Southeastern North Dakota Landsat TM Crop Mapping Project

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ABSTRACT

The purpose of this project was to establish a crop specific classification for a group of counties in Southeastern North Dakota. Landsat TM data (from May, June, July, and September 1994) provided 24 bands of multi spectral information (the thermal bands were not used). Extending this crop classification throughout North Dakota using AVHRR data and developing relationships to spring wheat yield are the focus of the North Dakota spring what yield modeling project (Doraiswamy 1996). Crop information came from both the National Agricultural Statistics Service (NASS) June Agricultural Survey (JAS) and the Farm Services Agency (FSA) for the 1994 growing season. Digitization of the field boundaries was done in ARC/INFO[1] from both CD-ROM digital images (processed from photographs) of JAS Area aerial photography and scanned images of photocopied FSA aerial imagery. ERDAS IMAGINE[2] software was used in the clustering and classification of the four dates of Landsat TM imagery. Although the primary focus of the project was to develop a crop specific mapping the Landsat Analysis Area, the crop information would also serve in an analysis of spring wheat yield models for North Dakota. Classification accuracies proved to be sufficiently high to consider the final classification of spring wheat and four other crops (corn, dry beans, soybeans, and sunflower) to be of map accuracy. The clear appearance of field boundaries confirmed this classification to be a map product. One possible use of this classified image would be in updating NASS land use stratum maps.

INTRODUCTION

NASS has worked with Landsat data since the launch of the first multi spectral Earth Resources Technology Satellite (ERTS) in 1972 (Allen and Hanuschak, 1988). Even with the arrival of the higher resolution Landsat IV and Landsat V, the accuracy of crop classification has always been very variable from one study to another (Graham 1993). NASS has had a primary interest in creating accurate acreage estimates from the Landsat analyses using a sample regression approach to correct for the inaccuracies of classifier performance. However, this study focused more on the mapping aspects of the classification rather than acreage estimates as did earlier NASS studies.

The purpose of this study was to provide an accurate classification of a subset of North Dakota using TM data that would help in establishing accurate classification of AVHRR data for the entire State of North Dakota. Of course, the classification has other valuable uses, for example, locating crops of interest within the counties to evaluate weather effects and to provide maps of crop fields. The primary use of the AVHRR data would be in yield estimation research to evaluate currently available models (Doraiswamy and Cook 1995) for spring wheat yield estimation. Also the TM data will provide another data source for evaluating the yield models' accuracy.

After spring wheat harvest was complete, available Landsat archives were examined to locate TM scenes in North Dakota that would have sufficient cloud free area to be of value. Southeastern North Dakota (with Northeastern South Dakota) was the area that had the most overpass dates available (seven dates, but clouds prevented use of all dates) with four dates during the growing season with the most potential for accurate crop classification. The chosen study area of seven at least partially contained counties in North Dakota (Barnes, Cass, Dickey, LaMoure, Richland, Sargent, Stutsman), and eight at least partially contained counties in South Dakota (Brown, Codington, Day, Edmunds, Grant, Marshall, McPherson, and Roberts) (see Figure 1). Four dates of 1994 imagery that were available were specifically: May 29, June 28, July 15, and September 17, 1994.

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[1] Environmental Systems Research Institute, Inc., Redlands, CA

[2] ERDAS, Inc., Atlanta, GA

The Foreign Agriculture Service (FAS) of USDA provided the four Landsat scenes for our use. NASS provided ground data form the JAS Area field data as ground training data for the crops in the scene. ARS helped to coordinate the project, provided project planning support, planned the yield research, and successfully overlaid the four dates of Landsat imagery to allow accurate crop classification. Also, the Farm Services Agency (FAS) of USDA provided copies of aerial photographs of farmer reported field information as a supplementary data source.

OBJECTIVES

This paper presents the area of study and methodology for classification of multi spectral Landsat TM scene in Southeastern North Dakota. Both maps and accuracy statements of the analysis are provided in the paper. The TM classification will be used as part of a future spring wheat yield study using TM and AVHRR data for the State of North Dakota.

METHODS

Selecting and Overlaying the Landsat TM Scenes

After evaluation of available Landsat TM scenes at EOSAT for the 1994 growing season in North Dakota, the area in North Dakota with the most TM scenes available during the growing season was Landsat 30, Row 28 that lies in Southeastern North Dakota and Northeastern South Dakota.

ARS selected registration points and calculated regression coefficients to overlay the Landsat TM scenes in the Universal Transverse Mercator (UTM) Projection. The TM thermal channel was excluded to improve the pixel size accuracy so that all data channels had a pixel size of exactly 30 meters. NASS completed the Landsat scene overlay by creating a single image of 24 channels in ERDAS Imagine.

Preparing JAS Area Segment and FSA Data

As part of an ongoing survey program, NASS conducts a Quarterly Agriculture Survey (QAS) Program in June (Allan, Hanuschak and Craig 1994). The QAS contains both area and list frame samples. This multiple frame survey provides several significant indications for estimation of crop acreage. The area frame stratifies the States into broad land use categories according to the percentage of cropland present. NASS randomly selects one square mile areas (called segments) based on the land use stratification to collect information of agricultural activity within the segment boundaries. The JAS Area portion of the QAS uses the selected segments to locate sampled fields drawn onto aerial photographs by field enumerators. This survey collects precise field-by-field information on crops planted or other land use.

The North and South Dakota State Statistical Office's (SSO) prepared aerial photos (approximately 55 from each SSO) taken from the National Aerial Photography Program to be photographed with the enumerators' writing and notations maintained. Since the aerial photographs are part of NASS's operational program, they provide a valuable resource for data archiving. Analog photography recorded the segment boundaries and identifier, along with any enumerator notations, such as tract, field identifier, and any other comments about the segment. The unprocessed film was converted by a photo lab to digital photo CD-ROM format.

The RSS had previously converted an Area Sample Frame of North and South Dakota on land use strata into an ARC/INFO vector coverage (Figure 2). To obtain a stratified sample of FSA fields based on percent cultivation, the vector coverage within the study area was rasterized into an ARC/INFO grid. That was a systematic sampling plan weighted by concentration of cultivated of land within each stratum was possible. Sampling the grid created on ASCII file for plotting the X and Y locations with strata numbers to decide the township, range, and section for each county. The North and South Dakota SSO's obtained FSA data from photographs in the FSA field offices by locating the field information according to the provided township, range, and section.

Processing the JAS Area Segment Data

Hi-Jack[3] Pro was used to convert the CD-ROM North and Dakota JAS Area digital data to TIFF images. The images were then registered in ARC/INFO using digital 1:100,000 scale transportation dig's and center of segment coordinates. The TIFF images were then rectified in ARC/INFO, and added to the ARC/INFO image catalog to

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[3] Inset Systems, Brookfield, CT

retain the necessary georeferencing information. The 1994 JAS Area survey data for North and South Dakota were converted to Dbase format by creating a unique identifies consisting of the state fips code, segment number, tract-id, and field identifiers. Creation of this identifier helped in joining the attribute data together in ARC/INFO.

Although RSS digitized the JAS Area fields from the digital JAS Area segment images with Arcedit, Arcview2[4] and its image contrast/stretching tools were indispensable in discerning boundaries from dark photos or reading nearly illegible handwriting. Unfortunately, ArcView2 did not have the functionality to add polygons, create labels, or compute acreage. Because Arcview2 did not have all these need capabilities, RSS used Arcedit to digitize and label the field boundaries according to the HAS Area field boundaries and unique identifiers. Providing this detailed information in Arcedit made possible queries on field identifier, area, land use type, and acreage. A comparison of the digitized JAS Area field acreage in ARC/INFO with those given by the JAS Area field acreage suggested that fields with acreage errors greater than 10 percent should be labeled as bad fields (called category 99).

RSS found 55 JAS Area segments containing 530 total polygons (fields) after carefully reexamining the JAS Area digital fields to reduce the amount of reported acreage error. Of these selected fields, there were 393 uniquely identified fields where JAS Area and ARC/INFO reported acreage differed by less than 10 percent. The remaining 137 fields were labeled as category 99. Because there were many reasons (for example, clouds, incorrect acreage, crop labeling errors, indistinguishable field boundaries, and so forth) for designating fields as category 99, category 99 needed additional subcategories to catalog these possible error types. This method would have made evaluation of the causes for error much easier, but would have introduced additional complexity into the final evaluation of classifier accuracy.

Processing the Scanned FSA Fields

FSA fields were selected according to commodity, and how well their digitized acreage agreed with the reported acreage. The FSA field data (on photocopies) were scanned to produce digital data using Adobe Photoshop[5]. The files were named with township, range, and section references to simplify querying and storage. All relevant attribute information was collected from the FSA photos and stored in Dbase format.

Locating each scanned FSA image on NASS Area Sampling Frame county highway maps was accomplished by registering and rectifying images in ARC/INFO using 1:100,000 scale transportation dlg's. The TIFF images were added to the ARC/INFO image catalog to retain the geo-referencing information. Selected fields were digitized in Arcedit to produce a vector coverage. FSA vector coverage and attribute information were joined through a common identifier.

Queries were done on FSA reported field acreage with the FSA vector coverage field area, fields with acreage errors more than 10 percent were labeled as category 99, as were the JAS Area fields. Careful examination of the FSA digital fields to reduce reported acreage error found that of 617 digitized polygons, there were 438 polygons with good field information. Finally, there were 209 unique farmer id's (each was equivalent to a tract in a JAS Area segment) and 184 polygons were category 99's.

Buffering Field Data and Selecting the Training Data

The shifted field coverages were buffered 45 meters inside the field for JAS Area survey items, but 30 meters outside for JAS Area fields marked as category 99 in ARC/INFO. The buffering excluded pixels lying on the field boundaries to reduce errors in clustering the field data due to mixed category boundary pixels (Grumblatt, 1987). Both the buffered and original coverages were intersected together to retain all the original coverage attribute information in ARC/INFO.

Since their were no potatoes fields among the JAS Area fields, three FSA potato fields were used as training. Some combining of crops did occur, such as the category of grains that included alfalfa, barley, hay for grain, and oats. Other combinations of crops in the tables were found during creation of the tables and are given in the Comments on Classification Accuracy Section.

Clustering and Classifying the Landsat TM Image

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[4] Environmental Systems Research Institute, Inc., Redlands, CA

[5] Adobe Systems Inc., Mountain View, CA

An evaluation of the Isodata clustering on the buffered field pixel data with principal and diagonal axis procedures demonstrated that the diagonal axis method would be the method of choice in the study. Clustering with a higher convergence threshold (100%) and with more iterations (up to 100) for the JAS Area items produced better clusters than using the defaults. The seed tool (which adds spectrally similar adjustment pixels) was utilized to add additional Areas of Interest (AOI's) such as wooded, urban, clouded, and water (sewage plants, rivers, lakes, and kettle holes) land use categories. Land covers were clustered repeatedly to obtain the optimum number of classes for each of the commodity and land use types.

Once the optimum class size for each commodity and land class was derived, all of the resulting signature files were appended into one combined statistics file separability and contingency matrix analysis. Only clusters with small variances and covariences were included in the final selection of clusters and crops in the final combined statistics file. Each crop or grouped crop category would have generally from five to ten clusters. Consequently, the final crop classification file contained 112 clusters in total.

A preliminary supervised maximum likelihood classification of North Dakota only, and then of the entire scene provided an early opportunity to evaluated the accuracy of the classification using these initial clusters. An evaluation of ERDAS's accuracy assessment procedures suggested that using any of its randomly selected points parameters would not provide a complete or adequate evaluation of the classification accuracy from the ground sample information. Therefore, after consultations with ERDAS technical support, ERDAS's GIS analysis summary tool helped compute the percent correct by field. Rasterizing the JAS Area coverage using a lookup-table was necessary to compare the ground training information with the classified results. Printouts and text files giving counts of pixels classified into each cluster were created, and evaluated for accuracy. Examining the classified image showed that classification accuracies appeared higher than the initial overall accuracy of 74 percent for the buffered JAS Area fields with category 99 fields seems to suggest. However, later corrections on the location of JAS Area segments made further improvements of classifier accuracy from more accurate location of the JAS Area fields.

A trip to North Dakota allowed presenting to the North Dakota SSO the preliminary classification. The North Dakota SSO staff help identify some problem segments based on their familiarity with the terrain. Segment photos were used to check against the digital JAS Area fields to ensure correctness. Also, they added information about why various physical anomalies occurred in the JAS Area fields, along with a general description of the geologic and geographic features native to the study area (for example, wind breaks, kettle holes, rock piles, and drumlins).

Final Location of the JAS Area Segments within the TM data

Each JAS Area segment was relocated as accurately as possible within the TM data. The previously classified image was overlaid to help verify field boundaries, and commodity types, and eliminate fields that were cloud contaminated. Comments from the North Dakota SSO staff, along with editing the vector JSA Area coverage were helpful in accomplishing the final segment shifting. The relocated HAS Area segments were then buffered using the previously mentioned buffering technique, to create a new training data set.

The preparation and processing of South Dakota JAS Area segments underwent similar procedures as those necessary with the North Dakota JAS Area segments. The previous classification was used as an overlay to help in crop and field boundary identification. Extensive cloud coverage throughout the South Dakota study area required elimination of additional fields. After labeling field boundaries according to unique identifiers, no acreage checking was done on the South Dakota JAS Area coverage.

There were 55 South Dakota segments photographed, however, only ten segments had field information. The reason that South Dakota had fewer fields was that the South Dakota SSO had already started field boundary erasure, in preparation for the upcoming June Agricultural Survey, before they received the request for the segment data. As a result, there were 109 uniquely identified fields containing 120 polygons of which 117 were labeled good and three were labeled as category 99.

Final Clustering and Classification of the TM data

All the commodities and associated land-cover classes (for example, water) required the same clustering and classification procedures as before. Because South Dakota data contained few fields, a decision was made to use only the North Dakota JAS Area data for both training and test while the South Dakota data was designated as test data only. FSA data was not used for training because early classifications of the FSA data did not exhibit accurate classification.

Running the clustering of the data required over a week full time on a SUN SPARCStation 10[6]. All commodities required multiple clustering runs to find the optimum class size because many initial clusters had large variances. Not eliminating clusters and not merging clusters seemed to give the greatest percent correct if enough clusters had been chosen. The various signature files were appended into one file, so that all signatures of the different crops and AOI's were together.

The urban class included some clusters from the cloud class, so a combined cloud/urban class was created. Each image was clustered separately into 80 spectral classes to separate cloud classes from urban areas. The pixels defined as clouds by clustering within each images were combined to create a final cloud mask overlaid onto the final classified image.

After examining percent corrects for various methods, not eliminating cluster classes provided the greatest classification accuracy of 88.4 percent overall for the buffered North Dakota JAS Area fields without category 99. This result was a 14 percent overall improvement in classifier accuracy for the adjusted segment locations. An evaluation of other data sets' accuracy will follow.

Classification Accuracy Assessment

Using the previously discussed GIS analysis summary tool, accuracy assessment was again done by commodity and other land uses. A FoxPro 2.5[7] program was created to process these files into conventional contingency matrices. Finally, Lotus 123[8] helped to use these files to calculate per cent corrects, Kappa statistics (Gong and Howarth, 1992), and commission errors (defined as the following:)

((Total Pixels classified to Crop) - (Pixels Correctly Classified to Crop))/(Total Pixels Classified to Crop) (1) for each category and Overall Kappa and Percent Correct for all crops combined.

These methods made possible the following tables giving the number of pixels classified by cluster for North Dakota JAS Area segments for fields defined in the following ways:

(1) Buffered fields with category 99 fields,
(2) Buffered fields without category 99 fields,
(4) Full fields without category 99 fields, and
(3) Full fields with category 99 fields (see Tables 1.1 and 1.2).

Tables for the number of pixels classified by crop for each of the following South Dakota JAS Area fields are the following:

(1) JAS Area full fields with category 99 fields, and
(2) JAS Area buffered fields without category 99 fields (see Tables 2.1 and 2.2).

Additional tables give the number of pixels classified by cluster for the following:

(1) FSA fields buffered with category 99 fields,
(2) FSA buffered without category 99 fields (see Tables 3.1 and 3.2)
(3) Water, Woods, Clouds, and Urban category AOI's (see Tables 4.1 and 4.2).

To create the tables listed above combining some crop information. The miscellaneous crop category consists of cropland pasture, mustard seed, rye, and sugar beets. Because the miscellaneous crop category had so few pixels in the training data, there are no clusters for this category in the final statistics file. Grains contain alfalfa, barley, hay for grain, and oats. Non-AG is more a land-use category than a crop so that all pixels categorized into water, wood, cloud, and urban were combined into the Non-AG crop category with land designated as Non-AG. Finally, since neither winter wheat nor potatoes had sufficient training data in this area, RSS combined potatoes and winter wheat into the winter wheat column of the tables although they are very different crops.

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[6] Sun Microsystems, Inc., Mountain View, CA

[7] Microdoft, Seattle, WA

[8] Lotus Development Corporation, Cambridge, MA

Comments on Classification Accuracy

Tables 1.1 and 1.2 give the classification accuracy of the classifies as given by all pixels in the training set, including the boundary pixels of fields and fields that were questionable, because of clouds or inaccurate digitized acreage. Even under this hindrance, the classifier shows three crops with Kappa accuracies greater then 80% (dry beans, spring wheat, and corn) and two crops better than 70% (sunflower and soybeans). Although these tables show accuracy on classification of the same fields used in training, the inclusions of the boundary and questionable pixels give a realistic appraisal of the accuracy obtained outside the segments. The appearance of the classified image also shows well-defined fields and logical transitions between crop and noncrop areas. Spring wheat was the crop of interest with low commission errors. The greatest errors for spring wheat occurred when some fields of other small grains (the category Grains) were categorized to spring wheat. This error in classification is understandable since spring wheat is both visually and spectrally close to the Grain category.

Tables 2.1 and 2.2 give the classification accuracy for the buffered field information (with category 99 fields) for those South Dakota segments for which field information was available. Buffered field data will exclude boundary pixels where errors are more likely in classification because of grasses at the field edge, roads, and other noncrop ground cover. Other researchers have noted boundary pixel problems (Grumblatt, 1987), so reporting field accuracies should relate to classification accuracies for other fields outside the areas of ground information. Boundary pixels will be more variable in their accuracies (reported at 40 to 60% classification error).

Surprisingly, for one crop, corn, the Kappa accuracy is higher than for the training set at 91.1%. This accuracy is much greater than for the North Dakota corn accuracy at 83.3%. The spring wheat kappa is nearly 9% less at 72.7% with the commission error of 54.0% caused by the large number of pixels of grain that are incorrectly called spring wheat.

Finally, the FSA data given in Tables 3.1 and 3.2 are the second set of data showing classification accuracy for fields not contained in the training set. Clearly, the accuracies of classification are significantly less than for the training fields for Non-AG, permanent pasture, dry bean, fallow, winter wheat, and grains. However, kappas for corn, soybeans, and sunflower, through lower, are still comparable. Finally, spring wheat shows a kappa at 84.9% that is larger than the kappa of 81.9% on the training fields. Clearly, spring wheat continues to show high accuracy on these test fields. This accuracy of classification is even more impressive since the FSA field data had no ground verification. Of course, as with the South Dakota data, these buffered fields excluded boundary field data that would increase accuracies over full field data.

The accuracy results vary significantly from the training set, FSA data, and the South Dakota segments. However, in all three cases, the crop of interest, spring wheat, is clearly highly accurate at a kappa of at lease 72.7%. Clearly, the use of four dates of TM data has helped to resolve spring wheat from other crops with sufficient accuracy to make accurate maps of spring wheat locations. Corn, soybeans, and sunflowers are three other crops that seem to have sufficiently accurate classification accuracy to provide mapping of their fields.

The accuracies for other crops are not as promising for accurate mapping. Nonagricultural land, permanent pasture, and fallow are really more land use descriptions rather than clearly defined crops, so lower mapping accuracies for these land uses are not surprising. Winter wheat was mixed with potatoes since neither crop has enough pixels in the training or test data to evaluate these crops fully. Finally, dry beans had high accuracy for the training set, but the FSA data set did not corroborate this accuracy.

Accuracies of the crop classification shows that at least four crops have acceptable accuracies for mapping. Besides crops, another concern is that of the water, woods, clouds, and urban areas. Tables 4.1 and 4.2 show the accuracies of classification for these categories. These AOI's contained over 600,000 pixels of training data for these categories. Errors of classification to crop categories were so small that incorrectly categorized pixels are simply summed into the totals and excluded from the tables. Urban areas had a 60% accuracy because clouds were often in the urban areas and the urban areas were more reflective. Their high reflectivity made urban areas more easily confused with clouds without the thermal channels to help in differentiating them. These two categories were the only categories for which thermal information would have been helpful.

Water, woods, and clouds have very Kappas in the upper 90% range showing that few classifier errors were made with these categories. Water is usually a distinct signature since its values are very much different from any crop or other land-associated land-cover. Four-overpass dates clearly made areas with water spectrally separate from other categories.

Classification Maps for North and South Dakota

ARC/INFO provide the capability to make county prints of the classified TM data, since RSS's Calcomp[9] printer did not yet support ERDAS's print drivers. Figures 3, 4, and 5, respectively, show eight category greyscale prints for North Dakota counties Ransom, Sargent, and Richland. Clearly, the segment maps shows well-delineated field boundaries, and a highly accurate classification of spring wheat. The county maps also show a distinct field pattern of crops. The presence of field patterns gives further confirmation that this classification is highly accurate.

Ransom county has a much larger portion consisting of nonagricultural land and pasture land with an interpenetrating mixture of spring wheat and sunflower fields to the north and south of the Sheyenne River that runs from the Northwest to the Southeast of the county. The western portion of the county has irrigated corn fields (seen as circular pivots) and a mixture of spring wheat, sunflower, and idle cropland (seen in the available 14 category color map).

Sargent county has primarily interspersed spring wheat, soybeans, and sunflower fields. The southwestern corner is primarily nonagricultural land and pasture land. also, Sargent County has a very extensive network of small and larger sized kettle holes. These kettle holes appear as dark water areas in many fields and are so prevalent that they appear to give a mottled appearance to the county. Because of the prevalence of such small bodies of water, often an acre or two in size, the first reaction might be that they are classification errors. However, the high accuracy of the water category as shown in Tables 4.1 and 4.2 clearly shows that this possibility is not so here.

Richland county, shows that the eastern third of the county contains primarily interspersed soybeans and spring wheat fields. As we go to the west, this field pattern changes to a mixture of interspersed spring wheat and corn fields. The southern part of the county varies east to west from a mixture of spring wheat and soybeans fields in the east, to primarily corn fields, and finally to a primarily spring wheat area in the southwestern part of the county.

Possible Uses of the Categorized Imagery

Besides using categorized TM imagery to classify AVHRR data for the State of North Dakota, the categorized TM scene could be used to update North Dakota's area frame. Other researchers (Mattikalli, 1995) have examined the use of vector-based geographical information systems for land-use change detection. This image classification raises the possibility of using ERDAS to generate an updated area frame for this area in North Dakota. The earlier vector based area frame for North Dakota dates to 1977 and so may need updating. Also, use of categorized Landsat TM imagery could create a special-use crop specific stratification to improve acreage estimates of the chosen crop. Crop acreage estimation for counties is also a possibility, but will require additional development work to achieve in ERDAS.

Weather researchers have expressed an interest in crop specific land cover as well. The potential exists for weather information to be tailored to specific areas or crops. Using the crop specific land cover maps, predicting the impact of weather on crops might be accomplished by using real-time weather information. Weather updates could be broadcast on radio and television (Beard 1996).

CONCLUSIONS

Spring wheat and small grains (alfalfa, barley, hay for grain, and oats) are difficult crops to classify using one and two date overpass Landsat TM data. However, four dates of TM imagery without the thermal channel do seem to have potential in separating spring wheat and four other crops (corn, dry beans, soybeans, and sunflower) sufficiently for mapping purposes. Although mapping accuracy of 85% correct is a generally considered minimum, this study had ground data not used in training to evaluate the classifier accuracy. Therefore, using a 75% Kappa accuracy seemed sufficient for accurate mapping potential. Had imagery dates that could better separate the crops been available (particularly, August), then better accuracies may have been obtained. Of course, evaluation of the ground data for errors during data collection would have helped as well. Many classifier errors included in the table could be attributed to the assumption that field data was accurate when there were many instances when the field data was probably incorrect. Excluding questionable fields and field boundaries would show accuracies for the field interiors to be much higher that shown in Tables 1.1 and 1.2. Such tables were calculated, but not included.

The North and South Dakota SSO's will continue evaluation of the county printouts for accuracy for field classification. Results from those evaluations should suggest further improvements to achieve improved classification

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9 Calcomp. Inc., Anaheim, CA

accuracy in future studies.

This image classification raises the possibility of using ERDAS to update the area frame in North Dakota since the current area frame for North Dakota dates to 1977. Also, use of categorized Landsat TM imagery would make possible creation of special use crop specific stratification to improve acreage estimates of the chosen crop. Finally, whether information could be targeted to areas where specific crops would be affected by the impending weather events.

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TABLE 1.1. Error Matrix for Four Date TM Classification of North Dakota Full JES Fields With Bad Fields, With Ten Categories and Miscellaneous

	G	C	NA	F	PP	DB	SB	SW	SF	WW	T
G	4,888	315	2,242	76	176	0	339	4,089	408	106	**12,639**
C	396	11,387	492	94	26	4	380	637	229	112	**13,757**
NA	374	1,195	3,693	646	1,076	2	675	1,317	367	96	**9,441**
F	270	331	1,458	4,436	850	0	212	390	110	87	**8,144**
PP	180	66	3,317	238	7,689	0	55	376	22	80	**12,023**
DB	27	19	8	1	0	1,274	116	16	6	8	**1,475**
SB	326	301	345	57	49	125	7,573	714	277	115	**9,882**
SW	314	530	1,501	244	131	47	542	28,054	653	143	**32,159**
SF	542	348	1,177	135	52	0	283	435	11,226	68	**14,266**
WW	2	26	117	0	23	0	8	89	10	17	**292**
M	171	41	357	20	287	3	19	118	270	141	**1427**
T	**7,490**	**14,559**	**14,707**	**5,947**	**10,359**	**1,455**	**10,202**	**36,235**	**13,578**	**973**	**115,505**

NOTE: Crops are as follows: Grains (G), Corn (C), Non-Agricultural Land (NA), Fallow (F), Permanent-Pasture (PP), Dry Beans (DB), Soybeans (SB), Spring Wheat (SW) Sunflower (SF), Winter Wheat (WW), Miscellaneous (M), and Total (T).

TABLE 1.2 Kappa, Percent Correct, and Commission Errors for the Crops in TABLE 1.1.

	KAPPA	PERCENT CORRECT	COMMISSION ERROR
GRAINS	34.4%	38.7%	34.7%
CORN	80.3%	82.8%	21.8%
NON-AG	30.2%	39.1%	74.9%
FALLOW	52.0%	54.5%	25.4%
PMNT-PAST	60.4%	64.0%	25.8%
DRY BEANS	86.2%	86.4%	12.4%
SOYBEANS	74.4%	76.6%	25.8%
SPRING-WHEAT	81.4%	87.2%	22.6%
SUNFLOWER	75.9%	78.7%	17.3%
WINTER WHEAT	5.0%	5.8%	98.3%
OVERALL	**63.9%**	**69.5%**	

TABLE 2.1. Error Matrix for Four Date TM Classification of South Dakota Buffered JES Fields With no Bad Fields, With Eight Categories and Miscellaneous

	G	C	NA	F	PP	DB	SB	SW	SF	WW	T
G	524	85	507	35	421	0	51	1,040	133	26	2,796
C	8	2.447	66	5	1	0	21	49	64	9	2,661
NA	24	25	320	16	178	0	11	14	19	2	607
F	180	66	1,400	114	420	0	46	242	25	3	2,493
PP	598	48	6,411	154	5,996	0	16	497	14	89	13,734
SB	572	12	119	2	0	0	753	3	13	12	1,474
SW	2	4	354	2	94	0	43	1,620	7	11	2,126
SF	68	60	366	13	2	0	105	58	1,227	1	1,899
T	**1,976**	**2,747**	**9,543**	**341**	**7,112**	**0**	**1,046**	**3,523**	**1,502**	**153**	**27,790**

NOTE: Crops are as follows: Grains (G), Corn (C), Non-Agricultural Land (NA), Fallow (F), Permanent-Pasture (PP), Dry Beans (DB), Soybeans (SB), Spring Wheat (SW) Sunflower (SF), Winter Wheat (WW), Miscellaneous (M), and Total (T).

TABLE 2.2 Kappa, Percent Correct, and Commission Errors for the Crops in TABLE 2.1

	KAPPA	PERCENT CORRECT	COMMISSION ERROR
GRAINS	12.7%	18.7%	73.5%
CORN	91.4%	92.0%	10.9%
NON-AG	28.4%	52.4%	96.6%
FALLOW	3.4%	4.6%	66.6%
PRMNT-PA	24.7%	43.7%	15.7%
SOYBEAN	49.6%	51.1%	28.0%
SP-WHEAT	73.2%	76.2%	54.0%
SUNFLOW	63.0%	64.6%	18.3%
OVERALL	**36.2%**	**46.8%**	

TABLE 3.1 Error Matrix for Four TM Classification of North Dakota Buffered CFSA Fields, With No Bad Fields, With Ten Categories and Miscellaneous

	G	C	NA	F	PP	DB	SB	SW	SF	WW	P	T
G	1,592	125	347	48	45	0	146	2,687	604	0	27	**5,621**
C	255	9,262	384	113	105	0	484	468	744	0	359	**12,174**
NA	0	0	0	0	0	0	0	0	0	0	0	**0**
F	1	0	15	1	0	0	4	145	2	0	7	**175**
PP	0	0	0	0	0	0	0	0	0	0	0	**0**
DB	174	136	85	672	8	0	378	415	87	0	257	**2,212**
SB	436	959	706	24	2	18	6,747	314	831	0	25	**10,062**
SW	247	137	577	146	105	3	382	17,362	127	0	107	**19,193**
SF	297	318	500	160	45	0	217	544	6,628	0	60	**8,769**
W W	0	0	0	0	0	0	0	0	0	0	0	**0**
P	0	0	1	0	0	0	0	0	0	0	1,031	**1,032**
T	**3,002**	**10,937**	**2,615**	**1,164**	**310**	**21**	**8,358**	**21,935**	**9,023**	**0**	**1,873**	**59,238**

NOTE: Crops are as follows: Grains (G), Corn (C), Non-Agricultural Land (NA), Fallow (F), Permanent-Pasture (PP), Dry Beans (DB), Soybeans (SB), Spring Wheat (SW) Sunflower (SF), Winter Wheat (WW), Miscellaneous (M), and Total (T).

TABLE 3.2. Kappa, Percent Correct, and Commission Errors for the Crops in TABLE 3.1.

	KAPPA	PERCENT ERROR	COMMISSION ERROR
GRAINS	24.5%	53.0%	47.0%
CORN	70.7%	84.7%	98.9%
NON-AG		0.0%	100.0%
FALLOW	0.0%	0.1%	99.9%
PRMNT-PA		0.0%	100.0%
DRY BEANS	0.0%	0.0%	100.0%
SOYBEAN	61.6%	80.7%	19.3%
SP-WHEAT	84.9%	79.2%	20.8%
SUNFLOW	71.2%	73.5%	26.5%
WINTER WHEAT		0.0%	0.0%
POTATOES	99.9%	55.0%	45.0%
OVERALL	**64.5%**	**72.0%**	

TABLE 4.1. Error Matrix for Four TM Classification of North Dakota, Water (W), Woods (W), Clouds (CL), and Urban (U) Categories

	W	WD	CL	U	O	T
W	41,148	0	13	0	345	**41,506**
WD	40	6,403	0	12	96	**6,561**
CL	110	0	569,770	639	405	**570,924**
U	23	19	3438	5,344	257	**9,081**
T	**41,321**	**6,432**	**573,221**	**5,995**	**1,103**	**628,072**

NOTE: Water, Woods, Clouds, and Urban categories were the only categories in this AOI. Pixels incorrectly classified to crops are included in the totals only.

TABLE 4.2. Kappa, Percent Correct, and Commission Errors for the Crops in TABLE 4.1.

	KAPPA	**PERCENT CORRECT**	**COMMISSION ERROR**
WATER	100.0%	99.1%	1.2%
WOODS	99.2%	97.7	1.8%
CLOUDS	98.5%	99.8%	0.7%
URBAN	60.2	58.3	14.5%
OVERALL	**94.8**	**99.1%**	

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