

# **DISCRIMINATING CROPPING PATTERNS FOR THE U.S. CENTRAL GREAT PLAINS REGION USING TIME-SERIES MODIS 250-METER NDVI DATA – PRELIMINARY RESULTS**

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## **ABSTRACT**

Agricultural practices are continually changing at various spatial and temporal scales in response to local management decisions and environmental factors. However, few regional scale land use/land cover (LULC) classifications have focused on characterizing the agricultural sector, particularly on a regular basis to reflect crop-related land use changes that occur from year to year. More detailed and timely LULC data sets are needed for the Central Great Plains region to better understand the role and consequences of cropping practices on climate change issues that potentially threaten the region's long-term agriculturally sustainability. Time-series MODIS (Moderate Resolution Imaging Spectroradiometer) 250-meter NDVI (Normalized Difference Vegetation Index) was evaluated to determine if major crop types (alfalfa, corn, sorghum, soybeans, and winter wheat) and crop-related land use practices (irrigation, fallow, and double cropping) in the Central Great Plains could be discriminated based on spectral-temporal differences. Median time-series NDVI curves were calculated for each crop class based on hundreds of field sites and the class' curves were compared for spectral-temporal differences. Specific crop types and irrigated and non-irrigated crops were discriminated based on differences in their median NDVI curves. Fallow, wheat-summer fallow, and double cropping practices were also identified based on their unique spectral-temporal characteristics. Regional differences in median NDVI curves were found for individual crop types. These regional curves appear to be related to differences in annual precipitation, growing season length, and planting dates. Time-series MODIS' 250-meter data appears to have the spatial, spectral, and temporal resolutions necessary to characterize relatively detailed regional-scale cropping practices on a repetitive basis.

## **INTRODUCTION**

Land use and land cover (LULC) change is a central theme of global environmental change issues; consequently, improved LULC data sets are needed by a diverse user community for policy- and science-driven applications. The remote sensing community is challenged to produce more consistent, detailed, and timely LULC classifications at regional to global scales to support various management, modeling, and monitoring activities (DeFries and Belward, 2000). LULC patterns must be mapped for large areas at a fine temporal resolution in order to identify changes occurring along a continuum of spatial and temporal scales (Reed et al., 1996). This is particularly true for agricultural-dominant regions, which are continually undergoing LULC changes (i.e., crop rotations and grassland-cropland conversion) across various spatial and temporal scales in response to management decisions driven by factors that include local environmental conditions, weather, market prices, government policies, and new technologies.

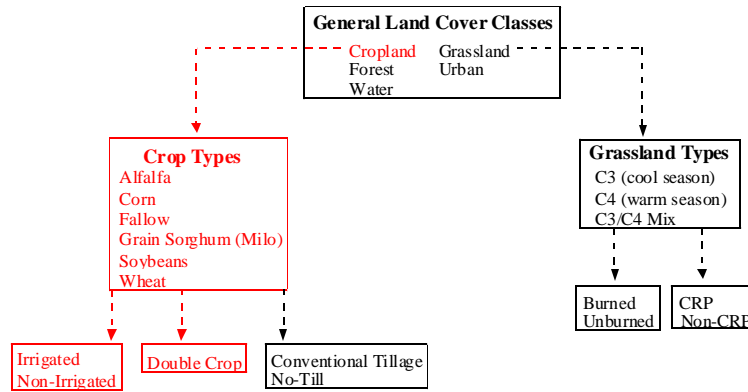
This research is part of a regional-scale LULC mapping protocol being developed for the Central Great Plains region using time-series MODIS 250-meter data. The protocol is designed to be repeatable on an annual basis to characterize 'current' LULC patterns and highlight major areas of LULC change that occur across the region's agricultural landscape. A hierarchical LULC classification scheme will be used to progressively map the region's general land cover types (cropland and grassland) into more detailed LULC classes (Figure 1).

This work represents the initial development stage of the cropland-related mapping component, which involved: 1) the selection of crop-related training sites on the MODIS 250-meter imagery, 2) the extraction of time-series MODIS NDVI (Normalized Difference Vegetation Index) data for each training site, 3) the calculation of statistics

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(median NDVI) by crop class from the training site data, 4) the development of crop-specific time-series NDVI curves, and 5) a comparison of the NDVI curves for spectral-temporal differences between crop classes. The primary research objective was to determine if the crop-related LULC classes highlighted in Figure 1 could be discriminated using time-series MODIS 250-meter NDVI data and evaluate the data sets' potential for regional-scale crop mapping.



**Figure 1. Hierarchical LULC mapping protocol for the Central Great Plains region with the crop-related component addressed by this research highlighted in red.**

## BACKGROUND

Few regional-scale LULC classification efforts have focused on the agricultural sector, particularly for classes such as crop types, irrigated versus dryland farming, and double cropping. Improved classification methods are needed to characterize the agricultural sector, which is one of the most intensively managed and modified components of the regional landscape. The ability to characterize these land use activities is critical in a region such as the Central Great Plains given the potential threat of climate change on the region's long-term agricultural sustainability. This section provides a brief discussion of the current state of large area LULC mapping, the relationship between climate change and land use in the Central Great Plains, and the potential of multi-temporal MODIS 250-meter NDVI data for regional-scale mapping in order to establish the context and potential contributions of this work.

### Large Area LULC Mapping and Crop-Related Classification

Over the past decade, improved large area land cover data sets have been derived globally (DeFries and Townshend, 1994; DeFries et al., 1998; Loveland et al., 2000; Hansen et al., 2000) and regionally for the U.S. (i.e., GAP and MRLC). However, these data sets poorly characterize the 'dynamic' and intensively managed agricultural landscape because they are 'static', infrequently updated, and often lack a strong land use component. Most agricultural-related classification work has been conducted at a localized scale (i.e., county level) using multiple dates (spring, mid-summer, and late-summer) of Landsat TM (Thematic Mapper) imagery to discriminate crop classes based on their phenological-related spectral-temporal differences throughout the growing season (Egbert et al., 1995; Price et al., 1997). However, a regional crop-related LULC mapping protocol that is repeatable on a time step comparable to many agricultural LULC changes (annually) is unlikely using Landsat ETM+ data due to cost and data availability.

### Central Great Plains Region and Climate Change

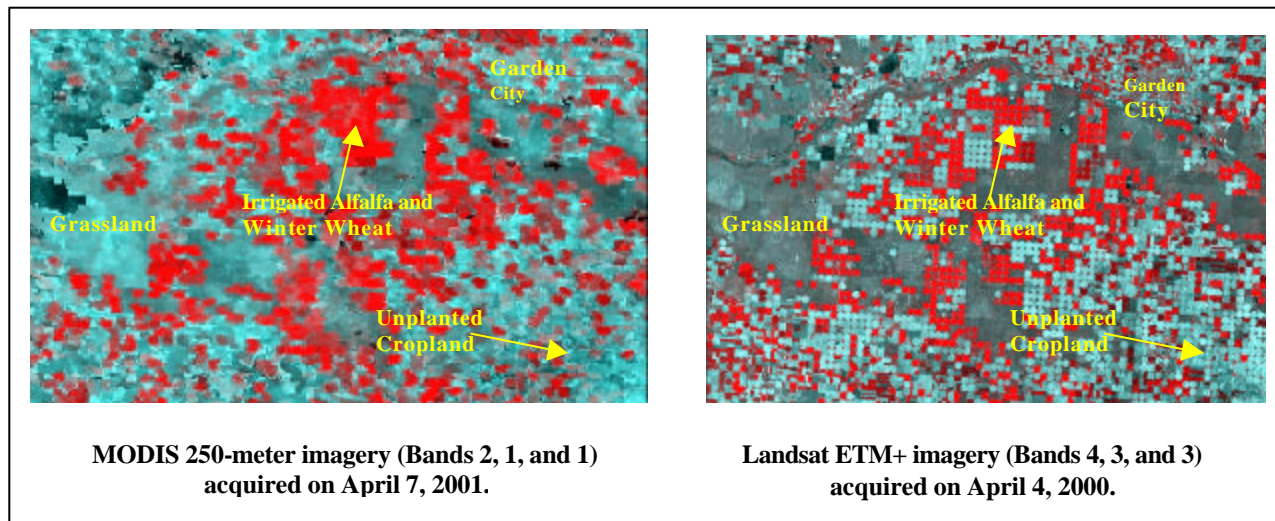
The Central Great Plains is a prime example of an agricultural-dominant region in need of more up-to-date and detailed LULC information regarding current cropping patterns and associated LULC changes. The long-term agricultural sustainability of this major U.S. crop-producing region is threatened by climate change. Climate change scenarios (Canadian and Hadley) predict that the Central Great Plains will experience substantial crop yield reductions in the future due to reduced precipitation and higher temperatures (National Assessment Synthesis Team, 2001). The region's current cropping patterns reflect its highly variable precipitation regime and reliance on

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irrigation to maintain high crop production levels. Characterizing the Central Great Plains' major agricultural land use patterns (crop rotations, irrigation, fallow, and tillage) is critical for better understanding the role and consequences of these human-environment interactions on climate change issues facing the region. Such land use practices and associated changes (e.g., grassland-cropland conversion) modify surface conditions and alter landscape patterns, which in turn can influence biogeochemical cycles (e.g., carbon cycling), climate (e.g., surface boundary conditions), hydrologic cycles (e.g., groundwater availability), native biodiversity (e.g., grassland fragmentation), and the economy (e.g., crop yields). A shift or change in regional patterns of cropping practices could have an impact on climate change (e.g., increased carbon sequestration through the adoption of no-till) or signal a response to climate change (e.g., cropland abandonment or increased acreage of more drought-tolerant crops). Developing techniques to better characterize cropping patterns at temporal frequency sufficient to identify annual agricultural LULC changes is needed to address climate change issues facing the Central Great Plains and better manage the region's resources.

### MODIS 250-Meter Data and Regional LULC Mapping

The launch of MODIS provides a unique opportunity for large area LULC characterization because of the instrument's global coverage, intermediate spatial resolution (250 meters), and high temporal resolution (daily). MODIS has substantial improvements in terms of resolution, number of spectral bands (7 land-related bands), and data quality compared to the commonly used coarse resolution Advanced Very High Resolution Radiometer (AVHRR). AVHRR time-series data has been used to create land cover maps at continental (Loveland et al., 1991) to global (DeFries and Townshend, 1994; DeFries et al., 1998; Loveland et al., 2000; Hansen et al., 2000) scales. However, AVHRR data has proven too spatially coarse to resolve many land use classes and LULC changes. MODIS' 250-meter resolution was specifically intended to monitor land use activities for large areas (Justice et al., 1998). Figure 2 illustrates the LULC patterns that can be spatially resolved from MODIS 250-meter imagery by comparing MODIS and Landsat ETM+ imagery. Given MODIS' improved spatial resolution and high temporal resolution, coupled with the large field sizes of the Central Great Plains, suggests that time-series MODIS 250-meter data can be used to characterize regional cropping patterns based on their phenological differences. Currently, the specific LULC classes that can be derived at MODIS' 250-meter resolution are relatively unexplored (Zhan et al., 2000) and merits further investigation.



**Figure 2. Comparison of MODIS 250-meter imagery and Landsat ETM+ imagery for the Garden City, Kansas area. Similar LULC patterns can be interpreted on both images, which include grasslands (dark gray), unplanted fields (light blue), and winter wheat and alfalfa (red). Circular center pivot irrigation can also be identified on both images.**

## RESEARCH QUESTIONS

The research objective was to determine if the highlighted crop-related LULC classes in Figure 1 could be discriminated based on the spectral-temporal information of time-series MODIS 250-meter NDVI data. Time-series NDVI data captures the phenological responses of vegetation and is particularly applicable for crop identification given the well-documented growth and development patterns of specific crops. This suggests that the crop types and related management practices evaluated by this research should have unique multi-temporal NDVI curves that can be used to discriminate these crop classes for classification purposes. Based on this premise, three research questions were addressed:

1. Can dominant crop types (alfalfa, corn, sorghum, soybeans, and winter wheat) be discriminated using time-series MODIS 250-meter NDVI data?
2. Can 'within crop' management practices (double cropping, fallow, and irrigation) be discriminated using time-series MODIS 250-meter NDVI data?
3. Are regional differences expressed in the time-series MODIS 250-meter NDVI data for a given crop class?
- 4.

## STUDY AREA

Kansas (Figure 3) was selected as the study area because its LULC patterns are representative of the Central Great Plains region. A cropland/grassland mosaic characterizes the state with specific LULC patterns being influenced by a pronounced east-west precipitation gradient (~1016 millimeters in east and ~508 millimeters in west). It also has a highly variable precipitation regime and is subjected to periodic drought events. The state's major crops (alfalfa, corn, sorghum, soybeans, and winter wheat) are grown under both irrigated and non-irrigated conditions. Crop production in semi-arid western Kansas is supported by irrigation in areas underlain by deep aquifer systems and dryland farming techniques (e.g., fallow, strip cropping). No-till farming practices are also being increasingly adopted, which is leading to a shift from traditional wheat-fallow rotations to more profitable wheat-summer crop or continuous summer crop rotations due to increased soil moisture levels. Crop production in eastern Kansas is much less reliant on irrigation, fallowing, and no-till practices due to higher annual precipitation.



**Figure 3. Map of Kansas' location in the United States.**

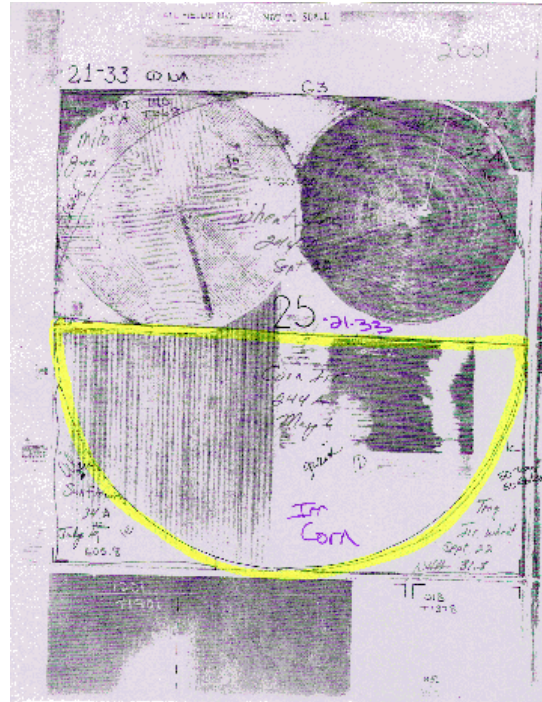
## METHODOLOGY

### Data

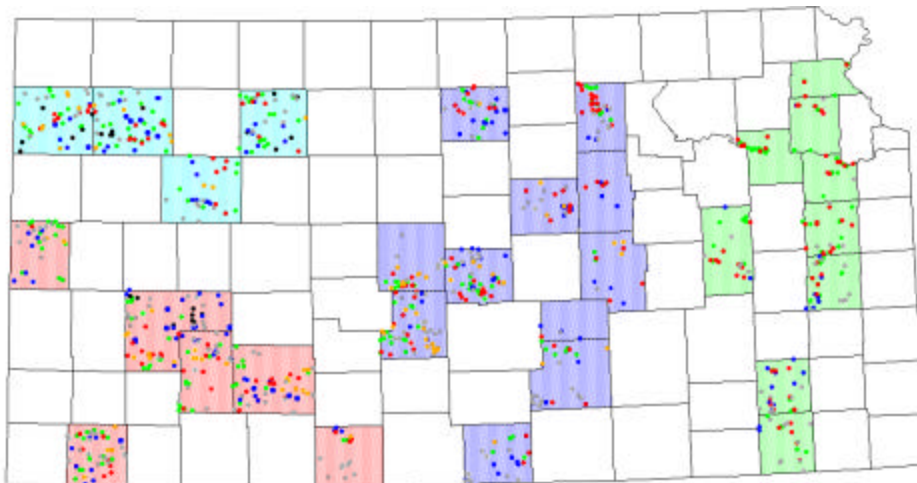
Twenty-one 16-day composites of MODIS 250-meter NDVI data for 2001 (January to December) were acquired from the University of Maryland's Global Land Cover Facility (GLCF) (<http://glcf.umd.edu/MODIS/usvi.htm>). MODIS data is not available for the June 9 and June 25 composite periods because MODIS did not collect data during that time due to instrument malfunctions. A gap in the time-series represents these composite periods. MODIS NDVI data were spatially subset for Kansas and the 21 images were composited to create a 12-month time-series of NDVI data. The NDVI time-series was projected to the Lambert Azimuthal Equal Area projection in order to be georeferenced with other geospatial data sets used in this research. Additional geospatial data sets included Landsat ETM+ imagery acquired in 2000 and 2001 over Kansas (Mercier et al., 2002) and Kansas county Public Land Survey System (PLSS) vector coverages.

Field site data were acquired in the form of annotated aerial photographs from 29 U.S. Department of Agriculture (USDA) Farm Service Agency (FSA) county offices throughout Kansas. Two criteria were used to select the specific counties: 1) the counties had to be distributed throughout the state to capture the variability in cropping practices and 2) the majority of the county's area is cropland. Each air photo corresponded to an individual field larger than 100 acres (40.5 hectares) and had annotations related to the field's cropping characteristics for 2001. The annotations included: a highlighted field boundary, the crop type, irrigated/non-

irrigated designation, additional land use notes (e.g., double cropping), the number of acres, and the PLSS township, range, and section number of the field's location (Figure 4). A total of 930 field sites were used in this research (Figure 5).



**Figure 4. A FSA aerial photograph with annotations that include: a highlighted field boundary (yellow), PLSS information (25-21-33), crop type (corn), management practice (irrigated), and number of acres (244).**



**Figure 5. Kansas counties and field sites used in the research. Counties are color coded by region (eastern- green, central - blue, southwest - red, and northwest - light blue). Field sites are represented by individual points colored by crop type (alfalfa – orange, corn – green, fallow – black, sorghum – blue, soybeans – red, and winter wheat – gray).**

## Development of a Multi-Attributed Field Site Database

A multi-attributed field site database (Figure 6) was created using a combination of annotated FSA air photo information, time-series MODIS NDVI data, Landsat ETM+ imagery, and Kansas PLSS coverages. The database contains multiple attributes (latitude and longitude, county name, confidence of field site interpretation, crop type, and NDVI values for the 21 dates) associated with each field site. The database approach provides the flexibility to select field sites based on single (e.g., crop type) or multiple criteria (e.g., crop type and irrigation). It will be used as the training and validation data set for the cropland component of the regional LULC mapping protocol being developed. For this work, it was used to select field sites by crop type/management practice for analysis and comparison. The following steps were used to create the database:

1. The PLSS township, range, and section number of the highlighted field site on the annotated air photo was used to select the corresponding section on the county PLSS vector coverage and identify the field's relative location on the georeferenced MODIS and Landsat ETM+ imagery.
2. The highlighted field site on the FSA air photo was visually compared to the corresponding location on the Landsat ETM+ imagery to verify the field on the photo corresponded to the same ground location on the ETM+ imagery.
3. The Landsat ETM+ imagery was used as a reference to select a single MODIS 250-meter pixel located completely within the field's boundaries as the training site for the field. A single 250-meter pixel was used rather than a  $n \times n$  window of pixels to ensure the pixel represented a single crop type and minimize the influence of 'mixed' pixels (multiple crop/cover types).
4. The pixel for the field site was entered into the database as a point location defined by X,Y coordinates. Other attributes associated with the field site's record included: crop type, irrigated/non-irrigated designation, county name, and interpretation confidence (e.g., scaled from 1 = lowest confidence to 3 = highest confidence).
5. Steps 1-5 were repeated for the 930 field sites.
6. The X,Y coordinates were used to extract the time-series NDVI data for each field site's pixel and the NDVI data were then added to the database.

1	X	Y	Crop Type	Confidence	County	January 1	January 17	February 2	February 18	March 6
2	104511.9	-783772	6	3	Stafford	0.27	0.21	0.31	0.35	0.29
3	110609.4	-760629	6	3	Stafford	0.26	0.22	0.24	0.27	0.25
4	97772.61	-757516	6	2	Stafford	0.32	0.22	0	0.67	0.26
5	87266.62	-799776	6	3	Stafford	0.36	0.32	0.4	0.45	0.41
6	105773.3	-784766	6	3	Stafford	0.29	0.21	0.21	0.24	0.27
7	114264.5	-775012	6	3	Stafford	0.27	0.22	0.23	0.24	0.2
8	105761.6	-792783	6	3	Stafford	0.38	0.23	0.3	0.29	0.31
9	95261.46	-786623	6	3	Stafford	0.36	0.34	0.37	0.38	0.46
10	-13229.2	-830019	6	3	Ford	0.33	0.23	0.28	0.45	0.48
11	5262.49	-819012	6	3	Ford	0.31	0.21	0.21	0.23	0.26
12	-15718.6	-816278	6	2	Ford	0.3	0.27	0.21	0.21	0.4

Figure 6. Example of multi-attributed field site database for irrigated corn.

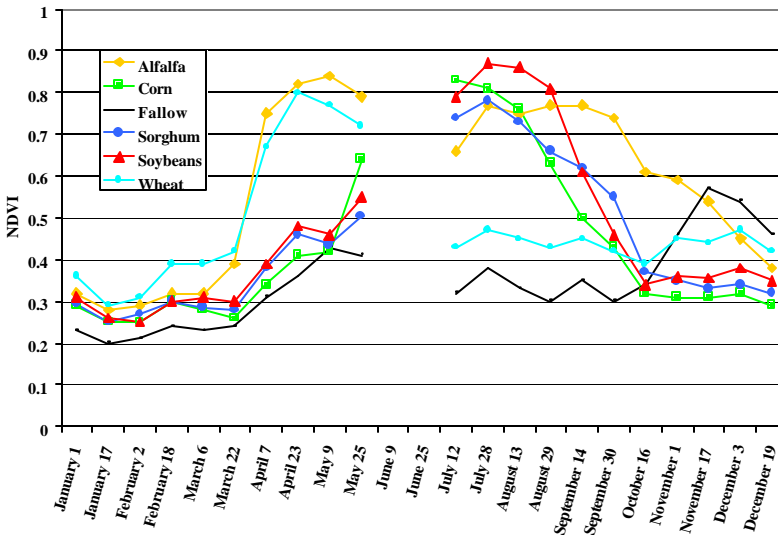
## Calculation and Comparison of Median NDVI Curves

The database was used to aggregate the field sites by crop type, management practice (by crop type), and Kansas region (by crop type). Five regions were defined in Kansas that were relatively homogeneous in terms of crop calendars (planting and harvest dates, growing season length) and annual precipitation. The median NDVI of each crop-specific aggregation was calculated for each composite period. The time-series of median NDVI values were then plotted as line graph to create a median NDVI curve for each crop class. Visual comparisons of the curves were made to determine if specific classes could be discriminated based on the spectral-temporal differences of their respective NDVI curves.

## RESULTS/DISCUSSION

### Crop Type Discrimination

The median NDVI curves in Figure 7 are consistent with the phenology of each crop in Kansas. This indicates that MODIS' 250-meter spatial resolution and 16-day temporal resolution is sufficient to detect the unique spectral-temporal signals of these crops. The NDVI curves of the five crop types and fallow clearly have spectral-temporal



**Figure 7. Comparison of median NDVI curves for corn, fallow, sorghum, soybeans, and winter wheat in Kansas.**

differences during the year. A brief discussion of the major differences between the crops' median NDVI curves in Figure 6 is provided.

Winter wheat and alfalfa are separable from the summer row crops in the early spring (April-May) when both crops have substantially higher NDVI values (~.80-.85). Winter wheat is separated from alfalfa during the mid-summer (mid-July). By July 12, winter wheat has senesced and been harvested, which results in a much lower NDVI (~.45) than alfalfa (~.75). Alfalfa maintains a relatively high NDVI (~.75-.85) throughout the entire growing season (April-October) with minor fluctuations in NDVI associated with the cut-growth cycles. For example, alfalfa has an increase in NDVI from .65 (July 12) to .75 (July 28) that likely corresponds to the regrowth of alfalfa following an early July cutting.

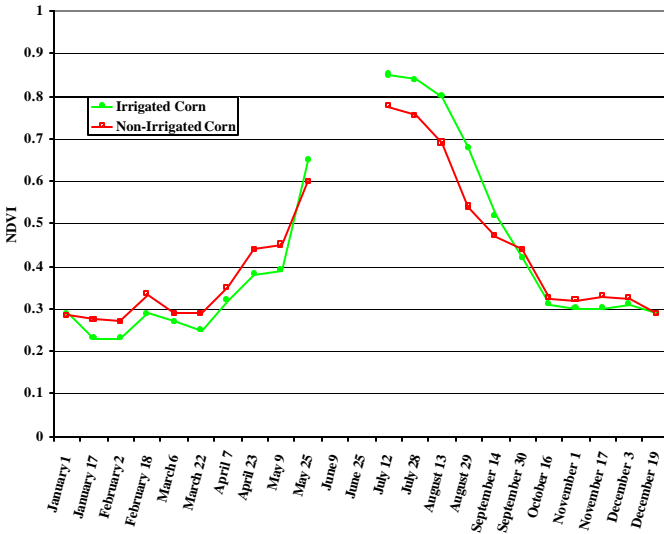
Fallow also has a distinctive median NDVI curve that is relatively flat and maintains a low NDVI (~.35) throughout the growing season. This is a typical NDVI response from a fallow field that is covered with crop stubble from the previous year during that time. However, fallow increases in NDVI in late-October and early-November, which corresponds to the emergence of winter wheat that is planted in early fall. The fallow NDVI curve is representative of the 'summer fallow-winter wheat' rotation that is predominate in Kansas.

The three summer row crops (corn, sorghum, and soybeans) have median NDVI curves that differ in: 1) early growing season NDVI (May 25), 2) time of maximum NDVI, 3) duration of greenness, and 4) rate of decreasing NDVI during senescence (August and September). On May 25, corn exhibits a higher NDVI (~.65) than both soybeans (~.55) and sorghum (~.50). This is consistent with corn having an earlier planting date and as a result, earlier growth and development than sorghum and soybeans. Corn's NDVI curve peaks on July 12 at ~.825 and gradually declines during senescence (July 12 to October 16). In contrast, soybeans' NDVI curve has a higher maximum NDVI of ~.875 that occurs later (July 28) than corn. Soybeans also maintain a higher NDVI later into the summer (July 12 to August 29), which is followed by a rapid decrease in NDVI during senescence (after August 29). Sorghum's maximum NDVI occurs at the same time as soybeans but at a lower NDVI of ~.75. Sorghum also has a gradual decline in NDVI during senescence, but maintains a higher NDVI than both corn and soybeans near the end of growing season (September and October). The higher NDVI is likely related to the green (photosynthetically-active) leaf cover that remains intact following the removal of sorghum's seed heads during harvest. Both corn and soybeans are completely senesced (non-photosynthetically active) at harvest. These spectral-temporal differences of the median NDVI curves indicate that the five crop types and fallow can be discriminated using a single year of time-series MODIS 250-meter NDVI data.

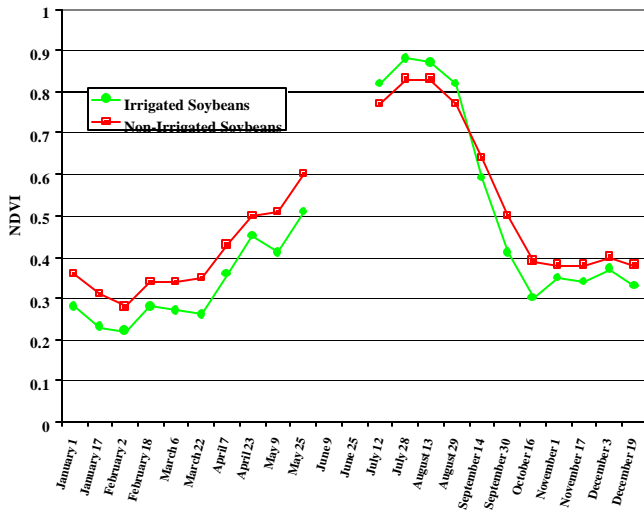
### Crop-Related LULC Discrimination

Irrigated and non-irrigated median NDVI curves have distinct differences both in the early spring (April) and mid-summer (July) for most crops. Median NDVI curves for corn (Figure 8) and soybeans (Figure 9) illustrate the spectral-temporal differences between an irrigated and non-irrigated crop. Non-irrigated corn and soybeans both

have higher NDVI values than irrigated corn and soybeans during the early growing season (April 23 and May 9). By mid-summer (July 12), irrigated corn and soybeans have a higher NDVI than non-irrigated corn and soybeans. The irrigated curves maintain a higher NDVI than the non-irrigated curves for the remainder of growing season until harvest. Irrigated and non-irrigated alfalfa and sorghum both have similar early- and mid-growing season NDVI differences. Winter wheat is the only exception with similar irrigated and non-irrigated NDVI values during the early growing season. Two possible factors may explain higher NDVI values for non-irrigated crops during the early growing season: 1) irrigation is typically not applied until mid-summer (July) when drought stress is higher and the crop is in its reproductive stage and 2) non-irrigated crops are often planted in areas of higher annual precipitation (i.e., eastern Kansas), higher soil moisture (i.e., loam soils), or shallower water tables (i.e., flood plains). If so, non-irrigated crops would have more soil moisture available early in the growing season and develop more rapidly (higher NDVI) than irrigated crops. By mid-summer, irrigated crops have a higher NDVI because



**Figure 8. Comparison of median NDVI curves for irrigated and non-irrigated corn in Kansas.**



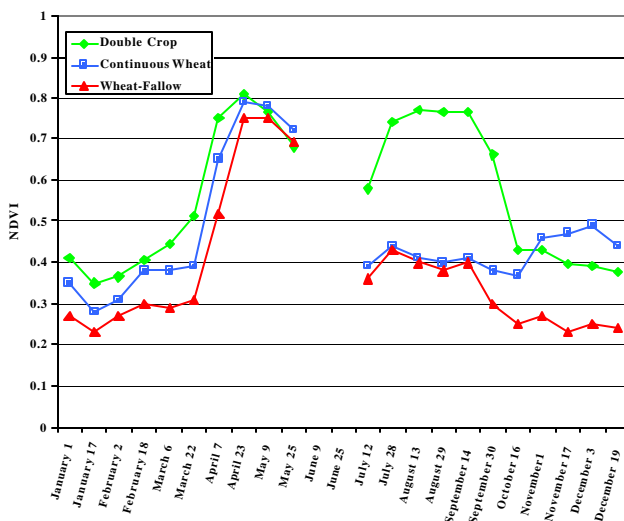
**Figure 9. Comparison of median NDVI curves for irrigated and non-irrigated soybeans in Kansas.**

their growth and development is not as limited by soil moisture availability and drought stress as it is for non-irrigated crops. These comparisons show that irrigated and non-irrigated crops can be discriminated based on NDVI differences throughout most of the growing season, but particularly at peak greenness (maximum NDVI).

Winter wheat has three distinct median NDVI curves related to different crop rotations (Figure 10). All three winter wheat-related rotations have an early spring peak in NDVI associated with the spring green up of winter wheat following its winter dormancy. The differences in the median NDVI curves of the three crop rotations occurs after wheat's early-summer harvest (late-June). Continuous winter wheat maintains a low NDVI (~.40) after harvest



until late-October/November when a smaller peak in NDVI (~.50) appears in response to the emergence of a new winter wheat crop planted in early-October. Fields with a continuous winter wheat rotation follow a cycle of fall planting and emergence, rapid spring growth, and early summer harvest each year. The winter wheat-summer fallow (W-SF) rotation also maintains a low NDVI (~.40) after harvest for the remainder of the calendar year. This rotation is a common dryland farming technique with fields remaining idle following wheat harvest in order to increase soil moisture reserves to support crop production the following year. A unique feature of the W-SF rotation is the decrease in NDVI from .40 to .25 in September, which may signal that these areas are being tilled for weed control (i.e., winter annuals) and/or to improve the infiltration of rain and snow melt into the soil during the fall and winter. Double cropping of winter wheat fields results in a second major NDVI peak (~.75) in late July and August associated with the growth/development of a summer row crop (soybeans or sorghum) planted immediately after wheat harvest. Fields that are double cropped produce a winter wheat harvest (June) and a sorghum or soybean harvest (October) in the same year. Based on the field site data, double cropping is almost exclusively associated with irrigated fields in western Kansas and non-irrigated fields in eastern Kansas. The east-west division of double cropping on irrigated versus non-irrigated fields is a direct reflection of annual precipitation differences across the state. A fourth winter-wheat related crop rotation appears in the fallow NDVI curve in Figure 6. Fallow maintains a low NDVI (~.35) for most of the year and has a peak NDVI (~.55) in the fall that corresponds to the emergence of a new winter wheat crop. These results show that time-series MODIS 250-meter data is capable of characterizing many of the dominant within crop management practices and crop rotations in the Central Great Plains region.



**Figure 10. Comparison of median NDVI curves for winter wheat-related crop rotations in Kansas.**

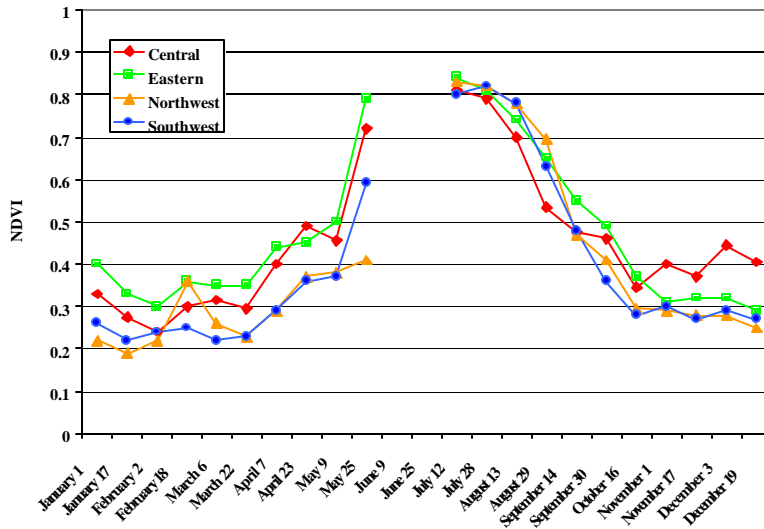
## Regional Median NDVI Curves

Median NDVI curves were compared by crop type for different regions in Kansas (Figure 5) to determine if the curves showed regional differences across the state. Annual precipitation and crop-specific planting dates were used to arbitrarily divide the state into five regions. The precipitation gradient is oriented from southwest (lowest) to northeast (highest). In contrast, the planting dates for the summer row crops are oriented from the southeast (earliest) to northwest (latest). Planting dates for winter wheat are oriented along the same axis as the other crops, but the northwest has the earliest fall planting dates and the southeast the latest. Each region is considered relatively homogeneous in terms of climatic conditions, timing of crop-specific development, and cropping practices. For example, the southwest region is semi-arid and dominated by a mix of cropland under irrigated and dryland farming techniques. In contrast, the northwest region is defined primarily by the area's later planting dates.

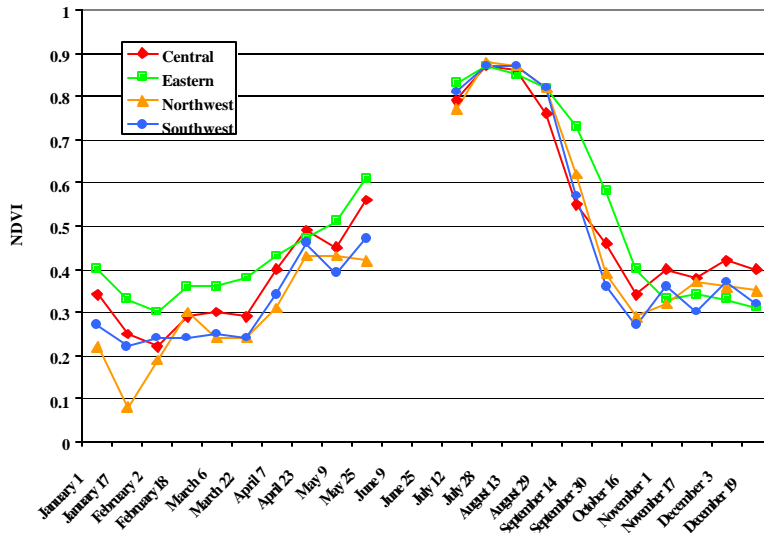
Figures 11 and 12 show regional differences in the median NDVI curves for corn and soybeans. Corn has higher NDVI values in the early spring (May 25) for the eastern (~.80) and central (~.70) regions. The higher NDVI indicates a better developed corn canopy, which is consistent with the earlier planting dates and higher precipitation of these two regions. The southwest region has an intermediate NDVI value (~.60), which may be the result of a later planting date or less spring precipitation. The northwest region has a low NDVI value (~.40) for corn on May 25. This low NDVI value is indicative of the later planting dates for corn in the northwest. The majority of corn fields in this region are usually recently planted (sparsely vegetated) or still unplanted (bare soil) in late-May. The

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regions have similar corn NDVI curves during peak greenness and senescence. The regional differences of soybean NDVI curves were very similar to those of corn. During the spring, the eastern and central regions have the highest NDVI values (~.60 and ~.55) and the northwest has the lowest NDVI (~.40). Soybeans also have similar regional NDVI curves during peak greenness and senescence. The only exception is the eastern region, which maintain a higher NDVI value later into September. Sorghum has the same regional differences in the NDVI curves as corn and soybeans. Winter wheat has less distinct regional differences. However, winter wheat has an earlier spring green up in the eastern region.



**Figure 11. Comparison of regional median NDVI curves for corn in Kansas.**



**Figure 12. Comparison of regional median NDVI curves for soybeans in Kansas.**

These results indicate that regional differences of median NDVI curves exist within crop types and need to be considered for regional scale crop mapping. The regional differences are greatest during the spring due to different timings of planting and initial plant growth/development among the regions. A more thorough analysis of these regional differences is needed to better define ‘agro-regions’ within which detailed crop mapping can be conducted.

## CONCLUSIONS

Although preliminary, these results indicate that MODIS has the spatial, spectral, and temporal resolutions and geographic coverage necessary to characterize the dominant cropping patterns of the Central Great Plains at a

### DISCRIMINATING CROPPING PATTERNS FOR THE U.S. CENTRAL GREAT PLAINS REGION USING TIME-SERIES MODIS 250-METER NDVI DATA – PRELIMINARY RESULTS

regional scale. Crop types, irrigated versus non-irrigated crops, and specific crop rotations were discriminated at a 250-meter resolution based on the spectral-temporal differences of their time-series NDVI curves. Different crop classes were discriminated at different times of the year (spring and summer), which illustrates the importance of a multi-temporal data set for crop mapping. The NDVI curves for a given crop were also found to be regionally variable across Kansas, which indicates that large regions should be subdivided into more homogeneous 'agro-regions' for detailed crop mapping.

Because this work represented the initial development stage of a regional LULC mapping protocol, several future research activities are planned, which include:

- The addition of more field sites across Kansas to the data base. Field sites from approximately 20 additional counties distributed throughout the state will be incorporated into the database.
- Assessment of MODIS' EVI (Enhanced Vegetation Index) data (MOD12Q1 product) for crop discrimination once a full 12-month time-series of EVI data for 2001 becomes available.
- A comparison of time-series EVI and NDVI curves for specific crop types to determine their similarities and differences.
- A statistical analysis (cluster analysis) of MODIS time-series data (EVI, NDVI and spectral bands) to better define agro-regions for detailed crop mapping. Also, statistical analysis will be repeated on a second year of MODIS data (2002) to determine if similar agro-regions are defined from year to year. Other variables such as soils (e.g., soil water capacity and texture) and topography (e.g., floodplain versus upland) may also be considered in defining the agro-regions.
- The application of a supervised decision tree classifier, using the field site database developed in this study for training and validation, to time-series MODIS data (EVI, NDVI, and spectral bands) to map cropping patterns (by agro-region) at a regional scale.
- Investigate the use of phenological metrics derived from either EVI or NDVI as a tool to monitor within crop intra- and inter-annual variability across the region.

This research demonstrates the wealth of LULC information present in time-series MODIS 250-meter data and its potential to characterize detailed cropping patterns for large geographic areas. MODIS provides us the opportunity to map and monitor how the agricultural sector is managed and modifies the regional landscape from year to year. Such detailed LULC data sets could be used to support activities such as crop yield and production estimations, weather forecasting, climate and carbon cycling modeling, and biodiversity studies. We hope to build upon this work and develop a near real-time mapping and monitoring protocol for the Central Great Plains region that characterizes agricultural-related LULC patterns and within class variability (intra- and interannual) on an annual basis.

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### **DISCRIMINATING CROPPING PATTERNS FOR THE U.S. CENTRAL GREAT PLAINS REGION USING TIME-SERIES MODIS 250-METER NDVI DATA – PRELIMINARY RESULTS**

**Pecora 15/Land Satellite Information IV/ISPRS Commission I/FIEOS 2002 Conference Proceedings**

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**DISCRIMINATING CROPPING PATTERNS FOR THE U.S. CENTRAL GREAT PLAINS REGION  
USING TIME-SERIES MODIS 250-METER NDVI DATA – PRELIMINARY RESULTS**