IMPROVED CROP AREA ESTIMATION IN THE MISSISSIPPI DELTA REGION USING LANDSAT TM DATA

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ABSTRACT

The USDA National Agricultural Statistics Service (NASS) used Landsat Thematic Mapper (TM) imagery to estimate planted acreage of major crops in Arkansas and Mississippi during the 1991 crop season. The Mississippi River Delta region of those two states is an important cotton and rice producing area. Ground data from NASS's June Agricultural Survey were edited and geo-referenced to TM data using digitization and registration procedures. Due to cloud cover and scene availability factors, the Landsat coverage area was divided into multitemporal and unitemporal analysis regions. Counts of pixels classified to specific crops were used as ancillary data in a regression formulation. Acreage indications were generated at the state and county levels. In both Arkansas and Mississippi, the state level TM based indications of cotton, rice, and soybean acreage were more efficient than corresponding estimates computed from ground data alone. The county level indications were consistent with official estimates from recent years. The results were submitted to NASS's Agricultural Statistics Board and to the State Statistical Offices in Arkansas and Mississippi. Color maps showing locations of specific crops within counties were also produced.

INTRODUCTION

The National Agricultural Statistics Service (NASS) in 1991 used Landsat Thematic Mapper (TM) data in conjunction with ground survey data to estimate planted acreage of major crops in Arkansas and Mississippi. This project represented the Agency's first operational use of TM data for crop area estimation. In late 1991, state level Landsat indications of cotton, rice, and soybean planted acreage were submitted to NASS's Agricultural Statistics Board (ASB), which sets the final national estimates, and to the State Statistical Offices (SSO's) in Arkansas and Mississippi. In early 1992, the two SSO's were provided with county level crop acreage indications and color maps showing locations of specific crops within counties.

The Mississippi River Delta region is the most important rice producing area in the United States and is also a major cotton producing area. The region, which includes all or part of five states, accounted for 76 percent of U.S. planted rice acreage and 29 percent of U.S. planted cotton acreage in 1991 (U.S. Department of Agriculture, 1992). Arkansas was by far the major rice state with 46 percent of the 1991 national total, while Mississippi was second to Texas with 9 percent of the 1991 national cotton total.

The Delta region provides an ideal setting for the use of remote sensing based estimation techniques. NASS's current general purpose area sampling frame is not designed for crops that are localized in specific areas. This condition leads to high state level relative sampling errors for crops such as cotton and rice. The Delta region's north-to-south orientation coincides directly with data acquired from polar orbiting satellites.

NASS's previous operational remote sensing program, the Domestic Crops and Land Covers (DCLC) program, ran from 1980 to 1987. Landsat Multispectral Scanner (MSS) data were used to obtain yearly crop acreage indications for as many as eight states (Allen and Hanuschak, 1988). The DCLC indications had lower sampling errors than conventional ground survey based estimates and were usually closer to the final ASB figures. The extra cost of processing the Landsat data was near the break even point for midwestern grain crops such as corn and wheat. However, results in Arkansas and Missouri showed that for cotton and rice, the Landsat estimator was clearly a cost effective improvement. Following the discontinuation of the DCLC program in 1987, research was conducted in several regions of the country to evaluate the TM and other sensors. The largest improvements for TM based estimates over survey based estimates were found for cotton and rice in Arkansas (Allen, 1990b).

Most data processing required for crop area estimation is done using PEDITOR, a special purpose software system developed at NASS (Ozga et al., 1992). PEDITOR is written mainly in PASCAL and maintained on a MicroVax 3500 computer at NASS. The software system also runs on IBM compatible personal computers. PEDITOR consists of a number of separate program modules, each of which reads input files and creates output files that may be used by other modules. Satellite scenes are stored on tapes at the Idaho National Engineering Laboratory Supercomputing Center in Idaho Falls, Idaho. Computationally intensive tasks such as multitemporal overlay and large scale classification are run on the Cray supercomputer at that facility.

DATA ACQUISITION

For the 1991 Delta Project, NASS's Remote Sensing Section (RSS) acquired ground data from the June Agricultural Survey (JAS) and Landsat data from EOSAT Corporation. Acquisition involved the JAS, a follow-up survey, spring scene selection, and summer scene selection.

NASS conducted the JAS on a state-by-state basis. The sample units were small land areas called segments, each about one square mile. Segments were selected randomly from an area sampling frame stratified with respect to land use. During the survey, field enumerators interviewed the land managers in each segment, recording the cover (crop/land use), size, and boundaries of every field.

After segment enumeration, NASS processed the JAS questionnaires through both manual and automated edits. The manual edit checked for questionnaire completion, omitted fields, and segment acreage accuracy. Problems were solved through examination of segment aerial photos, discussions with enumerators, and revisits to segments. The data were key-entered into the processing system, the automated edit run, and further corrections made. At this point, the survey data could be used to make NASS's usual preliminary crop area estimates having measurable precision, but based on ground data alone.

In order to use the survey as ground data for remote sensing purposes, a follow-up survey was needed. On the JAS questionnaire, each field within a segment could be described as planted, partially planted, or to be planted in a given crop. Acres left to plant in a field were termed intention acres. Flooding in late May caused late planting and many intention acres for soybeans. For the early August follow-up survey, enumerators revisited each segment with intention acres. To validate field covers, enumerators used segment individualized worksheets listing the information collected in June. Each worksheet provided a field level legend to a segment photo, indicating each field's cover, size, and intention acres. Enumerators recorded land cover changes on the worksheet based on their observations; the farmer was usually not contacted. After Arkansas and Mississippi updated their June data and segment field boundaries with the follow-up information, no additional on-the-ground validation of the ground data occurred.

RSS analysts selected Landsat TM scene dates to facilitate crop discrimination. Maximum normalized difference vegetative indices (NDVI), derived from Advanced Very High Resolution Radiometer (AVHRR) satellite data, were used to indicate the date of maximum greenness for the Delta area. The U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota provided the NDVI values on a county average basis for each biweekly period. The county averages were graphed to provide a selection process from among those dates most useful for the growing season. Summer TM scene dates were chosen as close as possible to the maximum NDVI dates, within the constraints imposed by cloud cover and scene availability factors. The spring TM scene dates were based on judgment of cropping practice differences.

Because of cloud cover and timing problems, the Landsat coverage area was divided into multitemporal and unitemporal analysis regions. Acquisition dates were April 1 and August 23 for the multitemporal scenes covering eastern Arkansas and western Mississippi. The unitemporal acquisition dates were July 31 for northeastern Mississippi and August 14 for central Arkansas. Due to the mixture of dimensionality and acquisition dates, analysis districts were created consisting of a poststratification of the state based on scene boundaries. Parts of Delta states not covered by Landsat data also defined analysis districts. Data from each analysis district and state were prepared and analyzed separately.

DATA PREPARATION

Preparation of data for analysis involved TM scene reformatting and registration, precise location of land segments in TM scenes, ground truth file editing, digitization of land use stratum boundaries, and creation of packed files for training.

Landsat TM scenes were reformatted to a band-interleaved-by-pixel format. Each scene was registered with a third order polynomial using thirty or more control points and a 1:250,000 map (Cook, 1982). For multitemporal analysis, the earlier (base) scene was registered as above, then the later scene was registered and correlated with the base scene. Pixels in the later scene were associated by the nearest neighbor rule and not averaged.

After TM scene processing, the remaining preparation consisted of establishing a geographic correspondence between TM pixels and JAS segments. Segment boundaries and calibration points were video digitized. The process involved drawing segment boundaries onto an aerial photo, manually tracing them onto a clear acetate sheet, capturing the boundaries to a raster format using a video camera, performing thinning and connectivity analysis of the rasterized boundaries, and adding field labels.

NASS's Area Frame Section (AFS), which designs new area sampling frames for states, stratified Arkansas and Mississippi by land use and defined the segments (Cotter and Nealon, 1987). To build the area frames, each county was stratified based on percent of cultivated land. The AFS drew the strata onto county maps and subdivided them into areas called primary sampling units (PSU's). The PSU's were sampled randomly in each state. Selected PSU's were further divided into secondary sampling units called segments, which were sampled randomly and used for several years in successive June surveys. The AFS delineated the segments so that they could be located easily on the ground. Cartographic technicians used roads, stream courses, and other geographic features to define a segment's outer boundary, which was drawn onto an aerial photo. The segment photos were used first by the RSS for segment calibration, then by the enumerators as they interviewed farmers working the land within a segment, and finally by the RSS for boundary tracing and digitization.

The RSS performed further processing on the segments to geo-reference them accurately. Each segment was located on a 7.5 minute map. Several easily identifiable features found on both the map and the aerial photo were used as control points. The latitude and longitude of the control points were digitized using a digitizing tablet. Five latitude and longitude referencing 1/8 inch dots were placed on the photo, with four of them forming a four cornered polygon that enclosed the segment's outer boundary. The fifth calibration dot was placed next to the upper right (NE) dot of the enclosing polygon for directional orientation. The latitude and longitude for the calibration dots were derived from the control points and stored.

During the June survey, enumerators drew field boundaries onto the processed segment photos, then recorded the cover in each field based on interviews with farmers. When a segment enumeration was completed, cover information was stored and segment boundaries and calibration dots were traced onto acetate sheets for video digitizing. Field labels, segment identification, and comments were written onto the acetate in ink not visible to the camera.

RSS staff scanned the traced field boundaries using a PC equipped with a PCvision-plus frame grabber board, video camera, and auxiliary video monitor. The scanned boundaries were then thinned on a VAX or PC and connectedness analyzed (Rosenfeld and Kak, 1976). After thinning, field labels were added interactively to the segment boundary files. These labels provided a correspondence with ground truth files. The RSS used boundary and field label information to create segment mask files. Two types of segment masks were created: shifting masks and final masks. Shifting masks were used to shift the outer segment boundaries to within one pixel of their true locations. Final masks were used to locate training data within TM scenes.

Segment boundaries were shifted as follows. Using the coordinates from the segment calibration points and the scene registration information, a small unsampled TM window was displayed in false color on the computer screen. The digitized network of segment outer and field boundaries was overlayed on the displayed window. The boundary network was then shifted using a mouse until its location corresponded with the features displayed in the data window. The shifts were stored in horizontal and vertical pixel units for use in creating final masks. In addition to enabling precise location of segments within scenes, the shifting process allowed the RSS to assess the quality of scene registration and segment calibration. All registration and calibration errors were corrected.

When shifting was complete, analysts created ground truth files and then final segment mask files. Segment ground truth files contained the following JAS information on each field: field label, field acreage, field cover, acreage planted to cover, unplanted arable acreage, waste acreage, irrigation status, and training suitability notes. The final segment mask files contained information at the segment, field, and pixel levels. Each segment mask file contained TM scene identification, window coordinates, and number of fields in the segment. For each field, the final masks contained the cover, area, and field label. Furthermore, the final masks indicated whether each pixel within a segment was background (not in a field), boundary (on the boundary between two fields), or pure (in one field).

Automated checking of final masks and ground data files was performed for each field. First, a one-to-one correspondence for mask and ground data field labels was done. The planted, unplanted, and waste acres were then checked to verify that they summed to total field acres. Lastly, each field size from the mask was compared to the reported size in the ground data. Any field having an unresolvable discrepancy was marked so that it would not be used for training.

RSS staff also manually digitized the counties. The county files contained the outer political boundary and an inner network of boundaries forming polygons that delineated the land use strata. The county strata files were used to locate the land use strata within TM scenes, allowing separate analysis by strata.

The validated final mask files were used to build files packed by cover type. Packing was done within each analysis district covered by TM data. The packing program searched the final mask files and gathered all TM pixels labeled to the same cover into a packed file for that cover. In addition, two large packed files were created: one containing all non-background pixels of all cover types, and the other similar except that fields marked as bad were excluded.

DATA ANALYSIS

Data analysis comprised the procedures used to produce state and county level crop acreage estimates. The steps required were pixel clipping, clustering, small scale classification, statistics file creation, regression analysis, large scale classification, aggregation, and estimation.

The analysis steps were done separately by RSS analysts within each analysis district except those with no TM coverage. A clipping algorithm based on principal components removed outlier pixels from the cover packed files. In the training process, supervised clustering was applied to the labeled pixels. For each cover, a clustering program created a signature (discriminant function) from the pixels in the clipped packed file of that cover. The collection of signatures for all cover types in the analysis district constituted the scene classifier. The clustering program used was an enhanced version of the Isodata algorithm, allowing for cluster merging and splitting (Bellow and Ozga, 1991).

Following clustering, analysts combined the clusters for the analysis district into a statistics file. This file contained the defining information for all categories (clusters). Each category was labeled to its known cover type. The statistics file edit program assigned prior probabilities to the cover types based on their pixel percentage in the packed files. These probabilities were then used to compute priors for categories within covers.

After the statistics file was finalized, small scale classification began. A maximum likelihood algorithm classified each non-background pixel in the JAS sample segments to a cover type (Johnson and Wichern, 1988). The priors for categories were used as inputs to the program. The packing program then tabulated the classified pixel counts, summing over categories within covers to obtain the segment level counts of pixels classified to each cover type. The overall number of pixels classified to each cover was determined by summing these counts over segments.

RSS analysts applied regression methodology to relate classified pixel counts to the ground data. Counts of pixels within each sample segment classified to a specific crop were regressed against the corresponding crop acreage values from the JAS enumeration. A separate first order model was used in each applicable stratum. Regression graphs and tables enabled detection of outlier segments. Some of these outliers were caused by errors in the ground data, which were then corrected. Other outlier segments were deleted from analysis, and the regression program was rerun.

In large scale classification, the maximum likelihood classification program assigned each pixel in the TM scenes covering the analysis district to a cover type, using the same statistics file as before. An aggregation program summed the large scale classified pixel counts across scenes to obtain analysis district level and county level pixel counts for each cover type within each stratum.

RSS analysts applied the stratum level regression models to the pixel counts in order to estimate acreage of each crop of interest within strata. Direct expansion of the JAS reported acreages was used to estimate crop acreages in the non-Landsat analysis districts, and on a per crop basis for strata where too few segments had positive crop acreage. Direct expansion estimation involves multiplying the total crop acreage for the sample segments in a given stratum by the ratio of the number of area frame (population) units to the number of sample segments in the stratum. An accumulation program summed the estimates over strata to get analysis district level estimates, then summed them over districts to obtain the state level Landsat indications. The program also computed estimates of the variance of the district and state level estimates (mathematical formulas for estimates mentioned here can be found in Allen, 1990a).

A Battese-Fuller model (Battese et al., 1988; Walker and Sigman, 1982) was applied to obtain estimates of crop acreage at the county level. The model assumes that segments grouped by county admit the same slope relationship as the analysis district but a different intercept is required. The estimation program applied the analysis district level regression equation to the within county pixel counts, then adjusted it by a portion of the vertical distance from the regression line to the county sample mean. Direct expansion based on district level JAS averages was used for the non-Landsat parts of counties. The RSS provided indications for 28 counties in Arkansas and 36 counties in Mississippi to the respective SSO's. Color maps showing locations of crops within counties were produced using PEDITOR graphics and printed on a Tektronix 4693D color printer.

RESULTS

The RSS submitted the 1991 Landsat crop acreage indications to the Agricultural Statistics Board and the State Statistical Offices in early December of 1991, for NASS's 1992 Annual Crop Production Report published in early January. The SSO's were provided with county level indications in March, 1992, and with categorized color maps showing locations of crops within counties in April.

Several measures are used by the RSS to assess classification and estimation accuracy. The regression determination coefficient is the square of the correlation coefficient between the independent and dependent variables, and measures goodness of fit of the regression equation. Relative efficiency (RE), a measure of the effectiveness of satellite data in improving upon the JAS estimates, is the ratio of the variance of the direct expansion (JAS) estimate to that of the Landsat regression estimate. The coefficient of variation (CV), usually given in percent, is the ratio of the estimated standard deviation of an estimate to the estimate itself. Percent correct is the percent of pixels of a given cover type correctly classified. Commission error is the percent of pixels classified to a cover type that belong to some other cover. Overall percent correct is the percent of pixels of all cover types correctly classified.

Table 1 gives the percent correct and commission error of the major crops in each analysis district where regression was done. The measures were computed using only pixels that were non-background and not in bad fields. The percent correct figure in the "total" row is the overall percent correct (for all covers). Of the major crops, rice showed the highest percent correct values and lowest commission errors in the regions where it occurred. In general, classification accuracy was higher in the multitemporal analysis regions (eastern Arkansas and western Mississippi) than in the unitemporal regions.

Table 1: Small Scale Classification Accuracy

Arkansas	------Eastern Region-------			-------Central Region------		
Cover Type	No. Pixels	% Corr.	% C.E.	No. Pixels	% Corr.	% C.E.
cotton	45,019	82.5	20.3	5,401	75.5	26.9
rice	45,523	82.7	12.4	5,988	79.0	18.2
soybeans	95,626	80.9	21.0	16,240	75.7	29.7
total	287,662	77.9	_	112,871	66.4	_

Mississippi	------Western Region-------			-----Northeast Region------		
Cover Type	No. Pixels	% Corr.	% C.E.	No. Pixels	% Corr.	% C.E.
cotton	37,241	78.4	22.4	8,626	81.5	14.7
rice	11,998	89.1	6.1	0	_	_
soybeans	56,666	79.1	19.4	11,236	66.8	29.6
total	283,834	77.0	_	150,983	73.5	_

Table 2 shows the stratum level sample sizes (n) and R^2 values for those strata where regression was used for a given crop. The table also gives the stratum level direct expansion CV's (CVD), Landsat regression CV's (CVL), and the RE's. For rice and cotton, the R^2 values were all above 0.9. The highest stratum level RE's occurred for cotton in Mississippi. Table 3 gives the state level CV's and RE's. The state level acreage indications cannot be shown due to confidentiality restrictions. The RE was highest in Arkansas for rice (3.9) and in Mississippi for cotton (4.3). The state level RE's were generally lower than the stratum level RE's from Table 2 because Landsat coverage was not used for the entire states.

Table 2: Stratum Level Estimation Efficiency

Arkansas

		Eastern Region		Central Region		-------Overall-------		
Crop	Stratum (Pct. Cult.)	n	R^2	n	R^2	CVD(%)	CVL(%)	RE
cotton	81-100%	97	.940	23	.930	12.4	4.0	13.1
	51-80%	13	-	9	-	-	-	-
	15-50%	7	-	16	-	-	-	-
	0-14%	6	-	3	-	-	-	-
rice	81-100%	97	.936	23	.961	10.9	5.7	4.0
	51-80%	13	.994	9	-	26.3	8.7	13.0
	15-50%	7	-	16	-	-	-	-
	0-14%	6	-	3	-	-	-	-
soybeans	81-100%	97	.832	23	.833	5.4	2.5	4.6
	51-80%	13	.941	9	-	19.8	12.9	3.6
	15-50%	7	.905	16	-	37.0	35.0	3.0
	0-14%	6	-	3	-	-	-	-

Mississippi

		Western Region		Northeast Region		------Overall--------		
Crop	Stratum (Pct. Cult.)	n	R^2	n	R^2	CVD(%)	CVL(%)	RE
cotton	76-100%	47	.903	2	-	13.4	4.9	7.5
	51-75%	19	.961	13	.989	26.4	4.9	24.0
	15-50%	41	.947	20	.995	22.3	5.5	28.5
	0-14%	31	-	24	-	-	-	-
rice	76-100%	47	.919	2	-	22.8	11.4	9.5
	51-75%	19	-	13	-	-	-	-
	15-50%	41	-	20	-	-	-	-
	0-14%	31	-	24	-	-	-	-
soybeans	76-100%	47	.838	2	-	9.5	4.2	5.8
	51-75%	19	.926	13	.937	16.8	18.8	0.8
	15-50%	41	.975	20	.816	22.4	18.0	1.7
	0-14%	31	-	24	-	-	-	-

Table 3: State Level Estimation Efficiency

State	Crop	CVD(%)	CVL(%)	RE
Arkansas	cotton	11.3	8.7	2.2
	rice	10.1	5.4	3.9
	soybeans	5.5	3.1	3.5
Mississippi	cotton	10.5	5.4	4.3
	rice	21.5	15.5	3.9
	soybeans	8.8	7.7	1.4

Tables 4 through 6 refer to county level estimation. For each crop, Table 4 shows the number of counties whose CV fell in a given range. Table 5 gives the estimates and CV's for the nine Arkansas counties whose Landsat rice indication was above 50,000 acres. The table also gives the three-year average of official county estimates published by the state for 1988-90, obtained from NASS's Published Estimates Data Base. The percent difference between the Landsat indication and three-year average is shown. Table 6 gives similar data for the nine Mississippi counties whose Landsat cotton indication was above 50,000 acres. The CV's of the Arkansas rice counties were all below seven percent, and only one county's indication was more than ten percent from the three-year average. The CV's of the Mississippi cotton counties were all ten percent or below. Overall, county estimation worked best for counties with large planted acreage of a given crop.

Table 4: Distribution of County Estimate CV's

		No. Counties with CV's in Range					
State	Crop	0-10%	10-20%	20-30%	30-40%	40-50%	Total
Arkansas	cotton	12	5	1	4	5	27
	rice	15	8	3	1	0	27
	soybeans	23	4	0	0	0	28
Mississippi	cotton	20	8	6	0	0	34
	rice	2	2	4	5	1	14
	soybeans	16	7	6	3	0	32

Table 5: Major Rice Counties in Arkansas

County	Landsat Rice Est.	CV(%)	3-Year Ave. (1988-1990)	% Diff.
Poinsett	99,364	5.1	98,233	1.2
Arkansas	89,243	4.8	92,800	3.8
Craighead	78,821	6.1	66,867	17.9
Cross	75,260	5.7	77,200	2.5
Jackson	71,982	4.9	72,500	0.7
Clay	64,216	6.5	59,867	7.3
Lonoke	63,996	4.2	70,933	9.8
Prairie	62,119	4.1	58,233	6.7
Woodruff	51,891	5.1	51,200	1.3

Table 6: Major Cotton Counties in Mississippi

County	Landsat Cotton Est.	CV(%)	3-Year Ave. (1988-1990)	% Diff.
Washington	102,443	3.9	77,667	31.9
Yazoo	93,921	8.0	83,433	12.6
Coahoma	88,329	4.7	85,833	2.9
Leflore	87,753	4.0	86,633	1.3
Sunflower	79,304	6.9	98,233	19.3
Tallahatchie	67,919	7.2	69,867	2.8
Holmes	66,888	10.0	58,267	14.8
Bolivar	61,606	9.9	58,600	5.1
Humphreys	57,332	5.9	55,733	2.9

CONCLUSION

The 1991 Delta Project provided timely end-of-year indications of state and county level planted acreage to the Agricultural Statistics Board and the Arkansas and Mississippi SSO's. The high estimation efficiencies justified NASS's decision to return to operational remote sensing in the Delta region. The improvement in computing capabilities available to the project staff enabled the processing of volumes of data that would not have been possible in the past.

The RSS gained valuable experience in all aspects of the project and identified areas that could be improved. Software revisions to the PEDITOR system were made during the course of the project as needs warranted. Hardware improvements included expanded data storage capacity and higher processing speeds.

Plans for the 1992 Delta Project include several changes and additions. Louisiana, another major cotton and rice producing state, will be added to the Landsat coverage area. The RSS will attempt to generate early season rice indications based on late spring unitemporal data for NASS's August Crop Production Update. The early scene in the multitemporal data set will have a later image date than in 1991. Segments from low cultivation strata will no longer be processed since they did not give good regression fits. Higher resolution color categorized maps will be produced.

REFERENCES

Allen, J.D., 1990a, A Look at the Remote Sensing Applications Program of the National Agricultural Statistics Service, Journal of Official Statistics, 6(4):393-409.

Allen, J.D., 1990b, Remote Sensor Comparison for Crop Area Estimation Using Multitemporal Data, in Proceedings of the IGARSS '90 Symposium, College Park, Md., pp. 609-612.

Allen, J.D. and Hanuschak, G.A., 1988, The Remote Sensing Applications Program of the National Agricultural Statistics Service: 1980-1987, U.S. Department of Agriculture, NASS Staff Report No. SRB-88-08.

Battese, G.E., Harter, R.M. and Fuller, W.A., 1988, An Error-Components Model for Prediction of County Crop Areas using Survey and Satellite Data, Journal of the American Statistical Association, 83(401):28-36.

Bellow, M.E. and Ozga, M., 1991, Evaluation of Clustering Techniques for Crop Area Estimation using Remotely Sensed Data, in American Statistical Association 1991 Proceedings of the Section on Survey Research Methods, Atlanta, Ga., pp. 466-471.

Cook, P.W., 1982, Landsat Registration Methodology Used by U.S. Department of Agriculture's Statistical Reporting Service 1972-1982, USDA/NASS/Remote Sensing Section.

Cotter, J. and Nealon, J., 1987, Area Frame Design for Agricultural Surveys, U.S. Department of Agriculture, NASS Area Frame Section.

Johnson, R.A. and Wichern, D.W., 1988, Applied Multivariate Statistical Analysis, Prentice Hall, Englewood Cliffs, N.J., ch. 11, pp. 501-513.

Ozga, M., Mason, W.W. and Craig, M.E., 1992, PEDITOR - Current Status and Improvements, in Proceedings of the ASPRS/ACSM Convention, Washington, D.C.

Rosenfeld, A. and Kak, A.C., 1976, Digital Picture Processing, Academic Press, New York, N.Y.

U.S. Department of Agriculture, 1992, Crop Production - 1991 Summary, Agricultural Statistics Board, NASS.

Walker, G. and Sigman, R., 1982, County-level Crop Area Estimates from Landsat: Evaluation of the Battese-Fuller Estimator, in American Statistical Association 1982 Proceedings of the Section on Survey Research Methods, Cincinnati, Ohio, pp. 473-478.