

# MAPPING IRRIGATED LANDS BY CROP TYPE IN KANSAS

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## ABSTRACT

We build on work by Pervez and Brown (2010) where they produced an irrigated cropland map of the conterminous United States using a crop mask from the 2001 NLCD, 2002 county-level irrigation statistics from the USDA Agriculture Census, and the peak or maximum MODIS NDVI value over the growing season. For each county, a threshold value was used to classify the highest MODIS NDVI cropland pixels as irrigated with the spatial extent restricted to the total irrigated area for the county listed in the Agriculture Census. The underlying assumption of this approach is that irrigated crops possess a higher peak, or maximum, NDVI value than non-irrigated crops. Recognizing that crop types may possess different annual maximum NDVI values, we incorporate crop type information into the mapping process to produce an irrigated cropland map of Kansas. We also incorporated a proximity measure to irrigation sources ("points of diversion") in an effort to reduce mapping errors. The irrigated cropland map was derived using MODIS NDVI imagery from 2005, county-level statistics by crop type from the USDA Agricultural Census, a crop mask of each crop type using a 2005 crop-type land cover map and buffers around irrigation sources. For each county, and for each crop type, an NDVI threshold value was identified from the masked imagery with the mapped area restricted to the irrigated area of each crop type as listed in the USDA Agricultural Census. An overall accuracy level of 87.7 percent was achieved using this approach. Incorporating the points of diversion slightly increased the overall accuracy and slightly improved errors of omission (Producer's Accuracy) and commission (User's Accuracy).

**Keywords:** Irrigation Mapping, MODIS NDVI, land use and land cover

## INTRODUCTION

The Biofuels and Climate Change: Farmers' Land Use Decisions (BACC: FLUD) project team consists of faculty and researchers from the social and natural sciences and engineering. The project focus is on farmers' decisions and impacts to grow crops as feedstock for renewable energy (i.e. biofuel production) and farmers' reactions and adaptations to climate change. This collaborative research between the University of Kansas and Kansas State University is funded by a five year grant (2009-2013) from the National Science Foundation (see [www.ipsr.ku.edu](http://www.ipsr.ku.edu) for more information). While the current project study area is defined as Kansas, the long-term vision is to develop data and research methods that are applicable to the entire U.S. biofuel crop industry.

One of the main objectives of the research described here is to develop a land use/land cover (LULC) time-series database for Kansas for the study period, 2000-2013. The LULC time-series will be used to identify and quantify spatial trends in LULC change as it relates to the biofuel industry, including biofuel intensification and extensification and the rate and spatial distribution of this change. In addition, the various research teams, ranging from social scientists to climate scientists, will use the LULC time-series as input into their models. These models

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will be used to examine the impacts of farmers' decisions to grow biofuel feedstock on water quantity and water quality and also potential impacts of climate change on Kansas agriculture. A LULC time-series database containing dominant crop classes (for Kansas, corn, soybean, sorghum, winter wheat, alfalfa, fallow, and double-crop) and irrigation status is necessary for these types of analyses. Since construction of thirteen years of statewide LULC data from scratch is not feasible within the timeframe of the project, existing LULC data will be used for portions of the time series. Kansas Applied Remote Sensing (KARS) program LULC data for 2001 and 2005 and the USDA NASS Cropland Data Layer (CDL) from 2006-onward are existing LULC databases that will be used. For the remaining years (2000, 2002-2004), crop-type LULC maps will be produced using a multi-sensor, multi-scale hierarchical classification approach developed for a previous mapping endeavor by the KARS Program (Peterson *et al.*, 2010). Although existing LULC data contain the crop type classes needed, they do not contain irrigation status.

Previous work by the KARS Program has shown that a supervised classification of irrigated lands using a decision tree classifier (DCT) produces relatively accurate results, with an overall accuracy level of 85 percent (Wardlow and Egbert, 2008). While the results are accurate, annual ground-truth data for training the image classification required for this approach is unavailable to map irrigated lands for the entire study period. Others have developed global irrigation maps (Ozdogan and Gutman, 2008 and Thenkabail *et al.*, 2009), however, they do not provide the temporal or spatial resolution needed for the objective of this research (i.e., farm-level decision-making).

Methods developed by Pervez *et al.* (2008) and Pervez and Brown (2010) at the EROS Data Center showed promising results to map irrigated cropland with overall accuracy levels of 75 percent in the semi-arid Great Plains. The method developed by Pervez *et al.* (2008) does not require ground-truth data for image classification. The methodology is based on the assumption that irrigated crops possess a higher peak, or maximum, NDVI value than non-irrigated crops. This assumption is based on the observation that well-watered crops tend to have higher NDVI values than their non-irrigated counterparts and the additional fact that irrigated crops are planted more densely (i.e., higher seeding rates) than non-irrigated crops, resulting in denser plant canopies and higher biomass. In their work, for each county in the conterminous United States, a threshold value was used to classify the highest NDVI cropland pixels as irrigated. The threshold was set so that it kept the area mapped approximately equal to the total irrigated area for the county as reported in the USDA Agriculture Census (Pervez *et al.*, 2008; Pervez and Brown, 2010). In their mapping, a single cropland class was used, not individual crop classes. Incorporating individual cropland classes would further refine the area of irrigated land mapped by each crop type, and likely produce a more accurate map of each county. Therefore we modified the methodology of Pervez and Brown (2010) by classifying and mapping individual crop types within the county, and then identifying NDVI threshold values for each crop type mapped. We also incorporated the locations of points of diversion from the Water Information Management and Analysis System (WIMAS) and surface canals from the National Hydrography Dataset (NHD), i.e., the sources of the irrigation water, to further restrict the spatial location of mapped irrigated land.

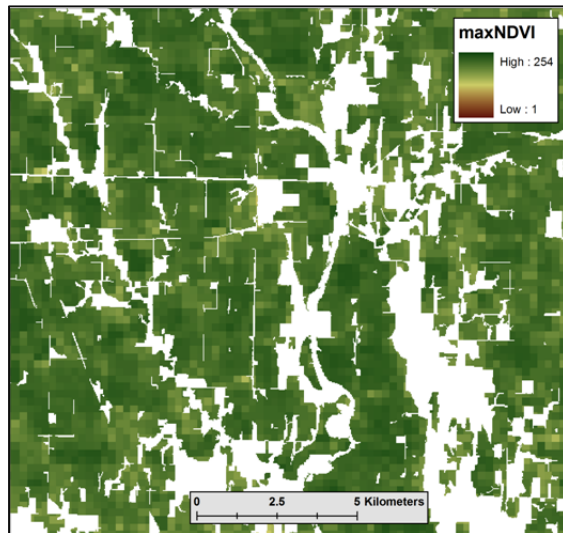
## METHODS

Data from 2005 were used to test the irrigation mapping methodology, since a relatively accurate crop type map (82%) (Peterson *et al.*, 2010) and ground-truth data were readily available. The 2005 map depicts the following dominant crop types, or field management in Kansas: alfalfa, corn, double-crop, fallow, sorghum, soybean and winter wheat. The Farm Service Agency common land unit (CLU) database consists of polygons that represent the smallest units of land with common ownership, land cover and management. Since each unit is typically homogenous in land cover, the CLU database was used to generalize the 2005 crop type map to produce field-level representation. The CLU database was also used to calculate field level mean peak NDVI values. To determine whether proximity measures to points of diversion and surface water irrigation canals would increase accuracy levels, irrigation mapping was done with and without the proximity measures. A formal accuracy assessment of the two maps followed. Once the methods for mapping irrigated lands are finalized using the 2005 dataset, a crop-type irrigation map will be produced for each year of the study period (2000-2013).

### Data Processing

**Image pre-processing.** The 231-meter MODIS NDVI data from 2005 were obtained from EROS Data Center. Twenty-three 16-day composite periods, corresponding to the 2005 growing season (March 22 through November 1, 2005), were downloaded for each of the three image tiles (10v05, 10v04 and 09v05) needed to cover the extent of

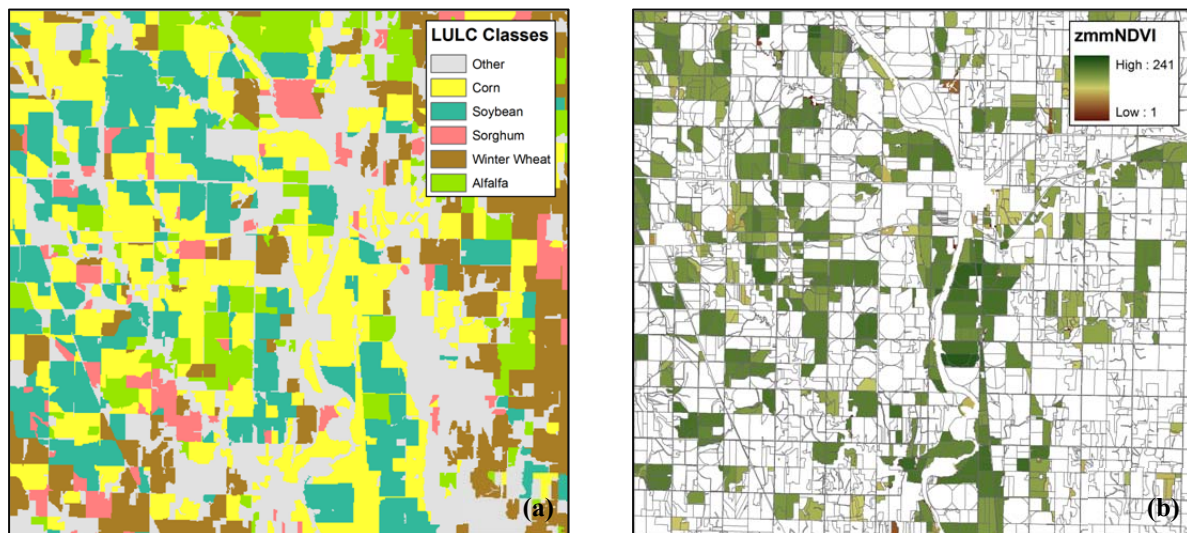
the research area. For each composite period, the three tiles were mosaicked together. Using the ERDAS Imagine Layer Stack function, the twenty-three composite periods were stacked to create a 23-band multi-temporal image. The layer stack image was then reprojected from its native projection, Sinusoidal, to Albers Conic Equal-Area.



**Figure 1.** The maximum NDVI over the 2005 growing season for cropland pixels identified in the 2005 LULC map. Non-cropland shown in white.

*Calculate the Mean Maximum NDVI Value for Each CLU by Crop Type.* For each pixel in the 23-period MODIS stack, the maximum NDVI (maxNDVI) value was extracted to a new grid. From this grid, the 231-m MODIS data was resampled to 30-m to match the cell size of the 2005 LULC crop type map, and the original maxNDVI value range was rescaled from 0-10,000 to 0-255 and output to a new grid. Rescaling the maxNDVI values was done to facilitate their later use in a spreadsheet by reducing the number of columns needed to hold the data. Using the cropland class from the 2005 crop map as a mask, maxNDVI values were extracted from the resampled and rescaled grid to create a new grid. Figure 1 shows the maxNDVI for a portion of Republic County, located in north-central Kansas. Farmers in this area use both groundwater and surface water to irrigate crops.

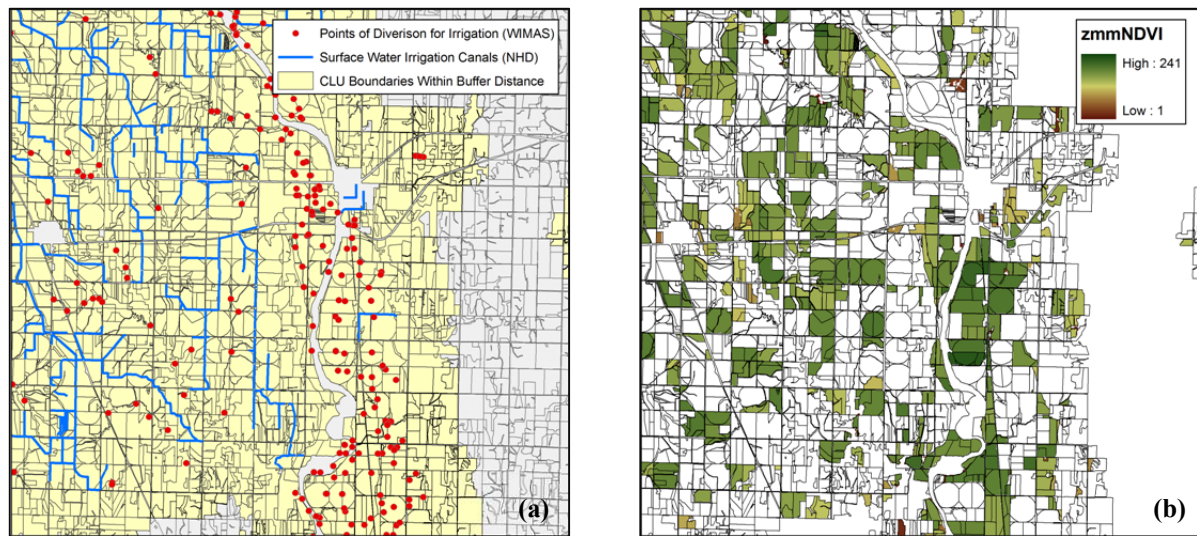
The unattributed CLU dataset was then used to calculate the zonal mean maxNDVI (zmmNDVI) value for each CLU boundary (i.e., zone). Next, the 2005 map was used to extract the zmmNDVI values for each of the five crop types into separate grids (Figure 2).



**Figure 2.** (a) The 2005 crop type map used to extract max NDVI for each crop type; (b) The calculated zonal mean maximum NDVI (zmmNDVI) for corn. Separate grids of zmmNDVI were created for each crop type.

*Create Buffers to Restrict Spatial Distribution of Mapped Irrigated Land.* To restrict the location of where irrigated lands were mapped, active points of diversion and surface irrigation canals from the WIMAS and NHD, respectively were incorporated into the methodology. Active points of diversion used for irrigation were extracted for the entire state and buffered by 1.5 km. Since surface water irrigation diverted from some surface reservoirs is a practice used in several irrigation districts in Kansas, primarily in north-central and western Kansas, canals from the NHD were extracted and buffered by 1.5 km. Next, CLU field boundaries that intersected the buffers and that were

identified as cropland in the 2005 LULC map were extracted and used to mask the zmmNDVI grids for each crop type. Overlaying the validation data on the buffers indicate that these distances were generous to include all potential irrigated land.



**Figure 3.** (a) Common Land Units within 1.5 km of irrigation sources were extracted and used to restrict mapping of irrigated land for each crop type; (b) Corn fields in the east of this subset were farther than 1.5 km from irrigation sources and consequently, would be mapped as non-irrigated corn.

**Prepare Crop Data from USDA National Agricultural Statistics Service (NASS).** Irrigated acres for individual crops for calendar year 2005 were obtained for each county in Kansas from the USDA NASS Quick Stats web site ([http://www.nass.usda.gov/Data\\_and\\_Statistics/Quick\\_Stats/](http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/)) in a comma-separated values (csv) file. The csv file was then imported into an Excel spreadsheet. Several adjustments to the raw data were required to prepare it for use.

Crops not mapped in the 2005 crop classification stage were dropped from the spreadsheet. Nearly all of these crops had relatively small planted and harvested acreage amounts. Such crops included barley, dry edible beans, and oats. Each remaining commodity was then copied to its own spreadsheet and sorted by state-county FIPS code. Where subclasses for a crop existed, they were grouped together. For example, the commodities ‘corn for grain’ and ‘corn for silage’ were grouped simply as ‘corn’. The last steps were to concatenate the FIPS codes for state and county and then remove extraneous data columns, leaving only the data columns ‘State-County FIPS Code’ and ‘Irrigated Acres’ (harvested). After the data for each crop and state had been processed, they were consolidated into a single spreadsheet containing all crops (Table 1).

**Table 1.** A portion of the spreadsheet containing summarized USDA NASS Quick Stats irrigated acreage values for each crop type in each county that were mapped to irrigated classes.

County	State-County FIPS	Alfalfa	Corn	Sorghum	Soybean	Wheat
Allen	20001	7	0	0	0	0
Anderson	20003	0	757	0	783	0
Atchison	20005	0	403	0	195	34
Barber	20007	179	1,877	377	677	1,700
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**Mapping Irrigation Status.** Scripts were written to map irrigated area for each crop. Briefly, the script performed the following steps for each crop, by county, using the previously attributed county grid files as input:

1. Identify the threshold zmmNDVI value where running total acreage best matches the stated Quick Stats acreage.
2. Map all zmmNDVI values greater than and equal to the threshold zmmNDVI value.
3. Generalize the results and merge them with the crop type map to create a crop type map with irrigation status. A portion of the spreadsheet for Alfalfa is in Table 2. The USDA NASS Quick Stats acreage values are under the column heading 'Alfalfa'. The running total acreage values appear under the columns 'zmmNDVI241' through 'zmmNDVI1'. The running total acreage value closest to the Quick Stats acreage established the zmmNDVI threshold value.

**Table 2.** A portion of the spreadsheet for Alfalfa. The USDA NASS Quick Stats acreage values are under the column heading 'Alfalfa'. The running total acreage values appear under the columns 'zmmNDVI241' through 'zmmNDVI1'. The running total acreage value closest to the Quick Stats acreage established the zmmNDVI threshold value.

St-Co FIPS	Reported Alfalfa Acres	Zmm NDVI 241	Zmm NDVI 238	Zmm NDVI 237	Zmm NDVI 236	Zmm NDVI 235	Zmm NDVI 234				Zmm NDVI 1
20001	7	0.00	0.00	0.00	3.56	3.56	3.56	.	.	.	1,511.84
20003	0	0.00	0.00	0.00	0.22	0.22	0.22	.	.	.	5,354.60
20005	0	0.00	0.00	0.00	0.00	0.00	0.00	.	.	.	7,366.61
20007	179	0.00	0.00	0.00	0.00	0.00	0.00	.	.	.	2,004.00
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**Accuracy Assessment.** All ground-truth sites larger than 80 acres were used for the accuracy assessment. Table 3 shows the sample size for each crop type stratified by irrigation status.

Because the 2005 crop type map is not 100 percent accurate, errors in the crop map would propagate through to the crop type irrigation map. In order to achieve a better assessment of how successful the methodology used for mapping irrigation performed, classification errors from the crop type mapping stage were eliminated from the corresponding accuracy assessment. For example, to assess the accuracy of mapping irrigation status, crop fields that were incorrectly classified at the crop type mapping phase were eliminated from the accuracy assessment and only crop fields that were correctly classified were considered.

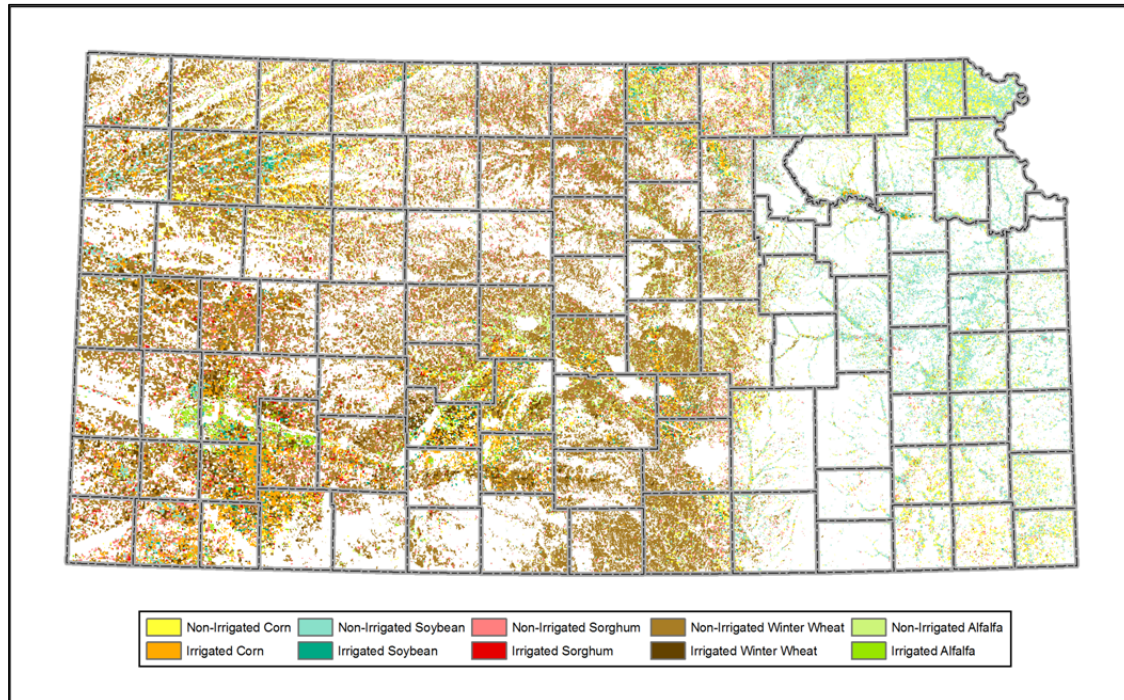
**Table 3.** The number of field sites used for accuracy assessment of the irrigation maps.

Crop Type	Non-Irrigated Sites	Irrigated Sites
Alfalfa	455	868
Corn	3,047	5,162
Sorghum	3,981	415
Soybean	2,124	1,183
Wheat	16,886	2,048



## RESULTS & DISCUSSION

The majority of cropland in Kansas is non-irrigated (88 percent versus 12 percent irrigated. See Figure 4). Irrigated cropland in the west is primarily situated over the Ogallala Aquifer, while in the east irrigated cropland is typically found along floodplains where surface water irrigation diversions are used.



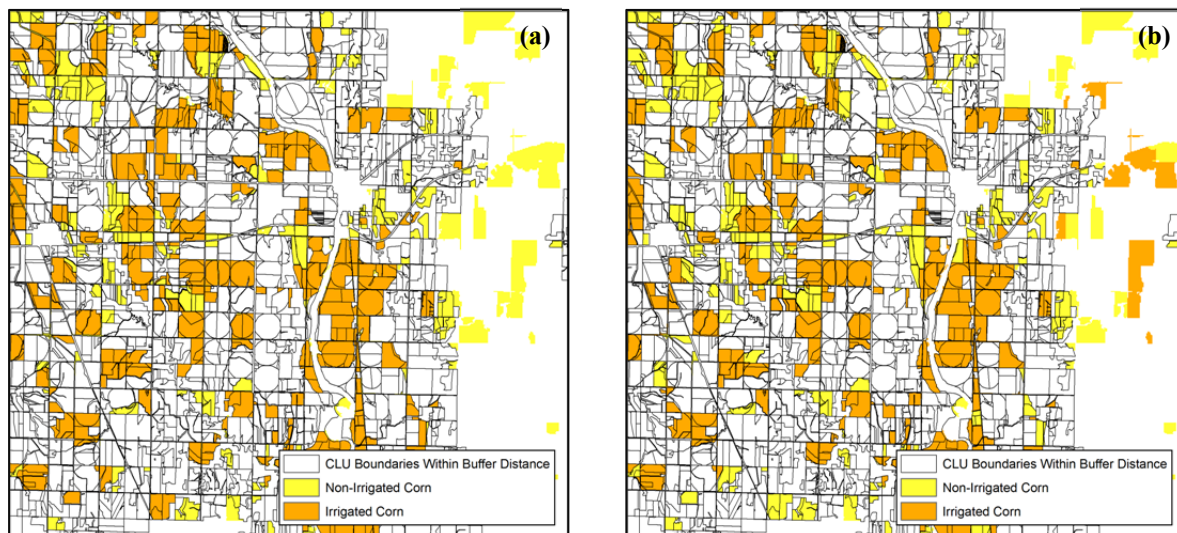
**Figure 4.** A map of Irrigated and Non-Irrigated cropland in Kansas using 2005 MODIS NDVI, national agricultural statistics and buffers around points of diversion and surface water irrigation sources.

While concentrations of corn and soybeans are mapped in both the eastern and western portions of Kansas, the eastern fields are primarily non-irrigated because precipitation is sufficient to support these water demanding crops (Figure 4). Meanwhile, in the semi-arid west, irrigation is necessary to sustain growing corn and soybeans. The map shows relatively small clusters of irrigated alfalfa in the southwest and also along several floodplains in the northwest and east. Only 5.4 percent of winter wheat in Kansas was reported, and thus mapped, as irrigated.

The overall accuracy levels for mapping crop type irrigation status in Kansas with and without incorporating buffers around irrigations sources was 87.5 percent and 86.6 percent, respectively. The addition of the buffers only slightly improved Producer and User accuracy levels, as well (Table 4). Figure 5 shows the distribution of irrigated corn in the subset area with and without the use of the 1.5km buffer around irrigation sources. The eastern side of the figures show corn fields that were mapped as irrigated without the buffers. It was unexpected that incorporating the irrigation source data did not improve the accuracy levels more than it did.

**Table 4.** Producer and User Accuracy Levels for each crop type and irrigation status. Irrigated sorghum and winter wheat had the lowest accuracy levels among the crop types.

Crop Type	No Buffer		1.5 km Buffer	
	<i>Producer's</i>	<i>User's</i>	<i>Producer's</i>	<i>User's</i>
Non-Irrigated Alfalfa	80.3%	72.3%	83.3%	75.2%
Irrigated Alfalfa	83.8%	89.0%	85.5%	90.7%
Non-Irrigated Corn	67.5%	80.3%	71.1%	82.0%
Irrigated Corn	88.5%	79.8%	89.2%	81.7%
Non-Irrigated Sorghum	94.0%	96.0%	94.6%	96.3%
Irrigated Sorghum	44.1%	33.8%	48.4%	38.6%
Non-Irrigated Soybean	93.0%	90.6%	94.0%	90.9%
Irrigated Soybean	75.8%	81.1%	76.5%	83.6%
Non-Irrigated Winter Wheat	92.8%	94.3%	92.5%	94.9%
Irrigated Winter Wheat	36.3%	30.7%	43.6%	33.7%



**Figure 2.** Map of Irrigated and Non-Irrigated Corn (a) with and (b) without 1.5km buffer of irrigation sources.

Based on the accuracy assessment, zmmNDVI mapped irrigated corn, soybean, and alfalfa more accurately than irrigated sorghum and winter wheat (Table3). One possible reason for the relatively low mapping accuracy for sorghum and winter wheat pertains to land management of these two crops. In western Kansas, strip cropping is a conservation practice used to reduce soil erosion where a field is partitioned into two or more equal width strips and planted with a specific crop rotation. Alternating strips of winter wheat and fallow or sorghum and fallow are common strip cropping patterns in portions of western Kansas. Perhaps the mapping difficulties arise from the 2005 crop type map that was used as one of the inputs for irrigation mapping. The crop type map utilized MODIS NDVI imagery, which may have been too coarse to capture the grain size of strip cropping, depending upon the width of the strips. If a field was divided into three strips of irrigated winter wheat, fallow, irrigated winter wheat, but the 2005 crop type map mapped the entire field as winter wheat, the zmmNDVI would be averaged across the entire field with the fallow strip causing a lower maxNDVI than a typical irrigated winter wheat field. Applying this methodology to the 2008 CDL, where higher resolution satellite imagery were used to derive the crop type map, will provide more insight on whether strip cropping impacted the 2005 mapping accuracies of irrigated winter wheat and sorghum.

Another explanation for the difficulty in mapping sorghum and winter wheat is there is simply not a significant difference between zmmNDVI values for irrigated sorghum and winter wheat versus zmmNDVI values for non-irrigated sorghum and winter wheat. Additional vegetation phenology metrics (VPMs) may be needed to improve the mapping of these crop types.

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