

USING ASTER DATA TO DETECT CROP RESIDUE AND TO IMPROVE CROP CLASSIFICATION

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ABSTRACT

The Terra/ASTER sensor has several advantages over other moderate spatial resolution sensors for studying agricultural systems. ASTER bands 5 and 8 are sensitive to lignin-cellulose spectral absorption features present in crop residue. In addition, nadir and oblique views from bands 3N and 3B, respectively, can be used to investigate bidirectional reflectance differences among crop canopies.

Studies were conducted in 2005 and 2006 in southern Michigan to test the ability of ASTER to determine crop residue during the non-growing season, and to distinguish major crops (including corn, soybean, wheat, oats, and alfalfa) based on their canopy structure and bidirectional reflectance differences. Results indicate that under certain circumstances the Lignin Cellulose Absorption (LCA) index has potential for estimating crop residue. Wheat and oats had much higher 3B:3N reflectance ratios than other land cover types within the study area.

The results of these studies are important in two respects. First, for soil conservationists, a reliable remote sensing-based crop residue index would be an objective, cost-effective alternative to estimating plant residue levels with “drive-by” field surveys. Second, the distinctive bidirectional reflectance properties of wheat and oats have allowed us to improve the accuracy of our land cover classification for the study site, originally based on spectral information alone.

INTRODUCTION

Remote sensing has been used extensively for extracting information from agricultural landscapes, such as land-cover classification, productivity, and plant stress. Recent advances in sensor technology and algorithm development offer new capabilities for estimating crop residue and for discerning plant canopy differences as another classification input.

Crop residue provides a number of soil conservation benefits, such as reduction of erosion, retention of soil moisture, enhancement of carbon sequestration, and improvements in soil structure (Bannari *et al.*, 2003; Bannari *et al.*, 2006; Nagler *et al.*, 2000). Because direct field measurements of crop residue cover are time-consuming and impractical over large regions, current methods for assessing crop residue commonly rely on qualitative assessments by trained personnel from moving vehicles (Hill, 1996).

As part of a research project supported by the U.S. Department of Agriculture (USDA), the Michigan Tech Research Institute (MTRI) has been exploring the capabilities of the Terra/ASTER sensor to detect crop residue more quantitatively and to detect unique crop canopy characteristics for improving classifications.

The study area (~16 km x 10.5 km) consisted of the Bean Creek and Lime Creek watersheds located in southern Michigan (see Figure 1), predominantly an agricultural area with patches of deciduous forest, USDA-Natural Resources Conservation Service (NRCS) Conservation Reserve Program (CRP) set asides, and a few water bodies. Major cultivated crops include corn, soybeans, wheat, and alfalfa, with a few fields of oats. Corn may be harvested either for grain production or for silage. Corn grain fields are typically harvested later than silage fields and contain much more crop residue.

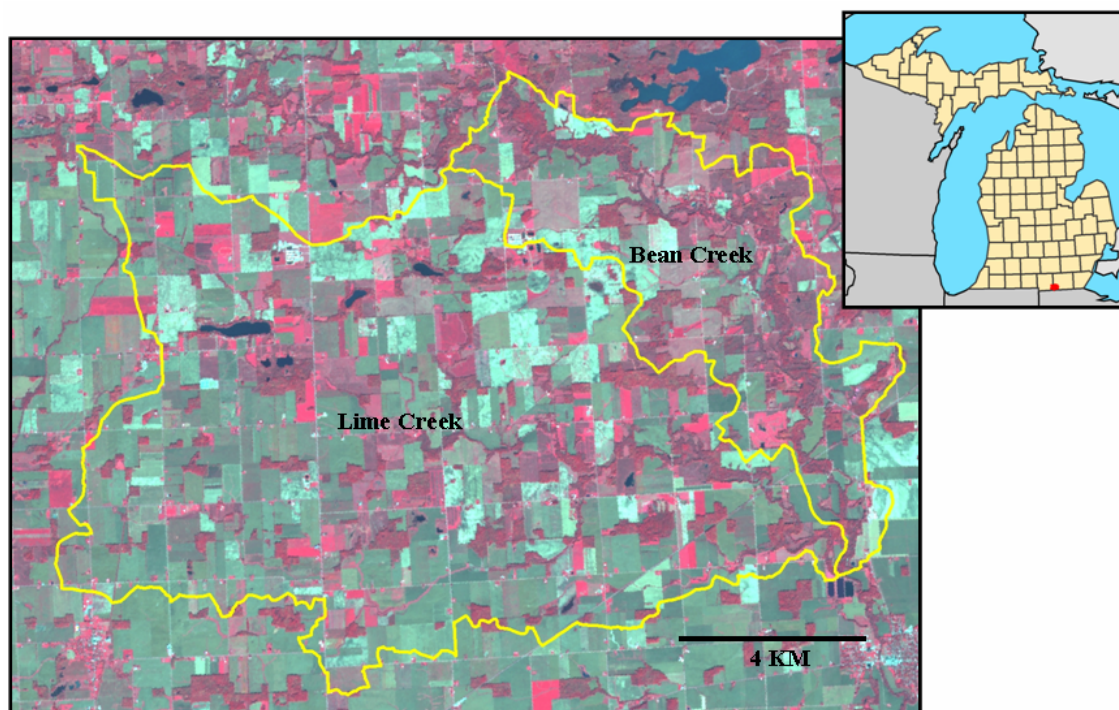


Figure 1. Outline of Bean Creek and Lime Creek watersheds (yellow) over an ASTER scene (Bands 1, 2, 3N) acquired on October 6, 2006. Inset shows location of study area (red) in southern Michigan.

BACKGROUND

Crop Residue

Several remote sensing indices have been developed to detect crop residue, including the Lignin-Cellulose Absorption (LCA) index, the Modified Soil Adjusted Crop Residue Index (MSACRI), and the Cellulose Absorption Index (CAI). All three indices take advantage of the unique spectral features of cellulose in the 2.0-2.2 μ m range, which can be used to distinguish plant residue from bare soil and green vegetation. The sensor requirements of the three indices are compared in Table 1.

Table 1. Sensor Requirement for Three Crop Residue Indices

Index	System	Bands	References
LCA	ASTER	Bands 5, 6, & 8	Daughtry <i>et al.</i> , 2005
MSCARI	Landsat	ETM+ or TM Bands 5 & 7	Bannari <i>et al.</i> , 2000
CAI	Hyperspectral (e.g., AVIRIS)	2031, 2101, & 2211 nm	Daughtry, 2001

Due to the limited availability of hyperspectral data and its high cost, the CAI approach is at a disadvantage with regards to implementing an operational crop residue monitoring program. In contrast, data from ASTER and Landsat are abundant and relatively low-cost, and have greater potential for broad applicability. Thus, our research has focused primarily on the use of the ASTER-derived LCA index for detecting crop residue in southern Michigan, with future plans to investigate MSACRI.

The LCA index is defined as:

$$LCA = 100[(ASTER6 - ASTER5) + (ASTER6 - ASTER8)] \quad (1)$$

where *ASTER5*, *ASTER6*, and *ASTER8* are reflectance values of ASTER's bands in the 2145-2365nm range, having a spatial resolution of 30m. Bands 5 and 8 are both more strongly absorbed by lignin-cellulose than by soil.

Bidirectional Reflectance Properties of Crop Canopies

Crop classifications based solely on spectral signatures can be inaccurate due to similarities in the spectral characteristics of closely related crops. Classification accuracy may be improved by analyzing phenological changes with multi-temporal data (Schaub *et al.*, 2006) and by exploiting the bidirectional reflectance differences among different crop canopies. This research explored the use of ASTER's multi-angle imagery capabilities to distinguish bidirectional reflectance differences among canopy types to improve crop classification. During an overpass ASTER collects both nadir and backward views of the same footprint in near-infrared wavelengths referred to as Bands 3N and 3B, respectively. It was hypothesized that a ratio of 3B and 3N would demonstrate differences in crop canopies which could be input into a classifier.

METHODS

Image Processing

A total of 27 ASTER scenes were obtained from the US Geological Survey Land Processes Distributed Active Archive Center (LP DAAC) or from the Earth Remote Sensing Data Analysis Center (ERSDAC) for southern Michigan representing acquisitions from 2000 through 2006. Four of these scenes, given in Table 2, were supported by field activities to facilitate image analysis and validation. The image collected on October 29, 2006, had partial cloud cover within the study area, whereas the other three images were clear.

Table 2. ASTER Scene Acquisition Dates and Application

Granule ID	Date of Acquisition	Source	Application
AST_L1B_0506291633220508020600	June 29, 2005	ERSDAC	Bidirectional Reflectance
AST_L1A_00303192006163922_03222006090731	March 19, 2006	LP DAAC	Crop Residue
AST_L1B_00310062006163321_20061023173604	October 6, 2006	LP DAAC	Crop Residue
AST_L1B_00310292006163922_20061106102423	October 29, 2006	LP DAAC	Crop Residue

The March 19, 2006, Level 1A scene was converted to Level 1B using SILCAST module within ENVI^{TM*}. All four Level 1B scenes were then converted from DN values to atmospherically-corrected reflectances, using the Dark Object Subtraction (DOS) method (Chavez, 1988).

For the three images used in the crop residue study, LCA indices were computed using bands 5, 6, and 8 as given in equation (1). Normalized Difference Vegetation Index (NDVI) layers were also produced for the 2006 images in order to evaluate the presence of green vegetation, which could confound the LCA results.

An indicator of bidirectional reflectance, band 3B was divided by band 3N (referred to as the "3B-3N ratio") for the June 26, 2005, scene. The resulting layer was evaluated in ArcGIS to detect fields with unusually high or low 3B-3N ratios.

Field Data Collection

The Adrian, Michigan USDA-Natural Resources Conservation Service (NRCS) provided crop data during 2004-2006. NRCS personnel also helped identify crop types and corn harvesting methods during field visits. Selected test sites were visited approximately twice a month during the 2005 growing season and after image acquisitions in 2006. During all site visits digital photos with GPS coordinates were taken of the fields to record conditions.

After computation of the 3B-3N ratio for the June 2005 scene, fields with unusually high ratio values were visited to determine their crop type. Field visits in March, April, and November 2006 were conducted specifically to observe crop residue cover at various fields. On November 14, 2006, six soybean and corn fields were sampled, each with six line-point 50-m transects. For each 50-m transect, point samples were collected at 1m intervals. The transect data were used as ground truth for LCA indices derived from the October 29, 2006, ASTER acquisitions.

* ENVI is a registered trademark of ITT Corporation.

RESULTS

Crop Residue

LCA index values for the March 19, 2006, acquisition are presented in Figure 2 with the locations of field site visits. As can be seen in Figures 3 and 4, former corn grain fields with abundant crop residue had LCA values of approximately 10, whereas soybean and corn silage fields with sparse crop residue had LCA values of approximately 6.

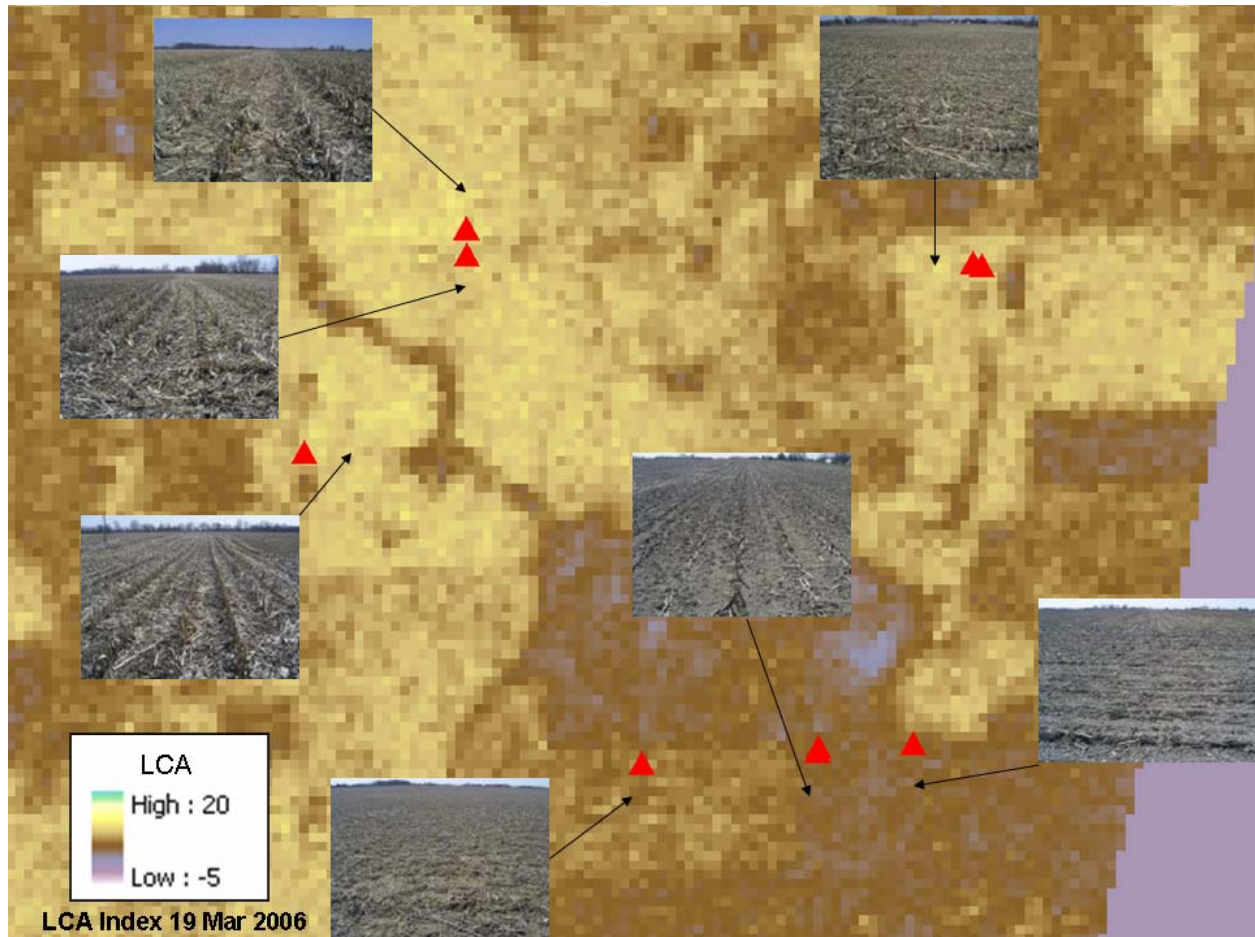


Figure 2. LCA layer for March 19, 2006, acquisition. Red triangles indicate site visit locations.

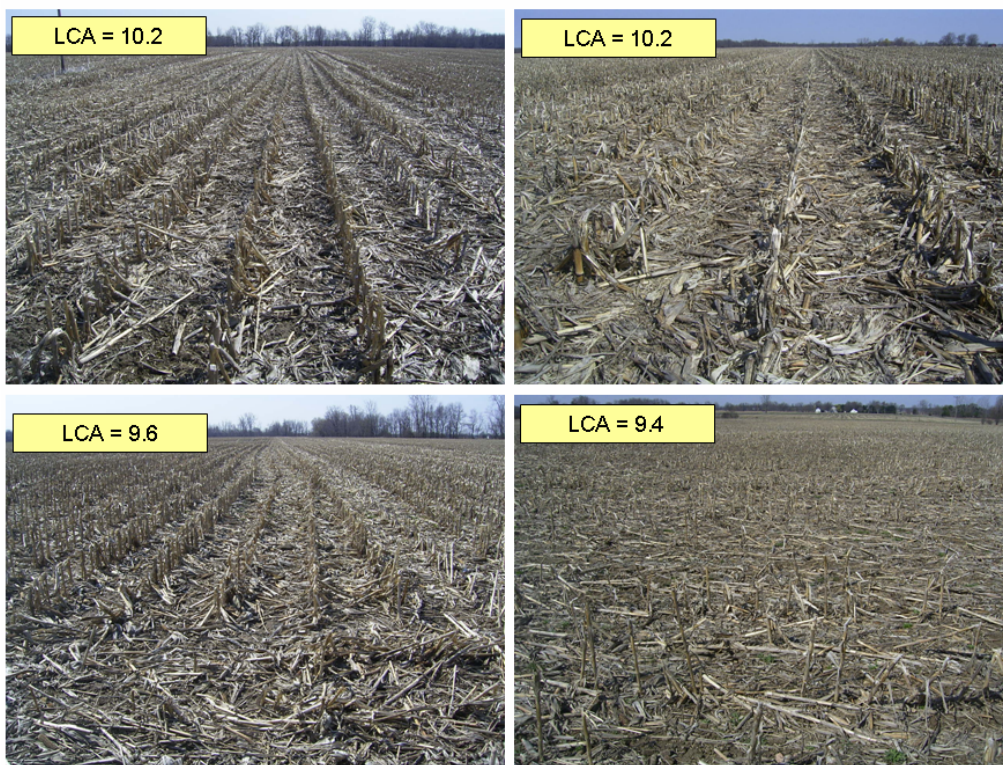


Figure 3. Four corn grain fields photographed April 13, 2006. Mean LCA = 9.9.

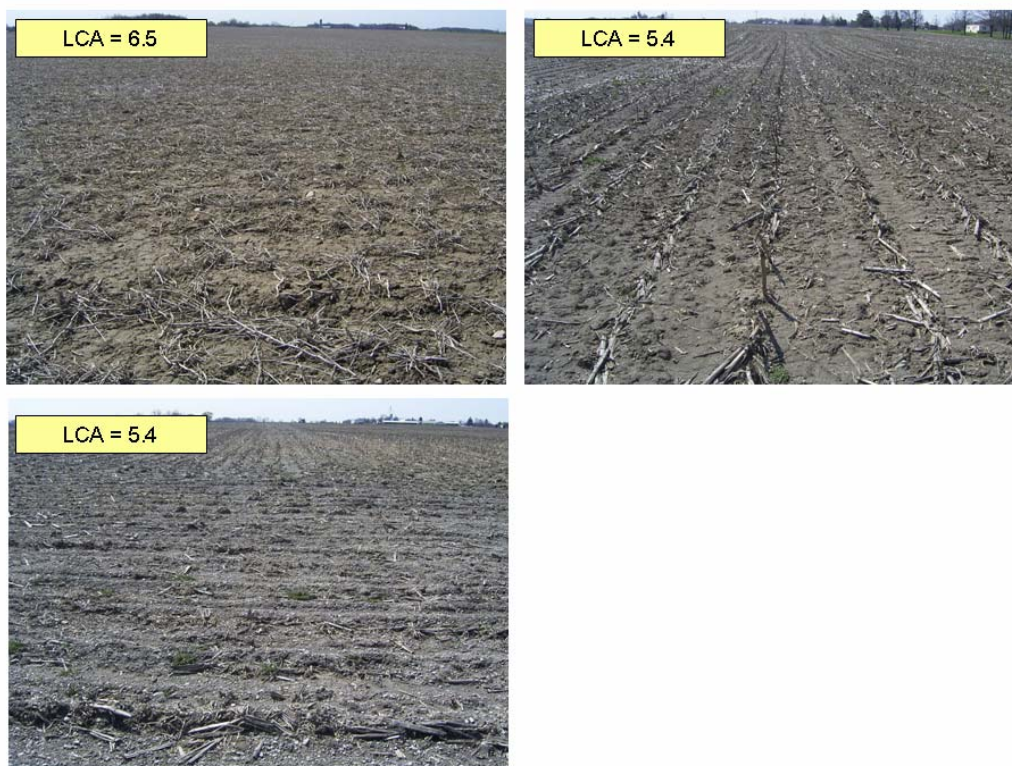


Figure 4. A soybean field (upper left) and two corn silage fields photographed on April 13, 2006. Mean LCA = 5.8.

LCA index layers for the two scenes acquired on October 6 and October 29, 2006, are given in Figure 5. As can be seen, there are considerable differences between the two images even though the collection dates differed by only 23 days. Some fields showed declines in LCA, whereas others, particularly in the southeast corner, showed increases.

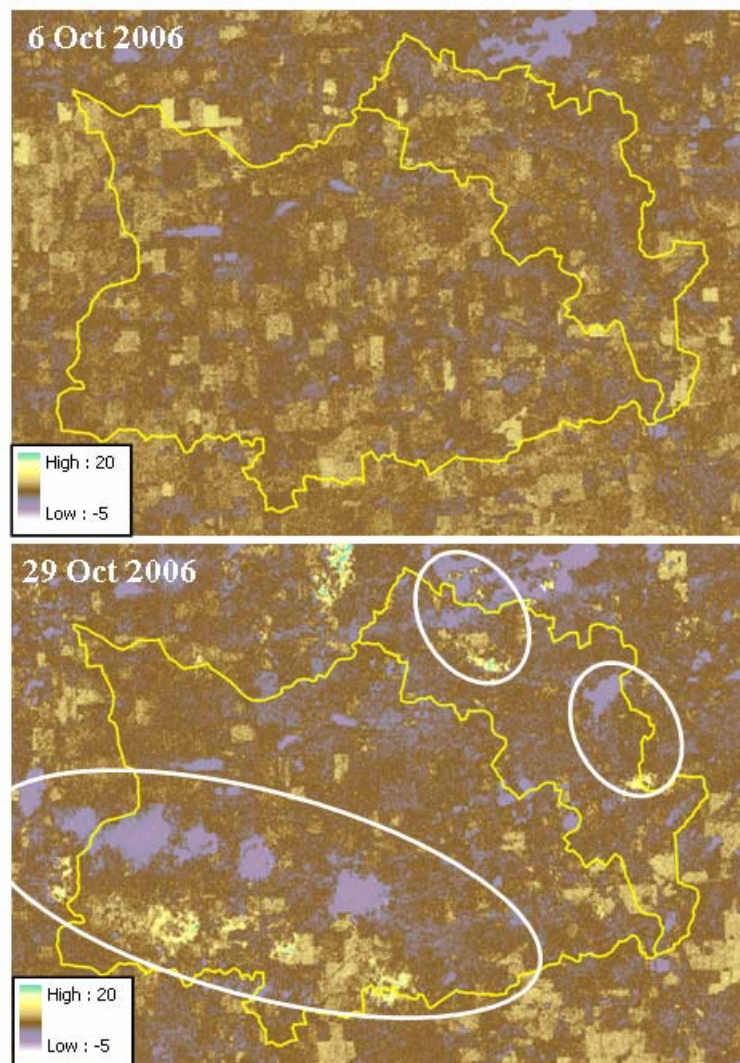


Figure 5. LCA index values for Bean and Lime Creek watersheds (yellow outline) for October 6 and 29, 2006. White ellipses in lower image indicate areas with severe cloud or cloud-shadow contamination.

A comparison of the LCA index values for the October 29, 2006, collection with the crop residue cover for the six fields sampled with transects on November 14, 2006, is presented in Table 3. While the mean LCA index values for the corn silage fields (3.89 and 5.35) were similar to corn silage fields observed in the March 2006 imagery, LCA values of the soybean and corn grain fields with high residue were only about half of what was expected.

Table 3. LCA Index Values and Crop Residue Cover for Six Fields

Field ID	Crop Type	LCA Index ¹ (29-Oct-06)		Crop Residue Cover ² (14-Nov-06)	
		Mean	St. Dev.	Mean	St. Dev.
Soy1	Soybean	5.60	1.04	0.73	0.14
Soy2	Soybean	6.58	1.19	0.75	0.07
CG1	Corn Grain	5.53	0.86	0.90	0.05
CG2	Corn Grain	5.56	0.65	0.94	0.03
CS1	Corn Silage	5.35	0.81	0.19	0.16
CS2	Corn Silage	3.89	0.88	0.27	0.18

¹ Derived from ASTER scene

² Determined from field transects

Bidirectional Reflectance Properties of Crop Canopies

The results of the 3B-3N ratio analysis from the June 29, 2005, ASTER scene is shown in Figure 6. Ratio values for land areas ranged from about 1.0 to 1.5, however several distinctive fields had ratios in 1.2-1.3 range. Subsequent field visits to nine of these sites found that they were, without exception, wheat or oats fields.

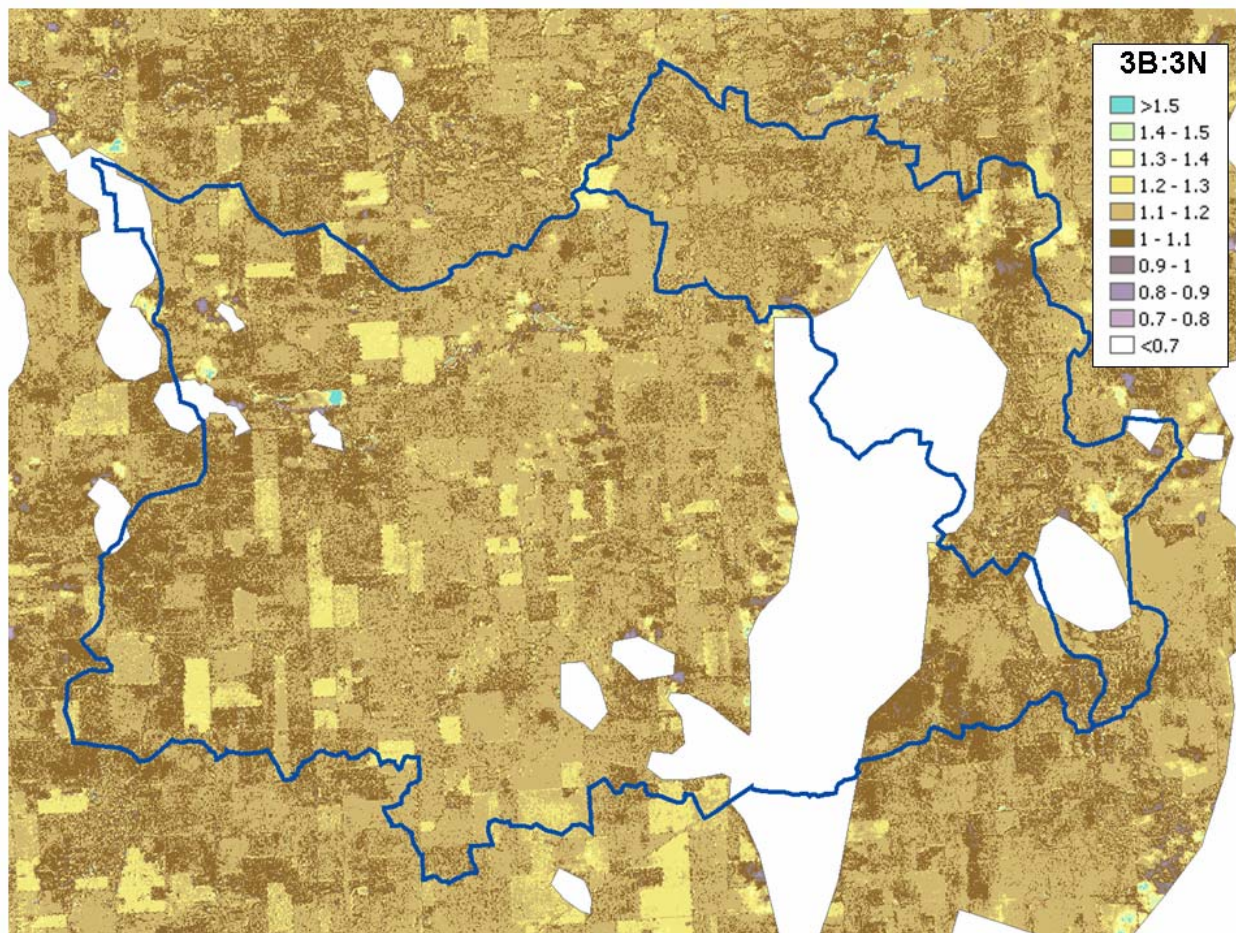


Figure 6. Ratio of 3B to 3N derived from ASTER scene collected on June 29, 2006. White polygons indicate areas of severe cloud or cloud-shadow contamination.

To test the hypothesis that fields with high 3B-3N ratio values (1.15-1.50) were wheat or oats, a set of 127 validation points of known land cover type were compared with the 3B-3N ratio image (Figure 7). A confusion matrix yielded an overall accuracy of 93.7% with a Kappa statistic of 0.83 (Table 4).

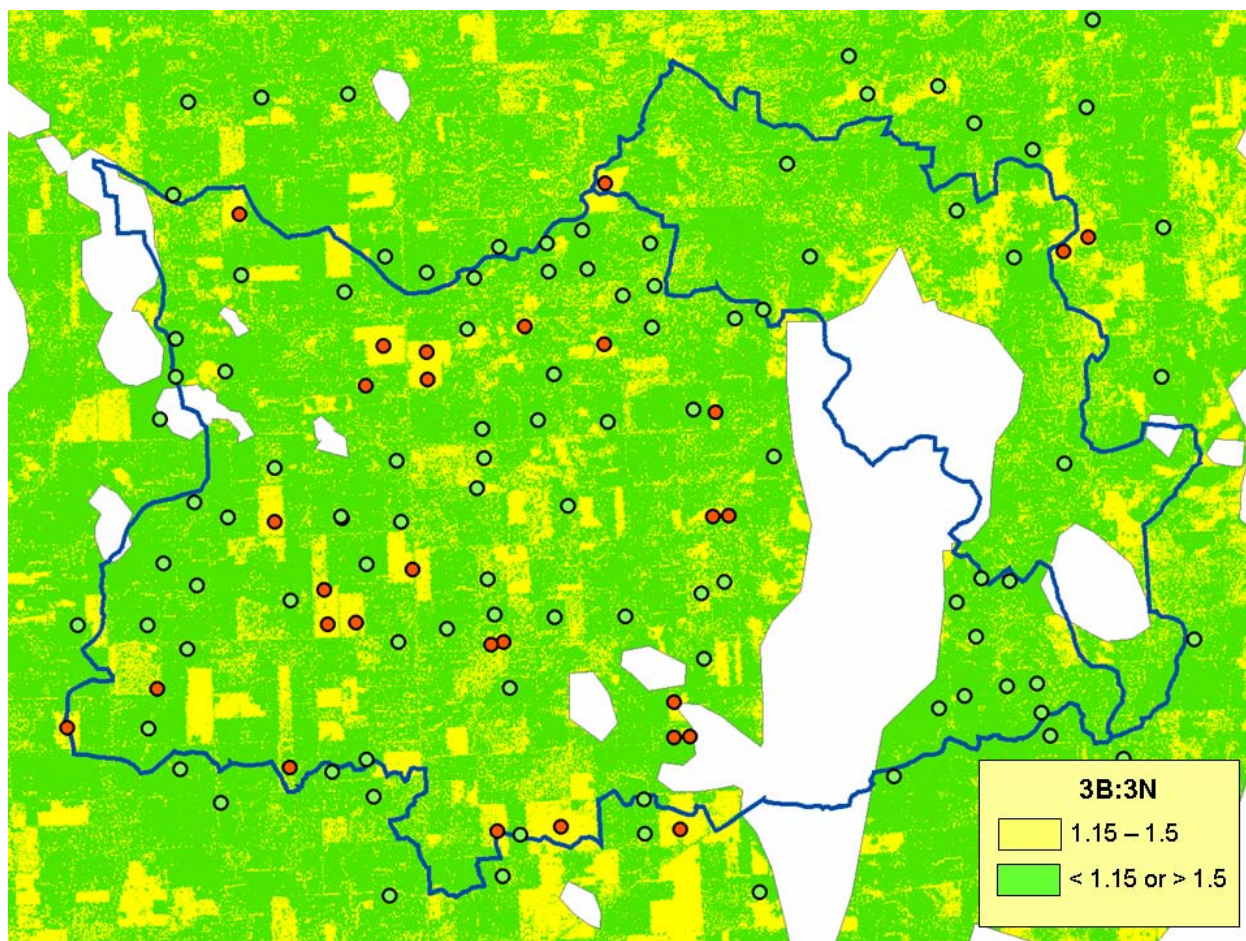


Figure 7. Ratio of 3B-3N overlaid with test points of known cover type. Orange points are wheat or oats, green dots are other crops or land cover classes, such as forest or water. As in Figure 6, the white polygons show areas of cloud or cloud-shadow contamination.

Table 4. Confusion Matrix for 3B-3N Ratio Test Sites

		Predicted			Omission Error	Producer's Accuracy
		Wheat/Oats	Other	Total		
Observed	Wheat/Oats	27	2	29	6.9%	93.1%
	Other	6	92	98	6.1%	93.9%
	Total	33	94	127		
	Commission Error	18.2%	2.1%			
	User's Accuracy	81.8%	97.9%			

Overall Accuracy **93.7%**
Kappa statistic **0.830**

DISCUSSION AND CONCLUSIONS

Measurement of crop residue and identification of canopy differences among crop types are both potentially useful applications for agricultural land managers. While the LCA index appeared to be sensitive to differences in crop residue during March observations, results were statistically non-significant during collections made in October. Factors such as soil, moisture, or age of residue may have depressed the LCA index values in the high-

residue fields, or perhaps the LCA parameter needs to be normalized. This avenue of research will be followed up with calculation of another index, the Modified Soil Adjusted Crop Residue Index (MSACRI), with Landsat imagery from November 2006. Additional collections of ASTER imagery and field data are planned for spring 2007, as well.

Wheat and oats appear to have unique canopy structures that result in a high 3B-3N ratio in ASTER imagery. The time of imagery acquisition in this study coincided with the ripening of the crops, according to field observations (Figure 8). It is not known whether the high 3B-3N ratio is characteristic of these crops before ripening occurs.



Figure 8. Ripe wheat field photographed on July 1, 2005, two days after the ASTER image collection.

Being able to distinguish wheat and oats from other land cover types based on their unique bidirectional properties has proved to be of great benefit in generating land cover classifications for these watersheds. Early attempts to produce a land cover classification with Landsat imagery based on spectral signatures were problematic, especially for wheat. The 'wheat' cover type was frequently confused with grassy CRP set asides and to a lesser extent, other crops. This work demonstrates that wheat and oat fields could be identified with accuracies exceeding 90% if their bidirectional reflectance properties are taken into consideration.

Further investigations involving collections of imagery over other time periods with additional field work are needed before these methods become operational tools for land managers. In particular, application of crop residue indices may be more complex than first thought.

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