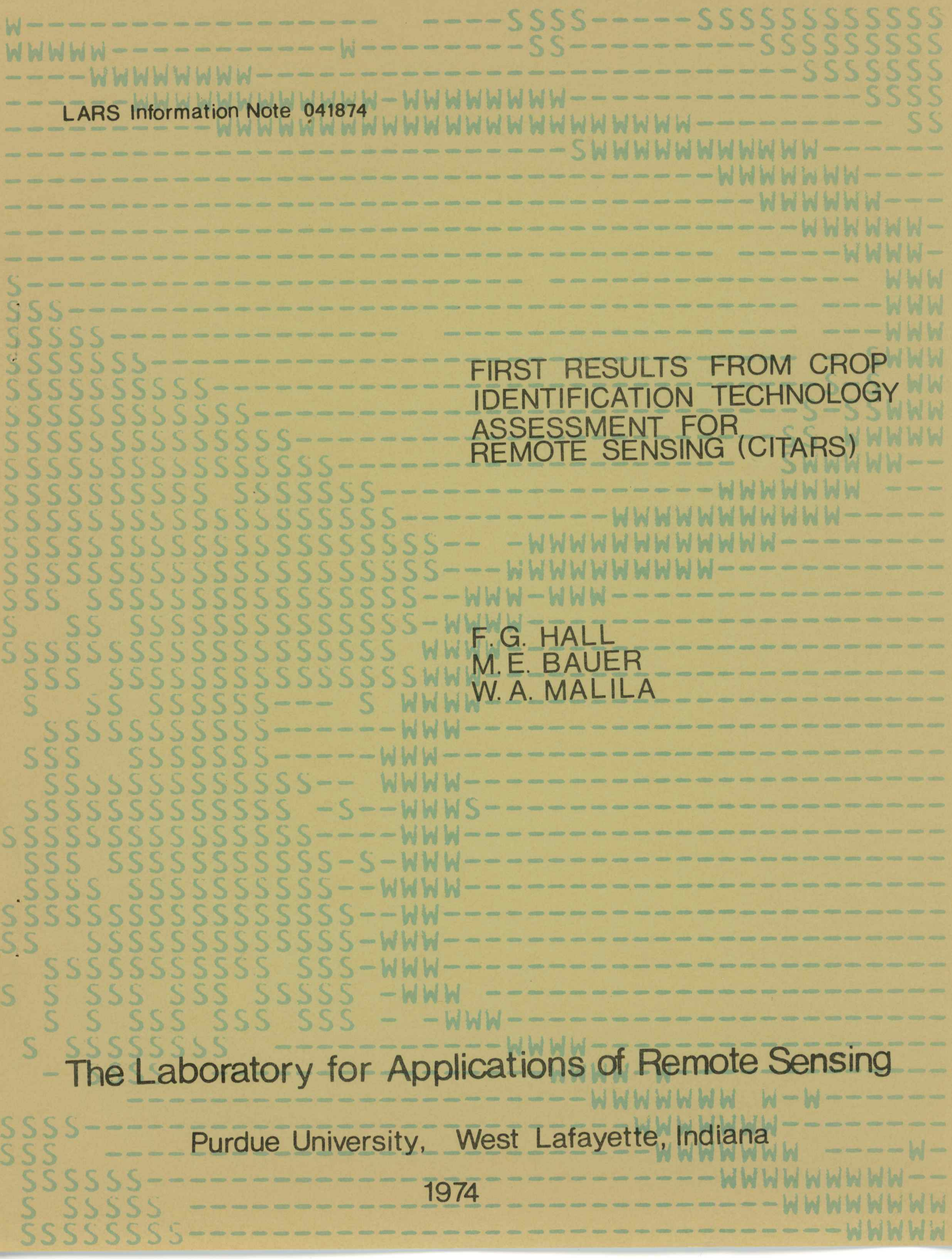

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FIRST RESULTS FROM CROP IDENTIFICATION TECHNOLOGY ASSESSMENT FOR REMOTE SENSING (CITARS)

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ABSTRACT

The CITARS task design, including objectives, analysis methodology and experimental procedures, is described and first results from this effort are presented. The extensive ground truth data set acquired for the CITARS task is described and discussed in some detail. Results of the accuracy tests for the photo interpretative CITARS ground truth are given. Results of the assessment of the ERTS MSS data for cloud cover and electronic quality are presented. Some results of the geometric correction and registration of the time sequential CITARS ERTS data are given. Finally, the field boundary location problem is addressed and the results of the use of new technology for boundary location are presented.

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1. INTRODUCTION AND OBJECTIVES

In 1973, the Earth Observations Division (EOD) of the Johnson Space Center (JSC), the Environmental Research Institute of Michigan (ERIM), the Laboratory for Applications of Remote Sensing, Purdue University(Purdue/LARS), and the Agricultural Stabilization and Conservation Service (ASCS) of the U. S. Department of Agriculture (USDA), undertook a joint task to quantify the crop identification performance, resulting from the remote identification of corn, soybeans and wheat using automatic data processing (ADP) techniques developed at ERIM, LARS, and EOD. These ADP techniques are automatic in the sense that subjective human interactions with the classification algorithms are minimized by the specification of the steps required for an analyst to convert multispectral data to a classification result. The crop identification performances resulting from several types of ADP techniques are to be compared and examined for significant differences. The multispectral data to be analyzed, consists of ERTS-1 data acquired over each of six 5 x 20 mile segments in Indiana and Illinois at six periods from early June through early September 1973. Crop identification and other information was gathered by the ASCS in each segment each 18 days coincident with an ERTS overpass.

The ADP techniques are to be evaluated on this data set in two basic remote sensing situations: (1) Crop signatures for classifier training will be obtained within the same segment in which crops are to be recognized by the classifier (local recognition). (2) Crop signatures for classifier training are to be obtained from a different segment than is to be classified (non-local recognition).

Once the crop identification performance is established for each of the ADP techniques for local and non-local recognition, differences in the performances of these techniques will be established for differences in geographic location, time of the year, etc.

The CITARS task was designed to quantitatively answer the following questions:

- How does corn, soybeans, and wheat identification vary with time during the growing season?
- How does the crop identification performance (CIP) vary among different geographic regions having different soils, weather, management practices, crop distributions, and field crops?

- Can statistics acquired from one time or location be used to identify crops at other locations and/or times?
- How much variation in CIP is observed among different data analysis techniques?
- Does the use of multitemporal data increase CIP?
- Does use of radiometric preprocessing extend the use of training statistics and/or increase CIP?
- How much variation in CIP results from varying the selection of training sets?
- Does rotation or multitemporal registration of ERTS data affect classification performance?

2. ANALYSIS METHODOLOGY

To establish and compare the capabilities discussed in the Introduction, an experiment was designed to: (1) accurately estimate the crop identification performance (CIP) and (2) determine whether differences in the CIP's for the various conditions are significant.

Each of the CIPs will be established as a result of specific "treatment" combination; such a treatment combination is characterized by several factors. These factors are: (a) ADP technique; (b) data acquisition period; (c) location; and (d) training-recognition method.

Each of these factors can, in turn, be characterized by levels. The levels of factor (a) are different ADP techniques to be assessed; the levels of factor (b) are the six data acquisition periods from June through September 1973; the levels of factor (c) are the six test sites in Indiana and Illinois. There are many possible levels in factor (d) but they can be characterized for the present by (1) local recognition and (2) non-local recognition.

Each treatment combination will have an associated CIP which will be quantified in three ways: (1) a classification performance <u>matrix</u> from which the errors of omission and commission for "non-boundary" pixels can be determined and (2) a proportion classification error <u>vector</u> and (3) a proportion error vector corrected for bias.

The classification performance matrix for "non-boundary" pixels will be established by comparing the ADP classification with the ground and photo interpretive identifications of about 12,800 acres within each data segment. Test field boundaries will be established on the digital data. To insure that only non-boundary pixels are used in training and classification, the boundaries will be selected such that no agricultural field boundary elements or field inhomogenieties are contained within the test field boundaries. The probability for correct classification for each class of corn, soybeans, wheat and "other" will be defined, for a particular test field set, as the frequency with which test field pixels of a particular class are correctly classified. The error of commission between class i and class j will be defined as the frequency with which the ADP identification of class i was determined from ground truth to actually have been a pixel from class j. For a four class data set this procedure will define a 4 x 4 error matrix.

The proportion classification error vector will be established by comparing the proportions of corn, soybeans, wheat and "other" as determined from the ADP technique to those proportions determined from ground truth. To establish the ground truth, 20 agricultural quarter-sections in each segment were visited each 18 days by ASCS personnel for crop type identification. In addition, 20 additional agricultural sections (one mile square) were photo interpreted to establish crop identification.

The proportion of each crop type in the sections within each segment were established by mensuration of the photography. These results will be compared to the proportions determined by the ADP techniques to determine the ADP proportion error vector. In addition, several methods have been proposed to correct the remote sensing estimates of the crop proportions for bias. Each of these methods require an estimate of the bias, which is obtained by examining classification performance in fields or areas for which ground truth is available. These fields and areas will be called <u>pilot</u> fields or areas, to distinguish them from the <u>test</u> fields where the crop identification performance <u>is</u> to be established. The methods proposed for bias correction and the method for pilot field selection are more fully discussed later in this section.

Thus for each treatment a performance matrix and a proportion error vector can be estimated using the procedures described above. These data, once computed, form a basis for comparison of the performances of the techniques under the various conditions. These comparisons will be made using standard statistical tests. The primary statistical test to be applied is the analysis of variance. The objective of such a procedure will be to test the hypothesis, that the classification performance for two or more different treatments (or combinations of treatments) are different. An example of a hypothesis to be tested is: "There are no significant differences in crop identification performance among test sites." Similar hypotheses can be formulated for each factor.

3. EXPERIMENTAL PROCEDURES

3.1 TEST SITE SELECTION

The test sites were chosen over as large a geographic area as possible, within the resources of the project, in order to include a wide variety of conditions. Even in the Corn Belt there is a great deal of variation in soils, weather, cultural practices, and crop distribution. All of the factors are related to geographic location. The best measure of the effects of these factors, then, can be obtained by including as many test sites as possible over as large an area as possible. This also increases the probability of obtaining cloud-free ERTS data.

Test sites were selected within the four overlap zones of the five ERTS passes over Indiana and Illinois. These areas shown in Figure 1 include some of the different conditions which could be expected to be encountered in the Corn Belt. By locating test sites within the zones where successive ERTS passes overlap the number of opportunities to obtain cloud-free data was doubled.

3.2 SELECTION OF SEGMENTS AND SECTIONS

Segments, five by twenty miles, were chosen at random within each of the six selected counties. These segments were oriented such that the twenty mile length was oriented north-south. This segment size was chosen to limit the area for field visits and yet include a large sample of agricultural cropland within a county. Within each segment, 20 sections and 20 quarter-sections from different sections were chosen at random.

3.3 FIELD OBSERVATIONS FOR CROP TYPE IDENTIFICATION

The ASCS of the USDA visited, each 18 days, the 20 quarter-sections within each segment and examined each field in the quarter-sections for crop type identification, other agricultural parameters shown in Figure 2. Atmospheric optical depth (related to visibility) at several locations, using tripod mounted solar spectrophotometers and subjective assessments of cloud cover and haziness during the ERTS overpass were also recorded by ASCS personnel.

3.4 PHOTOINTERPRETATION FOR CROP TYPE IDENTIFICATION

A more accurate estimate of the crop identification performance for each ADP technique can be obtained if a larger field sample is available from each segment. Thus, the field observation data was supplemented by photointerpretation of the 20 <u>sections</u> chosen in each segment.

The photointerpretation effort used large-scale color IR (scale) photography acquired at five times during the growing season, and large-scale metric photography acquired at two times, to establish proportions of ground cover classes and other agricultural parameters within each of the 20 sections in each segment.

A test procedure using ASCS visited quarter-sections hidden in the photograph was devised to determine the accuracy of the photointerpreted crop identifications. The photointerpretation procedure was designed to obtain as accurate an identification as possible. When the PI test procedure indicated errors in the photointerpreted field identifications, the effects of these errors on the estimates of the ADP crop identification performance were assessed, once the source and nature of the photointerpretative errors were ascertained.

3.5 TRAINING, TEST AND PILOT FIELD SELECTION

In addition to the training and test fields usually selected to train the classifier and to evaluate its performance, "pilot" fields were selected. The pilot fields will be used to determine if a correction for bias in the classified crop proportion, resulting from classification errors, is feasible. Classification errors will be estimated in the pilot fields and based on these estimates, a correction will be applied to the test field classification results. (See 3.8 FACTORIAL ANALYSES FOR PERFORMANCE COMPARISON for more details.)

For those analyses which require pilot fields, all fields from one half of the 20 photointerpreted sections will be used for pilot fields and the remaining ten sections for test fields. For those analyses which require no pilot fields, all photointerpreted sections will be used as test fields.

Training fields from the ASCS quarter-sections will be used to train the classifiers. All fields large enough to be accurately located in the scanner imagery will be available for training.

4.2 ERTS MSS DATA PREPARATION

ERTS data preparation for CITARS has consisted of (1) geometric correction, (2) multitemporal registration, and (3) section and field coordinate location. Geometric correction is performed to facilitate accurate location of section and field coordinates. Registration of the data from two or more ERTS passes over the same scene is required for multitemporal data analysis procedures and to reduce the number of times which section and field coordinates had to be located. With registered data the desired coordinates need to be found only once and the same coordinates are required for classifying the ERTS data and evaluating the results.

These procedures have been designed to allow each institution to use common training and test field boundaries and duplicate ERTS data tapes. Such a procedure was followed to permit more meaningful performance comparisons and to eliminate needless duplication of tasks and resources at each institution.

4.2.1 GEOMETRIC CORRECTION OF ERTS DATA

The digital form of the ERTS data (CCT's) contains several geometric distortions. These distortions include: scale differential, altitude and attitude variations, earth rotation skew, orbit velocity change, scan time skew, nonlinear scan sweep, scan angle error, and frame rotation. The major errors are the scale and skew errors. Also, rotation to North-orientation is highly desirable. A two-step process, developed by LARS, to geometrically correct ERTS data over small areas has been applied to all data for CITARS.

Briefly, the procedure uses four linear transformations to correct or adjust for horizontal and vertical scale differences, rotation, skew due to earth rotation and output scale factor. The process assigns radiance values in a rescaled, rotated, and deskewed coordinate system using data from the existing grid, i.e., the raw ERTS data. Because a fixed grid output device is used (i.e., the printer or digital display screen) some interpolation is required to produce new samples. The point nearest the desired sample location is used to represent the value at the desired location (Nearest Neighbor Rule). The procedures are fully described in reference 11.

The output form used for CITARS is such that when the data is printed on an 8 line per inch, 10 column per inch computer line printer the resulting scale is approximately 1:24,000 and the image is North-oriented (Figure 4). Comparisons to topographic maps indicate about a 1 to 2% scale error.

4.2.2 SPATIAL REGISTRATION OF TIME SEQUENTIAL ERTS DATA

Registration of multiple images of the same scene is accomplished through use of the LARS image registration system described in reference 12. The overlay processing operation consists of two basic operations: (1) image correlation and (2) overlay transformation. Many factors exist which prevent exact overlay of the images, thus this operation is approximate. Two major errors are: (1) It is unlikely that the samples from one time were imaged from exactly the same spot as samples from a later satellite pass; thus, in general, no data exists which exactly overlays for both times even if no other errors were present; and (2) Due to changes in the scene and other "noise" sources the two images cannot be exactly correlated or matched. The overlay procedure used consists of the following:

1. Initial checkpoints or matching points are manually selected in the two images to be overlayed using a digital display screen.
2. A two dimensional least squares quadratic polynomial is generated to represent the difference in position of points in the two images.
3. A block image cross correlator is employed to find the remaining image displacement at the nodes of a uniform grid using the approximate overlay polynomial generated in reference 12.
4. A new overlay polynomial is generated from the correlator-produced set of checkpoints and used to actually overlay the images. The two images are combined onto one data tape and a new data set is formed having M+N channels where M is the number of channels from image A and N is the number of channels from image B.

5. The overlay data tape is inspected to check image quality and overlay quality. Preliminary results on the evaluation of registration quality are discussed in Section 4.

4.7.3 SECTION AND FIELD COORDINATE LOCATION

Locating section and field coordinates has been a major task preparatory to classifying the ERTS data. This task was first attempted using a manual method for location of fields in ERTS data displayed as single-band gray-scale line printer maps (reference 13). This required that field boundaries be easily distinguished in the imagery. In cases where there was minimal spectral contrast among crop fields, non-supervised classifications have been performed to produce an enhanced image. Whether using gray-scale or computer-enhanced images, reasonably large fields are required to assure that pixels are selected from within the field boundaries.

With the CITARS data, there was little contrast among fields of interest, since the first data was collected early in the growing season (June 8-12). For instance, at this time of year corn and soybeans were only a few inches tall and the spectral response was primarily from the soil. And, roads were not as visible in the imagery as they generally are in data collected later in the season. Also, many fields were small (≤ 20 acres). Therefore, procedures for accurately locating fields, when individual fields could not be clearly seen in the imagery, were required to meet project requirements.

To improve the accuracy of the manual location method, ERTS images were geometrically corrected and rescaled to produce a nominal 1:24,000 scale map on a line printer (reference 11). This product alone made the location of fields more precise and more rapid than it would have been on uncorrected data. Photo overlays were prepared with section and field boundaries outlined. The initial overlays, made from photography enlarged to a nominal scale of 1:24,000 were helpful, but not completely satisfactory due to distortions in the photo. Following this, rectified photographs were produced at a scale of 1:24,000. This product could be manually overlaid to the line printer maps of the ERTS data.

After manually locating all field and section coordinates in the ERTS data, the precision was still not adequate to meet the requirement of a maximum error of one pixel. Therefore, a previously-developed, computer-assisted procedure was employed by ERIM to locate section corners and define ERTS data coordinates for sections (reference 14). A map transformation from Earth coordinates on a rectified aerial photograph to ERTS data coordinates was calculated for each segment using roughly 30 control points for each calculation. The control points were located visually in the rotated and geometrically corrected ERTS data and by coordinate digitization on the photograph. A map transformation then was computed by the method of least squares; ERTS coordinates of the few control points with large residuals (>1 pixel) were checked and modified or deleted, as appropriate, and the transformation was recomputed. Next, the transformation was applied to all section corners of interest (whose locations on the photograph had been digitized at the same time as the control points) to find their fractional line and column coordinates in the ERTS data. Final standard errors of estimate (for control points) were less than 0.5 and typically between 0.2 and 0.4 ERTS pixels, i.e., 15 to 30 meters on the ground. The RMS error in digitizing the location of the individual points was on the order of three meters on the ground (errors of roughly 0.005 inch or less on a photograph at a scale of 1:24,000).

These section corner coordinates (calculated in fractional ERTS line and column coordinates) were used to locate field boundaries of individual fields within the sections. A major advantage of the procedure is that it preserves the relative positions of all points considered with an accuracy that cannot be matched manually. Another feature of the ERIM procedure was utilized to generate ERTS data coordinates for each outlined section. All pixels whose centers fell inside lines connecting the vertices (again, located by fractional coordinates) were automatically included on coordinate definition cards.

3.6 ADP TECHNIQUES FOR MSS DATA PROCESSING

The basic ADP techniques will be grouped into three divisions: (1) "Standard" techniques, (2) preprocessing techniques, and (3) multitemporal techniques. The term "standard" ADP techniques is used to mean either Gaussian maximum-likelihood classifiers or a classifier employing a linear decision rule and classifies data which has not been radiometrically preprocessed and has not been acquired multitemporally.

Each of these ADP techniques consists of a computer-implemented software system and a method or procedure by which an analyst can convert multispectral data into ground cover class identification information on a pixel by pixel basis.

Since the crop identification performance of ADP techniques can be sensitive to the manner in which the classifier is trained, the types of MSS data input (e.g., preprocessed, multitemporal, etc.) and which spectral bands are used for recognition, a quantitative evaluation and subsequent comparison of the crop ID performances of such techniques will be most meaningful if the procedures used to obtain the classification results are well-defined and repeatable.

Most of the existing procedures currently developed for the use of the very generalized analysis algorithms, require decisions on the part of the analyst which can significantly affect the classification performance obtained. For the purposes of this assessment, the analyst factor will be minimized as much as possible in order to permit an evaluation of the automated techniques.

A necessary requirement for a small variance in the classification repeatability of an ADP technique is that the procedure for using such a technique be sufficiently well defined so that an analyst can follow the procedure without deviation; thus, each of the ADP techniques evaluated in this task will be documented in detail, and the documented procedures will be rigidly adhered to.

3.6.1 LARS ADP TECHNIQUES

The analysis techniques to be used by LARS utilize the LARSYS Version 3 multispectral data analysis system. Its theoretical basis and details of the algorithm implementation are described in references 1 and 2, respectively. A complete description of the analysis procedures is contained in reference 3. The procedures are designed to provide repeatable results, i.e., variation due to analysts is minimized. Briefly, the analysis procedures consist of:

1. Class Definition and Refinement. Four major classes, corn, soybeans, wheat (for selected missions) and all "other" ground covers are defined. These major classes are divided into subclasses where spectral variability within a class is so great as to result in multimodal probability distributions for that class. Clustering is used to isolate the subclasses. For clustering all four ERTS bands are used. A systematic method (see reference 3) which minimizes the total number of subclasses produced while ensuring that multimodal class distributions are avoided is used for interpreting information on the separability of subclasses.

2. Classification. Each data set is analyzed using two versions of the maximum-likelihood classification algorithm. Gaussian probability density functions are assumed for both procedures. The first classification method is the maximum-likelihood classification rule assuming equal prior probabilities for all classes and subclasses. This is the rule which has been in common usage for remote sensing data analysis for some time.

The second method uses "class weights" proportional to the class prior probabilities. This approach is more nearly optimal given that the Bayesian error criterion (minimum expected error) is preferred. Class weights may be based on any reasonably reliable source of information. In CITARS the weights are computed from county acreage estimates made by the USDA the previous year. Subclass weights are simply the number of points in each subclass divided by the total number of points in the class.

3. Results Display and Tabulation. The results of the classifications are displayed using a discriminate threshold of 0.1%. This light threshold eliminates only those data points very much different from the major class characterizations. Threshold points are counted in the "other" category. A computer program is used to generate results tabulations, in both printed and punch card form, for training fields, test fields, test sections, pilot fields, and pilot sections.

3.6.2 ERIM ADP TECHNIQUES

The digital data processing and analysis procedures defined by ERIM for use in the CITARS study reflect concern for the calculational efficiency of recognition processors and the need for extending recognition signatures from training areas to other geographic locations and/or observation conditions, as well as the CITARS requirement for minimizing the need for analyst judgment. A brief summary of the procedures is as follows:

1. Training. The training of the processor, that is, the establishment of class signatures for recognition, is a crucial step in multispectral data processing. Although multimodal signatures are frequently employed, the use of one signature per major class was selected for CITARS processing because of simplicity, processing efficiency, and the fact that a combination of

individual field signatures can result in a single signature that encompasses more of the variability of the class than is represented by a multimodal signature. An objective, reproducible procedure, based on an X^2 test, was devised to reject anomalous "outlier" fields before the formation of a combined signature, so as to develop signatures representative of healthy crops at a reasonable stage of maturity for the time of season. Signatures for classes other than the major ones are to be included only if they are found to be confused with the major crops on preliminary recognition runs over training data.

2. Recognition Without Preprocessing. Two types of decision algorithms are being used, a linear rule and a more conventional quadratic rule. The linear decision rule was chosen because it requires substantially less computer time for recognition calculations, has been used successfully in many applications at ERIM, and has been found to provide comparable recognition accuracy in previous tests (reference 4). Use of the quadratic rule will permit another, comprehensive comparison of the two rules. Both rules apply a threshold test (0.001 probability of rejection) based on a quadratic calculation for the signature of the "winning" class; points failing the test will be classified as being other than the major crops considered.

3. Recognition With Signature Extension Preprocessing. Changes in atmospheric and other local conditions can cause changes in the signal levels received at the scanner for different areas and at different times. The region of signature applicability can be extended beyond the region used for training by employing signature-extension preprocessing techniques. Non-local recognition denotes recognition performed on segments other than those from which signatures were extracted. Non-local recognition will be carried out once before and once after preprocessing corrections for signature extension have been applied (for both linear and quadratic decision rules). Several promising preprocessing methods have been developed (references 5 and 6) and are being tested on ERTS data at ERIM (reference 7). Only one method has been identified to date for use on the CITARS project--a mean-level adjustment procedure. The mean-level adjustment is

derived from an average over diverse ground covers within the "local" signature extraction segment and a comparable average within the "non-local" segment to be classified.

4. Results Summarization. The results obtained with each procedure will be summarized in a standardized form for subsequent analyses of variance. Separate summarizations will be made for field-center pixels and for entire test sections.

3.6.3 EOD ADP TECHNIQUES

EOD will evaluate two techniques. One technique is for single pass data and the other for multitemporal MSS data.

For single pass data the EOD will utilize the ISOCLS (reference 8) clustering algorithm implemented at JSC to generate the class and subclass statistics and the Gaussian maximum-likelihood classifier on the Earth Resources Interactive Processing System (ERIPS) (reference 9).

The training fields for corn, soybeans, and wheat will be submitted to independent runs on the Earth Resources Interactive Processing System (ERIPS) using the ISOCLS implemented clustering routine to generate class, and if necessary, subclass statistics, e.g., corn 1, corn 2, corn 3, etc. The training fields for "other" will then be submitted to the same clustering scheme to generate class and subclass statistics for all "other".

The training fields, test fields, and "test" sections will then be classified using the Gaussian maximum-likelihood classification algorithm on ERIPS and and the statistics as previously generated within the clustering process.

For multitemporal data ISOCLS will be used to separate spectral classes. A linear combination of features will be selected using an EOD algorithm (reference 10) and classification will be similar to the unitemporal technique.

3.7 PERFORMANCE COMPARISONS

The basic questions proposed in the objectives will be answered by a series of analyses of variance. There will be two basic quantities which will be used to characterize the crop identification performance of the

ADP techniques. These are (1) e_{ij}, the estimated probability of classifying a non-boundary pixel from class i as class j and (2) $\hat{p}_i - p_i$, the estimated proportion of class i minus the true proportion of class i.

In order to compute the e_{ij} from the ADP results, pixels which correspond to ground cover classes i and j must be precisely located with respect to the ground truthed areas. Test fields will be chosen to exclude agricultural field boundaries within pixels and also to exclude known inhomogenieties in the field, such as flooded areas, etc. As indicated in the above discussion, accomplishing this task was difficult and required the development of new technology.

Since in an actual remote sensing situation, the classification error resulting from pixels containing agricultural field boundaries (boundary pixels) and the error resulting from field inhomogenieties may represent a large part of the error, some method is required to estimate these errors. The use of e_{ij} to accomplish this was decided to be impractical because of the difficulty in locating the pixels containing field boundaries. Thus it was decided to use the proportion estimate to characterize this error. $\hat{p}_i$ will be computed for "pure test pixels" as well as for the agricultural sections and the differences in the resulting proportion error vectors will be used to estimate the error contribution resulting from boundary pixels and field inhomogenieties.

In addition to the performance quantities discussed above, some attempt will be made to correct the proportion estimates for statistical bias which is expected to result from misclassification. Two methods have been proposed for accomplishing this and the corrected $\hat{p}_i$ using each method (described below) will be compared to the $\hat{p}_i$ as determined from the photo interpretation to determine if either method improves the proportion estimates.

3.8 FACTORIAL ANALSES FOR PERFORMANCE COMPARISONS

For performance comparisons several dependent variables will be calculated for each of the 20 test areas per segment. The quantities e_{ij} will be estimated as discussed previously.

The proportion estimates p_i will be computed in one of three ways:

1. $\hat{p}_i = n_i/N$

2. $\hat{p}_i = \beta_i \, n_i/N$

3. $\hat{p}_i = \frac{1}{N} E^{-1}(n)$

where n_i = number of pixels classified as i.

N = total number of pixels in the area to be classified.

β_i = regression coefficient obtained by comparing n_i/N with the true proportion p_i for pilot data.

E = matrix of e_{ij}'s obtained from pilot data.

n = vector of n_i's.

Note that methods two and three require the use of "pilot" data, i.e., additional ground truth used to obtain estimates of E or β_i.

Once a dependent variable is decided upon, a typical analysis will consist of (a) obtaining cell means of the dependent variable over various combinations of factors, and (b) performing an analysis of variance.

4. FIRST RESULTS FROM CITARS

CITARS as designed and described above, was originally scheduled to begin in early June 1973 and to be complete by October 1974 with a majority of the actual ERTS data processing complete by April 1, 1974; however, as of April 1, 1974, CITARS is approximately 90 days behind schedule. This slip resulted primarily from difficulties encountered in field boundary coordinate location in the ERTS imagery.

Complete as of April 1 is the acquisition of ground truth by ASCS, the aircraft acquisition of large-scale color IR photography, the interpretation of that photography for supplemental ground truth, data quality evaluation of the ERTS data, and the geometric correction and registration of that data. To be completed are test, training and pilot field coordinate determination, ADP processing of the data and the subsequent performance comparisons. The remainder of this paper will be devoted to a discussion of the completed portions of CITARS.

4.1 DATA ACQUISITION

Data acquisition consisted of three major efforts: the periodic visitation of each segment by ASCS personnel for crop type identification, the periodic acquisition of large-scale aircraft photography and ERTS data acquisition. Each of these tasks have been completed and with some exceptions, each effort has provided data adequate for the accomplishment of the CITARS objectives.

4.1.1 Ground Observations

ASCS personnel completed all field visits to all segments. In addition, they made additional visits in the Fayette County, Illinois segment to determine additional training and test fields for wheat which were required as a result of late and incomplete aircraft coverage of Fayette County in early June.

Table 1 summarizes for each county the amount of acreage, the total number of fields by class, and the average field size for the fields in the 20 ASCS June-identified quarter-sections. In addition to these and the other agronomic data discussed in section 3.3, ASCS personnel successfully used the solar photometers to record atmospheric optical depths on successive ERTS orbits over the segments. For some of these segments, there are considerable differences in the atmospheric state from one day to the next. Thus, by training on a segment and classifying it on the subsequent ERTS orbit, the effect of atmospheric differences on crop identification performance can be evaluated.

4.1.2 Aerial Photography

Aerial photography was used for field annotation, extension of ASCS ground truth via photointerpretation and mensuration of field acreage. For accurate photointerpretation, large-scale color infrared photos were specified. This photography was acquired each 18 days from June through October by the Bendix Queen-Aire Aircraft at 4 km altitude using a Fairchild 224 camera. For accurate mensuration of fields, data was acquired in July and August with a Zeiss metric camera flown in the ERIM C-46 at about 4 km altitude. Base photography for the annotation of ground truth was acquired with an RC-8 camera carried at 18 km by the NASA RB57F.

4.1.3 Photointerpretation

The photointerpretation team at EOD has completed the tasks of determining crop identification, areal proportion of each crop, row direction and width and any field anomalies for each of 20 agricultural sections in all CITARS segments. This job, which took about 6 months from the acquisition of the first photography, was completed within three weeks of the originally projected schedule. About 18 man-months was expended in the effort. The photo interpreters, using large-scale color IR photography acquired six times during the growing season, identified 23 or 24 agricultural sections in each segment. The photo interpreters trained in 16 or 17 of the ASCS quarter-sections. Three or four of the remaining quarter-sections were withheld from the photo interpreters, but were included in the full sections to be interpreted so that a comparison of their results to the ASCS identifications could be made. The photo interpreters did not know which sections contained the test quarter-sections.

Comparisons of the ASCS crop identifications to the PI identifications have been completed in two of the six CITARS segments. In these counties the percent agreement with the ASCS identifications was 94% for soybeans, 96% for corn and 16% for wheat. These are percentages of fields from a sample of 32 soybean fields, 27 corn fields and six wheat fields. Of the two soybean fields misidentified as other, one field was planted two weeks late and the other one six weeks late. The corn field misclassification may be a result of mistaken field labeling. This problem is as yet unresolved. The wheat problem is a different matter since the first aircraft photography of June 28 was acquired during wheat harvest. Thus the photo interpreters had imagery of only mature (low IR reflectance) or harvested wheat which proved inadequate for wheat recognition.

4.1.4 ERTS-1 Multispectral Scanner Data

The ERTS-1 satellite passed over each of the six test segments twice (on successive days) during each 18-day period. Since there were six periods of interest, from early June to early September 1973 a total of 72 data sets were potentially available for processing and analysis. Cloud cover problems were identified by reference to the ERTS data catalog and visual inspection of imagery where available. Of the 72 possibilities, cloud cover was severe enough (20-30%) on 41 sets to cause their rejection outright, no data were collected for two sets, and several others were eliminated for other reasons. A total of 23 sets were selected for analysis and several of these were found to have cloud problems upon detailed examination. Thus, roughly 60% of the data sets were eliminated because of excessive cloud cover. Table 2 summarizes the cloud cover statistics.

A majority of the selected data were of good quality. However, a few problems were observed which are affecting data analysis procedures and/or results: (a) occasional erratic data throughout individual scan lines or portions of lines, (b) detector-to-detector* differences among the mean values obtained from the six detector channels that comprise each spectral band as averaged over a large sample of the data and (c) differences in the variances observed from the detector channels over the same data sample.

ERTS-1 data quality was assessed by several different methods. First, visual inspection was made for each spectral band on a digital display to determine the presence of any lines of bad data through one of the 5x20 mile segments. More than half (14) of the 23 sets had no bad lines, and the worst were one with 8, two with 19, one with 25, and one with 40 bad lines. Next, histograms and sample statistics (mean and standard deviation) were computed for samples of the data--every line and every 30th point for all cases, every line and every sixth point for many, and every line and every point for a few. These statistics were calculated separately for each detector in each spectral band; unrotated ERTS data were utilized for these tests.

One would expect some variation between values in the various detectors, because each is calibrated separately. To evaluate the degree of similarity between these statistics, a mean, m_μ, of the six detector means was calculated for each spectral band, as well as the sample standard deviation, s_μ, of the individual values from that overall mean. The ratio, s_μ/m_μ, was computed for each data set and a histogram of these values is presented in Figure 3. All values lie below 3%, except for one of 9.3%, which corresponds to the data set with 40 lines of bad data. No clear relationship could be found between the number of bad lines and s_μ/m_μ values below 3%. The number of good lines present was sufficient to mask effects of a few bad lines, and channel-to-channel variations existed in all data.

Similarly, the detector value standard deviations were analyzed and a histogram of s_σ/m_σ is presented in Figure 3. In this instance, the s/m values exhibit considerably more spread than they do for the detector means.

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*Detector is used here to denote the entire signal channel from individual detector element to CCT.

Most values are ≤5%, but they scatter up to 24%, with an extreme of 87% for the 40-bad-line case. Here again, except for extreme values there was no apparent direct correlation between s_σ/m_σ and the number of bad lines present.

The question now arises regarding the analysis of data exhibiting problems associated with clouds, lines of bad data, and channel-to-channel variations. Test section, test fields, and training fields affected by clouds and/or bad lines were determined by inspection and eliminated from the analysis. The one data set with 40 bad lines is being analyzed in three bands only, since all bad lines were in the same band. One could transform all data values to equalize the means and/or variances in each set of detector channels (omitting bad-line values) and perhaps effect some improvement in recognition results. However, geometric correction and spatial registration operations were being applied to these data sets in parallel with the data quality evaluations, so it was decided to start again and carry out radiometric correction procedures only if poor recognition performance were obtained and appeared to be attributable to such differences.

4.2 ERTS DATA PREPARATION

ERTS data preparation has included geometric correction, multitemporal registration, and section and field coordinate location. These tasks have been completed except for final checking of field coordinates.

4.2.1 Geometric Correction

Twenty-three segment-date combinations of ERTS data have been geometrically corrected as described above. This form of the data has greatly facilitated the location of sections and fields in the digital data since it can be matched to photo overlays of the same scale. Having the data in this format has reduced the degree of reliance on having to "see" fields in the spectral data to accurately locate them.

4.2.2 Multitemporal Registration

Data from 17 ERTS passes has been registered to the data from the earliest ERTS passes over the six segments having cloud-free coverage. With the exception of the Lee County, Illinois segment, the base data was collected during the June 8-12 ERTS passes.

Preliminary results indicate that the registration accuracy meets the project requirements. However, precise evaluation of overlay accuracy is difficult to accomplish. One measure of registration error is the residual of the least squares polynomial (RMS error); this statistic averages 0.5 of an image sample. These results are shown in Table 3. To insure that registration errors do not interfere with CIP, a "guard" row of one pixel surrounds the field center pixels chosen for training the classifiers and testing their performance.

In addition, to further evaluate the accuracy of registration and its effect on classification performance, a replicated comparison of CIP obtained when using field coordinates located in the base period ERTS data with classification results obtained when the data has not been registered will be made.

4.2.3 Section and Field Coordinate Location.

As mentioned above, accurately locating section and field coordinates in the ERTS data has been a difficult task. At this time, however, only a final checking of the coordinates remains to be done. One of the benefits resulting from CITARS will be the implementation of a capability to accurately locate the coordinates of specific fields or points in the ERTS data without complete reliance on the contrast in the spectral image. This capability has significantly improved the accuracy of the coordinate locations. Preliminary checks of field coordinates transformed from the base period to later ERTS passes indicates that coordinates have been accurately located and that by allowing a guard row or column around all sides of pixels, the multitemporal registration is accurate enough to allow the same coordinates to be used for all periods. This procedure eliminates the need to re-locate coordinates in each ERTS frame.

4.3 ADP ANALYSIS OF ERTS DATA

As a result of the difficulties encountered with the field boundary selection problem, the ADP analyses of the ERTS data and the subsequent performance comparisons as specified by the CITARS design plan, have not been completed. However, the preliminary analyses to date merit some brief discussion. The most significant result to date is the amount of training data acquired from the 20 quarter-sections in each of the 5 x 20 mile segments.

To insure that the pattern classifiers were being trained only on "pure" and correctly-identified ground classes, the CITARS task design specified that training data come from the quarter-sections visited by ASCS personnel and that no pixel (ERTS data resolution element) which contained a boundary between different ground classes be used in the computation of training statistics. During the CITARS design phase, the amount of ground truth required for classifier training was estimated by assuming that ten times the number of channels used for classification would be required to train the classifier for each ground cover class. Thus, based on 20 ground cover classes, and four channels, 800 "pure" or non-boundary pixels would be required for training. Other rough calculations (reference 15) indicated that no more than about one-half of all acquired pixels would contain agricultural boundaries based on a preliminary estimate of a 20 acre average field size for Indiana and Illinois. Thus for ERTS pixels of 1.1 acres in size, roughly 1600 acres would be required to obtain the 800 "pure" training pixels. In addition, an equal additional amount of training data was required to form replicate training sets to determine the effect of training set selection on classifier performance. Thus, ASCS was requested to visit and identify twenty 160-acre quarter-sections to obtain 3200 acres for training purposes.

It is of interest to see how this design worked out in practice. In each of the CITARS segments, training field boundaries have been selected and final boundary adjustments are nearing completion. Based on the number of training pixels selected to date, Figure 5 plots the percent of the training acres actually selected as "pure" training pixels versus the average field size in the ASCS quarter-sections. Except for the anomaly in Livingston County, the shape of this curve is as one would expect. However, the percent usable pixels are much smaller than the early estimates of 50%. This is a result of a subsequent design change in CITARS to include a row of "guard" pixels between the agricultural field boundary and the training field boundary. This was done to increase the probability that only non-boundary pixels were chosen for training, but prevented the selection of pixels in many fields, especially ones less than ten acres (20-40% of the fields) and larger but narrow fields.

5. SUMMARY

The CITARS task was designed as carefully as possible to insure an objective and quantitative assessment of the crop identification performance of currently available classification algorithms and procedures.

The ADP procedures were written to minimize the amount of subjective human interaction. This was done to permit a quantitative and repeatable evaluation of classification techniques which could be automated for operational implementation.

For the resources available, a data set was designed to permit an objective evaluation of these techniques over a wide as possible range of agricultural and climatological conditions. An extensive data set has been collected and the utmost care has gone into the preparation of this data set for ADP crop identification performance evaluation.

Based on the data set acquired and the stated objectives of CITARS, a statistical analysis has been designed to obtain the maximum amount of reliable information regarding classifier performance.

At this point in the progress of the CITARS task, the most major problem encountered was the selection of field boundaries in the ERTS data. This problem resulted from the requirement that no pixels which contained boundaries between different agricultural classes were included in the training or test data. This problem had to be resolved through the implementation of recently-developed technology and has resulted in a 90-day delay.

At this point, the combination of ASCS field visits with interpretation of low altitude temporally-acquired photography appears to be a relatively cost effective and accurate method for assembling a large ground truth set with stringent design requirements.

Of the 72 possible ERTS acquired data sets roughly 60% of the data sets were unusable as a result of excessive cloud cover. Of the remaining sets the electronic data quality was acceptable for processing.

6. ACKNOWLEDGEMENTS

The authors wish to thank those at ERIM, LARS, and EOD, who devoted and are continuing to devote their time, talents and effort to the design, implementation and execution of the CITARS task. There are too many to list here, but their work should gain the recognition it deserves as CITARS results appear in the literature.

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Table 1. Summary of acres, number of fields, and average field size of the quarter-sections.

Segment		Corn	Soybeans	Wheat	Other
Huntington	Acres	831	618	63	986
	No. Fields	39	25	6	54
	Avg. Size	21.2	24.7	10.4	18.3
Shelby	Acres	1888	540	323	753
	No. Fields	71	24	15	61
	Avg. Size	26.5	22.5	21.5	12.3
White	Acres	1836	510	38	954
	No. Fields	42	13	2	41
	Avg. Size	43.7	39.2	19.0	23.3
Livingston	Acres	1239	1073	39	569
	No. Fields	53	27	2	33
	Avg. Size	37.5	39.7	19.5	17.2
Fayette	Acres	733	287	416	1358
	No. Fields	37	11	26	92
	Avg. Size	19.8	26.0	16.0	14.7
Lee	Acres	1498	813	36	620
	No. Fields	42	31	2	34
	Avg. Size	35.6	26.2	18.0	18.2

Table 2. Percent cloud cover over the test sites during ERTS-1 passes.

		Date					
Segment	Pass	June 8-12	June 26-30	July 14-18	Aug. 1-5	Aug. 19-23	Sept. 6-10
Huntington	1	A	X	X	X	X	X
	2	A	X	A	X	A	X
Shelby	1	A	X	B	X	C	B
	2	X	X	X	X	X	X
White	1	A	X	X	X	X	X
	2	X	X	X	X	A	C
Livingston	1	A	X	B	B	C	X
	2	X	C	X	X	X	X
Fayette	1	A	X	A	X	A	X
	2	A	A	A	X	X	X
Lee	1	X	X	B	X	X	X
	2	X	X	A	A	X	X

Percent Cloud Cover

A	0-5
B	6-15
C	16-30
X	31-100

Table 3. RMS error of spatially registered multi-temporal ERTS-1 data.

Segment	Period	Number Checkpoints	RMS Error Lines	RMS Error Columns
Huntington	1	30	.44	.36
	3	27	.31	.39
	7	51	.30	.43
Shelby	3	23	.63	.38
	5	9	.27	.27
	6	43	.30	.47
	7	59	.31	.43
White	5	61	.32	.39
	6	16	.28	.14
Livingston	2	32	.31	.44
	3	9	.44	.37
	4	9	.16	.87
Fayette	1	41	.39	.33
	2	52	.37	.29
	3	53	.44	.34
	5	19	.57	.39
Lee	3	100	.34	.58
	4	84	.32	.41

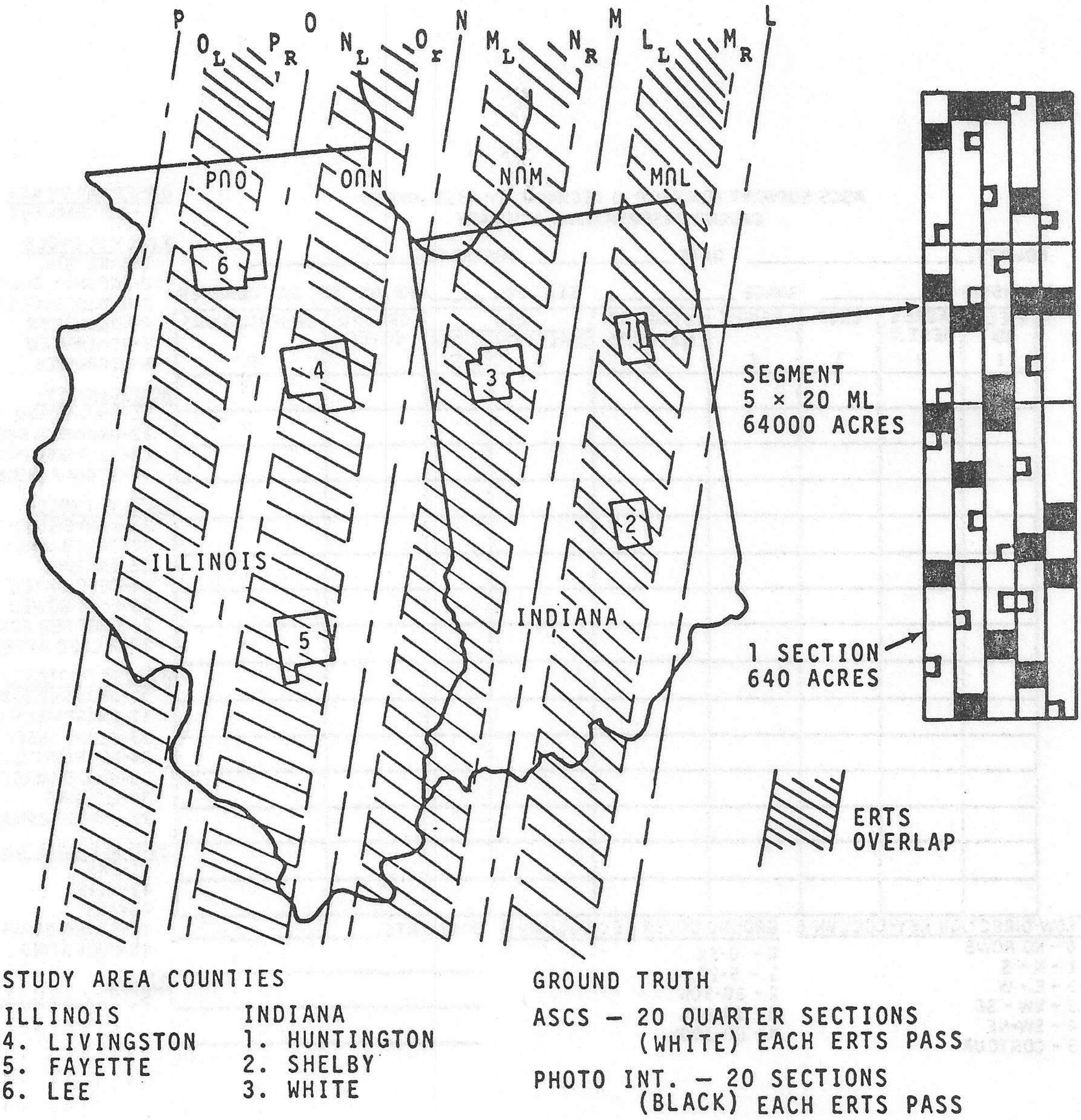
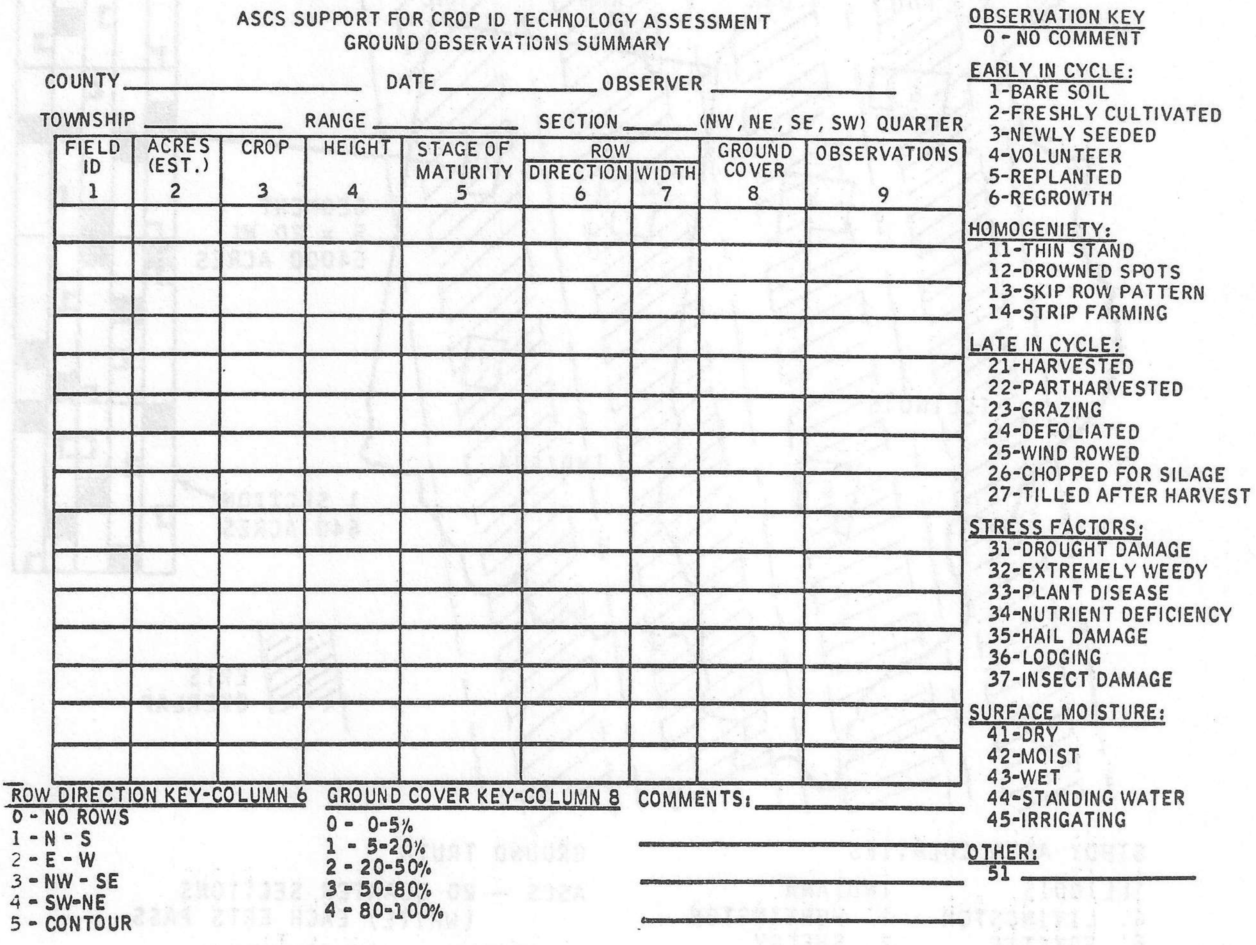


Figure 1. CITARS test site locations and ground truth sample design.



ASCS SUPPORT FOR CROP ID TECHNOLOGY ASSESSMENT
GROUND OBSERVATIONS SUMMARY

COUNTY ________________ DATE ____________ OBSERVER ______________

TOWNSHIP __________ RANGE __________ SECTION _____ (NW, NE, SE, SW) QUARTER

FIELD ID 1	ACRES (EST.) 2	CROP 3	HEIGHT 4	STAGE OF MATURITY 5	ROW DIRECTION 6	ROW WIDTH 7	GROUND COVER 8	OBSERVATIONS 9

OBSERVATION KEY
0 - NO COMMENT

EARLY IN CYCLE:
1-BARE SOIL
2-FRESHLY CULTIVATED
3-NEWLY SEEDED
4-VOLUNTEER
5-REPLANTED
6-REGROWTH

HOMOGENIETY:
11-THIN STAND
12-DROWNED SPOTS
13-SKIP ROW PATTERN
14-STRIP FARMING

LATE IN CYCLE:
21-HARVESTED
22-PARTHARVESTED
23-GRAZING
24-DEFOLIATED
25-WIND ROWED
26-CHOPPED FOR SILAGE
27-TILLED AFTER HARVEST

STRESS FACTORS:
31-DROUGHT DAMAGE
32-EXTREMELY WEEDY
33-PLANT DISEASE
34-NUTRIENT DEFICIENCY
35-HAIL DAMAGE
36-LODGING
37-INSECT DAMAGE

SURFACE MOISTURE:
41-DRY
42-MOIST
43-WET
44-STANDING WATER
45-IRRIGATING

OTHER:
51 ____________

ROW DIRECTION KEY-COLUMN 6
0 - NO ROWS
1 - N - S
2 - E - W
3 - NW - SE
4 - SW-NE
5 - CONTOUR

GROUND COVER KEY-COLUMN 8
0 - 0-5%
1 - 5-20%
2 - 20-50%
3 - 50-80%
4 - 80-100%

COMMENTS: ____________________

Figure 2. Crop identification and condition observation form.

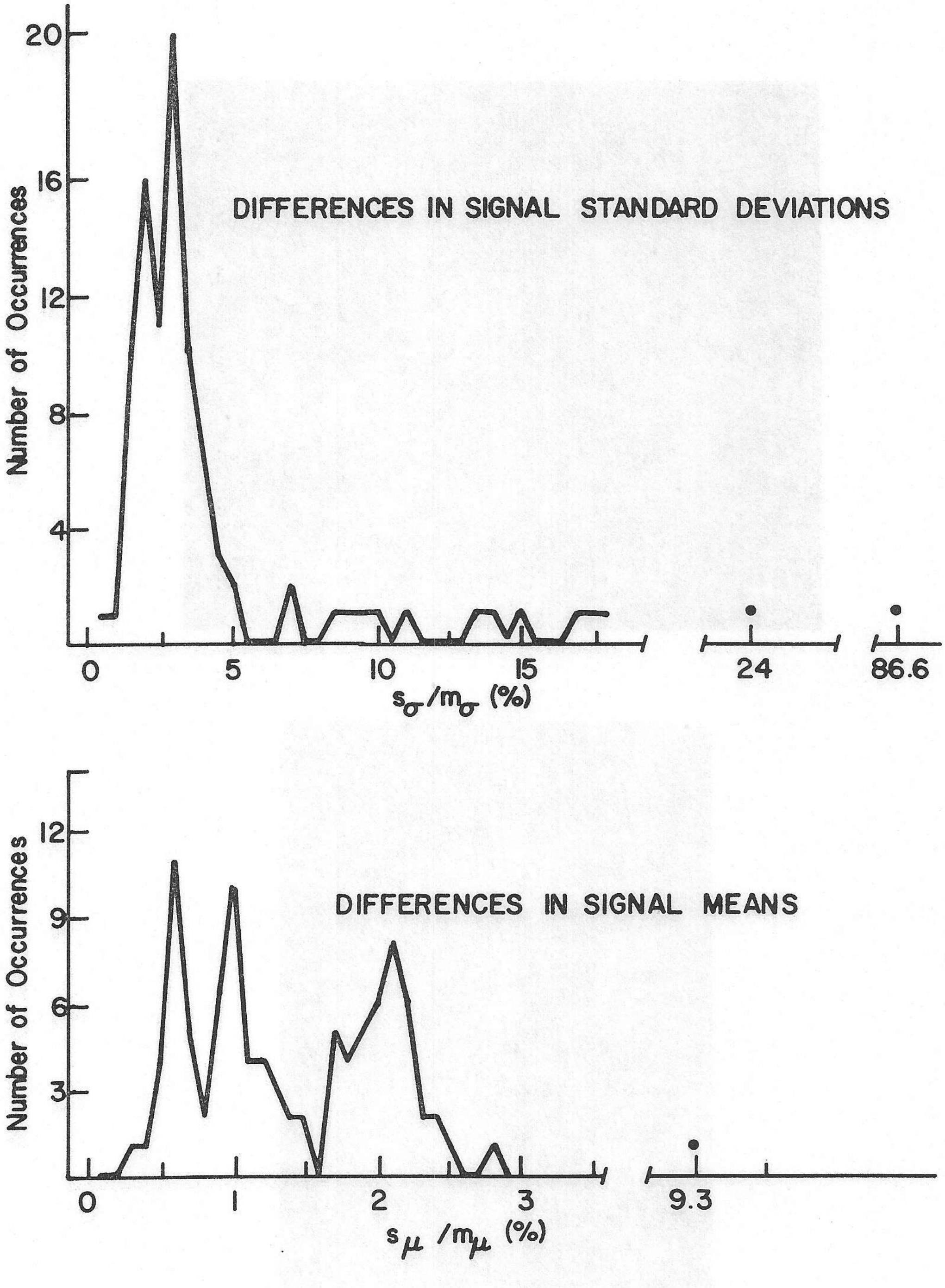


Figure 3. Variation between the six detector channels in single bands of ERTS-1 MSS data.

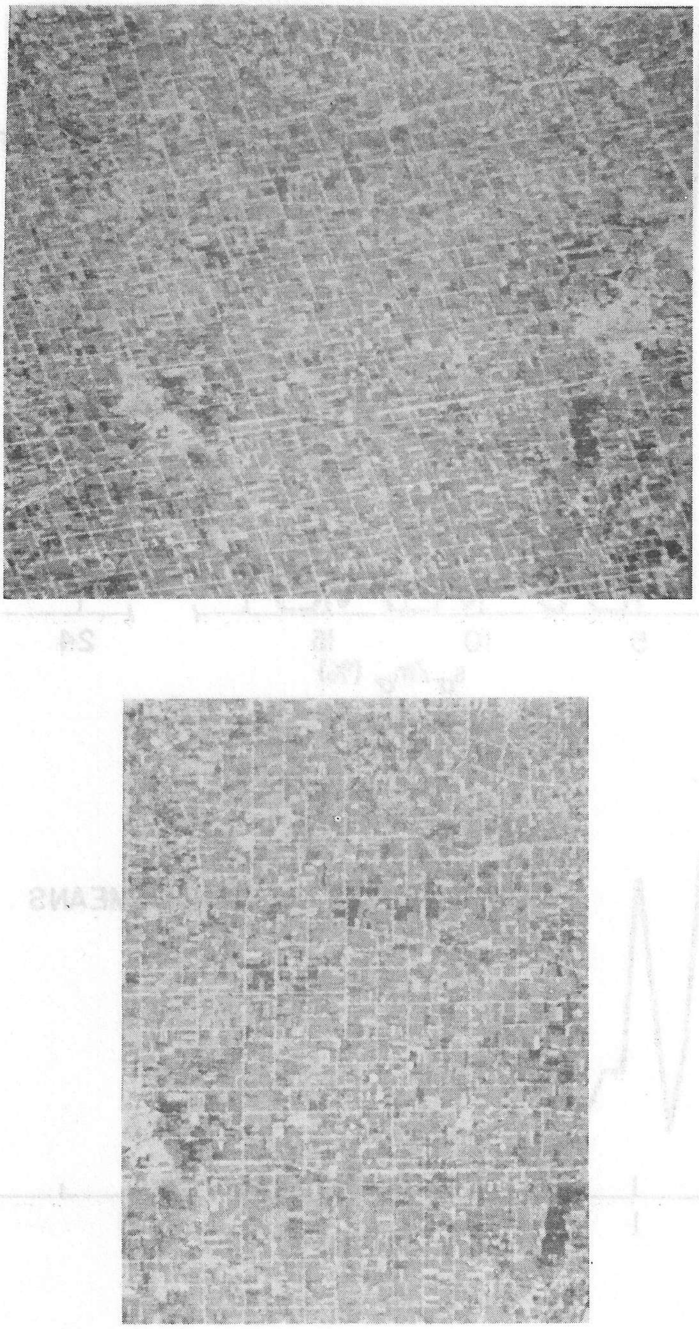


Figure 4. Comparison of original (upper) and geometrically corrected and rotated ERTS-1 MSS digital imagery.

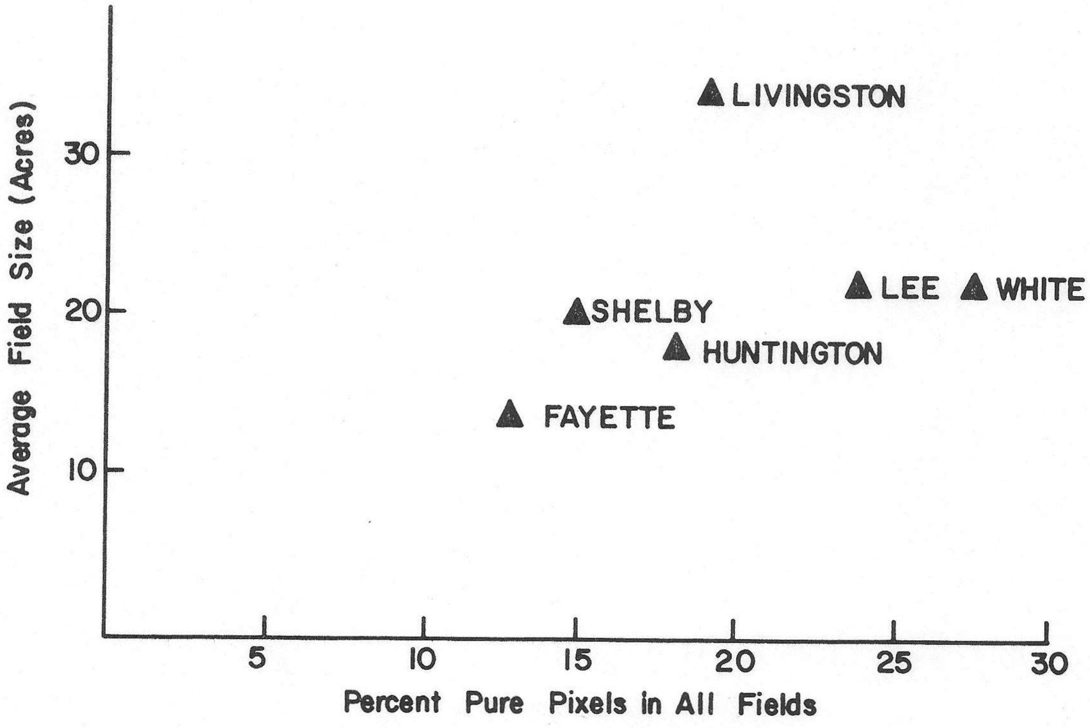


Figure 5. Effect of field size on the percent of non-boundary pixels available for classifier training.