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IDENTIFICATION AND MAPPING OF AGRICULTURAL
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Stephen R. South

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IDENTIFICATION AND MAPPING OF AGRICULTURAL TILLAGE METHODS UTILIZING REMOTELY SENSED DATA

By

Stephen R. South

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ABSTRACT

IDENTIFICATION AND MAPPING OF AGRICULTURAL TILLAGE METHODS UTILIZING REMOTELY SENSED DATA

By

Stephen R. South

The impact of widespread land use/land cover conversion from natural ecosystems to managed agricultural production has significantly altered long term ecological processes and balances. The methods employed in crop production, encompassing hundreds of thousands of individual fields, collectively account for 199 million acres of current land use. In order to assess the impacts of cropping methods, fundamental spatial data are required. Data regarding the total spatial extent and distribution of cropping methods would provide much needed data to assess and monitor the environmental impacts of widespread row crop agriculture.

Remotely sensed data provides a means to quickly and cost effectively monitor cropping methods over large areas. Increased use of conservation tillage methods may enhance carbon sequestration rates in soils and significantly reduce erosion of topsoil, the nations largest contribution of non point source pollution. The differentiation of cropping methods using remotely sensed data

would provide current estimates of environmental impacts, and data for use as input into environmental models, to predict future consequences and impacts of man's influence on the environment.

This study investigates the use of remotely sensed data to identify conventional and conservation tillage methods. Landsat 7 ETM + data, covering a 180 x180 km study area over portions of Michigan, Indiana, and Ohio were analyzed to document and map agricultural cropping practices. Several classification techniques, including spectral angle methods, were examined to assess their suitability to differentiate conventional and conservation tillage practices. The results indicate that of the 3.6 million acres of agricultural land use/land cover identified within the study area, 1.8 million acres (52%) were cropped using conservation tillage methods. The current yearly carbon sequestration potential of the study area conservation tilled fields is estimated at 228,490 metric tons/year.

In summary, remote sensing techniques and methods used in this study have the potential to provide a great deal of data regarding the implications of cropping methods. The results of this study, scaled up to larger regional or watershed scales, would provide a time and cost effective method to assess cropping methods and their associated environmental impacts.

Between the idea and the reality
Between the motion and the act
Falls the shadow

T.S. Eliot – The Hollow Men

TABLE OF CONTENTS

LIST OF TABLES VII

LIST OF FIGURES VIII

CHAPTER 1 INTRODUCTION 1
1.1 Introduction 1
1.2 Land Use and Environment 2
1.3 Cropping Methods 4
1.3.1 Conventional Tillage 5
1.3.2 Conservation Tillage 7
1.4 Research Needs 11
1.5 Statement of Problem 12

CHAPTER 2 LITERATURE REVIEW 14
2.1 Digital Remote Sensing 14
2.2 Spectral Characteristics/Considerations 16
2.3 Crop Residue Spectral Characteristics 17
2.4 Soil Spectral Characteristics 19
2.5 Classification Methodologies 20
2.6 Classification Decision Rules 26
2.6.1 Minimum Distance 26
2.6.2 Mahalanobis Classification 26
2.6.3 Maximum Likelihood 26
2.6.4 Spectral Angle Mapping 28
2.6.5 Cosine of the Angle Concept 29
2.7 Accuracy Assessment 32

CHAPTER 3 MAPPING TILLAGE PRACTICES 34
3.1 Study Area 35
3.2 Study Area Physical Characteristics 37
3.4 Study Area Agriculture 41
3.5 Ground Truth Data Collection 46
3.6 Laboratory Radiometric Sampling 47
3.7 Field Based Radiometric Sampling 48
3.8 Ground Truthing – Driving Transects 49
3.9 Temporal Considerations 56
3.10 Imagery Acquisition 58

3.11 Imagery Accessibility Considerations 60
3.12 Study Area Imagery 61
3.13 Imagery Processing 63
3.14 Radiance 63
3.15 Atmospheric Correction 64
3.16 Atmospheric Correction – 5s Method 68
3.17 Classification Methodology 71
3.18 Classification Accuracy Assessment 73

CHAPTER 4 RESULTS 76
4.1 Spectral Properties of Tillage Practices 76
4.1.2 Field Based Spectral Properties 79
4.1.3 Satellite Spectral Properties 84
4.1.4 Spectral Characteristics at Differing Spatial Scales 85
4.2 Classification Training Sites 89
4.3 Classification Methodology Comparison 89
4.4 Classified Imagery Results 98
4.5 Cosine of the Angle Concept – Spectral Angle Mapping 101
4.6 Angular vs. Geometric and Probability Based Classification 103
4.7 Validation 105
4.8 Potential Sources of Classification Error 111
4.8.1 Soil Background Effect 111
4.8.2 Mixed Pixels 113

CHAPTER 5 CONCLUSIONS / DISCUSSION 114
5.1 Carbon Cycle Implications 118
5.2 Regional Carbon Accounting 123
5.3 Carbon and Tillage 126
5.4 Study Area Total Carbon Sequestration 128
5.5 Regional Estimates of Carbon Sequestration Based on Tillage 129
5.6 Soil Erosion and Tillage 130
5.7 Scaling Up – Regional Measurements and Estimates 133
5.8 Further Research 135

BIBLIOGRAPHY 139

LIST OF TABLES

Table 1. Study Area Acreage and Production Value.. 37
Table 2. ETM+ Sensor Characteristics.....62
Table 3. 5s Derived Correction Parameters for ETM+ data. 71
Table 4. Maximum Likelihood Classification Error Matrix.....91
Table 5. Mahalanobis Distance Classification Error Matrix. 92
Table 6. Minimum Distance Classification Error Matrix. 93
Table 7. Spectral Angle Mapping Classification Error Matrix.....94
Table 8. Cosine of the Angle Concept Classification Error Matrix.....95
Table 9. Classification Results. 96
Table 10. Results of Classification Statistical Significance Pairings.....97
Table 11. Study Area Land Use/Land Cover.....100
Table 12. Validation Results of the Cosine of the Angle Classification Routine.111
Table 13. Yearly Carbon Sequestration Potential 130
Table 14. Temporal Image Acquisition for Crop Identification.....135

LIST OF FIGURES

Figure 1. Classification Decision Space. 23
Figure 2. Cosine of the Angle Concept Decision Space. 30
Figure 3. Diagram of Methods 34
Figure 4. Study Area Location. 36
Figure 5. Study Area Precipitation and Potential Evapotranspiration. 38
Figure 6. Study Area Yearly Temperature Graph. 38
Figure 7. Driving Transect Data Points. 51
Figure 8. Ground Truth Data Collection Flow Chart. 52
Figure 9. Landsat 7 P21 R31 Band 5 May 27th, 2002. 62
Figure 10. 5s Atmospheric Correction Flowchart. 69
Figure 11. Laboratory Reflectance Readings. 77
Figure 12. Field Based Spectral Reflectance Measurements, ... 80
Figure 13. Crop Residue – Photograph of Corn Residue 81
Figure 14. Crop Residue, Photograph of Corn Residues. 81
Figure 15. Crop Residue, Photograph of Soy Bean Residues. 82
Figure 16. Field Based Measurements of Reflectance. 83
Figure 17. Spectral Reflectance derived from ETM+ Data 84
Figure 18. Classified Data Based on the COTA Classification Routine. 99
Figure 19. Study Area Land Use/Land Cover in Acres. 101
Figure 20. Soil Types and Ground Truth Collection Locations 112
Figure 21. Agriculture and Carbon. 124

CHAPTER 1 INTRODUCTION

1.1 Introduction

A country drive through any midwestern state reveals that one land use dominates the landscape, row crops. The three primary row crops corn, soybeans, and wheat collectively account for 199,000,000 acres of land use (USDA, 2000). Corn and soybeans each account for 73 million acres and wheat production occurs on 53 million acres (USDA, 2000). Collectively these three crops account for 36.5 billion dollars of agricultural production (USDA, 2000).

The implications and consequences of cropping methods, comprising such a large area, are far reaching. The conversion of native ecosystems to managed agricultural production, consisting primarily of row crops, exhibits many environmental consequences. Cropping methods affect carbon sequestration rates, soil erosion and in turn water quality. Additionally, pesticide and herbicide applications vary according to cropping methods. Conservation tillage techniques exhibit many environmental benefits over traditional tillage techniques. Of these 199 million acres of row crops, how many acres are grown under conventional or conservation tillage cropping practices. To date, the only method of estimating the total acreage by each cropping method is through the use of driving transects. Driving transects are time consuming, costly, and most importantly, incomplete.

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While there are many articles in the current literature related to the environmental benefits of conservation tillage cropping systems there remains a significant gap in the literature regarding the spatial extent and location of these areas. Currently no data exists regarding the spatial distribution or total area of agricultural fields utilizing conservation tillage techniques. The primary objective of this study is to investigate the possibility of utilizing remotely sensed data to differentiate cropping methods.

1.2 Land Use and Environment

Natural physical and biotic processes have been the primary mechanisms shaping the surface of the earth for millions of years. Man's impact on the environment has substantially altered the balance of natural processes across the globe. In all but recent history, the activities of man took place on limited areas, and the effect of human settlement was relatively small compared to the total earth surface. Increasing human population and technological advancements (agricultural and industrial revolutions) have significantly changed the processes that shape the earth's surface. The surface of the earth is in a constant state of flux, and humans are playing an increasingly greater role in these processes. Land use/land cover change associated with row crop agriculture, deforestation, and urbanization major agents of widespread change of what was once a natural landscape.

The carbon cycle is a particular aspect of the ecosystem that has been significantly altered due to anthropomorphic processes. Several studies have shown that the overall atmospheric concentration of carbon dioxide has been dramatically rising over recent decades (Fan et al., 1998, Appenzeller, 1998). A significant amount of scientific research has been undertaken to better understand the carbon cycle and man's impact and influences on the natural flow of carbon through the atmosphere, land surface, and oceans (Tans 1990, Houghton 1999, Houghton 1999a, Field & Fung 1999). To better understand man's role in altering earth's processes, a better geographic understanding is required. To what extent has man changed the natural balance, where are these changes taking place, what is the total area of change, and how will these changes affect our environment, now and in the future.

The 199 million acres of cropland scattered throughout the United States used for agricultural production of corn, soybeans, and wheat accounts for a very large area spatially. In fact, if the total acreage were aggregated together, the resulting area would completely cover the states of Illinois, Indiana, and Iowa. Yet little to no data exists regarding the spatial distribution and total area of production practices used to raise the annual crops. The two primary management practices, differing significantly in terms of environmental impact, are routinely in use today but no accurate estimate of total acreage or the spatial distribution of cropping methods across the landscape exists. A single 100 acre field has the potential to sequester approximately 12 million grams (12 metric tons) of carbon annually and significantly reduce soil erosion. Applying the same carbon sequestration potential of 30 g/C/m^2/year to the 199 million acres of row crop agricultural production results in a staggering carbon sequestration potential of 24,159,732 metric tons of carbon per year. In order to better understand the impacts of cropping methods on the natural environment basic spatial information regarding the spatial distribution and total acreage of the two primary cropping methods are required. Quantifying the acreage of each cropping method will allow for the accurate estimate of carbon sequestration and soil erosion across agricultural lands as well as other environmental effects and benefits.

1.3 Cropping Methods

Conventional and conservation tillage methods are the primary agricultural production methods found throughout the Midwestern United States. Each cropping method has associated trade offs and benefits that every producer must evaluate based on environmental, conservation, social and economic implications. Generally, factors affecting cropping method decisions are first and foremost financial, with soil conservation and other environmental benefits being secondary. Producers however, also realize there is a temporal element in maximizing economic gains. Short-term economic gains, yearly crop production, may result in long-term environmental consequences such as topsoil erosion, ultimately leading to diminished yields and profits. Producers must weigh the short-term economic benefits or advantages against long-term sustainability.

While the decision as to which production method to utilize ultimately lies in the hands of the producer, society has an interest as well. "The negative impacts associated with agricultural production, and the use of conventional tillage systems in particular, include soil erosion, energy use, leaching and runoff of agricultural chemicals and carbon emissions " (Uri, 1999). Clearly, the impact of agricultural production methods, made by thousands of individual farmers, reaches well beyond the scope of single fields and farms.

The consequences of agricultural production affect not only farmer's fields but also, more importantly, the larger shared environment. Production methods vary significantly regarding environmental costs and benefits such as soil erosion. Soil erosion from agricultural fields is the largest source of non point source water pollution in the United States. The federal government currently has programs in place to create incentives to protect highly erodible lands but the future of conservation incentives may lie with the reduction or sequestration of greenhouse gasses.

1.3.1 Conventional Tillage

Conventional or traditional tillage consists of a combination of plowing, disking, and tilling to condition and loosen the soil, mix in organic matter, and to prepare a flat and uniform seed bed. Conventional tillage practices create a soil surface highly susceptible to erosion until the crop has grown sufficiently to provide protection from environmental conditions such as wind and precipitation.

Soil erosion is the primary disadvantage of conventional tillage from a producer's point of view. Conventional tillage methods also release CO_2 to the atmosphere, contributing to global warming. Moldboard plowing mixes oxygen into the soil which oxidizes soil organic matter carbon, releasing carbon to the atmosphere as carbon dioxide. Conventional tillage techniques are the primary mechanism for carbon dioxide release from soils (Reicosky, 1996). Conventional tillage, however, does provide some measure of weed control in the field. Spring plowing kills early emerging weeds and brings weed seeds to the surface where they are susceptible to late frosts, and other weather conditions.

Conventional tillage was initially required to convert native ecosystems such as grassland and forested areas into agricultural production. Additionally, before the advent of effective herbicides, moldboard plowing was the primary method of initial weed control in agricultural fields. The tradition of moldboard plowing remained a standard method of field preparation throughout most of the twentieth century. Farmers engaged in field crop production utilized moldboard plowing and the technique was passed from generation to generation. There was no reason to abandon conventional tillage techniques, it provided plentiful yields and was a technique with which farmers were familiar. It wasn't until the 1970s that the technology for conservation tillage methods became widely accessible in the marketplace. Most family operated farms saw the cost of a specialized seed drill, required for conservation tillage techniques, as cost prohibitive. However, technological advancements in machinery, crop varieties, and agricultural chemicals have significantly altered the economics of crop production and conservation tillage methods are quickly spreading throughout the land.

1.3.2 Conservation Tillage

Conservation tillage practices are characterized by leaving the stubble from the previous year's crop on the soil surface. The stubble from the previous year's crop, left on the soil surface, dramatically reduces soil erosion. The stubble binds highly productive topsoil in place on the farmer's field preventing it from blowing or washing away over the years. Carbon sequestration is an additional long-term benefit associated with conservation tillage cropping methods. Conservation tillage cropping has been shown to enhance carbon sequestration rates in agricultural soils (Robertson et al., 2000).

Conservation tillage cropping methods, which leave plant litter in place, generally improve soil conditions. Plant litter positively affects soil conditions by affecting soil properties such as water infiltration, evaporation, soil porosity and soil temperatures (Reicosky, 1996). Litter left in place on the soil surface influences the flow of nutrients, carbon, water, and energy in terrestrial ecosystems. The decay of litter adds nutrients to the soil, improves soils structure and reduces soil erosion (Aase and Tanaka, 1991).

Not only does conservation tillage cropping exhibit positive environmental benefits but economic benefits as well. Conservation tillage cropping methods increase overall cost efficiency by way of reduced operation costs. Conventional tillage practices require the additional steps of plowing, cultivation, and disking as compared to conservation tillage cropping techniques. The costs of operating the tractor, the time to perform these tasks, and the cost of the implements are saved under conservation tillage cropping methods (Parsch, 2001).

While the yearly operating costs are lower with conservation tillage cropping methods, they do require an initial capitol outlay to purchase the specialized planting equipment required to successfully raise crops using conservation tillage techniques. The longer term economic advantages must be weighed against the short term capitol expense of a specialized planter or "drill". A seed drill cuts through the previous year's crop stubble and the unplowed soil surface beneath to plant the seed at the appropriate depth below the soil surface. Most farmers already own a traditional planter and see the cost of a specialized conservation tillage planter as cost prohibitive to adopting conservation tillage cropping techniques. In the past conservation tillage yields were generally 5 – 10 bushels per acre less than conventional cropping techniques. Technological advances in machinery, agricultural chemicals and round-up ready crop strains have closed the gap in yield between the two cropping methods. Farmers, as well as research in the literature, report that difference in yield between the two cropping methods is now negligible (Parsch, 2001). In fact, research has shown that continued conservation tillage methods result in higher yields due to enhanced soil fertility (Boyd, 2001). Agricultural fields must be cropped by conservation tillage methods for six years in order to raise soil fertility levels enough to positively effect yields (Boyd, 2001).

Conservation tillage techniques have, in the recent past, required more herbicide treatment than conventional cropping techniques thereby increasing cost. The advent of GMO (Genetically Modified Organism) hybrids, such as round-up ready corn and soybeans, has changed this necessity. Herbicide treatment on GMO soybeans has become extremely effective, requiring only one or two herbicide applications to effectively control all weeds in a field. GMO crops are genetically designed to work with a specific herbicide; the herbicide kills everything but the genetically engineered plant. These advances in agricultural technology have given conservation tillage cropping methods the upper hand in production cost. Conservation tillage cropping methods are quickly spreading throughout the Midwest as the cost savings of conservation tillage cropping over conventionally cropped methods increases.

The associated benefits of conservation tillage are meaningful at a variety of scales. At the individual farm level conservation tillage production methods result in:

- Reduction of labor and time spent preparing fields for planting
- Reduced costs in maintaining and operating farm machinery
- Improved water infiltration and storage
- Improved soil fertility
- Increased profit

Scaling up to the regional level reveals that the benefits of conservation tillage are not reaped by the farmer alone, but also benefit the immediate surrounding area and region as evidenced by:

- Reduced soil erosion
- Improved water quality in lakes, rivers and streams
- Less flooding due to improved water infiltration
- More stable water flows in rivers and streams due to improved water infiltration and storage of water within the soil and water table dramatically reducing soil erosion and runoff during rain events.

At even larger global level scales the impacts of conservation tillage can be observed. Conservation tillage from a global perspective results in:

- Carbon sequestration in agricultural soils
- Reduced water pollution from both soil erosion and agricultural chemicals,
- Recharge of aquifers through enhanced water soil infiltration rates
- Overall reduction in agricultural fuel use

The two primary tillage practices, encompassing such a large area spatially, exhibit a great deal of influence on the environment. With agricultural row crop production taking place over such a large expanse it seems the research community would have a great deal of data regarding the spatial distribution of cropping methods and acreage. This is not the case; fundamental data regarding the spatial distribution of cropping methods does not exist. The scaling up of field level research to larger regional areas allows for the incorporation of results into larger modeling scenarios to better understand the complex role man has in changing and shaping the environment. In order to better understand the impacts and influences of tillage methods results from the field level must be scaled to larger areas to accurately model or portray the influences field level cropping practices have on the larger environment.

1.4 Research Needs

Clearly, to gain a better understanding of the environmental impacts of row crop agriculture and the techniques used to raise these crops, a better understanding of the spatial distribution of cropping methods is required. Remote sensing data and analysis, properly applied, can provide an invaluable tool to assess, map, and monitor agricultural areas over a variety of scales. The results of such analysis will provide fundamental data regarding the spatial distribution and total area of agricultural cropping methods.

To better understand the environmental implications of man's influence on the environment, including the carbon cycle, and especially the missing sinks, more detailed data are required. Agricultural production encompasses a vast area, yet little to no data exists regarding the spatial extent and distribution of agricultural crops and the associated cropping methods used in production. Knowledge of the spatial extent and distribution of agricultural tillage practices will provide new insights into complex environmental issues including carbon dynamics. Such data will add another piece to the carbon cycle conundrum, including perhaps, some insight into the missing carbon sink.

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An additional requirement of this research is to ensure that the findings are repeatable as well as accessible to a wide variety of researchers. The methods used in this study attempt to offer an accurate and cost effective alternative to current collection methods such as driving transects. The methods, software, and data requirements for this study were selected with these characteristics in mind.

1.5 Statement of Problem

While it is clear from the literature that conservation tillage techniques exhibit many environmental and societal benefits, there are no data regarding the spatial extent and location of conservation tillage acreage. In order to accurately estimate carbon sequestration potentials, erosion reduction, and other environmental benefits, conservation tillage acreage needs to be accurately identified and mapped. Remote sensing provides the tools to identify and map the spatial distribution of conservation tillage cropping acreage over local and regional scales quickly, cost effectively, and by the use of easily repeatable methods. Additionally, remote sensing data creates a unique and permanent record that can be used to monitor conservation tillage over a variety of temporal scales.

The spatial extent and location of conservation tillage acreage will allow for the scaling up of previous studies to more accurately estimate the impacts conservation tillage farming practices have on the environment. The successful identification and mapping of conservation tillage acreage allows for examining temporal change as well. Current results can be compared with past or future data to monitor change in the spatial extent and location of conservation tillage acreage.

The specific research objectives to be addressed by this study are to: 1) Characterize the spectral properties of agricultural fields with crop residues, (conservation tillage), and fields composed of bare soil (conventional tillage); 2) Determine the most appropriate method of classification based on overall classification accuracy and data availability; and 3) To estimate the extent (acreage) of conventional tillage versus conservation tillage within the study area.

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CHAPTER 2 LITERATURE REVIEW

2.1 Digital Remote Sensing

Remote sensing may be defined as techniques that utilize electromagnetic radiation to detect and quantify physical, chemical and biological properties about objects that are not in contact with the sensing apparatus (Jahne, 1997). Remote sensing platforms commonly in use include digitally based aerial and satellite systems designed to view the earth's surface from an overhead perspective. The resulting digital images consist of data (digital numbers) based on reflected or emitted electromagnetic radiation from the surface of the earth.

The resulting digital image formation is a combination of information layers consisting of digital numbers (DNs) representing the relative reflectance of surface elements per spatial unit area, pixels. The data layers are based on the available spectral bands of the remote sensing instrument and commonly include spectral bands beyond the visible spectral range. The width of the spectral bands, spectral resolution, describes the sensors sensitivity to particular wavelengths, or more commonly, bands of wavelengths. For example, a near infrared band may be sensitive to electromagnetic radiation ranging in wavelength from 700 – 900 micrometers, not individual specific spectral wavelengths such as 751 micrometers.

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Each layer or spectral band is comprised of individual pixels representing a spatial area on the surface of the earth. Each individual pixel encompasses a predetermined spatial area, commonly referred to as the spatial resolution, or pixel size, of the data. An image product comprised of 30-meter by 30-meter pixels means that each pixel covers a 30-meter by 30-meter spatial area on the surface of the earth. The spatial resolution of image data is commonly referenced to the nadir position, the point falling directly beneath the sensor.

Because both the spatial and spectral aspects of the data collection are not infinitely small, both information layers or contents are products of averaging, both spatial and spectral. For example, if an object on the surface of the earth occupies a 5 meter by 5 meter area the corresponding 30 meter pixel encompassing this area is termed a mixed pixel. The resulting reflectance value for this particular object will be a combination of the reflectance from the object and the surrounding 25 square meters of the earth's surface.

A great deal of design work over the decades has resulted in more detailed data. Digital satellite based information is now commonly available to the research community in a rich assortment of varying spectral, spatial, radiometric, and temporal resolutions. The decision as to which remote sensing instrument to use for data collection must be carefully assessed based on the phenomenon to be observed and the sensor's ability to provide data on the phenomenon based on the spatial, spectral, radiometric, and temporal resolutions of the sensor. Data

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accessibility and cost are other commonly considered criteria when selecting a remote sensing data product. If the data are not publicly available or the cost of data are prohibitive, these factors may play an overriding role in the decision process.

2.2 Spectral Characteristics/Considerations

The successful differentiation between conservation tillage and conventional tilled fields lies in the spectral seperability of the two classes. With only a few minutes of training, it is possible to differentiate the two tillage methods with the naked eye from ground level. Conservation tillage fields contain stubble and plant residue from the previous years crop on the soil surface, whereas conventionally tilled fields do not. This fundamental difference between the two cropping methods will be used to differentiate the cropping methods in remotely sensed imagery.

There exists a fundamental lack of knowledge regarding the spectral characteristics of crop residues under field conditions. Only a few articles are available in the literature regarding the reflectance properties of standing crop residues under field conditions. These articles focus on alternative methods such as fluorescence and laser based technologies for detecting crop residues. The research community has seemed to accept outright the findings of laboratory studies concluding that differentiation between crop residues and soils based on spectral reflectance in the visible to short wave infrared (commonly available spectral bands on current and future sensors) portions of the electromagnetic spectrum are unattainable.

2.3 Crop Residue Spectral Characteristics

Previous studies investigating the spectral reflectance properties of crop residues are found in the literature, Gausman and Gerberman 1975, Daughtry et al., 1995, Daughtry et al., 1996, and Nagler et al., 2000. These studies concluded that across the visible, near infrared, and shortwave infrared portions of the electromagnetic spectrum the spectral reflectance of soils and crop residues were similar. Therefore, classification based on these findings would result in ambiguous conclusions. The data indicate that crop residues generally exhibit higher reflectance than bare soils. However, soils or crop residues could exhibit higher or lower reflectance across the visible, near infrared and shortwave infrared based on the complex interaction of many factors, including organic matter, moisture, texture, iron oxide content, and surface roughness (Daughtry et al., 1996).

These studies, however, do not directly address the possibility of classifying remotely sensed data under field conditions. These studies included several shortcomings including sample size, residue condition and lighting conditions. The sample sizes of these studies were unrealistically small, measuring 6 – 20 cm in diameter. The crop residues were also cut and/or ground to fit them into the sampling apparatus. The sample preparation and size are both unrealistic representations of standing crop residue under actual agricultural field conditions. Crop residues are a complex assemblage of stems, stalks, and leaves which overlay and cast shadows, conditions which are not accurately represented in the laboratory setting.

Furthermore, these studies only investigated each target individually. That is, measurements of crop residues directly overlying soils were not presented. This is of minor consequence, due to the fact that even if these studies had investigated crop residues directly overlying soils the small sample sizes along with the sample preparation (chopping and grinding) would not have been representative of agricultural field conditions. Agricultural fields and associated management practices take place at a scale where texture and shadowing play a significant role in overall spectral reflectance.

An additional consideration affecting the spectral reflectance of crop residues not taken into account with previous studies is the overall condition of crop residues under field conditions, especially given the temporal requirements of imagery acquisition. To identify conservation tillage from conventional tillage techniques data collection must occur after field preparation in the spring. Crop residues used in these previous studies indicate that recent crop residues were used as opposed to crop residues under field conditions in the spring. From the time of harvest to early spring, crop residues have been subjected to environmental conditions such as wind, snow, and rain, as well as

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decompositional processes. These environmental effects and decomposition significantly weather the crop residues and reduce the overall reflectance as compared to freshly cut crop residues found in the fall after harvest.

A recent article by Bricklemyer et al., (2002) investigated the use of Landsat ETM+ imagery to document no-till and conventional tillage practices in Montana. The article only addresses wheat cultivation and the research was performed relying on a single producer and fields under the producer's control. The paper illustrates the need to produce low cost and efficient methods to map and quantify tillage practices but is limited in scope and application. The article illustrates the suitability of using Landsat ETM+ data to classify cropping methods, albeit on a limited scale. The research demonstrates the importance of assessing spectral response patterns of tillage methods under field conditions. Bricklemyer successfully classified cropping methods, based on spectral reflectance under field conditions, used in wheat production. The research indicates that under field conditions wheat fields utilizing conservation tillage methods exhibit lower DN (digital number) values, or less reflective. The research provides an important example of the use of remotely sensed data to capture data relating to carbon sequestration and cropping methods.

2.4 Soil Spectral Characteristics

The spectral characterization of soils underlying crop residues or completely bare soils are important to characterize because they make up a larg

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large part of the overall observed reflectance from row crop targets, especially early in the growing season. Stoner and Baumgardner (1981) conducted a study to investigate the reflectance of soils. The study examined 246 soil series from 481 sites throughout 39 of the 48 contiguous states of the U.S consisting of 485 soil samples. They found that the 485 soil samples could be described by five reflectance curves identified by curve shape and the presence or absence of absorption bands. The five representative reflectance curves were a) Organic dominated, b) Minimally altered, c) Iron affected, d) Organic affected, e) Iron dominated (Stoner and Baumgardner, 1981).

They found that all Vertisol soil samples and a majority of Mollisol soil samples exhibited the organic dominated curve form. Alfisols, Entisols, Inceptisols, Mollisols, Spodosols, and Ultisols under an aquic moisture regime also exhibited an organic dominated or organic affected curve. Alfisols and Ultisols with a humid moisture regime follow the iron affected curve form. This research shows that while there are a great deal of soil types, when viewed spectrally, this great diversity of soil types can be simplified to five representative spectral curves.

2.5 Classification Methodologies

Image classification is the procedure of grouping pixels into spectral clusters based on spectral characteristics (Strahler, 1990). Image classification, i.e. categorization of pixels based on their spectral characteristics, is one of the fundamental analysis techniques for remotely sensed data, with land cover

mapping arguably being the most frequent application (Cihlar et al., 1998). Classification of image pixels based on spectral response allows for the grouping of pixels based on class membership, thus producing a new data product that identifies pixels of similar values into unique classes. Classification routines are commonly used in remote sensing studies to aid in image interpretation and are a valuable tool for information extraction.

Digital image analysis, including classification routines, offers many advantages over conventional interpretation, primarily due to the numeric nature of digital data sets. The use of computers provides the ability to perform rapid mathematical computations within or between spectral bands with little to no computational error. An additional advantage is the ability to perform a series of analyses, successful or otherwise, without altering the original data set. The ability to discard or save results offers a powerful analytical tool in its own right.

Several classification routines exist for the classification of multispectral imagery including maximum likelihood, minimum distance, and spectral angle mapping classifiers. The classification routines fall into three main categories; distance Based, probability based, and angular based decision rules. New classification routines or, more commonly, modifications to existing classification routines are frequently reported in the literature, an indication that there is no one ideal classification routine to suit all needs and requirements (Kaminsky et al.,1997, Murai and Omata 1997, Cortijo and Perez de la Blanca 1998, Cihlar et

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al., 1998, Erol and Akdemiz 1998 Kartikeyan et al., 1998). Each classification routine consists of a series of trade offs regarding processing time, model complexity, and classification accuracy. The decision regarding the most suitable classification technique is made on a case by case basis with factors such as spectral seperability, number of classes to be identified, processing time, and model complexity each playing a role in the decision process.

Geometric or distance based classifiers such as minimum distance rely primarily on mean values, ignoring variance within classes. The primary advantage of geometric processing routines lies in the relatively quick processing time to perform the classification. In the recent past, during the widespread adoption of desktop computing, when processing speed governed by the CPU (central processing unit) and RAM (random access memory) were limited, processing time was an important consideration when deciding on a classification routine. The quickly advancing technology of both CPU processing speed and availability of RAM, coupled with decreasing cost has negated this advantage. The speed and memory of most common desktop computers are now able to run advanced classification routines without the need for several hours or days of computational time.

Statistical classification routines offer, in most cases, higher degrees of classification accuracy over geometric classifiers. Statistical classification routines incorporate both the mean and variance of the data set into the classification decision rule. The utilization of variance into the classification decision rule provides additional data on which to base the classification, thereby improving overall classification accuracies. An illustration of the classification decision rule for both statistical and geometric classification routines is provided in Figure 1.

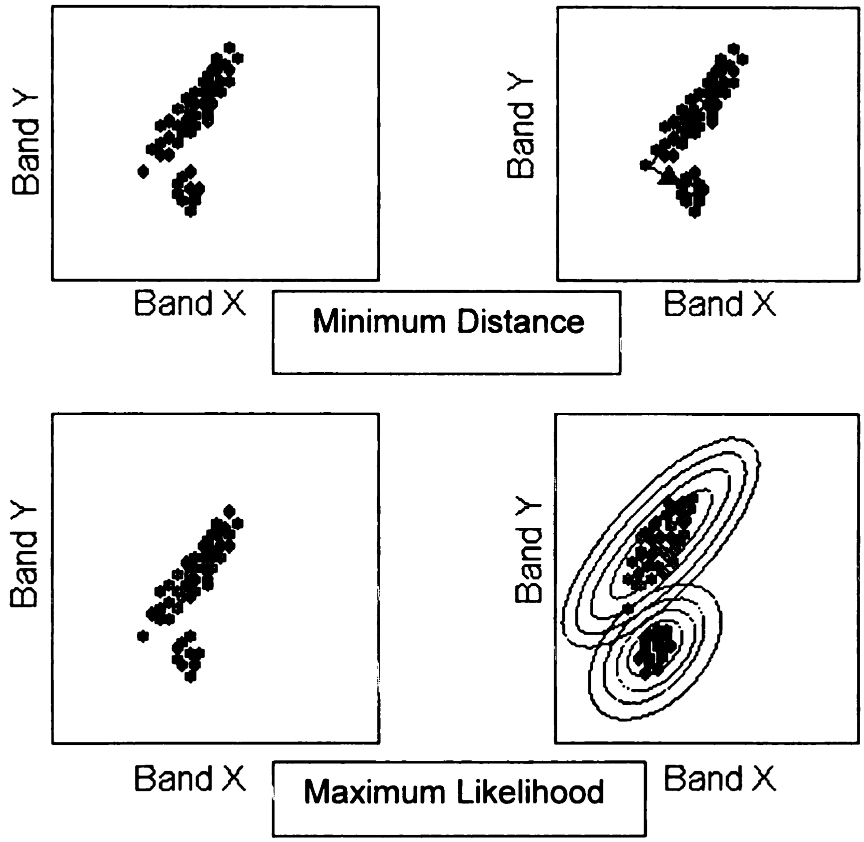

Figure 1. Classification Decision Space.

Image classification, or more specifically, digital image classification, uses the spectral information contained in the remotely sensed data to transform the data from digital numbers to information classes, a thematic data product. Data regarding the spectral response across each band for each pixel is used to classify pixels in the imagery based on spectral information. The resulting classified image is a representation of the original data merged into classes, the end result being a thematic map of the original image. The generated thematic map provides a means of representing spatial information in meaningful informational classes (land use/land cover).

The derivation of spectral classes is commonly performed using two primary procedures, supervised and unsupervised classification routines. Supervised classification techniques rely on the skill and knowledge of an analyst to identify representative training sites of various surface cover types or information classes. The basic steps to perform a supervised classification are:

-Determine ground cover type classes
-Establish training sites
-Signature collection of training sites
-Classification
-Classification accuracy assessment
-Presentation of classification results

The training sites, areas of homogenous pixels representing a particular informational class, are used to develop a spectral signature for each class. The analyst supervises the classification by identifying training sites and corresponding informational classes. Supervised classification techniques require ground truth information and/or knowledge and familiarity with the geographic area to accurately relate training sites with a particular land use/land cover type. The spectral information for pixels contained in the training sites are then used to develop spectral signatures for each training site. The software uses the spectral

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signatures derived from training sites to classify pixels in the remote sensing data set based on a variety of classification decision rules specified by the analyst.

Unsupervised classification uses clustering algorithms to partition the remote sensing data in multispectral space. These clustering algorithms are based on numerical and statistical measures resulting in classes that are based on natural breaks in the data, the basic steps for performing an unsupervised classification are:

-Specify number of output classes
-Perform unsupervised classification
-Assign/label classes to a land use/land cover
-Merge or expand classes based on results
-Classification accuracy assessment
-Presentation of classification results

Clustering algorithms are used to aggregate groups of pixels with similar spectral patterns into classes. These classes are only representative of class membership and may or may not represent individual informational classes (land use/land cover) on the ground. The classes are then examined by the analyst to determine if a particular clustering represents an informational class of interest. The only guidance or input to the classification scheme the analyst provides is the number of output classes prior to the clustering operation. It is common practice to specify a number of classes greater than the expected informational classes to ensure adequate separation of informational classes. The classes identified by the unsupervised classification are then examined by the analyst and associated with land use/land cover types. The decision rule in both classification methods can be statistically or geometrically based and the specific rules for assigning

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class membership can be explicitly stated in the classification routine or the default values provided by the software may be used.

2.6 Classification Decision Rules

2.6.1 Minimum Distance

Minimum distance classification decision rules are based on simple Euclidean distance. The mean value for each class is calculated and the unclassified pixel is evaluated against these mean values. The unclassified pixel is compared to the mean value of each class and assigned class membership based on the closest mean class value, or minimum distance.

2.6.2 Mahalanobis Classification

The Mahalanobis classification decision rule bridges the gap between simple Euclidean distance classification and probability based maximum likelihood classification routines. The Mahalanobis classification decision rule uses minimum distance as the main method of classification but also incorporates a directional weighting component derived from the covariance matrix based on a class average (Richards, Jia, 1999).

2.6.3 Maximum Likelihood

The maximum likelihood classification routine is generally regarded as a standard to which other classification routines are compared. The maximum likelihood classification routine is based on statistical probabilities. An unknown pixel is compared to training sites statistically and assigned to class membership based on probability theory. The maximum likelihood decision rule incorporates statistical measures and probabilities utilizing the covariance matrix to assign unclassified pixels to class membership. In order to sufficiently train the classifier a statistically significant number of training pixels must be utilized to accurately estimate the covariance matrix. To avoid a singular covariance matrix the number of training pixels for each class must be at a minimum N+1 pixels large, where N is the number of spectral bands. To further ensure accurate covariance matrix estimation a commonly recommended minimum is 10*N pixels for each class is desirable. Swain and Davis (1978) recommend a minimum of 10N pixels for each class with 100N for each class being even more desirable.

The classification accuracy for maximum likelihood classification routines depends heavily on the accurate estimation of the covariance matrix. To accurately estimate the covariance matrix a sufficient number of pixels for each class training site must be readily available. However, even if great care is taken to ensure a statistically significant number of training pixels are used to generate reference signatures, the underlying decision rule still requires an assumption of data normality with well defined variances in each spectral band (Sohn and Rebello, 2002). These assumptions are generally not met using multispectral data sets; spectral bands obtained from remotely sensed imagery often are skewed or exhibit non-normal distributions. Given the inherent limitations and assumptions that must be met with maximum likelihood classification decision rules

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rules in order to accurately estimate the variance and covariance matrix, it is evident that spectrally similar reflectance patterns may well be inaccurately classified.

2.6.4 Spectral Angle Mapping

Spectral angle mapping (SAM) is a classification decision rule based on spectral angles formed between a reference spectrum and an unclassified pixel in n-dimensional space where n is the number of spectral bands available. Spectral angle mapping offers an innovative technique to classify data. The decision rule is straightforward to understand; a vector is plotted in n-dimensional space for an unknown pixel. The angle this vector forms with the vectors of reference signatures is compared for each reference vector and the pixel is assigned class membership to the smallest angle formed with respect to one of the reference vectors. An advantage of this method is that SAM is relatively insensitive to illumination and albedo effects (ENVI, RSI Inc., online help). Because the vectors of both the unclassified pixel and the reference spectra are vectors in n-dimensional space, a variation between pixels due to illumination or albedo effects will have little effect on the vector.

The term spectral angle mapping is used loosely in the literature and may refer to any one of several SAM variations. Some references to SAM in the literature are referring to simple angular decision boundaries to partition multispectral space. Other references to SAM refer to a classification routine k

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known as the cosine of the angle concept, a technique that builds upon SAM principles.

2.6.5 Cosine of the Angle Concept

The cosine of the angle concept algorithm determines the spectral similarity between spectra by calculating the angle between the vectors of the spectra for each band in multi-dimensional space. The spectra are represented in multidimensional space (determined by the number of bands) as vectors and the angle between the reference spectra and target spectra are calculated similar to the SAM technique. The cosine of the angle concept takes SAM a step further by calculating the cosine of the angle formed between the vector representing the unclassified pixel and the vectors representing the reference spectra (Figure 2). The cosine of the angle concept effectively incorporates the length of the vectors of the reference signature and the pixel to be identified by incorporating the cosine of the angle. The cosine of the angle formed between the two vectors is defined by the adjacent over the hypotenuse. Thus, the length of the vectors are incorporated into the decision rule, adding additional information to the classification decision rule over spectral angle mapping. Spectral angle mapping uses only the angle formed between the vectors as the decision rule.

The angle that defines a spectral signature or class does not change and the vectors forming the angle from the origin delineate and contain all possible positions for the spectra (Sohn and Rebello, 2002). These parameters g

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encompass all the possible combinations of illumination for the spectra. The fact that the spectra of the same type are approximately linearly scaled versions of one another due to illumination and topographic variations is utilized to achieve accurate classification results (Sohn et al., 1999). Cosine of the angle concept relies on a normalized dot product, the cosine of the angle formed by the vectors of the spectra, which can be utilized to overcome shortcomings of statistical and geometric classification routines to successfully classify spectral groups (Sohn et al., 1999).

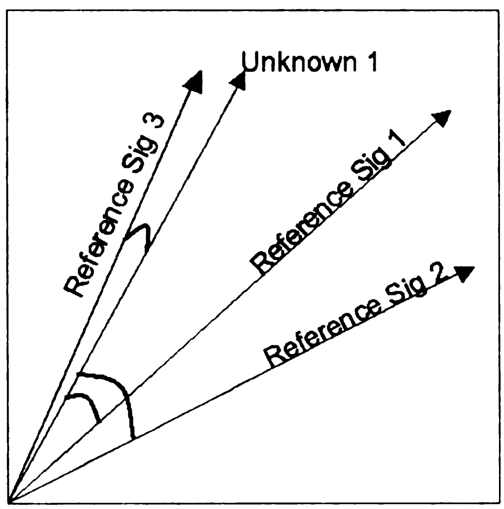

Figure 2. Cosine of the Angle Concept Decision Space.

The spectral signatures of healthy green vegetation and soil provide an example. The spectral signatures of the two targets, vegetation and soil, are distinct enough to permit accurate classification with traditional classification routines. Now compare the spectral signatures of soil and senescent vegetation. The spectral signatures of the two targets are much more similar. It is possible, due to illumination, topographic or soil moisture effects that variation between the

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two signatures may significantly overlap. If traditional classification routines, which rely on means and variances are utilized, the two classes will be misclassified in a number of instances. Cosine of the angle concept works around the shortcomings of traditional classification routines by encompassing all the possible illumination, topographic and soil moisture effects in a single class (Sohn et al., 1999). The underlying signature as defined by the angle of the vectors remains invariant; the vectors into multidimensional space form the boundaries for all possible illumination and topographic effects (Sohn et al., 1999). This method relies on the fact that the unique spectral signature as defined by the cosine of the angle for each signature set does not change. Changes in reflectance due to illumination effects are still within the class angle only the magnitude of the vector changes (Sohn et al., 1999).

New data sources and sensors coupled with improved classification routines show a great deal of promise in discrimination between conventionally tilled and conservation tillage cropping techniques under field conditions. The improved radiometric and spatial resolution of Landsat 7 ETM+ data provide a more detailed data source than previously available to the research community for large scale agricultural mapping studies (Goward et al., 2001). Improved data sources together with enhanced classification routines provide the basis for classifying previously difficult to discriminate spectrally similar targets such as soils and crop residues.

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2.7 Accuracy Assessment

The confusion matrix has been identified as a best practice standard for assessing overall accuracy as well as identifying errors of omission and commission (Foody, 2002). Recent literature suggests a commonly recommended target of 85% classification accuracy (Foody, 2002). The United States Geological Survey (USGS) has also set a guideline of 85% classification accuracy for remotely sensed data products.

The confusion matrix, or error matrix, is a representation of classification accuracy with the rows representing the findings of the classification and the columns containing the reference data. The error matrix, if all goes well, is read down the diagonal: the column and row totals for each class should match identically, if not, a classification error exists. This method allows for the identification of both errors of inclusion (commission errors) and errors of exclusion (omission errors).

The practice of using training site pixels in classification accuracy assessment is one that should be avoided. Campbell (1987) wrote regarding the use of training pixels as classification accuracy assessment that the "biased procedure is born of expediency and can have little use in any serious attempt at accuracy assessment." Pixels selected for classification signature collection should not be used again in the classification accuracy assessment. A better method is to compare classified pixels with known ground truth data points that were not used in classification signature collection.

CHAPTER 3 MAPPING TILLAGE PRACTICES

In principle, land cover mapping from satellite data is straightforward and consists of four steps: data acquisition, pre-processing, analysis/classification and product generation (Cihlar, 2000). In addition to the aforementioned procedures, a knowledge and familiarity with the landscape and management practices operating across the landscape also provide a great deal of information to be used in the overall analysis procedure. A diagram providing an overview of the methods is provided in Figure 3. This section provides a description of the study area and the methods utilized in data analysis and extraction.

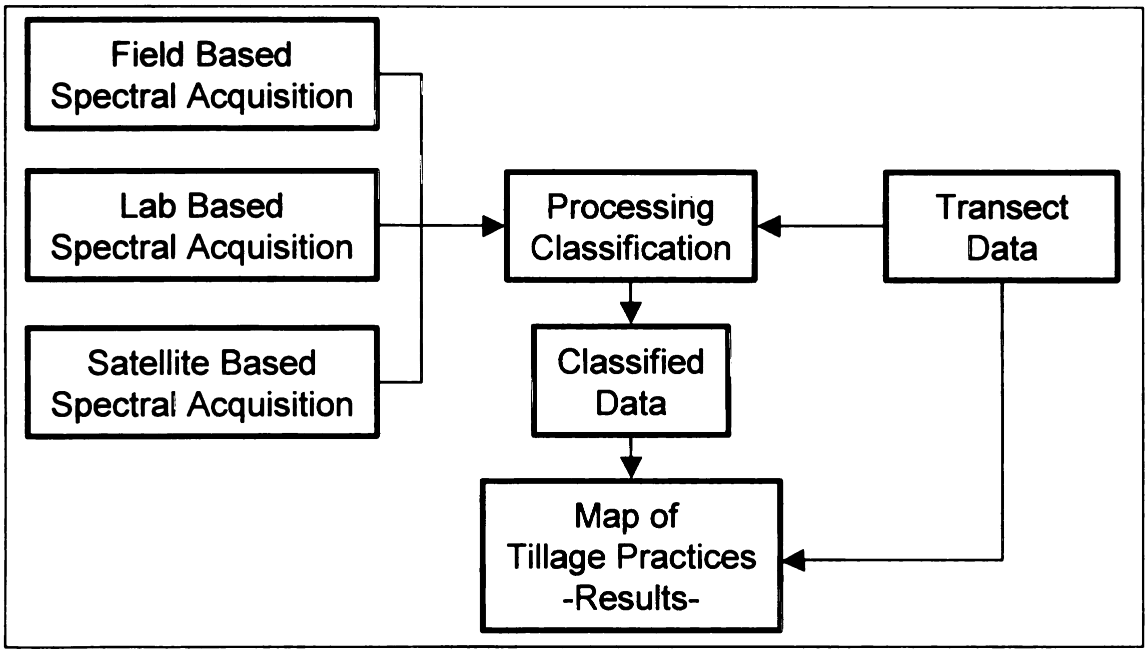

Figure 3. Diagram of Methods

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3.1 Study Area

The study area is delimited by Landsat path 21 row 31 an area that encompasses a 180 km by 180 km area of southwestern Michigan, northern Indiana, and a section of northwestern Ohio (Figure 4). The study area is primarily dominated by agricultural land use with intermixed forested areas. The study area also encompasses urban and suburban land uses as well but spatially these areas are small in comparison to the surrounding countryside. A total of 4,356,644 acres of farmland lie within the 22 counties encompassed by the study area. A cross section of the study area from Fort Wayne, Indiana to Lansing, Michigan is representative of the region; the landscape is dominated by row crops. Cropping systems in the area are typical of the U.S. corn belt, comprised mainly of corn/soybean acreage. Alfalfa and winter wheat are also produced throughout the region but spatially account for very little of the overall landscape. The 22 counties encompassed by the P21 R31 swath collectively produced $1,702,236,000 in agricultural sales for the year 2002 (Table 1) predominantly through corn and soybean production (USDA, 2002). The Great Lakes and Midwestern regions of the United States are some of the most productive areas in the United States for agriculture production. Agriculture has been a dominant industry in the region since settlement occurred with many of the farms under active cultivation for over one hundred years.

Figure 4. Study Area Location.
Landsat 7 P21 R31

County	State	Acreage	$ Production	$/Acre
Paulding	OH	209,983	$54,144,000	$257.85
Defiance	OH	186,385	$45,248,000	$242.77
Williams	OH	203,201	$51,383,000	$252.87
Steuben	IN	123,953	$25,641,000	$206.86
Lagrange	IN	189,932	$103,278,000	$543.76
Elkhart	IN	182,771	$124,038,000	$678.65
St Joseph	IN	154,142	$55,178,000	$357.97
Marshall	IN	201,637	$62,187,000	$308.41
Kosciusko	IN	246,907	$146,062,000	$591.57
Noble	IN	181,963	$58,841,000	$323.37
Dekalb	IN	162,936	$38,669,000	$237.33
Allen	IN	276,385	$89,877,000	$325.19
Whitley	IN	165,067	$51,930,000	$314.60
Allegan	MI	236,936	$186,757,000	$788.22
Van Buren	MI	177,360	$100,641,000	$567.44
Kalamazoo	MI	146,927	$105,494,000	$718.00
Calhoun	MI	243,151	$60,985,000	$250.81
Jackson	MI	181,287	$44,311,000	$244.42
Hillsdale	MI	257,469	$71,729,000	$278.59
Branch	MI	234,076	$77,249,000	$330.02
St Joseph	MI	217,345	$81,103,000	$373.15
Cass	MI	176,831	$67,491,000	$381.67
Total		4,356,644	$1,702,236,000	$390.72

Table 1. Study Area Acreage and Production Value. Source: USDA (2002).

3.2 Study Area Physical Characteristics

Annual rainfall measured at the Kellogg Biological Station averages 890 mm y^{-1} (54) (LTER). Potential evapotranspiration (PET) exceeds precipitation during the summer months with a maximum generally observed during the month of July. Mean annual temperature is 9.7 °C, (Figure 6) and the average growing season is approximately 140 – 160 days per year. The temperature and precipitation of the region are well suited for agricultural production. Within the Koeppen climatic classification system the climate of the region is characterized as moist continental mid-latitude with cold winters. These climatic conditions are well suited for corn, soybean and cover crop production.

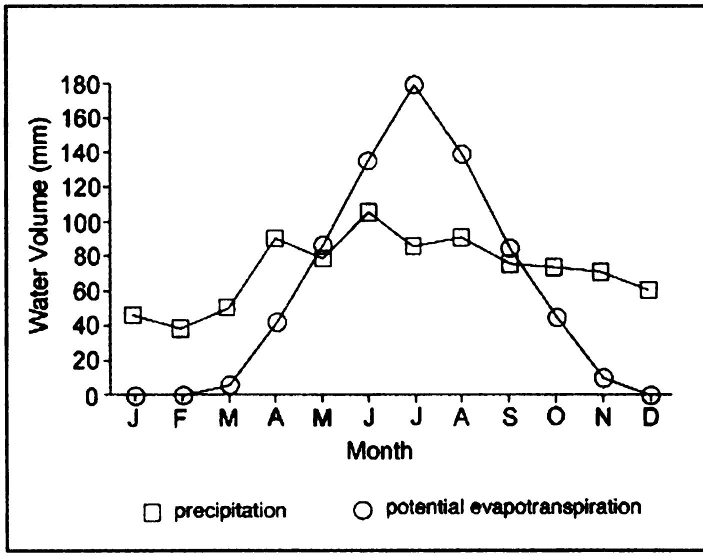

Figure 5. Study Area Precipitation and Potential Evapotranspiration.
Source: KBS LTER

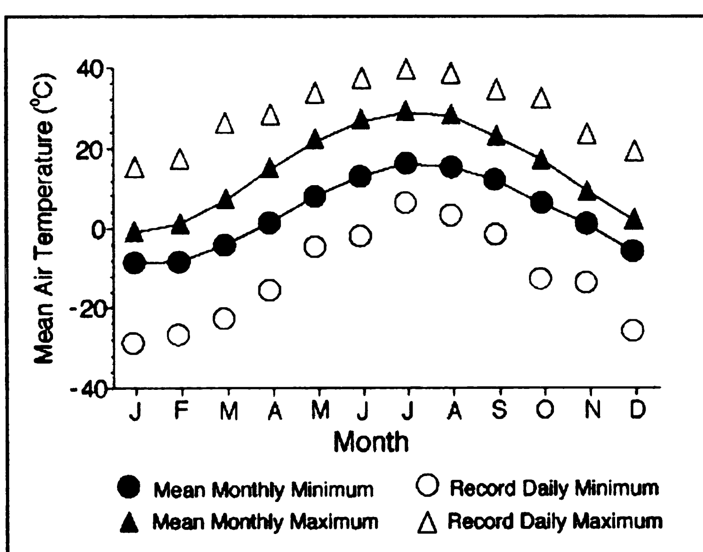

Figure 6. Study Area Yearly Temperature Graph.
Source: KBS LTER

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The study area landforms and soils have been extensively shaped by glacial processes. The last major glacial activity occurred during the Wisconsinan glaciation of the Pleistocene epoch approximately 13000 to 16000 years B.P. The study area encompasses a diverse, glacially-formed landscape including such features as outwash plains, ground and end moraines, and ice contact features such as kames and kettles (USGS, 1998).

Soils in the area developed on glacial till, and include well- and poorly-drained alfisols, mollisols, and entisols. Most regional soils are sandy loam and silty clayey loams of moderate fertility (KBS LTER). The major soil associations of the study area are predominantly alfisols of which udalfs are the dominant suborder (USDA, 2000). Loamy sands found primarily in outwash plains and sandy loams or loamy sands commonly associated with end and ground moraines (USGS, 1998).

The soils of the moraines are typically well and excessively well drained. Drainage conditions on the outwash are more variable, ranging from excessively well drained to very poorly drained. Thick outwash deposits are usually characterized by excessively well drained conditions. Shallow outwash deposits are underlain in some places by bedrock or fine textured till and lacustrine deposits, causing poor or very poor drainage conditions (USGS, 1988). On ice contact topography, soils are typically excessively drained on the upland kames and

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and eskers and poorly or very poorly drained in the kettles and outwash channels (USGS, 1988).

Soil textures range from sand to clay; the most common soil texture is sandy loam on the moraine ridges and sand on the outwash plains. The glacial drift that forms the moraines is largely derived from the local limestone bedrock. In the ice contact areas, soils are sands and gravels, which are well drained and not well suited for agricultural production.

Very poorly drained soils are common in the narrow outwash channels between drumlins and in ice-block kettles or abandoned stream channels (USGS, 1998). Poorly drained areas combined with significant inputs of organic materials can lead to peat accumulations of up to 6 to 10 feet thick. Soils on the end moraine and ground moraine are typically sandy loam or loamy sand, and most are well drained. A well-developed argillic horizon is common in these soils (USGS, 1998)

Poorly drained soils, if not reclaimed for agricultural production through drainage activities, are generally forested or remain as wetlands or swampy areas. Upland areas which tend to be well drained are dominated by agriculture. Many of the historical wetland areas have been drained and converted to agricultural production.

Soil erosion across the study area is well below the national average due to a maximum average slope of 3.2 feet/mile (USGS, 2000). The small slopes across the study area result in relatively small losses of soil from agricultural lands of 1.0 – 5.0 tons/acre/year compared to other reports of 21 tons/acre/year for a national average of erosional soil loss from agricultural lands (Aber, Melillo, 2001). For comparison, the estimated erosional soil loss from forested areas is estimated at 0.001 to 0.06 tons/acre (Kimberlin and Moldenhauer, 1977).

3.4 Study Area Agriculture

Agricultural production across the study area, and the Midwestern United States, is primarily comprised of corn and soybean rotations with lesser amounts of secondary crops such as alfalfa and winter wheat. Corn and soybeans are commonly grown on the same acreage alternating yearly. The practice of yearly crop rotation between corn and soybeans is primarily driven by the need to maintain soil fertility. Corn and soybeans are also readily marketable, ensuring that both crops are widely produced. Corn and soybeans are used not only in food production, both human and livestock, but also in a wide variety of corn and soybean based products.

Following settlement the study area was systematically logged, cleared, and in many cases drained to enable agricultural production. Historically crop production throughout the study are encompassed many crop types grown on small family owned and operated farms. Crops included corn, alfalfa, oats, wheat and other small grain varieties with the vast majority of acreage used for small grain and alfalfa production (USDA, 1993). Until mechanized machinery was widely available, shortly after WWII, most crop acreage was produced in relatively small fenced fields consisting of 5 – 10 acres (USDA, 1993).

Widespread adaptation of mechanized equipment used in agricultural production resulted in a significant change in crops, field size, and environmental impacts. As field sizes increased, tree lined fencerows that once separated individual fields and provided a measure of erosion control were lost. Large mechanized machinery resulted in a dramatic change in the amount of land that could be worked and also led to an economy of scales. Larger fields enabled farmers to make long uninterrupted passes through a field with implement and tractor, fewer turns and maneuvering of machinery results in less time working the land. Larger individual field sizes coupled with larger more powerful and efficient equipment resulted in larger farms (more acreage) even though the total number of farms was decreasing (Baker et al., 1998).

The shift in agricultural crops from small grains and alfalfa raised on small fields to the widespread production of corn and soybeans on larger individual fields has created a variety of environmental impacts. Small grains and alfalfa are planted in very close proximity of one another, that is the spacing of plants and overall density of plants is very tight and compact. The close plant spacing and tight canopy provide protection from erosional processes such as wind and water action. This is in marked contrast to corn and to a lesser degree soybeans. Individual corn plants are planted at a spacing of 10" – 14" apart from one

another along a row and rows are generally 20" – 30" apart, leaving a large portion of the soil exposed to erosional action. Even at full canopy development the soil beneath a corn crop is bare and the only protection from erosional action is the stalk and root system. Soybeans also leave a bare soil surface exposed to the elements under a fully developed canopy. The row spacing of soybeans is closer than corn, generally 18" –24", but still leaves a portion of unprotected soil until full canopy development.

In addition to erosional losses due to a shift in cropping methods, crops and field size associated with larger scale mechanized farming methods. Before the widespread adaptation of mechanized farming and implements, carbon implications associated with agricultural crop production were less severe than presently observed with conventional tillage methods. Smaller field sizes, which were required due to the amount of work that could be performed by an individual farming family with manual labor and livestock, meant that less overall area was impacted by farming during settlement and before widespread availability of mechanized farming equipment. Additionally, due to what some would term the inefficiency of horse drawn implements and manual labor a great deal of crop residue was left on the soil surface following harvest. Even if the stalks of small grain crops were harvested for straw the machinery of the day paled in comparison to the efficiency of modern day agricultural machinery and left a great deal of plant residue in place. Plowing was another aspect of farming that has undergone significant change following WWII.

Before mechanized farm machinery was available plowing a field consisted of either manual labor or livestock assisted plowing methods. Both methods were time consuming and labor intensive work, limiting the amount of soil that could be worked in a single year by a single farm. Plows designed to be pulled with tractors quickly changed the amount of acreage that could be worked by an individual or family farm. Tractors have become more powerful and efficient over the years leading to larger and larger field sizes.

In addition to market demands, corn and soybeans are widely raised on an alternating yearly basis for the benefits associated with soil fertility and long term production capacities. Corn production is nitrogen intensive, a nutrient that can be quickly diminished in topsoil if corn production is continuous on a particular piece of land. Corn yield is closely related to soil nitrogen availability and farmers routinely add nitrogen fertilizer to corn acreage on a yearly basis to increase yield. To offset or minimize the loss of soil nitrogen due to corn production farmers rotate crops between corn and soybeans on a yearly basis, one-year producing corn the next soybeans. The advantage of using a rotating corn/soybean crop system is that soybeans effectively fix nitrogen from the atmosphere and sequesters nitrogen in the soil. The added nitrogen from soybean production from the previous years crop adds to soil fertility and provides nitrogen so critical to achieving profitable corn yields.

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Winter wheat and alfalfa are two commonly occurring secondary agricultural crops produced across the study area. Winter wheat and alfalfa production occurs at a much smaller scale than corn or soybean production primarily due to market demands and crop values. Winter wheat production does not provide as much income on a per acre basis as compared to corn and soybean production so the amount of winter wheat production is correspondingly much lower throughout the study area. The majority of winter wheat production has shifted to the great plains area where the soils are not of suitable quality for corn and soybean production but are quite adequate for winter wheat production. As the value of corn and soybeans has risen over the past decades agricultural production has shifted to corn and soybean production on soils that will support intensive row crop agriculture. The soils found on agricultural lands throughout the study area are of sufficient quality to support corn and soybean production resulting in less land used for winter wheat production.

Alfalfa is an additional secondary crop found throughout the study area but again, as with winter wheat, does not provide the economic incentive for farmers to raise the crop over large areas. Alfalfa production thrives in the soils and climate found throughout the study area but is primarily used as feed for livestock. The production value of corn and soybeans exceeds the economic return for grazing and or feeding livestock and this is reflected in the land use/land cover of the study area. Alfalfa production that does occur within the study area is generally on smaller acreage fields in support of small family owned and operated farms that use the alfalfa production to raise a small number of livestock owned on the farm. Alfalfa is a crop in which a large portion of the entire above ground biomass is harvested, not just the seed or grain as in corn, soybean, and winter wheat production. Alfalfa, when harvested is baled, creating a very heavy and bulky commodity. A commodity that is very expensive to transport as opposed to corn, soybean and wheat production which is easily handled and of which only a small portion of the harvested plant is used. Alfalfa on the other hand is difficult to handle, expensive to transport due to the weight and size of the bales and also relatively expensive to store due to the size and bulk of bales. Additionally, alfalfa does not store or keep well for extended periods of time. These limitations make for a crop that has limited marketability and value, with farmers generally only producing limited amounts for personal on farm use or for sale to the immediate surrounding area.

3.5 Ground Truth Data Collection

Several large farms employing conservation tillage techniques have been identified through personal correspondence with agricultural field extension agents in the Landsat 7 P21 R31 study area. These farms will serve as classification accuracy assessment checks for image processing of Landsat 7 data. Driving transects were established to include these large farms. A subset of these fields were used as end members for spectral signature collection while the majority will be used as classification accuracy check of the classified image.

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The KBS LTER site provides field access to a variety of crops and cropping methods and provides full access to agronomic logs detailing the methods and dates of fieldwork. While the KBS LTER site manages the largest repetitive experimental agriculture plots in the country, they are too small (100 m by 100 m)to be used in a study relying upon Landsat 7 data (30 m by 30 m)pixel size). The KBS LTER plots provide access for hand-held radiometric reflectance readings, as well as a knowledgeable staff to provide assistance and advice relating to cropping systems. Making use of both the LTER site and larger privately held fields ensures field access and provides a target large enough to be used with Landsat 7 data.

3.6 Laboratory Radiometric Sampling

Laboratory radiometer measurements were performed using an Analytical Spectral Devices, Field Spec Pro. The Field Spec Pro collects spectral data in 2134 channels between 350 nm to 2500 nm of the electromagnetic spectrum. The spectral resolution from 350 nm to 1050 nm is 3 nm and 10 nm for the 1050 nm to 2500 nm portion of the spectrum. This level of spectral resolution provides a great amount of detail that has not been available until recently.

Laboratory measurements were taken from a height of 50 centimeters utilizing a 24 degree fore optic resulting in a field of view (FOV) of 21 cm. Crop residues of soybean and corn stubble were examined as well as bare soil. Measurements were taken under a variety of conditions including crop residue alone and crop residue directly overlying soil. Measurements were also taken of samples consisting only of soil. Laboratory measurements were taken under dry conditions, both the soil samples and crop residues were allowed to air dry for 48 hours before radiometric measurements were taken.

Radiometric sampling was performed using a direct overhead position, commonly referred to as NADIR. The illumination source consisted of laboratory grade halogen light source operated with a DC inverter. The DC inverter ensures any electrical fluctuations in current or voltage common with AC electrical sources are suppressed to minimize any potential fluctuations in illumination.

3.7 Field Based Radiometric Sampling

A backpack mounted hyper-spectral radiometer (Analytical Spectral Devices, Field Spec Pro) was used to collect spectral data of conservation tillage and conventionally tilled crops in situ. The data provided valuable information regarding the spectral response of the two cropping methods under field conditions. These data provide not only ground truth data but also a great deal of data regarding the placement of spectral windows for future remote sensing platforms. Additionally, field spec pro data can be utilized in the future to create classification end member inputs for a variety of other remote sensing platforms. The field spec pro data can be resampled and aggregated to approximate the spectral resolution of a wide variety of remote sensing platforms.

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The Field Spec Pro offers a variety of fore optics for controlling and adjusting the field of view (FOV). To investigate the issues of scaling and reflectance, spectral reflectance measurements were made using varying fore optics (8 and 24 degree) while holding the height of the instrument constant above the field surface at a height of two meters. Using the 8 degree fore optic at a height of 2 meters results in a FOV of 28 cm, a 24 degree fore optic at the same height results in a FOV of 85 cm. Overall field conditions were relatively dry with no noticeable moisture present. Measurements were taken in the principal plane at the NADIR position. Field measurements were calibrated using a spectralon panel and converted to reflectance utilizing readings of the calibrated reflectance panel.

3.8 Ground Truthing – Driving Transects

Driving transects consisting of approximately 960 miles were established within the Landsat 7 P21 R31 swath (Figure 7). These transects provided the ground truth data about crop type and cropping method. Along the driving transects agricultural fields were identified and recorded using a GPS video overlay system. This system incorporates a video camera and a GPS unit to record fields along the driving transect and overlays the GPS positional coordinates directly onto the videotape. This system provided digital ground truth data incorporating position, date, time and a video recording of the field condition observed during the driving transect. These transect data also provided ground truth information for the classification accuracy assessment. A definitive accuracy assessment requires the use of ground truth as part of the sampling design (Magnussen, 1997).

Driving transects were established using Landsat 7 P21 R31 ETM+ imagery from June 6th 2001 and input from agricultural extension agents. Imagery from 2001 was examined to identify areas within the scene that consist primarily of agricultural land use. Additionally, transects were developed to include areas identified by extension agents as places where conservation tillage cropping has historically taken place. Through personal conversation with these agents, many indicated that 50% - 80% of all agricultural fields in southwestern Michigan are cropped using conservation tillage practices. Using these two methods -- examining last years imagery to identify agricultural areas coupled with input from agriculture extension agents ensured that the driving transects sampled the appropriate areas.

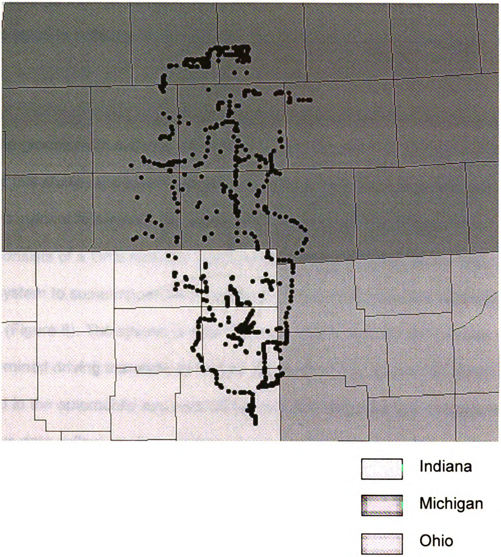

Figure 7. Driving Transect Data Points.

Collecting ground truth data for use in conjunction with remotely sensed data sets is commonly practiced. Ground truth data provide valuable information to assess classification results as well as ensuring training sites for supervised classification are accurately identified. The collection of ground truth data points is often limited by time. Ground truth data should ideally be collected as close to the time of imagery acquisition as possible, especially in areas with seasonal temporal change such as in agricultural settings. This study relies on the coupling of technologies to collect ground truth data quickly and accurately over large areas.

The ground truth data collection system employed for the driving transect portion of this study uses commonly available collection devices in a new and innovative manner to permanently collect and record ground truth data. The system consists of a GPS receiver, video camera, video recorder, and a text overlay system to superimpose GPS positional data directly onto the videotape in real time (Figure 8). The system is mounted in an automobile and driven over pre-determined driving transects across the study area. The system is entirely contained in the automobile and runs off the vehicle's electrical system ensuring continuous data collection. This method of collecting ground truth data could potentially be used anywhere accessible to automobiles or off road vehicles.

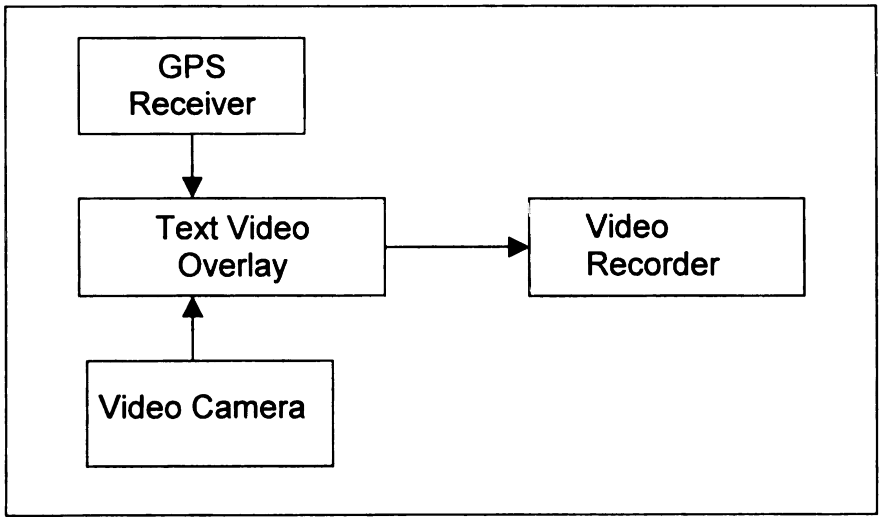

Figure 8. Ground Truth Data Collection Flow Chart.

A Garmin GPS 53 was used to collect positional data for the driving transect. The Garmin GPS 53 utilizes the WAAS (Wide Area Augmentation System) technology to provide a real time positional accuracy of 3.2 meters. More than sufficient to locate and identify agricultural fields within Landsat 7 imagery which consists of 30m X 30m pixels (Wilson, 2001).

The Garmin GPS 53 was coupled with a Sony digital video camera (Sony Model DCR-PC9), a Sea-Trak GPS video overlay unit and a Panasonic S-VHS video recorder (Model AG-7400). Together this system creates video imagery with the real-time GPS positions recorded directly onto a S-VHS videotape. The system was mounted in a motor vehicle and utilized throughout the driving transect survey to accurately and permanently record ground truth of field conditions and position.

In addition to continuous recording of the driving transects, utilizing the GPS video overlay system, waypoints were also regularly collected. Fields of interest, large agricultural targets with clearly discernable crops and cropping methods, were routinely recorded by collecting a GPS waypoint. These waypoints were downloaded from the GPS unit (UTM, WGS84) and imported into ArcView for analysis and display. The waypoints were converted to a point shapefile and overlaid directly onto the P21R31 Landsat 7 ETM+ imagery. The point shapefile was then used to create a polygon shapefile of the field of interest corresponding to the appropriate waypoint by on-screen digitizing.

Four hundred and eighty (480) fields were logged as waypoints during the transect. These 480 fields were used primarily as classification accuracy assessments but also provided known ground truth points to collect spectral signatures from the Landsat 7 imagery to be used as input in the supervised classification routines. Only a small subset of the 480 logged fields, thirty eight, were used to collect spectral signatures, ensuring that a significant number of logged fields were available for use as classification accuracy checks.

Traditional driving transects performed to collect data on crops and cropping methods only provide rough estimates of total field size. The area of fields are estimated through observation and are not directly measured. Data obtained from classified imagery on the other hand not only reflects the occurrence of a land use/land cover, but also provides data regarding the total land area of each class. Corn and soybean fields tend to be much larger spatially than either winter wheat or alfalfa, a factor that may not be accurately accounted for with traditional driving transect data collection methods.

Over the recent past, since no till machinery has become widely available, it has tended to be the larger farm operators who have embraced no till techniques rather than the smaller family farms. This is due, in large part, to the large capitol outlay required to obtain a specialized conservation tillage seed drill which is often cited by small operators as a financial barrier to adopting conservation tillage techniques. A related reason is economy of scale. The time required to recoup the costs of a conservation tillage seed drill is significantly extended on a small farm of limited acreage. There also exists a social/behavioral component with many small family operated farms that values time honored techniques and traditions that are passed down from generation to generation.

These examples illustrate the clear advantage of utilizing remotely sensed data for agricultural crop, tillage, and acreage assessment over relying solely on driving transect data. Driving transects only cover a small portion of an area, the results of the driving transect are then scaled up to estimate the total area for each crop/cropping method in the study area. Some driving transects make an attempt to quantify field acreage during the driving transect, but they fail to account for variation of field sizes throughout the study area. Remote sensing imagery, with its overhead vantage point, is able to capture large areas essentially in a single moment in time. This ensures that errors often made from ground level, including inaccurate estimation of field size and limited distance of sight, are avoided.

Another shortcoming of traditional driving transects is that they are not well suited for monitoring yearly temporal change associated with crop rotations.

Driving transects are not regularly performed on a yearly basis due to budget and time constraints. Agricultural extension agents, as well as the vast majority of people involved in agricultural production, are extremely busy with planting and field preparation activities during the time driving transects would have to be performed to characterize tillage methods. The lack of annual data fails to accurately capture the temporal change involved with agricultural crop rotations among fields.

Remotely sensed data, on the other hand, are well suited for monitoring temporal change. Satellite imagery is routinely collected at the beginning of each growing season. Coupling remotely sensed data with a driving transect to record ground truth capitalizes on the inherent advantages of both methods. In the case of Landsat 7 data there isn't even a need to pre-order imagery for specific areas since they are collected automatically on a set schedule and can be obtained well after the data are collected.

3.9 Temporal Considerations

Remote sensing imagery acquisition creates a data set unique in time and space, a process analogous to a photographic snapshot. The temporal resolution of the remote sensing platform must be of sufficient resolution to capture the target of interest. Agricultural row crops also have a temporal component, production follows a seasonal cycle and the timing of data acquisition must be taken into account when examining the data. Field preparation takes place prior

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to planting for conventionally tilled crops and the timing of data acquisition must fall within a specific temporal window to effectively capture the phenomenon of interest.

The temporal resolution of the remote sensing platform and the temporal window of the target of interest must be examined together to determine the best period of opportunity for capturing data. The remotely sensed imagery must be collected at a time when conventionally tilled crops have been plowed, but not so late in the growing season that the crop canopy has developed to such an extent as to cover the soil surface when viewed from above. Field conditions vary year to year, and farmers must wait until fields are sufficiently dry to support the weight of the tractor and implements. Farmers utilizing conventional tillage methods will begin plowing as soon as possible in the spring to prepare fields for planting. With plowing completed, planting will begin once the chance of frost has diminished to an acceptable level of risk. Following planting, there is a period of time before plants break the surface, usually 2 – 3 weeks. Once the crop breaks the surface and begins growing, there is another 3-4 week period when the plant is only 1 to 4 inches in height with no discernable leaf development. During these 5-7 week periods imagery must be obtained, after plowing, but before crop development. During this time, plowed conventionally cropped fields will be comprised of smooth bare soil with little to no crop stubble, while conservation tillage fields will be covered in crop residue from the previous years crop.

Discussions with agricultural field agents and farm managers confirm that all spring tillage activities were completed prior to imagery/data acquisition. Plowing, if it were to take place, would have been completed in advance of the date of data acquisition, May 27th 2002. Farmers at this point would have been well into, if not past, planting crops for the growing season. This was also confirmed during driving transects. Planting activities were observed during the driving transects, but no plowing was observed during this portion of this study. This indicates that the timing of data acquisition was well placed in terms of capturing the phenomenon of interest.

3.10 Imagery Acquisition

Landsat 7 ETM+ imagery was selected as the primary data source for a variety of reasons. Given the wide variety of sensors available for data collection the ETM+ sensor offers the best combination of temporal, spectral, spatial and radiometric resolution currently available for this study of any widely available and accessible remote sensing data set. Agricultural practices vary over a broad range of spatial scales and temporal frequencies; the data source must be of sufficient spatial and temporal resolution to capture these phenomenon and agricultural practices.

The ETM+ sensor onboard the Landsat 7 satellite offers a temporal resolution well suited to agricultural remote sensing applications with a repeat cycle of 16 days. The 16-day repeat cycle is sufficient to detect and monitor agricultural practices, as well as the phenological development of agricultural crops which take place over an entire growing season. The repeat cycle is also sufficiently frequent, that if a data collection opportunity is missed due to unfavorable atmospheric conditions, common in the spring months of the Midwest, the next pass (16 days) later will provide another opportunity for data collection.

ETM+ data are acquired every 16 days over the P21 R31 nominal center, as controlled by the Landsat 7 satellite orbit. Imagery need not be ordered in advance, the scene is collected and processed irrespective of standing orders. From an operational standpoint, Landsat 7 data are reliably collected as scheduled. The primary source of uncertainty associated with collecting the imagery is cloud conditions.

The spatial resolution of ETM+ (30 meters) data is an optimal resolution for monitoring agriculture fields across the study area which vary in size from a few acres to hundreds of acres. Thirty-meter resolution is adequate to monitor smaller fields while still permitting the capture of a relatively large swath width of 180 X 180 km.

The radiometric resolution of ETM+ data is also well suited to a study investigating spectrally similar targets. The ETM+ sensor provides data in 8 bit (2^8) radiometric resolution, an important consideration when examining spectrally similar targets. Eight bit radiometric resolution provides 256 discrete distinctions of energy levels received at the sensor. When reflected energy is received at the optical apparatus of the sensor and then transferred to the focal plane, charge coupled devices (CCD'S), through an analog to digital converter, assign a digital number of 0-255 to each pixel corresponding to the electrical charge generated by the analog to digital converter. The ability to discriminate between 256 energy levels means that small differences in the reflected energy received at the sensor are distinguishable from one another. If a system were used with less radiometric resolution such as a four bit system (2^4) only 16 discrete energy levels would be available. Lower radiometric resolution results in a diminished ability to discriminate spectrally similar targets.

3.11 Imagery Accessibility Considerations

The sensor characteristics that make Landsat 7 well suited for this study also play an important role in making this research available and repeatable to a wide variety of users. Landsat 7 imagery does not need to be ordered prior to its acquisition, the scenes are collected for every path and row every 16 days over North America according to the Long Term Acquisition Plan (LPSD, 1998). Other sensors only collect data over a specific area if the data are ordered in advance. Additionally, Landsat 7 data are archived by the EROS data center and are available for order at a later date. The temporal resolution of 16 days is sufficiently narrow to ensure 2 to 3 overpasses of an area at a time where the findings of this study may be applied to other areas. The cost of Landsat data is also an important aspect to ensure that this research is repeatable by others across the Midwestern United States. Each Landsat 7 scene can be obtained for approximately $600, a cost far below the expense of time and mileage to complete a limited driving transect. These are important considerations if the results of this study are to be expanded to other areas. The widespread availability, coverage, and cost are such that it will be possible for others to duplicate the results of this study over other areas.

3.12 Study Area Imagery

Landsat 7 ETM+ imagery for path 21 row 31 was obtained for May 27th, 2002 (Figure 9). There were four opportunities for Landsat 7 to acquire imagery of nominal center P21 R31 in the time window during 2002: April 25, May 11, May 27 and June 12. Imagery was delivered in Level 1G format, geometrically and radiometrically calibrated. The ETM+ imagery contains 8 spectral bands (Table 2), six of which were utilized in this study. The thermal band (band 6) and the panchromatic band (band 8) were not included in the analysis portion of this study. These two bands are of differing spatial resolution, and do not provide additional information useful in this study.

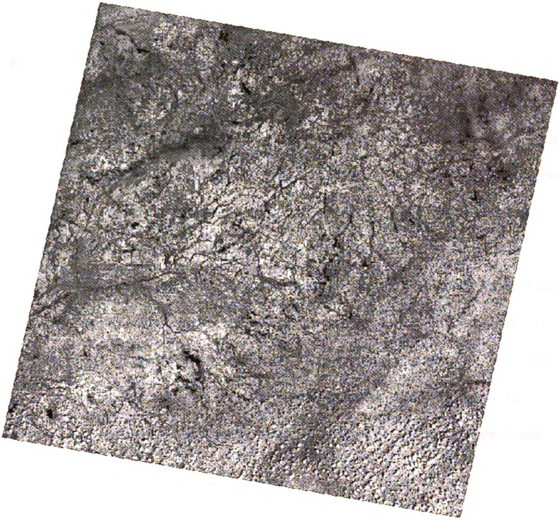

Figure 9. Landsat 7 P21 R31 Band 5 May 27th, 2002.

Enhanced Thematic Mapper (ETM+)

Band	Wavelength (µm)	Resolution (m)
1	0.450-0.515 (blue)	30
2	0.525-0.605 (green)	30
3	0.630-0.690 (red)	30
4	0.750-0.900 (near-IR)	30
5	1.55-1.75 (mid-IR)	30
6	10.4-12.5 (thermal-IR)	60
7	2.08-2.35 (mid-IR)	30
PAN	0.52-0.90	15

Table 2. ETM+ Sensor Characteristics.

3.13 Imagery Processing

Imagery pre-processing includes several steps to prepare raw satellite imagery for analysis. The conversion of raw digital number (DNs) to radiance and reflectance values as well as atmospheric correction and geometric registration techniques are the main pre-processing preparations. Digital sensors record a DN value for each pixel for each band. The assigned DN depends on the intensity of the electromagnetic radiation from each spot viewed on the surface of the earth (a pixel). The range of DNs that can be assigned to a particular pixel depends on the radiometric resolution of the digital imaging system. Radiometric resolution of imaging systems is commonly referred to as the bit value, for example, 8 bit radiometric resolution data (2^8) provides 256 gray scale levels (DNs) for each band.

3.14 Radiance

Digital numbers or brightness values assigned to each pixel are scene dependent; that is, the same ground feature could exhibit different DN values from scene to scene. The variance of the assigned DN from scene to scene is due to a variety of factors including, sun-target-sensor geometry and atmospheric conditions. Since DN values are scene dependent, a method to normalize the DNs to some standardized unit is required. The DN values assigned to pixels are proportional to upwelling electromagnetic radiation (radiance, watts/m^2/

steradian/μm. Converting DNs to radiance values is a rather straightforward procedure:

$$Radiance = (LMAX - LMIN)/255 * DN + LMIN$$

The values of LMAX and LMIN, in the case of ETM+ data, can be obtained from the header file included with the data.

3.15 Atmospheric Correction

Atmospheric effects must also be accounted for to obtain accurate spectral reflectance measurements of the earth's surface. Solar radiation striking the surface of the earth and received at the sensor must pass through the earths atmosphere twice, once on the way down from the sun to the earth and again as the radiation is reflected from the earth's surface back to the sensor. It should be noted that not all of the solar radiation that strikes the earth's surface is reflected back to the sensor. The electromagnetic energy can be absorbed, transmitted or reflected depending on the properties of the object the radiation encounters. The only portion that can be directly observed in remotely sensed data is the portion that is reflected from objects. The reflected electromagnetic energy is not interacting exclusively with the object it strikes, it also interacts with the atmosphere.

The atmosphere plays a significant role in transmission, reflection and absorption, and these atmospheric affects must be taken into account to generate an accurate dataset. Atmospheric constituents such as gasses and suspended particles interact with the electromagnetic radiation passing through the atmosphere and can significantly alter the amount of reflected energy received at the sensor due to atmospheric scattering. Atmospheric correction protocols provide a method to significantly reduce the effects of atmospheric scattering resulting in a more accurate data set.

Atmospheric correction procedures are important for not only producing accurate absolute reflectance values but are also an essential tool anytime data taken at different dates or geographic areas are directly compared. The atmosphere is in a constant state of flux, thus the atmospheric profile and constituents will vary at any point in time. In order to compare reflectance measurements from one scene to another, the atmospheric effects in both scenes must be corrected. Otherwise, inaccurate conclusions based on uncorrected reflectance values from one scene to another may be the end result. Digital number values are image specific, that is a particular land use may exhibit differing digital numbers from one to another. The digital number that is assigned to a specific pixel is a function of a variety of factors, including viewing geometry, location of the sun, and atmospheric conditions. Atmospheric correction can be thought of as a normalization technique, accounting for target, sensor, sun geometry and atmospheric conditions. Each scene is atmospherically corrected based on a set of atmospheric correction values and target, sensor, sun positions appropriate for each scene. Once atmospheric correction procedures have been carried out, the absolute reflectance values from one scene to another may be more accurately compared.

Visibility conditions of the atmosphere during data collection can lead to inaccurate reflectance values if atmospheric conditions are not taken into account. Top of atmosphere (TOA) reflectance is not only affected by visibility conditions, but also by the surface reflectance properties of the object as well. Atmospheric effects are both wavelength dependent and target (brightness) dependent. Due to the fact that atmospheric transmission properties are wavelength dependent, the atmospheric correction procedures must be applied to each spectral band with appropriate wavelength dependent correction values. The brightness or target dependencies are also important considerations and the atmospheric correction procedures must accurately model target brightness as well. Correction factors must be derived for a variety of brightness values, including bright and dark objects, across all spectral bands.

These considerations are critical when examining targets of different brightness conditions in a single scene. If atmospheric correction techniques are not performed properly, the results found in one study may not be directly comparable to other research. The ability to compare findings between data acquired at different times and even other sensors is essential.

The following equation illustrates atmospheric and brightness conditions and their relative influence on the signal received by the sensor:

TOA Reflectance = Path-radiance (Atmospheric reflectance) + (Surface reflectance)(Atmospheric transmittance)

If surface reflectance is set to zero, ((Surface-reflectance)(Atmospheric transmittance) = 0), then the entire signal received at the sensor is due to the first component of the equation (Path-radiance (Atmospheric reflectance)) which consists of path radiance and atmospheric reflectance. When an object with zero reflectance is imaged in a satellite scene, it follows that the reflectance values observed over this object should also be zero. This is, however, not the case; the non-reflective object will usually have reflectance values associated with it. These reflectance values are due to the interaction of path radiance. It can be inferred that the signal received at the sensor for dark objects (little reflectance) will be artificially inflated due to path radiance and atmospheric reflectance.

If, on the other hand, a very bright target is contained in the view of the sensor (Surface-reflectance = 1) the signal received at the sensor (TOA Reflectance) will consist of: Path-radiance (atmospheric reflectance) + transmittance of atmosphere. In this case, the reduction in transmittance due to poor atmospheric conditions exceeds the contribution from path radiance and thus lowers the overall reflectance signal received at the sensor.

For dark objects the atmospheric effect of path radiance and atmospheric reflectance have the effect of brightening the reflectance observed over these t

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dark objects. For bright objects (high reflectance), the transmittance of atmosphere term effectively reduces the observed TOA reflectance.

3.16 Atmospheric Correction – 5s Method

The 5s (Simulation of the satellite signal in the solar spectrum) atmospheric correction procedure incorporates atmospheric correction algorithms based on several parameters and accounts for brightness and wavelength as well. The 5s algorithm uses both an atmospheric and gaseous model based on atmospheric conditions at the time of data acquisition and uses a linear regression method to develop correction values based on both wavelength and brightness. The 5s method, a radiative transfer model, computes the attenuation of solar radiation and therefore the attenuation of the surface reflectance through a series of internal models. The 5s technique generates TOA reflectance for a set of surface reflectance values and establishes a linear relationship between TOA reflectance and the input surface reflectance values. Linear regression is then used to compute the surface reflectance values in the image.

The difference in relative brightness between the targets is significantly reduced if atmospheric correction techniques are not applied to the data set. In order to maximize the data content, and thus improve classification accuracy, atmospheric correction is imperative. Without atmospheric correction techniques, the brightness recorded for bare soil will be artificially inflated and the brightness values of crop stubble will be reduced, significantly hindering classification efforts. Atmospheric correction procedures ensure that the full range of brightness values are present in the data, leading to increased overall classification rates.

Atmospheric correction of Landsat 7 imagery was accomplished using the 5s radiative transfer modeling technique. The 5s atmospheric correction method, and radiative transfer methods in general, have been cited in the literature as robust and accurate for dealing with atmospheric correction. An overview of the atmospheric correction procedure is provided in Figure 10.

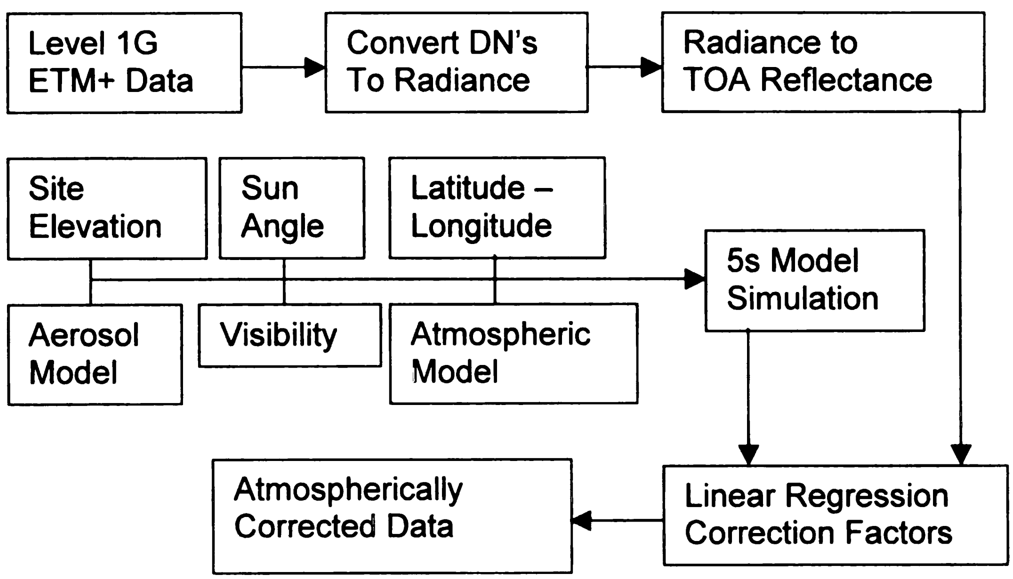

Figure 10. 5s Atmospheric Correction Flowchart.

Landsat 7 Data shipped in level 1G format are corrected for scan line direction and band alignment errors and have also had geometric and radiometric corrections applied as well. During level 1G processing, image pixels are converted to units of absolute radiance using 32 bit floating point values, these pixel values are then scaled to byte values or DNs (digital numbers). To convert the pixel values back to radiance (watts/(meter squared*steradian*micrometer) values a simple mathematical procedure is employed, provided by the Landsat 7 data team:

Radiance = (LMAX – LMIN)/255 * DN + LMIN

Computed radiance values can then be converted to top of atmosphere (TOA) reflectance using the following equation:

$$\rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{Esun_\lambda \cdot \cos\theta_s}$$

where:
ρ_p = Unitless planetary reflectance
L_λ = Spectral radiance at the sensor's aperture
d = Earth-Sun distance in astronomical units
$Esun_\lambda$ = Mean solar exoatmospheric irradiances
θ_s = Solar Zenith Angle

The TOA reflectance (ρ_p) relates the measured radiance (L_λ) to the solar irradiance incident at the top of the atmosphere and ranges in value from zero to one. Computed reflectance values are then used as input into the atmospheric correction procedure.

The 5s model calculates correction factors individually for each ETM+ band based on model input parameters. Model input parameters include visibility, e

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elevation, location, sun angle, atmospheric model and an aerosol model to compute correction factors. The model then generates a set of apparent reflectance values for a set of input reflectance values. Input and apparent reflectance values are then linearly regressed against one another to efficiently compute any correction value from zero to one. Linear regression parameters generated for this study are provided in Table 3.

Band 1	y = 0.8957x + 0.0486
Band 2	y = 0.8683x + 0.0231
Band 3	y = 0.8981x + 0.0128
Band 4	y = 0.8897x + 0.0053
Band 5	y = 0.8841x + 0.0007
Band 7	y = 0.9072x + 0.0002

Table 3. 5s Derived Correction Parameters for ETM+ data.

The linear regression parameters are then used as input to create a computer script, executed using commonly available built in scripting capabilities of standard remote sensing software packages such as Imagine and ENVI. The script opens the TOA reflectance file and applies the computed correction factors for each pixel for all six bands and saves the results to a new file.

3.17 Classification Methodology

The processed ETM+ imagery data will be used as input into classification routines to identify agricultural tillage methods. Several classification routines exist to aid in information extraction and these methods will be utilized and comp

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compared with one another to determine the most suitable classification method for this particular set of data and information extraction requirements.

As noted in section 2.5, two primary methods of classification are commonly in use, supervised and unsupervised classification methods. Supervised classification methods rely upon known ground truth information to serve as training sites for the classification routine. That is, known ground truth targets, in this case ground truthed fields with a known cropping method, are identified in the imagery. These sites are then used to collect statistical information regarding the set of identified pixels. The pixel information for each land use is termed a training site and the statistical information for each training site is then used to classify the rest of the image.

Unsupervised classification methods rely upon clustering algorithms to identify statistically different sets of pixels and group them together using a set of user defined rules. If ground truth information is available supervised classification routines are commonly used and preferable over unsupervised classification routines.

The ground truth data obtained during the driving transect of this study will be used to establish training sites for input into a supervised classification routine. The results of several supervised classification routines will be examined and compared to determine the most suitable classification routine for differentiation between conventional tillage and conservation tillage cropping methods. Classification Routines to be examined include:

- Spectral Angle Mapping
- Maximum Likelihood
- Cosine of the Angle Concept
- Minimum Distance
- Mahalanobis Distance

3.18 Classification Accuracy Assessment

Classification accuracy results will be analyzed in an error matrix format to examine and display errors of commission and omission, producers accuracy, users accuracy, and overall accuracy. An error matrix provides an easily interpreted data matrix with the main diagonal comprised of correctly classified pixels. Pixels off the main diagonal are either errors of commission or omission and can be readily identified as such in the error matrix. The overall classification accuracy is measured by dividing the sum of all values contained in the main diagonal by the total number of pixels in the error matrix. The producer's accuracy is a measure of omission error and is determined by the total number of correct pixels in a category divided by the total number of pixels in that category. The users accuracy is determined by the total number of correct pixels in a category divided by the total number of pixels that were actually classified in that category, a measurement of commission error. Both the users accuracy and producers accuracy will be presented along with the error matrices for each classification method in the results.

Kappa statistics were generated to provide an additional measure of classification assessment. The kappa statistic is a discrete multivariate technique which incorporates total overall classification accuracy and off diagonal elements (omission and commission errors) in a single statistic. Kappa statistics are derived using the following formula: Kappa =

$$\frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+}x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+}x_{+i}}$$

Kappa values range from zero to one with a value of zero indicating no agreement and a value of zero indicating perfect agreement. Montserud and Leamans (1992) evaluated kappa statistics and classification methodologies and propose that a kappa value of .75 or greater indicates very good to excellent classification performance. Kappa statistics were also used to evaluate the statistical difference between the possible classification pairings. A standardized Z-test incorporating the overall kappa score and kappa variance were used to determine if a pairing of classification algorithms resulted in statistically significant results.

Ground truth data collected during the driving transect portion of the study will also serve as a classification accuracy check and validation. The known ground truth data, obtained during the driving transect, will be compared to the classified image to check for agreement between the classified image and ground truth data. Accurate ground truth information is an important step in classification accuracy assessment. Rather than relying on image processing software algorithms that assess classification accuracy based on statistical conditions, ground truth data provides a more reliable method of assessing classification accuracy or lack there of. The validation of classified imagery through the use of driving transect data provides additional confirmation over and beyond error matrix analysis.

CHAPTER 4 RESULTS

4.1 Spectral Properties of Tillage Practices

To differentiate the two primary cropping methods, conventional and conservation tillage, using remotely sensed data, the spectral reflectance properties of each cropping method were examined. Bare soils (conventional tillage) and soils with crop residues (conservation tillage) interact with electromagnetic radiation in unique patterns. These differences in reflected radiation between the two surfaces are relied upon during classification to differentiate the two cropping methods. The results of spectral reflectance patterns, obtained through laboratory, field, and satellite based measurements are provided in the following section. Classification results based on spectral reflectance patterns immediately follow the spectral reflectance results.

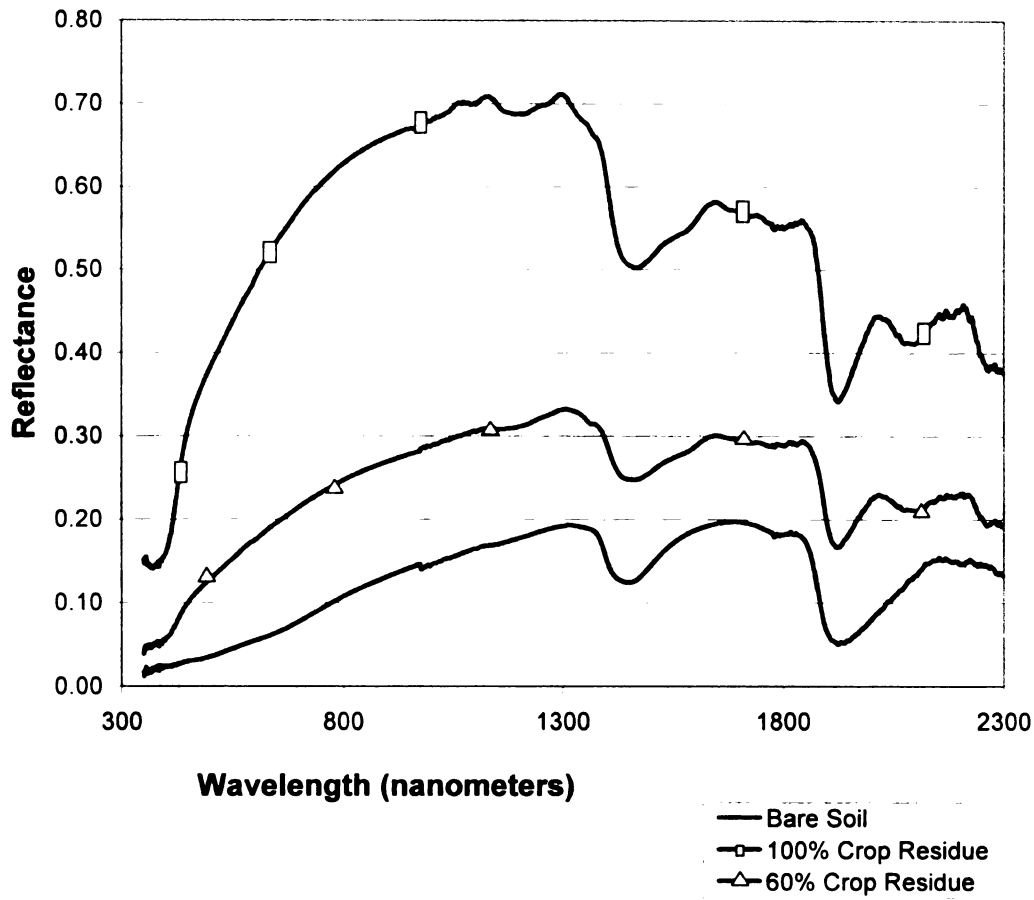

Figure 11. Laboratory Reflectance Readings.

Laboratory measurements provide data regarding the spectral response patterns of crop residues and soils individually. That is, laboratory measurements provide fundamental data regarding the spectral reflectance of crop residues and soils independently. However, they do not accurately represent the complex interaction of standing crop residues overlying soils found under field conditions.

This study confirms findings published by Gausman and Gerbermann (1975) regarding the spectral reflectance of crop residues under laboratory conditions. They found that crop residue exhibits a higher reflectance than bare soils under laboratory lighting and sample sizes. The findings are also in agreement with other studies examining crop residues under laboratory conditions (Stoner and Baumgardner 1980). Spectral reflectance measurements taken under laboratory conditions are presented in Figure 11. The spectral data reveals that crop residues (corn and soybean) exhibit greater reflectance than bare soil. Laboratory measurements require the use of small sample sizes and a correspondingly small field of view (FOV) with respect to the radiometer. The field of view used with laboratory equipment must be small enough to only record reflectance measurements from the sample itself and not surrounding materials. The combination of small sample size and small FOV (8 degree) results in limited measurements that do not accurately represent field conditions. The investigation of laboratory based reflectance measurements was made to confirm the findings of earlier research and to illustrate the differences obtained in reflectance measurements made under laboratory and field conditions.

Intuitively, based on laboratory measurements alone, the conclusion that fields with crop residues (conservation tillage) should exhibit higher reflectance than fields comprised of bare soil (conventional tillage) would be a reasonable expectation. These previous studies however, and laboratory studies in general, do not examine standing crop residues as found in agricultural field settings. Standing crop residues in field conditions were found to exhibit distinctly different spectral properties than those found under laboratory conditions. The results of laboratory measurements and those provided in the next section, field based measurements, illustrates the importance of field based measurements when working with remotely sensed data.

4.1.2 Field Based Spectral Properties

The Field Spec Pro was also utilized for collecting field based spectral measurements. Field measurements were collected at the Kellogg Biological Station's Long Term Ecological Research site, located in Hickory Corners, Michigan as well as research fields located on Michigan State University's East Lansing campus.

The data reveal that the FOV used to record the reflectance measurements has a large influence on observed reflectance readings (12). Using the 8 degree fore optic at a height of 2 meters results in measurements similar to those made under laboratory conditions, crop residues exhibit greater reflectance than bare soils. However, using the 24 degree fore optic at a height of 2 meters markedly changes the results. Crop residue reflectance is now found to be less than that of bare soil, similar to reflectance response patterns observed from ETM+ data.

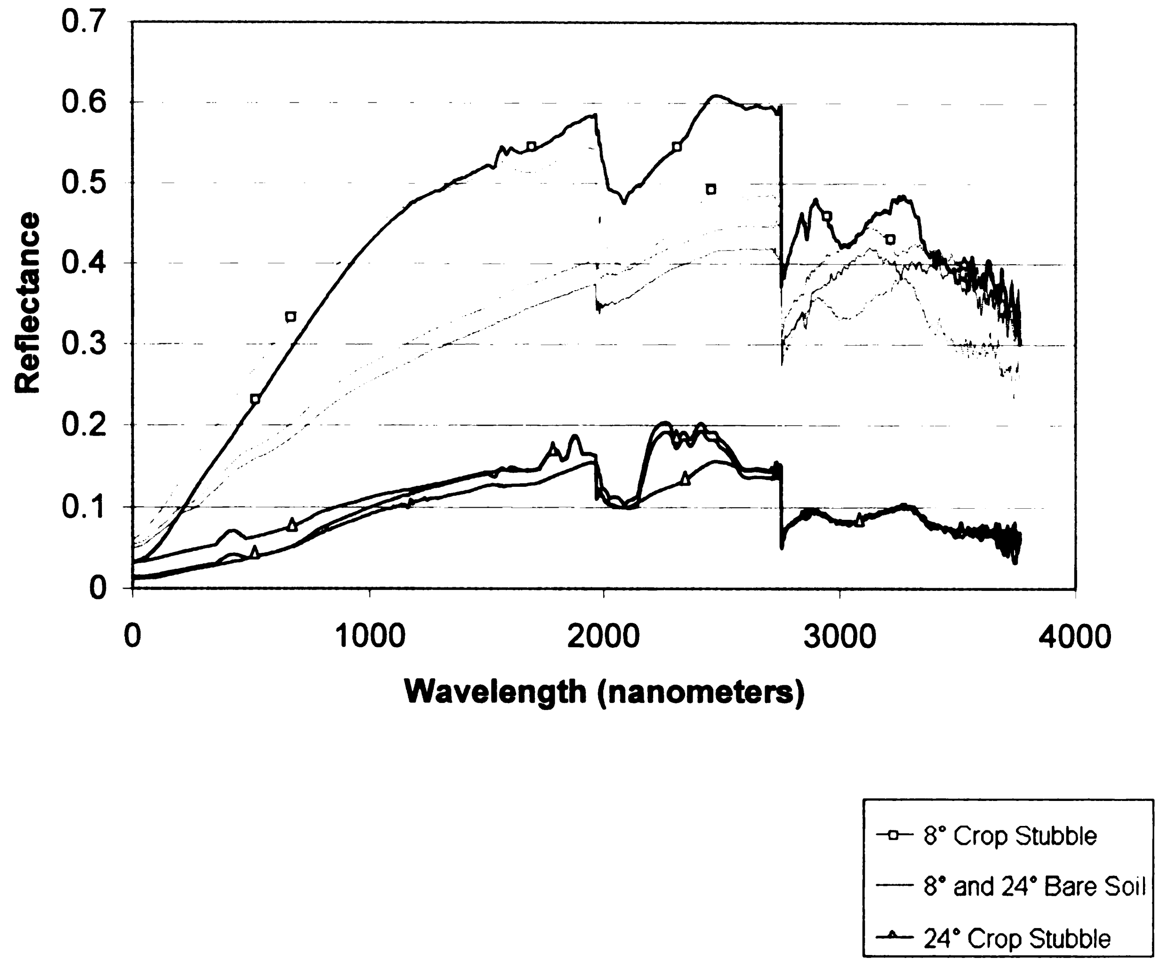

Figure 12. Field Based Spectral Reflectance Measurements, Spectral reflectance curves of soils and crop stubble taken with two FOV's.

Reflectance measurements taken under field conditions at a scale where texture, shadowing, and multiple scattering are significant reveal that fields with crop residues exhibit lower overall reflectance than fields comprised of bare soil alone. Field conditions consist of a complex assemblage of crop residues overlying the soil surface. Stalks and stems rarely lie flat against the soil surface under field conditions (Figure 13). Crop residues may lie upon one another and are often times found still attached to the main stalk, not completely cut off, but suspended 10 to 12" above the soil surface at the stalk end with the other end (what was once the top of the plant) resting against the soil (Figures 14 and 15). The complex assemblage and pattern of crop residues creates a scale-dependent surface that is overall less reflective than bare soils with larger FOV's for a number of reasons.

Figure 13. Crop Residue – Photograph of Corn Residue
Vertical overhead perspective showing shadowing and texture.

Figure 14. Crop Residue, Photograph of Corn Residues.
Oblique view showing overall field condition.

Figure 15. Crop Residue, Photograph of Soy Bean Residues. Oblique view showing overall field condition.

Fields containing crop residues are less reflective than fields comprised of bare soil by virtue of pattern, texture, and roughness. The rough texture associated with crop residues results in multiple scattering of electromagnetic energy. The end result of which is that less of the incoming radiation is reflected back to the sensor or collection device. Conventionally tilled fields comprised of relatively smooth soil, on the other hand, present a surface which acts more as a specular reflective surface. Even though bare soil is less reflective than crop residues independently, the agglomeration and texture of crop residues overlying soil creates an overall less reflective surface under field conditions.

Another contributing factor to the observed reflectance pattern of conservation tillage fields is shadowing. The complex pattern and texture associated with standing crop residues creates shadowing. Shadowing from crop residues also acts to reduce the overall observed reflectance associated with conservation tillage fields.

Under field conditions, handheld radiometric measurements indicate that standing crop residues, measured at a scale where texture and shadow come into play, exhibit lower overall reflectance than bare soils. Texture and shadowing by crop residues significantly reduces the amount of electromagnetic radiation reflected (Figure 16). Henderson (1985) notes that parameters and processes important at one scale are frequently not important or predictive at another scale.

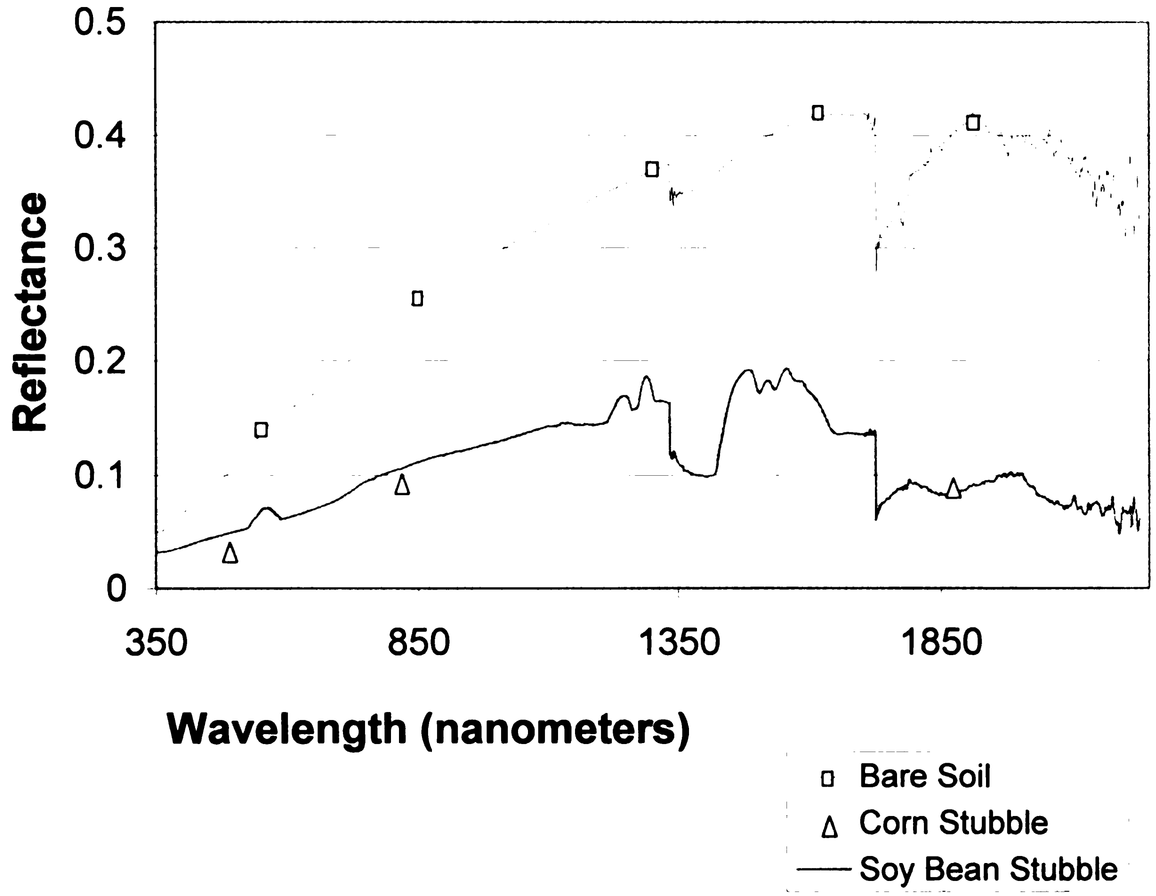

Figure 16. Field Based Measurements of Reflectance.
Recorded at MSU East Lansing Agriculture Fields.

4.1.3 Satellite Spectral Properties

Ground truth data were used to identify known land use/land covers in the ETM+ data set. The spectral reflectance of 38 representative fields were used to derive a characteristic spectral reflectance signature based on 30 m resolution ETM+ data for each land use/land cover class (Figure 17). The spectral reflectance signatures based on the ETM+ data reveal that the spectral reflectance of conservation tillage acreage, at this scale, is less than that of conventionally tilled fields comprised of bare soil.

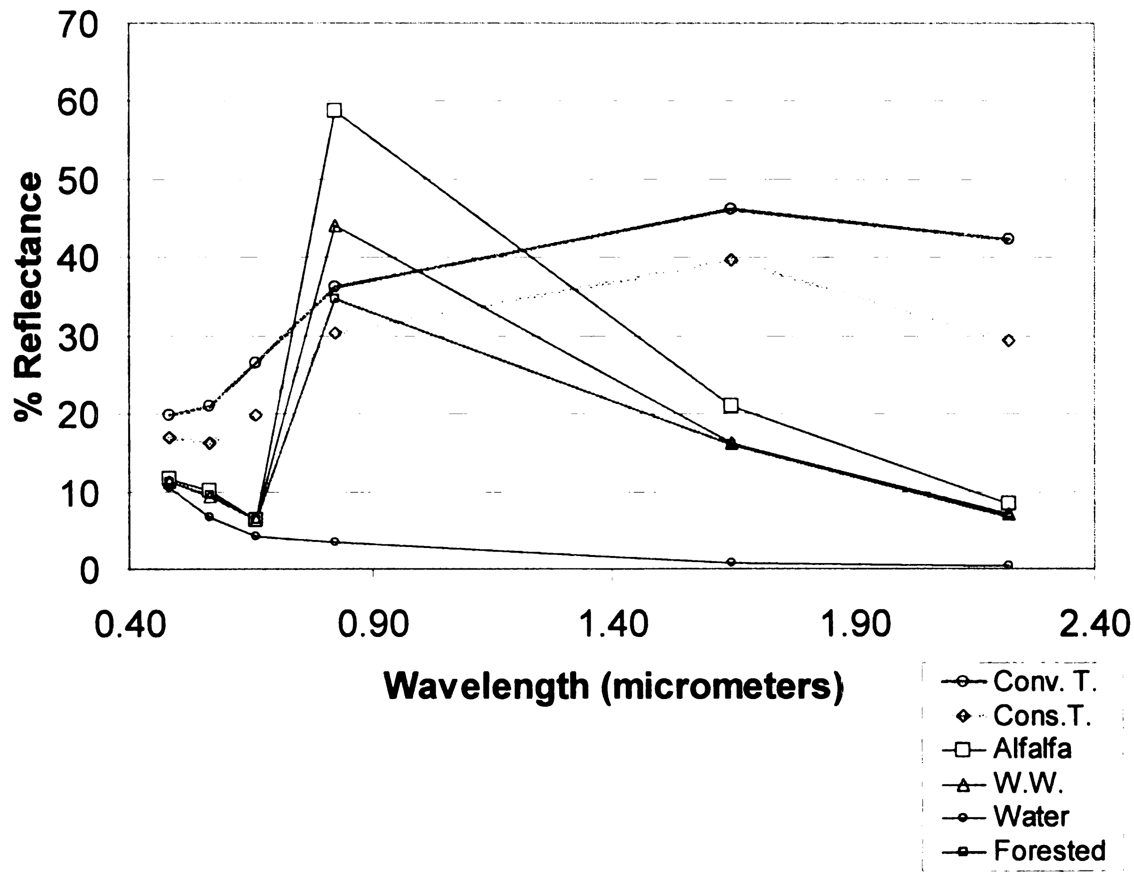

Figure 17. Spectral Reflectance derived from ETM+ Data

The effects of texture, shadowing, and crop residue lying directly on soil collectively create a spectral reflectance signature darker than that of a bare soil. These results are important considerations if this work is to be applied using different remote sensing platforms. The characteristic reflectance curve of conservation tillage may be significantly altered based on the FOV of the sensor.

4.1.4 Spectral Characteristics at Differing Spatial Scales

Spatial scale plays an important role in determining the appropriate spectral reflectance signatures to be used in analysis of remotely sensed imagery. Readings taken at one scale may not necessarily be used to assess or design a classification scheme for data taken at a different sampling scale. The scale of the data must be taken into account. Accounting for scale can be done operationally through the use of ground truth information. If known ground targets are present in the image, the spectral reflectance of the ground truth target can be obtained directly from the remotely sensed data source. The spectral reflectance of the known ground truth target will accurately reflect the spectral reflectance properties of the target, assuming the data was properly acquired and processed. Spectral reflectance measurements taken at differing scales than the remotely sensed data, to be used as input into classification routines, should be carefully examined to determine if the reflectance from the object or land use/land cover exhibits scale dependency. Confounding factors such as texture and shadowing play a significant role in the reflectance properties of surface objects or land use/land covers. If spectral data obtained through laboratory or field measurements are used directly as input into a classification routine, the results should be carefully evaluated to ensure classification accuracy.

Many man made phenomena, when examined using remotely sensed data, are not subject to texture and shadowing effects. Concrete and asphalt are two such surfaces. They both exhibit relatively uniform reflectance over small and large scales and are not affected by texture and shadowing at any useful mapping scale. However, the vast majority of natural targets are subject to texture and shadowing effects, including vegetation, both vigorous and senescent. Stalks, stems, and leaves create a complex texture and pattern, creating shadows and presenting a very complicated structure as viewed from the sensor. If spectral reflectance measurements are made at a scale too small to account for texture and shadowing of the phenomenon of interest, they fail to adequately characterize the spectral reflectance at larger scales.

The spatial resolution of ETM+ data is 30 meters, meaning that any object that contributes to the brightness value (DN) of a specific pixel that is smaller than 30 meters is a mixed pixel. For example, a pixel, entirely contained in an agricultural field consisting of plowed bare soil with a smooth uniform texture throughout would be termed a pure pixel. The pixel falls entirely within the field and the representative reflectance is comprised entirely of smooth bare soil, a pure pixel. Compare and contrast this pixel to a pixel obtained from a conservation tillage field. The reflectance value of this pixel, which also lies entirely in the field, is comprised of a contribution from crop residues, shadows, and soil, a mixed pixel. The terminology of pure and mixed pixels is scale dependent and can have a variety of meanings. Common usage of the term mixed pixel is one in which two land use/land covers are contained in a single pixel. A road bordering an agricultural field in which a single 30-meter pixel contains a portion of the road and a portion of the field is an example of the most common meaning of the term.

The spectral reflectance properties of crop residues under laboratory conditions show markedly higher overall reflectance values than the spectral reflectance of bare soil. It only follows that adding a more reflective material on top of bare soil should result in an overall increase in brightness for the pixel, but this not the case, in fact just the opposite is observed. A pixel with bare soil and standing crop residue when viewed from space, in 30m pixels, is darker or less reflective than bare soil alone. The underlying mechanisms responsible for the variation of reflectance observed for field and laboratory conditions are scale and texture.

Crop residues under agricultural field conditions are not smooth and homogenous, they can be thought of as a regular repeating pattern across the field at 30m scales, but they are still far from a smooth surface. Crop residues do not entirely lay down flat against the surface of the field but rather are a complex assemblage of stems, stalks, and leaves. A great deal of crop residue that may at first be regarded as lying down even with the surface of the field, when examined more closely, may in fact be suspended above the surface. Crop residues may be suspended at one end still attached to the main stalk, merely knocked over, and can also be found standing straight in the air to the level the combine cut them the previous year (usually a height of 8-12 inches). Residues that were cut with harvesting equipment may be completely suspended horizontally on top of other stalks. The suspended and standing residues produce a significant amount of shadowing, shadowing that significantly lowers the overall observed reflectance.

Another factor that comes into play is multiple scattering. As noted in the laboratory spectral reflectance measurements of crop residues section, reflectance is generally high for crop residues, assuming a flat and homogenous crop residue surface which neglects shadowing. The high reflectivity of crop residues results in multiple scattering of light photons. Photons striking a stalk may be bounced at irregular angles either once off the stalk and then into another direction (not received by the sensor) or may strike multiple stalks before being reflected into another direction. The end result being the same: the reflected energy that was radiant onto the crop stubble surface is never received back at the sensor, resulting in lower recorded reflectance values. Contrast this with reflectance from a field of recently plowed smooth soil. Even though the reflectance of soil is less than the reflectance of crop residues individually, because there is less scattering, and shadowing, more of the electromagnetic energy that strikes the bare soil areas is reflected back to the sensor producing higher reflectance measurements at the sensor relative to fields with crop residues.

4.2 Classification Training Sites

With ground truth data processed, it is now possible to extract spectral profiles from the atmospherically corrected ETM+ imagery to examine the spectral profiles of conventional and conservation tillage fields. Training site selection entailed examining available GPS logged fields in the ETM+ imagery and selecting training areas from the known land cover/land use located in the imagery. Thirty eight (38) of the four hundred and eighty (480) data points collected during the driving transect portion of this study were used to identify areas in the ETM+ to collect training pixels for each class. Each class is represented by a minimum of 900 pixels. Eleven thousand four hundred eighty pixels (11,481) were used to collect spectral information from the ETM+ scene as input for signature training:

Pixels	Class
908	Conventional Tillage
1481	Conservation Tillage
942	Alfalfa
1038	Winter Wheat
1163	Water
5948	Forested

4.3 Classification Methodology Comparison

The classification portion of this study was performed using the same training site areas and ground truth data points for each classification routine examined. This ensures that the results of each classification are based and evaluated only on the classification algorithm itself and that differences in classification accuracy are not attributable to differences in training site selection or ground truth data. The classification routines examined for this study include:

Minimum Distance
Mahalanobis Classifier
Maximum Likelihood
Spectral Angle Mapping (SAM)
Cosine of the Angle Concept (CTAC)

Error matrices and ground truth data were examined for each classification method to assess the suitability of the classification scheme for this study. Classification accuracy results and error matrices are reported tables 4 through 8.

Maximum Likelihood

	1	2	3	4	5	6	Total
1	55	33	0	0	0	0	88
2	34	171	0	0	0	0	205
3	0	0	36	20	0	0	56
4	0	0	0	22	0	10	32
5	0	0	0	0	27	0	27
6	0	0	0	0	0	34	34
Total	89	204	36	42	27	44	442

1 - Conventional Tillage, 2 - Reduced Tillage, 3 - Alfalfa,
4 - Winter Wheat, 5 - Water, 6 - Forested

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
1	89	88	55	61.80%	62.50%
2	204	205	171	83.82%	83.41%
3	36	56	36	100.00%	64.29%
4	42	32	22	52.38%	68.75%
5	27	27	27	100.00%	100.00%
6	44	34	34	77.27%	100.00%
Total	442	442	345		

Overall Classification Accuracy = 78.05%

Kappa Statistics = 0.6940

Table 4. Maximum Likelihood Classification Error Matrix.

Mahalanobis Distance

	1	2	3	4	5	6	Total
1	55	33	0	0	0	0	88
2	34	171	0	0	0	0	205
3	0	0	36	20	0	0	56
4	0	0	0	22	0	11	33
5	0	0	0	0	27	0	27
6	0	0	0	0	0	33	33
Total	89	204	36	42	27	44	442

1 - Conventional Tillage, 2 - Reduced Tillage, 3 - Alfalfa,
4 - Winter Wheat, 5 - Water, 6 - Forested

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
1	89	88	55	61.80%	62.50%
2	204	205	171	83.82%	83.41%
3	36	56	36	100.00%	64.29%
4	42	33	22	52.38%	66.67%
5	27	27	27	100.00%	100.00%
6	44	33	33	75.00%	100.00%
Total	442	442	344		

Overall Classification Accuracy = 77.83%

Kappa Statistics = 0.6909

Table 5. Mahalanobis Distance Classification Error Matrix.

Minimum Distance

	1	2	3	4	5	6	Total
1	52	13	0	0	0	0	65
2	37	190	0	0	0	0	227
3	0	0	36	13	0	0	49
4	0	0	0	28	0	6	34
5	0	0	0	0	27	0	27
6	0	1	0	1	0	38	40
Total	89	204	36	42	27	44	442

1 - Conventional Tillage, 2 - Reduced Tillage, 3 - Alfalfa,
4 - Winter Wheat, 5 - Water, 6 - Forested

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
1	89	65	52	58.43%	80.00%
2	204	227	190	93.14%	83.70%
3	36	49	36	100.00%	73.47%
4	42	34	28	66.67%	82.35%
5	27	27	27	100.00%	100.00%
6	44	40	38	86.36%	95.00%
Total	442	442	371		

Overall Classification Accuracy = 83.94%

Kappa Statistics = 0.7719

Table 6. Minimum Distance Classification Error Matrix.

Spectral Angle Mapping

	1	2	3	4	5	6	Total
1	87	8	0	0	0	0	95
2	2	196	0	0	0	0	198
3	0	0	35	5	0	0	40
4	0	0	0	15	0	9	24
5	0	0	0	0	27	0	27
6	0	0	1	22	0	35	58
Total	89	204	36	42	27	44	442

1 - Conventional Tillage, 2 - Reduced Tillage, 3 - Alfalfa,
4 - Winter Wheat, 5 - Water, 6 - Forested

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
1	89	95	87	97.75%	91.58%
2	204	198	196	96.08%	98.99%
3	36	40	35	97.22%	87.50%
4	42	24	15	35.71%	62.50%
5	27	27	27	100.00%	100.00%
6	44	58	35	79.55%	60.34%
Total	442	442	395		

Overall Classification Accuracy = 89.37%

Kappa Statistics = 0.8524

Table 7. Spectral Angle Mapping Classification Error Matrix.

Cosine of the Angle Concept

	1	2	3	4	5	6	Total
1	88	6	0	0	0	0	94
2	1	198	0	0	0	0	199
3	0	0	36	5	0	0	41
4	0	0	0	37	0	1	38
5	0	0	0	0	27	0	27
6	0	0	0	0	0	43	43
Total	89	204	36	42	27	44	442

1 - Conventional Tillage, 2 - Reduced Tillage, 3 - Alfalfa,
4 - Winter Wheat, 5 - Water, 6 - Forested

Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
1	89	94	88	98.88%	93.62%
2	204	199	198	97.06%	99.50%
3	36	41	36	100.00%	87.80%
4	42	38	37	88.10%	97.37%
5	27	27	27	100.00%	100.00%
6	44	43	43	97.73%	100.00%
Total	442	442	429		

Overall Classification Accuracy = 97.06%

Kappa Statistics = 0.9592

Table 8. Cosine of the Angle Concept Classification Error Matrix.

Of the five classification routines examined only two provided overall classification accuracy results of greater than 85%: spectral angle mapping (SAM), and the cosine of the angle concept (CTAC). The overall classification accuracies obtained for all six land use/land cover classes are as follows:

	Overall Classification Accuracy	Kappa Statistic
Mahalanobis Classifier	77.83%	.6909
Maximum Likelihood	78.05%	.6940
Minimum Distance	83.94%	.7719
Spectral Angle Mapping	89.37%	.8524
Cosine of the Angle Concept	97.06%	.9592

Table 9. Classification Results.

When examining the overall classification accuracies of all six land use/land cover types, particular attention must be paid to the individual contributions of the six land use/land covers to the overall classification results. The water class was correctly identified by all five classification routines with 100% accuracy, thus raising the overall classification accuracy results.

An examination of the individual land use/land cover type classification accuracies also indicates that the spectral angle mapping and cosine of the angle classification routines were the only classification routines to achieve 85% classification accuracy for conventional tillage and conservation tillage land use/land covers. The remaining classification routines fell below the 85% classification accuracy level for both conventional tillage and conservation tillage land use/land cover classes.

Statistical analysis utilizing Kappa statistics and measures of variance derived from the classification error matrix were examined to determine if the results of the classification methods are statistically different from one another at a 95% confidence interval. The error matrices were examined and analyzed using a method outlined by Congalton (1983). The method involves computing the variance of the error matrices as well as row and column residuals to calculate kappa variance. Statistical analysis indicates that of all the possible pairings of the classification methods only the pairing of maximum likelihood and mahalanobis distance classifiers were not significantly different examined at a 95% confidence level (Z-Score < 1.96). All other classification method results were statistically different using a 95% confidence interval (Z-Score > 1.96).

Classification Pairing	Z-Score
Max. Like. vs. Mah. Dist.	0.08
Min. Dist. vs. Max. Like.	2.08
Min. Dist. vs. Mah. Dist.	2.16
SAM vs. Min. Dist.	2.53
SAM vs. Max. Like.	4.65
SAM vs. Mah. Dist.	4.73
COTA vs. SAM	5.10
COTA vs. Min. Dist.	7.15
COTA vs. Max	9.13
COTA vs. Mah. Dist.	9.22

Table 10. Results of Classification Statistical Significance Pairings.

4.4 Classified Imagery Results

Results of total land use/land cover for the study area, using the cosine of the angle classified image, the classified data with the highest classification accuracy results, are presented in Table 11 and an image of the classified data is presented in Figure 18. The results indicate that overall corn and soybean production under both conservation and conventional tillage practices account for a total of 2,956,309 acres or 47% of the total land use/land cover. If only agricultural land use/land cover classes are examined, then corn and soybean production accounts for 82.28% of all agricultural land use/land cover throughout the study area. Of the 2,956,309 acres of land use/land cover used for corn and soybean production, 63.63% (1,881,241 acres) are cropped using conservation tillage techniques, while the remaining 36.37% (1,075,067 acres) are produced utilizing conventional tillage techniques (Figure 19).

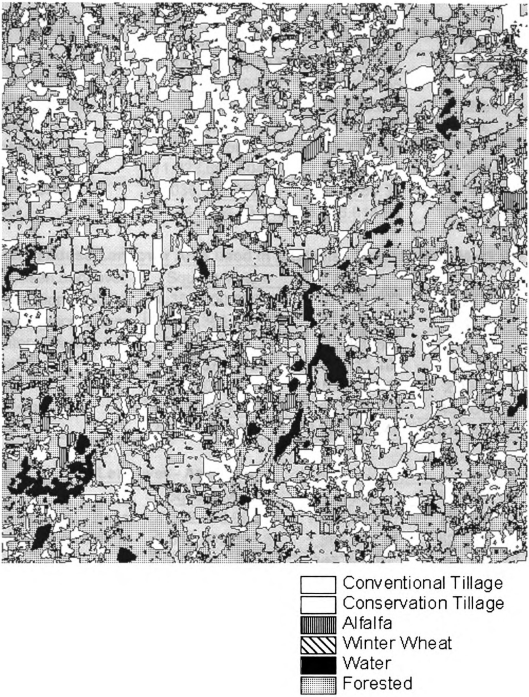

Figure 18. Classified Data Based on the COTA Classification Routine.

Total Landuse/Landcover

	Square Meters	Acres	%
Conventional Tillage	4,352,500,690.73	1,075,067.67	12.49%
Conservation Tillage	7,616,362,599.87	1,881,241.56	21.86%
Winter Wheat	600,593,799.34	148,346.67	1.72%
Alfalfa	1,977,373,212.72	488,411.18	5.67%
Water	638,604,589.74	157,735.33	1.83%
Forested	11,623,696,504.34	2,871,053.04	33.36%
Cloud, Urban	8,035,462,958.75	1,984,759.35	23.06%
Total	34,844,594,355.49	8,606,614.81	100.00%

Total Landuse/Lancover Area used in Analysis - Urban/Cloud Masked

Landuse/Landcover	Square Meters	Acres	%
Conventional Tillage	4,352,500,690.73	1,075,067.67	16.24%
Conservation Tillage	7,616,362,599.87	1,881,241.56	28.41%
Winter Wheat	600,593,799.34	148,346.67	2.24%
Alfalfa	1,977,373,212.72	488,411.18	7.38%
Water	638,604,589.74	157,735.33	2.38%
Forested	11,623,696,504.34	2,871,053.04	43.36%
Total	26,809,131,396.74	6,621,855.45	100.00%

Total Landuse/Lancover - Agriculture

	Square Meters	Acres	Total %
Conventional Tillage	4,352,500,690.73	1,075,067.67	29.92%
Conservation Tillage	7,616,362,599.87	1,881,241.56	52.36%
Winter Wheat	600,593,799.34	148,346.67	4.13%
Alfalfa	1,977,373,212.72	488,411.18	13.59%
Total	14,546,830,302.66	3,593,067.08	100.00%

Total Major Row Crop

	Square Meters	Acres	Total %
Conventional Tillage	4,352,500,690.73	1,075,067.67	36.37%
Conservation Tillage	7,616,362,599.87	1,881,241.56	63.63%
	11,968,863,290.59	2,956,309.23	100.00%

Table 11. Study Area Land Use/Land Cover.

The results reveal the extent to which corn and soybean acreage dominates agricultural land use/land cover throughout the study area (Figure 19). Winter wheat and alfalfa only account for 9.62% of the total land use/land cover throughout the study area. If the results are examined only in terms of agricultural land use/land cover, winter wheat and alfalfa account for 17.72% of agricultural land use/land covers.

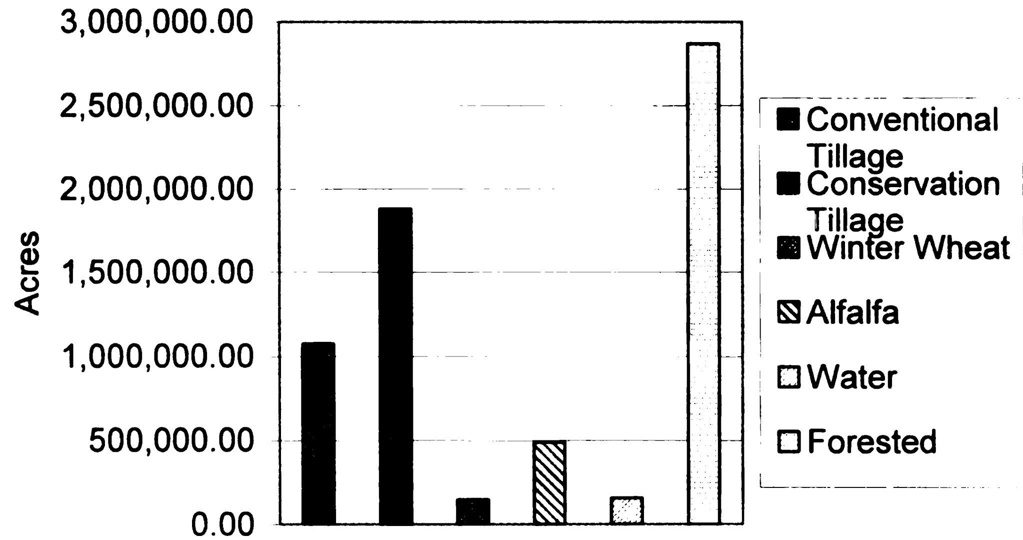

Figure 19. Study Area Land Use/Land Cover in Acres.

4.5 Cosine of the Angle Concept – Spectral Angle Mapping

Two relatively new classification routines were examined to assess their suitability for successful discrimination of cropping types using remotely sensed data. Spectral angle mapping is a technique that uses angular measures to match image spectra to reference spectra in n-dimensions using a physically based spectral classification method. The reference end member spectra used in a spectral angle mapping classification are no different than the end member spectra used in any other classification routine and can imported or derived from a variety of sources including ASCII text files, spectral libraries, statistics files, or can be extracted directly from the image (as ROI or AOI average spectra). SAM compares the angle between the end member spectrum (considered as a n-dimensional vector, where n is the number of bands) and each pixel vector in n-dimensional space. Smaller angles represent closer matches to the reference spectrum. This technique, when used on calibrated data, is relatively insensitive to illumination and albedo effects. (ENVI 3.5 Online Documentation). Sohn et al. (1999) has also developed a classification method based on spectral angle mapping known as the cosine of the angle concept (CTAC). Their technique is similar to the spectral angle mapping algorithm available in ENVI with the notable difference that the cosine of the angle concept uses the cosine of the angle as the decision rule rather than just the angle. While spectral angle mapping uses the angle between the reference spectra and the pixel to be classified in n dimensional space (n being the number of bands). The CTAC technique takes the procedure one step further and bases the classification rule on the cosine of the angle formed between the reference signature and the pixel being classified. The cosine of the angle concept is reported to be less sensitive to illumination and linear scaling (Sohn et al., 1999), an important attribute when trying to differentiate spectrally similar targets.

As illustrated by the classification results, both the spectral angle mapping and cosine of the angle concept classification routines produced overall classification results in excess of 85%. More importantly, both classification routines were successful in discrimination between conventional and conservation tillage cropping methods, surpassing 85% classification accuracy for both tillage methods. Both methods claim to be insensitive to illumination and albedo effects and successfully discriminate between spectrally similar targets, a task where other classification methods failed to produce classification accuracies of greater than 85%.

With such spectrally similar targets (bare soil vs. bare soil with senescent plant material) traditional classification methods such as geometric or probability decision rules are simply not robust enough to successfully classify the phenomena of interest. Geometric and probability based classification routines do not provide a decision rule or surface sufficiently discriminatory to successfully classify spectrally similar targets.

4.6 Angular vs. Geometric and Probability Based Classification

Geometric classification routines, based on the nearest neighbor principle, where the unclassified pixel is assigned class membership based on the minimum distance to a class mean provides a simple and time efficient method of classification. However, minimum distance to means classification routines, due to their inherent simplicity, often lead to inaccurate classification results when trying to differentiate class membership of spectrally similar targets, as is the case in this study. The mean value of conservation tilled and conventionally tilled classes are relatively similar to one another, and the classification decision rule based on minimum distance can often lead to inaccurate classification results when working with such spectrally similar classes.

Probability based classification decision rules such as maximum likelihood, which incorporate variance and covariance data into the decision rule, are generally expected to outperform distance based classification decision rules. Contrary to this commonly held belief, this study indicates that minimum distance classification decision rules outperformed probability based classification decision rules. Whereas the minimum distance classification decision rule produced overall classification accuracy results of 83.94%, the mahalanobis distance and maximum likelihood classification decision rules resulted in overall classification accuracies of 77.83% and 78.05% respectively.

The differences observed between distance based and probability based classification decision rules are a result of data normality, or more appropriately, the lack thereof. Probability based decision rules such as maximum likelihood operate under the assumption of data normality, if the data do not follow a normal distribution the calculation of variance data is fundamentally flawed from the beginning. The lack of normality in the data sets resulted in lower overall classification accuracies for classification decision rules working under normality assumptions. Distance based classification decision rules outperformed these classification routines for the same reason.

4.7 Validation

A total of 480 GPS data points were created during the ground truth driving transect portion of the study. The locations of fields were mapped within an accuracy of 4 meters to identify and locate these fields in the ETM+ data set. Of the 480 data points six main classes were identified from ground level observations:

1. Conventionally tilled fields comprised of bare soil
2. Conservation tilled fields comprised of soil and crop residue
3. Winter wheat
4. Alfalfa
5. Forested
6. Water

These six feature classes represent the great majority of land use/land cover throughout the ETM+ scene. Of the 480 GPS points, 38 were used to identify and develop classification training sites. For validation purposes only the remaining 442 data points were used.

In addition to these six primary classes, several other land use/land cover types occur in the imagery but were not included in this analysis for a variety of reasons. Urban land use/land cover types such as residential, commercial and industrial sites were masked out/ignored due to the fact that virtually no agricultural production occurs in urban areas. Several rural land use/land cover types were also not included as classification types due to the small spatial extent of these areas. Barnyards and pastures were not separated from alfalfa acreage for due to the fact that these open grass areas do not cover much acreage spatially, both the driving transect portion of this study and the ETM+ imagery confirm this.

Winter wheat is a row crop that differs from corn and soybeans in several aspects. The most evident difference is crop phenology; winter wheat is planted in the late fall/early winter and harvested in late spring/early summer. At the time of ETM+ imagery acquisition, most winter wheat was still in the field in the final stages of plant development. Winter wheat fields during this time period are a deep green color with a very tightly spaced plant pattern offering an almost uniformly closed and tight crop canopy.

Alfalfa is grown throughout the Midwestern United States as a forage crop. Alfalfa cropping is significantly different than any other crop grown in the region. Alfalfa is an annual crop that is planted once every three to four years. Once planted, the crop will reestablish itself for several years without replanting. The temporal cycle of harvesting is also unique to alfalfa, the alfalfa is cut and harvested several times a year. The number of cuttings for each growing season is dictated primarily by temperature and precipitation; in the study area, three to four cuttings per growing season is typical. Because alfalfa is harvested numerous times throughout the growing season, remotely sensed imagery collected during the growing season may capture any particular alfalfa field in a continuum of plant development from recently cut to full growth. Alfalfa fields were recorded during the driving transect in a variety of conditions across the study area, including recently harvested fields as well as fields in peak development. During this time (late May to early June), most alfalfa fields were found in the late stages of peak development, just prior to the first cutting of the year. However, some fields had just been recently harvested. Alfalfa also has a very tight and closed canopy during the final stages of plant development, but differs from winter wheat in color and overall canopy texture. Alfalfa is generally a lighter green color than winter wheat and the plant itself is leafier and more spread out.

The temporal aspects of alfalfa and winter wheat, which are green during the time of imagery acquisition, lend themselves well to agricultural classification. Throughout the Midwest, and the study area, any conventional or conservation tillage field will be used for corn or soybean production with few exceptions. During the driving transect portion of this study both conventionally tilled and conservation tillage fields were recorded, of which either corn or soybeans will be produced. While differentiation between corn and soybeans in not possible at this time, however, a second image acquired later in the growing season would allow for classification between the two crops.

Forested areas across the study area were recorded during the driving transect as well. Forested areas were found in a leaf on stage of plant development, with deciduous trees exhibiting full canopies. Water bodies such as lakes and ponds were also logged during the driving transect, although no effort was made to explicitly include water bodies in the driving transect development. Both forested areas and water bodies are easily distinguished in remotely sensed imagery, therefore most of the driving transect data points were focused on collecting data regarding agricultural crops and cropping methods, the primary focus of this study. An effort was made to collect ground truth data for forested areas, water bodies, and secondary agricultural crops such as winter wheat and alfalfa to ensure that the classified thematic map is as accurate as possible. It should be recalled, however, that the primary goal of this study is the differentiation of cropping methods utilizing remotely sensed data.

All six major classes were documented using GPS data logging methods with an accuracy of 4 meters or less. These GPS data points, waypoints, were then overlaid onto the ETM+ imagery to locate the ground truthed fields in the imagery. The waypoints were converted to an ArcView point shapefile to represent the GPS waypoints in both a GIS vector layer that can be used independently as well as serve as a vector overlay onto the ETM+ imagery. The point shapefile was used for both accuracy assessment and training site selection for the supervised classification portion of this study.

The GPS data was exported from the GPS unit (Garmin GPS V) in a .dbf format which provides the GPS information in a tabular format providing such information as x,y coordinates, date and time, elevation, heading and other information. The DBF file was then imported into ESRI's ArcView GIS software and converted to a point shapefile. The GPS data was recorded in UTM WGS84 coordinates, the same projection properties as the ETM+ data, so no reprojection of either the GPS or ETM+ data was required. Attribute information was added to the point shapefile from notes taken during the driving transect.

During the driving transects, when GPS data points were recorded, a notebook was used to record the waypoint number and class. For example, when waypoint 10 was recorded with the GPS unit, an entry was made into the notebook with the waypoint number and a description of the field associated with waypoint 10. Recall that the entire driving transect data collection process was also recorded on digital videotape with GPS position overlay to further ensure accuracy. The GPS data recorded as waypoints and the GPS overlaid video recording both contain UTM coordinates and a time stamp. Positional data along with a time stamp ensures data collected as waypoints can be identified and correlated with data contained in the continuous video recordings.

The field description information was then entered into the point shapefile attribute table providing descriptive information for each point. Each point was manually adjusted spatially to account for the fact that the GPS data was recorded from a road and not the actual field itself. The appropriate offset was determined from the directional heading information provided by the GPS data in the attribute table in conjunction with the field notes to ensure that each point location was spatially repositioned in the appropriate field or representative location. The 442 GPS data points are comprised of:

89	Conventional Tillage
204	Conservation Tillage
36	Alfalfa
42	Winter Wheat
44	Forested
27	Water

During GPS data collection an effort was made to concentrate primarily on agricultural targets. Forested areas and water are easily discernable in ETM+ imagery and so in the interest of time and effort many forested areas and water bodies were not logged with GPS positional data. However, throughout the driving transect every effort was made to log large (greater than approximately 80 acres) agricultural fields encountered during the course of the driving transect. Larger agricultural fields were used for several reasons, including spatial accuracy and pixel purity. Because these points provide ground truth data, the spatial accuracy of the GPS points and the associated fields must be made with a great deal of accuracy. Focusing on large fields during GPS data acquisition ensures that the data points will be located in the appropriate field. Large fields also provide better targets for training sites and classification accuracy assessments due to the fact that large fields will be comprised of pixels entirely contained in the field. Small agricultural fields have a much higher chance of being represented by mixed pixels in 30 meter ETM+ imagery.

The results of validation, comparing the classified image to known ground truthed data points collected during the driving transects, are reported in Table 12.

Ground Truth Data Points	Class	Classified Correctly
89	Conventional Tillage	88
204	Conservation Tillage	198
36	Alfalfa	36
42	Winter Wheat	37
44	Forested	43
27	Water	27

Table 12. Validation Results of the Cosine of the Angle Classification Routine.

4.8 Potential Sources of Classification Error

4.8.1 Soil Background Effect

Analysis of the classified data indicates that soil background has little if any affect on the accuracy of the classified imagery. The study area contains 35 soil types based on MLRA types. Of the 35 soil types located in the study area, 30 are suitable for agricultural production. The remaining soils are either too wet (mucky) or predominately glacial tills (low in organic matter, high in sand and gravel). A GIS analysis was performed to assess the classification rates based on MLRA soil types, and the classification accuracy was found to be the same over all agricultural soils (Figure 20). The MLRA identified agricultural soils may vary to the soil scientist, but when viewed based on their spectral properties, the soils are very similar spectrally. The spectral similarity of the agricultural soil types works well for this study, as the background effect of soils is essentially the same throughout the scene. If the findings of this study are carried out in other areas of the Midwestern United States, the spectral properties of the background soils should be assessed to ensure that soil types do not affect classification results.

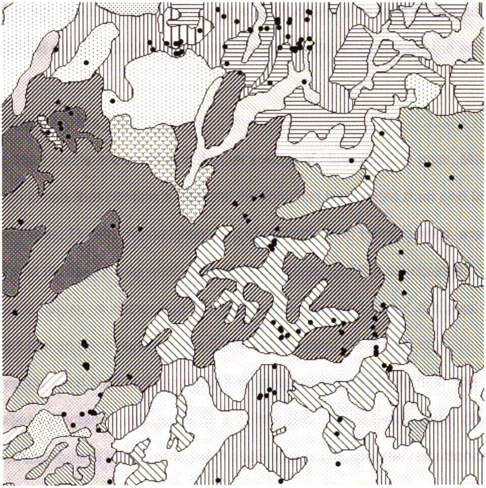

Figure 20. Soil Types and Ground Truth Collection Locations
Shadings correspond to STATSGO soil types.

Weather across the study area was also examined to determine if soil moisture across the area was uniform. Data from eight weather stations across the study area indicate that there was a uniform light rain event three days prior to image acquisition amounting to .05" across the study area. Prior to this rainfall event, no rain was reported across the study area through May 20th, 7 days prior to imagery acquisition. Based on these findings, the assumption that soil moisture was relatively uniform for each soil type found throughout the study area is being relied upon. While some soils may retain moisture more efficiently than other soil types, the classification results indicate that soils and/or soil moisture had no impact on overall classification accuracies across the soil types.

4.8.2 Mixed Pixels

Mixed pixels are another potential source of classification error. Mixed pixels are pixels that contain a spectral contribution from more than one land use/land cover. During the development of classification training sites, areas are chosen that completely lie within a field. Each pixel, and the associated reflectance values, is comprised of a single land use/land cover. If a pixel to be classified lies on the boundary of a field, half the pixel contained in a conservation tilled field and the other half contained in an alfalfa field, the associated reflectance values will be a combination of the two targets. When a classification routine is presented with such a target or spectral reflectance pattern, it will not be readily identified as belonging to a particular class membership and may be misclassified.

CHAPTER 5 CONCLUSIONS / DISCUSSION

A significant gap in the literature exists regarding the spectral characteristics of tillage methods, as well as the application of classification routines to accurately identify and map tillage methods. While many articles have been published on the environmental impacts and consequences of cropping methods, they lack fundamental spatial data regarding the total area and the spatial distribution of cropping methods. Without fundamental spatial data, the results of research investigating the environmental impacts of cropping methods from field based experiments cannot be scaled up to larger watershed or regional scales.

The classification of conservation and conventional cropping methods was achieved using spectral angle classification techniques. The two spectral angle techniques examined were spectral angle mapping and the cosine of the angle concept. Of the classification routines investigated, only the two methods based on spectral angles satisfied the requirement of 85% classification accuracy, a commonly accepted guideline set forth by the USGS standards for interpretation of remotely sensed data.

The underlying mechanism and explanation of the success of spectral angle classification techniques over geometric and statistical based classification routines, lies in the ability of spectral angle mapping techniques to account for illumination and brightness effects. The reflectance properties of individual land use/land cover types or objects on the surface of the earth interact with electromagnetic radiation across the electromagnetic spectrum in a unique way. However, these unique reflectance patterns associated with the interaction of electromagnetic radiation and the surface of the object can be perturbed a number of ways. The most common of which is a linear scaling of the spectral reflectance pattern above and below the mean reflectance value due to illumination and brightness effects.

Individual land use/land cover types captured in remotely sensed imagery exhibit a range of reflectance values throughout the remotely sensed data product. These variations are caused by lighting and illumination effects such as shadowing and are also exacerbated by the atmosphere. While the overall reflectance for any particular land use/land cover may be higher or lower than the mean reflectance values across the electromagnetic spectrum, the reflectance pattern is a linearly scaled version of the mean overall reflectance pattern. While individual land use/land covers exhibit a range of linearly scaled possibilities, this knowledge can be used advantageously within the classification decision rule.

Traditional geometric and statistically based classification methods rely on classification decision rules that do not account for the linear scaling of overall reflectance patterns. The linear scaling of overall reflectance patterns are often times mistakenly classified as altogether different land use/land cover classes using geometric or statistically based decision rules for classification. Spectral angle mapping techniques incorporate linearly scaled reflectance patterns into the decision rule. This avoids the problem of misclassifying land use/land covers, which are linearly scaled versions of a particular reflectance pattern.

Spectral angle mapping techniques more accurately account for illumination and brightness effects than standard statistical or geometric classification decision rules. Spectral angle classification routines are able to account for brightness and illumination effects by virtue of the decision rule, one based on an angle formed between the reference spectral reflectance pattern and an unknown spectral reflectance pattern. Rather than partitioning the decision space based on geometric or statistical measures, the unknown reflectance signature is compared to a reference signature based on the angle formed between the two. Comparing reflectance patterns using these angular methods better accounts for spectral variations due to brightness and illumination effects.

As reported by Sohn and Rebello (2002), the cosine of the angle approach is well suited for discrimination of linearly scaled reflectance patterns. This is due to the fact that linearly scaled reflectance patterns, when compared to the reference spectrum, result in a cosine of the angle value of zero or very close to it. Atmospheric and topographic effects act to linearly scale reflectance patterns. That is, atmospheric and topographic effects may brighten or darken the overall observed reflectance, but the overall reflectance pattern is, in fact, a linearly scaled version of the reference reflectance pattern.

Traditional geometric and statistical classification routines base classification decision rules on statistical measures, whereas spectral angle mapping techniques rely on spectral pattern shape. The reliance on spectral angles, rather than probabilities, offers other advantages as well. A primary advantage of using angular measures is that assumptions regarding data normality, which are often violated with remotely sensed data sets, can be avoided all together. "Spectral angle classifiers do not require the data to be normally distributed and they are insensitive to data variance and the size of the training data set" (Sohn and Rebello, 2002).

Results indicate that the discrimination of cropping methods through the use of remotely sensed data is not only possible, but can be performed using widely available data sources. These results provide a method to quantify carbon sequestration potentials based on agricultural management practices over a broad geographic area. The findings of this study can be further applied to other Landsat scenes across the Midwestern United States to more accurately quantify the carbon sequestration potential of agricultural lands. The findings of scaled up research can then be used as input into carbon modeling algorithms to determine the impact of agricultural cropping methods across the landscape as they relate to the overall carbon budget.

Additionally, the findings can be used for a wide variety of environmental studies where widespread agricultural production occurs. These studies may include the assessment of water quality and soil erosion over entire watersheds, providing new insight into the relationship of row crop agriculture and the environment.

5.1 Carbon Cycle Implications

The processes and dynamics controlling the global carbon cycle have been the subject of a great deal of research over the past decades. Research has provided a better understanding of the carbon cycle, however, fundamental data to provide a full account of the carbon cycle and budget has eluded researchers. Additional data regarding the spatial extent and areal distribution of carbon storage and release are required to arrive at more accurate estimates of carbon sinks and sources. The United States Global Change Research Program (USGCRP) notes that a need exists for "comprehensive, unbiased scientific understanding of sources and sinks of carbon dioxide on continental and regional scales..." (USGCRP, 2003).

Carbon is the basis of all life on earth and is the primary building block of plant life. Plant growth is driven by photosynthesis, the process by which plants convert sunlight to chemical forms of energy which drive biological systems. Plants, through the process of photosynthesis, take in carbon dioxide from the atmosphere and store it as plant material (carbohydrates) as illustrated by the following equation:

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Extraction of atmospheric carbon dioxide through photosynthetic action by plants is only one of the many processes and interactions that transforms and cycles carbon through the biosphere.

The carbon cycle is comprised of a series of interactions among large carbon pools consisting of atmospheric, terrestrial and oceanic components. Carbon cycles through these large pools or reservoirs much like the hydrologic cycle and carbon is regularly exchanged between all three major carbon pools through a complex series of interactions. The carbon cycle was once primarily controlled by nature and natural processes governed flows between and among carbon reservoirs. The actions of man have significantly altered the natural flow of carbon and, now more than ever, have a large impact on the carbon cycle. Land use conversions from natural ecosystems to managed production and fossil fuel combustion are two examples of man's impact and influence on the carbon cycle. Conversion of native ecosystems to managed production has resulted in a redistribution of carbon from plants and soils to the atmosphere. The extent to which anthropomorphic changes have on natural processes is crucial to a better understanding of mans role and influence on the carbon cycle.

Recent observations of atmospheric carbon dioxide levels taken at the Mauna Loa observatory in Hawaii since 1958 show a rapidly increasing trend in atmospheric levels of carbon dioxide. The primary drivers behind the rise of atmospheric carbon dioxide levels are thought to be due to land use/land cover change and the combustion of fossil fuels. Land use/land cover change releases carbon in large part due to deforestation activities including slash and burn agriculture. Human land use/cover change has transformed one third to one half of the earth's ice free surface (Vitousek, 1994). This land cover change, taking place over such great spatial extents, has resulted in a large release of carbon dioxide to the atmosphere. Additionally, the mining of old carbon in the form of fossil fuels and the ensuing combustion of these fuels has also been a primary source of atmospheric carbon dioxide.

A significant scientific effort has been underway over the past decades to more thoroughly understand the carbon cycle. These efforts have provided a great deal of knowledge and understanding regarding the carbon cycle but several questions remain unanswered. The carbon cycle can be represented by the following equation:

$$A = F + B - O - \beta \quad \text{Units: Pg or } 10^{15} \text{ g/year}$$

A = Atmosphere, F = Fossil Fuels, B = Terrestrial Biota, O = Oceans, ß = Error Term or Missing Sink

Substituting values based on current research (Schimel et al., 1995) the carbon cycle equation can be restated:

$$3.0 = 5.2 + 1.8 - 2.0 - \beta$$
$$3.0 = 5.0 - \beta$$
$$\beta = 2.0 \text{ Pg of Carbon, the missing carbon sink}$$

The error term in the preceding equation, the missing carbon sink, is an amount of carbon that has not been readily accounted for. While the values associated with the atmospheric, oceanic and fossil fuel components of the carbon cycle are believed to be reliable, an accurate estimate of the terrestrial component has thus far eluded researchers. The influence of widespread land use/land cover change and the ensuing human management of these lands (forestry, agriculture) has not been accounted for accurately enough to reach a reliable estimate of mans influence on the terrestrial component of the carbon cycle (Follett, 2001). The missing sink, many believe, may be a part of the terrestrial biota term. The missing sink may be accounted for by enhanced carbon sequestration rates in soils due to past and present management practices, lengthening of the growing season, especially in the northern hemisphere due to warming, CO_2 fertilization through elevated CO_2 levels in the atmosphere, and sequestration of carbon in soils and sediments.

More detailed and accurate information regarding the carbon consequences of land use/land cover change and subsequent land use management practices are required to more accurately estimate the carbon implications of such land use/land cover change. Conversion from forested land covers to agriculture resulted in a large amount of carbon released to the atmosphere. The carbon that was released during land use/land cover conversion, by soils in particular, now have the potential to sequester carbon due to changes in agricultural production methods. Prior to settlement and cultivation, the long term balance of carbon stored in soils was dramatically disrupted. The advent of large scale cultivation resulted in a large scale release of soil organic carbon to the atmosphere (Follett, 2001).

Additional research has focused on what is termed the greening of the north. Models by Dai and Fung (1993) suggest that the carbon sink is predominately located in the northern middle latitudes (20-60° N). Dr. Fan and other researchers have concluded that the missing sink is caused primarily by increased terrestrial biosphere carbon storage (Fan et al., 1998). This has been corroborated in part by satellite observations, which indicate that the growing season for the northern mid latitudes has increased by several weeks (Myneni, 1996). Snow cover melts earlier in the spring and does not form until later in the fall, a consequence of overall higher than average temperatures.

Feedback is another process suspected in increased carbon storage by plants. Plants rely upon atmospheric carbon dioxide during photosynthesis; elevated levels of carbon dioxide in the atmosphere due to anthropomorphic activities may be responsible for increased plant growth. Increasing ambient levels of carbon dioxide in laboratory studies has been shown to increase overall plant growth. Increased plant growth leads to more carbon dioxide taken out of the atmosphere and sequestered in plant materials. Research examining this phenomenon indicates that vegetation has, in fact, experienced increased growth in the northern latitudes due to increases in atmospheric carbon dioxide (Keeling et al., 1996). These findings have been further substantiated by Tucker, who examined the relationship between atmospheric carbon dioxide variations and satellite derived vegetation indices (Tucker, 1986).

Houghton has noted "the rate at which carbon is accumulating in terrestrial ecosystems in the United States is uncertain, as are the mechanisms responsible for the current sink" (Houghton, 1999). Houghton based his research on historic land use change, and related this data to carbon changes which are direct results of land use change. The research considered the conversion of natural ecosystems to cultivated cropland and pastures but did not take into account the cropping method used for the agricultural production. Houghton states, "the evidence is more compelling that carbon is accumulating in agricultural soils as a result of changes in management but our book keeping model did not consider these changes" (Houghton, 1999).

5.2 Regional Carbon Accounting

Conversion of natural ecosystems to managed agricultural production during the 17th, 18th and 19th centuries has resulted in a dramatic loss of soil organic matter due to mineralization and erosion. Since land use conversion occurred, both vegetation and soils have undergone extensive changes (Lal and Follett, 1999). Clearing, tilling, and draining of these soils for long term agricultural production has released large amounts of carbon dioxide to the atmosphere from the soils' fertile soil organic matter (Figure 21) (Lal and Follett, 1999). The soil organic carbon in topsoil often was depleted by up to half of its original content (Cambardella, 1992). Lal and Follett (1999) estimated the loss of soil organic content from U.S. cropland soils at about 5 Pg. Therefore, U.S. cropland has a potential to sequester approximately 5 Pg of carbon through improved soil management practices (Lal, 2000).

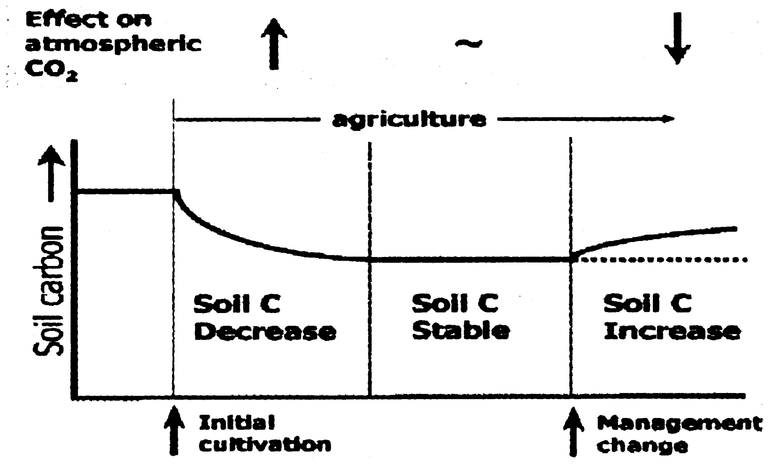

Figure 21. Agriculture and Carbon.
From Follett, 2001

Regional estimates of the carbon sequestration potential of conservation tillage cropping practices are crucial if policy makers are to plan future land uses to reduce national CO_2 emissions (Falloon, 1998). Questions related to the distribution and spatio-temporal dynamics of the terrestrial carbon fluxes are at the core of current scientific and policy debates (Cihlar, 2000):

> Improved knowledge of the carbon cycle, its variability, and its likely future state is essential. There are large uncertainties in the magnitudes and locations of carbon fluxes between the land, atmosphere, and oceans. We currently lack the understanding and observations needed to close the annual carbon budget. It is not (currently) possible to unambiguously

determine the spatial distribution and longevity of carbon sinks at regional to landscape scales, and previous attempts to do so have suffered from inadequate data.

Atmospheric concentrations of carbon dioxide may be lowered by reducing emissions or by taking carbon dioxide from the atmosphere via photosynthesis and sequestering it in different components of terrestrial, oceanic, and freshwater aquatic ecosystems (Bruce et al., 1999).

Soil organic matter represents a major pool of carbon within the biosphere. It is estimated to contain 1550 Pg globally, which is roughly twice that found in the atmosphere (Follett, 2001). Soil can act as both a source and a sink for carbon and nutrients. Changes in agricultural land use and climate can lead to changes in the amount of carbon held in soils, thus affecting the fluxes of CO_2 to and from the atmosphere. Carbon levels in soils are determined by the balance of carbon inputs and outputs. Carbon inputs such as crop residues add carbon to the soil balance. Over time, if carbon inputs are continual, soil carbon stocks will build to a point where they outpace carbon loss, leading to net carbon sequestration in soils. Conservation tillage methods have been shown to sequester carbon in the soil over time, whereas conventionally tilled fields are considered a net source of CO_2.

The management of crop residue plays a significant role in the fate of the carbon stored in these residues. Under conventional tillage 60 – 80% of the carbon stored in crop residues is released to the atmosphere as carbon dioxide due to microbial soil respiration (Cavigelli, 2000). Conservation tillage practices significantly slow decomposition rates, resulting in a net sequestration of carbon in soils versus the net carbon loss found under conventional tillage practices.

5.3 Carbon and Tillage

The increase of atmospheric CO_2 is partly the result of increasing the oxidation of the two main sources of organic carbon stored in the land – fossil fuel (old organic carbon) and conventional tillage (recent organic carbon). The studies by Robertson et al. (2000) at the Kellogg Biological Station (KBS) Long Term Ecological Research site (LTER) has shown that fields that have never been in agricultural production contain 40% to 50% more carbon by weight than active agricultural fields. Agricultural fields under no-till conservation tillage cropping methods were found to sequester 300 kg carbon per hectare per year, whereas conventionally tilled crops exhibit no annual carbon sequestration (Robertson et al., 2000). Other estimates of carbon sequestration rates for conservation tillage range from 500 kg/C/ha/yr to 600 kg/C/ha/yr (Lal and Follett, 1999). The United States Department of Energy also estimates the conversion from conventional tillage to conservation tillage methods to potentially sequester 300 kg C/ha/yr.

Conservation tillage cropping methods result in improved carbon retention due to the fact that less organic matter is lost to oxidation from mixing of the soil, and soil temperatures tend to be lower, which slows oxidation rates (Uri, 1999).

Uri also notes conservation tillage cropping methods require less energy inputs by function of fewer field activities, thereby reducing carbon emissions due to decreased fuel use (Uri, 1999).

Robertson et al. (2000) state that agriculture plays a major role in the global fluxes of greenhouse gasses. They note that radiative forcing of Earth's atmosphere is increasing at unprecedented rates, largely due to increases of greenhouse gases. Carbon dioxide is produced anthropogenicly primarily through the burning of fossil fuels, deforestation and conventional plowing. Decaying plant material also produces carbon dioxide through the decomposition process. Conservation tillage practices delay decomposition, which results in increased soil carbon storage. Increased soil carbon leads to improved overall soil quality and fertility. In the United States, half the organic matter in soils has been oxidized by more than 100 years of conventional tillage (Falloon, 1998). The depletion of soil carbon from agricultural lands has many farmers concerned and is another associated benefit of conservation tillage practices that are drawing farmers to the technique.

Two types of processes affect terrestrial carbon fluxes: relatively slow accumulation over large areas in vegetation and soils, and the relatively rapid release over small areas through disturbances (Cihlar et al., 1998). There are numerous studies in the literature focusing on the rapid release of carbon over small areas due to human disturbances such as deforestation, fire, and slash and burn agriculture (Foody, 1997, Houghton, 1999). Regarding the relatively slow accumulation over large areas in vegetation and soils, there are several articles focusing on forestry, the "greening of the north", and the impacts of agriculture and carbon. However, while there are many articles regarding the potential of agricultural soils to sequester carbon, none of these articles are able to accurately quantify these estimates due to the fundamental lack of knowledge regarding the spatial distribution and total acreage of conservation tillage methods.

5.4 Study Area Total Carbon Sequestration

The carbon sequestration potential of the study area based on the cosine of the angle concept classification, the most suitable classification method identified in this study, is estimated currently at 228,490,877,995.98 grams (7,616,362,599.87 square meters * 30g/m^2) or 228,490.87 metric tons.

The classified data indicate that conservation tillage cropping methods are utilized on 1,881,241.56 acres (64% of major row crop agriculture) within the study area. This estimate is based on the total acreage in the classified data and the findings published by Robertson et al. (2000) of carbon sequestration rates of 30 g/m^2/year utilizing no-till conservation tillage techniques.

These estimates can be taken a step further to estimate the total carbon sequestration rate for the study area if all corn and soybean acreage were to be raised using conservation tillage cropping methods. For this estimate, the total acreage of conventional and conservation tillage acreage were aggregated to arrive at a total acreage of the study area and then multiplied by Robertson's estimates of carbon sequestration rates to arrive at a figure of potential carbon sequestration of 359,065,898,717.7 grams (359,065.8 Metric Tons). This represents the overall carbon sequestration potential of agricultural land use/land cover across the study area.

5.5 Regional Estimates of Carbon Sequestration Based on Tillage

Agricultural production occurs on over 200 million acres of land use/land cover across the United States, yet little data exists regarding the methods used to produce crops and the associated benefits and costs related with each cropping method. The methods and data presented here may prove useful for analyzing the spatial distribution and extent of cropping methods and, by extension, environmental and ecological impacts.

If the results found throughout the study area are representative of the cropping methods across the Midwestern United States, then the findings here may provide a useful starting point for assessing and possibly revising carbon sequestration estimates currently available for agricultural soils. If the study area is indeed representative of the larger Midwestern, then the 146 million acres used in the production of corn and soybeans across the Midwestern United States has the potential to sequester 17.725 million metric tons of carbon on a yearly basis using a sequestration rate of 300 kg/hectare. The ranges of potential yearly carbon sequestration rates are shown in Table 13.

Carbon Sequestration Rate	Potential C Sequestration (Metric Tons)
300 kg/C/ha/yr	17,725,231.03
500 kg/C/ha/yr	29,542,051.72
600 kg/C/ha/yr	35,450,462.06

Table 13. Yearly Carbon Sequestration Potential

The carbon sequestration rates are based on published figures in the literature, 300 kg/C/ha/yr (Robertson, 2000 and United States Department of Energy), 500 and 600 kg/C/ha/yr (Lal, 1999) for conservation tillage practices as compared to a net carbon sequestration rate of zero (0) for conventional tillage practices. As Follett (2002) notes, even a small annual percent change in the amount of carbon stored or released from large terrestrial carbon stocks could easily affect the net change in atmospheric carbon dioxide.

5.6 Soil Erosion and Tillage

Soil erosion is a major environmental problem in the US and worldwide (Nyakatawa et al., 2001). Soil erosion exhibits four primary effects on cropland: nutrient loss, decreased water storage capacity, crop damage and decreased yields, and ultimately if severe, field abandonment (Kohl, 1998). Soil loss due to erosion under conventional tillage practices can occur at astounding rates of 21 tons/acre/year (Aber, Melillo, 2001). Conservation tillage cropping methods often reduce the soil erosion rate to 0.8 tons/acre/year (Aber, Melillo, 2001). The overall annual soil loss due to agriculture practices in the United States is estimated by the USDA at 1.25 billion tons per year (USDA, 1991). With such enormous erosional rates, it is not surprising that soil erosion is the largest source of non point source pollution in the United States (USEPA, 1995).

Runoff from agriculture fields chokes streams with excessive sediment loads, altering stream ecology and the streambed itself. Intensive row crop agriculture has resulted in elevated amounts of suspended sediments, fertilizers, and pesticides (Baker, 1993). When pesticides and herbicides are applied to fields, these components are also washed away in the eroding soil, polluting fresh water streams and lakes. Runoff containing fertilizers, when washed into streams and lakes, can provide the nutrients necessary for algae blooms. The growing algae deplete the water of oxygen creating a eutrophic environment where little can live but algae and bacteria. Uri (1999) reports 70% less herbicide runoff for conservation tillage versus conventionally tilled fields.

A United States Geological Survey (USGS) study investigating soil erosion and tillage methods found a correlation between agricultural cropping methods and suspended sediment loads in water bodies (USGS, 2000). The USGS performed the study on the Maumee river basin, contained in the southwestern portion of this study area, encompassing portions of Ohio, Michigan, and Indiana. They found that sediment loads in water bodies are closely related to agricultural cropping methods. They also noted that as conservation tillage has increased in some areas the corresponding watershed units showed lesser amounts of sediment loads in individual watershed units. Areas identified in the USGS study as contributing the highest amounts of soil erosion to water bodies were areas characterized by the lowest rates of conservation tillage.

Soil erosion associated with agricultural production represents a tremendous loss of a valuable natural resource. Conventional tillage practices create a soil surface highly susceptible to erosional processes. Loss of topsoil due to erosional action may eventually lead to loss of production capabilities if left unchecked. In addition to loss of productivity, the eroded soil significantly impacts overall water quality in water bodies across the United States. The eroded soils also play a role in the carbon budget as well.

The suspended sediment load carried through the nations waterways is deposited in the waterway itself or ultimately to the oceans. The redistribution of carbon through erosion and deposition, which effectively sequesters carbon, is yet another portion of the carbon cycle that has yet to be fully accounted for. The spatial distribution and the total area of conservation tillage and conventional cropping methods by watershed may provide data to more accurately quantify the erosional potential of agricultural lands.

5.7 Scaling Up – Regional Measurements and Estimates

In order to fully take advantage of the findings of this study, the results should be scaled up to a regional level encompassing the Midwestern states that account for the nations vast majority of row crop agriculture. Scaling the results to larger geographic areas would provide for additional data regarding the spatial distribution of cropping methods including both total area and the spatial distribution of cropping methods.

Data regarding the total area of each cropping method could then be used to more accurately derive carbon sequestration potentials of agricultural lands. Data regarding the spatial distribution of cropping methods could be used in a wide variety of studies investigating soil erosion and, in turn, water quality. Perhaps watersheds with higher percentages of conservation tillage acreage can be correlated with water quality measurements. Knowledge of the spatial distribution and total acreage under each cropping method may also lead to more accurate estimates of soil erosion estimates. An enhanced understanding of the total extent and spatial distribution of cropping methods at larger regional scales holds a great deal of promise for a variety of ecosystem studies.

Data sources and analytical procedures used in this study were based not only on best methodology, but also ensured that the study could be repeated by other researchers with a minimum amount of specialized software and at reasonable cost. Landsat 7 ETM+ data are arguably the most widely available high resolution and cost efficient satellite based source of remotely sensed data currently available. Additionally, the analytical procedures used in this study rely upon industry standard software and hardware configurations widely available in research, industry, and governmental settings.

The findings of this research indicate that the mapping of agricultural crops and cropping methods is possible over entire Landsat ETM+ scenes with only two ETM+ images per season. The first image, taken after field preparation activities in the spring, as illustrated by this study, can be used to differentiate cropping methods. Adding a temporal component, a second image acquired later in the growing season towards peak plant development, in conjunction with the first image, allows for differentiation between common agricultural crops.

The first image obtained early in the season, after field preparation activities, provides data regarding cropping method: conventional tillage vs. conservation tillage. The first image also contains data regarding other secondary crops. While it is too early in the season to distinguish corn acreage from soybean acreage in this early image, the data contains information regarding winter wheat and alfalfa acreage. Winter wheat acreage is in peak growth at this time, and exhibits a very strong healthy green vegetation reflectance pattern. The only other field crop in the region that may be in vegetative growth at this point in time is alfalfa, which can be differentiated from winter wheat based on spectral reflectance properties. The first image provides data regarding cropping method for corn/soybean acreage as well as acreage for winter wheat, and alfalfa acreage. The second image, obtained later in the growing season, could then be used in conjunction with the earlier image to determine corn and soybean acreage as well as alfalfa and winter wheat (Table 14). Utilizing crop phenological development with a temporal data collection scheme allows for complete characterization of crop and cropping method for the major agricultural crops commonly found throughout the Midwestern United States.

	Image 1	**Image 2**
Corn	Bare soil/Crop Residue	Peak Growth
Soybean	Bare soil/Crop Residue	Peak Growth
Winter Wheat	Peak Growth	Senescent/Bare Soil
Alfalfa	Early Growth	Variable

Table 14. Temporal Image Acquisition for Crop Identification.

5.8 Further Research

The findings and conclusions of this research have resulted in the identification of suitable classification methods to differentiate between conventionally tilled crops and those raised using conservation tillage methods. However, the topic has not yet been exhausted, and research potential still exists for improvement and further knowledge.

The differentiation between conventional tillage and conservation tillage cropping practices is possible using commonly available data sources, software, and analytical methods. To successfully apply these findings to other areas throughout the Midwestern United States several considerations concerning scale and timing must be carefully examined to ensure a successful outcome.

The spatial resolution of the remote sensing instrument must be carefully considered to ensure that the phenomena of interest is accurately captured. The findings presented here indicate that 30 meter spatial resolution is sufficiently detailed to capture the phenomena of interest (conventional vs. conservation tillage cropping methods) while sufficiently large to enable data acquisition over large spatial areas. Additionally, the data source (Landsat 7 ETM+ data) is widely available to the research community and the public at a reasonable cost. The possibility of using other data sources with differing spatial resolutions, either lesser or greater, has not been specifically addressed, and these scaling issues should be examined if these techniques and methods are to be applied using different data sources.

The use of other sources of remotely sensed data may yield improved classification accuracies due to improved spatial, spectral, or radiometric resolutions of newer sensors. Much of the data from new experimental satellites and remote sensing instruments are not yet available to the research community. Advanced remote sensing instruments with improved resolutions (spectral, radiometric, temporal) may provide more information regarding the target of interest, thus leading to improved classification results.

Additional studies regarding scaling issues are warranted, based on the conclusions of hand held and satellite based sensor readings. The interaction of electromagnetic energy with the target of interest and the scale at which the reflected electromagnetic energy is measured shows a dependent relationship. A study utilizing a wide variety of spatial resolutions (4, 10, 30, 60, 120 meters) from a variety of satellite based sensors would provide basic data regarding scaling effects on the complex interaction of reflection, scale, and texture.

Further studies utilizing these techniques should also consider the broad range of moisture conditions that could be encountered in future research. While spectral angle mapping and the cosine of the angle concepts take into account variations in illumination due to a broad range of conditions, including in theory moisture, additional research to ensure tillage methods are differentiatable under a wide range of moisture conditions is warranted. The possibility exists that the soil and crop residue moisture conditions at the time of imagery collection for this study were ideal. Data acquired under differing soil and crop residue moisture conditions may have an impact on classification results. For example a rainfall event just prior to imagery collection may result in wet or moist soils and relatively dry crop residues. While the classification methods utilizing spectral angle concepts should theoretically account for such variations further investigation and caution is warranted before relying upon these methods and techniques under differing conditions.

The possibility also exists for examining historical change over time. Landsat data are available from 1972, providing a rich historical record of land use/land cover change. An assessment to determine the suitability of using earlier Landsat remote sensing systems to study cropping methods is warranted. If earlier Landsat based systems are found suitable for the differentiation of cropping methods it would provide valuable data regarding the past spatial distribution and extent of cropping methods and their associated environmental implications. Archived data regarding atmospheric carbon dioxide concentrations or stream flow sediment loads could be linked to past land use/land cover change to more accurately assess the environmental impacts of intensive row crop agriculture production methods.

BIBLIOGRAPHY

Aase, J.K., Tanaka, D.L., 1991, Reflectance from four wheat residue densities as influenced by three soil backgrounds, Agronomy Journal, vol. 83, 753-757.

Aber, J.D., Melillo, J.M., 2001, Terrestrial Ecosystems, Harcort Academic Press, New York.

Albert, Dennis A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: a working map and classification. Gen. Tech. Rep. NC-178. St. Paul, MN: U.S. Department of Agriculture, Forest Service.

Allmaras, R.R., Schomberg, H.H., Douglas, C.L., Dao, T.H., 1999, Conservation tillage's unforeseen advantage. Research Engineering Technology, vol. 6, pp 7-8.

Appenzeller, C., Stocker, T.F., Anklin, M., 1998, North Atlantic oscillation dynamics recorded in Greenland ice cores, Science, vol. 282, 446-448.

Atkinson, P.M., Curran, P.J., 1997, Choosing an appropriate spatial resolution for remote sensing investigations. Photogrammetric Engineering and Remote Sensing, 63, 1345-1351.

Atkinson, P.M. Tatnall, A.R.L., 1997, Neural networks in remote sensing. International Journal of remote sensing, vol. 18, no. 4, 699-709.

Baker, D.B., 1993, Lake Erie agroecosystem program – Water quality assessments: Agriculture, Ecosystems, and Environment, v. 46, p. 197-215.

Baker, D.B., Calhoun, F.G., Matisoff, G., 1998, LEASEQ, the Lake Erie agricultural systems for environmental quality project: Fact Sheet, 2 p.

Baker, D.B., Calhoun, F.G., Matisoff, G., 1998, LEASEQ, the Lake Erie agricultural systems for environmental quality project.

Batjes, N.H., 1996, Total C and N in soils of the world, European Journal Soil Science, vol. 47 pp 151-163.

Batjes, N. H., 1998, Mitigation of atmospheric carbon dioxide concentrations by increased carbon sequestration in the soil, Biological Fertility and Soils, vol. 27, 230-235.

Boyd, R., Uri, N.D., 2001, A note on the use of conservation practice in U.S. agriculture, Environmental monitoring and assessment, vol. 72, 141-178.

Bricklemyer, R., Lawrence, R., Miller, P., 2002, Documenting no-till and conventional till practices using Landsat ETM+ imagery and logistic regression, Journal of Soil and Water Conservation, vol. 57, no. 5, 267-271.

Bruce, J.P., Frome, M., Haites, E., Janze, H., Lal, R., Paustian, K., 1999, Carbon sequestration in soils, Journal of Soil Water Conservation, vol. 54, pp 382-389.

Cavigelli, M.A., Mutch, D.R., 2002, Cover Crops and Carbon, Michigan State University Extension, Info-Sheet.

Campbell, J., 1987, *Introduction to Remote Sensing*, New York: Guilford Press.

Cihlar, J., Xiao, Q., Chen, J., Beaubien, J., Fung, K., Latifovic, R., 1998, Classification by progressive generalization: a new automated methodology for remote sensing multichannel data. International Journal of Remote Sensing, vol. 19, no. 14, 2685-2704.

Cihlar, J., 2000, Land cover mapping of large areas from satellites: status and research priorities, International Journal of Remote Sensing, vol. 21, no 6 &7, 1093-1114.

Cipra, J.E., Baumgardner, M.F., Stoner, E.R., MacDonald, R.B., 1971, Measuring radiance characteristics of soil with a field spectroradiometer. Soil Science Society of America Proceedings, 35, 1014-1017.

Congalton, R.G., 1983, Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques. Photogrammetric Engineering and Remote Sensing, Vol. 49, 1671-1678.

Cortijo, F., and Perez de la Blanca, N., 1998, Improving classical contextual classifications. International Journal of Remote Sensing, vol. 19, no. 8, 1591-1613.

Coulson, K.L., Reynolds, D.W., 1971, The spectral reflectance of natural surfaces. Journal of Applied Meteorology, vol. 10, 1285-1295.

Dai, A., Fung, I.Y., 1993, Can climate variability contribute to the missing carbon dioxide sink?, Global Biogeochemical cycles, vol. 7 599-609.

Daughtry, C.S.T., J.E. McMurtrey J.E., E.W. Chappelle, W.J. Hunter and J.L. Steiner, 1996, Measuring Crop Residue Cover Using Remote Sensing Techniques, Theoretical and Applied Climatology, 54, 17-26.

Daughtry, C.S.T., McMurtrey, J.E., Dulaney, W.P., Irons, J.R., Satterwhite, M.B., 1995, Potential for discriminating crop residues from soil by reflectance and fluorescence, Agroclimatology, Agronomy Journal, 87:165-171.

Elvidge, D.D., 1990, Visible and near infrared reflectance characteristics of dry plant materials. International Journal of Remote Sensing, 11, 1775-1795.

Erol, H., Akdeniz, F., 1998, A new supervised classification method for quantitative analysis of remotely-sensed multi-spectral data. International Journal of Remote Sensing, vol. 19, no 4, 775-782.

Falloon, P.D., 1998, Regional estimates of carbon sequestration potential: linking the Rothamsted carbon model to GIS databases. Biological Fertility of Soils, vol. 27, 236-241.

Fan, S., M. Gloor, J. Mahlman, S. Pacala, J. Sarmineto, T. Takahashi, P. Tans, 1998, A large terrestrial carbon sink in North America implied by atmospheric and oceanic carbon dioxide data and models. Science, vol. 28, 442-446.

Field, C.B., Fung, I.Y., 1999, The not so big U.S. carbon sink, Science, vol. 285, 544-545.

Foody, G.M., 1997, An evaluation of some factors affecting the accuracy of classification by an artificial neural network. International Journal of Remote Sensing, vol. 18, no 4, 799-810.

Foody, G.M., Palubinskas, G., Lucas, R.M., Curran, P.J., Honzak, M., 1996, Identifying terrestrial carbon sinks: classification of successional stages in regenerating tropical forest from landsat TM data, Remote Sensing of the Environment, vol. 55, 205-216.

Follett, R.F., Paul, E.A., Leavitt, S.W., Halvaorson, A.D., Lyon, D., Peterson, G.A., 1997, The determination of the soil organic matter pool sizes and dynamics. Soil Science Society of America Journal, vol. 61, 1068-1077.

Follett, R.F., McConkey, B., 2000, The role of cropland agriculture for carbon sequestration in the Great Plains. Proceedings of the conference on Great Plains soil fertility, vol. 8, 1 –15.

Follett, R.F., Samson-Liebig, S., Kimble, J.M., Pruessner, E.G., Waltman, S.W., 2001, Carbon sequestration under the CRP in the historic grassland soils in the USA, Soil Carbon Sequestration and the Greenhouse Effect, SSSA Special Publication, No. 57, Madison, WI.

Follett, R.F., 2001, Soil management concepts and carbon sequestration in cropland soils, Soil and Tillage Research, vol. 61, 77-92.

Gausman, H.W., Gerbermann, A.H., Wiegand, C.L., Leamer, R.W., Rodriguez, R.R., 1975, Reflectance Differences Between Crop Residues and Bare Soils, Soil Science Society of America Proceedings, vol. 39, 752 – 755.

Goward, S., Masek, J., Williams, D., Irons, J., Thompson, R., 2001, The Landsat 7 mission Terrestrial research and applications for the 21st century. Remote Sensing of the Environment, vol. 78, 3-12.

Houghton, R.A., Davidson, E.A., Woodwell, G.M., 1998, Missing sinks, feedbacks, and understanding the role of terrestrial ecosystems in the global carbon balance. Global Biogeochemical Cycles, vol. 12, No. 1, 25-34.

Houghton, R.A., Hackler, J.L., Lawrence, K.T., 1999, The U.S. Carbon budget: Contributions from land-use change, Science, vol. 285, 574-578.

Henderson-Sellers, A., Wilson, M.F., Thomas, G., 1985, The effect of spatial resolution on archives of land cover type, Climatic Change, vol. 7, 391-402.

Jahne, B., 1997, Practical handbook on image processing for scientific applications, CRC Press, Boca Raton, NY.

Janzen, H.H., Campbell, C.A., Izaurralde, R.C., Ellert, B.H., Juma, N., McGill, W.B. and Zentner, R.P., 1998. Management effects on soil C storage on the Canadian prairies. *Soil Till. Res.* 47, pp. 181–195.

Kaminsky, E., Barad, H., Brown, W., 1997, Textural neural network and version space classifiers for remote sensing. International Journal of Remote Sensing, vol. 18, no. 4, 741-762.

Kanellopoulos, I., and Wilkinson, G., 1997, Strategies and best practice for neural network image classification. International Journal of Remote Sensing, vol. 18, no. 4, 711-725.

Kartikeyan, B., Sarkar, A., Majumder, K., 1998, A segmentation approach to classification of remote sensing imagery. International Journal of Remote Sensing, vol. 19, no. 9, 1695-1709.

Keeling, R.F., Piper, S.C. and Heimann, M., 1996, Global and atmospheric CO_2 sinks deduced from changes in atmospheric 02 concentration, Nature, vol. 381, 218-221.

Keeling, C.D., Chin, J.F.S., Whorf, T.P., 1996, Increased activity of northern vegetation inferred from atmospheric carbon dioxide measurements, Nature, vol. 382, 146-149.

Kimberlin, L.W., Moldenhauer, W.C., 1977, Predicting soil erosion, Proceedings of the national symposium on soil erosion and sedimentation by water: Chicago, IL., Dec 12 –13, 1977, American Society of Agricultural Engineers, Publ. 4 – 77.

Kohl, Kris, 1998, Conservation Tillage – Effects on soil erosion, Department of agricultural and biosystems engineering, Iowa State University, Extension Publication # AE-3050.

Lal, R., Follett, R.F., 1999, Managing U.S. cropland to sequester carbon in soil. Journal of Soil and Water Conservation, First Quarter, 374 – 381.

Lal, R., Kimble, J.M., 2000, Soil carbon sink in U.S. cropland.

LPSO (Landsat Project Science Office), 1998, Landsat 7 Science Data Users Handbook,http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter5/chapter5.html#section5.4.

Magnussen, S., 1997, Calibrating photo interpreted forest cover types and relative species compositions to their ground expectations., Canadian Journal of Forest Research, vol. 27, 491-500.

Montserud, R.A., Leamans, R., 1992, Comparing global vegetation maps with the kappa statistic. Ecological Modeling, vol. 62, 275-293.

Moulin, S., 1998, Combining agricultural crop models and satellite observations: from field to regional scales. International Journal of Remote Sensing, vol. 19, no. 6, 1021-1036.

Murai, H., and Omatu, S., 1997, Remote sensing image analysis using a neural network and knowledge-based processing. International Journal of Remote Sensing, 1997, vol. 18, no. 4, 811-828.

Myers, D.N., Metzker, K.D., Davis, S., 2000, Status and trends in suspended sediment discharges, soil erosion and conservation tillage in the Maumee river basin – Ohio, Michigan and Indiana, U.S. Department of Agriculture, Natural Resources Conservation Service, Lima, Ohio.

Myneni, R.B., Keeling, C.D., Tucker, C.J., Asrar, G., Nemani, R.R., 1997, Increased plant growth in the northern high latitudes from 1981 to 1991, Nature, vol. 386, 698-702.

Myneni, R.B., Tucker, C.J., Asrar, G., Keeling, C.D., 1998, Interannual variations in satellite-sensed vegetation index data from 1981 to 1991, Journal of Geophysical Research, vol. 103, 6145-6160.

Nagler, P.L., Daughtry, C.S.T., Goward, S.N., 2000, Plant Litter and Soil Reflectance. Remote Sensing of the Environment, vol. 71, 207-215.

Nyakatawa, E.Z., Reddy, K.C., Lemunyon, J.L., 2001, Predicting soil erosion in conservation tillage cotton production systems using the revised universal soil loss equation. Soil and Tillage Research, vol. 57, 213-224.

Parsch, L.D., Keisling, T.C., Sauer, P.A., Oliver, L.R., Crabtree, N.S., 2001, Economic analysis of conservation and conventional tillage cropping systems on clayey soil in eastern Arkansas, Agronomy Journal, vol. 93, 1296-1304.

Post, W.M., Peng, T.H., 1998, The Global Carbon Cycle. American Scientist, vol. 78, 310-326.

Reicosky, D.C. 1996. Tillage as a mechanism for CO_2 emission from soils. Proceedings of International Symposium on Soil--Source and Sink of Greenhouse Gases., 14-20 September, 1995. Nanjing, China.

Richards, J.A., Jia, X., 1999, Remote Sensing Digital Image Analysis, Springer, New York.

Robertson, G.P, Eldor, P., Harwood, R., 2000, Greenhouse Gases in intensive Agriculture: Contributions of Individual Gases to the Radiative Forcing of the Atmosphere. Science, vol. 289, 1922 – 1925.

Schimel, D., Alves, D., Enting, I., Heimann, M., 1995, Carbon dioxide and the carbon cycle, Climate Change.

Sohn, Y., Moran, E., Gurri, F., 1999, Deforestation in north-central Yucatan (1985-1995): Mapping secondary succession of forest and agricultural land use in Sotuta using the cosine of the angle concept. Photogrammetric Engineering and Remote Sensing, vol. 65, No. 8, 947-958.

Sohn, Y., Rebello, N.S., 2002, Supervised and unsupervised spectral angle classifiers. Photogrammetric Engineering and Remote Sensing, vol. 68, No. 12, pp 1271 – 1280.

Stoner, E.R., Baumgardner, M.F., 1980, Extension of laboratory measured soil spectral to field conditions. Soil Science Society of America Journal, vol. 44, 572-574.

Stoner, E.R., Baumgardner, M.F., 1981, Characteristic variations in reflectance of surface soils. Soil Science Society of America Journal, vol. 45, 1161-1165.

Swain, P.H., Davis, S.M., 1978, Remote Sensing: The Quantitative Approach, N.Y., McGraw-Hill.

Tans, P.P., Fung, Y., Takahashi, T., 1990, Observational constraints on the global atmospheric carbon dioxide budget. Science, vol. 247, 1431 – 1438.

Tucker, D.J., Fung, I.Y., Keeling, C.D., Gammon, R.H., 1986, Relationship between atmospheric carbon dioxide variations and a satellite derived vegetation index, Nature, vol. 319, 195-199.

Uri, N.D., 1999, The environmental benefits and costs of conservation tillage. Environmental Geology, Vol. 38, no. 2.

Uri, N.D., 2001, Conservation practices in U.S. Agriculture and their impact on carbon sequestration. Environmental monitoring and assessment, vol. 70, 323-344.

USDA, 1991, Agricultural Statistics, National Agricultural Statistics Service, US Government Printing Office, Washington, D.C.

USDA 1991, Yearbook of Agriculture, Agriculture and the environment, US Government Printing Office, Washington D.C.

U.S. Department of Agriculture, 1991, State soil geographic data base (STATSGO): Soil Conservation Service Miscellaneous Publication 1492.

USDA, 1993, Erosion and sedimentation dynamics of the Maumee River Basin and their impact on Toledo Harbor: Columbus, Ohio, Soil conservation service, publication 1492.

USDA, 2000, Agricultural Statistics, National Agricultural Statistics Service, US Government Printing Office, Washington, D.C.

USDA soil taxonomy
http://soils.usda.gov/classification/taxonomy/maps.pdf

USEPA, 1995, Non Point Source Agricultural Pollution, USEPA, Washington, DC.

USGS, 1998, Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin, Northern Prairie Wildlife Research Center.

USGCRP, 2003, www.usgcrp.org

Vitousek, P.M., 1994, Beyond Global Warming: Ecology and Global Change. Ecology, vol. 75(7), 1861-1878.

Wilson, D.L., 2001, GPS WAAS Accuracy,
http://users.erols.com/dlwilson/gpswaas.htm.