Reprinted from

Symposium on Machine Processing of Remotely Sensed Data

June 3 - 5, 1975

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
75CH1009-0 -C

AGRICULTURAL ANALYSIS OF LANDSAT DIGITAL DATA FROM WILLIAMS COUNTY, NORTH DAKOTA, USING G.E. IMAGE 100 SYSTEM

D. D. Egbert, D. L. Dietrich
and R. E. Fries

General Electric Company
Space Systems Organization
Beltsville, Maryland

I. ABSTRACT

The General Electric IMAGE 100 multispectral image processing and analysis system was utilized to perform man-machine interactive analysis of LANDSAT digital data for two agricultural study areas. The results of this investigation produced crop acreage estimates of greater than 90% accuracy. An in-depth discussion of investigation methods and numerical calculations is presented in the paper.

II. INTRODUCTION

As the world food situation becomes more critical, there is increasing interest in both the scientific and political arenas to determine the feasibility of employing remotely sensed data to survey world agriculture. Such an application will probably require an interactive automated approach to the analysis of satellite digital data collected over large areas.

Crop identification and quantitative determination of crop acreage are necessary parameters in agricultural surveys. The ability to extract these parameters from LANDSAT-1 digital data, using the General Electric IMAGE 100 processing system, was investigated in two study areas. LANDSAT digital data and detailed ground truth for the two study areas (Williams County, North Dakota and Melfort, Saskatchewan) were provided by the U.S. Department of Agriculture Statistical Reporting Service (USDA/SRS).

The investigation emphasizes the utility of a man-machine interactive, multispectral digital information analysis system, the G.E. IMAGE 100, to perform multispectral training and classification mapping of specific agricultural crops, and to determine accurate crop acreages within the selected 3x13 km (2x8 mile) study areas. The results are encouraging since they demonstrate the abilities of efficiently achieving high crop identification and acreage accuracies and point out the potential utility of interactive machine processing of satellite data for large area surveys.

III. BACKGROUND

LANDSAT digital data from July 11, 1973 (scene #1353-17165; Williams County, North Dakota) and August 1, 1973 (scene #1374-17324; Melfort, Saskatchewan) were examined during this study. The ground truth supplied by the USDA/SRS was for 3x16 km (2x10 mile) areas. However, clouds, covered part of this area on the North Dakota LANDSAT data, so to eliminate this problem as well as produce consistent results both study areas were limited to 3x13 km (2x8 mile). Results from analyses of these 3x13 km study areas can still be related to the USDA statistical crop survey results and procedures, which rely on the use of 3x16 km sampling unit data sets.

In both Williams County, North Dakota and Melfort, Saskatchewan, agricultural practices are strongly influenced by the severe winters and limited precipitation characteristics of this region of the country. As a result, spring wheat is planted rather than winter wheat and the practice of "summer fallow" is commonly employed. The practice involves allowing a field to lie idle during the growing season, tilling as necessary to control weeds and keep the surface soil loose. This cuts down on moisture loss by soil surface evaporation and plant evapotranspiration while allowing for efficient catchment of the infrequent rains.

According to the USDA/SRS ground truth information used, 99+% of the 3x13 km Williams County study area is represented by the following crop classes: spring wheat, barley, oats, sod, grass, and fallow. Based on the experience by Erb

(1974), it was suspected that wheat, barley, and oats separability would be difficult due to close and/or overlapping spectral responses. It was also suspected that sod and grass categories, consisting of a range of poor to fair quality permanent pastures and hay harvesting areas, might have similar spectral signatures. Consequently, the initial Williams County study area classes analyzed were small grains (spring wheat, barley, oats), sod (sod, grass), and fallow.

In the 3x13 km Melfort, Saskatchewan study area, the major crop classes (approximately 90% of the area) were spring wheat, barley, rape, and fallow. Again, a composite spring wheat-barley class was used. As a result, the number of Melfort study area classes analyzed also totaled three; in this case the designations were small grains, rape, and fallow.

In Williams County, the fields ranged in size from 1 to 240 acres; the average field area being about 25 acres. In Melfort, Saskatchewan the fields tended to be larger, ranging in size from 10 to 320 acres with the average being about 55 acres. In both cases field shapes varied and were oftentimes quite irregular, including everything from small and narrow to large and amorphous.

IV. APPROACH

The General Electric IMAGE 100 multispectral image processing and analysis system was used in this investigation to perform the digital data processing. This system exemplifies the state-of-the-art in user interactive special purpose image analysis computer systems. The prime concept around which all IMAGE 100 design parameters were considered was the efficient operation of a man-machine interface. It was assumed from the outset that man could not be completely replaced by the machine in image analysis; his pattern recognition powers are indispensable. However, the "number crunching" process is too time consuming for the man; therefore, the obvious solution was to build a hybrid system - man and machine.

In the operation of the IMAGE 100 the man can second guess the computer. An interactive capability to modify computer parameters and decisions is always available. Changes are quickly made and evaluated. In fact, in almost all modes of operation the system responds to man at least as quickly as he can decide what to do next. The complexity of the system, in addition to the fast reaction time requirements, necessitated a human factors approach to the man-machine interface. The operator sits directly in front of the primary display device, a color television monitor. A combination of panel switches and adjacent alphanumeric graphics terminal is employed for a relatively fast and efficient software interface.

A DEC PDP-11 series computer, with standard peripherals, is used as the system process controller. The system has the capability of storing 4 eight-bit video channels of imagery, and in addition, eight theme channels (binary maps of classification results which can be overlaid on the video display in false color). The IMAGE 100 uses a television compatible format of 512 by 512 picture elements (pixels) to put the storage requirements at approximately 10 million bits. For this, a solid state (or rotating disc option) memory is used as a refresh and storage device. LANDSAT digital data can be entered directly from computer compatible tapes into the refresh memory, or photographic transparency data can be entered via the video scanner and analog-to-digital converter sub-system. A variety of preprocessing, multispectral analysis, and theme synthesis functions are then accomplished under interactive operator-computer control.

In operation, a user specified training area is delineated on the image under analysis through the use of an adjustable electronic cursor which is both displayed on the monitor and scanned by the hardware for size and position coordinates. The multispectral brightness data (gray levels) within the training area are automatically measured, and their limits are used to define a four dimensional parallelepiped in spectral space. Then, the entire image is scanned pixel by pixel and compared to the parallelepiped limits. All pixels which lie within the bounds defined by the training data are flagged or alarmed and displayed on the monitor as a color map. This entire process takes on the order of five seconds, so the operator may make subtle changes to the training area and receive "real time" response enabling him to very rapidly go through several iterations.

If after a few iterations of the basic training and classification procedure the operator is not satisfied with the results he may then turn to several more sophisticated procedures. One of the more valuable of these is histogram analysis. Each time the system performs a parallelepiped training it calculates and stores complete histogram data for each of the four spectral channels. The operator can call these data to be displayed on the graphics terminal and alter any of the parallelepiped limits as defined on the histograms. Again in real time (1/30 second) he can see the results of any changes he might make. If he is still not satisfied with the results he can then proceed to other techniques.

Once the desired classification results have been achieved they are then stored on one of the eight binary theme channels to form a thematic map which can be displayed on the original image data base. Ultimately, hard copy black and white or color thematic maps containing as many themes as desired are generated. The operator can then proceed to a new area by loading the refresh memory with new data. For subsequent analysis he can rely on spectral signatures or parallelepiped limits previously derived by recalling them from storage or reentering them. Thus, he will not have to repeat the entire analysis procedure for the new data base. But, he can still make evaluations as to the accuracy of the new results and institute additional changes if needed.

During the course of this investigation several of the IMAGE 100 analysis techniques were applied. The following discussion presents the flow of the investigation in a series of discrete steps. The steps are presented here in approximately the same order in which they were performed.

1. The LANDSAT digital data for the Williams County study area were entered into the IMAGE 100 at a magnification of 2X. At this magnified scale each LANDSAT pixel is represented by a 2x2 array of system pixels to facilitate visual examination of the small study area. The entire scene was 15x15 km (9x9 miles) (Figure 1) and the study area was 3x13 km (2x8 miles) (Figure 2).

2. The 3x13 km study area was outlined through the use of a polygon cursor software routine. The result of this polygon cursor is a single polygon area defined in the refresh memory which covers the entire study area. The reason for generating this polygon cursor was so that the results of multispectral training and classification could be restricted to only the study area to obtain numerical area data.

3. Within the cursored study area, small uniform portions of each of the crops of interest (small grains, fallow, and sod) were selected to form training and test fields. For each of the crops five training and five test fields were defined, and each set of five was used to generate a separate composite cursor. These sets are shown in Figure 3 and Figure 4. Each set of five fields was chosen to represent in size approximately 2.5% of the total study area.

4. A first cut approximation for the spectral signature of each crop was obtained by training on the composite cursor representing the set of five training fields for that crop. As a result of this training, a classification alarm is generated for the entire area as described previously. The classification alarm is a real time binary map which when stored, on the refresh memory, becomes a theme.

5. Each classification alarm for those areas within each of the test field composite cursors was stored on the refresh memory to create a theme (i.e., alarm AND cursor=theme). The pixel count for each theme generated in this sequence resulted in a measure of errors of commission and errors of omission. For this investigation these errors are defined as follows:

$$\text{Commission Error (e.g., fallow)} = \frac{\text{Number of pixels incorrectly delineated as a crop (e.g., fallow) in other test fields (e.g., small grains and/or sod)}}{\text{Total number of pixels within the crop test fields (e.g., fallow)}}$$

% Commission Error=Commission Error X100

$$\text{Omission Error (e.g., fallow)} = 1 - \frac{\text{Number of pixels correctly delineated as a crop in its test fields (e.g., fallow)}}{\text{Total number of pixels within the crop test fields (e.g., fallow)}}$$

% Correct = (1- Omission Error) X100

6. Steps 4 and 5 were repeated with the IMAGE 100 gray level resolution set at first 128 levels, then at 64 levels, and finally at 32 levels. This series was performed to evaluate the sensitivity of the accuracy of classification to the number of gray levels available.

7. For each of the cases described in step 6 the first cut signatures were refined through the multiparallelepiped signature technique. In this technique the large parallelepiped is divided up into many smaller ones as defined by the gray level resolution. For example, if the large parallelepiped is 10x10x10x10 gray levels in size, then it will result in 10,000 smaller ones (i.e., $10 \times 10 \times 10 \times 10 = 10^4$). Each of these smaller parallelepipeds is then examined to see if it contains the gray level vector of one or more pixels from the training area. If it does, then it is retained in the signature, otherwise it is de-

leted from the signature. Thus, in spectral space this technique reduces the signature from a box-like hypervolume into a series of smaller hypervolumes which more closely fit the true cluster or irregular distribution of the training pixel gray levels.

8. Errors of commission and omission were found for each of the classification alarms generated in step 7 by reapplying step 5.

9. For each of the cases described in step 6 the first cut signatures were refined through histogram trimming. This was accomplished through an iterative man-machine procedure. For each of the first cut signatures the set of four histograms was displayed on the graphics terminal. As well as showing the distribution of training pixel gray levels the histograms also show the signature or parallelepiped limits. Further, these limits are adjustable either manually or under computer control. In this study only manual adjustment was made. The first change was made on a qualitative evaluation of the histograms in terms of variance, skew, etc. Then, the new classification alarm was evaluated on the color monitor and new limit adjustments made. The final signature limits were derived from quantitative error measurements of the resulting classification alarms as described in step 5.

10. The first cut and refined signatures giving the best results were selected for further study. "Best results" in the context of this study were defined to be those which minimized both errors of commission and errors of omission when considered together, and at the same time represented a time efficient analysis technique. That is, some slight trade-off between accuracy and speed of analysis was allowed.

11. The better classification alarms for the area within the 3x13 km study area were then used to generate themes. The pixel count for each of these themes then represents the total number of pixels within the study area which were classified by the application of each refined signature. Pixel counts were then converted to acres to result in the acreage estimates for each crop in the study area. The best resulting classification maps are shown in Figure 5 and Figure 6.

12. Those signatures which produced the best results were applied to data containing less than the full four spectral bands available from LANDSAT. This part of the study was performed because it was found during the first part of the study that some spectral bands, as seen from the histograms, provided greater separation between different crops. Particularly MSS bands 5 and 7 provided good separation. Also, the reduction in the number of spectral bands required reduces the memory requirements of automated data processing systems and facilitates the use of a combination of multispectral and multitemporal input data.

13. The techniques and parameters which were found to produce the best results were applied to the Melfort, Saskatchewan study area. This provided a check on the results obtained with the Williams County study area as well as a measure of the time requirements for producing results as opposed to investigating techniques. The Melfort study area is shown in Figure 7. The best results of crop classification are shown in Figure 8.

V. RESULTS

The results of interactive analysis of both study areas were encouraging. The developed techniques yielded acreage accuracies greater than 90% for each crop category in both the Williams County and Melfort study areas.

A. WILLIAMS COUNTY, NORTH DAKOTA

The 3x13 km study area in Williams County was used as the test case in developing the most efficient agriculture application techniques on the IMAGE 100. Later, these techniques were tested on the Melfort study area to evaluate their general utility.

Initial training and test statistics were utilized as the decision criteria for determining the number of spectral gray levels, which could be used most effectively on the interactive system. Three gray level resolutions were tested; 32, 64, and 128 levels. A gray level resolution of 32 levels was not specific enough to adequately differentiate between vegetative classes. Though initial test field percent correct classification was excellent, the commission errors were also quite high. A resolution of 128 levels introduced too many gray levels which tended to be too restrictive and decrease the percent correct classification within some of the test fields. This was particularly true when multiparallelepiped training was performed. Also, it was found that visual examination of the histograms was difficult at 128 levels. At 64 gray level resolution, initial training and testing yielded the most equitable trade-off between percent correct classification, commission error, and ease of operation within the test fields.

The primary criteria in selecting the most effective classification mode was user interaction efficiency coupled with accurate classification results. Single parallelepiped classification was accepted as the mode capable of providing the most rapid response to interactive commands on the IMAGE 100. In addition, data operations and statistical results are more readily performed and effectively displayed and interpreted in the single parallelepiped mode, thus reducing the time and costs of classification.

Initial crop classification, based on the spectral characteristics of the pixels within the training fields, yielded high test field classification accuracies, but also yielded high commission errors. Manual refining of the signatures, achieved through histogram trimming, was then attempted to result in signatures with the highest percent correct classification with the lowest commission errors. Final interactive results of training and testing are represented in the first four columns of Table 1. For the three categories, (small grains, fallow and sod) the average percent correct classification of test fields was 93.3% with an average commission error of 3.6%. Some tests were performed to determine if barley or oats could be accurately distinguished from wheat, or if grass could be spectrally exclusive of sod. The similarity of the spectral responses within these categories, however, made more detailed stratification impractical. Therefore, all classification and acreage determinations were made using the small grains, sod, or fallow category.

The refined signatures were then applied to obtaining individual crop acreages over the entire 3x13 km area. The number of LANDSAT pixels classified in each category were converted to acres (1 LANDSAT pixel= 1.12 acres) and then compared to USDA ground truth. The best results show acreage accuracies of 99.3%, 98.2%, and 91.7% for small grains, fallow, and sod respectively (see Table 1). Unclassified pixels amounted to 4.5% of the study area or 447 acres. Overlap or conflict pixels, which were classified as two crops, amounted to 1.8% of the study area. Most of the conflict was between the vegetative classes of small grains and sod. Fallow fields were of high enough contrast with vegetated areas to minimize conflict pixels.

The same results were achieved using either two (MSS bands 5 and 7) or four LANDSAT spectral bands for classification. This result supports the findings of other LANDSAT-1 investigators (Landgrebe, 1974 and Wiegand, 1974) and others who have indicated that MSS bands 5 and 7 alone are sufficient for most agricultural applications. Band 5 (.6-.7u) is in a spectral region which is selectively absorbed by chlorophyll. Almost all energy in the spectral region of band 7 (.8-1.1u) is reflected by vegetation. These two bands are therefore quite sensitive to changes in vegetation and vegetation cover, and little if any advantage is gained by using all four bands. Band 4 may actually introduce an obscuring effect due to the low contrast characteristic of this spectral range as a result of atmospheric scattering. The important advantage of utilizing only bands 5 and 7 and still achieving comparable results, is in the reduction of interactive manipulations and data operations used throughout the classification procedure. Also, anticipating the use of multitemporal data analysis, it becomes an advantage to reduce the number of spectral bands from each date to be combined.

In summary, the techniques and parameters which were found to produce best results were 64 gray level resolution single parallelepiped classification with manual histogram trimming using MSS bands 5 and 7. The achieved acreage accuracies for the 3x13 km study area all exceeded 90%. The developed techniques present an efficient accurate way of extracting crop information from LANDSAT data using the IMAGE 100.

B. MELFORT, SASKATCHEWAN

To provide a check of the developed procedures and their ability to extract accurate results, the best classification techniques were applied to quantify a 3x13 km study area near Melfort, Saskatchewan. The Melfort scene was expected to provide a reliable test of the techniques since it contains larger fields, somewhat different crops, the crops are farther into the growing season, and is 350 miles north of the Williams County, North Dakota study area.

Interactive classification, using the IMAGE 100, yielded crop acreage accuracies of 98.9%, 96.3%, and 98.9% for small grains, fallow, and sod respectively (Table 2). The unclassified area was 11.8% or 1231 acres of the total 10,460 acres within the polygon cursor defining the 3x13 km study area. The unclassified areas were primarily composed of roads, spaces between fields and other nonhomogeneous areas. The overlap pixels represented 4.7% or 492 acres of the study area. The majority of overlap or conflict existed between the small grain and rape classes. The ground truth indicates that a few of the rape fields contained portions of wild oats and weeds. The spectral variations within these fields influenced both crop identification and crop acreage results. Similar to the Williams County site, the fallow category was in less conflict than the vegetative classes.

During the training and classification of the small grains crop category within the Melfort study area it was found that unsatisfactory results were obtained using 64 gray level resolution. Consequently, the system parameters were changed back to 128 gray level resolution. The spectral properties of small grains and rape were so nearly the same that the difference of only one gray level on the 128 level scale made a significant difference in the commission errors. This points out the need to exercise caution when generalizing from the previous results obtained with only 64 gray level resolution. It also demonstrates the advantages of the man-machine interactive appraoch which allows periodic human intervention in the automated classification. So, the results for small grain crops in the Melfort study area shown in Table 2 are for a gray level resolution of 128. All other figures in both Table 1 and Table 2 are for 64 gray level resolution.

VI. CONCLUSIONS

The General Electric IMAGE 100 system was utilized to perform man-machine interactive analysis of two agricultural study areas to evaluate the interactive approach to agricultural inventory needs. The techniques developed resulted in crop acreage measurement accuracies as high as 99%. These techniques involved the use of 64 LANDSAT gray level resolution, (in some cases 128 level resolution) single parallelepiped classification, manual histogram parallelepiped-limit trimming, and the use of only MSS bands 5 and 7. These techniques resulted from evaluating the effectiveness and speed of many available techniques as described previously. The results obtained with the final techniques were similar for both study areas which differed in geographic location and crop characteristics. Thus, conclusions can be made to the effect that these techniques will be useful for large scale agricultural inventory applications. Implementation of these techniques to a large area inventory for final evaluation was beyond the scope and resources of this pilot investigation.

The results illustrate the capability for extracting agricultural survey information from LANDSAT digital data via an interactive data processing system. Man-machine interactive data processing systems such as the IMAGE 100 provide rapid and accurate crop classification through the utilization of the most efficient analysis capabilities of both man and machine.

One topic only briefly mentioned in this paper is the use of multitemporal input data for agricultural inventory purposes. Many investigators, both at General Electric and elsewhere, concur that regardless of the analysis system or techniques used the accuracy of an agricultural inventory will be improved through the combination of multispectral and multitemporal input data. The authors agree with this conclusion. However, limited resources and lack of enough useable multidate LANDSAT data coincident with the USDA/SRS ground truth prevented the examination of multitemporal analysis techniques in this investigation.

VII. REFERENCES

Erb, R. B. ERTS-1 Agricultural Analysis. Type III Final Report, LANDSAT-1 Investigation No. 1600A. August, 1974.

Landgrebe, D. A Study of the Utilization of ERTS-1 Data From the Wabash River Basin. Type III Final Report, LANDSAT-1 Investigation No. 1049A. October 1974.

Wiegand, C. Reflectance of Vegetation, Soil and Water. Type III Final Report, LANDSAT-1 Investigation No. 1039A. November, 1974.

Table 1. Williams County, North Dakota Test, Training, and Study Area Analysis

CROP CATEGORY	TRAINING FIELDS		TEST FIELDS		3X13 KM STUDY AREA		
	OMISSION		COMMISSION				
	PIXEL NO. CORRECT	% CORRECT	PIXEL NO. INCORRECT	% ERROR	COMPUTER CLASSIFIED AREA (IN ACRES)	GROUND TRUTH AREA (IN ACRES)	% CORRECTLY CLASSIFIED
SMALL GRAINS	212	99.5	8	3.8	3871	3899	99.3
FALLOW	188	87.0	9	4.2	3475	3538	98.2
SOD	196	93.3	6	2.9	2409	2628	91.7

Table 2. Melfort, Saskatchewan Test, Training, and Study Area Analysis

CROP CATEGORY	TRAINING FIELDS		TEST FIELDS		3X13 KM STUDY AREA		
	OMISSION		COMMISSION				
	PIXEL NO. CORRECT	% CORRECT	PIXEL NO. INCORRECT	% ERROR	COMPUTER CLASSIFIED AREA (IN ACRES)	GROUND TRUTH AREA (IN ACRES)	% CORRECTLY CLASSIFIED
SMALL GRAINS	189	87.5	6	2.8	4094	4140	98.9
FALLOW	217	100	5	2.3	4033	4190	96.3
SOD	216	99.5	6	2.8	1592	1610	98.9

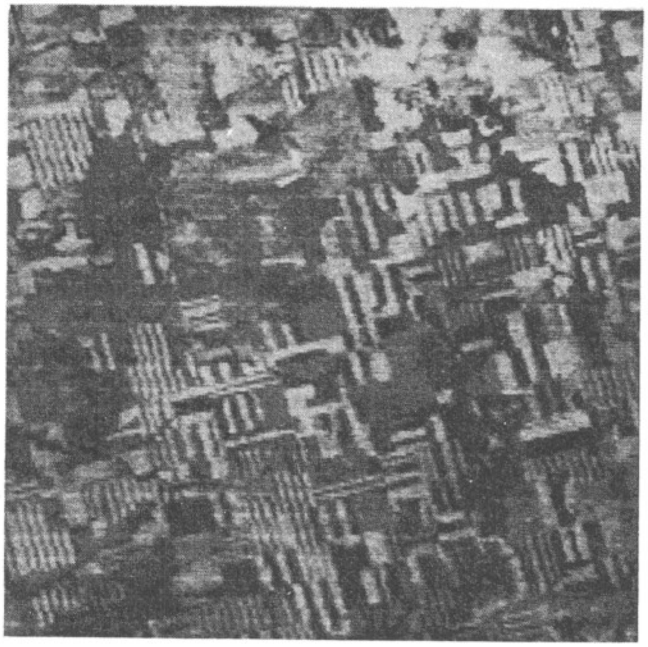


Figure 1. MSS band 5 image containing Williams County study area.

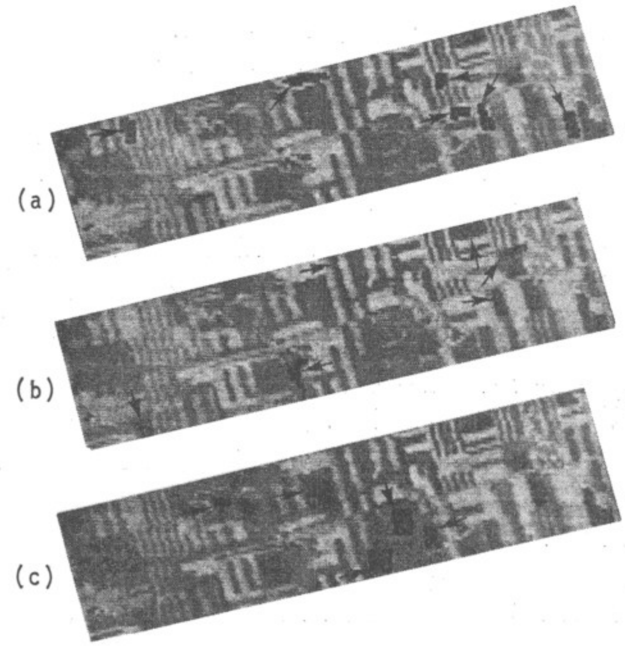


Figure 3. Training fields for a) small grains, b) fallow, and c) sod. (Williams County)

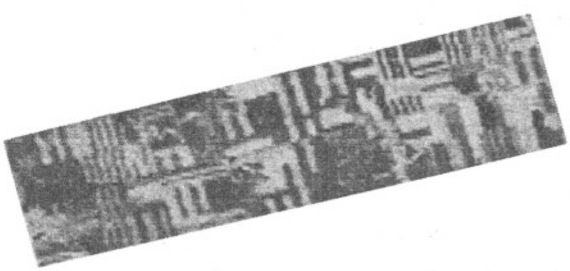


Figure 2. MSS band 7 image of only Williams County study area.

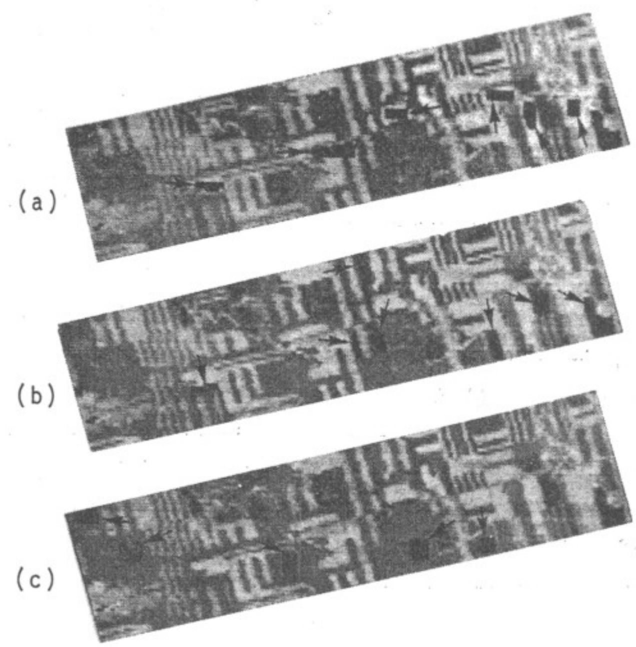
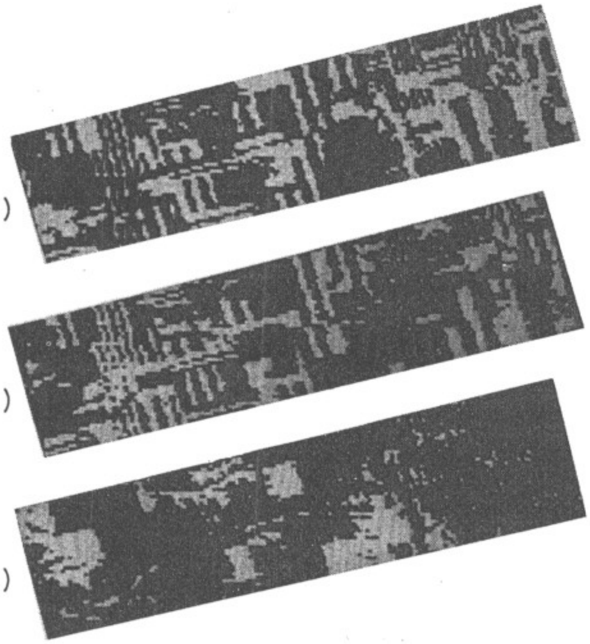


Figure 4. Test fields for a) small grains, b) fallow, and c) sod. (Williams County)



(a) (b) (c)

Figure 5. Classification results for Williams County study area a) small grains, b) fallow, and c) sod.

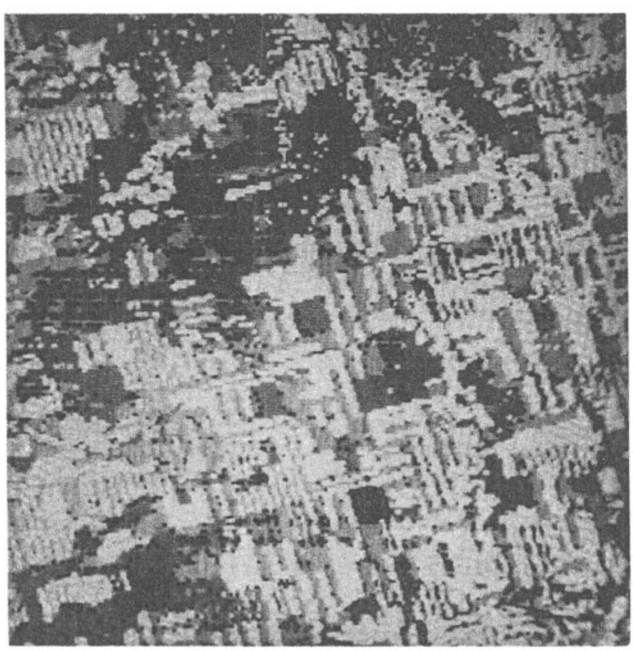
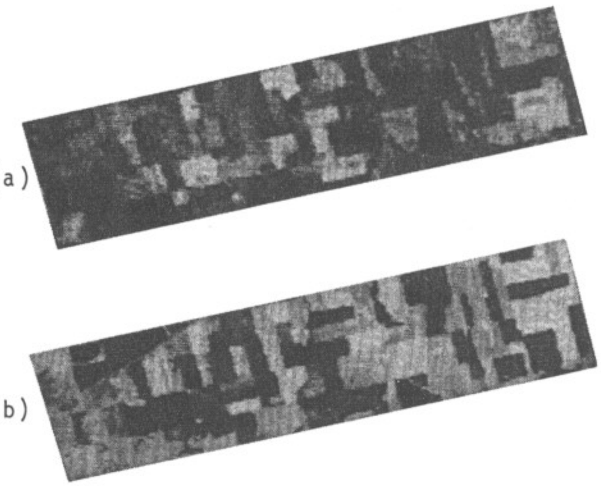


Figure 6. Classification results for image containing Williams County study area; white-small grains, medium gray-fallow, dark gray-sod, and black-unclassified.



(a) (b)

Figure 7. Melfort study area a) MSS band 5, b) MSS band 7.

Figure 8. Melfort study area classification results; white-small grains, medium gray-fallow, dark gray-sod, and black-unclassified.