STATE-LEVEL CROP MAPPING IN THE U.S. CENTRAL GREAT PLAINS AGROECOSYSTEM USING MODIS 250-METER NDVI DATA

Brian D. Wardlow
Stephen L. Egbert
Kansas Applied Remote Sensing (KARS) Program/Department of Geography
University of Kansas
2101 Constant Avenue – Higuchi Hall
Lawrence, KS 66047-3759
wardlow@ku.edu
segbert@ku.edu

ABSTRACT

Improved and up-to-date land use/land cover (LULC) datasets are needed for intensively cropped regions such as the U.S. Central Great Plains, in order to support a variety of science and policy applications focused on understanding the role and response of the agricultural sector to environmental change issues. The Moderate Resolution Imaging Spectroradiometer (MODIS) holds considerable promise for detailed crop-related LULC mapping in this region, given its global coverage and unique combination of spatial (250-meter), spectral, temporal (16-day composites), and radiometric (12-bit) resolutions. In this study, a hierarchical MODIS-based crop mapping protocol, which incorporates a time-series of MODIS 250-m NDVI data and a decision tree classifier, was tested for the state of Kansas. The protocol produced a series of three crop-related LULC maps that classified: 1) general crop types (alfalfa, summer crops, winter wheat, and fallow), 2) summer crop types (corn, sorghum, and soybeans), and 3) irrigated/non-irrigated crops. A statistical accuracy assessment and state and sub-state areal comparisons with USDA crop acreage information were conducted for each map to assess its overall quality and highlight any major areas of regional misclassification. The MODIS NDVI-derived maps generally had overall and class-specific accuracies of greater than 80%. Overall accuracies ranged from 84% (summer crop map) to 94% (general crop map). The classified crop areas were within 1-5% of USDA reported crop areas for most classes at the state level. Sub-state comparisons found that for most classes the areal discrepancies were relatively minor throughout the state. The largest areal differences occurred in eastern Kansas due to the omission of many small cropland areas that were not resolvable at the 250-m resolution. Regional areal differences were also found for selected classes that were the result of localized precipitation patterns and specific crop practices (i.e. double cropping). These results illustrate the considerable potential of the MODIS-based mapping protocol for spatially and thematically detailed regional-scale crop classification.

INTRODUCTION

Land use/land cover (LULC) data are among the most important and universally used terrestrial data sets and represent key environmental information for a variety of science and policy applications (Cihlar 2000; DeFries and Belward, 2000). Geo-referenced LULC is a primary input for biogeochemical (e.g., carbon and nitrogen), climate, ecological, and hydrologic modeling, natural resource management, and policy development. The emergence of global environmental change issues has led to a growing and diverse user community that requires more accurate, detailed, and timely large-area LULC information for their respective applications (DeFries and Belward, 2000). The remote sensing community has been challenged to produce regional- to global-scale data sets on a repetitive basis that characterize ‘current’ LULC patterns, document major LULC changes, and include a stronger land use component (Turner et al., 1995; NRC 2001; NASA 2002).

Crop-Related LULC Patterns

Improved LULC information is particularly needed for intensively cropped regions such as the U.S. Central Great Plains. Cropland is one of the most intensively managed and modified components of any landscape. Regional crop-related land cover patterns are continually changing over various spatial and temporal (e.g., seasonal to annual) scales in response to different agricultural management practices (e.g., crop rotations, irrigation, fallow,
Collectively, these LULC changes and associated management activities can rapidly modify the landscape and influence environmental processes and conditions, as well as the economy (crop market prices). As a result, detailed cropping patterns must be mapped on a repetitive basis in order to characterize ‘current’ LULC patterns and monitor common LULC changes. Such information is particularly needed for the U.S. Central Great Plains to better understand the role and response of cropping practices across the region to the various environmental issues (e.g., climate change and groundwater depletion) that potentially threaten the area’s long-term agricultural sustainability.

Existing Large-Area LULC Data Sets for the U.S. Central Plains Region

Existing state- to regional-scale LULC classifications for the region, such as the United States Geological Survey (USGS) National Land Cover Dataset (NLCD) (Homer et al., 2004) and the GAP Analysis Program (GAP) land cover products (Egbert et al., 2001), generally lack detailed crop-related classes and are infrequently updated. The exception is the United States Department of Agriculture (USDA) National Agricultural Statistics Service’s (NASS) Cropland Data Layer (CDL) product, which is a detailed, state-level crop classification that is produced on an annual basis (Craig 2001). However, the CDL is only produced for a limited number of states and is only available for Nebraska in the U.S. Central Great Plains.

The development of a regional-scale crop mapping protocol that can be applied on a time step that is consistent with common crop-related LULC changes (i.e., crop rotations) is challenging because it requires remotely sensed data that have: 1) large geographic coverage, 2) high temporal resolution to capture the ‘phenology-driven’ spectral-temporal differences among the various crop classes, 3) adequate spatial resolution relative to the grain (i.e., typical field size) of the landscape, and 4) minimal cost. Remotely sensed data from traditional sources do not have all of these required characteristics. Medium resolution, multi-spectral data from sensors such as Landsat Thematic Mapper (TM and ETM+) and SPOT have commonly been used for detailed crop mapping at local scales (Price et al., 1997), but are limited for large-area applications due to the considerable costs associated with the acquisition and processing (e.g., rectification, atmospheric correction, mosaicking, edge matching, and classification) of the data and data availability/quality issues (i.e., cloud cover) associated with acquiring imagery at optimal times during the growing season. Coarse resolution, high temporal data from sensors such as the Advanced Very High Resolution Radiometer (AVHRR) and SPOT Vegetation have been widely used for large-area applications, but are limited by their coarse 1-km spatial resolutions and are most appropriate for mapping general, broad-scale land cover patterns (Turner et al., 1995).

The Moderate Resolution Imaging Spectroradiometer (MODIS)

The launch of the Moderate Resolution Imaging Spectroradiometer (MODIS) marks a new era in large-area terrestrial remote sensing by providing a global, repetitive coverage of multi-spectral, multi-resolution imagery and a suite of higher-level science quality products in support of global environmental change research. The MODIS 250-m Vegetation Index (VI) product (MOD13Q1), which consists of NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) data composited at 16-day intervals, holds considerable promise for regional-scale crop mapping given its resolutions, large area coverage, and cost free status. VIs represent dimensionless radiometric measures of green vegetation amount/condition and are well correlated with biophysical parameters such as biomass and leaf area index (LAI) (Baret and Guyot, 1991). As a result, time-series (or multi-temporal) VI data have been widely used for classifying land cover types based on their seasonal spectral differences (DeFries and Townshend, 1994; Loveland et al., 2000) and characterize major phenological events (Reed et al., 1994). In a preliminary assessment of time-series MODIS 250-m VI data for 2,000+ field sites in Kansas, Wardlow and Egbert (2002) found that the data had the necessary spatial, temporal, and radiometric resolutions to discriminate the state’s major crop-related LULC types at the pixel level. They found that unique multi-temporal VI signatures were detected in the MODIS data for each crop type that were consistent with the crop’s reported phenology (Figure 1). Each of the crops could clearly be separated by spectral-temporal differences in the VI data at some point during the growing season. They also found that many individual fields (typically 32 hectares (ha) (80 acres) or larger) were visible in the 250-m imagery, which suggested that relatively detailed cropping patterns could be mapped at this resolution. Thus far, the application of time-series MODIS 250-m VI data for LULC mapping has been limited (Wessels et al., 2004) and further research is needed to evaluate its potential for detailed crop mapping.
RESEARCH OBJECTIVE

The objective of this research was to evaluate the applicability of time-series MODIS 250-m NDVI data for detailed, regional-scale crop mapping in the U.S. Central Great Plains. In this study, a crop mapping protocol, which consisted of a time-series of MODIS 250-m NDVI data and a supervised decision tree classifier, was applied for the state of Kansas. The protocol’s classification scheme was hierarchical in nature and produced a series of three crop-related LULC maps that progressively classified cropland areas into more detailed thematic classes. Kansas was an ideal study area because its cropping patterns are representative of the larger Central Great Plains and it has a range of environmental conditions, general landscape patterns, and crop management practices across which to test this MODIS NDVI-based mapping protocol. Two primary research questions were addressed in this study.

1. Can general crop types (alfalfa, summer crops, winter wheat, and fallow), specific summer crop types (corn, sorghum, and soybeans), and irrigated and non-irrigated crops be accurately mapped at a regional-scale using this MODIS NDVI-based mapping protocol?

2. Do the classified patterns of the crop maps exhibit any major deviations from the reported crop patterns that may signal a limitation in the protocol’s applicability in certain parts of the state or for specific crop-related LULC classes?

To answer these questions, three state-level assessments were conducted for each map, which included: 1) a traditional statistical accuracy assessment, 2) a visual comparison of the classified maps and higher resolution Landsat ETM+ imagery for selected areas, and 3) an areal comparison of the classified and USDA reported crop areas. Sub-state evaluations were limited to areal comparisons between the maps and USDA statistics for the state’s nine agricultural statistics districts (ASDs) in an attempt to identify any areas of the state in which the classified crop patterns considerably deviated from the reported patterns. ASDs were appropriate spatial units for evaluating the regional quality of the maps because they represent ‘agronomically-defined’ subdivisions of the state, which have relatively homogenous cropping practices and environmental conditions (USDA 2004). Individual ASD-level accuracy assessments were not feasible due to the limited number of validation sites for certain classes in some districts.

STUDY AREA

Kansas is an agriculturally dominated state located in the Central Great Plains that has 46.9% (10.0 million ha) of its total area dedicated to cropland. The state’s major crops include alfalfa (Medicago sativa), corn (Zea mays), sorghum (Sorghum bicolor), soybeans (Sorghum bicolor), and winter wheat (Triticum aestivum). Over the past decade, Kansas has ranked in the top 10 nationally in terms of both acreage and production for most of these crops.

The state’s pronounced east-west precipitation gradient strongly influences the specific cropping patterns and associated management practices. On average, western Kansas receives 460-510 millimeters (mm) of precipitation per year while eastern Kansas receives 890-1020 mm. In semi-arid western Kansas, extensive irrigation from...
groundwater sources and dryland farming techniques (e.g., crop-fallow rotations and no-till) are used to maintain high levels of crop production despite the limited precipitation regime. In eastern Kansas, adequate precipitation is generally received to support high crop production levels without irrigation. Land use practices such as fallow are virtually non-existent and irrigation is limited (primarily to lowland floodplain areas) in this part of the state.

The general grain size of the landscape also changes from western to eastern Kansas. Western and central Kansas are characterized by a coarse-grained landscape comprised of very large individual fields and large contiguous tracts of both cropland and grassland/shrubland areas. Field sizes commonly range from 65 to 245 ha. In contrast, cropland areas in eastern Kansas are more fragmented and interspersed with primarily grassland and deciduous forest. Individual field sizes are also smaller, with most fields being 65 ha or less.

DATA

A 12-month time-series of MODIS 250-m NDVI data (MOD13Q1 V004) spanning one growing season (January 1 to December 13, 2001) was used for this study. The MODIS EVI data were not included in this study because preliminary research showed that comparable crop classification accuracies were achieved using either VI and that the NDVI produced slightly higher accuracies for some classes. Twenty-three 16-day composite periods of 16-bit integer NDVI data (scaled by a factor of 10,000) were acquired for three MODIS tiles (h09v05, h10v05, and h10v04) from the USGS EROS Data Center (EDC) Land Processes Distributed Active Archive Center (LP DAAC) at no cost. The NDVI data were extracted from the MODIS VI product by tile for each composite period, mosaicked, reprojected, subset, and sequentially stacked to produce a 23-date time-series of NDVI data for Kansas.

A training/validation database of field site locations of specific crop types and management practices (e.g., irrigated/non-irrigated) was created using information from annotated aerial photos provided by the USDA Farm Service Agency (FSA) for 48 counties (of a total or 105 counties) throughout Kansas. Field sites were geolocated on the MODIS imagery using a combination of Public Land Survey System (PLSS) information (township, range, and section number) on the photos, a PLSS vector coverage, and georeferenced Landsat ETM+ imagery. A single MODIS 250-m pixel from the center of each field was selected to represent each site in the database. A single pixel was used rather than a pixel window (e.g., 2 x 2 pixels) to eliminate mixed edge pixels from being included in the training and validation sets. Each field site was attributed with its geographic location, crop type in 2001, irrigated/non-irrigated status, and area. The database used in this study consisted of 2,205 field sites.

Planted crop acreage data for 2001 were acquired from the USDA NASS agricultural statistics database (http://www.nass.usda.gov:91/iupedb/) at both the state and ASD levels for Kansas. The data represent a statistical estimate of crop area calculated from crop information provided by farmers and field enumerators from a probability-based sample survey (USDA 1999). As a result, the USDA planted area information was used as a relative measure to identify any major areal deviations (i.e., over- or underclassification) in the MODIS-derived maps. The data for some crop types had to be aggregated to conform to some classes in the hierarchical classification scheme (e.g., corn, sorghum, and soybean data summarized for the summer crop class).

A MODIS 250-m crop/non-crop map was produced for Kansas from the time-series MODIS 250-m NDVI dataset used for this study. The map was generated from a 17-date NDVI time-series (March 22 to November 17) using an unsupervised ISODATA (Iterative Self-Organizing Data Analysis Technique) classification method. The map served as a mask to remove the non-crop areas prior to the crop classifications. The map had an overall accuracy of 90.9%, its classified total crop area was comparable to the USDA reported area (4.5% or .93 million ha difference), and the state’s major crop areas and general crop/non-crop patterns were well depicted. ASD-level areal evaluations found a high level of agreement (correlation (r) = 0.98) between the map and USDA area figures across the state’s nine ASDs with relative differences (i.e., percent area) generally ranging between 0.2 (7,110 ha) and 5.0% (.10 million ha). The eastern ASDs (80 and 90) were the only districts with larger areal deviations, with 7.3% (.17 million ha) and 8.3% (.22 million ha) less cropland in the MODIS map, respectively. The higher level of underclassification was attributed to omission of many small, fragmented crop areas, which are characteristic of these two districts, at the 250-m resolution. These omissions in the crop mask were propagated to the crop maps and major omissions, such as those in ASDs 80 and 90, need to be considered in the areal results of this study.

Multi-seasonal Landsat ETM+ imagery (spring and mid-summer dates) acquired in 2001 for the state was obtained from the Kansas Satellite Image Database (KSID) (http://gisdac.kgs.ku.edu/kgcc/catalog/coredata.cfm). A total of 16 path/rows of imagery were acquired and geo-referenced to the MODIS data. In instances where a 2001 Landsat ETM+ scene was not available, a comparable date of imagery from 2000 was used.
METHODS

A four-level hierarchical crop classification scheme (Figure 2) was implemented in this study. The specific crop classes incorporated into the hierarchical scheme represent the major crop types and crop-related land use practices of the Central Great Plains. The protocol’s hierarchical structure was designed to progressively classify cropland into more detailed LULC classes across the four levels. The initial stage (Level 1), which separated the study area into crop and non-crop classes, will not be presented in this paper beyond the general discussion provided early in the Data section because of space limitations and the primary emphasis on crop-specific classification in this work. A hierarchical classification structure was selected because it allowed the landscape to be segmented into relatively homogeneous LULC units within which more detailed classes could be discriminated. It also gives users of the LULC products the flexibility to use a classification from a single level (e.g., general crops) or combine classifications from multiple levels (e.g., general crop and summer crop maps), depending on their specific needs.

Figure 2. Four-level hierarchical crop classification scheme

The classification methodology used to produce the crop-related LULC maps (Levels 2-4) consisted of a supervised, decision tree classification algorithm (See5) being applied to a time-series of MODIS 250-m NDVI data. A decision tree approach was selected because it offers several advantages over traditional classifiers (Hansen et al., 1996) for large-area LULC mapping, which include: 1) its non-parametric nature, 2) its ability to handle both continuous and nominal data, 3) its ability to handle non-linear and hierarchical relationships between the input variables and classes, 4) its explicit and interpretable classification structure, and 5) its efficient processing of large volumes of data. Advanced options such as pruning and boosting have also been incorporated into the decision tree classification process to better generalize the model’s predictive ability on unseen data (i.e., avoid overfitting to training data) and improve the accuracy of the base classification algorithm. The See5 decision tree classifier in combination with these advanced options has proven to be an accurate and efficient approach for LULC mapping at both regional (Homer et al., 2004) and global (Friedl et al., 2002) scales.

For this study, the See5 base classification algorithm along with the pruning and boosting (10 iterations) options were used. Only NDVI data collected during the growing season were classified in order to eliminate the influence of any non-vegetation-related variations (e.g., snow or soil background) in the non-growing season periods on the classification results. The growing season was defined for each map based on the crop calendar of its respective classes. For the general crop and irrigated/non-irrigated crop maps, the growing season was defined from the March 22 to November 1 composite period (15 periods). A short window was defined for the summer crop map, spanning the April 7 through October 1 composite periods (13 periods). The FSA field site data were divided into training (80%) and validation (20%) datasets using a stratified random sampling scheme, which was repeated 10 times to generate 10 different random draws of data. A separate classification run was performed using each training set to produce 10 maps. The final crop map was then produced using a pixel-level ‘majority’ vote across the 10 maps. A separate accuracy assessment was also performed for each classification run and the final accuracy reported for each map was the average accuracy across the 10 runs. A multiple classification run approach was adopted to avoid a potential spurious classification result (i.e., extremely high or low accuracy) that might result
from a single draw of training and validation data. In a single random draw, an unusual sample could be drawn overall or for a specific class that could lead to misleading classification results. Multiple runs minimize the chances of this occurring and produce a more representative result of the mapping protocol’s true performance.

Traditional accuracy assessment measures (overall, user’s and producer’s accuracy and Kappa) were calculated at the state level for each map. A visual assessment of each map’s general classified patterns (in comparison with both Landsat ETM+ imagery and reported cropping patterns) was also performed across the state. Finally, an areal comparison of the classified and USDA reported crop areas were conducted at both the state and ASD-level.

RESULTS/DISCUSSION

General Crop Map

The general crop map produced using the time-series MODIS 250-m NDVI data is presented in Figure 3. The classified general crop patterns were consistent with the state’s reported cropping patterns. Summer crops were the dominant class throughout the eastern ASDs (70, 80, and 90), where corn and soybeans are mainly grown. In the central ASDs, the Winter Wheat Belt in ASD 60 and several other major winter wheat areas in ASDs 40 and 50 were clearly represented. The summer crops in northeastern ASD 40 correspond to corn and soybeans planted in the Republican River Valley and cropland at the edge of the Western Corn Belt. summer crops in northern ASD 60 highlight areas of irrigated corn and soybeans. In the western ASDs (10, 20, and 30), the common dryland crop classes of winter wheat and fallow define the non-irrigated cropland areas. Some areas of summer crop (primarily sorghum) also appeared in non-irrigated parts of ASD 20. Large areas of alfalfa and summer crops highlighted core areas of irrigated cropland in both ASDs 10 and ASD 30, which are primarily planted to alfalfa, corn, or soybeans.

The general crop map had a high average overall accuracy of 93.9% across the classification 10 runs (Table 1). Class-specific user’s and producer’s accuracies were greater than 90% for most classes. The majority of confusion in the error matrix was associated with the fallow class, which was equally confused with summer crops and winter wheat. Most of the confusion between these classes likely occurred in the marginal cropland areas of semi-arid western Kansas where these three crop classes are common. On marginal cropland, crops can experience extreme drought stress (e.g., wilting, stunted growth, or failure) due to limited soil moisture and fallow areas can exhibit a wide range of surface conditions that include weed cover, crop residue, and bare soil. As a result, the multi-temporal NDVI signal from these three classes in marginal areas can be highly variable, which can result in classification confusion. Several summer crop and winter wheat sites were also misclassified as alfalfa, which was unexpected considering the distinct multi-temporal NDVI signals of these classes. However, an evaluation of the NDVI signals for the misclassified sites revealed that several had been mislabeled during data entry and were actually alfalfa.

State-level areal comparisons found a high level of agreement between the classified and USDA reported general crop areas. The classified crop-specific areas were generally within 5% or less (.80 million ha or less) of the USDA figures. ASD-level comparisons (Figure 4) found a high overall correlation (r = 0.93) and class-specific correlations (r > .90 for most crops) between the classified and USDA reported areas across the 9 districts. Summer crops had the lowest correlation (r = 0.72) and exhibited a clear east-west division in terms of the specific areal differences. In eastern Kansas (ASDs 80 and 90), the MODIS map classified considerably less summer crop area than the USDA reported (.12 and .20 million ha). This was attributed to the considerable omission of small cropland areas in the initial crop/non-crop mask that occurred in these two ASDs. Summer crops are dominant in both districts and most omitted cropland areas were likely planted to these crops, which would result in considerably less summer crops being mapped. In western Kansas (ASDs 20, 30, and 40), summer crops were consistently overclassified (.07 to .19 million ha). This was unexpected and further work is needed to investigate this result. The dryland classes of winter wheat and fallow were consistently underclassified in the western ASDs. This trend was likely the result of cropland omissions during the unsupervised classification of the initial crop/non-crop mask. Several marginal cropland areas in western Kansas, that were either fallow of planted to winter wheat, had very indistinct multi-temporal NDVI signals and were often inseparable from the surrounding sparse rangeland areas. During cluster labeling, some of these areas were likely assigned to the non-crop class and omitted from the crop mask, which result in a slight, but consistent underclassification of these classes relative to the USDA figures in western Kansas. Alfalfa also had a larger areal deviation in ASD 90 with 15.9% (.06 million ha) more area classified in the MODIS map than reported by the USDA. A visual inspection of the time-series NDVI data for the classified alfalfa areas in ASD 90 revealed that several areas were not alfalfa, but rather double cropped with winter wheat followed by a summer crop. The assignment of double cropped areas to the alfalfa class was not surprising considering that both maintain relatively high NDVI values for most of the growing season unlike the other crops.
Figure 3. General crop map derived from the time-series MODIS 250-m NDVI data.

Table 1. General crop map accuracy assessment

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Alfalfa</th>
<th>Summer Crops</th>
<th>Winter Wheat</th>
<th>Fallow</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>43</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>Summer Crops</td>
<td>2</td>
<td>272</td>
<td>0</td>
<td>0</td>
<td>274</td>
</tr>
<tr>
<td>Winter Wheat</td>
<td>1</td>
<td>1</td>
<td>81</td>
<td>0</td>
<td>82</td>
</tr>
<tr>
<td>Fallow</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>273</td>
<td>82</td>
<td>27</td>
<td>428</td>
</tr>
</tbody>
</table>

Reference Data

Overall Accuracy: 98.7 +/- 0.5%

Producer's Accuracy

- Alfalfa: 97.1 +/- 3.2%
- Summer Crops: 99.2 +/- 0.5%
- Winter Wheat: 98.2 +/- 1.6%
- Fallow: 98.2 +/- 2.5%

User's Accuracy

- Alfalfa: 94.1 +/- 3.2%
- Summer Crops: 99.6 +/- 0.4%
- Winter Wheat: 98.1 +/- 1.4%
- Fallow: 99.3 +/- 1.5%

Kappa: 0.98

(* The +/- percentage value represents the percent accuracy variation within 1 standard deviation of the average class accuracy across the 10 decision tree classification runs. Also, the row and columns total s in the error matrix may not equal the number of sites in the rows and columns because the numbers represent averages across the 10 runs and were rounded to the nearest whole number in the matrix.)

Figure 4. Scatterplot of the general crop areas classified in the MODIS map versus the areas reported by the USDA for the Kansas ASDs.

Pecora 16 “Global Priorities in Land Remote Sensing”
October 23-27, 2005 * Sioux Falls, South Dakota
The influence of double cropping was most pronounced in ASD 90, where it has been widely adopted due to favorable climate conditions, but also may have contributed to the slight overclassification of alfalfa in other ASDs that have adopted this land use practice on a more limited basis.

**Summer Crop Map**

Figure 5 presents the summer crop map produced using the MODIS NDVI-based mapping protocol. The classified summer crop patterns were in agreement with the known cropping patterns for Kansas. The dominance of corn and soybeans throughout eastern Kansas was clearly represented. In central Kansas, the corn and soybeans in the Republican River Valley (northeastern ASD 40) and the irrigated cropland in northwestern ASD 60 were accurately characterized. The core areas of irrigated cropland in the western ASDs (10, 20, and 30), which are commonly planted to corn and soybeans, were classified in the map. The east-to-west transition from corn and soybeans to sorghum in central Kansas (ASDs 40 and 50) was also characterized. Sorghum, which is the primary dryland summer crop in Kansas, was consistently classified in the non-irrigated cropland areas of western Kansas.

The summer crop map had a average overall accuracy of 84.0% (Table 2). Class-specific producer’s and user’s accuracies were generally greater than 80%. The error matrix showed that the misclassification was relatively evenly distributed among the three summer crops.

State-level areal comparisons found a high level of agreement between the MODIS map and USDA figures. The MODIS map classified more area for all three summer crops, but the areal differences were less than 2.0% (.24 million ha) for each class. However, ASD-level comparisons found an overall correlation of 0.76 across the 9 districts (Figure 6). This correlation was lower than expected considering the map and USDA areal figures were fairly comparable for the three classes at the state-level. Class-specific comparisons across the ASDs revealed relatively high correlations for corn (r=0.92) and sorghum (r=0.86), but a much lower correlation for soybeans (r=0.42). This lower correlation was primarily attributed to the considerable underclassification of soybeans in ASDs 80 (13.0% or .03 million fewer ha) and 90 (32.5% or .19 million fewer ha). These soybean area omissions were primarily due to the cropland omissions in the initial crop mask for these districts discussed earlier, which were propagated into the summer crop map. Soybeans are the dominant summer crop in both ASDs and most areas omitted in the crop mask were likely planted to this crop. When the soybean areas for ASDs 80 and 90 were excluded from the correlation analysis, the overall and soybean class correlations increased to 0.88 and 0.93, respectively. Other notable areal trends included the consistent overclassification of corn and soybeans in the western ASDs (10, 20, 30, and 60), where they are primarily irrigated, and the underclassification of sorghum in several west/central ASDs (10, 20, and 40), where the crop is primarily non-irrigated. Overall, the areal differences were relatively minor for the three summer crops across the state (< .10 million ha).

**Irrigated/Non-Irrigated Crop Map**

The irrigated/non-irrigated crop map is presented in Figure 7. The state’s major irrigated crop areas were clearly represented in the map. Large areas of irrigated crops in southern ASD 10, west-central ASD 20, and throughout ASD 30 correspond to the dominant irrigated crop areas in western Kansas. In central Kansas, the irrigated croplands south of the Arkansas River (northwest ASD 60) and along the Republican River (northeast ASD 40) were mapped. In eastern Kansas, the irrigated crops in the Kansas River floodplain (boundary between ASDs 70 and 80) and along other rivers throughout ASDs 80 and 90 were classified. The map had an average overall accuracy of 85.0% (Table 3) and class-specific producer’s and user’s accuracies generally greater than 80%.

The only major area of misclassification was the large area of irrigated cropland in two counties (Brown and Doniphan) in extreme northeast Kansas (ASD 70). This area mainly supports non-irrigated corn and soybeans and irrigation is very limited. Local county FSA officials reported that only 1-2% of both counties’ total cropland is irrigated. In the MODIS-derived map, 26.7% and 34.9% of Brown and Doniphan Counties’ cropland was classified as irrigated. This major overclassification of irrigated crops was likely due to much higher than normal precipitation, particularly during the early- to mid-summer (June and July), received by this area compared to the rest of the state. In 2001, Brown and Doniphan Counties received 206 and 218 mm of precipitation above the 10-year average, respectively (USDA 2002). Precipitation totals for most of the state’s other counties were much closer to the 10-year average. Typically, non-irrigated summer crops in Kansas experience a higher level of drought stress than irrigated crops due to soil moisture deficits during the summer. This results in wilting and a slower rate of plant growth for the non-irrigated crops relative to the unstressed, irrigated crops, which is reflected by the lower NDVI values of the stressed crops during this time. However, the increased precipitation in late-June and July for northeast Kansas likely mitigated much of this drought stress on the non-irrigated crops, which resulted in improved crop conditions (e.g., large plants/higher biomass) and a multi-temporal NDVI response similar to an irrigated crop.
Figure 5. Summer crop map derived from the time-series MODIS 250-m NDVI data.

Table 2. Summer crop map accuracy assessment

<table>
<thead>
<tr>
<th>Reference Data</th>
<th>Corn</th>
<th>Sorghum</th>
<th>Soybeans</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classified Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>103</td>
<td>10</td>
<td>10</td>
<td>123</td>
</tr>
<tr>
<td>Sorghum</td>
<td>5</td>
<td>51</td>
<td>5</td>
<td>64</td>
</tr>
<tr>
<td>Soybeans</td>
<td>5</td>
<td>4</td>
<td>70</td>
<td>79</td>
</tr>
<tr>
<td>Total</td>
<td>116</td>
<td>65</td>
<td>85</td>
<td>266</td>
</tr>
</tbody>
</table>

| Overall Accuracy | 84.0 +/- 3.5 % |
| User's Accuracy  |               |
| Corn             | 88.7 +/- 3.7 % |
| Sorghum          | 78.2 +/- 5.6 % |
| Soybeans         | 82.0 +/- 6.0 % |
| Producer's Accuracy |           |
| Corn             | 83.5 +/- 3.5 % |
| Sorghum          | 79.4 +/- 7.0 % |
| Soybeans         | 88.5 +/- 3.4 % |
| Kappa            | 0.76           |

(* The +/- percentage value represents the percent accuracy variation within 1 standard deviation of the average class accuracy across the 10 decision tree classification runs. Also, the row and column totals in the error matrix may not equal the number of sites in the rows and columns because the numbers represent averages across the 10 runs and were rounded to the nearest whole number in the matrix.)

Figure 6. Scatterplot of the summer crop areas classified in the MODIS map versus the areas reported by the USDA for the Kansas ASDs.
Table 3. Irrigated/non-irrigated crop map accuracy assessment

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Irrigated Crops</th>
<th>Non-Irrigated Crops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated Crops</td>
<td>113</td>
<td>23</td>
<td>136</td>
</tr>
<tr>
<td>Non-Irrigated Crops</td>
<td>42</td>
<td>258</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>155</td>
<td>281</td>
<td>436</td>
</tr>
</tbody>
</table>

Overall Accuracy 85.0 +/- 1.4 %
User’s Accuracy
- Irrigated Crops 72.0 +/- 4.0 %
- Non-Irrigated Crops 91.7 +/- 1.8 %
Producer’s Accuracy
- Irrigated Crops 82.8 +/- 2.8 %
- Non-Irrigated Crops 86.0 +/- 1.7 %
Kappa 0.67

(* The +/- percentage value represents the percent accuracy variation within 1 standard deviation of the average class accuracy across the 10 decision tree classification runs. Also, the row and column totals in the error matrix may not equal the number of sites in the rows and columns because the numbers represent averages across the 10 runs and were rounded to the nearest whole number in the matrix.)
The classified and USDA reported areas were in close agreement for the irrigated and non-irrigated classes (5.0% difference in relative area) at the state level. ASD-level comparisons found a correlation of 0.95 for irrigated crops across the 9 ASDs. The classified irrigated area was generally within 5.0% or less (<.12 million ha) of the USDA statistics for most ASDs. The largest areal discrepancies occurred in Kansas’ three irrigation-dominant ASDs (10, 30, and 60), where the MODIS map consistently underclassified irrigated cropland. ASD 30, which is the most heavily irrigated district (32.6% of its total cropland and 49% of the state’s total), had the largest areal deviation with 17.5% (.33 million ha) less irrigated crop area in the MODIS map. The consistent trend to underclassify irrigated crops in all the western and central ASDs was likely due in part to mixed pixels (comprised of irrigated and non-irrigated crops) at the edges of irrigated areas being consistently classified as non-irrigated. The spectral contribution of the non-irrigated cover type, which tends to have a relatively low NDVI value in these relatively semi-arid ASDs, will lower the NDVI value of these mixed edge pixels compared to homogeneous irrigated crop pixels and produce a multi-temporal NDVI signal similar to a non-irrigated crop. Collectively, the assignment of these mixed, edge pixels to the non-irrigated crop class would result in less irrigated area being mapped with the greatest areal reductions in the ASDs with extensive irrigation. In contrast, the MODIS map consistently classified more irrigated crops in eastern Kansas. The largest areal difference occurred in ASD 70 (12.5% or .07 million ha), which reflected the major overclassification of irrigated crops in extreme northeast Kansas. The areal differences for the other two eastern ASDs (80 and 90) were much less (4.0% (.02 million ha) and 1.3% (.01 million ha)). The trend to overclassify irrigated crops in eastern Kansas is likely associated with the area’s higher annual precipitation, which tended to minimize the separability of the two classes in the NDVI data, resulting in some non-irrigated crops having a multi-temporal response NDVI similar to an irrigated crop.

CONCLUSIONS

This study has demonstrated that time-series MODIS 250-m NDVI data is a viable option for accurate and detailed regional-scale crop mapping in the U.S. Central Great Plains. The crop-related LULC maps had relatively high classification accuracies (generally > 84%) and the classified crop patterns were consistent with the reported cropping patterns and crop distributions for Kansas. The state’s diverse range of environmental conditions, general landscape patterns, and cropping practices had only a minimal influence on the classification results. The inability to discriminate small, fragmented cropland areas at the 250-m resolution in parts of eastern Kansas had the greatest influence on the classification results. Omissions in the initial crop mask in this area were propagated to the subsequent crop maps and resulted in underclassification of the dominant crop class. The influence of unusually high annual precipitation levels in extreme northeast Kansas led to major, localized classification errors in the irrigated/non-irrigated crop map. In general, the impact of the state’s climate variations and the specific weather patterns for the year of this study were negligible for most of the crop maps. However, the northeast Kansas case illustrates the importance of further evaluating the influence of inter-annual variability on the NDVI-based mapping protocol. The classification of specific crop types was unaffected by their underlying management practices (e.g., irrigated versus non-irrigated or conventional tillage vs. no-till) with the exception of double cropping, which was not included in this study. The sensitivity of the multi-temporal 250-m NDVI to such a land use practice illustrates the potential of this dataset for characterizing specific crop rotation sequences.

The MODIS NDVI-based crop mapping protocol proved to be a cost- and time-efficient means for large area crop mapping. The MODIS, FSA, and NASS data sources used in the protocol are publicly available in the U.S. at little or no cost. The classification of the time-series MODIS 250-m NDVI data with a decision tree classifier resulted in rapid map production. On average, the processing time required from the initial generation of the decision tree model to the final map output was less than five minutes. The majority of time involved in implementing the protocol at the state level was associated with the collection of training/validation data from the FSA aerial photos, which required approximately three months. This time requirement will be greatly reduced in the near future with the development of statewide, field-level GIS databases by the FSA, which will allow site selection to be automated and more stringent sampling schemes to be used.

This study should be viewed as an initial step towards the evolution of this MODIS-based mapping protocol for large-area crop characterization. The classification results from this work represent a ‘baseline’ accuracy achieved using only multi-temporal NDVI data. Numerous other variables can be derived from the MODIS 250-m spectral and VI data such as vegetation phenology metrics (VPMs), spectral metrics, and harmonic analysis variables that might improve the classification of particular classes. The mapping protocol should also be tested for additional crop types (e.g., cotton and sunflowers) and for other major agricultural regions to determine its range of applicability.
ACKNOWLEDGEMENTS

This research was supported by NASA Headquarters under the Earth System Science Fellowship Grant NGT5-50421. The work was conducted at the Kansas Applied Remote Sensing (KARS) Program (Edward A. Martinko, Director; Kevin P. Price, Associate Director). The authors thank the USGS NLCD program (Collin Homer, Coordinator) for the use of their decision tree module for ERDAS Imagine.

REFERENCES