AN EXPLORATORY STUDY ON THE EFFECTS OF FIELD SIZE AND FIELD BOUNDARY PIXELS ON CROP SPECTRAL SIGNATURES

by

Manuel Cárdenas
ASA/USDA FELLOW
New Mexico State University

and

George A. Hanuschak
USDA/ESCS

Internal Working Paper/New Techniques Section

Research and Development Branch
Statistical Research Division
Economics, Statistics, & Cooperatives Service
U.S. Department of Agriculture

June 1978

Acknowledgments

The authors wish to extend special thanks to Kathleen Whyte and Karen Vogel for their time and patience in typing this report, and to Kathleen Morrissey for providing the necessary data from a previous study. Also, Martin Ozga and Walt Donovan, Center for Advanced Computation, University of Illinois, provided the software for the analysis in this internal working paper.

Table of Contents

List of Tables

List of Figures

An Exploratory Study on the Effects of Field Size and Field Boundary Pixels on Crop Spectral Signatures

I. Abstract

The LANDSAT data for the sample segments in a LANDSAT scene in each of California and Illinois was analyzed for the purpose of determining whether or not size of field and/or boundary pixels significantly influences the spectral signature of certain ground cover types. The data was divided into 4 field size classes: (1) less than 20 acres, (2) greater than or equal to 20 but less than 80 acres, (3) greater than or equal to 80, but less than 200 acres and (4) greater than or equal to 200 acres. The pixels for each field size class were combined and mean vectors and variance-covariance matrices were derived. Then concentration ellipses were plotted. Apparently the larger field sizes produce somewhat different signatures than the smaller ones. The smallest field size class (less than 20 acres) was subdivided into field size classes of (a) less than 10 acres and (b) greater than or equal to 10 acres, but less than 20 acres. The smaller field sizes tend to produce a more compact ellipse in California; not so in Illinois. These two smaller field size classes were also used to study the difference in signature, if any, produced by the inclusion and exclusion of boundary pixels. Not much difference was observed. Tables of descriptive statistics on the MSS bands by field size as well as concentration (90%) ellipses are presented.

II. Introduction

In the present decade, much research has been devoted to classification of LANDSAT imagery data into distinct spectral classes. This research is of particular interest to the Economics, Statistics, and Cooperatives Service (ESCS) of the United States Department of Agriculture (USDA), for distinguishing the different types of crops from satellite data. If done successfully, it could prove to be of great value in efficient estimation of crop acreage. In a recent experiment in Illinois conducted by ESCS in collaboration with the Center for Advanced Computation (CAC) at the University of Illinois, satellite data was used as an auxiliary variable in estimating crop acreage using a regression estimate.[1] Only a limited degree of success was achieved due to crop types spectral signatures not being distinct. The search goes on for deriving distinct signatures and better classification techniques for LANDSAT data. Currently, the ESCS is engaged in using multitemporal LANDSAT data in Illinois in the hope that this will lead to better results.

An alternate approach in the search is to investigate some of the factors which might contribute to differences in signatures for varying field sizes for the same crop. Conceivably the management practices on small fields differ from those on large fields. Also, small fields may have different shapes than large fields. These along with other undetermined factors might effect crop spectral signatures for varying field sizes. This paper, then, is concerned with investigating differences in the spectral signature of a crop due to field size.

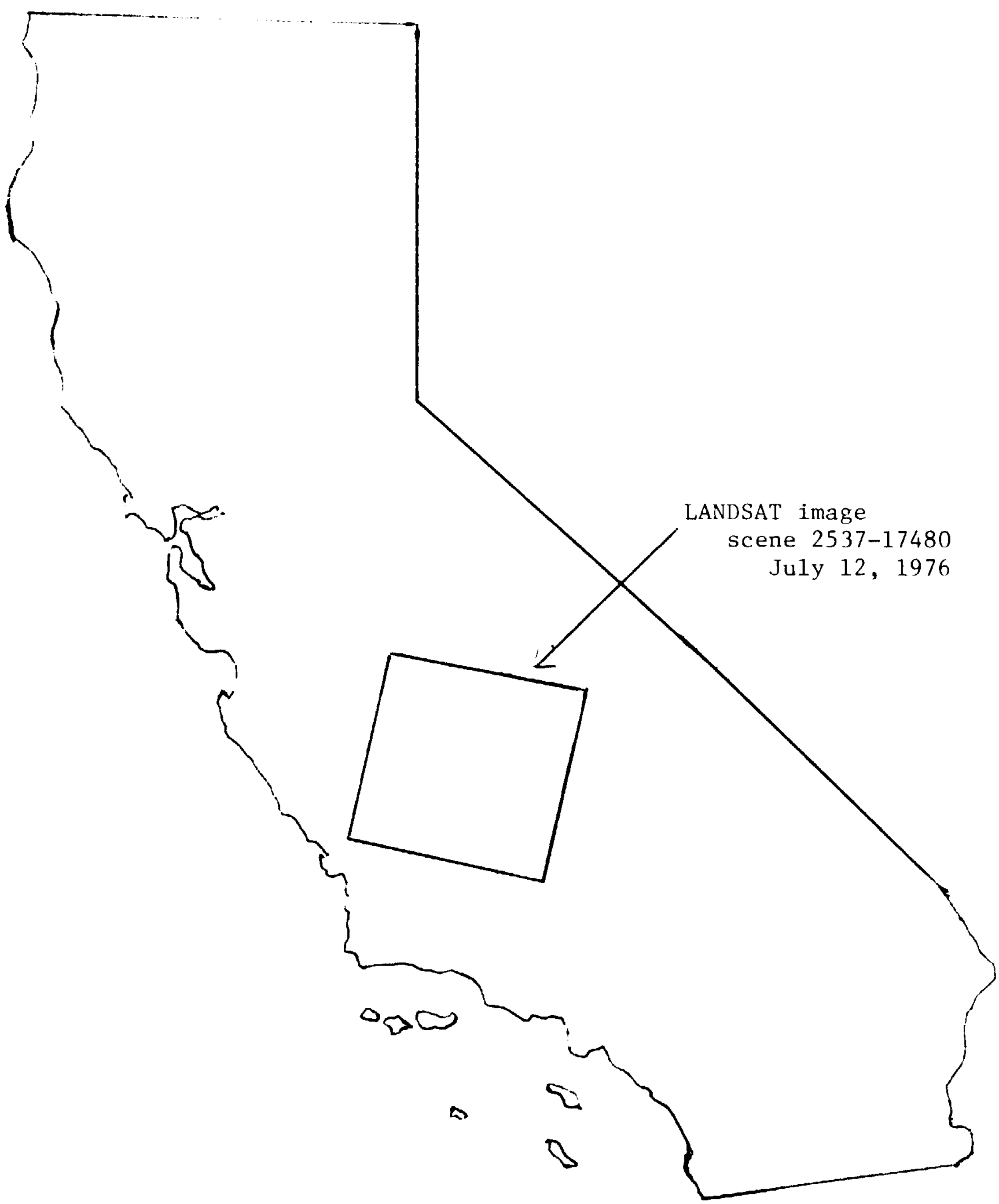
Mistakes can be made in registration which will cause pixels not within the field boundary to be included and vice-versa. Even when registration errors are not committed, parts of boundary pixels may be outside the field limits, boundary pixels are normally not considered in training the classifier. However, with small fields, such as those found in foreign countries, this procedure omits most if not all of the pixels in many of these small fields leaving little data with which to work. If the signatures when using boundary pixels do not change significantly from those without boundary pixels, then perhaps boundary pixels could also be used for training the classifier for small fields. The present paper, therefore, also deals with exploring the possibility of including boundary pixels in training the classifier for small fields.

III. Study Area

Forty-eight segments selected for an area sample were located in Kings and Tulare Counties which were used in the California portion of the study. The segments were covered by LANDSAT scene 2537-17480 dated July 12, 1976 which was used in the analysis. This scene's geographic location on a California state map is shown in Figure 1. The image was cloud free and of excellent quality. Further details on LANDSAT or ground data utilized in this work can be found in "Pilot Study of the Potential Contribution of LANDSAT Data in the Construction of Area Sampling Frames," a report published by USDA.[2]

In Illinois, data from the 38 segments selected for the 1975 June Enumerative Survey and included in the LANDSAT scene 2194-16035 dated August 4, 1975 were employed in the analysis. This scene consists of the north-western most part of Illinois (see Figure 2). Details on data acquisition can be found from the report on the previously mentioned Illinois experiment.

Figure 1: Location of the California Study Area
With Respect to the State Map.



LANDSAT image
scene 2194-16035
August 4, 1975

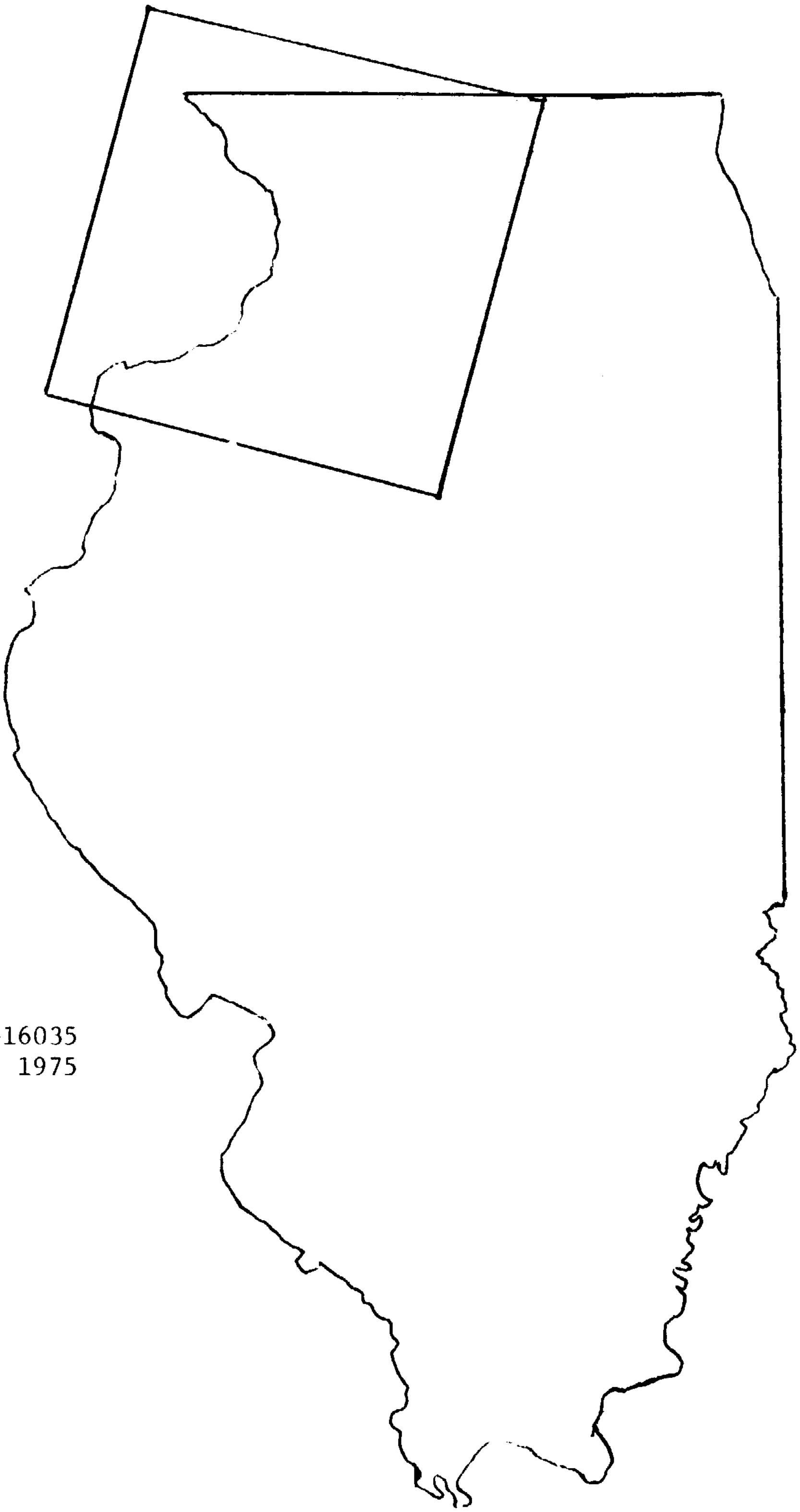


Figure 2: Location of Illinois Study Area
With Respect to the State Map.

IV. Field Size

The factor, field size, was subjectively broken down into the four classes: (1) less than 20 acres, (2) greater than or equal to 20, but less than 80 acres, (3) greater than or equal to 80, but less than 200 acres and (4) greater than or equal to 200 acres. These classes were selected by first plotting (band 5 vs band 7) for crop types in increments of 20 acres and finally grouping those field size classes that appeared most similar clustered in two spaces. The analysis was carried out on the EDITOR software system, an interactive data analysis system for processing LANDSAT data which was developed jointly by CAC and ESCS.

The decision was made to consider only ground cover types consisting of at least 400 pixels not including the boundary. This resulted in twelve distinct ground cover types being considered in California and six in Illinois; however, due to the fact that rangeland and dense woodland in California consisted only of large fields, they were eliminated from consideration. The ground cover types finally included in the analysis are indicated in Table 1.

Concentration ellipses were plotted using bands 5 and 7 of the multispectral scanner (MSS). The plots for a subset of those ground covers with data in all of the four field size classes are displayed in Figures A.1-A.4.

For the most part, field size classes (3) and (4) exhibit different signatures than (1) and (2) in that they have smaller variances (more compact ellipses). However, in assessing the reliability of this observation one must keep in mind the small number of large fields.

Figure
A-1

90.0% CONCENTRATION ELLIPSES FOR BANDS 5 AND 7
ILLINOIS CORN BY FIELD SIZE

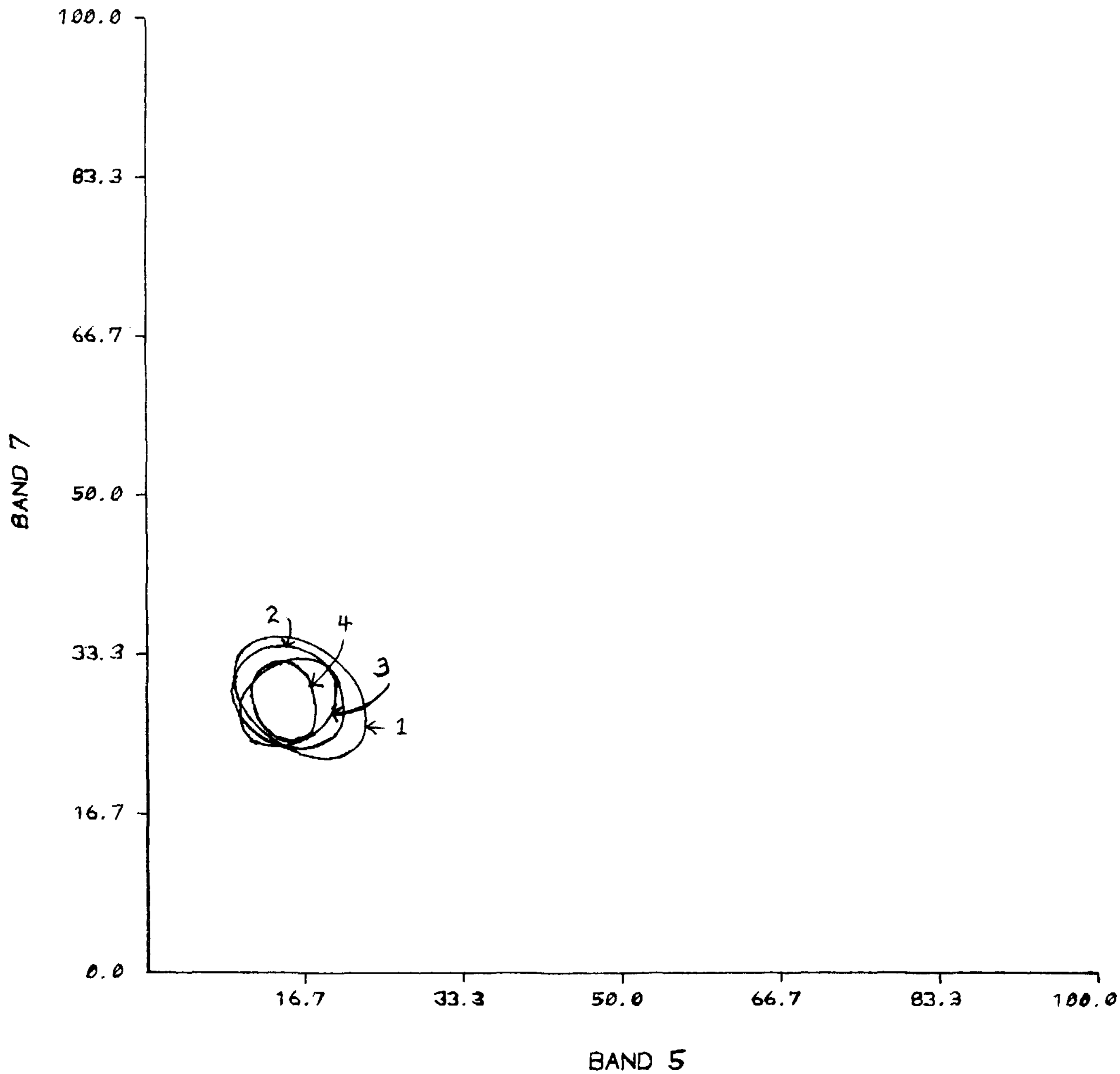


Figure
A-2

90.0% CONCENTRATION ELLIPSES FOR BANDS 5 AND 7
CORN BY FIELD SIZE - CALIF.

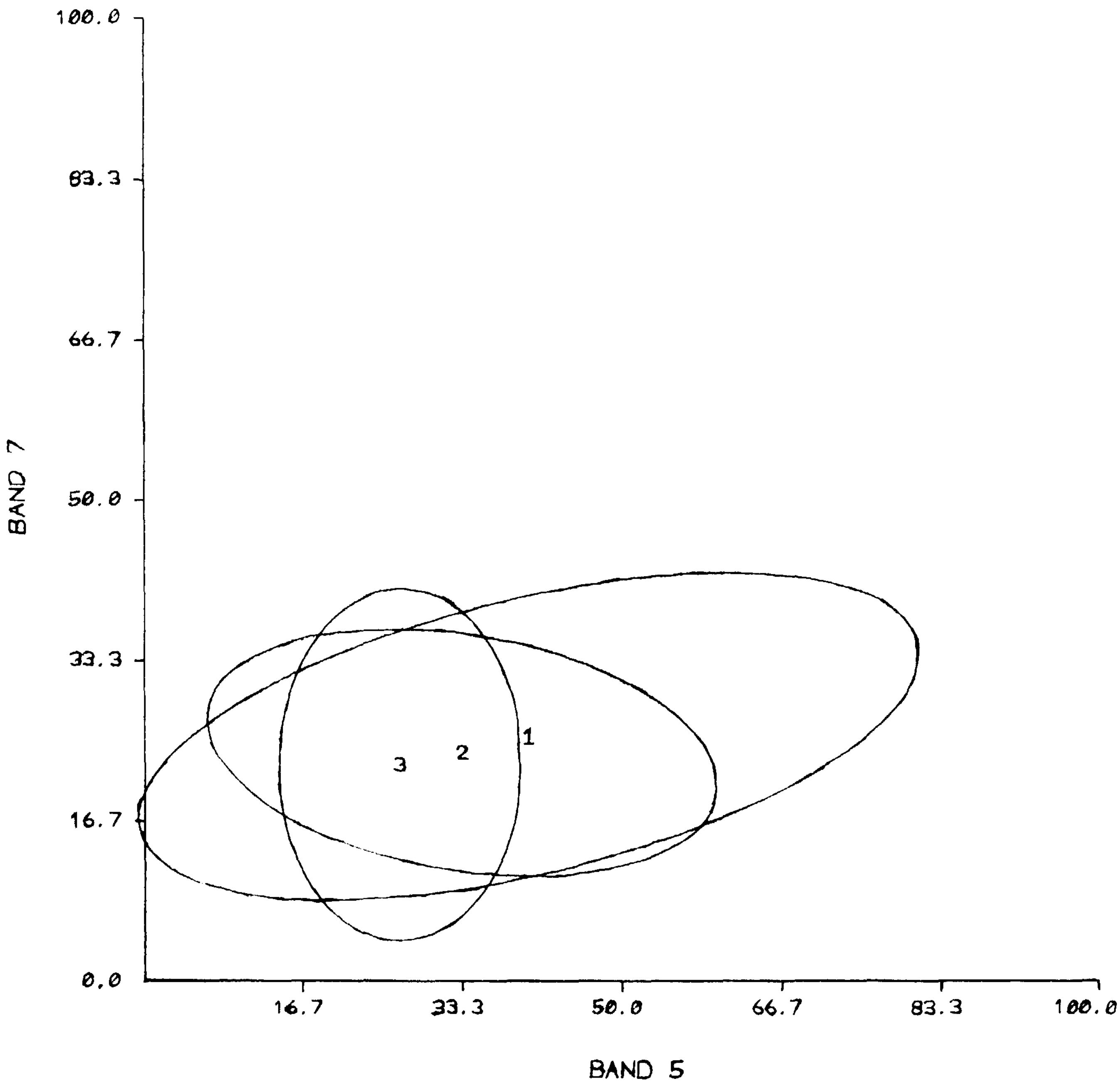


Figure
A-3

90.0% CONCENTRATION ELLIPSES FOR BANDS 5 AND 7
ILLINOIS PASTURE BY FIELD SIZE

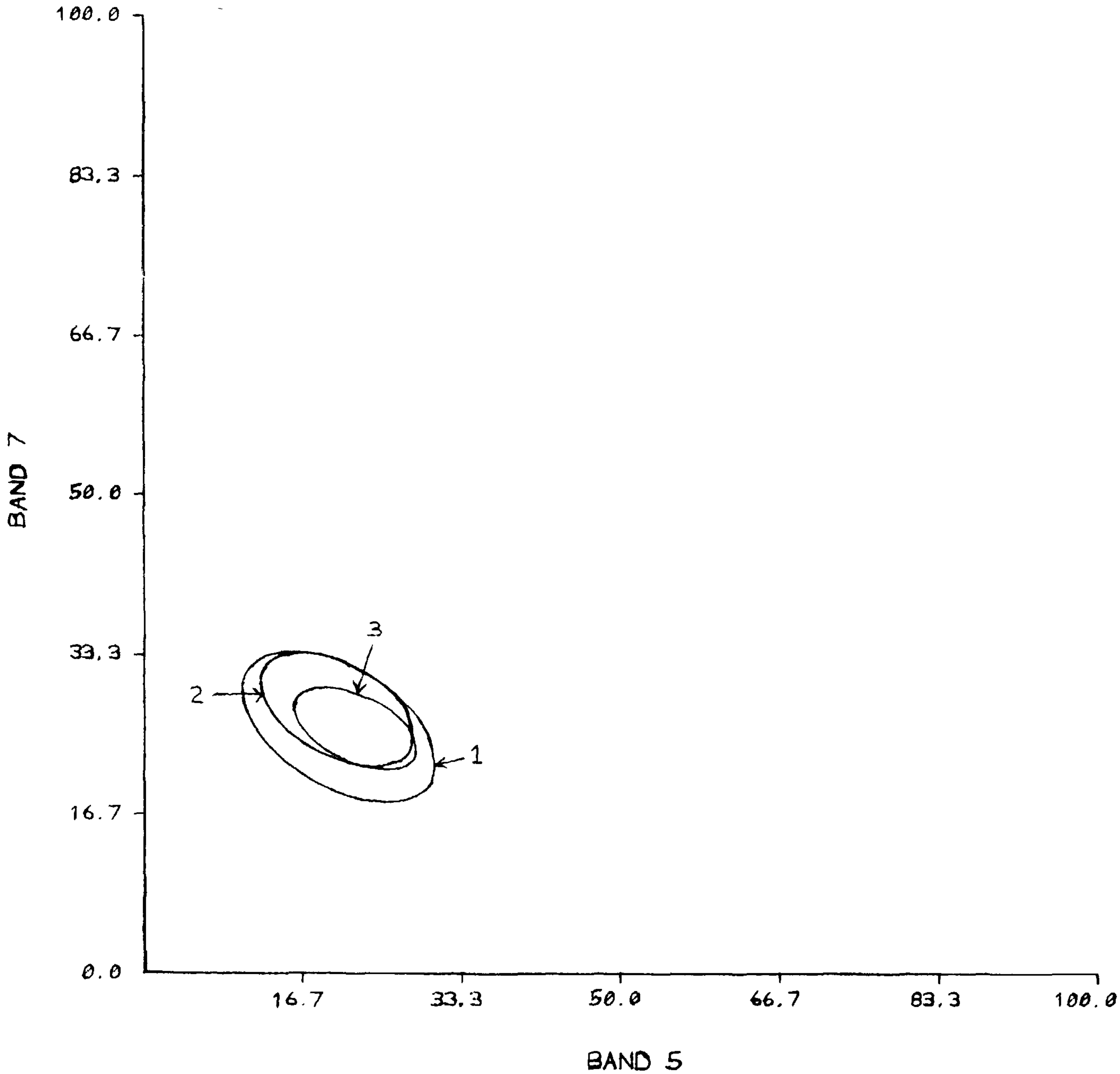


Figure
A-4
90.0% CONCENTRATION ELLIPSES FOR BANDS 5 AND 7
GRAPES: BY FIELD SIZE - CALIF.

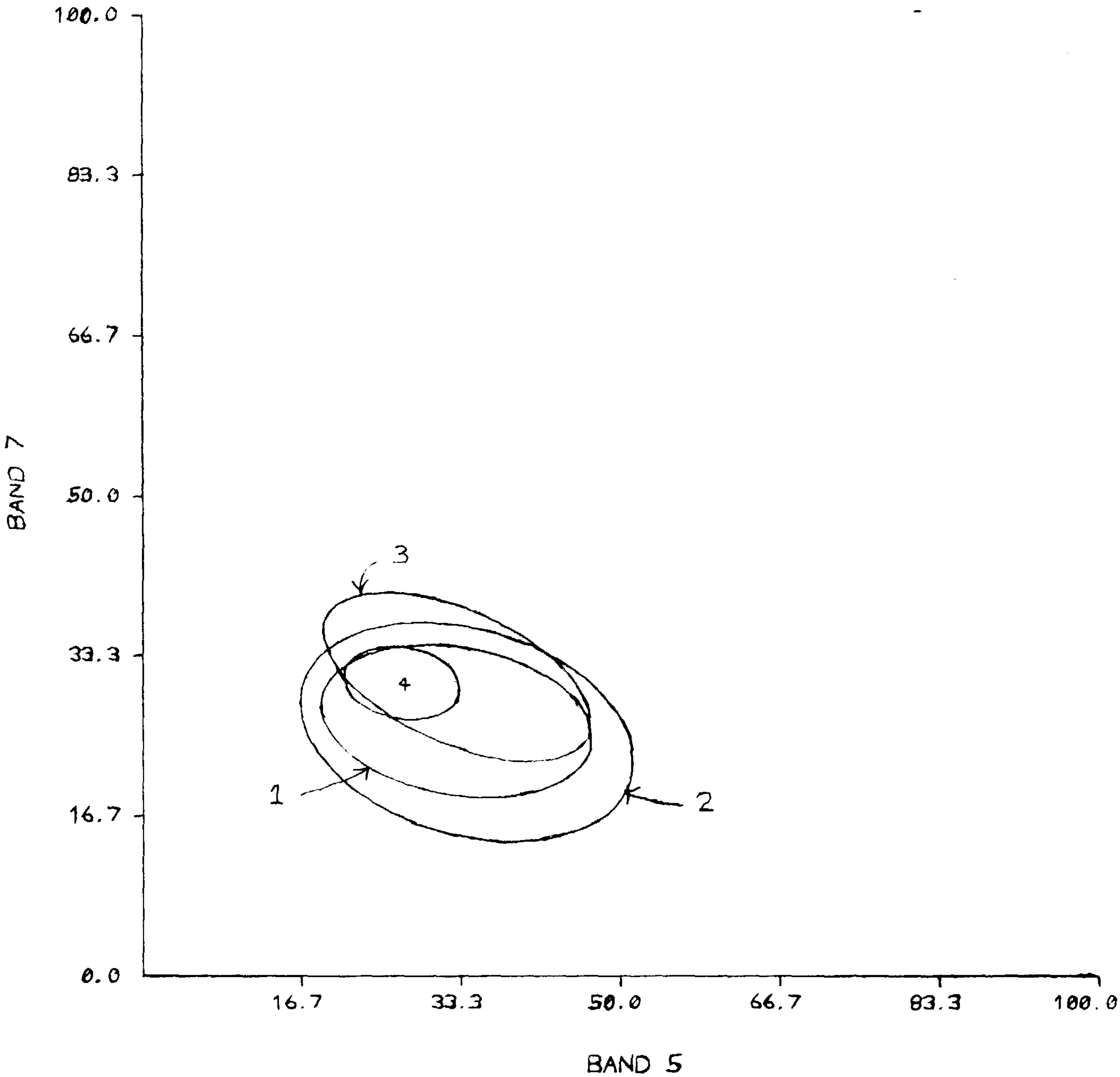


TABLE 1: Ground Cover Types Considered in the Analysis

Ground Cover	California	Illinois
Alfalfa	X[1]	X
Barley	X	
Citrus	X	
Corn	X	X
Cotton	X	
Dense Woodland		X
Fruit Trees[2]	X	
Grapes	X	
Permanent Pasture	X	X
Soybeans		X
Wasteland	X	X
Winter Wheat	X	

[1] X indicates that the ground cover was included in the analysis.

[2] Excludes citrus.

As can be seen in Table A the number of large fields is quite small with the exception of corn in Illinois which contains 20 fields of sizes ranging from 80 to 200 acres. In this case, the ellipse for this class is not only more compact, but its major axis is almost perpendicular to those of the ellipses of the other classes (Figure A.1). Interestingly, the same situation holds in California corn (Figure A.2) even though in this case only 4 fields are present and different stages of maturity are represented.

No distinction could be made between field size classes (1) and (2). On occasions the ellipses for class (1) were more compact than those of class (2) but on other occasions the reverse was true. Tables A.1-A.16 display the descriptive statistics of the MSS bands for all sixteen cover types.

In undertaking the study concerning boundary pixels it was necessary to break down the class consisting of field sizes less than 20 acres into two classes: (a) field size less than 10 acres and (b) field size greater then or equal to 10, but less than 20 acres. These subclasses also furnished information on field size. In California field size subclass (a) apparently produced distinct means as well as more compact ellipses than subclass (b) however, the number of small fields in California was very small (Tables A.23-A.32). In contrast, in Illinois the number of small fields was much greater, but here no consistent pattern existed (Tables A.17-A.22).

V. Boundary Considerations

In practice, only the inner pixels are used in training a classifier. Boundary pixels might be contaminated, i.e. not entirely contained within the field boundaries, and are therefore eliminated. Due to large sizes of fields in the United States, this procedure eliminates only a small percentage of the available pixels for the study. However, in foreign countries where field sizes are generally smaller, this practice will exclude a large percentage of the available pixels. For this reason, a study on the use or nonuse of boundary pixels seems desirable. Because the concern lies with small fields, the class of field sizes less than 20 acres was subdivided as explained in the previous section.

The mean and variance for each of the 4 MSS bands were calculated with and without boundary pixels for each of the ground cover types considered. Only the crops in Illinois are discussed since the primary interest is in crops and since the number of the required size fields in the California study area is small.

Looking at alfalfa in Illinois (Table A.17), one can see that the variance increased on all 4 bands for the small size fields when boundary pixels were considered; however the opposite occurred for the larger fields. In contrast, for soybeans the variances for both size classes increased for bands 4 and 5, but decreased for bands 6 and 7 when using boundary pixels. Obviously, the inclusion of boundary pixels does not systematically expand the variances and therefore it seems that the inclusion of boundary pixels does not significantly effect the classifier.

VI. Conclusions

Valid inferences can not be drawn due to the fact that the fields were not drawn at random. The segments were randomly drawn but they contain different sizes of fields. Moreover, although winter wheat and barley were mature at the time the ground truth was collected approximately half of these crops had been harvested by the time the LANDSAT image was taken. The assumption was, therefore, implicitly made that the change in signature by field size caused by harvesting the crop is proportional. Notwithstanding there is enough evidence that large fields have different signatures than small fields to warrent further experimentation. A possible approach is to stratify by field size for classification purposes. A different classifier could be used for each stratum. Also, a single classifier for both strata could be used and a misclassification study could then be conducted comparing both methods. This is similar to the approach of masked classification by land use stratum presented by Hanuschak and Morrissey.[2]

As far as the boundary consideration study is concerned it appears that the inclusion of boundary pixels when dealing with small fields does not significantly worsen the classifier.

References

1. Gleason, C., Starbuck, R., Sigman, R., Hanuschak. G., Cook, P., Allen, R., "The Auxiliary Use of LANDSAT Data in Estimating Crop Acreages: Results of the 1975 Illinois Crop Acreage Experiment", Statistical Reporting Service, U.S. Department of Agriculture, SRS-21, October, 1977.

2. Hanuschak, George A., Morrissey Kathleen M., "Pilot Study of the Potential Contributions of LANDSAT Data in the Construction of Area Sampling Frames", Statistical Reporting Service. U.S. Department of Agriculture, October 1977.

TABLE A: Distribution of Fields and Pixels by Field Size and Ground Cover Types

Ground Cover Type	FIELD SIZE (1) No. of Fields	(1) No. of Pixels	(2) No. of Fields	(2) No. of Pixels	(3) No. of Fields	(3) No. of Pixels	(4) No. of Fields	(4) No. of Pixels
California								
Alfalfa	15	58	27	721	6	438	0	0
Barley	5	13	14	407	7	374	4	932
Citrus	36	133	31	487	2	188	0	0
Corn	9	30	26	591	4	175	0	0
Cotton	23	113	46	1257	8	625	5	1683
Fruit Trees	48	172	15	297	1	54	0	0
Grapes	12	75	13	265	9	594	1	536
Permanent Pasture	47	56	12	336	2	190	2	405
Wasteland	170	138	28	468	3	181	3	679
Winter Wheat	13	55	14	314	3	345	3	634
Illinois								
Alfalfa	87	261	27	357	0	0	0	0
Corn	196	659	167	3545	20	1593	6	1032
Dense Woodland	64	133	17	255	4	224	0	0
Permanent Pasture	66	109	29	514	2	122	0	0
Soybeans	51	167	57	1222	2	128	0	0
Wasteland	280	214	19	255	0	0	0	0

TABLE A.1

Alfalfa (Illinois): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	87	261	19.66	4.95	20.03	23.29	55.95	76.77	28.75	31.13
20-80	27	357	18.90	3.95	18.16	22.08	59.12	120.20	30.73	46.96
80-200	0	0	-	-	-	-	-	-	-	-
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.2

Corn (Illinois): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	196	659	17.43	3.68	16.21	10.62	53.27	23.20	28.79	8.87
20-80	167	3545	16.71	2.63	14.97	7.64	52.24	18.10	28.78	6.37
80-200	20	1593	16.45	1.58	14.49	2.52	51.13	12.19	28.33	3.91
≥ 200	6	1032	16.48	2.54	14.91	5.76	51.09	16.91	28.28	4.62

TABLE A.3

Dense Woodland (Illinois): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	64	133	15.49	3.39	13.65	5.77	53.19	26.31	29.29	10.28
20-80	17	255	15.00	2.20	13.02	3.59	53.06	14.91	29.45	5.64
80-200	4	224	14.71	2.24	12.69	2.40	53.35	17.33	29.78	8.47
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.4

Permanent Pasture (Illinois): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	66	109	19.31	6.61	20.43	22.45	50.24	27.85	25.65	13.62
20-80	29	514	19.36	5.17	20.20	13.98	53.19	19.98	27.50	7.77
80-200	2	122	19.77	2.97	22.16	9.19	50.21	12.58	25.49	3.99
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.5

Soybeans (Illinois): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	51	167	16.11	1.37	13.90	2.36	63.12	74.02	35.81	38.50
20-80	57	1222	15.99	1.76	13.54	3.33	69.40	72.22	39.40	31.25
80-200	2	128	15.91	1.41	13.16	1.93	71.20	84.95	40.24	31.49
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.6

Wasteland (Illinois): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	280	214	20.52	19.92	21.53	48.41	51.76	72.62	25.87	26.29
20-80	19	255	21.14	38.13	23.74	129.09	53.43	52.36	26.10	22.33
80-200	0	0	-	-	-	-	-	-	-	-
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.7

Alfalfa (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	15	58	25.22	22.35	28.62	94.56	68.24	99.91	34.52	44.01
20-80	26	721	25.82	43.97	29.71	56.36	62.06	87.99	30.89	37.04
80-200	6	438	23.23	18.48	25.35	91.92	71.62	161.50	37.38	77.23
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.8

Barley (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	5	13	41.54	79.94	66.92	364.74	77.23	379.36	32.46	70.77
20-80	14	407	42.77	118.14	66.39	501.06	79.22	383.99	34.21	74.19
80-200	7	374	42.48	76.04	67.01	345.45	76.97	469.27	32.81	89.30
≥ 200	4	932	45.62	13.07	70.81	62.78	76.30	150.94	31.35	42.66

TABLE A.9

Citrus (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	36	133	25.98	12.42	34.77	54.68	55.89	27.90	26.26	5.93
20-80	31	487	26.11	8.87	35.17	33.30	56.98	30.55	26.90	4.44
80-200	2	188	25.30	6.66	33.29	29.16	56.25	10.85	27.22	1.32
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.10

Corn (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	9	30	30.47	106.60	40.17	362.42	56.07	289.44	25.37	62.52
20-80	26	591	26.66	54.30	33.23	154.52	50.67	80.43	23.69	35.67
80-200	4	175	23.85	14.08	26.71	34.90	48.49	196.19	22.45	72.28
≥ 200	0	0	-	-	-	-	-	-	-	-

TABLE A.11

Cotton (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	23	113	27.27	15.63	33.84	49.44	59.42	51.69	27.73	16.55
20-80	46	1257	24.53	30.28	27.73	75.42	59.25	61.94	28.51	19.11
80-200	8	625	23.85	16.55	26.38	97.41	62.73	45.28	30.74	13.81
≥ 200	5	1693	31.07	34.83	36.53	76.23	71.95	86.70	33.48	25.91

TABLE A.12

Fruit trees* (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	48	172	21.93	24.39	24.95	101.06	55.35	58.57	27.97	28.12
20-80	15	297	22.79	21.58	26.49	63.25	54.57	109.10	26.85	33.80
80-200	1	54	25.15	1.90	32.78	6.18	48.65	4.65	22.46	0.63
$\geq$ 200	0	0	-	-	-	-	-	-	-	-

*does not include citrus

TABLE A.13

Grapes (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	12	75	26.59	13.60	32.88	43.46	56.91	38.87	26.43	13.71
20-80	13	265	27.01	22.29	33.91	65.93	54.57	79.19	25.34	28.07
80-200	9	594	27.21	6.57	32.94	42.69	63.84	39.97	31.04	16.76
≥ 200	1	536	24.01	27.79	27.14	8.26	61.64	8.53	30.41	3.11

TABLE A.14

Permanent Pasture (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	47	56	27.64	26.45	33.39	85.08	60.04	66.76	29.27	38.16
20-80	12	336	30.12	38.48	39.45	166.24	61.02	66.62	29.07	42.38
80-200	2	190	33.95	5.21	49.21	18.95	55.96	22.37	24.19	7.46
≥ 200	2	405	34.40	43.78	52.09	94.37	58.75	122.61	25.14	30.17

TABLE A.15

Wasteland (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	170	138	35.04	61.59	[illegible]0.00	198.39	62.70	106.21	27.32	28.13
20-80	28	468	37.13	91.75	51.64	191.02	58.81	124.26	24.57	25.23
80-200	3	181	40.02	52.02	55.80	119.34	60.73	132.31	24.96	17.80
≥ 200	3	679	38.57	74.53	53.05	182.58	56.99	164.40	23.11	34.79

TABLE A.16

Winter Wheat (California): MSS bands' statistics and distribution of fields and pixels by field size

Field size (in acres)	No. of fields	No. of pixels	MEAN AND VARIANCE							
			band 4		band 5		band 6		band 7	
			mean	var	mean	var	mean	var	mean	var
< 20	13	55	31.55	73.18	46.20	304.90	58.07	407.70	25.71	93.28
20-80	14	314	34.73	68.63	52.22	361.48	67.87	378.24	30.79	107.19
80-200	3	345	36.81	33.94	59.36	188.28	69.77	227.50	30.75	54.51
≥ 200	3	634	37.50	77.02	55.78	144.17	61.13	154.82	25.60	32.51

TABLE A.17

Alfalfa (Illinois): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	46	without	36	19.42	3.96	19.53	12.54	56.75	44.14	29.14	15.49
		with	227	18.96	5.43	18.74	13.71	55.41	47.56	28.80	17.83
10-20	41	without	225	19.69	5.12	20.12	25.03	55.82	82.09	28.69	33.69
		with	521	19.15	4.28	19.01	18.86	56.82	73.10	29.48	28.31

TABLE A.18

Corn (Illinois): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	104	without	127	17.78	3.74	16.94	13.77	53.28	18.55	28.47	8.01
		with	503	18.13	5.27	17.62	16.28	53.45	25.90	28.43	11.20
10-20	92	without	532	17.34	3.64	16.04	9.74	53.27	24.35	28.86	9.07
		with	1215	17.36	3.45	16.12	9.24	53.68	26.02	29.01	9.69

TABLE A.19

Dense Woodland (Illinois): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	44	without	44	15.80	4.45	14.36	7.91	52.98	45.05	29.00	17.35
		with	209	16.90	6.89	16.01	18.85	53.44	34.96	28.78	13.86
10-20	20	without	89	15.34	2.84	13.30	4.42	53.29	17.41	29.43	6.88
		with	263	16.23	4.49	14.61	9.21	52.71	25.48	28.76	10.58

TABLE A.20

Permanent pasture (Illinois): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	50	without	24	19.12	5.07	20.17	17.62	50.67	43.97	25.75	18.28
		with	205	18.49	3.76	18.90	12.03	52.12	36.03	27.00	14.06
10-20	16	without	85	19.36	7.09	20.51	24.01	50.20	23.70	25.62	12.50
		with	222	18.88	5.74	19.69	22.26	51.70	52.14	26.96	25.05

TABLE A.21

Soybeans (Illinois): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	24	without	25	16.84	1.06	14.68	1.14	64.36	77.66	36.52	42.59
		with	186	17.35	3.09	15.62	6.35	63.17	58.70	34.78	32.14
10-20	27	without	142	15.98	1.33	13.77	2.46	62.90	73.61	35.69	37.97
		with	317	16.29	1.84	14.24	4.67	63.01	68.98	35.24	35.09

TABLE A.22

Wasteland (Illinois): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	253	without	99	21.16	28.34	22.42	71.29	54.24	55.12	27.12	15.72
		with	709	19.85	14.55	20.54	38.86	53.66	39.28	27.51	17.41
10-20	27	without	115	19.97	12.20	20.77	27.88	49.79	79.87	24.80	33.09
		with	408	19.62	16.52	20.13	45.52	51.89	54.60	26.29	24.66

TABLE A.23

Alfalfa (California): Small field statistics of MSSbands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	5	without	13	27.23	11.36	34.69	66.40	64.31	125.06	31.69	53.13
		with	46	28.17	16.37	36.67	59.51	63.54	71.81	30.61	29.04
10-20	10	without	45	24.64	24.33	26.87	90.35	69.38	89.42	35.33	39.22
		with	79	25.05	21.66	27.96	79.78	67.25	93.99	33.97	40.92

TABLE A.24

Barley (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	2	without	0	-	-	-	-	-	-	-	-
		with	5	34.80	11.70	50.60	56.30	65.60	10.80	29.40	4.30
10-20	3	without	13	41.54	79.94	66.92	364.74	77.23	379.36	32.46	70.77
		with	31	40.68	78.89	63.84	417.14	76.74	258.06	33.42	42.32

TABLE A.25

Citrus (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	10	without	14	26.86	17.82	37.07	114.38	58.29	12.84	27.21	4.49
		with	53	27.02	11.13	36.53	63.79	56.83	16.49	26.25	4.69
10-20	26	without	119	25.87	11.82	34.50	47.86	55.61	29.04	26.14	6.02
		with	297	26.12	15.35	35.01	47.94	55.18	22.91	25.82	5.74

TABLE A.26

Corn (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	3	without	3	24.06	39.93	28.75	155.00	57.44	38.93	28.06	34.60
		with	16	19.00	1.00	17.67	2.33	61.67	4.33	33.67	2.33
10-20	6	without	27	31.74	101.97	42.67	339.15	55.44	318.49	24.44	10.72
		with	48	30.42	64.63	39.94	221.46	56.15	196.55	25.44	41.57

TABLE A.27

Cotton (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	10	without	20	27.20	9.85	33.65	24.98	56.50	58.79	26.25	15.88
		with	35	27.63	11.42	34.37	34.24	57.54	70.20	27.03	21.56
10-20	13	without	93	27.29	16.29	33.88	55.02	60.05	48.53	28.05	16.29
		with	175	27.05	16.04	33.44	51.19	59.34	52.22	27.82	16.85

TABLE A.29

Grapes (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	4	without	2	33.00	8.00	41.00	8.00	55.00	2.00	25.00	2.00
		with	7	31.43	20.29	39.71	69.24	56.29	8.57	25.00	5.00
10-20	8	without	73	26.41	12.69	32.66	42.67	56.96	39.82	26.47	14.00
		with	133	26.68	16.72	33.36	51.16	56.32	59.32	26.16	19.01

TABLE A.30

Permanent Pasture (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	39	without	28	26.71	21.32	32.50	88.78	60.79	39.51	30.57	27.51
		with	132	27.02	21.68	33.30	83.26	59.65	92.35	28.94	26.74
10-20	8	without	28	28.57	30.77	34.29	82.88	59.29	95.32	27.96	46.70
		with	93	28.81	29.22	35.43	101.97	60.77	90.15	28.90	39.44

TABLE A.31

Wasteland (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	140	without	24	35.17	70.06	49.25	244.63	62.79	201.48	27.25	46.72
		with	244	31.82	41.57	42.82	147.78	59.90	107.78	26.83	25.12
10-20	30	without	114	35.02	60.41	50.16	190.59	62.68	87.76	27.33	24.60
		with	406	33.73	57.99	47.25	197.15	60.89	89.30	26.50	20.56

TABLE A.32

Winter Wheat (California): Small field statistics of MSS bands

Field size (in acres)	No. of fields	Boundary pixels	No. of pixels	MEAN AND VARIANCE							
				band 4		band 5		band 6		band 7	
				mean	var	mean	var	mean	var	mean	var
< 10	6	without	13	24.92	42.74	30.85	102.97	41.23	237.86	18.00	63.33
		with	42	27.38	29.38	35.71	94.70	50.26	189.56	22.86	53.93
10-20	7	without	42	33.60	65.66	50.95	273.56	63.29	349.57	28.10	79.65
		with	75	31.89	61.18	46.19	259.05	59.67	323.44	26.49	76.96