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Spatial and temporal dimensions of agricultural land use changes, 2001–2012, East-Central Iowa

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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. Such changes have influenced agricultural practices, land uses, and their spatial character. This study examines site-specific temporal and spatial patterns of agricultural land use dynamics from 2001 to 2012 in a nine-county region of East-Central Iowa using the United States Department of Agriculture National Agricultural Statistics Service Cropland Data Layer. Results indicate that increases in corn production in response to US biofuel policies and high grain prices have been achieved mainly by altering crop rotation patterns. These changes may be correlated with market forces, although variations suggest a multiplicity of causes. This study also examines spatial relationships between cultivated fields and crop rotation practices with respect to underlying soils and terrain. Intensity of cultivated land use depends on topographic and pedologic properties, although motivations and constraints perceived by producers and managers as they plan their use of landscapes are important. The most intensively cultivated lands have shallower slopes and fewer pedologic limitations than others, and corn was planted in higher quality soil while soybeans were moved to lesser quality soils. Declining acreage in the Conservation Reserve Program since 2007 indicates that they may be used for other crops displaced by corn.

1. Introduction

The Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 requires blending of renewable fuels such as ethanol and biodiesel in transportation fuels, thereby increasing demand for corn and other dedicated energy crops such as switchgrass that can supply fuels to meet this requirement. Increased corn production has been achieved through combinations of conversion of noncropland into corn production (which we label as “extensification”) and switching to intensive production practices to increase yields (which we label as “intensification”). The former might be based upon cultivation of lands formally held in the Conservation Reserve Program (CRP) or upon use of marginal lands previously devoted to less intensive uses (Langpap and Wu, 2011; Swinton et al., 2011; Westcott, 2007). The latter could be achieved through changes in existing crop rotation practices (Plourde et al., 2013; Stern et al., 2012), or by more intensive use of fertilizers (Simpson et al., 2006).

Broad-scale production of biofuels has wide impacts on agriculture and land use (Keeney and Hertel, 2009; Miao, 2010; Miyake et al., 2012; Mueller and Copenhaver, 2009; Stan et al., 2014; Wallander et al., 2011; Wu et al., 2012). Researchers recognize that meeting increased demand for corn driven by ethanol production must be based upon either extensification or intensification of production, but have disagreed about specifics. Wright and Wimberly (2013) analyzed spatial changes from grassland to cropland between 2006 and 2011 in the western Corn Belt based upon analysis of the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL). They reported that increased corn and soybean production is based upon extensification, not intensification. This study generated a rebuttal from a study in Kansas (Brown et al., 2014). Brown et al. (2014) examined CDL and interview data from Kansas farmers to explore relationships between distance to ethanol plants and extensification and intensification of corn production at county level between 2007 and 2009. Their study indicated that farmers devoted much more land to intensification than to extensification. In addition, recognition of spatial and temporal dimensions of land use changes in agricultural systems caused by biofuel production is important if we seek to understand local economic and environmental consequences, and to improve predictive models used in decision support. Recent papers have incorporated spatially explicit analyses (Johnston, 2014), focus primarily on particular land use change practices, such as crop rotation or reclamation of CRP lands, and their environmental impacts. 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

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data as inputs. They predict changes in land use, crop rotation, and tillage practice, including the environmental impact of these choices, under different corn price scenarios in Iowa. They assessed environmental impacts on the extensive margin (CRP lands with no cropping) and the intensive margin (lands currently under row crop agriculture) using the Environmental Policy Integrated Climate (EPIC) model. They found that land already in row crops would be converted to continuous corn cropping before any land in CRP would be converted to any corn production. Stern et al. (2012) examined crop rotation practices based upon USDA CDL information, aggregated by county. They examined relationships between corn production increases and crop rotation changes in Iowa, finding regional differences in crop rotation decisions relative to expansion of cultivated land.

There is yet little research devoted to immediate and long-term impacts of increased ethanol production for domestic agriculture, especially the spatial dimensions of these impacts. Spatial details of crop location, extent and distribution, and patterns of changes in crop rotation illuminate how agricultural practices have responded to changes in ethanol policy. Existing work pays less attention to examination of spatial relationships between cultivated fields, and crop rotation practices, with respect to underlying soils and terrain.

We provide an in-depth geographical analysis of land use dynamics to better understand spatial dimensions of cropland change. We examine two hypotheses. First, as there has been a notable increase in biofuel production over previous years, crop production expanded into areas such as those formerly enrolled in the CRP, and into marginal or poor lands that are less suitable for growing crops. Second, as most of the land in Iowa is already used for agriculture, increases in corn production have been largely achieved by altering crop rotation patterns, causing a decline in crop diversity and redistribution of cornfields to most fertile and productive lands. We examine these hypotheses by analyzing 12 years of sequential Landsat imagery of a nine-county region of East-Central Iowa.

2. Study area

This research investigates a nine-county region in East-Central Iowa (Fig. 1), an area of low relief and gentle topography formed as glacial terrain and loess deposits. The southern half (approximately) of this area 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 the Mississippi River 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.

Approximately 90% of the total land in Iowa is used for agriculture with cropland mainly in private ownership (Petrov and Sugumaran, 2005). 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, corn 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 (Bain and Selfa, 2013; Secchi et al., 2011; Stern et al., 2012). The study area covers three main markets for corn inputs (Gallagher et al., 2005). At least eleven biodiesel and ethanol plants within and near the study area rely upon local corn crops (Fig. 1), including three established during the past seven years, after the change in biofuel policy (Iowa Department of Natural Resources, 2007). 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.

3. Methods

3.1. Data

Four sources of data were used to identify changes of agricultural land use. The first set of data was the CDL for Iowa from 2001 through 2012 produced by USDA NASS (http://nassgeodata.gmu.edu/CropScape/). The spatial resolution is 56 m for CDLs from 2006 to 2009 and 30 m for CDLs from other years. In order to analyze crop

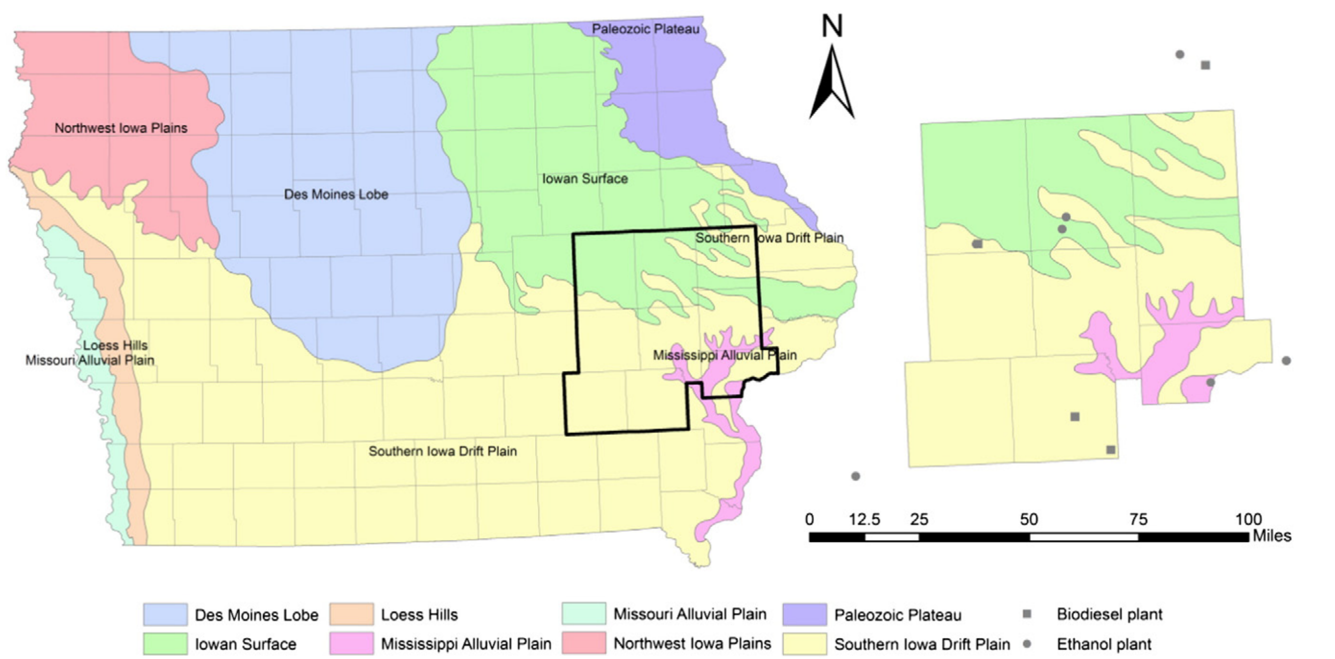

Fig. 1. Study area in south-eastern Iowa, shown with major landforms of Iowa, adapted from Prior (1991). Locations of ethanol plants are symbolized with grey filled circles and locations of biodiesel plants are symbolized with grey filled boxes.

rotation changes over 12 years and compare with other data sets, CDLs from 2006 to 2009 were resampled to 30 m. NASS indicates that CDLs have high user's and producer's accuracies for corn and soybeans, usually above 90% for Iowa (Stern, Doraiswamy, and Hunt). Thus, the CDL appears to be a reliable source of data for crop rotation analysis. The second set was county-level CRP statistics from the US Department of Agriculture and a spatial data (a polygon shapefile) of land enrolled in USDA CRP in Iowa in 2008 from University of Iowa. There was no publically available spatial data on CRP lands for other years. The third set was the USGS National Elevation Data (NED) at 30 m for Iowa (http://viewer.nationalmap.gov/viewer/), used to extract topographic slope. Lastly, Gridded Soil Survey Geographic (gSSURGO) Database for Iowa produced by USDA Natural Resources Conservation Service (NRCS) was used to identify Corn Suitability Rating (CSR) and land capability class (http://datagateway.nrcs.usda.gov/GDGOrder.aspx).

3.2. Analysis of land intensity

The CDLs from 2001 to 2012 were used to identify patterns of summer crops (corn and soybeans) within our region. These CDLs were converted to binary images, labeling pixels classified as corn or soybeans as "1" and labeling other land cover types as "0". A 3×3 majority filter was applied to all binary images to reduce "salt and pepper" effects. Intensification of production practices for summer crops on a pixel-by-pixel basis were obtained by summarizing lands that were kept in production during 12 years. A five-year moving window (8 windows from 2001 to 2012) was applied to track spatial patterns of such intensification.

3.3. Characterizing physical factors

To evaluate the impacts of implementation of 2005/2007 biofuel policies upon long-term sustainability of agricultural land use, we associated land use (re)distribution with land quality and investigated the utilization of lands that have been under the CRP.

Firstly, we used slope, land capability class and CSR to determine whether higher corn prices may have encouraged farmers to use land that is not suited for production. Topographic slope values were extracted from USGS NED 30 m DEM. Land capability class values and CSR values were obtained from 10 m gSSURGO Database and they were resampled to 30 m using the majority class value of 3×3 matrixes to represent each new pixel value. Land capability classification shows the suitability of soils for most kinds of field crops which is based on landscape location, slope of the field, depth, texture, and reaction of the soil (Douglas, 1992). It includes eight classes — classes 1 to 4 are arable lands in which classes 3 and 4 have severe to very severe limitations, respectively, and classes 5 to 8 are suitable mainly as pasture or rangeland. The CSR is a standard index of soil suitability for row crop production developed by the Iowa State University Extension (Miller, 2012). This index is based on soil type, slope, drainage, weather, and frequency of use for row crop production. The CSR varies from 0 to 100, where 100 is ideal soil and climate for corn production. CSR for high productivity lands typically exceeds 80, and for low productivity lands generally remains under 65. We computed and compared the percentages of planted corn/soybeans in areas where the CSR was above and below 65 prior to and after the implementation of 2005/2007 biofuel policies.

Secondly, we used county-level CRP statistics to determine CRP change pattern during 12 years. This data does not specify the land cover for CRP land as the great majority of CRP land in Iowa is covered with grasses (USDA Farm Service Agency, 2007). We then used the 2008 CRP shapefile data to determine overlap with lands planted with corn or other crops to identify weather CRP lands were used in production after the widespread of biofuel production. For our study area, the shapefile has 33,327 polygons covering 223,422 acres. Many of the areas that are set aside for CRP land are wetlands or drainage-ways and therefore are frequently small and irregular in shape. In order to remove these lands from the analysis, any polygons with areas <15 acres were excluded. Those remaining were intersected with the 2009 CDL to estimate an amount of 2008 CRP land converted to corn cultivation in 2009.

3.4. Determination of crop rotation patterns

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 (Bain and Selfa, 2013; Sahajpal et al., 2014; Stern et al., 2012). Alternatively, some crop producers have chosen to plant corn or soybeans in the same field for two or more than two consecutive years. For the purpose of this study, CDLs were combined in two ways to determine changes in crop rotation before and after the widespread increases in biofuel production. First, areas with corn for three consecutive years from 2001 to 2012 were measured using conditional statements. A binary classification was created where pixels classified as corn were labeled 1 and other land cover types were labeled 0. Three years were added sequentially and pixels with 3 were considered as continuous corn rotation. Second, we analyzed crop rotation patterns for corn and soybeans over six-year intervals (2002–2007 and 2007–2012), which will give us 64 possible permutations. Except for the standard crop rotation, two or more years of continuous corn provide several choices of rotation sequences. Continuous soybean rotation is not a common occurrence in Iowa (Secchi et al., 2011) because growing soybeans year-after-year in the same field creates serious problems with soybean nematodes which have negative effects on soybean yield (Koenning et al., 1995). For a six-year period, we classified all the possible rotation choices into 5 classes by the number of years with corn: corn-soybean/soybean-corn, corn-corn-soybean/soybean-corn-corn, continuous corn, more than three years of continuous corn, and other which includes two or more years of continuous soybean.

4. Results

4.1. Intensity of cultivated land

Using a five-year moving window, production trends can be analyzed. Over five years, the area in summer crop cultivation for both more than two years and more than three years increased in the period from 2001 to 2012 (Fig. 2). These trends corresponded to price trends for corn and soybeans based on NASS statistics. From 2001 to 2012, both corn and soybean prices increased from 2009, reaching a maximum in 2012, with, at the state level, other peaks in 2003 and 2007 (USDA National Agricultural Statistics Service, 2014). These 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).

Summer crops were cultivated in a way that illustrates place-to-place differences in timing and intensity of land uses (Fig. 3). Most areas were planted with continuous summer crops, but fragmented terrain bordering rivers and valleys were used less intensively, perhaps because floodplains may be narrow, have steep slopes, or problematic soils. Areas at edges of fields, known as *headlands*, or *turnrows* (narrow, uncropped, strips for turning farm machinery at the ends of rows), were often uncultivated or used less intensively. Together, such conditions may lead these areas to be used for secondary crops, grasslands, or pastures.

At county level, Benton County had the smallest proportion of area (10.21%), used only for 1 to 3 years while Keokuk County had the most proportion of such areas (27.07%). Cedar County had the most proportion of areas (67.87%) that were used for 11 or 12 years while Keokuk County had the least proportion of such areas (41.86%).

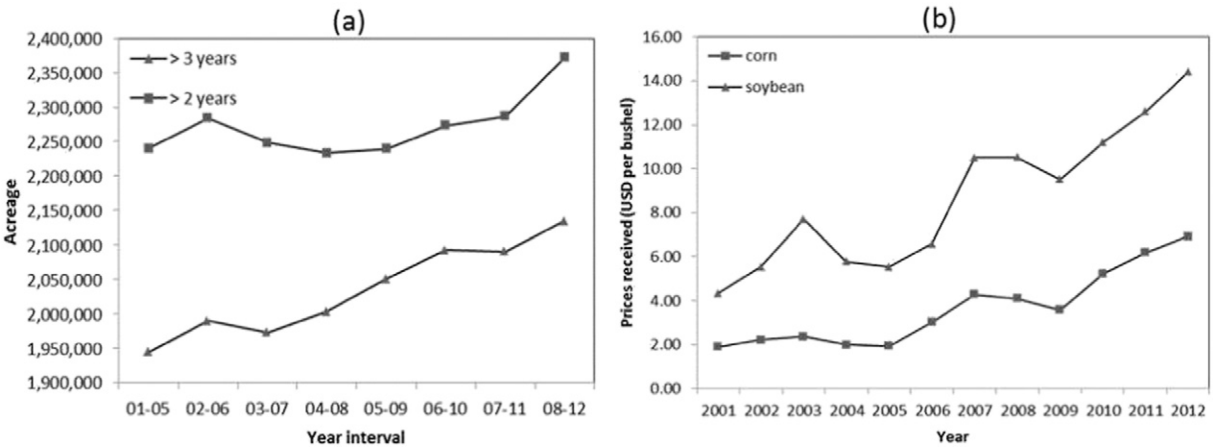

Fig. 2. Left: total acres of summer crops by a five-year moving window from 2001 to 2012 in the study area. Lines with black squares indicates more than two years within five years of summer crops, and lines with black triangles indicate more than three years within five years with summer crop within a five-year window. Right: prices in US dollars (USD) for corn and soybean in Iowa, 2001–2012.

4.2. Cropland redistribution and land suitability

Slope values for areas with different cultivated land intensity within the study area were compared. Land with shallow slopes was used more intensely (Fig. 4). The most intensively used land (11 or 12 years with summer crop) had slopes of less than six degrees, 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 <0.01% outliers (black crosses in Fig. 4), most located at edges of fields. Some had extremely high slopes which are impossible for cultivation, perhaps labeled by misclassification.

Capability class values for areas with different cultivated land intensities in the study area were compared (Fig. 5). The smaller the class value designation, the fewer limitations for cultivation. The majority of lands (above 82%) in the study area are arable, within which 56% have few limitations. As land intensity (measured by numbers of years in cultivation) increased, more land with fewer limitations was brought in cultivation (Fig. 5). Thirty-five percent (35%) of the least intensively

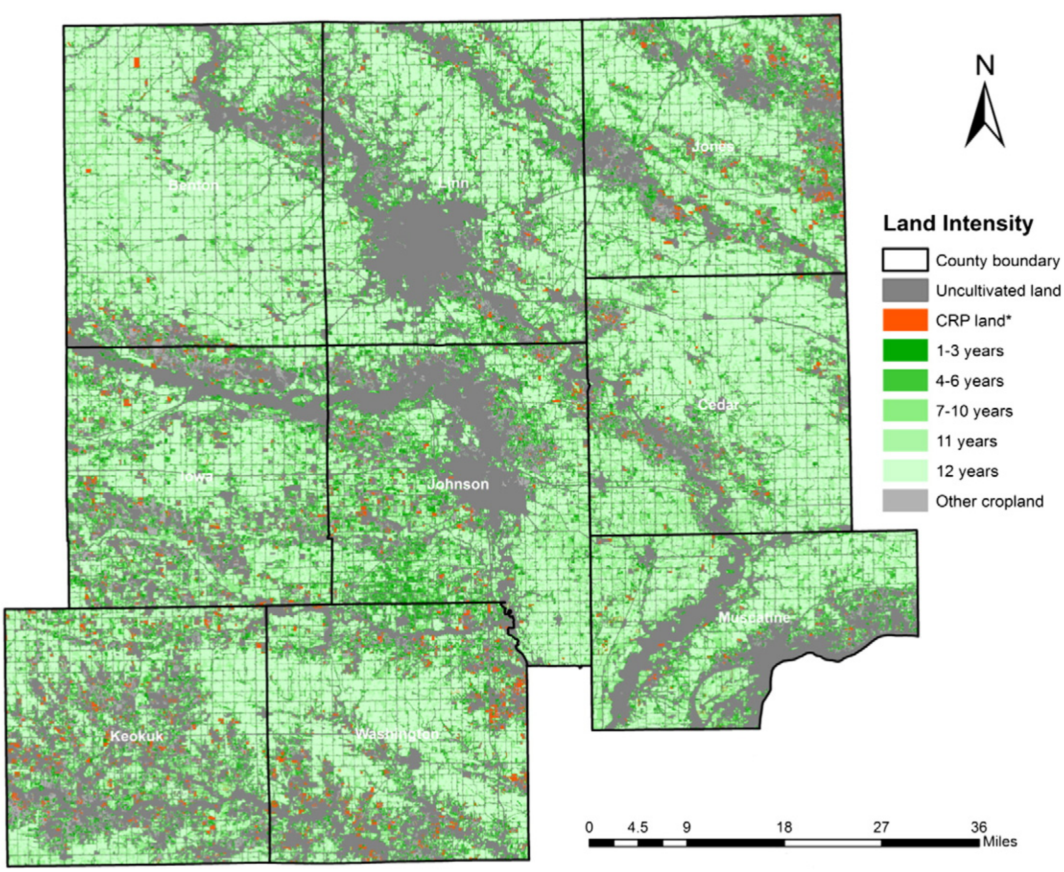

Fig. 3. Cultivated land intensity class from 2001 to 2012 in the study area, the lighter the color, the more intensively the land in cultivation. CRP land is only for 2008.

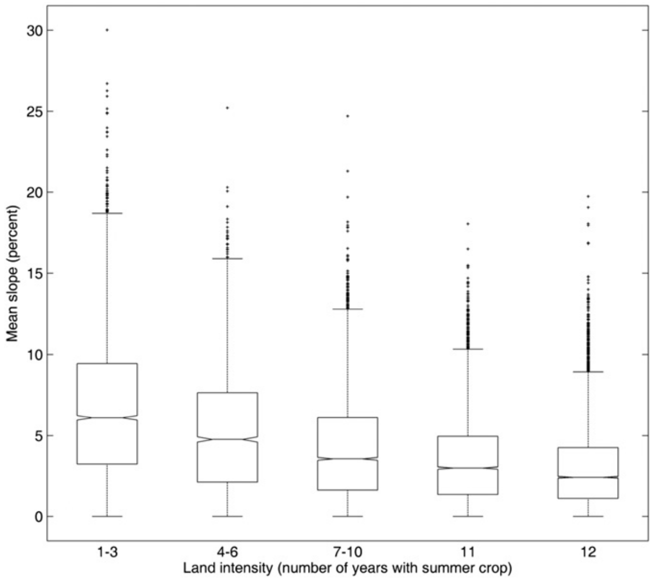

Fig. 4. Relationships between cultivated land intensity and terrain slope (percent slope) within the study area. Lands with shallower slopes are used more intensely. Black crosses represent outliers (they are few in number relative to the totals, almost all located at edges of fields). In the box plot, an outlier is a value that is >1.5 times the interquartile range away from the top or bottom of the box.

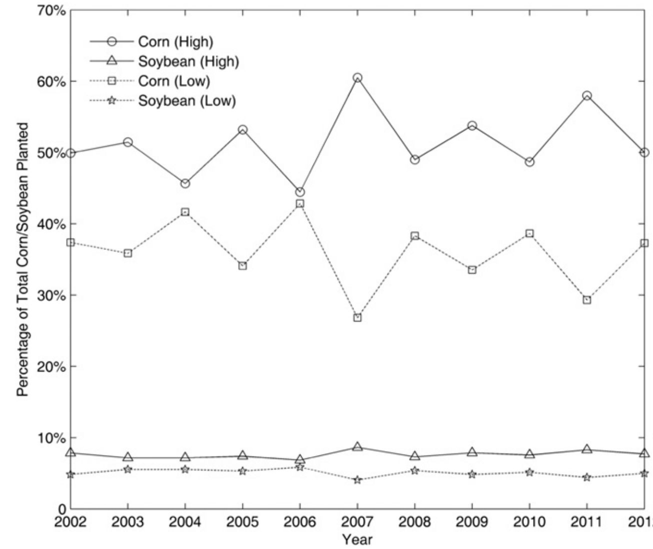

Fig. 6. The percent of corn and soybeans on high (CSR > 65) and low (CSR < 65) CSR soil for 2002 to 2012. The percentage of total corn-planted land on high CSR soil increased from 2002 to 2007, and then fluctuated; while the percentage of total soybean-planted land on high CSR soil decreased from 2002 to 2007, and then fluctuated thereafter. During the same time, area both under corn and soybeans planted in low CSR soils remained constant.

used land (1–3 years with summer crops) had fewer limitations while above 63% most intensively used land (11 or 12 years with summer crop) had fewer limitations.

The quality of agricultural land in Iowa is often assessed using CSR for a given type of soil (Miller, 2012). Lands with CSR higher than 65 are generally considered as highly productive lands. The percentage of total corn planted land on high CSR soil increased from 50% in 2000 to 60% in 2007. Since 2007, the percentage of corn on high CSR soil has fluctuated and returned to 50% in 2012. In contrast, the percentage of total soybeans planted land on high CSR soil decreased from 37% in 2000 to 27% in 2007, but has fluctuated and back up to 37% in 2012 (Fig. 6). At the same time, both area under corn and soybeans planted in low CSR soil remained constant, with about 0.7% increase for corn and about 0.7% decrease for soybeans from 2000 to 2007. These data provide evidence that the most productive lands were used the most intensively (Fig. 7) and were allocated to grow corn (Fig. 6). During the interval 2006 to 2007, more and more corn was placed on high-quality soils whereas soybeans were removed from high quality soils. Major corn acreage gains were generally at the expense of soybeans. At the same time, the increasing percentage of corn on low quality soils suggest that expansion of lands used for planting corn also occurred at the expense of other land cover types, such as grasslands (Wright and Wimberly, 2013) and wetlands (Johnston, 2013).

USDA stated that CRP has shifted from designating entire fields for conservation purposes towards the alternative of implementing high-priority “buffer” practices (e.g., filter strips, grassed waterways) that support working lands by reducing the environmental implications of on-going agricultural production (USDA National Agricultural

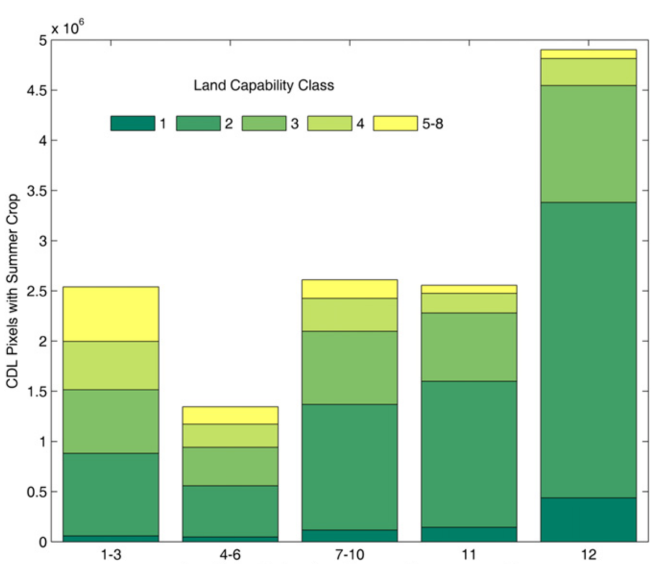

Fig. 5. Relationships between cultivated land intensity and land capability class within the study area. The most intensively used lands tend to have fewer limitations (capability classes 1 and 2).

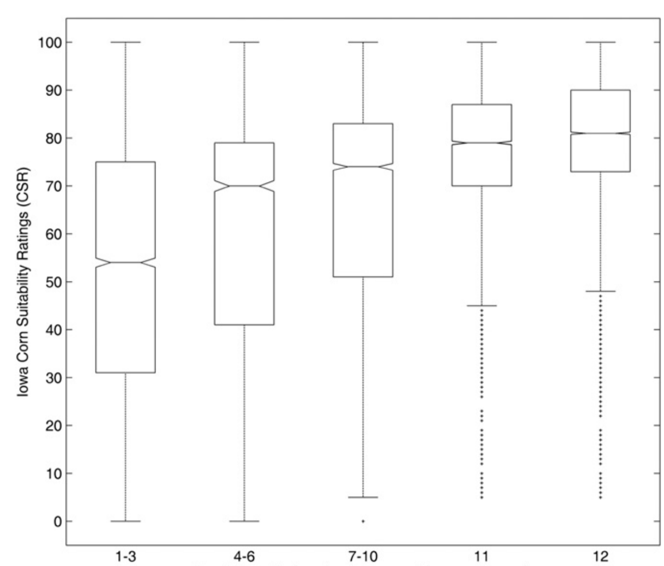

Fig. 7. Relationship between cultivated land intensity and Corn Suitability Rating in the study area. Lands with high CSR soil are used more intensely. Black crosses represent outliers.

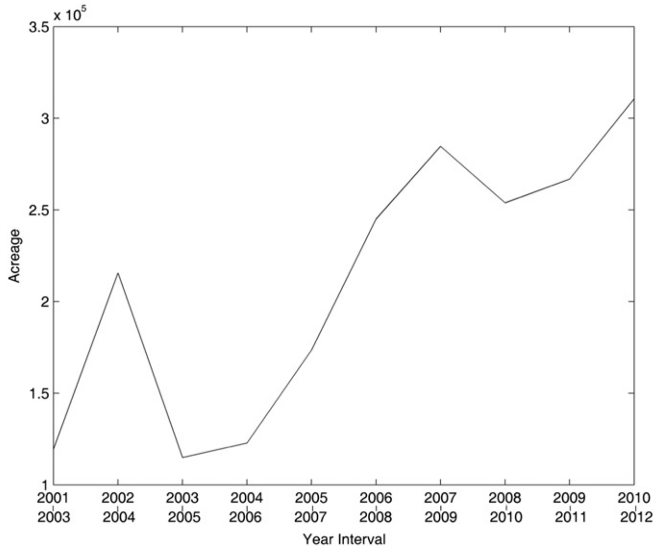

Fig. 8. Acreage of three-year consecutive plantings of corn in the study area.

Statistics Service, 2006). CRP statistics show that in 2007 the total amount of area under CRP remained high. CRP land dynamics depend on enrollment and re-enrollment cycles set by a 10–15 year contract that commits CRP status until the expiration date. This 10-year cycle resulted in over 16 million acres enrolled in 1997, potentially expiring in 2007 (Stubbs, 2014). Thus, there were very few CRP contract expirations before the widespread increases in biofuel production. Since 2007, CRP enrollment declined sharply, especially for Iowa County and Keokuk County (USDA Farm Service Agency, 2014). This trend indicates that producers may be allowing their contracts to expire in favor of using productive land for crops. Econometric models also predict that landowners will be likely to withdraw some land from expiring CRP contracts and put the land back into crop production within the high-priced commodity market (Hellerstein and Malcolm, 2011; Secchi et al., 2009).

With spatial data analysis, total amount of CRP land classified as corn in 2009 was extremely small: in 2009 only about 4200 acres of cornfield were in 2008 CRP areas. This area is not significantly large, as it represents only 2% of the total CRP acreage in the study area and could be a result of misclassification. According to 2007 FSA (USDA Farm Service Agency, 2007), only about 2% of corn and soybean farms in 2008 brought CRP acreage into production between 2006 and 2008. It is very difficult to appropriately attribute certain CRP lands to particular land cover types because of differences in the spatial resolution of CRP data in comparison to CDL data. Thus, there is no indication that widespread increases in biofuel production have had a particularly negative effect on the CRP program. Given the tendency to plant more corn on higher quality soils that we mentioned earlier, it is unlikely that CRP lands would be used for corn production.

4.3. Crop rotation

NASS's Prospective Plantings (USDA Agricultural Statistics Board, 2007) report indicated that much of the 2007 increase in corn acreage would come from reduced soybean plantings. Based on our crop rotation analysis over three-year intervals, more crop producers chose to plant corn for three consecutive years in the year of 2007 (Fig. 8). As mentioned earlier (Fig. 2a), corn prices were high in 2003, 2007 and

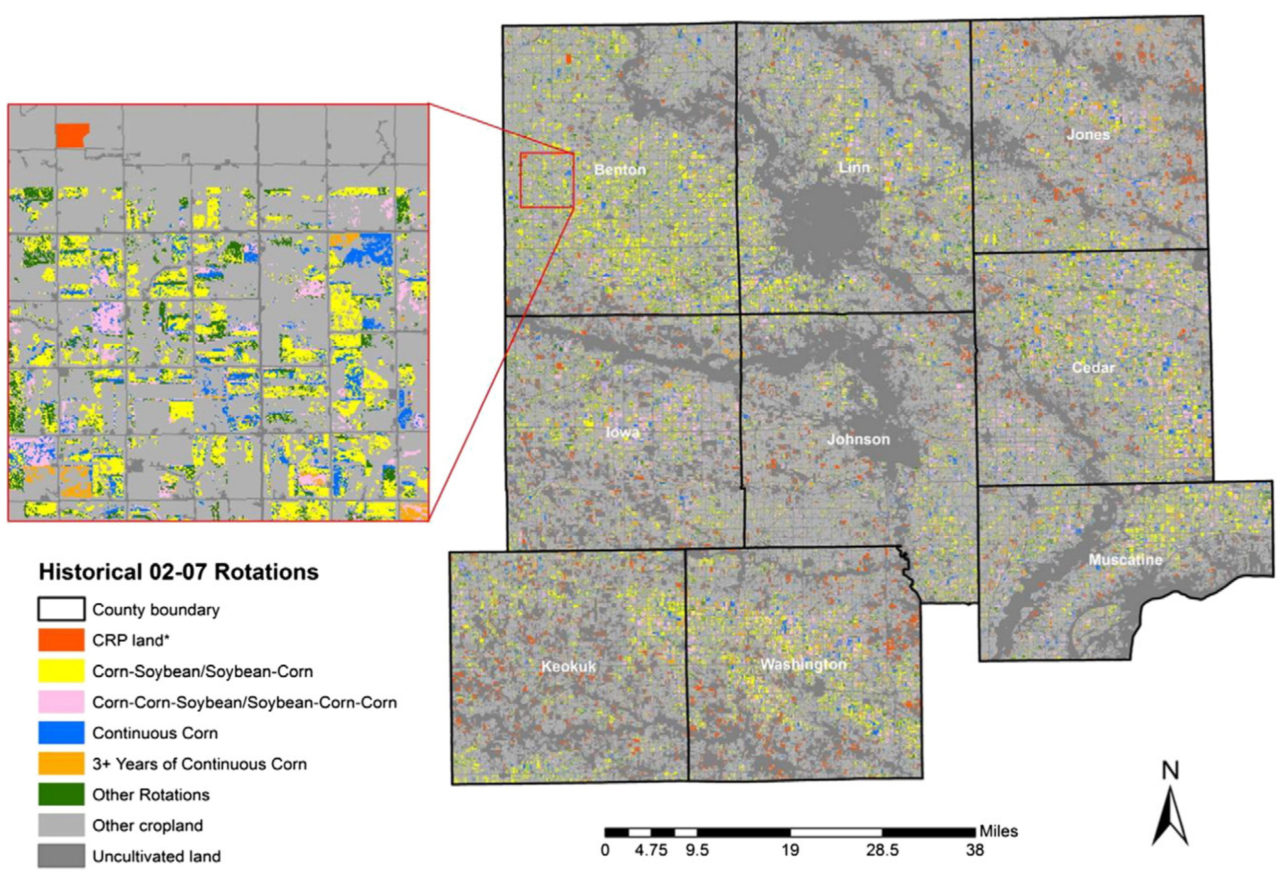

Fig. 9. Location of 2002–2007 crop rotations in the study area. Rotation types include standard rotation (either corn-soybean or soybean-corn), two years of continuous corn, three years of continuous corn, more than three years of continuous corn, and other rotation including two or more years of continuous soybeans, along with 2008 CRP land.

after 2009, thus, producers preferred to plant corn in that year and the following year (Wallander et al., 2011).

All 64 possible permutations of corn and soybean rotations were recorded before 2007 but only half of them were used after 2007. Crop producers 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) (Fig. 9). These lands were located in the most intensively used lands. Two years of continuous corn was another common occurrence during this period. Both lands with more than three years continuous corn and lands with two or more years of continuous soybeans were <10%. During the 2007–2012 periods, standard rotation was replaced by more intensive rotation, such as continuous corn or soybeans for two years, or even longer (Fig. 10). Two or more years of continuous soybeans also became a common occurrence. Despite its negative effects on soybean yield (Koenning et al., 1995), this kind of rotation was likely selected because of high soybean prices or perhaps there is classification error within the CDLs. During this period, area under corn-corn rotations decreased, while area under three and more years of continuous corn and area under two or more years of continuous soybeans increased. Our results are inconsistent with the rotation change patterns reported in the central US for four-year intervals (2003–2006 and 2007–2010), where area under corn-soybean rotations decreased, and area under corn-corn rotations increased (Plourde et al., 2013). One explanation might be that we used six-year intervals, so crop rotation patterns for two or more years of continuous corn during the 2007–2012 periods were determined by the first four years after 2007 — >80% of such rotations were during the 2007–2010 periods. After 2010, the standard rotation pattern appeared again.

Table 1 shows conversion between different crop rotation patterns before and after 2007. Standard rotation in the 2002–2007 interval was mainly replaced by three years of continuous corn rotation and intensive soybean rotation. Two years of continuous corn rotation was mainly replaced by three years of continuous corn rotation and intensive soybean rotation and three years of continuous corn rotation was mainly replaced by more than two years of continuous corn rotation. More than 50% of lands with more than three years of continuous corn rotation, and intensive soybean rotation were unchanged.

It is obvious that crop rotation changed after 2007 (Fig. 11). 59.11% of standard rotation was changed to more two or more years of continuous corn, and 40.89% of standard rotation was changed to two or more years of continuous soybeans. Lands with two or more years of continuous corn were more abundant than lands with two or more years of continuous soybeans. These results clearly indicate that increases in corn production over multiple years have been achieved mainly by altering crop rotation.

Table 1
Confusion matrix of crop rotation patterns in 2002–2007 and 2007–2012 interval in the study area. SR is standard rotation (either corn-soybean or soybean-corn), 2 Y CC is two years of continuous corn rotation, 3 Y CC is three years of continuous corn rotation, 3 + Y CC is more than three years of continuous corn rotation, and OR is other rotation including two and more years of continuous soybeans.

		07–12					
		SR	2Y CC	3Y CC	3 + Y CC	OR	
02–07	SR	0	121,924	412,817	167,398	401,136	1,103,275
	2Y CC	0	108,066	104,936	272,762	239,401	725,165
	3Y CC	0	53,701	207,233	195,248	107,436	563,618
	3 + Y CC	0	26,245	49,754	166,174	47,379	289,552
	OR	0	21,882	50,488	65,799	237,338	375,507
		0	331,818	825,228	867,381	1,032,690	

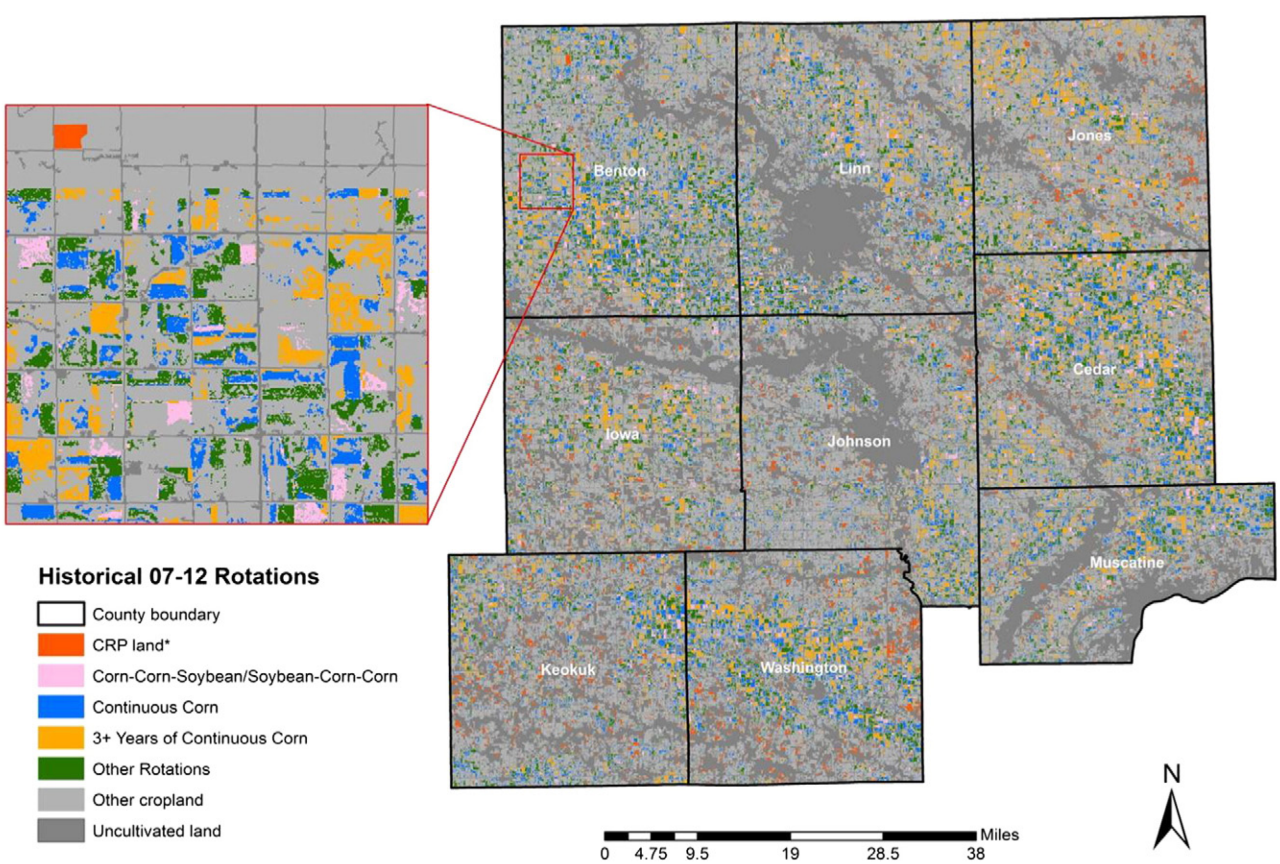

Fig. 10. Location of 2007–2012 crop rotations in the study area. Rotation types include two years of continuous corn, three years of continuous corn, more than three years of continuous corn, and other rotation including two or more years of continuous soybeans, along with 2008 CRP land.

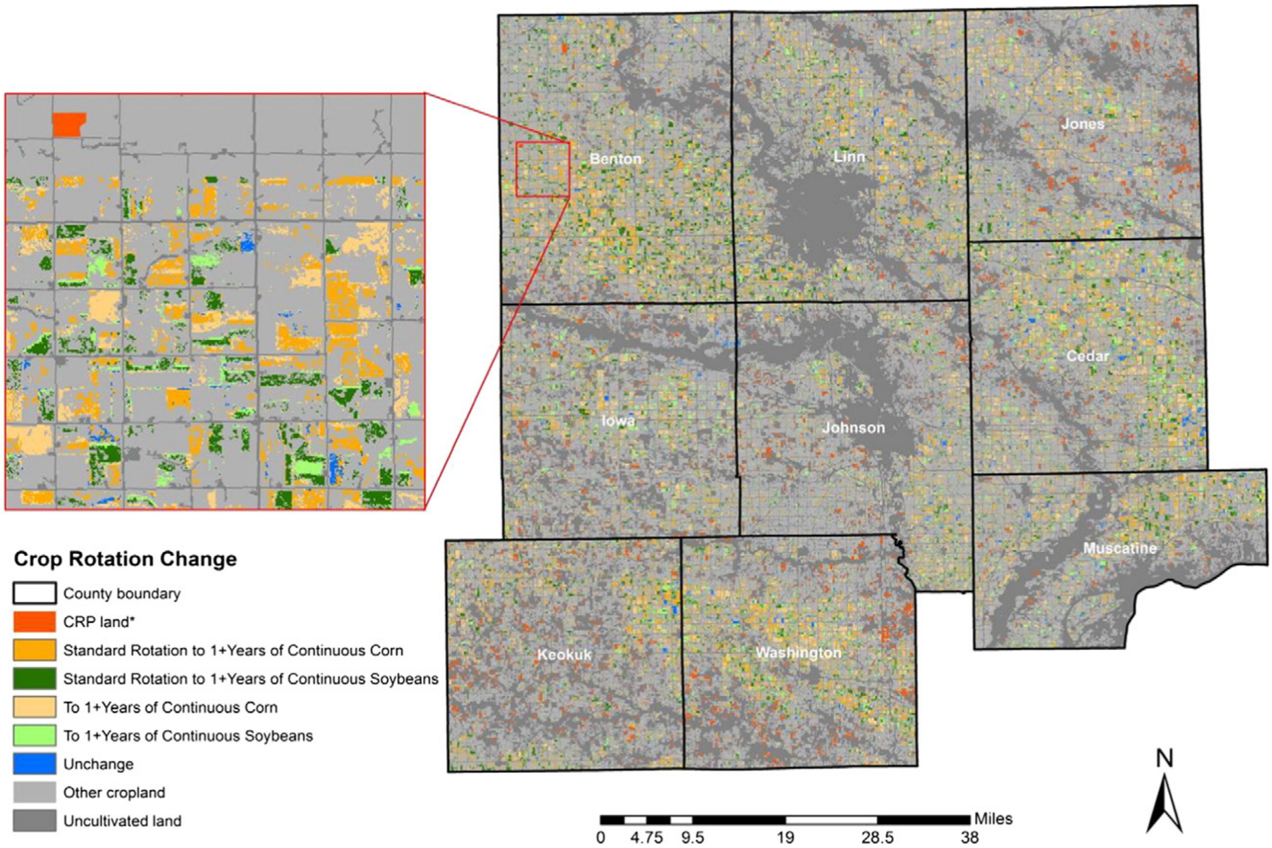

Fig. 11. Location of crop rotation changes and 2008 CRP land in the study area. Rotation change types include standard rotation to two and more years of continuous corn, standard rotations to two and more years of continuous soybeans, other rotation to two and more years of continuous corn, and other rotations to two and more years of continuous soybeans.

5. Discussions

This study examines both spatial and temporal dimensions of agricultural land use dynamics using NASS CDLs. According to the Iowa's CDL metadata, most of the producer's accuracies and user's accuracies (starting in 2007) for corn and soybeans for each year are above 90% (Table 2). When compared to the county-level, survey-based planted acreage data for corn and soybeans for each year (USDA National Agricultural Statistics Service), CDLs underestimate corn and soybeans acreage in most years (Table 3). Large differences occur in 2001 (for corn), 2002 (for soybeans), 2003 (for soybeans), and 2007 (for corn and soybeans). The uncertainty caused by misclassification would influence the patterns of total acreage of summer crops within a five-year moving window and land intensity. For example, more land was actually used for summer crops production than CDLs estimates in the 2003–2007 moving window, thus, the total acreage of more than two/three years within five years of summer crops should be larger than the values based on CDLs estimates (Fig. 2a). Crop rotation patterns for corn and soybeans over six-year intervals based on these data would be more accurate as the differences have fewer impacts for longer periods.

In order to measure effects of ethanol plants on land use choices, we calculated land use change from 2004 to 2010 within a 10-mile radius of each ethanol plant. According to the interview response from some farmers in Iowa, farmers would like to sell their corn products directly to ethanol plants if the ethanol plants are not far away (i.e., around 10 min driving). Thus, a 10-mile radius is reasonable for our analysis. We first calculated corn acreage and soybean acreage for each year within a 10-mile radius of each ethanol plant. We found that compared

Table 2
Producer's accuracy (Prod.Acc.) and user's accuracy (User Acc.) for corn and soybeans, and overall accuracy (Overall Acc.) by year for the Iowa Cropland Data Layer (CDL).

	Corn		Soybeans		
	Prod.Acc.	User Acc.	Prod.Acc.	User Acc.	Overall Acc.
2001	89.6%	NA	91.0%	NA	81.3%
2002	96.3%	NA	95.0%	NA	88.6%
2003	92.5%	NA	93.0%	NA	88.5%
2004	97.4%	NA	98.7%	NA	93.2%
2005	94.0%	NA	95.4%	NA	88.0%
2006	87.5%	NA	86.9%	NA	83.2%
2007	97.5%	97.6%	97.0%	96.7%	97.2%
2008	96.6%	97.9%	96.2%	95.8%	95.7%
2009	97.9%	98.1%	97.0%	97.7%	95.5%
2010	96.6%	97.6%	95.8%	97.3%	93.2%
2011	98.3%	98.4%	97.4%	97.8%	94.3%
2012	96.6%	98.3%	95.6%	97.0%	93.6%

NA: User's accuracies are not provided in CDL metadata from 2001 to 2006.

Table 3
Total acreage for corn and soybeans based on Cropland Data Layers (CDLs) and USDA National Agricultural Statistics Service (NASS) Acreage data, and the differences between these two datasets, 2001–2012.

	Corn			Soybeans		
	CDL (acre)	Survey (acre)	Diff	CDL (acre)	Survey (acre)	Diff
2001	892,279	1,056,000	−16%	953,263	962,000	−1%
2002	1,203,476	1,112,500	8%	694,836	920,000	−24%
2003	1,143,077	1,133,500	1%	785,676	933,000	−16%
2004	1,118,461	1,165,000	−4%	908,376	897,500	1%
2005	1,053,451	1,158,000	−9%	831,540	884,500	−6%
2006	1,078,191	1,125,000	−4%	898,897	906,500	−1%
2007	1,161,047	1,317,000	−12%	634,356	733,500	−14%
2008	1,149,874	1,213,000	−5%	780,460	838,200	−7%
2009	1,159,278	1,243,000	−7%	820,395	851,500	−4%
2010	1,253,974	1,237,500	1%	819,436	860,200	−5%
2011	1,263,732	1,304,500	−3%	780,382	818,900	−5%
2012	1,182,490	1,283,000	−8%	776,598	844,900	−8%

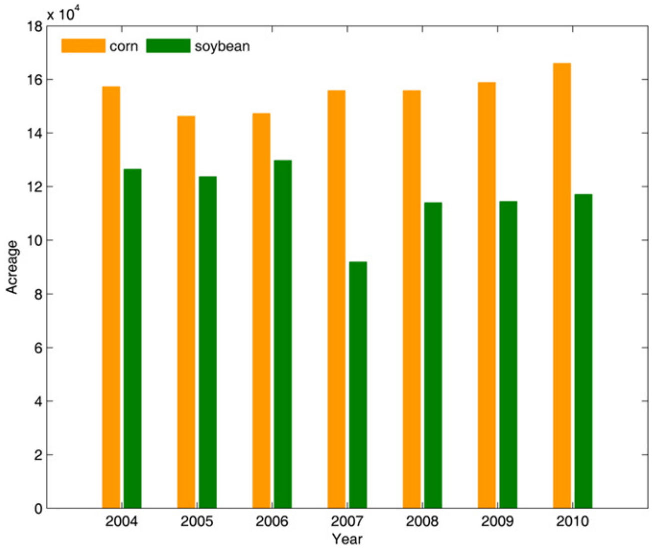

Fig. 12. Acreage of area planted in corn and soybeans within a 10-mile radius of each ethanol plant, 2004–2010.

to 2006, corn acreage in 2007 increased by 6% while soybean acreage decreased by 29%, and the total summer crop decreased by 11% (Fig. 12). In 2007, more land was used for corn production and expansion of corn acreage may result from a reduction in soybean acreage. After 2007, corn acreage increased steadily and soybean acreage increased to a stable level. We than examined three crop rotation patterns for corn and soybeans over three-year intervals (i.e., standard corn-soybean/soybean-corn, two years of continuous corn, and continuous corn) within a 10-mile radius of each ethanol plant. We found that land under standard corn-soybean/soybean-corn rotation increased constantly, land under two years of continuous corn rotation reached its highest level in 2006–2008, and land under continuous corn rotation reached its highest level in 2007–2009 (Fig. 13). The expansion of corn acreage after 2007 was also realized by altering crop rotation patterns to more intensive corn rotation.

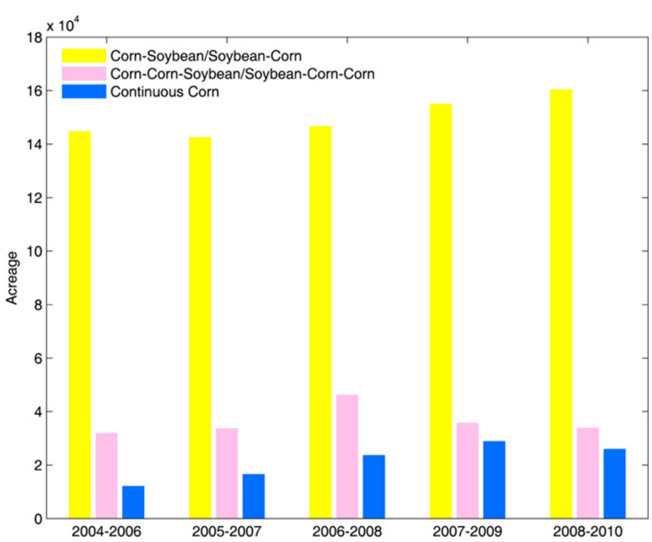

Fig. 13. Three-year period with acreage of area planted in standard corn-soybean/soybean-corn, two years of continuous corn, and continuous corn within a 10-mile radius of each ethanol plant, 2004–2010.

6. Conclusions

This study examines both spatial and temporal dimensions of agricultural land use dynamics 2001–2012 in east-central Iowa, based upon analysis of sequential CDLs. This interval includes the years immediately preceding and immediately following changes in US biofuel policy, which has resulted in notable changes in the region's agricultural land use. Agricultural producers can respond to demands or incentives for increased production either through land extensification or land intensification.

From 2001 to 2012, biofuel production has increased in Iowa. As biofuel production increased, demand for corn and its market price have increased, likely leading to changes in land-use intensity and changes in crop rotation. Corn acreage growth occurred generally at the expense of soybeans, other crops, and grasslands. As recorded by NASS CDLs, after 2007, cultivated acreage increased, and standard crop rotation was changed to more intensive series of corn or soybeans plant, on a pixel-by-pixel basis. In addition, area used for both corn cultivation and soybeans cultivation increased. The most intensively cultivated land had shallower slopes and fewer pedologic limitations than others, and the most valuable crop (corn) was planted on the most suitable soils. CRP lands were brought into cultivation since 2007, but they may be used for other crops displaced by corn because they are usually unsuitable for corn production. From our analysis, it is clear that the expansion of corn production after 2007 was realized by altering crop rotation patterns.

References

Bain, C., Selfa, T., 2013. Framing and reframing the environmental risks and economic benefits of ethanol production in Iowa. Agric. Hum. Values 30 (2013), 351–364. http://dx.doi.org/10.1007/s10460-012-9401-y.

Brown, J.C., Hanley, E., Bergtold, J., Caldas, M., Barve, V., Peterson, D., ... Earnhart, D., 2014. Ethanol plant location and intensification vs. extensification of corn cropping in Kansas. Appl. Geogr. 53, 141–148. http://dx.doi.org/10.1016/j.apgeog.2014.05.021.

Douglas, H., 1992. Readings in the History of the Soil Conservation Service.

Gallagher, P., Wisner, R., Brubacker, H., 2005. Price relationships in processors' input market areas: testing theories for corn prices near ethanol plants. Can. J. Agric. Econ. 53 (2–3), 117–139. http://dx.doi.org/10.1111/j.1744-7976.2005.00414.x.

Hellerstein, D., Malcolm, S., 2011. The Influence of Rising Commodity Prices on the Conservation Reserve Program.

Iowa Department of Natural Resources, 2007. Ethanol and Biodiesel Facilities in Iowa Retrieved from ftp://ftp.igsb.uiowa.edu/gis_library/ia_state/infrastructure/facilities/ethanol_biodiesel_facilities.zip.

Johnston, C.A., 2013. Wetland losses due to row crop expansion in the Dakota Prairie Pothole Region. Wetlands 33 (1), 175–182. http://dx.doi.org/10.1007/s13157-012-0365-x.

Johnston, C.A., 2014. Agricultural expansion: land use shell game in the US Northern Plains. Landsc. Ecol. 29 (1), 81–95.

Keeney, R., Hertel, T.W., 2009. The indirect land use impacts of United States biofuel policies: the importance of acreage, yield, and bilateral trade responses. Am. J. Agric. Econ. 91 (November), 895–909. http://dx.doi.org/10.1111/j.1467-8276.2009.01308.x.

Koenning, S.R., Schmitt, D.P., Barker, K.R., Gumpertz, M.L., 1995. Impact of crop rotation and tillage system on *Heterodera glycines* population density and soybean yield. Plant Dis. 79 (3), 282–286.

Langpap, C., Wu, J., 2011. Potential environmental impacts of increased reliance on corn-based bioenergy. Environ. Resour. Econ. 49, 147–171. http://dx.doi.org/10.1007/s10640-010-9428-8.

Miao, R., 2010. The Land-use Change Effect of Ethanol Plants in Iowa: 1997–2009. p. 22 (Retrieved from http://www.aeaweb.org/aea/2011conference/program/retrieve.php?pdfid=506).

Miller, G., 2012. Corn suitability ratings — an index to soil productivity. Staff General Research Papers. Iowa State University, Department of Agronomy.

Miyake, S., Renouf, M., Peterson, A., McAlpine, C., Smith, C., 2012. Land-use and environmental pressures resulting from current and future bioenergy crop expansion: a review. J. Rural. Stud. 28 (4), 650–658. http://dx.doi.org/10.1016/j.jrurstud.2012.09.002.

Mueller, S., Copenhaver, K., 2009. Determining the Land Use Impact of Two Midwestern Corn Ethanol Plants.

Petrov, A.N., Sugumaran, R., 2005. Monitoring and modeling cropland loss in rapidly growing urban and depopulating rural counties using remotely sensed data and GIS. Geocarto Int. 20 (4), 45–52. http://dx.doi.org/10.1080/10106040508542363.

Plourde, J.D., Pijanowski, B.C., Pekin, B.K., 2013. Evidence for increased monoculture cropping in the Central United States. Agric. Ecosyst. Environ. 165, 50–59. http://dx.doi.org/10.1016/j.agee.2012.11.011.

Prior, J.C., 1991. Landforms of Iowa. Iowa City, IA.

Renewable Fuels Association, 2013. Annual industry outlook. Retrieved from http://www.ethanolrfa.org/pages/annual-industry-outlook.

Sahajpal, R., Zhang, X., Izaurralde, R.C., Gelfand, I., Hurtt, G.C., 2014. Identifying representative crop rotation patterns and grassland loss in the US Western Corn Belt. Comput. Electron. Agric. 108, 173–182. http://dx.doi.org/10.1016/j.compag.2014.08.005.
Secchi, S., Gassman, P.W., Williams, J.R., Babcock, B.a., 2009. Corn-based ethanol production and environmental quality: a case of Iowa and the conservation reserve program. Environ. Manag. 44 (4), 732–744. http://dx.doi.org/10.1007/s00267-009-9365-x.
Secchi, S., Kurkalova, L., Gassman, P.W., Hart, C., 2011. Land use change in a biofuels hotspot: the case of Iowa, USA. Biomass Bioenergy 35 (6), 2391–2400. http://dx.doi.org/10.1016/j.biombioe.2010.08.047.
Simpson, T.W., Sharpley, A.N., Howarth, R.W., Paerl, H.W., Mankin, K.R., 2006. The new gold rush: fueling ethanol production while protecting water quality. J. Environ. Qual. 37, 318–324. http://dx.doi.org/10.2134/jeq2007.0599.
Stan, V., Fîntîneru, G., Ion, V., 2014. Increase of biofuel crop production in Romania over the last decades - possible impacts on environment, greenhouse gas emissions and land use. Notulae Bot. Horti Agrobot. Cluj-Napoca 42 (2), 325–332. http://dx.doi.org/10.1583/nbha4229740.
Stern, A.J., Doraiswamy, P.C., Hunt, E.R., 2012. Changes of crop rotation in Iowa determined from the United States Department of Agriculture, National Agricultural Statistics Service cropland data layer product data layer product. J. Appl. Remote. Sens. 6 (1), 063590. http://dx.doi.org/10.1117/1.JRS.
Stubbs, M., 2014. Conservation Reserve Program (CRP): Status and Issues.
Swinton, S.M., Babcock, B.a., James, L.K., Bandaru, V., 2011. Higher US crop prices trigger little area expansion so marginal land for biofuel crops is limited. Energ Policy 39 (9), 5254–5258. http://dx.doi.org/10.1016/j.enpol.2011.05.039.
USDA Agricultural Statistics Board, 2007. Prospective Plantings. vol. 4. Washington, D.C., pp. 1–34.
USDA Farm Service Agency, 2007. The conservation reserve program: summary and enrollment statistics 2007. Retrieved from http://www.fsa.usda.gov/Internet/FSA_File/annual_consv_2007.pdf.
USDA Farm Service Agency, 2014. CRP enrollment and rental payments by county, 1986–2013. Retrieved from www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp-st.
USDA National Agricultural Statistics Service, 2006. 2007 Farm Bill Theme Papers: Conservation and the Environment.
USDA National Agricultural Statistics Service, 2014. Agricultural prices via quick stats. Retrieved from http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1002.
Wallander, S., Claassen, R., Nickerson, C., 2011. The ethanol decade: an expansion of U.S. corn production, 2000–09. Retrieved from http://www.ers.usda.gov/media/121204/eib79.pdf.
Westcott, P., 2007. Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust? p. 20 (Washington DC. Retrieved from http://www.ers.usda.gov/publications/AboutPDF.htm)
Wright, C.K., Wimberly, M.C., 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proc. Natl. Acad. Sci. U. S. A. 110 (10), 4134–4139. http://dx.doi.org/10.1073/pnas.1215404110.
Wu, Y., Liu, S., Li, Z., 2012. Identifying potential areas for biofuel production and evaluating the environmental effects: A case study of the James River Basin in the Midwestern United States. GCB Bioenergy 4, 875–888. http://dx.doi.org/10.1111/j.1757-1707.2012.01164.x.