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Characterizing major agricultural land change trends in the Western Corn Belt

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ABSTRACT

In this study we developed annual corn/soybean maps for the Western Corn Belt within the United States using multi-temporal MODIS NDVI products from 2001 to 2015 to support long-term cropland change analysis. Based on the availability of training data (cropland data layer from the USDA-NASS), we designed a cross-validation scheme for 2006–2015 MODIS data to examine the spatial generalization capability of a neural network classifier. Training data points were derived from a three-state sub-region consisting of North Dakota, Nebraska, and Iowa. Trained neural networks were applied to the testing sub-region (South Dakota, Kansas, Minnesota, and Missouri) to generate corn/soybean maps. Using a default threshold value (neural network output signal $\geqslant 0.5$), the neural networks performed well for South Dakota and Minnesota. Overall accuracy was higher than 80% (kappa > 0.55) for all testing years from 2006 to 2015. However, we observed high variation of classification performance for Kansas (overall accuracy: 0.71–0.82) and Missouri (overall accuracy: 0.65–0.77) for various testing years. We developed a threshold-moving method that decreases/increases threshold values of neural network output signals to match MODIS-derived corn/soybean acreage with the NASS acreage statistics. Over 70% of testing states and years showed improved classification performance compared to the use of a default 0.5 threshold. The largest improvement of kappa value was about 0.08. This threshold-moving method was used to generate MODIS-based annual corn/soybean map products for 2001–2015. A non-parametric Mann-Kendall test was then used to identify areas that showed significant ($p < 0.05$) upward/downward trends. Areas showing fast increase of corn/soybean intensities were mainly located in North Dakota, South Dakota, and the west portion of Minnesota. The highest annual increase rate for a 5-km moving window was about 6.8%.

1. Introduction

From the early 2000s until now, the US Corn Belt has experienced a significant land use and land cover change (LUCC) event characterized by conversion of grasslands and wetlands to croplands (Wright and Wimberly, 2013) and intensive corn/soybean production (Lunetta et al., 2010; Sahajpal et al., 2014; Ren et al., 2016). Assessing LUCC in such a large agricultural landscape presents an important challenge, given that agricultural land use is continuously changing and may have sharp year-to-year differences. The Cropland Data Layer (CDL), developed by the United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS), is currently the only ready-to-use data product for evaluating large-scale agricultural land change at annual intervals (Boryan et al., 2011; Hansen and Loveland, 2012; Lark et al., 2015). Using CDLs, researchers are just beginning to characterize and understand rates and patterns of agricultural-specific LUCC in the Corn Belt. For example, Wright and Wimberly (2013) examined CDLs from 2006 to 2011 and reported a 1.0–5.4% of annual grass-to-corn/soy conversion in the Western Corn Belt (WCB). Their research mainly focused on two temporal snapshots (2006 and 2011), thus the authors suggested that change rates may be attributed to both an underlying trend of land use change and short-term crop rotation patterns (e.g., grassland/hay-corn/soybean rotation). Analyses of longer-term annual corn/-soybean map products may reduce the confusion from short-term crop rotation patterns and highlight overall change trends and spatial patterns.

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Complete CDLs are now available for the conterminous United States for 2008–2015. The spatial resolution of CDLs ranges from 30 m to 56 m, depending on the satellite data source used and processing protocols. Older CDLs, however, are not available for several states in the WCB region. For Kansas, Minnesota, Missouri, and South Dakota, CDLs are entirely missing for 2001–2005 (Fig. 1). Without CDLs for 2001–2005 as baseline datasets, it is a challenge to conduct a thorough analysis of corn/soybean-related agricultural land changes and examine their links to key US biofuel energy policies such as the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007. Developing CDLs requires multiple cloud-free images for each crop-growing season. It also requires good training/validation data. In the early 2000s, the USDA-NASS primarily used NASS June Area Survey (JAS) data as training/validation and an in-house software package (Peditor) for developing CDLs. In 2006–2007, NASS started to use high quality training/validation data points derived from detailed Common Land Unit (CLU) data from the Farm Service Agency (FSA) and commercial software (See5 Decision Tree) to improve CDL quality (Johnson, 2010; Johnson and Mueller, 2010; Boryan et al., 2011). By 2008, CDLs are considered nationally operational and the production was expanded to include all 48 conterminous states in the US. The availability of high quality training data (e.g., CLU from FSA) is one of the main reasons that the USDA-NASS did not provide high quality CDLs for the conterminous US before 2008. It is unclear whether the USDA-NASS plans to generate CDLs backward in time to extend the available time-series of cropland map products.

Several studies showed promise for multi-temporal Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data to perform crop-specific mapping with reasonable accuracy (Chang et al., 2007; Doraiswamy et al., 2007; Wardlow and Egbert, 2008; Shao et al., 2010; Wardlow and Egbert, 2010; Zhang et al., 2014; Chen et al., 2016; Zhong et al., 2016). However, many of these studies focused on short-term (e.g., 1–3 year) image classification experiments and their methods have yet to be expanded for annual cropland mapping. Furthermore, it was found that the main summer crops such as corn and soybean have similar spectral-temporal signals that typically lead to moderate-low cropland map accuracy (Wardlow et al., 2007; Shao et al., 2010). A combined corn/soybean class, as defined by Wright and Wimberly (2013), may substantially improve thematic map accuracy to support longer-term cropland change analysis. Both corn and soybean are considered to be intensive cropping compared to hay/pasture or natural lands. Analyzing trends in corn/soybean planting thus might be sufficient to characterize key agricultural intensification processes and patterns in the WCB.

Annual corn/soybean mapping with multi-temporal MODIS data requires high quality training data points for image classification. The currently available, but spatially-limited, 2001–2005 CDLs (North Dakota, Nebraska and Iowa, Fig. 1) could be used for reference to generate a large number of training data points for corn/soybean mapping. This possibility raises an interesting question of the capability of spatial generalization of US crop mapping through image classification – whether a trained multi-temporal classifier for a region can be directly applied to a different region (Kansas, Minnesota, Missouri, and South Dakota) where CDLs are not available. There is no guarantee that a trained classifier would produce acceptable results because corn/soybean phenologies and general land cover compositions may vary substantially across regions. Previous published studies showed promising results for Neural Networks (NN) and Random Forest in both spatial and temporal generalization (Shao and Lunetta, 2012; H. Wang et al., 2014,

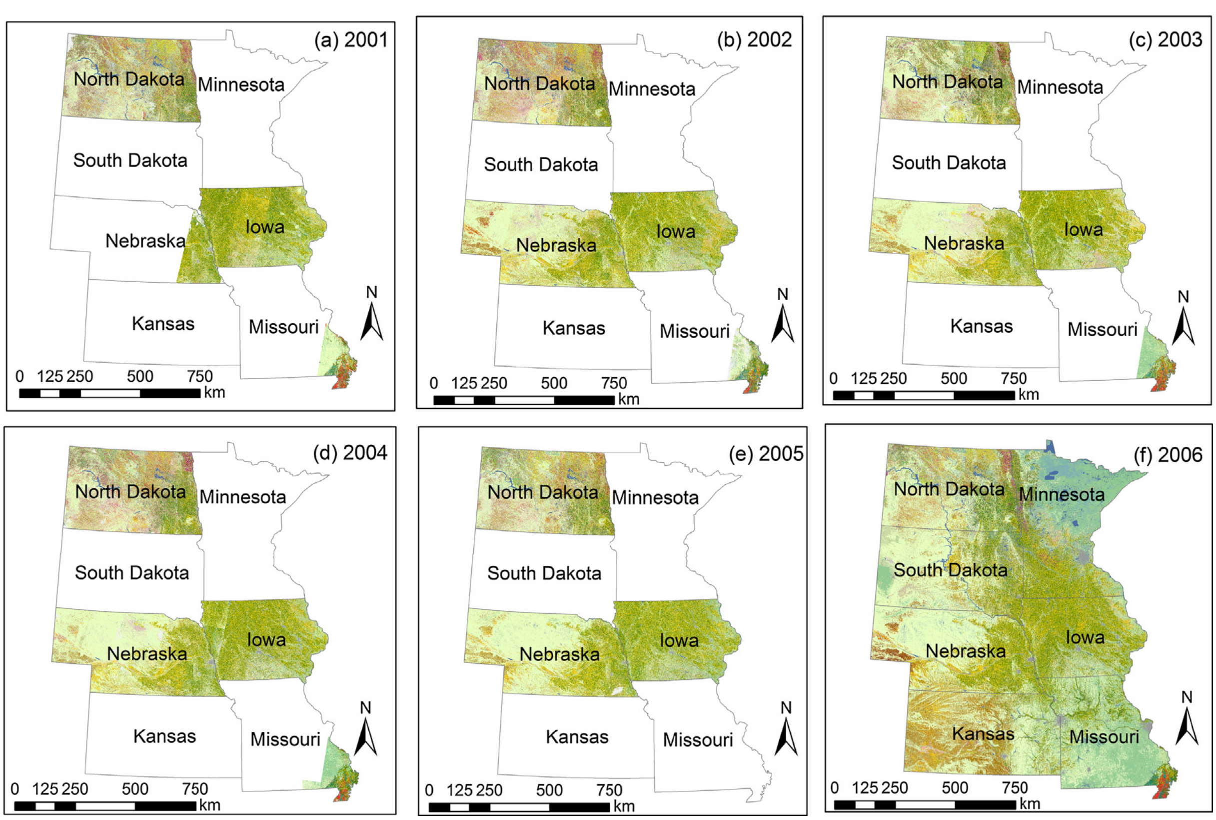

Fig. 1. Spatial coverage of the Cropland Data Layer for the Western Corn Belt, 2001–2006.