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Land Use Change and Policy in Iowa's Loess Hills

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Abstract

Land use changes have important implications on ecosystems and society. Detailed identification of the nature of land use changes in any local region is critical for policy design. In this paper, we quantify land use change in Iowa's Loess Hills ecoregion, which contains much of the state's remaining prairie grasslands. We employ two distinct panel datasets, the National Resource Inventory data and multi-year Cropland Data Layers, that allow us to characterize spatially-explicit land use change in the region over the period 1982-2010. We analyze land use trends, land use transitions and crop rotations within the ecoregion, and contrast these with county and state-level changes. To better comprehend the underlying land use changes, we evaluate our land use characterizing metrics conditional on soil quality variables such as slope and erodibility. We also consider the role of contemporary agricultural policy and commodity markets to seek explanations for land use changes during the period of our study. Although crop production has expanded on the Loess Hills landform since 2005, much of the expansion in corn acres has been from reduced soybean acreage. We find that out of the total 258 km^2 increase in corn acreage during 2005-'10, about 100 km^2 transitioned from soybeans. Data also indicate intensifying monoculture with higher percentage of corn plantings for two to four consecutive years during 2000-'10. In addition, crop production is found to have moved away from more heavily sloped land. Cropping does not appear to have increased on lands with higher crop productivity.

Keywords: agro-environmental policy, land use change, land quality, erodibility, monoculture, crop rotations

1. Introduction

This paper seeks to describe land use change in the Iowa Loess Hills landform (ILHL). The Missouri Valley's Loess Hills (figure 1) are comprised of wind-deposited silt hills just east of the Missouri River in Southeast Iowa and Northeast Missouri. Cut through by river tributaries and generally steepest on the west side, hill elevation seldom exceeds 259 feet above the river plain (Note 1). No wider than 15 miles, the landform extends about 320 km from Plymouth County, IA, south through Woodbury, Monona, Harrison, Pottawattamie, Mills and Fremont counties in Iowa as well as Atchison and Holt counties in Missouri. We focus on Iowa's 2800 km^2 portion of the landform, which comprises more than 80% of its total area. The ILHL contains more than 50% of Iowa's remnant prairie (Loess Hills Alliance, 2011).

Mostly under private ownership and largely grass-covered until the 20th Century, row crop production now dominates large patches of this fragmented and erosion-prone landscape (National Resource Inventory (NRI), 2013 p.11). Maize, soybeans and grass are the major land uses while the area also straddles two Metropolitan Statistical Areas (MSAs) from which demand for non-agricultural land uses, such as residences with scenic river overviews, are to be expected. These MSAs are Sioux City to the north and Omaha-Council Bluffs to the south with, respective populations of about 170 000 and 900 000 circa 2014. In addition, fire suppression has led to encroachment by tree species, especially the fire intolerant Eastern Red Cedar, threatening rare native plant species and leaving the loose soil more vulnerable to erosion.

The literature on land use change in western Iowa's Cornbelt is extensive and diverse in direction of inquiry. Secchi, Tyndall, Schulte and Asbjornsen (2008) addressed how high commodity prices can confound conservation efforts, thus placing greater emphasis on the need for targeted practices to obtain highest benefit per unit cost. Secchi, Kurkalova, Gassman and Hart (2010) used the Cropland Data Layer (CDL) to simulate the extent to which biofuels-related expansion may tilt Iowa crop rotations toward more corn intensive rotations. Brown and Schulte (2011) studied aerial photographs to document the decline of small grains and grass agriculture in three Iowa townships between 1937 and 2002. Miller (2006) commented on the roles of urban pressure, topography, erodibility constraints and agro-economic incentives on assembling a remnant prairie, the Broken Kettle Grassland Preserve, at the ILHL's north end. Many technical contributions to our understanding of soil and water conservation on the landform have also been published (e.g. Tomer, Moorman, Kovar & James, 2007).

Specific to the Loess Hills ecoregion, and most relevant to our study, Farnsworth, Schulte and Hickey (2010) connected privately obtained, remotely sensed data on land cover with crop productivity information to develop a conservation priority index that also seeks to account for benefits from tract connectivity. Their inquiry was static with 2006 land uses, just before major changes in United States cropping activities. Arora, Wolter, Feng and Hennessy (2015) used CDL data to quantify land use transitions in the ILHL between 2001 and 2013. They found that grass acres had declined during this period in the ILHL, having moved into wooded categories, and that corn acres had expanded largely at the expense of soybean acres. They expressed surprise, however, at the limited expansion of row-crop production in the region.

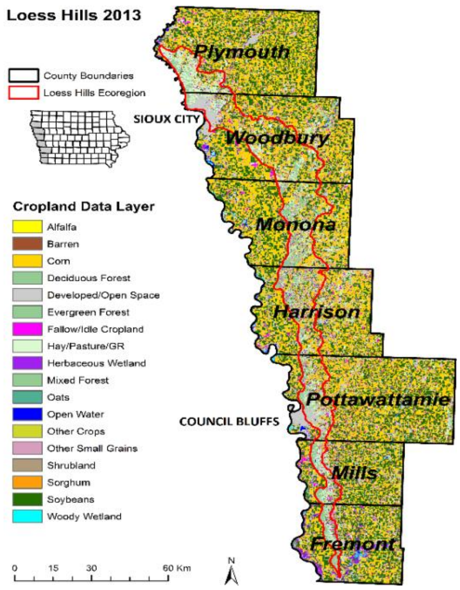

Figure 1. Iowa's Loess Hills landform study area (inside red boundaries, 2797 km^2) and the seven counties in Western Iowa that contain it.

The main objectives of this study are twofold. First, we seek to provide detailed scrutiny of recent land use changes across the ILHL. We characterize regional grassland conversions along with potential factors that impact such conversions such as expansion of cultivated area, urbanization, and invasive wooded species like the Eastern Red Cedar. For this purpose, we utilize longitudinal data from two distinct sources, NRI and CDL, which differ in their scope for spatial as well as temporal dimensions to analyze regional land use. We specify land use trends, land use transition matrices and the structure of corn rotations for the ILHL and contrast these across the counties that skirt the ecoregion. We also conduct a conditional analysis of land use trends on four land quality metrics: erodibility, slope, Corn Suitability Ratings and Land Capability Classification, discussed hereafter under Section 3. Since richer soils are more productive and are expected to offer lower cropping risk, we expect a greater tilt towards crop cultivation on lands with higher productivity. The second objective of this study is to better understand the impacts of commodity markets and agricultural policy on land use decisions in the ILHL. In particular, we determine whether past land use changes in the ILHL are consistent with those in its encircling counties and the state of Iowa. We expect consistency since the private landowners within the landform face a policy and market environment that is very similar to that in neighboring counties. One other contribution of this study is that it provides an approach to identifying spatial errors due to the CDL's land classification scheme and attempts to reduce such errors by employing various remote-sensing techniques.

In Section 2 we provide an overview of relevant policies and the evolving market environment. This is followed by an explanation of our materials and methods; primarily different land use data sources and data processing procedures. After analyzing results, we summarize land use conversion trends with a brief discussion.

2. Policy and Market Environment

The past thirty years has seen a shift in the emphasis of United States agricultural policy away from food and feed production toward energy outputs and also toward environmental outputs that are not generally supported through market incentives. The main agricultural policies of relevance have been those regarding conservation, biofuels and crop insurance.

Although antecedents existed, the Conservation Reserve Program (CRP) was established under the 1985 Farm Bill to incentivize voluntary retirement of environmentally sensitive land from crop production, at least temporarily. Rental contracts with the federal government are typically for ten or more years. The program has proved popular among many land owners and environment advocates, but less popular among agribusinesses and crop producing tenants who identify competition for land and have concerns about lost support for local cropping infrastructure. The program has been renewed in each farm bill through to 2014 although enrollment criteria and maximum enrolled acres have changed over the years. The enrollment cap as well as the enrolled acres have declined under CRP. National enrollment peaked at about 146 000 km^2 in 2007 and declined to about 101 000 km^2 in 2014 (Lubbins and Pease 2014), largely because the offered rental rates were not competitive relative to returns from cropping.

Public funding of conservation easements is another government policy. Easements are legal agreements between a land owner and another party to attenuate owner property rights. Typically the owner obtains monetary compensation and estate tax benefits while the easement has indefinite duration. The *Loess Hills Alliance* seeks to use easements to preserve designated Special Landscape Areas. Other conservation organizations active in the area include *The Nature Conservancy* and the *Iowa Natural Heritage Foundation*. The limited funds available for easement purchases in the ILHL come from private and State of Iowa sources as well as U.S. Department of Transportation's National Scenic Byways Program. In 2014, an initiative to seek National Reserve designation for parts of ILHL, and so open opportunities for additional easement funds from the federal government, failed to gain adequate support among Loess Hills Alliance Board members, where opposition emerged from local land owners. (Note 2)

The 1985 Farm Bill also saw the introduction of conservation compliance provisions whereby those who farm highly erodible lands may be ineligible for some forms of agricultural income support. Growers planting on highly erodible land commit to a conservation plan in order to become compliant. Between 1996 and 2014, eligibility for crop insurance premiums was not conditioned on conservation compliance but linkage was re-established under the 2014 Farm Bill. Recent trends in cropping systems, to be discussed later, have made compliance easier than was the case before the middle 1990s.

For decades preceding the 1996 Farm Bill the commodity-specific income support that growers received depended in large part on cropping choices (Novak, Pease & Sanders, 2015). Some crops, collectively labeled 'program' crops, received support in proportion to acres and yields. Corn was a program crop but soybeans and grass/hay were not. The de-linking of cropping choices and subsidies in the 1996 Farm Bill was motivated by the costs of inflexibility in marketplace response (as growers would lose non-market support upon adapting to market prices) and by International Trade Agreement commitments.

Crop insurance has had at least some federal support since the 1930s, but was not seen as an integral component of income support until the 1990s (Glauber, 2013). In an effort to promote program performance by expanding participation, commencing in 1994 a series of legislative enactments increased premium subsidies and expanded contract choices. Upon passage of the 2014 Farm Bill, crop insurance support had become a firmly established primary pillar of agricultural income support. Although pre-subsidy rates are required to be actuarially fair, as far as is practical, the U.S. Government Accountability Office (U.S. GAO, 2015) has discerned underpricing in production riskier counties where none of these are in Iowa. Nonetheless the growth of crop insurance subsidies, unavailable or less generous for grass-based activities, is likely to promote crop production (Claassen, Cooper & Carriazo, 2011; Feng, Hennessy & Miao, 2013; Miao, Hennessy & Feng, 2014).

Corn-based ethanol has been, indirectly or directly, promoted by the U.S. federal government since the 1970s. Direct support for ethanol production as a renewable fuel came through federal laws passed in 2005 and 2007, which mandated that minimum quantities of certain fuel types be blended with gasoline. As of 2015, more than 200 ethanol plants exist in the United States. Most use corn as feedstock and are located in the Midwest. April 2015 data in Ethanol Producer Magazine identify several plants around the ILHL, including in Council Bluffs (125 mill. gal. capacity), Shenandoah (65 mill. gal.) and Denison (55 mill. gal.) to the south as well as Jackson, Nebraska (50 mill. gal.) and Merrill, Iowa, (50 mill. gal.) to the north. (Note 3). See figure 2 for local cropping infrastructure.

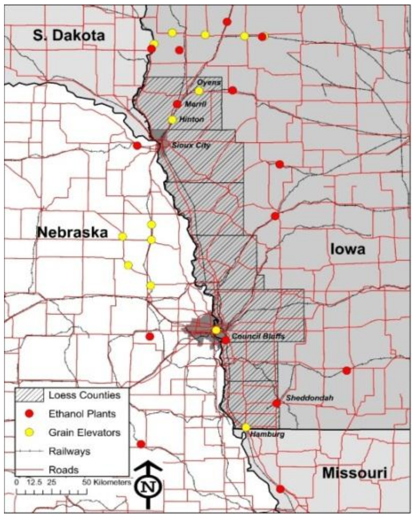

Figure 2. Crop production infrastructure in Iowa’s Loess Hills landform study area.

Apart from weather-stressed years, Cornbelt commodity market prices traded in a historically narrow range between 1980 and 2006. A gradual decline in real prices occurred due to technology-driven growth in supplies when compared with slower growth in demands. The aforementioned 2005 and 2007 energy acts changed the output price environment in several ways. The mandates instantly generated higher, assured demand for corn. The corn price range increased from $2-3 in 2004-2007 to $3-7 in 2007-2014. Other commodities also saw price increases so that they remain a competitive use of land resources. A secondary effect was through beef markets. Farm-level beef prices rose in part because feedlot owners needed to cover higher corn input costs or go out of business. The U.S. national beef herd has declined over the 1996-2014 period in the face of higher feed input prices and also adverse weather conditions, where the decline was sharp after 2008. Even so, grassland rental prices also increased as they provide an alternative to corn-based cattle feed.

Marked technological change has occurred in crop production during recent decades. Perhaps most relevant to this study are expanded use of conservation tillage and the advent of genetically modified corn and soybean seeds. Conservation tillage can reduce production costs and can also preserve moisture as a risk management strategy against drought. The Loess Hills area, though far from arid, is among the driest in Iowa. Conservation tillage also protects against soil erosion and is viewed as an acceptable strategy for conservation compliance. However, tillage also provides weed control (Carpenter & Gianessi, 1999) so that growers had been reluctant to adopt conservation tillage. The advent of glyphosate tolerant seeds allowed for cost-effective weed control by use of a single chemical after planting. There is substantial evidence that glyphosate tolerant seed complements less intensive tillage (Perry, Moschini & Hennessy, 2016). In reducing the cost of conservation compliance, these seeds may facilitate corn and soybean production on erodible land. Growers in the seven county area (SCA) have been early and extensive adopters of both conservation tillage and glyphosate tolerant seed. (Note 4)

3. Materials and Methods

To address land use changes in Iowa’s Loess Hills and related policy implications, we conducted a comprehensive data analysis at two levels of aggregation: SCA and ILHL. We used two data sources: National Resource Inventory (NRI) data and CDL data. NRI data allow for evaluation of historical land use changes at the county level of aggregation in the SCA (1982-2010), where CDL data are only available for recent years (2000-’14). Given that factors like agricultural policy and agri-infrastructure change incrementally, their impact on regional land use is better understood when longer time-series of land use transitions are used in analysis. For example, inavailability of CDL data prior to year 2000 leaves this data source incapable of informing on change in cropping incentives and regional land use due to the farm bills introduced in 1985 and 1996. On the other hand, and in contrast with NRI data, CDL data are spatially-delineated and so allow us to evaluate changes specific to ILHL.

3.1 National Resource Inventory Data

We utilized National Resource Inventory (NRI 2013) data to evaluate land use/land cover (LULC) trends for the SCA encompassing the ILHL. Focusing on point-level data, the NRI is a survey-based longitudinal database that provides comprehensive information on land characteristics as well as historical uses. In order to conform with

USDA confidentiality protocols, and unlike the CDL, NRI data suppress spatial geo-coordinates (NRI, 2013) although county location is provided. NRI data collection is based on a robust survey methodology that assures reliable and temporally-consistent estimates of land use and land quality parameters. Specifically, the included sample points are intended to represent the overall geographic spread and heterogeneity of natural resources at national and regional levels (Nusser, Breidt & Fuller, 1998). Each sample point is accompanied by its representative weight measured in 100 acre (0.405 km^2) units that differ across sample points. A total of 2,600 NRI points span the SCA's 12 985 km^2 area. Data range from 1982 - 2010, where each NRI point was observed every five years from 1982 to 1997 but annually commencing 2000.

The NRI dataset provides land quality parameters such as land capability classification (LCC) and erodibility index (EI). LCC groups soils into eight classes with regards to limitations for cropping, with higher class codes referring to more severe limitations. LCC classes I and II are most suitable for cropping whereas classes III and IV are more limited in use. Higher LCC classes have severe limitations and are considered to be unsuitable for cultivation (p. 65 in Helms 1992). EI measures soil's erosion potential whereby soils with higher index values are costlier for cropping as they entail pertinent management costs to limit erosion and preserve crop productivity (NRI, 2013). About 1% of NRI points had non-constant LCC and/or EI values during the 1982-2010 period. These points were excluded when assessing land use by LCC and/or EI status. Within this domain of constant LCC lands; 6.6% of points have missing LCC for all years, 40.2% were in classes I-II, 48.3% were in classes III-IV, and 4.9% were assigned higher classes.

Locations with EI values that were either missing or temporally varying accounted for 31.1% of NRI points, where a disproportionate fraction were in the urban category. Among the non-missing, constant EI points, the index ranges from 0.8 to 160.2 where 32.2% had EI $\geq$ 8. The USDA's Natural Resource Conservation Service (NRCS) defines soils with EI $\geq$ 8 as highly erodible. Since the 1996 Farm Bill, soils with EI $\geq$ 8 have been eligible for CRP regardless of other attributes.

3.2 Cropland Data Layers

Pre-processing: Spatially explicit raster CDL data were downloaded from the CropScape portal of the National Agricultural Statistics Service (United States Department of Agriculture National Agricultural Statistical Service (USDA NASS), 2012) and clipped by the SCA encompassing the ILHL (figure 1). These CDL data are produced annually for the 48 contiguous states (since 2000 for Iowa) using a combination of (1) multiple satellite imagery dates each year to capture crop phenology differences, (2) concurrent USDA Farm Service Agency's (FSA) training/validation data, and (3) augmented versions of the raster-based National Land Cover Data (NLCD) from 2001 and 2006 (Fry, Coan, Homer, Meyer & Wickham, 2009; Boryan, Yang, Meller & Craig, 2011). Landsat-based CDL data (30 m pixels) from 2001, 2005, 2010, and 2013 were selected to quantify LULC change trends for the ILHL. Advanced Wide Field Sensor-based (AWiFS) CDL data (56 m pixels) from years 2006-'09 were excluded since differences in spatial resolution are known to negatively affect area estimation precision in remote sensing-based studies (Lunetta, Knight, Ediriwickrema, Lyon & Worthy, 2006; Wright & Wimberly, 2013).

Downloaded CDL data could not be analyzed directly due to inherent difference in (1) classes from 2001 to 2013 (table 1); (2) missing classes (e.g., roads in 2001 and 2005), (3) class confusion between dominant crop types and non-crop types (figure 3), and (4) because later improvements in the CDL processing stream reduced spatial errors due to single-pixel salt-and-pepper effects (D.M. Johnson [NASS], personal communication) that remain in earlier CDL years (figure 3). Similar preprocessing was necessary for early versions of NLCD (1992 and 2001) so that class structure and pixel-wise effects were equivalent (Wolter, Johnston & Niemi, 2006). For instance, the 2001 and 2005 CDLs did not specifically include a 'developed' class that contained roads as did later years (figure 3). Also, spatial inconsistencies within the 'Fallow/Idle Cropland' class through time have been identified in prior studies (Kline, Singh & Dale, 2013). Laingen (2015) has recommended that all data be treated with circumspection, placing emphasis on the data generation processes.

NASS warns against the use of non-agricultural classes such as Grass/Pasture and Fallow/Idle as these classes have low classification accuracy (USDA NASS, 2013). (Note 5) Rather, NASS suggests substituting NLCD's non-agricultural classes. Hence, non-agricultural classes from the 2001 CDL were used to clip the recently improved 2001 NLCD layer. Resulting NLCD classes were recoded to fit the CDL class structure and then overlain back on the 2001 CDL. We also used the 2001 CDL agricultural classes to clip the 2001 NLCD under the suspicion that 2001 CDL agricultural classes were being confused with the non-agricultural classes, especially 'Forest' (figure 3). Again, resulting NLCD classes were recoded and overlain in the 2001 CDL. A similar approach, using 2006 NLCD, was used to reconcile such errors in the 2005 CDL (figure 4).

Table 1. CDL cover type classes pertinent to Iowa and the disparity between years. An 'X' denotes that the class existed and was adequately represented, while 'U' denotes that the class existed but was grossly under-represented. No value '-' indicates that the class did not exist or had zero total area.

CDL Cover Type	2001	2005	2010	2013
Corn	X	X	X	X
Soybeans	X	X	X	X
Barley	-	-	X	X
Oats	X	X	X	X
Rye	-	-	X	X
Flaxseed	-	-	X	-
Spring Wheat	-	-	X	-
Winter Wheat	-	X	X	X
Other Small Grains	X	X	-	-
Other Crops	X	X	U	-
Alfalfa	X	X	X	X
Other Hay/Non-alfalfa	-	-	X	X
Fallow/Idle Cropland	X	X	U	U
Forest	X	X	X	-
Deciduous Forest	-	-	X	X
Evergreen Forest	-	-	X	X
Mixed Forest	-	-	X	X
Developed	U	X	-	-
Dev/Open Space	-	-	X	X
Dev/Low intensity	-	-	X	X
Dev/Med Intensity	-	-	X	X
Dev/High Intensity	-	-	X	X
Grass Pasture	X	X	X	X
Non-Ag/Undefined	-	X	-	-
Shrubland	-	-	U	U
Barren	-	-	X	X
Wetlands	-	X	X	-
Herbaceous Wetland	-	-	X	X
Woody Wetlands	-	-	X	X
Water	X	X	X	X

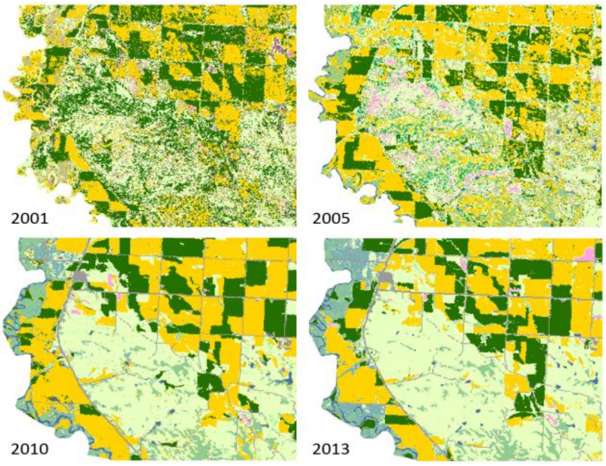

Figure 3. Speckling and misclassifications between old (top) and newer (bottom) CDL data processing for a 127 km^2 area in western Iowa. Soybeans (dark green) and Corn (orange) are confused with Grass/Pasture (light green) in 2001, while Corn, Forest (intermediate green), and Alfalfa (magenta) are confused with Grass/Pasture in 2005. Also note that roads (gray) are missing from 2001 and 2005.

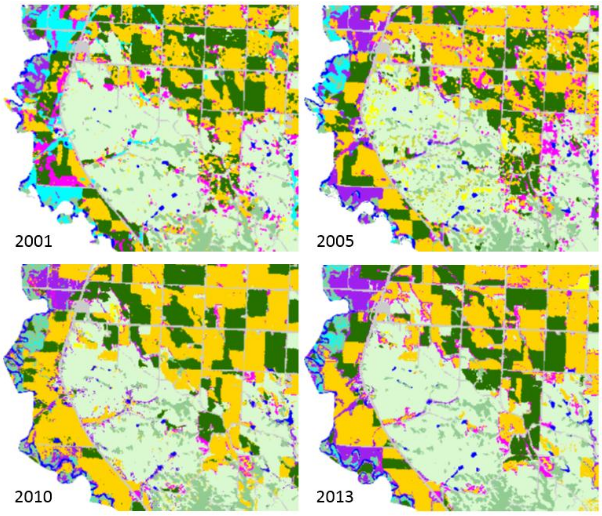

Figure 4. Results of class parity correction using 2001 and 2006 NLCD and subsequent, simultaneous, despeckling of the 2001, 2005, 2010, and 2013 CDLs. Despeckling was achieved via a 3 x 3 majority filter applied to the union of the four respective CDLs into one thematic image with a four-year, change vector, attribute assigned to each pixel. This change vector attribute was used afterward to recreate the individual CDLs in figure 3.

Once CDL classes were equivalent among the {2001, 2005, 2010, 2013} time steps, we then used a matrix union function to combine the information into one physical image. This matrix union function, when applied to two consecutive CDL years (e.g., Y_1-Y_2), provides a "from-to" attribute in the resulting thematic output attribute table with which one may track land cover changes between those years. Here, we simply applied this function three consecutive times (Y_1 -Y_2, Y_{1-2} -Y_3, and finally Y_{1-2-3} -Y_4) to achieve the four-year ($Y_{1-2-3-4}$) "from-to" vector of change for each pixel. A 3 x 3 pixel majority despeckling function was then applied to this resulting image to simultaneously weed out spurious and illogical single pixels of changes through time (e.g. water-corn-forest-soy). After the multi-temporal despeckling operation was complete, the four-year "from-to" change vector attribute was then used to guide recoding of the single, thematic image back into the four respective CDL years as separate, thematic, image layers.

To allow for further consideration on the sorts of land that have seen changing use, we have linked CDL data to land quality. Corn Suitability Ratings (CSR, Miller 2005) and slope data were obtained from the SSURGO database maintained by USDA NRCS. (Note 6)

Quantifying Land Use/Land Cover Change: Quantifying change among CDL crop types and other land uses for the four selected years was performed within the SCA and the ILHL. We considered four slope percent classes [0-5, 6-10, 11-15, ≥16] and four CSR classes [1-69, 70-79, 80-89, >90] across the SCA and within the ILHL. Given that CDL and NRI are two distinct data sources with different data generating processes, we did not expect the comparable land use numbers to match exactly. We did expect to see reasonably similar trends for the SCA among the common land use categories and this is largely true. Surprisingly though, while in table 2 the NRI data show an increase in corn acreage and decrease in hay and pasture over the 2001-'05 interval, the CDL data in table 3 provide a reverse trend.

The pre-processing exercise and land use analysis that uses CDL were performed using the ERDAS Imagine software, and the analysis that used NRI data was conducted with SQL in SAS software and the Pivot Tables application in Microsoft Excel.

4. Results and Discussion

We present land use trends and land use transition matrices to characterize conditional (on land quality) and unconditional land use changes for SCA and ILHL. We report comparisons among the two independent datasets, as well as among the two aggregation levels within the unconditional land use trends. In addition, linkages have been established, when applicable, between the observed land use change within the landform and agricultural policy. A comparison with state and national level land use change is also considered. Last, but not least, to facilitate further scrutiny we empirically specify the structure of rotations for corn over the 2000-'10 period to assess whether cropping in this region is moving toward monoculture. We present our findings below.

4.1 Unconditional Land Use Trends

To utilize the full extent of NRI data while emphasizing more recent available data, table 2 provides summary data on cultivated area under crops, hayland and pastureland for 1982, 1992, 2001, 2005 and 2010 (NRI, 2013). It is evident that area under crop cultivation, at about 70% of total area in the SCA, dominates 'other' land uses. Corn and soybeans account for almost all land under tilled crops. Area under corn fell by 734 km^2 from 1982 to 2001, before returning to 1982 levels in 2010, trends that are broadly consistent with the nation as a whole. Soybean area has largely counterbalanced corn area where total acres under either crop increased by 5% over 1982-2010 and by 3% over 2001-2010. Soybean acres did decline in area between 2005 and 2010 whereas they increased by 7.5% nationally over the same period. This contrast may have been due to limited opportunities to substitute other crops out in favor of corn in the SCA. 'Other crops' declined over the interval but mainly before the 1996 Farm Bill. Area allocated to pasture saw a declining trend over the three decades, losing 551 km^2 between 1982 and 2010, whereas the decline in area under hay was more modest.

Table 2. Land use trends for Seven County Area (in km^2).

Land Use Category	1982	1992	2001	2005	2010
Corn	5,372	5,077	4,638	4,858	5,655
Soybeans	3,527	3,475	4,472	4,449	3,727
Other Crops	402	109	102	26	62
Hay	392	280	413	358	358
Pasture	1,544	1,369	1,140	1,022	993
Forest	563	591	640	657	645
CRP	0	746	331	316	130
Urban	297	309	353	379	405

Source: National Resource Inventory data.

NRI records acreage under the CRP general sign-up scheme, introduced in the 1985 Food Security Act. (Note 7) Acreage under such CRP sign-ups had fallen substantially (83%) by 2010, when compared to 1992. Table 2 also shows a 60% decline in the CRP general-sign up acreage in the SCA between 2001 and 2010. Note that acres reported by the USDA Farm Service Agency (USDA FSA) under continuous sign-up in Iowa almost doubled in this period and their contribution towards total CRP acres also grew substantially from 16.7% in 2001 to 42.5% in 2013. However, as much of the ILHL landform is characterized as highly erodible, we expect continuous sign-ups to be a small fraction of all sign-ups for this region. In addition, at 1.1% growth per year, land under urban uses grew at a definite but modest rate during 1982-2010. (Note 8)

Turning to CDL data, corn acres have increased by about 75 km^2 in the ILHL between 2001 and 2013, see bottom right panel in table 3. Soybean acres have declined over the period by about 100 km^2 so that, perhaps surprisingly, there has been no net change in total acres devoted to row crops over the period. There has been expansion of the forest (+67 km^2) and fallow/idle cropland (+70 km^2) categories. The ILHL is topographically variable, especially in regard to slope and land quality. Within the region there have been some subtle changes. Crop production has expanded toward the north, especially in Woodbury and Monona counties where cropping is extensive. Crop production has declined in the more southerly counties where the landform is thin and cropping is limited. Crop production has generally moved from soybeans and toward corn overall along the hills but corn has not expanded in Plymouth County to the north or Pottawattamie, Mills and Fremont counties along the landform's narrowing tail. Forests have expanded uniformly over the area.

Land use in marginal growing areas should, by definition, be more sensitive to price movements than should other areas. Over 2005-'10 Iowa's planted corn acres increased by 4.7% while planted soybean acres decreased by 2.5%. Over 2010-'13 Iowa's planted corn acres increased by 1.5% while planted soybean acres decreased by 4.1%. Table 3 shows that over 2005-'10 the ILHL's planted corn acres increased by 62% while planted soybean acres declined by 2%. Over 2010-'13 the ILHL's planted corn acres decreased by 8% while planted soybean acres decreased by 20%. The area does appear to have had more variable responses to external conditions than the state as a whole, likely due to the challenging production environment that it poses for growers.

Because CDL classification protocols for developed acres have evolved substantially through these years, CDL data do not directly allow for an assessment of change to this category. In a separate query that appropriately adjusted for the redefinitions, we found a 2.6% increase in ILHL development acres (from 103 km^2 acres to 106 km^2) over the 2001-'13 period. We had expected a larger increase.

Table 3. County level and aggregate changes on Loess Hills landform (in km^2).

	Plymouth				**Woodbury**			
	2001	2005	2010	2013	2001	2005	2010	2013
Corn	42.5	28.3	53.2	41.8	235.0	191.7	287.0	278.2
Soybeans	27.7	33.4	35.4	27.5	196.4	211.3	219.7	182.0
Fallow/Idle Cropland	26.6	17.2	8.0	14.8	77.7	77.8	32.1	53.4
Hay/Pasture/Grass	115.4	127.3	125.7	137.0	158.6	184.9	132.6	156.9
Forest	41.7	48.2	40.1	42.3	47.1	55.1	53.9	52.3
Developed (all years)	19.4	19.4	19.4	19.4	135.4	135.4	135.4	135.4
	Monona				**Harrison**			
Corn	102.4	88.4	150.4	138.9	121.0	88.1	144.3	130.1
Soybeans	95.6	92.2	88.7	71.5	104.4	104.9	82.4	64.2
Fallow/Idle Cropland	24.9	28.8	18.7	31.5	25.2	40.3	26.5	44.7
Hay/Pasture/Grass	129.9	134.7	86.2	99.1	69.6	80.1	62.4	73.5
Forest	120.5	129.2	132.0	133.0	97.3	104.4	102.6	106.9
Developed (all years)	38.3	38.3	38.3	38.3	40.7	40.7	40.7	40.7
	Pottawattamie				**Mills**			
Corn	74.5	50.7	79.8	74.0	25.0	11.7	20.5	18.8
Soybeans	52.5	50.6	52.8	37.4	17.6	17.1	20.5	14.9
Fallow/Idle Cropland	14.7	31.6	17.6	27.3	9.3	17.9	9.3	12.5
Hay/Pasture/Grass	72.0	77.0	57.9	67.0	46.7	49.4	41.7	46.9
Forest	62.2	66.6	67.3	69.4	45.9	49.0	51.0	51.2
Developed (all years)	68.3	68.3	68.3	68.3	19.7	19.7	19.7	19.7
	Fremont				**Loess Hills Polygon**			
Corn	11.4	3.7	11.6	5.5	611.7	462.4	746.8	687.4
Soybeans	9.3	8.8	7.4	8.5	503.4	518.2	506.9	406.1
Fallow/Idle Cropland	2.4	11.2	5.7	7.7	180.7	224.8	118.0	192.0
Hay/Pasture/Grass	28.8	30.8	26.6	29.0	621.1	684.1	533.1	609.4
Forest	51.9	52.8	55.4	55.0	476.6	515.7	507.3	517.1
Developed (all years)	9.6	9.6	9.6	9.6	331.2	331.2	331.2	331.2

Source: Cropland Data Layer data.

Note: Acres in the 'Developed' category were fixed at 2001 levels.

4.2 Conditional Land Use Trends

Seven-County-Area: Table 4 presents land use trends conditional on being in LCC classes I-II and on being in classes III-IV. Classes I-IV contain almost all of the region's corn and soybean acres. Furthermore, 75% or more of hay and pasture acres also lie on LCC I-IV lands. Although, we find relatively higher acreage-shares of hay, pasture, forests and CRP lands on LCC III-IV lands. Corn acres have seen a slight migration to better land, perhaps because of incentives that the CRP provides to more limited land, while hay and pasture acres have shifted away from LCC classes I-II.

Table 4**.** Land use trends for Seven County Area (in km^2), conditional on Land Capability Class. Percent of all land in that use is in parentheses.

LCC I, II Land Use Categories					
	1982	1992	2001	2005	2010
Corn	2,500 (46.5)	2,472 (48.7)	2,253 (48.6)	2,447 (50.4)	2,750 (48.6)
Soybeans	1,712 (48.5)	1,841 (53.0)	2,207 (49.4)	2,172 (48.8)	1,812 (48.6)
Other Crops	120 (29.9)	30 (27.5)	26 (25.5)	9 (34.6)	19 (30.6)
Hay	117 (29.8)	56 (20.0)	88 (21.3)	33 (9.2)	53 (14.8)
Pasture	443 (28.7)	391 (28.6)	324 (28.4)	251 (24.6)	245 (24.7)
Forest	105 (18.7)	93 (15.7)	103 (16.1)	102 (15.5)	105 (16.3)
CRP	0 (-)	81 (10.9)	13 (3.9)	13(4.1)	1 (0.8)
LCC III, IV Land Use Categories					
	1982	1992	2001	2005	2010
Corn	2,790 (52)	2,558 (50.4)	2,330 (50.2)	2,355 (48.5)	2,866 (50.7)
Soybeans	1,747 (49.5)	1,563 (45.0)	2,245 (50.2)	2,258 (50.8)	1,895 (50.8)
Other Crops	263 (65.4)	79 (72.5)	77 (75.5)	17 (65.4)	43 (69.4)
Hay	268 (68.4)	213 (76.1)	304 (73.6)	311 (86.9)	294 (82.1)
Pasture	777 (50.3)	693 (50.6)	548 (48.1)	516 (50.5)	499 (50.3)
Forest	196 (34.8)	200 (33.8)	227 (35.5)	247 (37.6)	234 (36.3)
CRP	0 (-)	629 (84.3)	302 (91.2)	294 (93.0)	119 (91.5)

Source: National Resource Inventory data.

Table 5. Land use trends for Seven County Area (in km^2), conditional on Erodibility Index.

EI < 8					
Land Use Category	1982	1992	2001	2005	2010
Corn	2,799	2,732	2,431	2,568	3,211
Soybeans	2,178	2,251	2,660	2,613	1,857
Other Crops	134	35	26	9	19
Hay	114	78	86	40	56
Pasture	10	6	17	17	0
CRP	0	51	4	4	0
EI ≥ 8					
Land Use Category	1982	1992	2001	2005	2010
Corn	2,151	1,761	1,615	1,679	1,789
Soybeans	944	962	1,319	1,351	1,397
Other Crops	227	73	77	17	43
Hay	224	120	243	212	215
Pasture	0	11	5	5	0
CRP	0	593	294	288	108

Source: National Resource Inventory data.

Note: Urban land and forest land are generally not assigned EI values.

Table 5 provides trends for the EI <8 and EI ≥ 8 categories. Although almost 40% of land in the SCA had to be excluded from evaluating the trend statistics, due to missing and transitioning EI values, 88-91% of cropped acres lie within the land parcels that had constant, non-missing EI values for all years. About 40% of the region's cropped acres with reported, constant EI values were on land with EI ≥ 8, along with only 13-23% of total hay and pasture lands over the period of our analysis. Acres under hay, pasture and CRP categories generally had higher erodibility index values. It is noteworthy that corn acres on EI ≥ 8 land was lower in 2010 when compared with its 1982 counterpart. This may be, in part, due to the advent of CRP, and partly due to conservation compliance constraints.

ILHL: Table 6 shows that corn presence and recent corn expansion have been concentrated on less steeply sloped river valley tracts that cut through the landform, see figure 5. Total acres to corn and soybeans on slopes >10% has changed minimally over the period. A moderate decline in the hay/pasture/grass category over 2001-'13 occurred mainly on shallow slopes while expansion in forest occurred throughout. Expansion in the fallow/idle cropland category occurred mainly on lower (≤ 5%) and higher slopes (> 15%) where the highest proportional expansion of this category has been on higher slopes, a notable observation given that overall CRP acres on the landform likely declined over the 2001-'13 period.

Table 7 reports land use changes by four corn suitability rating (CSR) categories: ≤ 69, or least suitable lands, 70-79, 80-89 and ≥90, or most suitable lands, see Miller (2005). Corn expanded and soybean contracted in each category over the 2001-'13 period. Total land in either corn or soybeans increased slightly on lower quality land but decreased slightly on better quality land, a perplexing finding that also applies for the SCA (table not shown). Land area under forest has expanded or trended sideways for all land quality categories while the data indicate that area in the hay/pasture/grass category has declined slightly for better land categories. Fallow/idle cropland is found to have expanded on higher quality land and to have contracted on lower quality land, perhaps due to high error in the category (as previously mentioned) or forest encroachment.

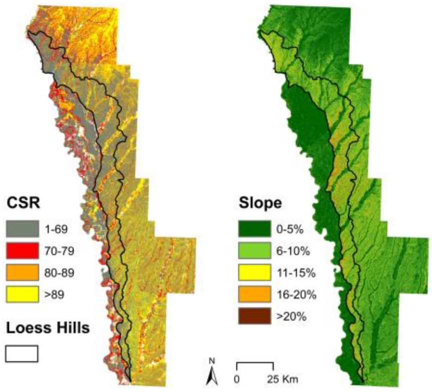

Figure 5. Landscape stratification classes for the seven-county study area. Corn suitability rating (CSR) on the left side and percent slope of terrain classes on the right side.

Table 6. Change in crop and other land use/cover areas on the ILHL, by four slope categories (km^2).

	0-5 % Slope				**6-10 % Slope**			
	2001	2005	2010	2013	2001	2005	2010	2013
Corn	257	216	317	298	206	152	252	236
Soybeans	233	235	219	181	167	176	177	142
Other Crops	1	2	0	0	1	3	0	0
Alfalfa	6	4	6	5	9	7	8	6
Fallow/Idle Cropland	49	66	34	62	68	85	42	65
Hay/Pasture/Grass	136	151	107	129	215	238	184	210
Forest	71	81	78	80	116	128	126	129
Developed (all years)	124	124	124	124	110	110	110	110
	11-15 % Slope				**>15 % Slope**			
	2001	2005	2010	2013	2001	2005	2010	2013
Corn	92	60	113	101	43	22	49	36
Soybeans	67	70	74	57	24	24	25	17
Other Crops	0	2	0	0	0	1	0	0
Alfalfa	6	5	4	3	3	2	2	1
Fallow/Idle Cropland	42	48	25	37	20	24	16	25
Hay/Pasture/Grass	160	176	144	161	106	116	96	106
Forest	117	126	127	128	159	168	169	171
Developed (all years)	55	55	55	55	36	36	36	36

Source: Cropland Data Layer data.

Note: Acres in the 'Developed' category were fixed at 2001 levels.

Table 7. Change in crop and other land use/cover areas within the ILHL, by four CSR categories (km^2).

	1-69 CSR2				**70-79 CSR2**			
	2001	2005	2010	2013	2001	2005	2010	2013
Corn	309	211	371	342	38	36	52	47
Soybeans	227	243	256	201	39	37	30	26
Other Crops	14	6	1	1	0	0	0	0
Alfalfa	17	14	12	9	1	0	1	1
Fallow/Idle Cropland	127	146	73	108	5	5	4	8
Hay/Pasture/Grass	455	504	410	456	13	14	11	14
Forest	390	415	417	422	6	8	6	7
Developed (all years)	194	194	194	194	14	14	14	14
	80-89 CSR2				**90-100 CSR2**			
	2001	2005	2010	2013	2001	2005	2010	2013
Corn	158	128	197	178	99	79	117	111
Soybeans	139	141	131	106	91	91	83	68
Other Crops	2	2	0	0	10	0	0	0
Alfalfa	4	3	5	4	2	1	2	2
Fallow/Idle Cropland	34	44	26	49	14	28	15	25
Hay/Pasture/Grass	104	114	79	97	44	47	32	39
Forest	45	54	50	51	22	26	25	26
Developed (all years)	64	64	64	64	53	53	53	53

Source: Cropland Data Layer data.

Note: Acres in the 'Developed' category were fixed at 2001 levels.

4.3 Temporal Transition Matrices

We present temporal transition matrices for the SCA using NRI data as well as CDL land cover data. Pivot tables such as table 8 provide a matrix of land use transitions over time. They allow us to identify interesting transitions among the land use categories under study, which may have important policy implications for this region. We analyze pivot tables using NRI data for 2001-’05, 2005-’10 and using CDL data for 2001-’05, 2005-’10, and 2010-’13 periods. Whereas CDL data allows us to capture the most recent transitions, NRI data helps in quantifying conversions into urbanization.

Table 8 provides further perspective on cropping pressure in the ILHL. The table is a transition matrix that categorizes CDL data to be broadly consistent with NRI categories. (Note 9) Net movement from corn and soybeans into hay/pasture/grass was large during 2001-’05, a period of stable corn planted acres in the United States, at about 324 000 km^2, and of comparatively low commodity prices. Strong net movement in the other direction occurred between 2005 and 2010, consistent with the national movement toward more cropland to meet growing demand for commodities. The shift back to hay/pasture/grass and fallow/idle cropland over 2010-’13 as well as contraction in both corn and soybean acres is not consistent with national trends. In 2013, corn and soybean area planted in the United States were, respectively, 384 000 km^2 and 308 000 km^2. In 2010 the corresponding numbers were 348 000 km^2 and 312 000 km^2. Many of the additional corn acres have come from outside the traditional Cornbelt, especially from Great Plains states such as North Dakota and Kansas.

Table 8 shows that much of the corn acreage that moved out of cropping between 2001 and 2005 in the ILHL likely went into grass and fallow cropland, a pattern that was reversed in the subsequent five years so that corn acres were 138 km^2 larger in 2010 than in 2001. High corn acreage was sustained in the 2010-’13 period through declining soybean acres. While shifts occurred into grass and fallow cropland categories, net grass acres have declined due to outward transitions into the forests category (not included here) where invasive eastern red cedar is a problem in the area.

Table 9 reveals that corn and soybean areas are sources of urbanized land in the SCA with 10 km^2 converted during 2001-’05 and 15 km^2 converted during 2005-’10. CRP in 2001-’05 (6 km^2) and pasture in 2005-’10 periods (7 km^2) are other sources of conversion. Also, CRP lands transitioned into corn and soybean production (116 km^2) at a very high rate during 2005-’10, relative to the 2001-’05 period (6 km^2 CRP lands into corn and soybean). Hay and pasture have also lost considerable areas to corn and soybean production, i.e., 176 km^2 in 2001-’05 and 133 km^2 in 2005-’10.

Table 8. Pivot table for ILHL using CDL data but NRI specific land use categories (in km2), 2001-’05, 2005-’10 & 2010-’13.

		2005				
		Corn	Soy	Hay/Pasture/Grass	Fallow/Idle Crop	*Grand Total*
2001	Corn	335	129	53	70	588
	Soy	106	349	1	42	498
	Hay/Pasture/Grass	1	16	559	18	594
	Fallow/Idle Crop	16	17	50	83	167
	Grand Total	457	512	663	213	1,846
		2010				
		Corn	Soy	Hay/Pasture/Grass	Fallow/Idle Crop	*Grand Total*
2005	Corn	168	262	4	18	452
	Soy	362	113	12	20	506
	Hay/Pasture/Grass	113	69	415	17	613
	Fallow/Idle Crop	68	48	49	47	213
	Grand Total	710	492	480	102	1,784
		2013				
		Corn	So	Hay/Pasture/Grass	Fallow/Idle Crop	*Grand Total*
2010	Corn	255	341	68	61	726
	Soy	397	50	22	31	501
	Hay/Pasture/Grass	15	5	494	0	514
	Fallow/Idle Crop	12	7	1	89	110
	Grand Total	680	404	585	181	1,850

Source: Cropland Data Layer data.

Table 9. Pivot table for Seven County Area using NRI specific land use categories, 2001-'05 & 2005-'10.

		Specific Land Use 2005 (km^2)						
		Corn	Soy	Hay	Pasture	CRP	Urban	*Grand Total*
Specific Land Use 2001 (km^2)	Corn	3,904	680	20	0	0	7	4,611
	Soybeans	741	3,677	15	0	0	3	4,435
	Hay	74	15	324	0	0	0	413
	Pasture	57	30	0	1,020	0	5	1,113
	CRP	6	0	0	2	316	6	331
	Urban	0	0	0	0	0	353	353
	Grand Total	4,782	4,402	358	1,022	316	361	11,272
		Specific Land Use 2010 (km^2)						
		Corn	Soy	Hay	Pasture	CRP	Urban	Grand Total
Specific Land Use 2005 (km^2)	Corn	1,448	3,263	42	0	0	14	4,766
	Soybeans	3,974	398	7	0	0	1	4,379
	Hay	53	58	243	0	0	0	354
	Pasture	22	0	0	993	0	7	1,022
	CRP	107	9	66	0	130	0	312
	Urban	0	0	0	0	0	379	379
	Grand Total	5,605	3,727	358	993	130	383	11,230

Source: National Resource Inventory data.

4.4 Structure of Rotations

As all indicators hold that corn acreage has expanded in the region dominated by corn-soybean rotations while cropped acreage has seen very limited change, it is certain that more corn intensive rotations are being used. Table 10 provides confirmation using CDL data for the ILHL. The table shows that the percent of all corn land in a given year that returns to corn the next year has trended upward over the years. The pattern is more obvious when three and four year corn sequences are viewed. Figure 6 depicts CDL data that provide evidence of more intensive corn rotations toward the landforms thick north end. Our finding corroborates Plourde, Pijanowski & Pekin (2013), who used CDL data across much of the Greater Mississippi watershed to discern an intensification of corn in rotations during 2003-2010.

Table 10. Cropping sequence as evidence on narrowing cropping patterns on the ILHL, 2000-2010. The sequences are characterized as acreages, measured in km^2.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
C_t	668	773	545	614	522	529	628	582	571	642
C_tC_{t+1}	172	115	111	109	113	191	259	184	180	197
% CC sequence	26	15	20	18	22	36	41	32	31	31
$C_tC_{t+1}C_{t+2}$	46	50	37	45	59	135	107	108	108	-
% CCC sequence	7	6	7	7	11	26	17	19	19	-
$C_tC_{t+1}C_{t+2}C_{t+3}$	19	14	16	26	39	49	66	72	-	-
% CCCC sequence	3	2	3	4	7	9	11	12	-	-

Source: Cropland Data Layers.

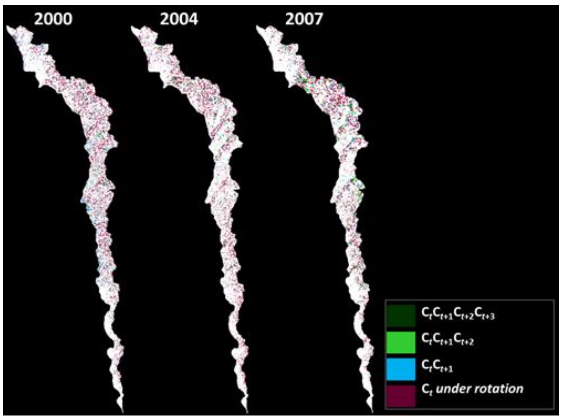

Figure 6. Evidence of more intensive corn rotations in the ILHL.

Notes: For 2000, 'C_{2000}' gives the are in corn that year, '$C_{2000}C_{2001}$' gives the area in corn both that and the following year, while '% CC sequence' gives $(C_{2000}C_{2001}/C_{2000})\times100$. To compute the above statistics we apply multi-temporal despeckling and re-coding operations, as discussed under 'Materials and Methods', on CDL years 2000-'10.

5. Concluding Remarks

Several factors have led to growth in tilled acres across the United States since 2006. In the Loess Hills we conclude that corn production has increased where much of the expansion has been through displacement of soybeans. The evidence does point to grassland loss in the area where we remind the reader that pixel-level misclassification rates is very high for CDL data on grass and fallow/idle categories. Tables 2 and 3 show that the hay/pasture/grass category declined by about 12% and 17%, respectively, over 2005-2013 while the respective figures for the fallow/idle category are declines of about 15% and 21%. Even if evidence on grassland loss is discarded, there are adverse implications for environmental services as corn production in rotation is believed to improve soil quality (Karlen et al., 2006) as well as reduce demand for chemicals that improve fertility (Stanger & Lauer, 2008) and manage pests (Gassmann et al. 2014).

Some parts of the ecoregion have seen cropland expansion, most notably southeast of Sioux City, while crop production has declined toward the less heavily cropped south. Both corn and forest acres have expanded everywhere in the hills over 2005-’13 but it should be noted that separating forested land and grass cover is problematic, especially in the presence of invasive shrubs. There is little evidence that cropping has moved to better quality land although there is some evidence that it has moved away from steeper slopes. The limited evidence available does not point to urban development as a major factor in the area but our view is that the matter warrants further inquiry. Land identified as fallow/idle has declined, likely due to a net decline in CRP acres.

Given the various forces that have aligned in recent years to incentivize row crop production and given national trends, it is not clear why row cropping has not expanded by more along the hills. Perhaps, for some reason, trends toward mechanization have favored less hilly land. Perhaps too, notwithstanding the growth in reduced tillage methods throughout the United States, conservation compliance regulations and targeted CRP sign-ups have proven to be more effective in protecting grass and wooded land in the area than elsewhere? Whether the Loess Hills are distinctive or our finding reflects a more general pattern of comparative constraint in row crop activity on hill terrain in recent years is a matter that warrants further inquiry and will be an important issue for policy design.

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Notes

Note 1. Source: http://iowa.sierraclub.org/LoessHills/LoessHillsHome.htm.

Note 2. See 'National Park Reserve designation causes controversy in western Iowa's Loess Hills' by Brianna Clark, posted at KTIV News Channel, February 18, 2014, http://www.ktiv.com/story/24755375/2014/02/18/controversy-surrounding-the-national-park-reserve-designation-of-the-loess-hills, last visited 8/7/2015.

Note 3. See www.ethanolproducer.com/plants/listplants/US/Existing/Sugar-Starch/.

Note 4. Over the 1998-2001 period 47% of soybean growers in the SCA adopted both conservation tillage and glyphosate tolerant soybean seed, when compared with 37.4% nationwide. For the 2007-2011 period the comparable figures were 72.5% and 65.3%. See table 1 and supporting text in Perry et al. (2015) for explanations of data. Ed Perry kindly made SCA summary data available to us.

Note 5. Land assigned to the 'Fallow/Idle' is considered to be cropped but is not currently under a discernible crop. Much of this land may be in CRP.

Note 6. The spatially-delinated soil data can be retrieved from http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053627. Farnsworth et al. (2010) also used CSR data to measure productivity. They use the original rating whereas we use CSR2, as made available in 2013 and 2014 by the USDA NRCS.

Note 7. High erodibility is the only eligibility criterion for the CRP general sign-up. The continuous sign-up, introduced in the 1996 Farm Bill, also targets land that adopt certain conservation practices, such as wetland restoration and conserving riparian buffers. Continuous sign-up contracts with high priority conservation practices can be enrolled any time during the year. The NRI records CRP lands under continuous sign-up in their respective categories like cropland, forest, grassland, etc. (p. 12, NRI 2013).

Note 8. Perceptions among concerned observers in the area are that developed areas are expanding more rapidly than these data would suggest (personal correspondence with Susan Hickey, *The Nature Conservancy*).

Note 9. Numbers are somewhat smaller than in table 3 as minor categories have been removed.