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Monitoring agricultural cropping patterns across the Laurentian Great Lakes Basin using MODIS-NDVI data

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ABSTRACT

The Moderate Resolution Imaging Spectrometer (MODIS) Normalized Difference Vegetation Index (NDVI) 16-day composite data product (MOD12Q) was used to develop annual cropland and crop-specific map products (corn, soybeans, and wheat) for the Laurentian Great Lakes Basin (GLB). The crop area distributions and changes in crop rotations were characterized by comparing annual crop map products for 2005, 2006, and 2007. The total acreages for corn and soybeans were relatively balanced for calendar years 2005 (31,462 km^2 and 31,283 km^2, respectively) and 2006 (30,766 km^2 and 30,972 km^2, respectively). Conversely, corn acreage increased approximately 21% from 2006 to 2007, while soybean and wheat acreage decreased approximately 9% and 21%, respectively. Two-year crop rotational change analyses were conducted for the 2005–2006 and 2006–2007 time periods. The large increase in corn acreages for 2007 introduced crop rotation changes across the GLB. Compared to 2005–2006, crop rotation patterns for 2006–2007 resulted in increased corn–corn, soybean–corn, and wheat–corn rotations. The increased corn acreages could have potential negative impacts on nutrient loadings, pesticide exposures, and sediment-mediated habitat degradation. Increased in US corn acreages in 2007 were related to new biofuel mandates, while Canadian increases were attributed to higher world-wide corn prices. Additional study is needed to determine the potential impacts of increases in corn-based ethanol agricultural production on watershed ecosystems and receiving waters.

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1. Introduction

Ethanol production, especially corn ethanol, increased rapidly across the mid-western USA from 2005 to 2007 (RFA, 2007). Recently, the environmental implications associated with corn based ethanol production has received increasing attention (Pimentel, 2003; Pimentel and Patzek, 2005; Zah et al., 2007; Scharlemann and Laurence, 2008). The research of Zah et al. (2007) suggested that corn ethanol may have greater overall environmental cost than using fossil fuels. Water quality, soil erosion, air pollution, biodiversity and the loss of natural habitats are concerns at both local and regional scales (Hodge, 2002; Huston and Marland, 2003; Pimentel and Patzek, 2005; Searchinger et al., 2008).

Environmental assessments often need site-specific information about crop distributions (e.g., SWAT, 2007). Researchers are not only interested in the total area of ethanol crop production, but also require data documenting geographic distributions and changes over time to support distributed modeling efforts. Such information is particularly useful for identifying watersheds subject to potential environmental damages or ecological degradations. Due to the limited availability of National Agricultural Statistics Service (NASS) Crop Data Layer (CDL) products, researches often rely on agricultural statistics estimates (i.e., state or county-level), developed by the United States Department of Agriculture (USDA) NASS program (Sheehan et al., 2004). The spatial details of the crop location, extent and distribution, and the pattern of crop change are generally unavailable from the estimated agricultural statistics. Researchers are thus forced to use unrealistic assumptions of crop distributions and crop rotation patterns, which may lead to high uncertainties in modeling predictions of potential environmental impacts.

The mapping of crops using remote sensor data has shown good potential for characterizing the extent, distribution and condition of croplands (Moran et al., 1997; Frolking et al., 1999; Doraiswamy et al., 2005; Thenkabail et al., 2009). The Moderate Resolution Imaging Spectroradiometer (MODIS) data, which combine moderate spatial resolution (250 m) and a high temporal resolution (1–2

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day repeat cycle), were found to be particularly useful to differentiate general cropland versus non-cropland and to categorize individual crop types (Lobell and Asner, 2004; Chang et al., 2007; Wardlow et al., 2007; Wardlow and Egbert, 2008). The phenology-based categorization (or time-series analysis) of MODIS-NDVI (Normalized Difference Vegetation Index) is one of the most used approaches (DeFries and Townshend, 1994; Shao et al., 2010; Hansen et al., 2003). Most previous MODIS-NDVI crop-mapping applications have focused on single year crop mapping efforts. MODIS-NDVI datasets have rarely been used to study the crop changes or rotations over multiple years. The potential of multi-year MODIS-NDVI crop mapping has not yet been fully exploited.

The principle objective of this research was to examine the cropland changes across the Great Lakes Basin (GLB) using map products derived from MODIS-NDVI data. The GLB is a region thought to have undergone significant changes in cropping patterns, because the US government implemented substantial subsidies to encourage corn ethanol production during the study period (2005–2007). Research questions of interest included the following: (1) how did crop acreage distributions (i.e., corn, soybean, and wheat) change through the GLB? (2) Was there a change in crop rotational patterns due to increased corn ethanol demand? (3) If yes, were there any geographic differences associated with variations in crop rotation patterns across the GLB (i.e., US versus Canadian)? The answers to these questions are particularly important for identifying areas or regions with a high potential for environmental degradation. Two specific research objectives of this paper were to map annual crop distributions across the GLB for 2005, 2006, and 2007, and compare the two-year crop change or rotation patterns for 2005–2006 and 2006–2007.

2. Study area

The GLB region includes all or part of eight states of US and a portion of the Province of Ontario, Canada (Fig. 1). While the basin is among the most industrialized regions in the world, the southern portions of the GLB are prime areas for corn, soybean and other types of agricultural crop production (USEPA, 2008). GLB agricultural production represents 7% and 25% of the total US production and Canadian production, respectively (USEPA, 2008). The total agricultural land in the US portion of GLB has decreased slightly from 1970 to 2001 (Erickson, 1995; Wolter et al., 2006). The loss of agricultural land mostly occurred near urban edge areas. For example, southeast Michigan alone lost 13% of agricultural land area from 1990 to 2000; mainly due to the urban expansion (SEMCOG, 2003). A majority of Ontario's prime agricultural lands are located in the southern part of the province; which have also been subject to extensive urban expansion. Approximately 18% of the prime agricultural land in Ontario has been converted to urban from 1976 to 1996 (Statistics Canada, 1998). However, crop yields associated with major crop types have increased dramatically over the past decades due to technology improvement (Matson et al., 1997). Urbanization and intensive agricultural production are believed to cause a number of environmental problems including: (a) sedimentation and excessive nutrient loading (Crosbie and Chow-Fraser, 1999); (b) hydrological modifications (Environment Canada and EPA, 2003); and (c) the loss of natural habitats and diminished biodiversity (Detenbeck et al., 1999).

3. Methods

3.1. Data

The MODIS-NDVI data were pre-processed using the method developed by Lunetta et al. (2006). MODIS-NDVI data preprocessing was conducted to provide a filtered (anomalous data removed) and cleaned (excluded data values estimated) uninterrupted data stream to support time-series analysis. MODIS-NDVI 16-day composite grid data (MOD13Q1, version 5.0) in HDF format

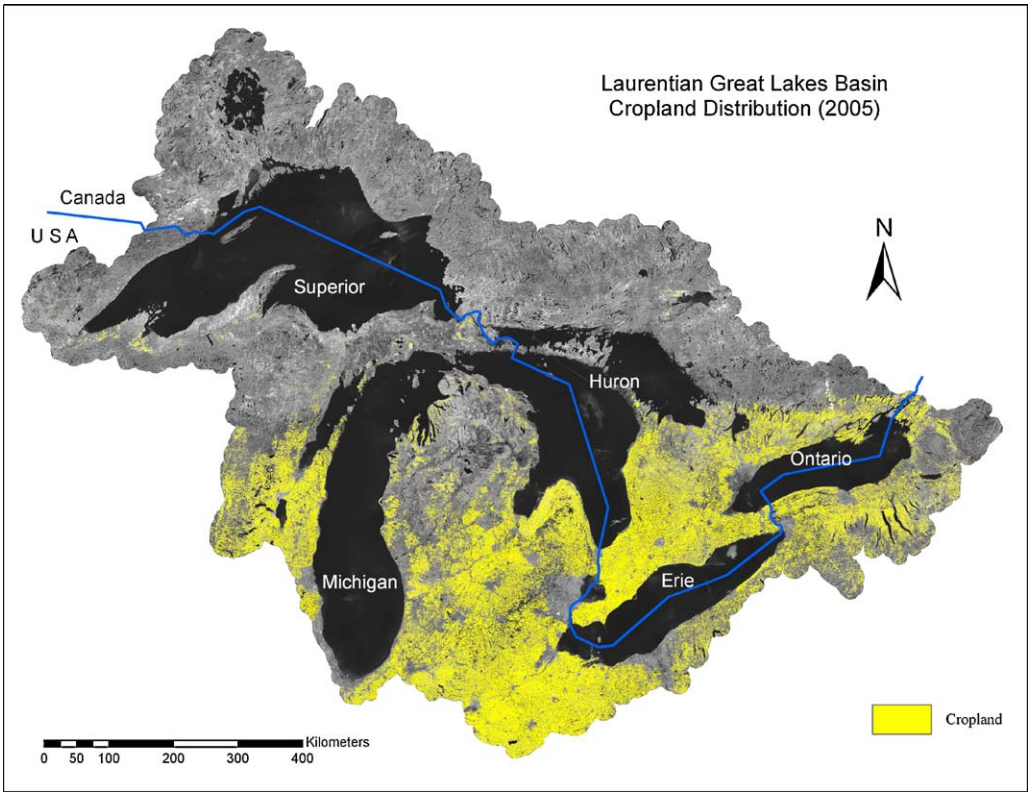

Fig. 1. MODIS-NDVI derived cropland extent and distribution across the GLB in 2005.