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Article

New Cropland on Former Rangeland and Lost Cropland from Urban Development: The "Replacement Land" Debate

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Abstract: In this study, a land use/land cover change analysis method was developed to examine patterns of land use/land cover conversions of cropland to urban uses and conversions of rangeland to cropland uses in the United States (US) Midwest region. We used the US 2001 and 2006 National Land Cover Datasets (NLCD) for our spatial analyses of these conversion trends. Our analysis showed that the eastern part of the Midwest, like prior periods, continued to experience losses of cropland to urban expansion but at a much more rapid rate, as this was during an expansion phase of the US real estate construction cycle. The period showed a very small net loss of cropland as the loss was being balanced by gains in cropland at the expense of rangeland lost in the western part of the Midwest. We refer to this rangeland to cropland conversion as "replacement land". We do not suggest by replacement that there is a signal in the system that interconnects the loss of a hectare of cropland to urban land by converting a hectare of rangeland to cropland, rather we highlight this spatial trend as it raises concerns about the environmental sustainability of agriculture in the western part of the region, as production is dependent on the use of irrigation and the already stressed High Plains aquifer.

Keywords: cropland; rangeland; land-cover change; urban development; water resources; GIS

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1. Introduction

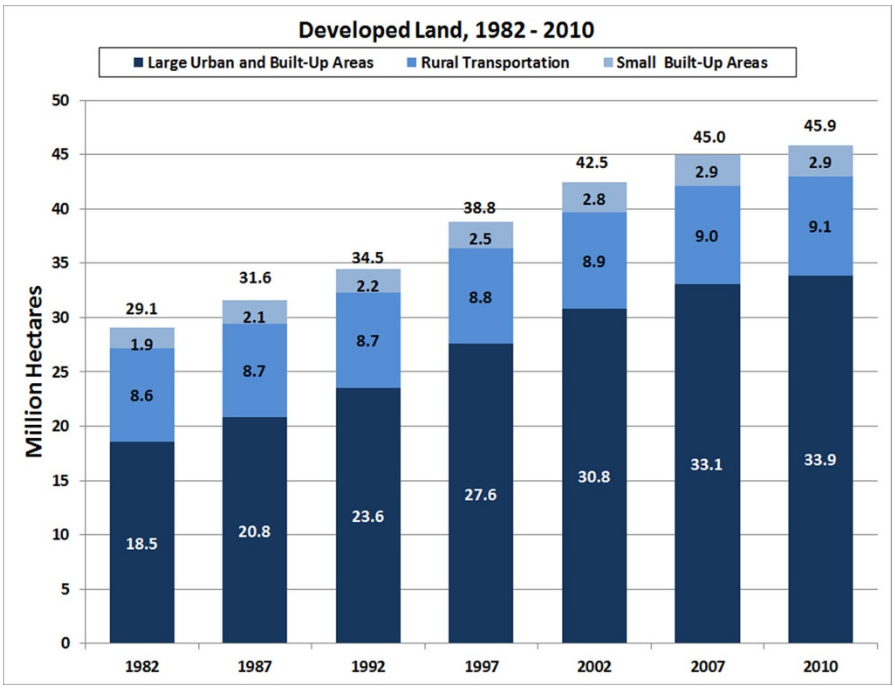
The loss of cropland to urban expansion is an issue of global concern affecting the net supply of high quality farmland [1–3]. In the United States, total cropland has been declining since 1978 and by 2007 it accounted for 18% (165 million hectares (M ha)) of land use [4]. While the overall rate of loss has remained relatively constant over time [5], the amount of farmland has decreased in some areas and increased in others as a result of cropland shifts to more marginal lands as an offset (replacement) to cropland lost to urban development [6,7]. We do not suggest by replacement that there is a signal in the system that interconnects the loss of a hectare of cropland to urban land by converting a hectare of rangeland to cropland. On marginal lands, the use of irrigation for cropland is of concern, particularly in the arid western states where there are competing demands for a limited supply of water [8,9]. Marginal systems also have higher rates of agricultural land use fluctuation in response to climate variability and drought and socio-economic and technological factors [10]. The United States Department of Agriculture (USDA) Farm and Ranch Irrigation Survey [11] found a nearly 5% increase in irrigated farmland (22 M ha in total) since 2003.

In addition to the national level trend of cropland shifting to western states as “replacement” for lost urban-fringe prime farmland [12], there has also been a regional scale trend of cropland shifting westward. Laingen [13] found that since 1997, cropland planted to corn in the Midwest has continued to shift west and north of the traditional “Corn Belt”. Laingen [13] suggests that some of this new corn production may be attributed to declining participation in the USDA’s Conservation Reserve Program (CRP), whereby it has become economically advantageous for farmers to grow crops instead of keeping land in grassland conservation. Several other studies have found increasing rates of grassland conversion to cropland in the Midwest [14–16]. These changes in land use can significantly impact soil and water quality [17,18] and pose a threat to ecological systems [16].

The Energy Independence and Security Act (EISA) of 2007 which seeks to increase energy efficiency and the availability of renewable energy, requires an increase in the production of biomass derived fuels to 136 billion liters per year by 2022 [19]. The resulting large and rapid expansion of ethanol production has greatly increased the demand for corn and the continued expansion of bio-fuel production and biomass energy crops could further influence a trend away from land retirement [20].

In the United States, public and conservationist concerns over the expansion of urban development into agricultural landscapes, has been expressed in terms of the impact of urban/suburban sprawl [21]. Sprawl, the encroachment of commercial and residential development into farmland at the rural-urban fringe, has displaced large areas (4.5 M ha) of cropland [6]. For many years, sprawl driven by economic development has been the dominant form of growth in American metropolitan areas (see review, [22]). Alig *et al.* [23] provide a concise outline of historic trends in urbanization for the United States. From 1960 to 2000, United States Census Bureau data show a 130% increase in urban area. The United States National Resource Inventory (NRI) estimate of developed area increased 34% between 1982 and 1997 [24]. Extending the time period to 2010, the NRI estimate of urban and built-up land had increased 57% over the 28-year period (Figure 1).

Figure 1. Developed land (M ha) in the United States for the period 1982–2010, United States Department of Agriculture [24].



On the basis of the 28-year period, United States residents added an average of 0.6 M ha of urban land every year between 1982 and 2010, peaking in the 1990s. The annual rate of increase has slowed since 1997, even more so since 2007 when it dropped under a 500,000 ha increase (Table 1).

Table 1. Rate of annual increase of urban land (ha), 1982–2010.

5 Year Intervals	Annual Increase (ha)
1982–1987	500,000
1987–1992	600,000
1992–1997	900,000
1997–2002	700,000
2002–2007	500,000
2007–2010	300,000

Trends in urban growth in the Midwest were consistent with the broader scale national trends. Radeloff *et al.* [25] found increasing sprawl fueled by strong housing growth from 1940 to 2000, with the strongest growth occurring in the 1970s and 1990s. Pijanowski *et al.* [26] found a doubling in urban area for major metropolitan areas in Illinois, Wisconsin and Minnesota from 1980 to 2000. Based on projected increases in population density, Alig *et al.* [23] predict continued urban expansion in the Midwest extending to 2025.

With these urban development trends in mind, determining the spatial and temporal dynamics of land use conversion trends is critical to the environmentally sustainable use and development of agricultural resources and land use policy [3,27]. Accurate up-to-date land cover change information is necessary to understanding the underlying causes of land use conversion and the environmental consequences [28]. A wide variety of techniques and disparate data sources have been used to characterize farmland conversion trends at the local scale. Clark *et al.* [5] used farm parcel data to track the rate and pattern of farmland conversion at the individual tax parcel level for a single county in Tennessee. Other studies, such as Levia and Page [29] and Hasse and Lathrop [30], have used surrogate landscape (e.g., loss of natural wetlands, land surface slope) and location (e.g., distance to nearest city center and highway) variables as indicative of land use conversion at the individual farm and local municipality levels, respectively. Polimeni [2] has referred to the combined use of such surrogate variables as bio-physical attributes which he used in conjunction with socio-economic and county-level tax parcel data to calculate and project urban growth trends for undeveloped land parcels.

In the Midwest, Rashford *et al.* [31] modeled economic land use decisions, based on NRI data, at the parcel level using a conditional logit model. They found that the probability of grassland conversion to cultivated crops was a function of soil quality and changes in economic returns of alternative land uses. Sohl *et al.* [32] have developed spatially explicit, scenario based predictions of land use/land cover change for the Great Plains region for the period 2006–2100 that explore a wide range of potential land changes resulting from the interaction of multiple driving force variables including population, economic growth, market forces and climate change. They used the National Land Cover Dataset (NLCD, 1992, 2001–2006) and United States Geological Survey (USGS) Land Cover Trends data (1992–2000) to calibrate the model's spatial component for land use/land cover transitions. Economically-oriented scenarios (driven by increasing population, higher standards of living and technological innovation) showed an increased demand for agricultural land use both for cultivated crops for food and for bio-fuels; this new agricultural land appeared in more marginal areas on the central Great Plains.

More recently, several studies have used satellite data from the National Agricultural Statistics Service Cropland Data Layer (CDL) to investigate land use change associated with grassland to corn or com-soybean conversion in the Corn Belt and northern Plains [15,16]. Wright and Wimberly [15] point to the need for studies of "where, at what rates and on what types of land" current grassland conversion is occurring. They found a net decline in grass-dominated land cover in the Corn Belt, with changes to corn/soybean predominantly occurring on the western margin for the period 2006–2011.

The increasing availability of national level datasets and long-time series of satellite images has provided an opportunity to improve land cover change analysis at greater spatial and temporal scales [27]. Spatial data analysis provides an alternative to the survey method employed by the Census of Agriculture for determining the rate of farmland conversion to developed uses [33]. Previous efforts to quantify the rate and pattern of farmland conversion have relied upon the Census of Agriculture, the NRI or USDA data sources (soil classifications, NLCD, CDL). Hart [34] has found a lack of consistency in conversion rates derived from these sources. In general, there is a lack of longitudinal studies.

There is a paucity of analysis on the rangeland to cropland-urban relationship and the implications for agricultural production shifting towards more environmentally fragile areas which have comparatively more land, but limited water resources. The goal of our study was to examine land cover change dynamics for the 2001 to 2006 time period across the twelve states comprising the Midwest region focusing on the changing spatial trajectory of cropland and the relationship to cropland irrigation. We have developed a new method to deriving land use transitions from the NLCD to address the spatial and temporal patterns of land cover conversion from cropland to urban use and from rangeland to cropland use. By focusing on critical shifts in cropland, we highlight the potential value of new strategies for land and water resource conservation.

2. Methods

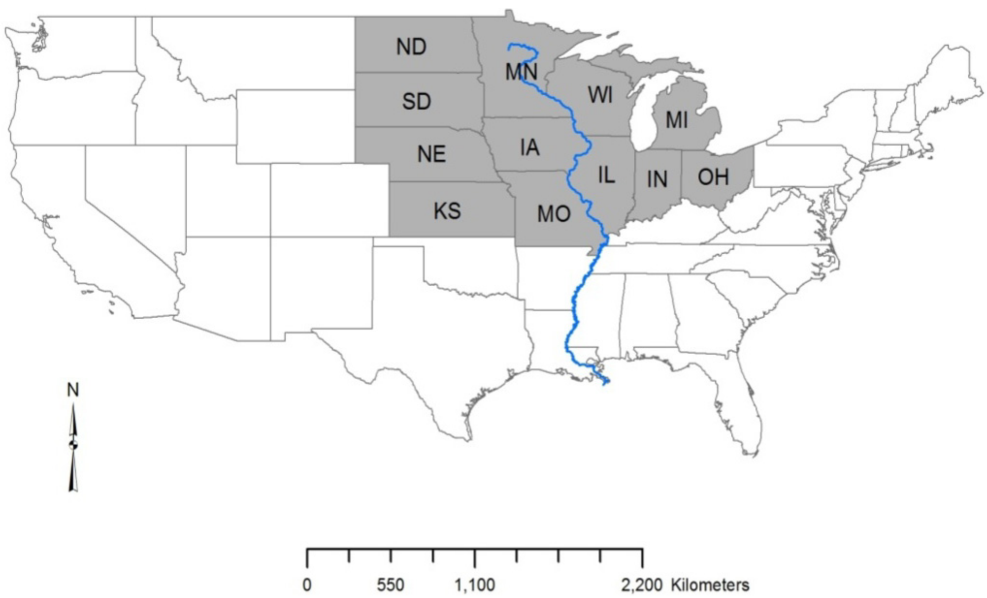
2.1. Study Area

The study area comprises the Midwest region (2.1 million km^2) of the United States (Figure 2). The United States Census Bureau divides the Midwest region into the East North Central Division: Ohio, Indiana, Illinois, Michigan, Wisconsin and the West North Central Division: Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas [35].

The Midwest accounts for 44% of all agricultural commodities and 45% of the agricultural exports of the United States, leading the nation in the production of cattle, corn and soybeans [36]. The Midwest produces approximately 23% of the world's grain supply [37] and coincides with the area of greatest corn production in the United States, known as the Corn Belt. Illinois and Iowa are the "heart" of the Corn Belt, with 70% of their area consisting of primary cropland [38], *i.e.*, land with the ideal combination of soil quality, growing season and moisture supply needed to economically produce sustained yields [39].

The region is characterized by relatively flat grassland, shrub plains and prairies with few trees. The continental location contributes to large seasonal swings in air temperature from hot, humid summers to cold winters [40]. While the total population of the Midwest grew at a 3.8% rate from 2000 to 2009, counties located near metropolitan areas grew at an average rate of 5.3% [40]. The Chicago-Naperville-Joliet metropolitan area is the region's largest urban conglomeration with a population approaching 9.6 million in 2009 [41].

Figure 2. The twelve states of the Midwest study area denoted in gray: Illinois (IL), Indiana (IN), Iowa (IA), Kansas (KS), Michigan (MI), Minnesota (MN), Missouri (MO), Nebraska (NE), North Dakota (ND), Ohio (OH), South Dakota (SD), Wisconsin (WI). The Mississippi River is shown in blue.



2.2. Spatial Data

The United States Geological Survey (USGS) and the United States Environmental Protection Agency (USEPA) generated the National Land Cover Database (NLCD 1992, 2001 and 2006–2011; the latter not published at time of this writing), a 30 m resolution, 16-class land cover classification scheme for the contiguous United States based primarily on the classification of Landsat Enhanced Thematic Mapper (ETM) satellite data [42]. Homer *et al.* [43] using a cross-validation check produced a classification estimate across mapping zones ranging from 70% to 98% with an average classification accuracy of 83.9%.

An additional NLCD2006 product was released that quantifies land cover change between the years 2001 to 2006. This first-time released change product was ideal for our needs as it included a raster layer identifying a from and to land cover class index value label for each pixel in the conterminous United States based on a matrix for all possible land cover change combinations [44]. A detailed description of the pre- and post-processing of this spectral change analysis and land cover classification product is found in [45].

To explore long-term trends in land conversion, we use this change product to replicate the Greene and Stager [6] study which used the National Resource Inventory (NRI) to estimate cropland to urban transitions and rangeland to cropland transitions for the period 1982–1997. However, the NRI definition of rangeland is both a land use and land cover definition while the NLCD is strictly land cover based. To best approximate the NRI definition of rangeland we operationalized this by using the NLCD herbaceous grassland class. Although the categories are not exactly comparable, stemming from the classic conceptual issues related to land use *versus* land cover, they do have significant crossover as shown by comparing the two definitions starting with the NRI rangeland definition:

> "*Rangeland is defined by the NRI as a land cover/use category on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This includes areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and such practices as deferred grazing, burning, chaining, and rotational grazing are used, with little or no chemicals or fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland*" [24].

> "*The NRI definition has land cover attributes as illustrated by the physical descriptors such as grasses and shrubs, but it also includes land use descriptors such as management practices. Meanwhile the NLCD herbaceous grassland definition is physical as it is derived by remote sensing techniques: Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation*" [44].

Disagreement in grass-dominated classes such as developed open, grassland, pasture/hay and emergent wetland accounts for approximately 26% of the classification error for the 2001 and 2006 NLCD, with reported user accuracies of grassland loss and gain of 57% and 69%, respectively [46].

These lower accuracies are in contrast to the greater than 80% accuracy for the water, developed, forest and cropland classes. With these limitations in mind, we use the NLCD 2006 change product to geo-visualize broad scale trends in the conversion of rangeland to cropland.

2.3. Change Detection

In order to assess the spatial distribution of land use change for the 2001 to 2006 study period, we re-classified the NLCD land use/land cover classes into five aggregate categories according to Table 2, with the objective of calculating a land use/land cover transition matrix.

Table 2. Re-classified aggregated land use classes.

Major Land Use	NLCD Class
Cropland	Cultivated crops
Rangeland *	Grassland herbaceous
Forest	Deciduous, evergreen, mixed
Urban	Developed open, developed low intensity, developed medium intensity, developed high intensity
Other	Open water, perennial ice/snow, barren land, shrub/scrub, pasture/hay, woody wetlands, emergent herbaceous wetlands

* NLCD does not have a category called rangeland. By NLCD definition, grassland/herbaceous is utilized for grazing.

Post-classification change detection analysis was performed by direct pixel counting of each transition type, e.g., cropland in 2001 to rangeland in 2006 (Table 3). We selected two transition types (rangeland to cropland and cropland to urban) for the creation of change maps that quantify the amount of area changing from or staying in the same class for the period 2001 to 2006 (Figure 3). We performed a GIS intersection of our 1 km × 1 km grid with the land cover conversions and summed up the hectares. The benefit of the grid method is that as long as the original grid values are retained, any number of derivate variables can be calculated and new data added from other sources.

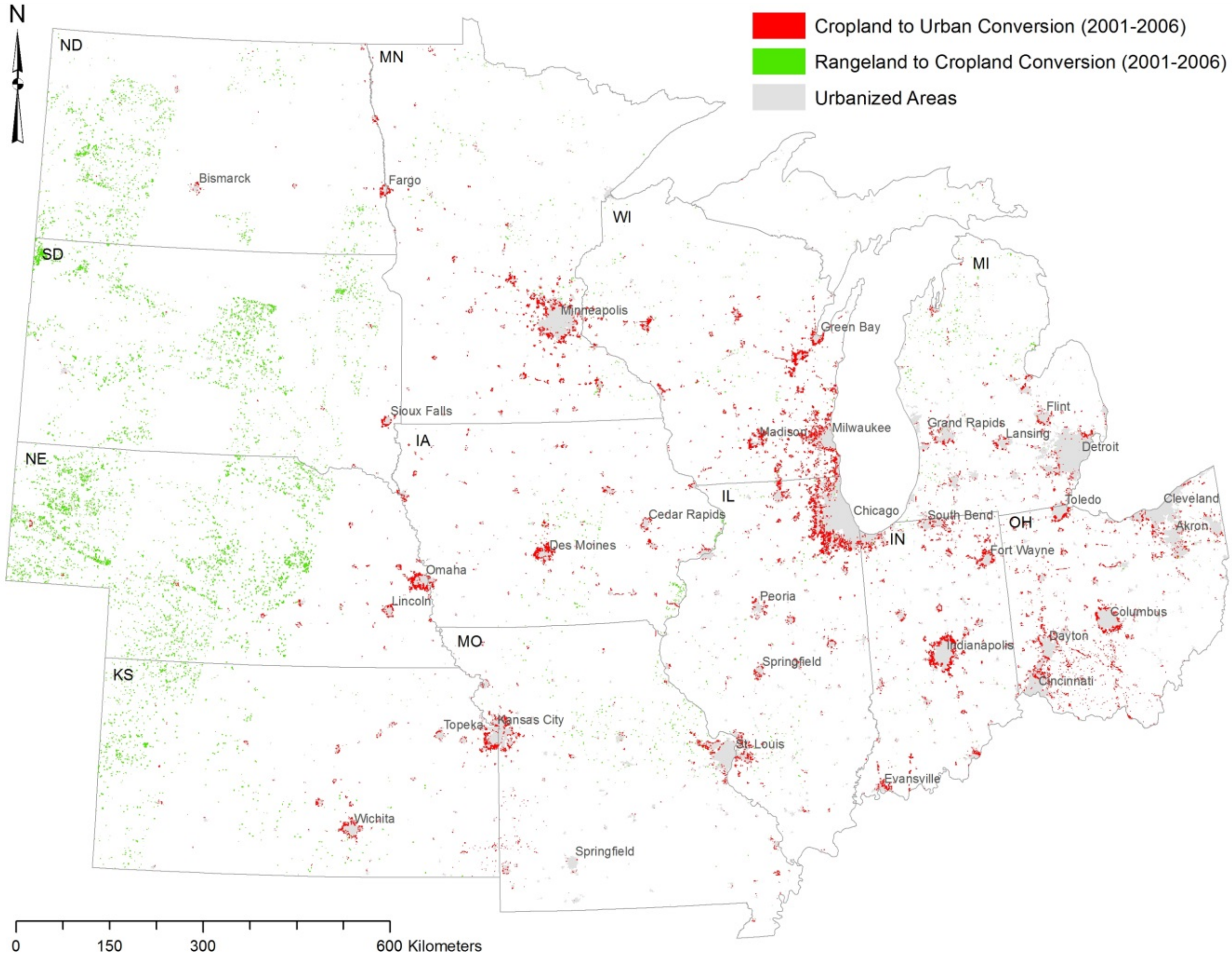
Raster data were converted to polygons and a spatial intersection was performed. A frequency analysis was performed to calculate the number of hectares converted for each grid cell and the resulting table was joined to the grid.

Table 3. Land change (M ha) by major land use in the Midwest United States 2001–2006.

Major Land Use	2006					Total (2001)
2001	Cropland	Rangeland	Forest	Urban	Other	
Cropland	76.11	0.04	0.003	0.13	0.13	76.41
Rangeland	0.11	36.53	0.005	0.02	0.08	36.76
Forest	0.02	0.08	32.45	0.04	0.11	32.70
Urban	1.03×10^{-5}	8.46×10^{-6}	1.89×10^{-6}	13.24	3.73×10^{-5}	13.24
Other *	0.07	0.17	0.02	0.06	38.88	39.19
Total (2006)	76.32	36.82	32.47	13.49	39.21	198.31

* This category comprises open water, barren land, pasture, woody wetlands and emergent wetlands.

Figure 3. Cropland to urban land use conversion and rangeland to cropland conversion for the period 2001 to 2006 in the Midwest United States. Source: National Land Cover Dataset [44].



3. Results and Discussion

3.1. Land Cover Changes 2001–2006

We examined the transitions occurring throughout the 2001 to 2006 time period using the land use transition matrix (Table 3). A row in the matrix shows the transition a given land use type made in the 5 year period. Columns show changes in the overall quantity of the category over time. In 2001, cropland composed 39% (76 M ha) of land in the Midwest (Table 3). Rangeland, forest and urban uses composed 19%, 16% and 0.07%, respectively. From 2001 to 2006, only cropland experienced a 1% decrease. Actual changes in hectares were modest with forest experiencing the greatest loss of 230,000 ha, followed by a 90,000 ha loss of cropland. Urban land increased by 250,000 ha and rangeland by 60,000 ha. The contrast in the trend of an increase in urban land and a decrease in cropland might suggest that urban land is drawing from rural land uses; we show the extent of this below. Further examination of annual changes is needed to determine the rate at which urban land is replacing cropland.

Cropland transitions shown in row one of the matrix, indicated that 99.6% of the land starting out as this category in 2001 remained in the category through the end of the period in 2006. Pijanowski *et al.* [26] also found persistence values for most land uses near 99% in the upper Midwest. For the remaining less than 1%, 130,000 ha of cropland were converted to urban uses, 40,000 ha were converted to rangeland, 3000 ha were changed to forest and the remaining 130,000 ha showed a change to the "other" category composed of open water, barren land, pasture, woody wetlands and emergent wetlands. While cropland was being lost to urban land (130,000 ha), it was gaining land from rangeland (110,000 ha). This conversion trend raises the question about the quality of the cropland being lost to urban development as well as the environmental sustainability of the cropland that was previously range.

3.2. Cropland to Urban Conversion and Replacement Rangeland to Cropland Conversion

Cropland converted to urban use (Figure 3) was concentrated in south-east Minnesota, north-east Illinois, south-east Wisconsin, southern Michigan, central Indiana, with other concentrations centered on large Midwestern cities and suburban fringe areas indicating conditions of sprawl. Examination of Figure 3 shows that large urban areas such as Minneapolis, Indianapolis, Columbus, and Kansas City have perfect circles around their fringes representing cropland to urban conversion while others like Chicago and St. Louis have large arcs of conversion due to the obstacle of Lake Michigan and the Mississippi River, respectively. Greene and Stager [6] found similar conversion patterns for cropland to urban land for the periods 1982 to 1987, 1987–1992 and 1992–1997 for the nation as a whole.

Kazmierczak [47] found similar results for the 2002 to 2007 rangeland to cropland conversion in the Midwest region. Using Anselin Local Moran's I-test, he determined that there was no significant clustering of rangeland to cropland conversion east of the Mississippi River. The swath of clusters was located west of the Mississippi River, with the largest clusters of rangeland to cropland conversion located in the central and western halves of Kansas, Nebraska, North Dakota and South Dakota. Our study results are comparable to Greene and Stager [6] and Kazmierczak [47] in that the location of the clusters coincides with the High Plains region characterized by lower average annual rainfall as compared to the central and eastern portion of the Midwest; indicating that agriculture is moving into areas where irrigation is necessary.

Higher temperatures and lower rainfall amounts tend to reduce crop yields and induce irrigation [48]. In the Midwest, growing season (April–September) temperatures increase along a north-south gradient and rainfall decreases westward with corresponding increases in irrigation [49,50] (Table 4). The western margin states (North Dakota, South Dakota, Nebraska, Kansas) receive 70%–72% of their annual rainfall during the growing season, as compared to 60%–68% received during the growing season in the central Midwestern states (Iowa, Minnesota, Missouri). This pattern of rainfall distribution makes the western margin states sensitive to growing season (April to September) drought. In 2002, when much of the Midwest had experienced above normal rainfall in the early spring [40], 44% of the climate divisions in South Dakota, Nebraska and Kansas were experiencing severe and/or extreme drought conditions during the latter part of the growing season [40]. During the regional drought of 2012 [51], Nebraska had the highest incidence of climate divisions with severe and/or extreme drought conditions (48%) [52].

Table 4. Climate normals for rainfall and temperature (1981–2000) [49] and change in irrigated land [50] for three of the central and the western states of the Midwest region.

State	Rainfall (mm) [1]		Temperature (°C) [1]		Change in Irrigated Land (ha)	
	Annual	Growing Season [2]	Annual	Growing Season	2002–2007	2007–2012
Iowa	915	621	10.5	17.1	+19,186	−7228
Minnesota	704	466	6.1	13.2	+20,844	+7146
Missouri	1117	645	13.3	18.8	+67,586	−7727
North Dakota	453	327	6.1	13.2	+13,485	−7175
South Dakota	508	360	8.6	15.2	−11,024	+1957
Nebraska	600	434	9.4	15.4	+377,729	−106,022
Kansas	771	541	13.3	19.3	+34,184	+47,973

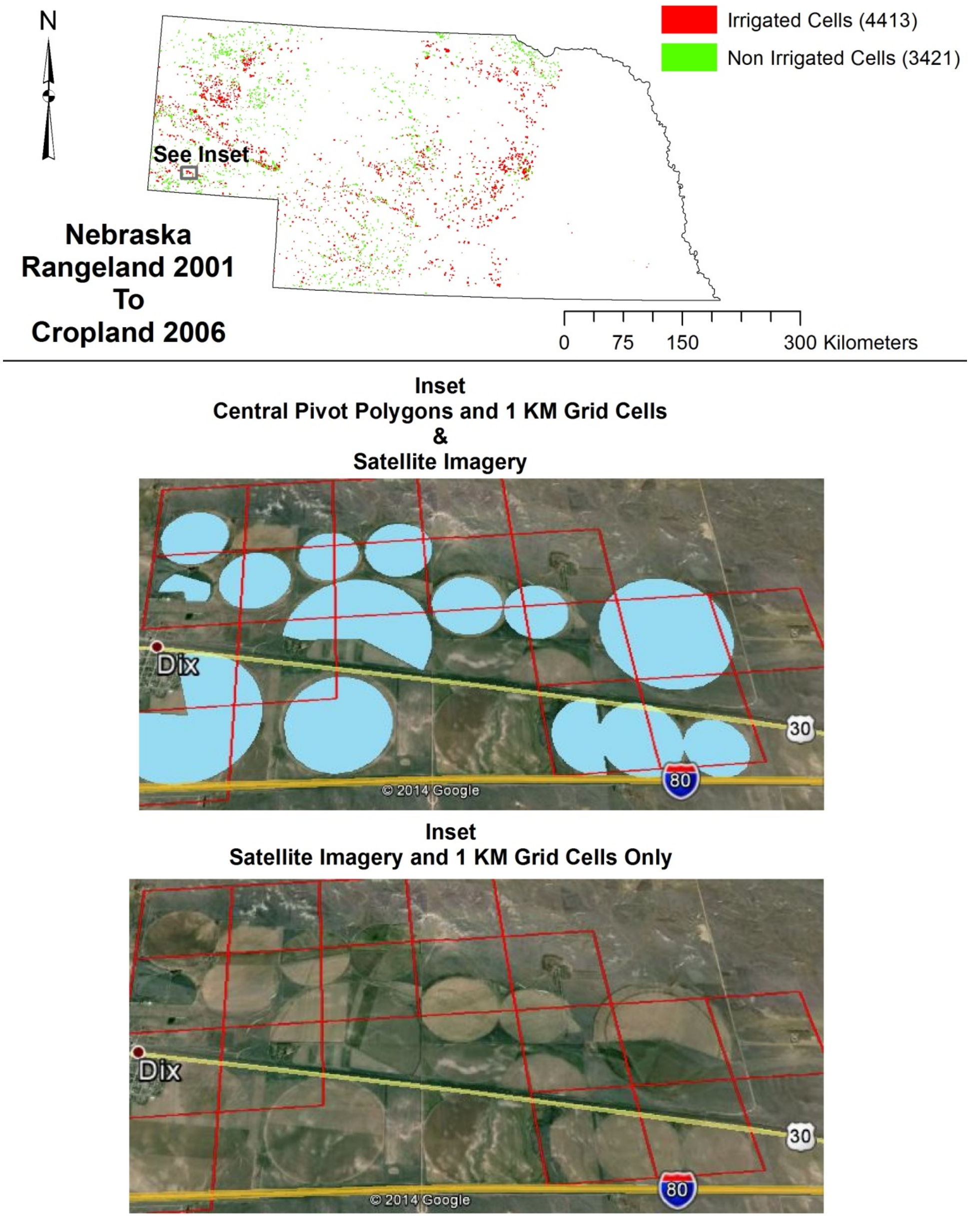
[1] Reported for airport meteorological stations located approximately in the geographic center of the state; [2] The growing season comprises the months April to September.

The replacement land for lost cropland was drawn largely from rangeland in the western portion of the Midwest with the highest concentration in Nebraska (Figure 3). Over this same time period, Nebraska has experienced significant increasing in the amount of land under irrigation (Table 4) and demand on groundwater resources [53]. Between 2002 and 2007, Nebraska was the fourth largest user of groundwater in the United States, with 73% of counties experiencing an increase in irrigated land [50]. This trend continued from 2007 to 2012 with almost half (49%) of the counties experiencing an increase. Of the approximately 22.5 M ha under irrigation nationally, 14.8% are located in Nebraska [50] and center pivot irrigation systems account for almost 98% of the land under sprinkler irrigation in the state [11]. Fifty-six percent of our 1 km grid cells that had incidents of rangeland to cropland conversion intersected with central pivot irrigation polygons [54] (Figure 4). There is a growing need to reduce the consumptive use of groundwater for irrigation in Nebraska related to overuse and the threat to endangered species [55].

The mean annual water application rate on irrigated land in the central and eastern Midwest is approximately 168 mm compared to the higher rate of 313 mm in the more arid Plains states [56]. Irrigation water in the western portion of the study area is being drawn from the Ogallala Aquifer in the High Plains region; a shallow aquifer that stretches from South Dakota to Texas [57]. The aquifer supplies water to seven states and irrigates 25% of the grain produced in the United States [58]. Groundwater depletion has lowered water tables, decreased well flow rates and increased pumping and production costs [59]. Dominguez-Faus *et al.* [58] have predicted a 9% increase in irrigation rates associated with forecasted increases in evapotranspiration rates and decreased rainfall, particularly in Iowa, Minnesota, Nebraska, Kansas and South Dakota. These increased demands raise concern regarding groundwater resource conservation and the ability of replacement cropland to support future food production needs.

A recent study of the sustainability of irrigation in the High Plains [57] found that current withdrawals from the northern part of the aquifer (Nebraska) are balanced by high recharge rates, but lower recharge in the central and southern part of the aquifer (Kansas, Texas) has resulted in depletion of groundwater. This study predicts that the southern portion of the aquifer will be unable to support irrigation in the next 30 years. Although recharge has maintained groundwater storage in the Nebraska portion of the aquifer, groundwater pumping has reduced discharge (stream base flow) in local rivers by 50% [57]. Withdrawals in the western part of the state are now restricted due to interstate usage agreements, litigation over endangered species and the need to protect surface and groundwater interaction [55,57]. Continued pressure on water resources in the Midwest is expected to continue, with climate models predicting increases in temperature and the severity and length or drought conditions despite predicted increases in rainfall [48,56].

Figure 4. Rangeland to cropland conversion for the period 2001 to 2006 in the state of Nebraska intersected with center pivot irrigation. Insets show center pivot irrigation [54] intersected with the 1 km grid (in red).



3.3. Land Use Change

Land use patterns are a function of a number of different variables including agricultural returns (e.g., returns to land, yield, soil quality), market conditions (e.g., price of commodities), urban pressure indicators (e.g., population growth or density, per capita income) and government payments [60–62].

Given a fixed land base, relative land rent (the returns to land after the costs of all other factors of production have been subtracted) is a key determinant of the allocation of land among competing uses [23,60]. An increase in the return of a particular land use will increase the probability of conversion to that use and decrease the probability of conversion from that use to another use [31].

In the Midwest, urbanization is a competing demand for land for non-agricultural use [26,32]. Population growth and rising per capita income have increased the demand for land in urban and suburban areas, thereby increasing the value of land in developed use relative to rural agricultural land uses [23]. In contrast to the competing demands of urban and agricultural uses in the central and eastern Midwest, cropland is competing with grassland in the western part of the region. Rashford *et al.* [31] found that the conversion of grassland to cropland was driven by the economic returns associated with increasing commodity prices, with the probability of conversion generally lower on land of lower agricultural quality. There are net returns from government policies associated with the CRP to protect grassland and bio-fuel subsidies. Government subsidies and the growing market conditions for bio-fuel crops will continue to induce grassland to cropland [31], a trend opposite to what Lubowski *et al.* [61] found between 1982 and 1997 when declining crop market conditions and government payments through the CRP, led to a decrease in cropland.

The recent ethanol mandates (EISA) have resulted in increased commodity prices and higher crop rents (annual per hectare net return to cropland use). Crop prices are expected to rise by 17%–20% by 2022 with a subsequent rise in cropland rent of 2%–4% [59]. Choi *et al.* [62] predict significant losses of grassland and forest in the Midwest associated with higher crop rents. They found that raising crop rents by 1% per year had predicted increases in cropland of 12,141 hectares, with a significant portion (70%) drawn from forestland in Ohio, Indiana and Illinois. Our results show that forestland converted to cropland was not a significant conversion for the region over our study period.

4. Conclusions

While several studies have shown that urban expansion occurs through the reduction of agricultural land (see review in Shalaby *et al.* [3]), comparatively few studies in the United States have looked at where the agricultural land is being replaced. Greene and Stager [6] found that rangeland converted to cropland had a 97% survival rate over a 15 year period (1982–1997), suggesting that rangeland that converts to cropland remains as cropland for extended periods of time and may not be temporary replacement land. Central to the replacement land debate is the issue of environmental sustainability, *i.e.*, the concern that the land that is replacing cropland lost to urban development is more marginal and therefore not as reliable in the long term. This trend is not isolated to the United States. Studies in China (e.g., [63]) have also found the expansion of urban development to be the main reason for cropland loss in traditional agricultural areas. Similarly, arid climate grasslands were reclaimed to meet rising food demands, creating conservation concerns as the reclaimed croplands were more sensitive to climate changes. Additionally, marginal lands are more susceptible to land use change fluctuation as a result of socio-economic and biophysical factors [10].

The spatial analysis approach used in this study has demonstrated that the Midwest is currently experiencing losses of cropland to urban expansion in the eastern part of the region. These losses are being balanced by gains in cropland at the expense of rangeland in the western part of the region.

An important aspect of the trend towards replacement land in more arid regions is the use of irrigation for cropland. Irrigation water in the southwestern portion of the study area is being drawn from the Ogallala Aquifer in the High Plains region. While the aquifer has supported productive agriculture, it has been at the expense of the lifetime of the reservoir [59]. An understanding of these changes is critical to designing both local and state land uses policies aimed at resource conservation and sustainability.

Many of the consequences of cropland conversions highlighted by this study would require a broader level of land use decision-making, for instance at the multi-state level. In order to promote sustainable agricultural practices, policies aimed to conserve natural resources and limit urban sprawl need not be mutually exclusive. A combination of traditional policies such as fiscal incentives, e.g., taxes, subsidies could be combined with sustainability policies, e.g., payment for ecosystem services and smart growth [56,64]. These policies could be coordinated and administered by multi-jurisdictional agencies similar to water or natural resource districts.

We have successfully mapped and analyzed the dynamics of agricultural land use conversion in the Midwest and identified where change is occurring. The use of available datasets allows the methods developed in this study to be replicated by other researchers exploring land use conversion in other areas of the country. Due to the grid cell nature of our change transition tool, other variables can be aggregated to the grid cells and the analysis scaled up or down as needed.

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Author Contributions

Lisa A. Emili is the principal author of the manuscript, Lisa A. Emili and Richard P. Greene. conceived the approach and study design for this paper, Richard P. Greene performed the GIS modeling, Lisa A. Emili and Richard P. Greene interpreted the results and Lisa A. Emili drafted the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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