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Technical Report

THEMATIC MAPPER SIMULATOR DATA COLLECTED OVER EASTERN NORTH DAKOTA

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16. ABSTRACT

This report presents results of the analysis of aircraft-acquired Thematic Mapper Simulator (TMS) data, collected in August 1980 as part of the AgRISTARS Domestic Crops and Land Cover (DCLC) Project. The investigations presented in this document were carried out under the Sensor Implementation and Evaluation Research element of the project. The overriding thrust of the research reported herein was to investigate the utility of Thematic Mapper (TM) data, through simulation, in crop area and land cover estimates.

Results of the analysis indicate that the seven-channel TMS data are capable of delineating the 13 crop types included in the study to an overall pixel classification accuracy of 80.97% correct, with relative efficiencies for four crop types examined between 1.62 and 26.61. SRS considers any relative efficiency above 1.5 indicative of a significant reduction in variance, and hence an improvement in the technique used to derive land cover estimates.

Both supervised and unsupervised spectral signature development techniques as developed at NASA/NSTL/ERL were evaluated. The unsupervised methods proved to be inferior (based on analysis of variance) for the majority of crop types considered. Given the ground truth data set used for spectral signature development as well as evaluation of performance, it is possible to demonstrate which signature development technique would produce the highest percent correct classification for each crop type.

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NATIONAL SPACE TECHNOLOGY LABORATORIES

EARTH RESOURCES LABORATORY

TABLE OF CONTENTS

		PAGE
I.	SUMMARY	1
II.	INTRODUCTION	1
III.	THEMATIC MAPPER SIMULATOR DATA	2
IV.	GROUND TRUTH	5
V.	DATA PROCESSING AND ANALYSIS	6
VI.	SUPERVISED SPECTRAL SIGNATURE DEVELOPMENT	8
VII.	UNSUPERVISED APPROACH TO SPECTRAL SIGNATURE DEVELOPMENT	9
VIII.	LAND COVER ESTIMATION	10
IX.	RESULTS AND DISCUSSION	10
X.	CONCLUSIONS	14
	REFERENCES	17
	APPENDIX A - TMS SPECIFICATIONS	18
	APPENDIX B - ORIGINAL AND EDITED SRS SEGMENT CROP TYPE ACREAGES FOR THE 15 SEGMENTS USED IN THIS STUDY	20

LIST OF FIGURES

Figure	Title	Page
1	Spectral Wavelength Characteristics of the TMS and Landsat Earth Resources Satellite Systems	3
2	Before Editing and After Editing Distributions for TMS Data Corresponding to Barley Crop Type	7
3	Wasteland Data Distribution	13
4	Dry Beans Data Distribution	15

LIST OF TABLES

Table	Title	Page
1	Percent Correct Classification Values - North Dakota TMS Data - 7 Channels	11
2	Relative Efficiencies for Four Crops	16

AN ANALYSIS OF THEMATIC MAPPER SIMULATOR DATA
COLLECTED OVER EASTERN NORTH DAKOTA

I. SUMMARY

This report presents results of the analysis of aircraft-acquired Thematic Mapper Simulator (TMS) data, collected in August 1980 as part of the AgRISTARS Domestic Crops and Land Cover (DCLC) Project. The investigations presented in this document were carried out under the Sensor Implementation and Evaluation Research element of the project. The overriding thrust of the research reported herein was to investigate the utility of Thematic Mapper (TM) data, through simulation, in crop area and land cover estimates.

Results of the analysis indicate that the seven-channel TMS data are capable of delineating the 13 crop types included in the study to an overall pixel classification accuracy of 80.97% correct, with relative efficiencies for four crop types examined between 1.62 and 26.61.

Both supervised and unsupervised spectral signature development techniques as developed at NASA/NSTL/ERL were evaluated. The unsupervised methods proved to be inferior (based on analysis of variance) for the majority of crop types considered. Given the ground truth data set used for spectral signature development as well as evaluation of performance, it is possible to demonstrate which signature development technique would produce the highest percent correct classification for each crop type.

II. INTRODUCTION

The purpose of this report is to present results obtained from the analysis of TMS digital data collected in August 1980 over the Walsh

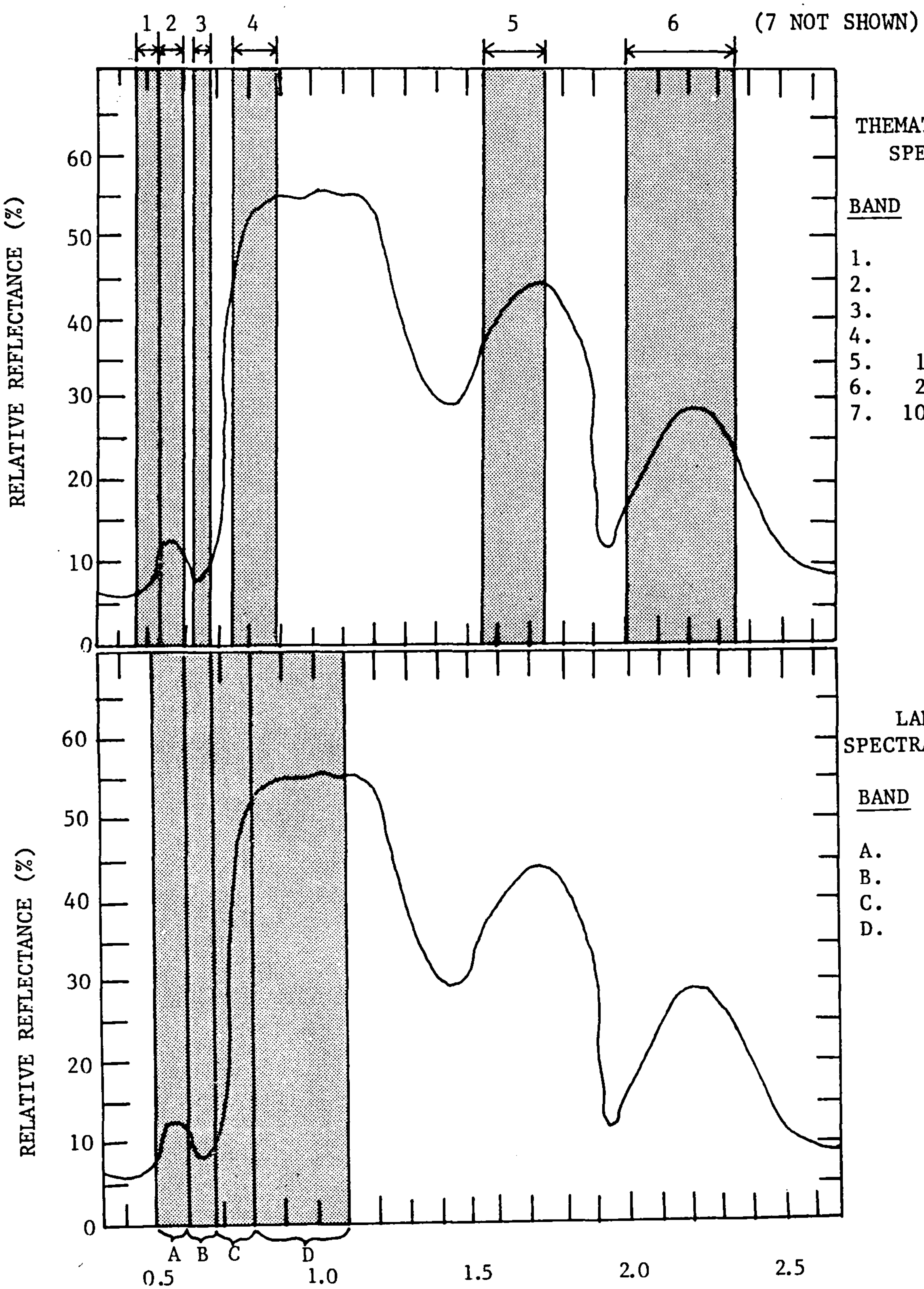
County area in the drainage basin of the Red River Valley in eastern North Dakota (ND site). The data collected represent only a portion of the data which will be included in the total DCLC Project. Subsequent reports will deal with the analysis of TMS data collected over other study sites for additional crop land cover types.

The work conducted in this investigation falls under the Sensor Implementation and Evaluation Research element of the project. The specific area of research is contained in Task 4.7.1, Thematic Mapper Procedure Development. The overall objectives of the task are (1) to provide an evaluation of the anticipated utility of the TM for crop and land cover estimates, and (2) to provide software/procedure development for the analysis of the TM data.

This portion of the DCLC Project is conducted as a cooperative research effort between the National Aeronautics and Space Administration (NASA), Earth Resources Laboratory (ERL), located at the National Space Technology Laboratories (NSTL), and the United States Department of Agriculture, Statistical Reporting Service (SRS). The ERL collected and analyzed the TMS data, while SRS supplied the registered segment (ground truth) data, upon which performance evaluations were made.

III. THEMATIC MAPPER SIMULATOR DATA

Data used in this study were obtained by an airborne TMS scanner system (see Appendix A for TMS specifications). The TMS was designed to produce data with spectral and spatial characteristics (Figure 1) similar to those of the TM scanner, which will be on board Landsat D (scheduled for launch in late FY82). The TM will have spectral resolution of 30-m (100-ft) spatial resolution in channels 1, 2, 3, 4, 5, and 7 and 120-m (about 396 ft) resolution in channel 6.



THEMATIC MAPPER SIMULATOR
SPECTRAL RESOLUTION

BAND	WAVELENGTH REGION
1.	.45 - .52μ
2.	.52 - .60μ
3.	.63 - .69μ
4.	.76 - .90μ
5.	1.55 - 1.75μ
6.	2.08 - 2.35μ
7.	10.40 - 12.5 μ

LANDSAT MSS
SPECTRAL RESOLUTION

BAND	WAVELENGTH REGION
A.	.50 - .60μ
B.	.60 - .70μ
C.	.70 - .80μ
D.	.80 - 1.1 μ

Figure 1. Spectral Wavelength Characteristics of TMS and Landsat MSS Systems

Figure 1 also presents the spectral resolution of currently available Landsat MSS data, as well as a generalized green leaf reflectance curve (after Knipling, ref. 1) for comparison of the two sensor systems. While the TMS channels are numbered in order of their occurrence in the electromagnetic spectrum from short (blue) to long (IR) wavelengths, the channels of the TM do not follow this system. The reader should be aware of this channel numbering difference while reading this report. (TMS channel 6 is equivalent to TM channel 7; all others are identical.)

TMS data were collected on August 11, 1980, from an altitude of 12,000 m (39,370 ft) above mean terrain elevation. With a 2.5-milliradian aperture, this resulted in a spatial resolution (at nadir) of 30 x 30 m (100 x 100 ft) for channels 1 through 6, and 120 x 120 m (394 x 394 ft) for channel 7. The TMS scanned through a 50-degree angle on either side of nadir, but data processing and analysis were restricted to 30 degrees on either side of nadir to provide a closer simulation of TM data. Data collected by the TMS are subsequently converted by the scanner to an 8 bit (256 levels of gray) digital format for use in data processing and analysis activities. The data were viewed on an image display device, and examined for radiometric fidelity and the presence of abnormal data values (detector noise, dropouts, loss of sync, etc.). Since the spatial resolution of channel 7 is four times as coarse as the other six channels, it contains only one-sixteenth the number of pixels. This situation was rectified by expanding the data for channel 7 by repeating each "pixel" in channel 7 three times in both the scan line and element directions. This resulted in blocks of 16 pixels (four by four pixels in size) each containing the radiometric value of the initial channel 7 pixel. In this manner, a channel-to-channel registration with the other six channels was performed, while at the same time the geometric relationship of channel 7 to the other six channels (four-to-one) was preserved.

When all problems had been corrected, the center 60 degrees of the data were examined for sun angle/angle-of-look related trends. No such problem existed with this data set, as the aircraft data collection flight occurred "into the sun" and was within one half hour of solar noon.

IV. GROUND TRUTH

Field enumeration in SRS segments served as the ground-truth data source (ref. 2). An SRS segment is a parcel of land (at the subcounty level) delineated by natural or recognizable boundaries which is used to make statistical estimates about agricultural commodities. Segments are chosen by random selection procedures from an area frame stratified by general land uses. For the ND site, regular SRS segments were approximately 1 sq. mi. in area, containing from three-to-eight land cover types. The segment data represent a random sampling of the major crop cover types of interest within the ND site. Numerous fields within segments were used for each crop cover type of interest to ensure the statistical reliability of results obtained.

Each segment was visited in the field during the 1980 June enumerative survey (ref. 2) by trained field personnel, who recorded the boundaries of each field and the land cover/land use. Several additional "mini-segments" were visited on 10 August 1980. Such sites were established to provide additional fields for training purposes for matching with remotely sensed data. Segment and field boundaries were drawn onto small-scale vertical photography. Ground truth information corresponding to these segments was placed into a ground truth book and filed for later comparison with the TMS data analysis results.

For the five flight lines of TMS data collected, a total of 15 segments (including mini-segments) were used in the study, representing approximately 2,064 ha (5,100 acres) total. This network of ground truth included fields representing wasteland (non-cropped), sunflowers, spring wheat, sugar beets, "other" crops, alfalfa, barley, potatoes, corn, dry beans, flax, durum wheat, and summer fallow.

V. DATA PROCESSING AND ANALYSIS

The initial phase of data processing dealt with registering the segment data to the seven channels of TMS data already located on a data file. This was done by geographically registering the TMS data to a map, and subsequently overlaying the geographically registered segment data to the map-registered TMS data. TMS data-to-map registration was accomplished using ERL software developed for that purpose (ref 3). The registered data were subsequently sent to SRS for the segment-to-TMS data registration.

After SRS had completed the segment-to-TMS overlay, the data were sent back to the ERL for analysis. Using a color image display device and aerial photography, each segment was examined. It was determined that the land cover in several fields had been modified since the fields had been visited on the ground. The most prominent change had resulted from harvesting operations which removed the crop cover and left stubble, etc. Thus, numerous fields were edited and renamed from the specific crop types to a generic "fall fallow" crop type. All flax fields had been harvested by August 11. Thus, flax does not appear in the remainder of this report. However, all other crop types were represented by fields in the edited segment file.

One other significant problem was encountered with the segment file. It was found that several segments were not registered to the TMS data very well, presumably due to the instability of the aircraft platform at the time of data collection. Thus, when the data were registered to a map, certain areas did not fit well. This problem was corrected by simply re-establishing the segment locations in the TMS data and editing the file sent by SRS.

The combined effect of harvesting and poor registration of segments can be seen in Figure 2, which presents "before editing" and "after editing"

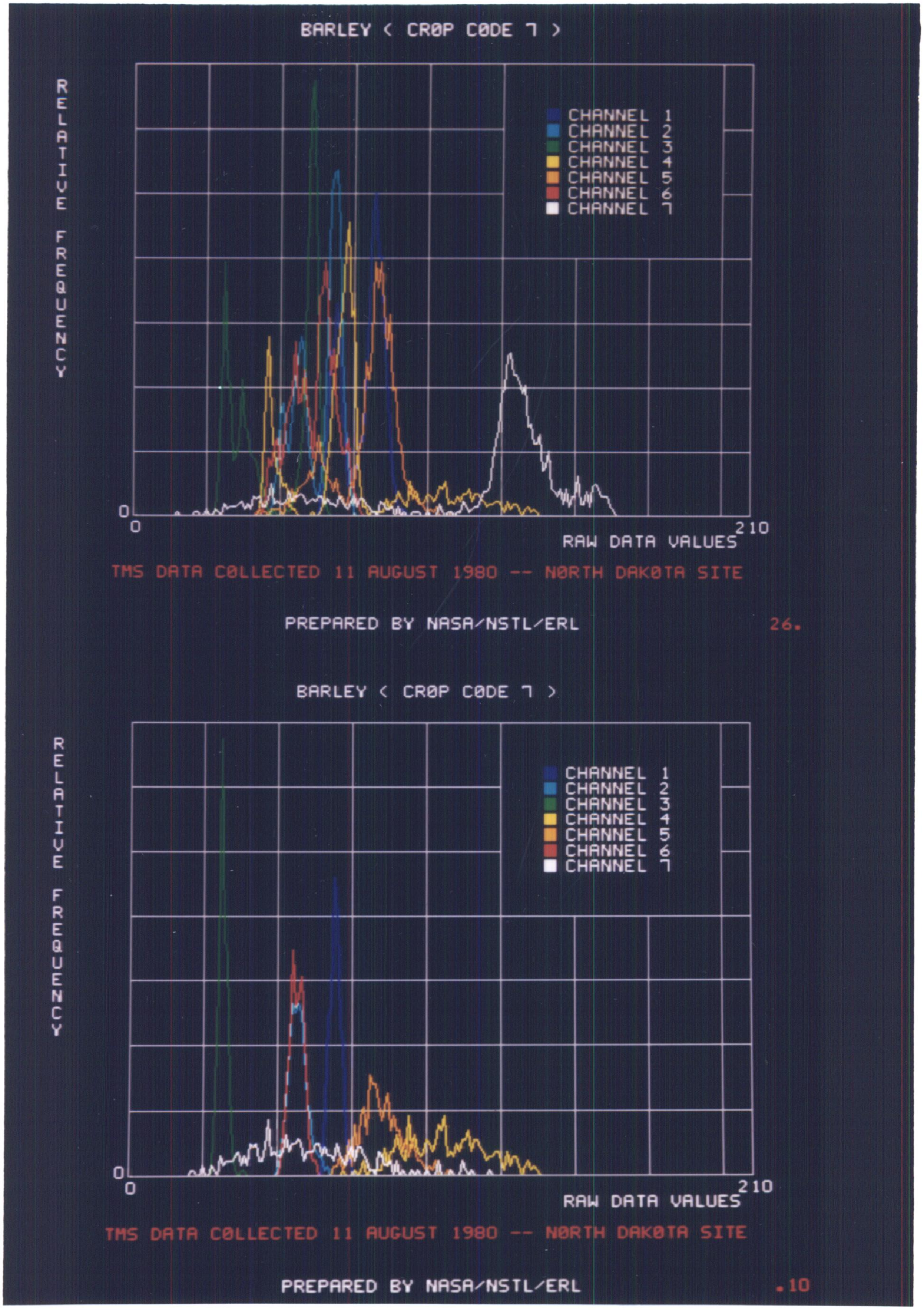


Figure 2. Before Editing and After Editing Distributions for TMS Data Corresponding to Barley Crop Type

distributions for the TMS data corresponding to the barley crop type. As can be seen, both the multimodal and large variance tendencies for all channels of data are dramatically changed by editing, producing a much more uniform spectral distribution for barley. Similar results were noticed for other crop types affected by the same problems. Edited segment data were then copied (as an additional channel) into the computer file containing the TMS data (Appendix B).

VI. SUPERVISED SPECTRAL SIGNATURE DEVELOPMENT

After preprocessing the TMS digitial data and registering and editing the segment data, the next step in the investigation was to develop supervised spectral signatures for each of the crop types present. Spectral signatures were developed through the use of software which uses a directional index table approach (MUCS - ref. 3). This software can be instructed to examine one channel of data (a mask file) and to develop spectral signatures from other channels of data (data file) for specified values in the mask file. The channel containing the SRS segment data was used as the mask file, and the software was instructed to develop a seven-channel spectral signature for the edited crop types. Since every crop type in the "SRS segment" channel had been assigned a unique value, spectral signatures were developed for each crop type individually. This technique was required because, in some instances, boundary pixels of fields within segments had to be eliminated. Where harvesting activities had modified the condition of the crop present, the harvested areas were used to develop supervised spectral signatures. These were added to those defining crop types of interest to the SRS. A total of 19 spectral signatures developed in this manner were stored in a computer disk file for later use in a quadratic maximum likelihood classifier (WMAX - ref. 3).

VII. UNSUPERVISED APPROACH TO SPECTRAL SIGNATURE DEVELOPMENT

In addition to the supervised spectral signature development approach already mentioned, an unsupervised technique was examined. Fundamentally, unsupervised spectral signature development differs from supervised techniques in that unsupervised techniques "scan" the entire data set and, within limits established by the investigator, develop spectral signatures defining spectrally distinct features without prior knowledge of the land cover types which are contained within the data set. It then becomes a matter of relating the spectral signatures developed to actual land cover present, using aerial photographs, ground truth, a portion of the segment data for each crop cover type, and an image display device. The signatures developed were used to classify a portion of the ground truth set. Then, based on the manner in which each signature classified the various crop types present, each was assigned a "label." The label was identified to that of the crop type most frequently classified by each signature. Once the spectral signature/land cover relationships have been established, performance can be evaluated.

Of the various techniques for unsupervised spectral signature development found in the literature, point clustering was used for this study. Point clustering techniques (e.g., WCCL, PTCL, - ref. 3) develop spectral signatures by examining individual pixels of data, with the frequency of sampling normally input by the user. As each point is examined, a decision is made as to whether the new pixel is spectrally similar to points already examined. If similar, it is grouped with the similar pixel(s). If not, it remains as a separate spectral signature, and the next pixel in the data file is examined. The process continues until all data have been processed.

Various parameter settings of the unsupervised software were tried and the results of subsequent maximum likelihood classification were compared with the results obtained from the supervised approach outlined earlier in this document.

VIII. LAND COVER ESTIMATION

Acreage estimates were obtained using the USDA/EDITOR system. Classification results from the ERL system were edited into the "segment total file" created during direct expansion estimation. This file was then processed using the USDA system.

Several problems were encountered in deriving estimates for the various land covers. Five of the 15 segments were located in Minnesota, so these segments were reassigned to Walsh County, North Dakota. A second problem was that nine segments were mini-segments, which should be handled differently than the normal JES segment; however, splitting out these mini-segments would not leave enough segments for estimation. To alleviate this problem, the ground data and classification acres for the mini-segments were multiplied by four so that a total of 15 equal size segments from Walsh County, stratum 11, could be used in estimation.

Due to the problems discussed above and because of limited ground data after editing, the direct expansion and regression estimates computed from this data set are not statistically sound. Enough sample segments were available to compute the correlation between the ground truth and classification data for soybeans, potatoes, spring wheat, and sunflowers. These R-square (R^2) values were used to compute the relative efficiency (RE) using the following formula:

$$RE = \frac{1}{1-R^2}$$

The RE measures the improvement in terms of increased precision of the regression estimate, which combines both ground and Landsat data, over the direct expansion estimate, which utilizes only ground data (ref. 4).

IX. RESULTS AND DISCUSSION

As shown in Table 1, the results obtained from the supervised approach (based on 19 signatures) were significantly better in most cases than the

Table 1. Percent Correct Classification Values North Dakota 7-Channel TMS Data.

LAND COVER CROP (SRS)	NUMBER OF PIXELS EVALUATED	SUPERVISED (MUCS)	UNSUPERVISED (WCCL)
1. Wasteland	190	57.78	73.34*
2. Sunflowers	91	47.37	84.72*
3. Spring Wheat	342	72.99	84.41*
4. Sugar Beets	56	69.85	75.98
5. Other Crops	46	87.90	82.86
6. Alfalfa	45	85.93*	63.97
7. Barley	38	91.67*	81.25
8. Potatoes	234	90.87*	68.23
9. Corn	53	90.68*	89.53
10. Beans	50	69.57*	35.81
11. Durum Wheat	50	91.53*	61.58
12. Summer Fallow	61	97.10*	89.86
13. Fall Fallow	268	90.46	86.93
"Overall"		80.97*	79.54

*Significantly better statistically than corresponding value for this cover type unsupervised approach (based on 59 signatures). Comparisons made were accomplished through analysis of variance and Newman-Keuls analysis using the arcsin $\sqrt{P}$ transformation. It is of interest to note that no matter which of the techniques is used, ground truth polygons must be established to relate the spectral signatures to land cover types, and an independent set of data should be used to evaluate the performance of the final results produced. Such areas must be spectrally homogeneous in order to prevent the introduction of error into the analysis. Since this is the case, the work required to incorporate ground truth into the data analysis framework is the same for supervised and unsupervised approaches. In this respect, the SRS segments represent a convenient source of data useful for both spectral signature development/naming and evaluation of performance. Values that are significantly better statistically than the corresponding values of the alternative procedure for a given cover type are indicated with an asterisk in Table 1. For instance, point clustering produced higher accuracy values for wasteland, sunflowers, and spring wheat, and performed (statistically) as well for sugar beets, other crops, and fall fallow.

In each case where a statistically significant difference exists in favor of the unsupervised approach, an analysis of the frequency distribution of the raw TMS data corresponding to that crop type is enlightening. For instance, wasteland as defined by the SRS contains all land within a segment which is not dedicated to the production of agronomic crops (Figure 3). This would include such features as buildings, roads, ditches, trees, water bodies, lawns, and highway medians, etc. With such an amalgamation of spectrally diverse land covers into one crop type, supervised spectral signature development techniques (one signature for each crop type) cannot be expected to perform very well. Unsupervised techniques, like point clustering,

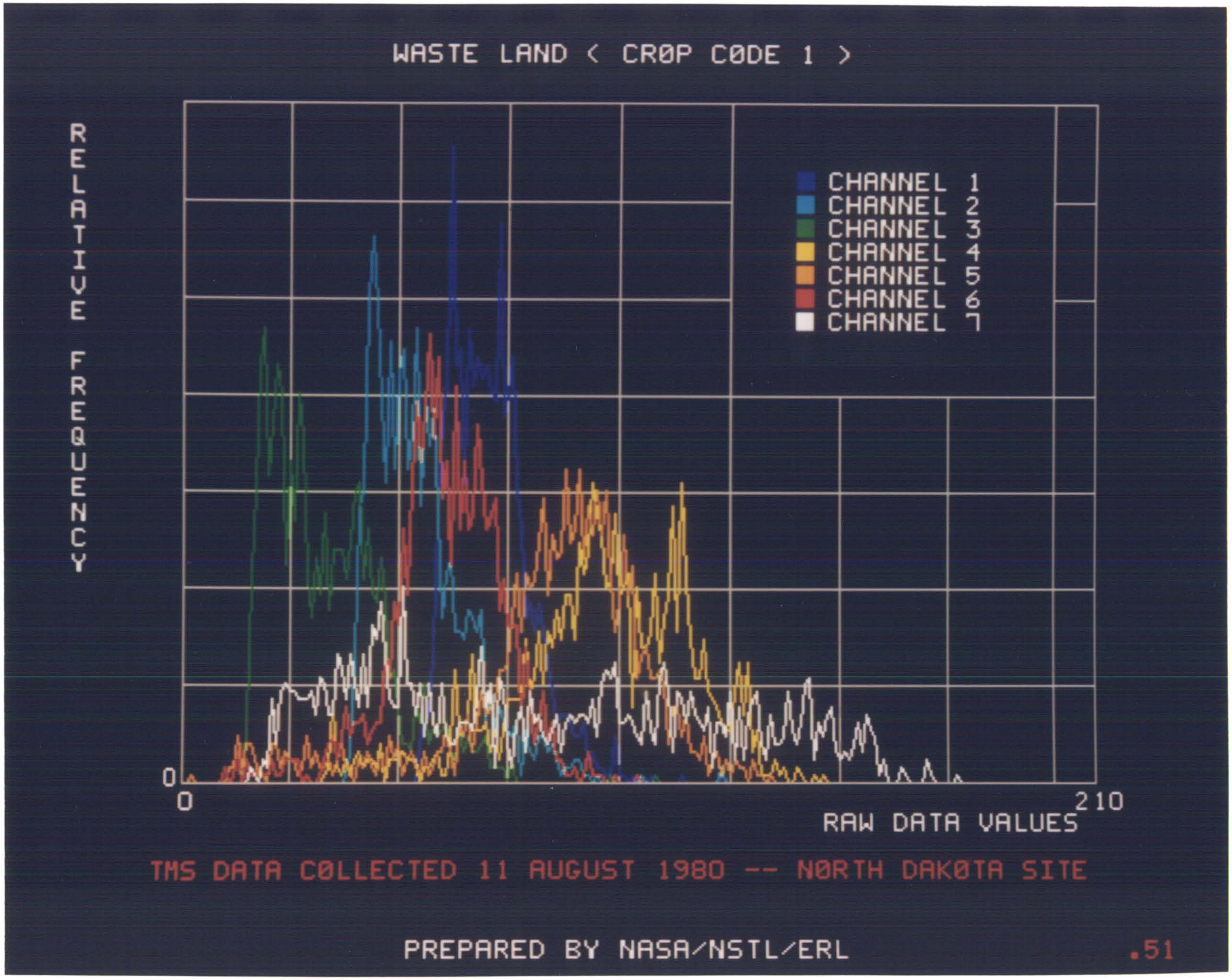


Figure 3. Wasteland Data Distribution

were designed to work in this type of environment, since they were created to develop spectral signatures which might better define subclasses within heterogeneous land cover types (such as "wasteland" as defined in the context of this study). The sunflowers and spring wheat crops were nearing maturity and were heterogeneous to some extent. This manifested itself in somewhat broad distributions of raw data for several of the TMS channels. Supervised statistics developed for such data would have large variances in numerous channels, and performance based on such variance would not be expected to be good.

In the other crop types, the TMS data were very "clean," with well defined distributions and relatively small variance (Figure 4). In these cases, the supervised approach did well, as these conditions are those assumed for supervised spectral signature development. This can be seen in the percent correct figures listed in Table 1.

The Relative Efficiencies for the four crops are given in Table 2. The RE's range from 1.6 to 26.6, which indicates the estimates obtained by incorporating the TMS data with ground truth show a significant reduction in the variance. SRS considers any RE above 1.5 indicative of a significant reduction in variance, and hence an improvement in the technique used to derive land cover estimates.

X. CONCLUSIONS

Based on results of the TMS data analysis conducted in this study, the following conclusions may be made:

1. Simulated Thematic Mapper digital data and a supervised spectral signature development procedure performed to an overall level of 80.97% correct for the 13 crop types of interest in the Walsh County, ND, study area.
2. Performance was significantly affected by the choice of the spectral signature development technique for specific crop types. The

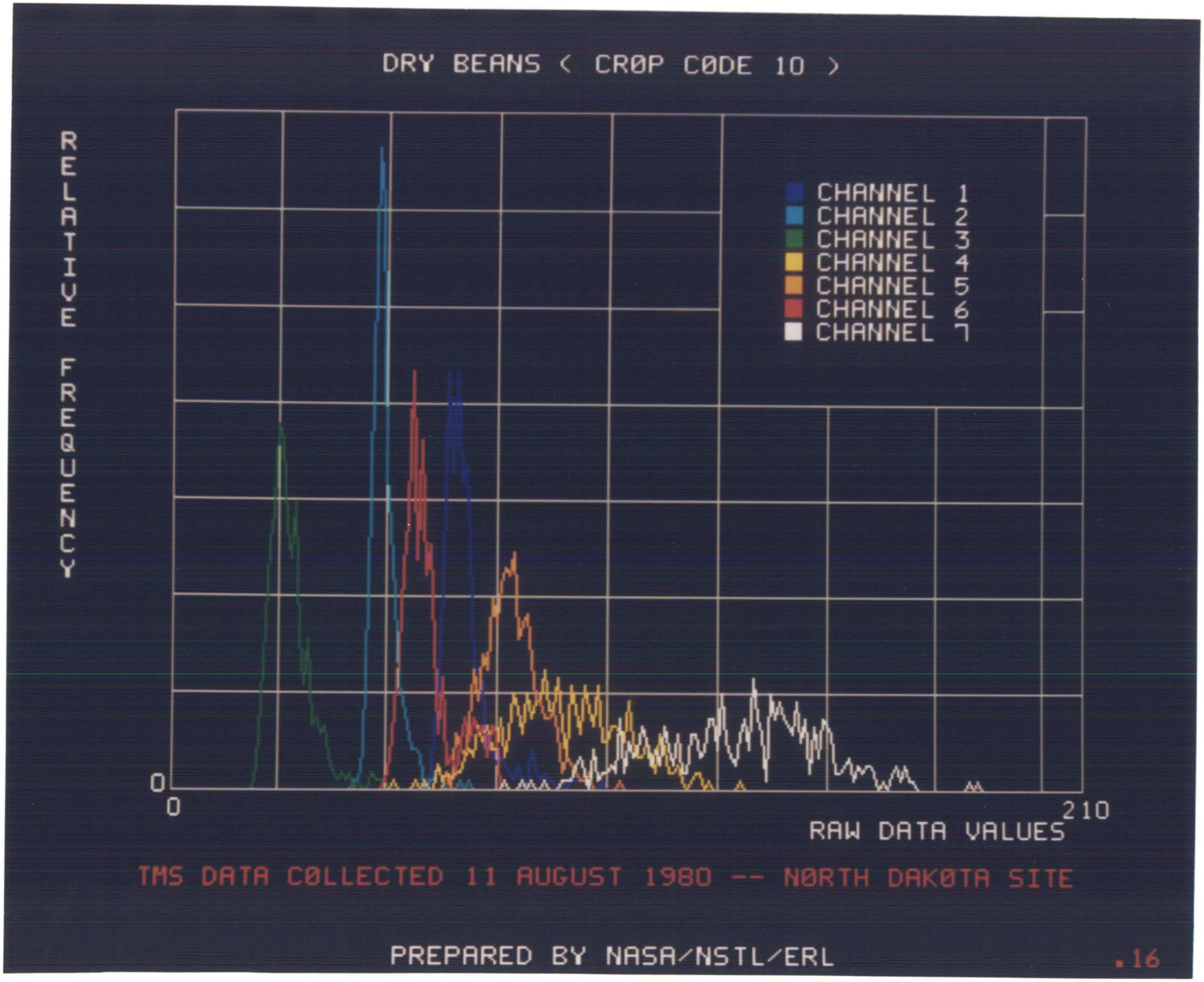


Figure 4. Dry Beans Data Distribution

Table 2. Relative Efficiencies for Four Crops.

CROP	RELATIVE EFFICIENCY
Sugarbeets	1.62
Potatoes	26.61
Spring Wheat	4.37
Sunflowers	2.09

supervised technique was significantly better for seven cover types, the unsupervised (point clustering) technique was significantly better for three cover types, and there was no significant difference between the two techniques for three cover types. Overall (for all 13 cover types), the supervised techniques performed significantly better.

3. The selection of the signature development technique should be determined by the spectral homogeneity of the crop of interest, as measured by variance (SRS uses a different technique for developing signatures).
4. Relative Efficiencies calculated for sugar beets, potatoes, spring wheat, and sunflowers ranged from 1.62 to 26.61, indicating a significant reduction in variance attributable to the use of TMS data.

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APPENDIX A

TMS SPECIFICATIONS

The TMS is a modified Texas Instruments RS-18 scanner with a 2.5m Instantaneous Field of View mounted in a Gates-Learjet 23/24 aircraft. Operational altitudes normally are at or near 12,000m (39,370 ft) above mean terrain elevation, resulting in a 30m nadir spot size.

Bands 1-4 of the TMS consist of individual silicon detectors, and receive incoming energy through a combination scanning mirror/modified Cassegrainian telescope assembly. The incoming energy is passed through a dichroic beam splitter which separates out the longer wavelength (infrared) energy. After passing through a collimating lens assembly, the short wavelength energy is directed onto individual fiber optics, located on the focal plane of the final lens assembly, which transmit the energy to individual detectors. Bands 5 and 6 utilize germanium and indium antimonide detectors, respectively, to sample energy in the intermediate wavelength (mid-IR) region, with optics similar to bands 1-4, although optimized for energy of 1.3μ - 3.0μ wavelengths. Band 7 utilizes a restrictive filter and a mercury-cadmium-telluride detector assembly to measure incident energy in the thermal IR region.

APPENDIX B

ORIGINAL AND EDITED SRS SEGMENT CROP TYPE ACREAGES

FOR THE 15 SEGMENTS USED IN THIS STUDY

SEGMENT	CROP	SRS* GROUND TRUTH	EDITED GROUND TRUTH	COMMENTS
830	Boundary	6.48 ha.	10.26 ha	
	Waste	14.58	14.58	
	Sp. Wht	17.55	5.67	
	Beets	16.20	Ø	
			24.30 (Fall Fallow)	
816	Boundary	3.78	14.40	Reinterpreted
	Waste	23.40	25.56	
	Sp. Wht	5.67	2.16	
	Other	55.53	44.64	
			1.62 (Fall Fallow)	
6599	Waste	17.46	49.23	
	Sunflowers	10.53	9.27	
	Sp. Wht	118.26	29.34	
	Beets	27.90	25.83	
	Barley	43.56	25.92	
	Dur. Wht	27.99	15.93	
			90.18 (Fall Fallow)	
819	Boundary	1.89	13.14	Segment Shifted
	Waste	3.33	12.42	
	Sp. Wht	12.87	6.12	
	Barley	25.20	Ø	
			11.61 (Fall Fallow)	
818	Boundary	Ø	12.69	
	Alfalfa	59.40	46.71	
831	Boundary	0.18	6.03	
	Waste	0.09	0.0	
	Sum.Fallow	55.44	49.68	
7543	Boundary	20.07	57.60	Reinterpreted
	Waste	14.22	15.84	
	Sun Flowers	43.29	15.57	
	Sp. Wht	81.81	Ø	
	Barley	72.81	Ø	
	Dry Beans	24.48	Ø	
			167.67 (Fall Fallow)	
821	Boundary	Ø	1.08	Reinterpreted
	Waste	Ø	2.07	
	Sp. Wht	52.74	49.59	
9167	Boundary	10.26	13.59	Segment Relocated
	Waste	7.56	7.56	
	Sp. Wht	59.22	57.96	
	Potatoes	128.97	128.97	
	Corn	56.16	54.09	

*Training pixels only.

824/825	Boundary	4.59	10.80	
	Sp. Wht	35.10	Ø	
	Potatoes	20.34	18.99	
			20.24 (Fall Fallow)	
7035	Boundary	16.20	123.75	Clouds & Shadows over some fields
	Waste	5.58	3.60	
	Sp. Wht	57.87	Ø	
	Beets	22.50	11.25	
	Barley	37.44	Ø	
	Potatoes	99.36	89.73	
	Dry Beans	4.05	3.96	
			10.71 (Fall Fallow)	
822	Boundary	1.44	10.89	
	Waste	0.27	0.27	
	Sp. Wht	56.61	13.86	
			33.30 (Fall Fallow)	
7024	Boundary	29.88	76.95	Clouds
	Waste	31.23	3.51	
	Sunflowers	22.05	17.28	
	Sp. Wht	122.76	54.63	
	Dry Beans	32.31	31.23	
	Flax	15.21	Ø	
			69.84 (Fall Fallow)	
178	Boundary	19.44	36.99	Segment relocated in data
	Waste	17.28	33.57	
	Sunflowers	34.65	27.99	
	Sp. Wht	115.92	94.41	
	Beets	21.60	15.75	
832	Boundary	Ø	6.93	
	Sp. Wht	58.41	40.77	
			10.71 (Fall Fallow)	