AGRICULTRAL LAND USE CHANGES, 2001-2012, SOUTHEASTERN IOWA, USING LANDSAT 4 & 5 TM IMAGERY

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ABSTRACT

In central regions of the U. S. Corn Belt, agricultural production since 2001 has changed in response to federal policies implemented to encourage production of biofuels. As a result, increasing demand for sustainable bioenergy resources has accelerated biofuel production, and led to changes in agricultural land use. This study examines: (1) increases and decreases in cultivated area, and (2) pixel-by-pixel crop rotation sequences within a region of southeastern Iowa. The practice of agriculture brings lands in and out of production in response to variations in local landscapes, markets, and technologies. Further, crops are rotated in response to environmental and market concerns. Knowledge of how such lands are used, and of their topographic and pedological properties, forms a prerequisite for understanding the context for developing sustainable management practices and policies. This study examines temporal and spatial patterns of agricultural land use from 2001 to 2012 in a region of southeastern Iowa within a single Landsat scene (Path 25/Row 31). After 2007, intensity of cultivated land use increased and crop rotation changed from standard corn-soybean or soybean-corn cycle to more intensive rotations. These changes may be correlated with market forces. Intensity of cultivated land use depended on topographic and pedological properties, although motivations and constraints perceived by farmers and managers as they plan their use of landscapes are important.

KEYWORDS: agricultural pattern, land use change, biofuels

INTRODUCTION

Beginning in the early 2000’s, U.S. biofuel production begin a steady growth that continues today. These increases have been linked to increases in corn production over the same interval, although climatic and social factors have created year-to-year fluctuations. Increased corn production is achieved through various combinations of increases in cultivated land and intensification of production practices. The former might be based upon cultivation of lands formally held in Conservation Reserve Program (CRP) or use of marginal lands previously devoted to less intensive uses. The latter could be achieved through changes in existing crop rotation practices, or by more intensive use of fertilizers.

Broad-scale production of biofuels has wide impacts on energy supplies, economic fundamentals, and environmental quality, creating vigorous debate (Farrell et al. 2006; Huang et al. 2013; Kim, Kim, and Dale 2009; Pimentel and Patzek 2005; Shapouri et al. 2004; Rajagopal et al. 2007). Although most of the literature analyzed these impacts from varied perspectives with statistical data; spatial dimensions of these impacts were neglected, largely because of the complex and integrated nature of the modeling efforts. However, such information is important if we want to understand whether there are disproportional effects in some areas, and to help direct policies. Recent papers have incorporated spatially explicit analyses. For example, Secchi et al. (2011) linked economic, geographical and environmental models by using spatially explicit common units of analysis and used remotely sensed crop cover maps and digitized soils data as inputs. They considered impacts of the biofuels industry both on current cropland and on land in the CRP in Iowa. Stern et al. (2008) considered, for Iowa, impacts of ethanol production both on current cropland and on land which was not in cultivation and determined which one is taking place and the distribution of changes throughout a state or in localized places. Stern et al. (2012) examined crop rotation practices based upon USDA Cropland Data Layer information, aggregated by county. They examined the relationship between corn production increases and crop rotation changes in Iowa.

This study analyses sequential remote sensing imagery of a nine-county region of East-Central Iowa to examine temporal and spatial patterns of agricultural land use, 2001 – 2012. These data record, on a site-specific basis, changes in agricultural land use (cropped areas and crop rotation patterns) during the years preceding, and the period just following, these policy changes. The spatial details of the crop location, extent and distribution, and the pattern of crop change will support environmental modeling. Objectives of this study are to: 1) examine spatial dimensions of cultivated cropland and corn-soybean rotation on a pixel-by-pixel basis, 2001-2012; and 2) examine spatial relationships between cultivated fields, and crop rotation practices, with respect to underlying soils and terrain, using sequential Landsat imagery.

STUDY AREA

This research investigates a nine-county-region in East-Central Iowa (Figure 1), an area of low relief and gentle topography formed as glacial terrain and loess deposits. The southern half (approximately) includes a portion of the Southern Iowa Drift Plain, rolling hills of Wisconsin-aged loess superimposed on Illinoian glacial till, forming some of the world's most productive agricultural land. Here northwest-southeast oriented drainage interfingers into glacial surfaces as forested channels. The southeastern corner includes a section of the Mississippi Alluvial Plain— alluvial deposits associated with Mississippi and its tributaries, bordered by limestone and dolomite cliffs. Locally it is formed largely as stream terraces, abandoned river channels, oxbow lakes, and backwater sloughs. The northern edge of the study area is the Iowan Surface, a low-relief surface of glacial till covered by shallow loess.

Iowa agriculture focuses upon production of cattle, hogs, corn, soybeans, oats, and eggs— a list that includes several products that compete for corn. Iowa is the United States' largest producer of corn and ethanol, and often leads in soybean production. As is typical for Corn Belt agriculture, maize and soybeans are grown in rotation— as noted below, increases in ethanol production have disrupted the accepted corn-soybean rotation, now often replaced by corn-corn-soybean rotation cycles. At least fourteen biofuel and ethanol plants within and near the study area, rely upon local corn crops. These plants are situated not only in proximity to corn production, but also near transport, including road, rail, and water. Despite the significance of ethanol production, locally and nationally, not all ethanol plants are successful, and are often they are locally regarded as noxious facilities, due to increases in local traffic, pollution, and damage to local highways that have accompanied their growth. The study region has an unexpected demographic diversity, including Amana Colonies, and Amish and Mennonite populations, who may vary in their motivation to change agricultural practices, and face differing constraints in responding to policy changes. This area includes two cities, sizable by Iowan standards— Iowa City, and Cedar Rapids, with larger areas such as Waterloo, Ames, and Des Moines positioned just outside the study region.

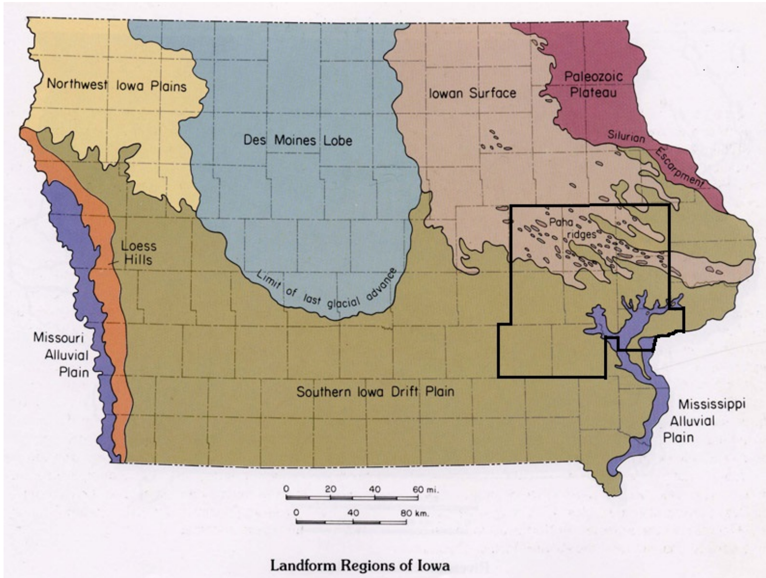

Figure 1. Study area in south-eastern Iowa with major landforms of Iowa, adapted from Prior (1991).

METHODS

Data Sources

Six sources of data were used to identify marginal agricultural lands. The first set was Landsat 4 & 5 TM imagery (Path 25/Row 31), 2001 to 2007 and 2009 to 2011, including 14 cloud-free scenes in which 2003, 2004, 2005 and 2010 had two images in spring and summer and the other six years just had one image in spring or summer. The second set was National Land Cover Database 2006 (NLCD2006) produced by United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (http://www.mrlc.gov/nlcd06_data.php). The third set of data was the Cropland Data Layer (CDL) for Iowa from 2001 through 2012 produced by United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) (http://nassgeodata.gmu.edu/CropScape/). The fourth set was defined by a shapefile of land enrolled in USDA Conservation Reserve Program (CRP) in 2008 from University of Iowa. The fifth set was the USGS National Elevation Data (NED) 30m for Iowa (http://viewer.nationalmap.gov/viewer/), the elevation data were used to extract slope. Lastly, Gridded Soil Survey Geographic (gSSURGO) Database for Iowa produced by USDA Natural Resources Conservation Service (NRCS) was used to identify land capability classes (http://datagateway.nrcs.usda.gov/GDGOrder.aspx).

Analysis of Sequential Imagery

Landsat imageries were classified using the maximum likelihood decision rule to get cultivated land with summer crops. Overall accuracies are above 80.75%, and producer's accuracies for summer crops are above 83.64%. The classified images were masked using NLCD2006 to retain herbaceous and cultivated land. Masked images with "Salt and pepper" effects were processed by a 3 by 3 majority filter. Intensification of production practices for summer crops on a pixel-by-pixel basis were obtained by tracking lands that were kept in production during 12 years. A five-year moving window (8 windows from 2001 to 2012) was applied to track different changes of such intensification.

Characterizing Physical Factors

Topographic slope values were extracted from USGS NED 30m using ArcGIS. Land capability class values were obtained from gSSURGO Database. It was rescaled to 30m and used the majority class value of 3 by 3 matrixes to represent each new pixel value. For different intensification classes, slope values and land capability class values were selected 1 per 100 samples and compared.

Determination of Crop Rotations

Crop rotation refers to the sequence of crops from year to year for a single field. The standard crop rotation in Iowa has been to alternate between corn and soybeans in consecutive years. Alternatively, some farmers have chosen to plant corn or soybeans year after year in the same field. For the purpose of this study, we focus upon crop rotation with two crops (corn and soybeans) over six-year intervals, which will give us 64 possible permutations.

Crop rotation patterns for corn and soybeans over six-year intervals before (2002-2007) and after (2007-2012) the widespread increases in ethanol production were analyzed using CDL. This study generated a crop rotation index based on the Shannon-Wiener index (Barrett 1992), originally developed to examine ecological diversity:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i$$

Where *p* is simply the frequency across years of crop type *i*, in this case, the frequency across 6 years of corn or soybean.

Over six-year intervals, lands with three years corn or soybeans have the highest value of this index, while lands with six years corn or soybeans have the lowest value of this index. This index indicates the intensity of land used for a single crop but it fails to differentiate crop types and to explain the continuity of a single crop.

RESULTS

Intensity of Cultivated Land

Using a five-year moving window, various production trends can be analyzed. Over five years, area in summer crop cultivation for both more than two years and more than three years reached a maximum in the period from 2007 to 2011, with another peak in the period from 2003 to 2007 (Figure 2). These trends corresponded to the price trends for corn and soybeans based on NASS statistics. From 2001 to 2010, both corn and soybean prices reached a maximum in 2010, with other peaks in 2003 and 2007 at the state level (Stern, Doraiswamy, and Hunt 2012). These increasing trends indicated increases in cultivated land intensity, which may be attributed to the higher demand for corn created by the increasing production capacity of ethanol plants (Renewable Fuels Association 2013).

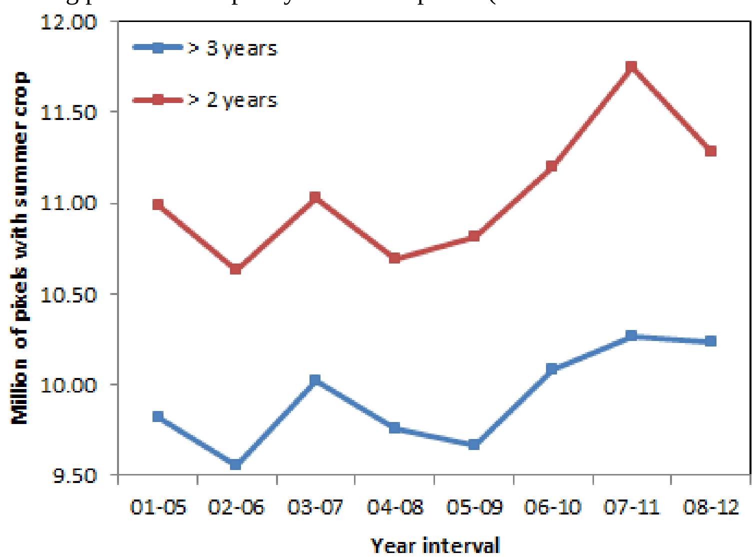

Figure 2. Total pixels with summer crop by a five-year moving window from 2001 to 2012 in the study area. Red lines indicate more than two years over five years with summer crop and blue lines indicate more than three years over five years with summer crop within a five-year window.

Pixels of different number of years with summer crops were mapped to show intensity of use of land (Figure 3). Most areas are planted with continuous summer crops. Area along rivers and valleys are used less intensively, perhaps because slopes in valleys are usually steep and soils are not fertile enough.

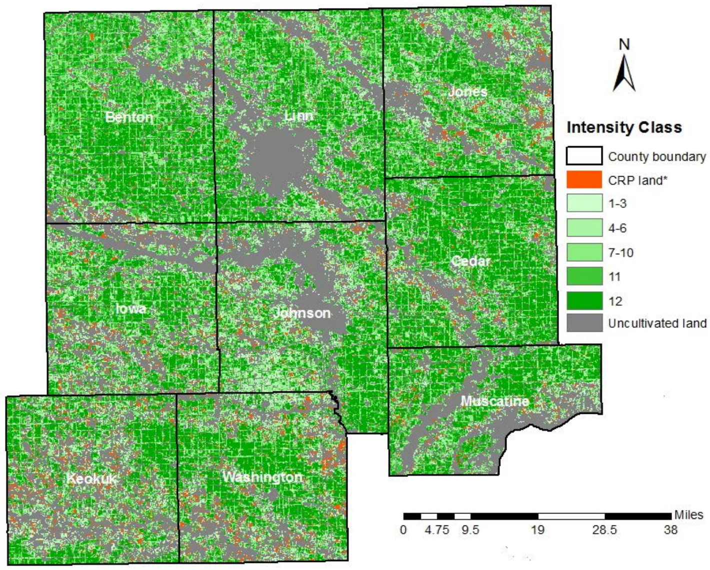

Figure 3. Cultivated land intensity class from 2001 to 2012 and 2008 CRP land in the study area.

Terrain Slope and Land Capability

Slope values for areas with different cultivated land intensity within the study area were compared. As land intensity increased, slope decreased (Figure 4). The most intensively used land (11 or 12 years with summer crop) had slopes less than six degrees, which is suitable for mechanization. Slope values of these five classes were significantly different ($P < 0.0001$) according to Wilcoxon Rank Sums/ Kruskal-Wallis Tests. There were less than 0.01% outliers (red crosses in Figure 4) and most were located at the edges of fields. Some had extremely high slopes which were impossible for cultivation, perhaps caused by misclassification.

Land capability classification shows the suitability of soils for most kinds of field crops, the smaller the class value designation, the fewer limitations for cultivation. Capability class values for areas with different cultivated land intensities in the study area were compared. In Figure 6, sizes of circles represent the area of land cultivated and sizes of the wedge-shaped pie segments represent the proportion of each land capability class. The majority of land (above 80%) in the study area has fewer limitations. As land intensity increased, more land with fewer limitations (capability class of 1, 2 and 3) was brought in cultivation. Class 7 and 8 soils are unsuitable for cultivation, thus pixels allocated to these two classes may be caused by misclassification.

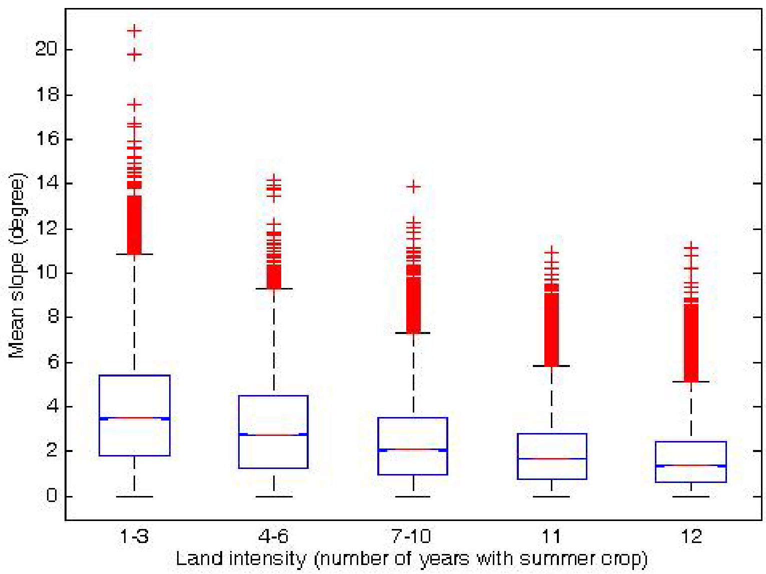

Figure 4. Relationship between cultivated land intensity and terrain slope (degree) in the study area.

Figure 5. Relationship between cultivated land intensity and land capability class in the study area. Numbers within the pie segments indicate land capability designations. The most intensively used lands tend to use the higher land capability classes.

Crop Rotation

All 64 possible permutations of corn and soybean rotations were recorded before 2007 but only half were used after 2007. Famers preferred to plant corn or soybean consecutively after 2007. During the 2002-2007 periods, there was 36.09% cultivated land with standard rotation (either corn-soybean or soybean-corn) (Figure 6). These lands were located in the most intensively used lands. Lands with continuous corn were more abundant than lands with continuous soybeans. During the 2007-2012 periods, standard rotation was replaced by more intensive rotation, such as continuous corn or soybeans for three years, or even longer (Figure 7).

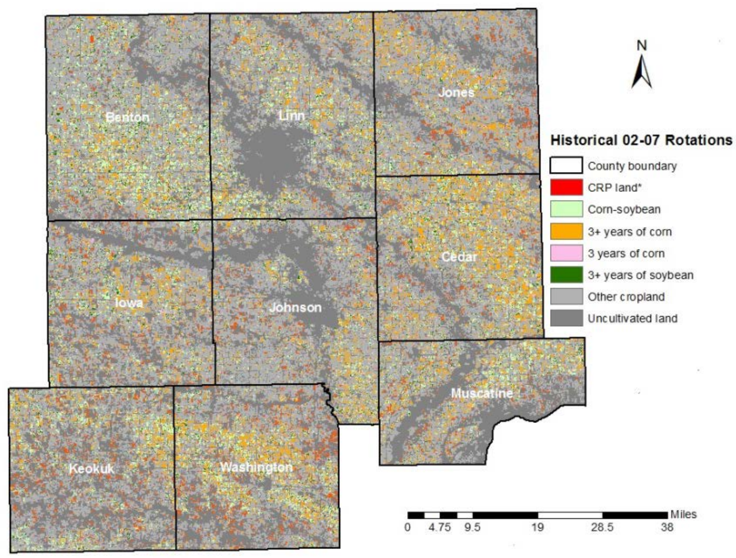

Figure 6. Location of 2002-2007 crop rotations and 2008 CRP land in the study area.

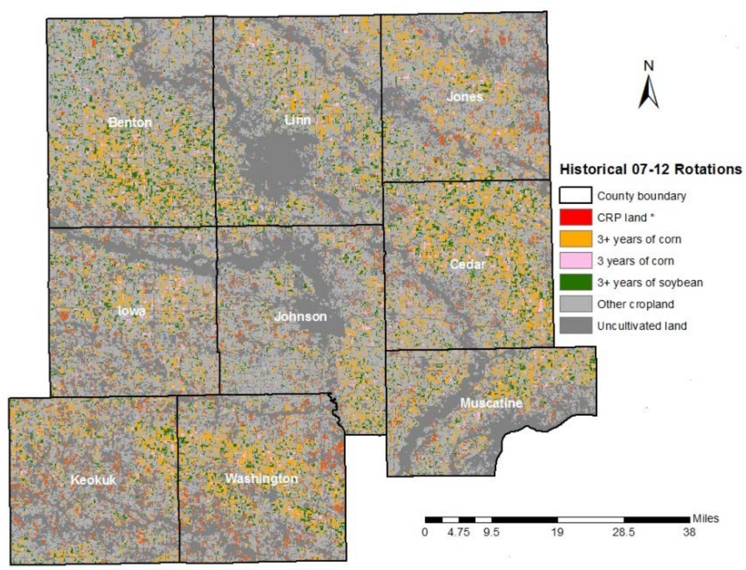

Figure 7. Location of 2007-2012 crop rotations and 2008 CRP land in the study area.

Lands with crop rotation changes after 2007 to continuous corn or continuous soybeans were increased to 27.43% and 25.48%, respectively (Figure 8). According to our crop rotation index, diversity of land use decreased dramatically, in other words, farmers preferred to use their lands for a single crop (Figure 9).

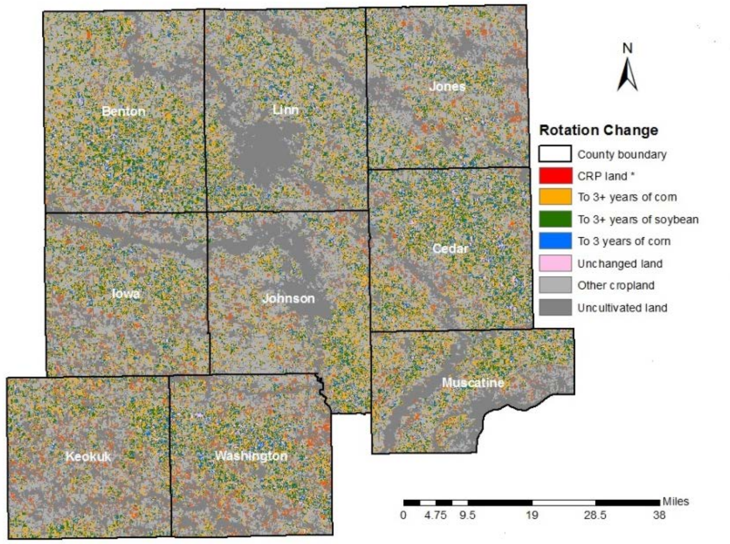

Figure 8. Location of crop rotation changes and 2008 CRP land in the study area.

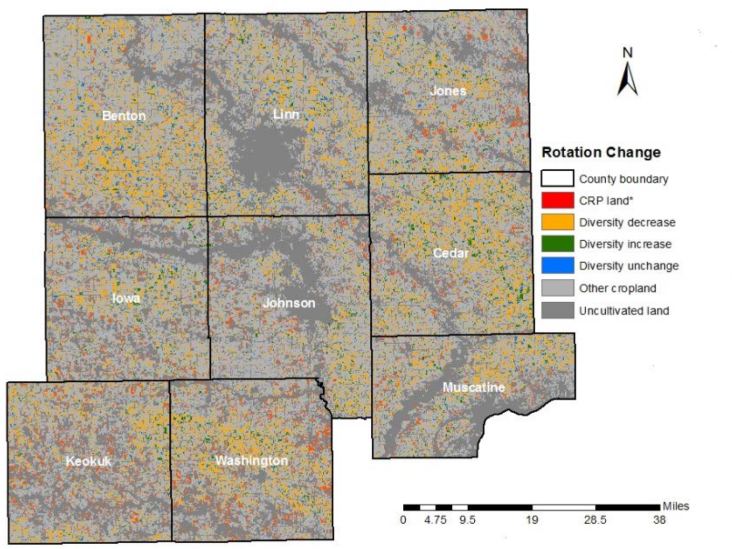

Figure 9. Location of crop rotation changes and 2008 CRP land in the study area based on crop rotation index.

CONCLUSIONS

From 2001 to 2012, biofuel production has increased in Iowa. As biofuel production has increased, demand for corn and its market price has increased, probably leading to changes in land intensity and changes in crop rotation. With Landsat imagery and NASS CDL, after 2007, more lands were brought into cultivation and standard crop rotation was changed to plant more corn or soybean on a pixel-by-pixel basis. In addition, the area used for both corn cultivation and soybean cultivation increased. Most intensive cultivated land had shallower slopes and less pedologic limitations than others. In the future, we will explore the context in which farmers and other agricultural managers are motivated and constrained in their land use and cropping decisions.

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