the magnetic tapes being readily adapted to computer processing. Data produced by multispectral scanners can also be telemetered without appreciable loss of information. Spectral detail can be increased with photographic systems by manipulating film/filter combinations and using multiple lens systems such as the EREP S-190A. The only real avenues to increasing geometric detail with multispectral scanners are to reduce the pixel size or to obtain data from several angles of view.

The second major consideration is the vehicle used to carry the sensor and the altitude at which it operates. Conventional aircraft and satellites constitute the two major categories. Within the aircraft category, the higher the altitude of operation the more loss of geometric detail through reduced resolution. However, high altitudes do offer cost savings because fewer frames and flight miles are needed to cover an area. High flying altitudes also extend the area which can be covered in a single mission since fuel and other expendables along with sun angle windows normally limit the area that can be covered. After each mission the aircraft returns to its ground base, so there are no problems in transporting data from the vehicle back to the ground. Satellites operate at such high altitudes that resolution becomes very critical. The minimum requirement for resolution in crop survey work is that the observational unit, normally the field, be distinguishable. Satellite altitudes offer the major advantage of allowing synoptic coverage of large areas in a short period of time, and orbits can be adjusted to give repeating coverage at regular intervals. The fact that satellites remain in orbit rather than returning to the ground introduces the problem of transporting data back to the ground in timely fashion.

Conventional aircraft carrying either photographic cameras or scanners have been used for studies of agricultural crops for some time. When operated at sufficiently low altitude, either type of sensor is capable of giving both the geometric and spectral detail needed to classify crops, measure acreage, and detect major crop stresses. For example, photointerpretation of crop type and acreage measurement from CIR U-2 imagery at a scale of 1:130,000 was used frequently as pseudo ground truth in the present project. A study of classification accuracy for interpretation of this imagery was conducted, with the results shown in Table 37. Normally in working with imagery of this type, the interpreter can classify the typical signatures without difficulty and ground checks

Table 37. Classification accuracy for photointerpretation of CIR imagery with scale 1:130,000.

Category	Actual no. of fields	No. classified correctly	Percent accuracy
Grass/forage	63	58	92
Bare soil	16	16	100
Corn	72	64	89
Stubble	11	8	73
Beans	12	12	100

are necessary only for atypical fields. Imagery from conventional aircraft has not been used extensively for broad-area crop surveys, however, because of the cost and logistical difficulties involved in obtaining new imagery for large areas each year at the needed times.

Since synoptic coverage in short periods of time is one of the major advantages of remote sensing from satellites, potential for use in crop surveys was extensively studied under the Earth Resources Technology Satellite program (now LANDSAT). The ERTS-1 satellite carried a 4-channel multispectral scanner for which the ground resolution element, pixel, was approximately one acre in size. The utility of ERTS-1 data for agricultural and forestry purposes was studied under a NASA sponsored cooperative research program between MSU and ERIM[1/]. The one-acre resolution was found to be too coarse for many applications in agriculture and forestry, particularly so when interpretation was done manually. Within fields and forest stands the geometric clues of size, shape, shadow pattern, texture, and association of features normally used by the human interpreter are lost, leaving spectral signature as the primary clue for identification. Most human interpreters are not particularly adept at detecting tonal differences corresponding to 2 or 3 counts of the sensor, and comparison of bands is largely limited to the process of color

---

1/ Wayne Myers, et. al. "Use of ERTS Data for a Multidisciplinary Analysis of Michigan Resources," MSU, Report prepared for Goddard Space Flight Center, November 1974.

compositing or color-additive viewing.

It was found that forest stands of about 80 acres or larger could be identified and mapped consistently. Detection of smaller stands was inconsistent and depended mainly upon the degree of target to background contrast provided by bordering types. Since forests were the most readily interpretable of the vegetation types occurring in Michigan, even more stringent limitations applied to manual interpretation of agricultural crops. The ability to interpret at this level provides useful information only where field sizes are large, as for example, in the Imperial Valley of California and portions of the midwest grain belt. Even with such large tracts, however, the existence of a well-developed crop calendar and repeated coverage within the growing season is needed for interpretive purposes. In areas characterized by smaller fields, the utility of manually interpreted ERTS-type imagery is limited to designing the ground phases of surveys and in detecting shifts of land away from agriculture. The telemetered nature of ERTS data makes it much more adaptable for computer analysis than for manual interpretation. Using multivariate techniques of pattern recognition, the full complement of spectral information can be extracted from the MSS data and utilized in classification. Using these techniques, a classification accuracy on the order of 85 percent was achieved for pixels that were entirely within a cover type (Table 38) using ERTS-1 data. For large fields where most of the pixels are pure, an 85 percent accuracy level approach was needed for making automated

Table 38. Summary of ERTS-1 classification results*.

Actual condition	Number of plots	Number of points	Percent classified as: Corn	Soybeans	Trees	Bare soil	Senescent vegetation
Corn	32	444	75.5	0.3	7.1	---	16.8
Soybeans	7	51	---	84.9	---	---	6.7
Trees	5	75	11.8	---	88.2	---	---
Bare soil	5	36	---	---	---	95.0	5.0
Senescent vegetation	47	258	9.1	4.5	0.7	7.8	76.8
Total	96	864	96.4	89.7	96.0	102.8	105.3

* Data from Eaton County, Michigan, August 25, 1972. Analysis performed at ERIM.

surveys of crop acreage, provided the errors are random. The problems arise for areas where the tract size is small (5 to 20 acres) as it is in many parts of Michigan. From earlier tables, for instance, it can be seen that 67 percent of the fields and 33 percent of the acreage in the Ingham County test strip were included in fields of 20 acres or less. Table 39 shows the results of an analysis performed at ERIM laboratories on average numbers and ranges of resolution elements, pixels, that fell within fields of various sizes in a sample of ERTS imagery. As is evident from Table 39, field sizes must approach 20 acres before there is a high probability that even a few resolution elements will be entirely within the field so that they are not affected by mixed signatures with neighboring fields. In the present study a surprisingly large

Table 39. Average numbers and ranges of resolution elements falling within various field sizes.*

Field size	No. fields	Avr. points	Range of points
0 - 4.9 A.	7	0.43	0 - 1
5 - 9.9 A.	19	2.11	0 - 9
10-14.9 A.	14	2.50	0 - 6
15-19.9 A.	12	3.42	1 - 6
20-29.9 A.	13	7.54	3 - 13
30-49.9 A.	5	10.20	8 - 13
50 and above	11	74.91	17 - 485

* Data from Eaton County, Michigan, August 25, 1972. Analysis performed at ERIM.

number of pixels were "pure" and the attempt to improve accuracy through a mixtures processor was fruitless. This unexpected result may have occurred because of the poor S-192 data quality rather than because of an error in estimating the expected number of mixed pixels for the field sizes in the test area.

With completely pre-programmed computer analysis there is also difficulty in segregating estimates by small sampling units such as fields or sections in order to use them for calculating contributions to sampling error in random sampling designs. This difficulty can be circumvented by interactive computing in which an operator uses a cursor on a cathode ray display to select subsets of the data, but this requires sophisticated computational equipment. Another approach is to determine the corner coordinates for the sampling units and input these to preprogrammed search routines, but this also adds significantly to the cost of the analysis.

Skylab S-190A photography interpreted manually has an effective resolution similar to or slightly better than computer processed ERTS data. The ability to discriminate crop types is much better with computer processed ERTS data than with manually interpreted S-190A data. Since the S-190A imagery was quite variable in quality and cannot be telemetered as can MSS data, S-190A appears to offer little in the way of increased utility for crop acreage estimation. The excellent resolution of the S-190B camera system constitutes a major advance over other sensor systems previously available to the public for analysis of earth resources. The resolution of S-190B is sufficient for rapidly locating individual fields or larger sampling units, delineating the boundaries, and measuring the acreage. These operations are either difficult or not possible at all with the other sensors discussed. Although the SO-242 natural color film did not provide enough contrast in spectral signatures for accurate recognition of individual crops, such as soybeans, on a single occasion, separation would be possible through temporal overlays of coverage obtained on several dates. Furthermore, the S-190B imagery can be enlarged photographically without excessive loss of detail to produce a mapping base for subsequent interpretations. There is a problem in manning a space station such as Skylab over the length of time necessary to obtain imagery at several dates in different parts of the country as well as in transporting the exposed film to the ground at frequent intervals so that it will not be out-of-date before it reaches the survey analysts. The only apparent solution to these problems is through development and routine use of a space shuttle. Development of high-resolution color-infrared film would reduce the need for multiple coverage since there is a high probability that most crops could be distinguished on a single date with such film.

Perhaps the most desirable approach of all, if technically feasible, would be development of a multi-spectral scanner capable of resolution equivalent to that of the S-190B camera system. With a scanner such as this, spectral detail could be fully utilized in automated computer processing and the data could be telemetered immediately to ground stations upon collection providing timely survey results.

There seems to be little hope of assessing crop condition as opposed to identification and acreage measurement with any satellite sensor likely to be available in the near future, since it would be necessary to detect small groups of plants in order to accomplish this to any extent. Assessment of condition, for example, is on the margin of capabilities for high-altitude CIR imagery and aircraft MSS data. Very large scale imagery in combination with ground visitation is required for the more detailed aspects of assessing crop condition. This is not to imply that large-scale stress conditions cannot be detected, but such conditions are already evident without the use of satellite sensors.

Performance of the S-192 has been discussed earlier. In general, the accuracy of classification was not high and there were significant under and overestimation of acreages for some crops. Better resolution and a greater signal range in the data are needed if a feasible system is to be developed.

Possible Configurations for Crop Surveys Incorporating the Use of Satellite Data

One possible approach is to base crop acreage surveys primarily on satellite data from a further development of the S-192 type scanner supplemented by a network of ground surveyed plots that would serve for developing training sets and checking the accuracy of classification. This would require substantially complete coverage of the sample areas on either 3 or 4 occasions during the year. A late fall pass would serve for assessing harvest and identifying winter wheat. A pass immediately following the planting season would serve to separate perenniel forage crops from fields under current cultivation for row crops. A late summer pass after senescence of beans but prior to senescence of corn would serve to separate these two major row crops. There would be some indeterminism in such a 3-pass system between spring grains such as oats, rye, and barley and fallow fields. A fourth pass might be added in the middle of the growing season to remove this indeterminism. Given differences in crop phenology across the country, this sort of system would require a satellite station to be operated essentially year-round, with telemetric return of data in order to provide timely results. It must also be recognized that portions of a region may be cloud covered at any given satellite pass, thus necessitating supplemental passes to fill the gaps. The existence of such complete coverage for a region would also serve as a good basis for defining sampling frames and setting up efficient probability sampling designs.

Such complete reliance on satellite imagery, however, makes the survey subject to severe disruption from malfunction in satellite systems or related logistical problems. Reasonably clear weather conditions on a regional scale are also assumed to occur at critical points in the growing season. Furthermore, the lag time to be expected between acquisition of data in the spacecraft and delivery to regional laboratories for analysis will create a continual time pressure on the release of survey results. Yet another problem will be lack of provision for information on crop condition, which is a key component of the ability to predict yields. In view of these potential difficulties, some diversification of data sources would be desirable. Existing information on major crop types, soils, and meteorology would provide the data needed to break each region into sampling strata on the basis of agricultural characteristics such as percent of area available for cultivation, distribution of field sizes, generalized crop mix, and productive potential. A multi-stage sampling system nested within these strata could be drawn up. A set of satellite imagery would be collected in early summer at the close of the planting season. From this imagery, percentages of tillable acreage under cultivation for row crops and small grains could be determined on a sample of primary units in each strata. Each primary unit in this sample would be further subdivided into secondary sampling units, a sample of which would be flown periodically during the growing season with an inexpensive and readily available combination of small camera (35mm or 70mm) and light aircraft (for example, Cessna 172). Interpretation of the small camera imagery coupled with acreage measurement from the satellite imagery would give percent of acreage under cultivation devoted to each major crop type and stage of maturity. The secondary units sampled would be further divided into tertiary units, a sample of which would be visited on the ground for assessment of crop condition and verification of interpretations from the small camera imagery. Estimates obtained from this type of integrated survey would allow yield prediction, give increased accuracy, and be more timely than surveys based primarily on more frequent satellite coverage. Furthermore, the total cost of the integrated survey would probably be less if real costs of obtaining the more frequent satellite coverage are considered. Speculation on survey designs incorporating multispectral scanner data obtained from satellites assumes that the resolution of these sensors is improved by about a factor of two over that obtained with the LANDSAT systems.