COMPARING 30 METER IMAGERY FROM LANDSAT 5 AND 7 FOR CROP AREA ESTIMATION

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ABSTRACT

This paper compares digital, multi-spectral imagery from the Landsat 5 Thematic Mapper with that of the Landsat 7 Enhanced Thematic Mapper when used to discriminate crop types for area estimation. Comparisons are done for different types of crop areas in several states, using images that are only one day apart. The overlaps between adjacent paths in several major crops states are used to define the analysis areas. A simple non-parametric paired sample sign test is used to determine statistical significance of differences. Standardized techniques as used in the Agency's Cropland Data Layer Project are used for image processing, including a modified supervised pattern recognition /clustering approach for cover type signatures and maximum likelihood for categorization. Ground truth data consist of 211 one and two square mile areas selected in a stratified random sample and visited in June of the corresponding crop year. Sampling rates for the ground data range from one in 30 to one in 166 depending on the state and land use stratum.

INTRODUCTION

The National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture has used digital multi-spectral satellite imagery since the 1970's to aid in the acreage estimation of large area crops in major producing states. Early research and later operational NASS remote sensing programs used imagery from the Landsat multi-spectral scanner instruments until the late 1980's; research on the Landsat Thematic Mapper started in 1986 and it was adopted for operational acreage estimation use in 1991. The current NASS Remote Sensing Acreage Estimation Program (Craig 2001b) encompasses Landsat-based major crops estimates at the state and county levels plus digital Cropland Data Layer GIS products for six major crop producing states. Numerous documents about the history of this Program are included in the References section.

Landsat Digital Imagery

Two Landsat satellites are currently operational; Landsat 5 with the Thematic Mapper (TM) sensor, and Landsat 7 with a somewhat upgraded Enhanced Thematic Mapper (ETM) sensor. Imagery from both sensors was at 30 meter resolution, and delivered in the UTM coordinate system. Landsat data from both sensors is obtained through a cooperative agreement with the USDA Foreign Agriculture Service (Bethel and Doorn 1998). The polar orbits of these two satellites are controlled to give eight day coverage to any area from one of the sensors. The eight day repeat coverage is very important to any vegetation related remote sensing analysis, and is particularly important for real time, within season crop acreage and or yield estimation. Crop types are distinguishable from each other for only a short period during the crop season, and thus have a very limited number of chances to be covered by cloud-free satellite imagery.

There is a side by side overlap of approximately 30 percent of a scene between adjacent paths of the satellites; this overlap can be covered by scenes (one from each satellite) that are one day apart. This research compares the two types of digital imagery using only the areas in the overlap of scenes separated by one day. These overlap areas define ‘analysis districts’ which will be processed the same way for each Landsat satellite sensor; highlights of the image processing and estimation methodology will be discussed in a later section.

Ground Truth Data

Ground truth for the Remote Sensing Acreage Estimation Program comes from a pre-existing Agency nationwide survey program, called the June Agricultural Survey (JAS). One part of the JAS utilizes an area frame to select areas of land, called segments, for field visits. The area frame for a given state is a land use stratification of the state based on percent cultivation of crops. The sample is randomly drawn by strata, with an emphasis toward minimizing the variances of major crops and livestock estimates. For the 2001 crop season, sample sizes ranged from 260 in Indiana to 452 in Iowa for our six Program states. Segments are visited in early June, with data collected directly from personal contacts with farmers. The size of an individual segment is approximately one square mile in high percent cultivation strata, larger in less cultivated but open area strata, and small in urban areas. Field boundaries are drawn on black and white aerial photo enlargements of the segment area, and later entered into digital form and geo-registered to a Landsat scene in the NASS field office. It should be noted here that crops estimates at the state (but not county) level can be produced using only the ground survey data without the application of remote sensing imagery. Table 1 below gives an idea of the normal sampling rates for the states involved in this analysis, plus the number of samples actually used. Two states have two analysis districts (AD's) included, the same center scene with an overlap area on each side.

Table 1. Area frame description and sampled segment* information for overlap areas.

State	Year	Strata	Strata Percent Cultivated	State Number Segments	State Selected Segments	State Expansion Factor	Seg's in First AD	Seg's in Second AD
Arkansas	1999	11	76-100	11673	260	45	80	n/a
	"	21	25-75	2718	24	113	5	n/a
Mississippi	1999	11	76-100	3875	40	39	7	n/a
	"	20	15-50	16003	78	82	8	n/a
North Dakota	1999	11	76-100	29271	231	127	23	19
	"	12	51-75	7469	90	83	10	13
	"	20	15-50	7990	85	94	15	20
	2000	11	76-100	29271	231	127	15	n/a
Iowa	2000	13	76-100	43415	378	115	38	48
	"	20	25-75	10963	66	166	10	n/a

* **Note:** Average segment sizes for strata 12 and 20 in North Dakota are 2 square miles each, all other state/strata combinations shown in this analysis average 1 square mile each.

Analysis Districts

Seven analysis districts (AD's), based on path overlap regions and one day date differences, were selected from the 1999 and 2000 crop year estimation analyses. These AD's offer a selection of most major crops and crop producing regions, with the exception of the winter wheat great plains states. Four states (and eight crops) were selected: North Dakota (barley, canola, sunflower, all wheat, and all small grains), Arkansas (rice, cotton, soybean), Mississippi (cotton and soybean), and Iowa (corn and soybean). Note that 'all small grains' includes all wheat, barley, oats, and rye for the purposes of this analysis. Table 2 shows the states, imagery dates, imagery path/row locations and number of segments used in the comparisons.

Table 2. Definitions and specifications of analysis districts

AD	State	Project	Crops	Number Segments	TM Path/Row(s) Overpass Date	ETM Path/Row(s) Overpass Date
1	Arkansas	AR99	Rice, Cotton, Soybean	85	P:23 R:35,36,37 August 13, 1999	P:24 R:35,36,37 August 12, 1999
2	Mississippi	MS99	Cotton, Soybean	15	P:23 R:36 July 28, 1999	P:22 R:36 July 29, 1999
3	North Dakota	ND99	All Wheat, All Small Grains	52	P:34 R:26,27,28 July 25, 1999	P:33 R:26,27,28 July 26, 1999
4	North Dakota	ND99	Sunflower, All Wheat, All Small Grains	48	P:32 R:26,27,28 July 27, 1999	P:33 R:26,27,28 July 26, 1999
5	North Dakota	ND00	All Wheat, Canola, Barley	15	P:32 R:26 August 14, 2000	P:31 R:26 August 15, 2000
6	Iowa	IA00	Corn, Soybean	48	P:27 R:30,31,32 August 11, 2000	P:26 R:30,31,32 August 12, 2000
7	Iowa	IA00	Corn, Soybean	48	P:27 R:30,31,32 August 11, 2000	P:28 R:30,31,32 August 10, 2000

HIGHLIGHTS OF IMAGE PROCESSING AND ESTIMATION METHODOLOGY

The current NASS system for processing satellite remote sensing data and the statistical methodology used for estimation of crop acreage was discussed in detail in the ASPRS 2001 proceedings (Craig 2001a). This section presents the highlights of these procedures for review.

Software and Hardware

NASS uses the PEDITOR software system (Ozga 1995,2000) to process Landsat digital imagery on high-end desktop computers using the Windows NT operating system. There is usually at least one dual processor Win NT computer at each site for large volume batch processing. PEDITOR is an in-house created and maintained software system of over 100 program modules, some of which are expert systems designed to automate parts of the process by running other modules in sequence. There is one main difference between this software and commercial software: the regression analysis procedure and its concept of a segment as a clustered sample (as opposed to just as individual fields for training) from a specific stratum.

Imagery Import and Review of Sample Segments

Location and review of sampled areas in the current years imagery starts with the reformatting (import) of selected imagery into PEDITOR format. NASS uses all seven Landsat TM and/or ETM bands for training and classification. Where available, multi-temporal (two date) imagery is created using an automated block correlation approach. Segment and internal field boundaries are overlaid on the new imagery, and are reviewed on a field by field basis to identify any ‘bad’ fields where the reported data does not match the information seen in the digital satellite imagery. This process includes such things as cropland already harvested, poor crop stands, cloud and haze affected areas, poorly drawn boundaries, and areas where the planted cover observed during enumeration does not match the farmer reported cover. Fields with problems that cannot be corrected are identified and later marked as ‘bad for training’. Cloud affected segments are removed from consideration with respect to the specified scene.

Training the Classifier Based on Known Sample Information

The NASS automated procedure uses a modified supervised approach in the creation of cover type signatures. In this approach interior (non-boundary) pixels from known fields, not labeled as bad for training, are sorted according to cover type into separate files. Using a principle components analysis, additional outlier pixels are deleted ('clipped') from the files (Winings, 1990). Each updated file is then clustered, using a modified ISODATA algorithm which allows cluster splitting and merging (Bellow, 1991a). A similar process is used to cluster 'extra' cover types, such as clouds, urban, and deep water. The resultant signature statistics for clusters from all cover types are then combined into one statistics file for input to the maximum likelihood classifier. All available known pixels from the sample segments are categorized using this classifier for regression analysis.

Evaluation of the Maximum Likelihood Classifier

Several statistics are calculated for evaluation of the classifier. Known pixels are tabulated comparing ground truth labels with the category assigned during classification. Percent correct, commission errors, and kappa coefficients are calculated automatically from the tabulation. These statistics are calculated (and reported) based on the 'not bad for training' set of known pixels from the segments. A field by field analysis is also performed to check which signatures cause the most classification errors. Another module calculates regression coefficients by crop/cover type for farmer reported versus categorized data at the segment level. Segments identified (by the software) as regression outliers can be reviewed and deleted from the analysis for final estimation purposes. Table 3 below shows percent correct and kappa comparisons over all cover types plus the number of signatures used in the final classification.

Table 3. Overall Percent Correct and Kappa Statistics

State	AD	Sensor	Percent Correct	Kappa	# Signatures with 'extra'	#Signatures from Seg's
AR99	1	ETM+	75.46	67.94	103	83
AR99	1	TM	79.97	73.42	107	73
MS99	2	ETM+	92.49	90.77	87	36
MS99	2	TM	93.43	91.97	56	23
ND99	3	ETM+	62.83	51.13	137	106
ND99	3	TM	58.91	46.53	118	102
ND99	4	ETM+	61.97	48.58	95	95
ND99	4	TM	63.80	52.13	93	93
ND00	5	ETM+	82.01	77.85	27	23
ND00	5	TM	79.67	75.22	57	25
IA00	6	ETM+	88.81	84.29	44	44
IA00	6	TM	88.67	83.99	39	39
IA00	7	ETM+	96.26	93.49	51	51
IA00	7	TM	96.29	93.54	40	40

Estimation

Full scene classifications provide the last piece of the estimation process. The classification output is summarized based on land use strata and boundaries from the area sampling frame. A regression estimation approach is then applied, using classified pixels as the auxiliary variable and farmer reported acres as the dependent variable in a set of area frame stratum based simple linear regressions. The county and state crop acreage estimates produced by this system greatly reduce the sampling variation ('error') found in the estimates produced by the ground data alone; and have the added benefits of producing county estimates with measurable precision. Table 4 below displays the various statistics available to compare at the crop type level. Regression line slopes were also calculated, but are not shown in the table. In order to compare data with the least possible analyst interference, no segment outlier analysis was performed on any of the AD's. No Kappa statistics were available for the grouped categories (all wheat and all small grains) due to software limitations.

Table 4. Percent correct and combined strata regression R-squared statistics by crop type

State	AD	Crop Type	Sensor	Percent Correct	Commission Error	Kappa*	Combined R-squared
AR99	1	Cotton	ETM+	90.25	29.78	89.53	.926
AR99	1	Cotton	TM	90.72	13.15	90.17	.909
AR99	1	Rice	ETM+	96.17	15.74	94.34	.865
AR99	1	Rice	TM	90.92	9.19	87.32	.858
AR99	1	Soybean	ETM+	71.07	7.15	57.99	.673
AR99	1	Soybean	TM	78.50	8.61	67.05	.624
MS99	2	Cotton	ETM+	97.09	6.29	96.28	.770
MS99	2	Cotton	TM	96.59	10.98	95.61	.609
MS99	2	Soybean	ETM+	95.28	3.95	93.26	.424
MS99	2	Soybean	TM	90.60	2.71	87.00	.299
ND99	3	All Wheat	ETM+	69.58	23.78	n/a	.621
ND99	3	All Wheat	TM	63.64	33.19	n/a	.527
ND99	3	Small Grains	ETM+	73.88	22.37	n/a	.753
ND99	3	Small Grains	TM	73.23	28.21	n/a	.655
ND99	3	Sunflowers	ETM+	93.46	3.04	93.37	.985
ND99	3	Sunflowers	TM	87.51	8.54	87.32	.973
ND99	4	All Wheat	ETM+	38.10	25.66	n/a	.609
ND99	4	All Wheat	TM	36.02	27.73	n/a	.546
ND99	4	Small Grains	ETM+	51.81	24.78	n/a	.768
ND99	4	Small Grains	TM	44.35	25.91	n/a	.643
ND99	4	Sunflowers	ETM+	46.09	32.48	44.77	.644
ND99	4	Sunflowers	TM	66.07	41.79	64.70	.707
ND00	5	All Wheat	ETM+	83.46	6.60	n/a	.022

State	AD	Crop Type	Sensor	Percent Correct	Commission Error	Kappa*	Combined R-squared
ND00	5	All Wheat	TM	76.24	4.24	n/a	.515
ND00	5	Barley	ETM+	90.62	18.78	87.13	.098
ND00	5	Barley	TM	93.00	23.03	90.04	.487
ND00	5	Canola	ETM+	91.59	6.23	90.85	.874
ND00	5	Canola	TM	92.68	23.56	91.86	.730
IA00	6	Corn	ETM+	97.96	3.69	96.55	.887
IA00	6	Corn	TM	96.63	5.04	94.25	.832
IA00	6	Soybean	ETM+	98.99	1.29	98.52	.924
IA00	6	Soybean	TM	98.96	2.16	98.49	.903
IA00	7	Corn	ETM+	96.82	2.76	93.62	.705
IA00	7	Corn	TM	97.27	2.06	94.57	.618
IA00	7	Soybean	ETM+	98.04	0.90	96.68	.846
IA00	7	Soybean	TM	98.08	2.22	96.71	.882

* No Kappa statistics were available for the grouped categories: all wheat and all small grains.

COMPARISON OF STATISTICS FOR LANDSAT 5 TM AND LANDSAT 7 ETM

Statistical comparisons in this analysis consist of simple, non-parametric sign tests (Siegel 1956)since the data are all based on paired samples (ETM+ versus TM for the same areas), and there are not enough pairs to assume normal distributions for paired ‘t’ tests. Under the sign test, the null (H_0) hypothesis is that the median difference between ETM+ and TM is zero, with a two sided alternative (H_A) hypothesis that it is non-zero. Critical values for the sign test are based on the binomial probability function.

Hypothesis Tests

This set of hypotheses was tested for percent correct (by crop type and overall), commission error (by crop type), kappa statistic (by crop type and overall), and combined strata r-squared. For the percent correct and kappa statistics, both by crop type and overall, there was no reason to reject the H_0 of the median difference between TM and ETM+ being zero. However, the same tests, using commission error and combined r-squared do show a significant difference at the 5% level. Table 5 below shows the sign test values associated with these tests. Although not shown in this paper, comparisons were also done using only large analysis districts, as defined by those analysis districts with 45 or more segments. The sign test results for the large AD only analyses mirrored the ‘all AD’ results shown in Table 5. Also considered were number of signatures created from the segment data, both at the AD level, and by crop. The differences using number of signatures were not significant for either AD level or by major crop type.

Table 5. Sign Test Results

Variable	Summary Level (Within AD)	(+) ETM+ > TM	(-) TM > ETM+	Significant at P=X%
Percent Correct	Overall Cover Types	3	4	n/s
Kappa	Overall Cover Types	3	4	n/s
Percent Correct	Major Crop Type	11	7	n/s
Commission Error	Major Crop Type	5	13	10%
Kappa *	Major Crop Type *	6	7	n/s
Combined Regr. Slope	Major Crop Type	6.5	11.5	n/s
Combined R-Squared	Major Crop Type	14	4	5%
Slope Single Regression	Major Crop & Stratum	18	20	n/s
R-Squared Single Regr.	Major Crop & Stratum	29	9	5%

* No Kappa statistics were available for the grouped categories: all wheat and all small grains.

CONCLUSION

The importance of the Landsat 5 TM sensor is that it allows an eight day repeat coverage for imagery acquisition. This fact is particularly important for crop area estimation, because most intensively cultivated areas have cloud cover problems. You might think of this as the relationship between intensive cultivation and rain fed cropping practices. Half of the NASS statewide analysis would be missing if not for the presence of Landsat 5 TM.

Percent correct related statistics are important for 'map' and visual image creation, such as for the Cropland Data Layer distributed by NASS. These statistics include percent correct, commission error, and kappa coefficients. Although the commission error statistics are different, this measure is usually considered only a complement to the percent correct, and not as a stand-alone statistic. Considering only the visual side of remote sensing based outputs, the two sensors would not be significantly different.

However, the r-squared and slope statistics are more important when the aim is to produce crop acreage indications (estimates) as these are directly related to the standard error of the estimates. The slope statistics are not significantly different between the two sensors, but the r-squared regression statistics are significantly different. The r-squared significant differences are perhaps the result of the better commission errors, but for whatever reason, the differences are small but significant. Under the acreage estimation scenario, the ETM+ data seems to be slightly better, and given a choice of similar dates between the two sensors, the ETM+ should be used. An interesting point to consider is how close in performance the data from Landsat 5 TM, launched in March 1984, is to the data from the Landsat 7 ETM+ sensor, launched in April, 1999.

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