Midwest U.S. Landscape Change to 2020 Driven by Biofuel Mandates

Megan Mehaffey[1]*, Elizabeth Smith[2], and Rick Van Remortel[3]

1. Environmental Sciences Division, National Exposure Research Laboratory, U.S. Environmental Protection Agency, 109 T.W. Alexander Dr. RTP, N.C., USA mehaffey.megan@epa.gov.

2. Environmental Sciences Division, National Exposure Research Laboratory, U.S. Environmental Protection Agency, 109 T.W. Alexander Dr. RTP, N.C., USA, smith.betsy@epa.gov

3. Lockheed Martin Information Technology RSSS, 1050 E. Flamingo Rd, Suite N-240, Las Vegas, NV, 89119, USA rvanremo@lmepo.com

*To whom the correspondence may be addressed:

Megan Mehaffey
USEPA MCE243-05
109 T.W. Alexander Dr.
RTP, NC, USA
(v) 919-541-4205
(f) 919-541-4329
Email:mehaffey.megan@epa.gov

Abstract

Meeting future biofuel targets set by the 2007 Energy Independence and Security Act (EISA) will require a substantial increase in production of corn. The Midwest, which has the highest overall crop production capacity, is likely to bear the brunt of the biofuel driven changes. In this paper we set forth a method for developing a possible future landscape and evaluate changes in practices and production between base year (BY) 2001 and biofuel target (BT) 2020. In our 2BT 2020 Midwest landscape a total of 25 million acres of farmland was converted from rotational cropping to continuous corn. Several states across the Midwest had watersheds where continuous corn planting increased by more than 50%. The output from the Center for Agriculture and Rural Development (CARD) econometric model predicted that corn grain production would double. In our study we were able to get within 2% this expected corn production. The greatest increases in corn production were in the Corn Belt as a result of conversion to continuous corn planting. In addition to changes to cropping practices as a result of biofuel initiatives we also found that urban growth would result in a loss of over 7 million acres of productive farmland by 2020. We demonstrate a method which successfully combines economic model output with gridded landcover data to create a spatially explicit detailed classification of the landscape across the Midwest. Understanding where changes are likely to take place on the landscape will enable the evaluation of tradeoffs between economic benefits and ecosystem services allowing proactive conservation and sustainable production for both human well being into the future.

Key Words: Biofuels, Corn Ethanol, Agriculture, Future Scenarios, Landscape Change

Introduction

In 2007, Congress passed the Energy Independence and Security Act (EISA 2007) which sets targets for the proportion of transportation fuels that are to be renewable including conventional biofuels (e.g. corn-based ethanol) and "additional renewable fuels" (e.g. advanced biofuels, biomass-based diesel, and cellulosic). EISA also amended the Renewable Fuels Standard (RFS2) created as part of the 2005 Energy Policy Act such that the total amount of renewable fuels targeted by 2022 would increase from 9 billion gallons in 2009 to 36 billion gallons or approximately 13% by volume of all transportation fuels. Through this revised program, the U.S. Environmental Protection Agency established new statutory requirements in 2010 for the production of biofuels, including annual targets for individual fuels that initially consist entirely of corn starch-based fuels (9 billion gallons), but then shift to more advanced biofuels as we approach 2022 when the amount of conventional biofuels is estimated to reach 15 billion gallons, or roughly 42% of the total renewable fuels produced (U.S. EPA, 2010)

The original text from the RFS2 limited planted and crop residue based "renewable fuels" to actively farmed or fallow lands (EISA, 2007). The EPA later published an amendment under the Federal Registry which interpreted fallow lands to include both pasture and Conservation Reserve Program (CRP) lands that are intentionally left idle (FR 14865, March 26, 2010). While this modification of the original RFS2 allows extra lands for possible inclusion in biofuel production the requirement for remaining idle for the previous period would exclude CRP lands that are being actively managed (mowed and burned). Larson et al. 2010 suggest that it is appropriate to exclude pasture from conversion to corn due its strong connection to livestock production and these lands slow response to commodity prices. Therefore, meeting the needs for biofuel targets under EISA without a loss of livestock, animal feedstock or grain for human consumption would require a substantial increase in production of corn on already existing farm land. Greater corn production can be accomplished by increased yield via improved corn varieties, increased acreage of corn planting by expansion into non-traditional corn growing areas, or changes in cropping practices to greater continuous corn planting. It is likely that all three of these options will be needed to meet the greater demand for corn by 2022. The market based incentives for the sale of grain for biofuel have already spurred a 15% increase in corn production in the United States (USDA 2010). This trend is likely to continue into the future to meet the demand for biofuels and to capitalize on government incentives currently in place.

The Midwest, which has the highest overall crop production capacity, is likely to bear the brunt of the biofuel production-driven changes. The increase in biofuel demand in the region will likely increase continuous cropping of corn, stover removal near biorefineries, and conversion to corn on less suitable lands. There is growing concern that these changes in agriculture practices will result in increased ecological and economic costs (Dale et al. 2010, Secchi et al. 2009, Jordon et al. 2007). If the ecosystems of the Midwest are unable to absorb these changes there is increased risk to biodiversity, air and water quality, and human health. Of particular concern for the Midwest are issues associated with greater fertilizer use to support continuous corn, greater need for irrigation in areas where corn is not traditionally grown, and loss of top soil and soil-building residues with increased stover removal. The costs and benefits of these practices will not be evenly distributed due to differences in economic and landscape spatial heterogeneity. Determining where the likely changes in cropping practices will occur is a critical piece of information needed to anticipate local and regional benefits and vulnerabilities

(Dale et al. 2010). For example, an increase in irrigated corn in drier areas of the Midwest might result in greater profit to the farmer but cause unsustainable withdrawals to limited groundwater resources. However, if large numbers of farms within the Mississippi-Atchafalaya river basin change to continuous corn, nitrogen runoff may increase resulting in a further expansion of the hypoxia zone in the Gulf of Mexico. Supplying and maintaining water quality are two of the many ecological services that might be affected by altering current farming practices to meet biofuels targets. Others would include green house gas emissions, carbon storage, nesting habitat, contaminant retention, pest reduction, and soil productivity.

For this study we assume that, given the current state of the technology for manufacturing ethanol, a majority of the initial biofuel production will be provided by switching to greater corn planting. According to data from the National Agriculture Statistical Service (NASS) the total acres of row crops have not changed between 2001 and 2010 (USDA 2010). However, the amount of planted corn has increased by 13.8 million acres. These changes in corn planting have been offset by an equivalent decrease in wheat, sorghum and cotton, suggesting a preferential shift to corn planting in the Midwest. In this paper we demonstrate a method for developing a possible future landscape driven by biofuel demand for corn and evaluate the resultant spatial changes between a 2001 base year (BY) and 2020 biofuel target (BT). These landscape changes can then be used to model or calculate ecosystem function and evaluate tradeoffs in services under different choices in management.

Materials and Methods

Study Area

We delineated a boundary based on the USGS 12-digit hydrologic units (HUCs) intersecting the 12 most productive Midwest states in the U.S (Figure 1). This study area provided a contiguous landscape encompassing large portions of the Midwestern plains and prairie ecoregions (Omernik 1987). The ecoregions are home to at least 34 threatened and endangered species The 12 states also include 165 out of 211 operational U.S. bioethanol production facilities as of July 14, 2009 making them the primary location for increased corn planting to meet the demand for ethanol production (Renewable Fuels Association, 2010).

Datasets

Base year data

We used the 2001 base year (BY) Midwest land cover dataset (Mehaffey et. al., in press) as the starting point for developing the future 2020 BT landscape. The BY 2001 Midwest land cover classification contained 18 classes of agriculture, 155 natural cover, three urban, one barren, and water. The land cover was developed from a combination of the National Land Cover Database (NLCD), the Crop Land Datalayer (CDL), and Landfire Existing Vegetation layers (Homer et al., 2004, US Dept of the Interior, Geological Survey, 2007). The dataset also contained values for the Moderate Resolution Imaging Spectroradiometer (MODIS) based irrigated lands, Soil Survey Geographic Database (SSURGO) soil map unit crop yields; National Agriculture Statistics Service (NASS) county and district-level crop yields; and Agricultural Resource Management Survey (ARMS) state-level tillage practices and fertilizer/pesticide applications. The complete dataset contained 15.5 million grid values and 15 variables.

SSURGO and NASS crop yields

The highest resolution of crop yield data available across the Midwest was from the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO) soil map unit database (USDA, 2010). A total of 1,142 discrete SSURGO soil survey area databases were procured or downloaded from NRCS to encompass the vast majority of the Midwest study area. The component crop yield table within each database was compiled from yield estimates generally calculated by NRCS agronomists knowledgeable about the specific soils and yields in the area. At the time we were developing our dataset SSURGO had not been completed for the whole of the Midwest and we included the county level NASS data to fill in for those locations without yield. The average yield by crop type used to assign yield to all agriculture fields within the county where SSURGO data was missing. For our purposes, annual report data from the 2004-07 time periods were downloaded by state and year from NASS and separated into tables by county and agricultural district entities (USDA 2004-2007).

ICLUS Dataset

The Integrated Climate and Land Use Scenarios (ICLUS) were developed by the U.S. Environmental Protection Agency's Global Change Program (U.S. EPA 2008). The scenarios are based on the Intergovernmental Panel on Climate Change (IPCC) Special Report storylines that are adapted to the United States (U.S. EPA 2008). The ICLUS scenarios were developed for 10 year increments to the year 2100 using demographic and spatial allocation models. For this study we used the baseline 2020 scenario housing units land cover which depicts housing density to determine the location of new urban development. We designated as new urban those areas where density was 1 unit per 4 hectares or less.

Protected Area Database Version 4

The Protected Area Database Version 4 (PAD v4) represents protected areas in the coterminous United States, Alaska, and Canada, and their associated protection levels presented as Gap Analysis Program (GAP) codes. It was built upon the Managed Areas Database (MAD), a dataset depicting major managed areas of the United States (McGie, R.G. 1996). Version 4 of PAD contained additional GAP data including stewardship data for CO, UT, NV, NM, and AZ; nearly all National Wildlife Refuge boundaries of the U.S. Fish & Wildlife Service datasets and a number of wilderness area boundaries.

Econometric Model Data

We wanted to create a future landscape scenario which included potential changes in farming practices and land use resulting from increased demand for biofuel. To do that we relied on economic models based on optimal decisions made as a result of forcing factors in the economy. For this study we used modeled output from the Food and Agricultural Policy Research Institute's (FAPRI). FAPRI consisting of both the Center for National Food and Agriculture Policy at the University of Missouri-Columbia and CARD (Center for Agricultural and Rural Development) at Iowa State University explores the market effects and costs of actual and proposed policies over a 10-year forward-looking period (FAPRI 2008, Tokgoz et al. 2007). The CARD model run we used was structured on provisions of the EISA and the 2008 Farm Bill.

The CARD output data contained state level estimates of agriculture acreage for the base year 2001 and yield by region necessary to meet ethanol demand in the year 2020. CARD crop yield projections were based on USDA's most recent forecasts through 2018, and then extrapolated out through 2020. While the model itself is available only via FAPRI, reviews of the CARD baseline projection for the U.S. agricultural sector and international commodity markets are conducted annually by several groups prior to publication, including USDA, various international organizations, other academic institutions, and other industry experts (EPA 2010).

Scenario Development

Masking unavailable lands

In order to apply crop cultivation scenarios to the BT 2020 we first had to distinguish between lands readily available for cultivation versus protected or unavailable lands. Three grids served as inputs in the preparation of an unavailable lands mask. The BY 2001 Midwest land cover classification was used to identify existing urban land use. The Conservation Biology Institute's Protected Area Database (PAD Version 4) was used to identify designated protected lands (i.e. federal, state, local, and tribal conservation or recreational lands). ICLUS 2020 baseline data of housing density was used to designate the location of future urban land use. The final binary mask grid had values of '0' for unavailable for cultivation and values of '1' for cells available for cultivation.

Assigning 2020 crops to the landcover

We used the CARD model output data for 2020 to determine total planted acres of each crop (i.e. corn, soybean, and wheat) to be assigned to the BT 2020 land cover. The biggest change from 2001 to 2020 was for corn (Table 1). Spatial allocation of the cropped acres were assigned base on soil productivity and land use for agriculture. We used SSURGO yield estimates as a surrogate for soil productivity, the BY 2001 landcover for previously farmed land and binary mask of unavailable lands to select pixels to be assigned to a crop. We used best professional judgment from agricultural experts in the region to set up a sequential selection of crops most likely to shift between classes or from rotation to continuous planting in order to meet the demand for biofuels. For example where yield potential was high (i.e. above ~150 bushel/acre) and the agricultural land was available for conversion (i.e. not protected lands or in new urban), the following rotation classes in the BY 2001 land cover were sequentially reclassified to continuous corn: 1) corn/soybean, 2) corn/other, 3) corn/fallow 4) corn/wheat until total demand was met. For most states shifting from rotation to continuous planting provided sufficient acreage to meet the 2020 CARD corn acreage.

In the Northern and Western states where other rotations were more prevalent (i.e. wheat rotation) we looked to other crop classes to reach the desired corn acreage. In general, the order of preference after corn rotation was the following: soybean and rotations other than corn, cotton plus rotations, alfalfa, wheat plus rotations, other grains, other crops, and fallow idle. The selection of which crops where converted was determined by available acreage and potential yield. Where large acres of soybean or soybean rotation were available those pixels were converted to continuous corn first. The reclassification of soybean to corn would then proceed until the acreage was reduced to match the projected acres of planted soybean from CARD for 2020.

As land cover was shifted to reflect the 2020 CARD targets a check was done for each of the three main cash crops to ensure that they did not shift too far from the model's predicted acreage. Using Statistical Analyst Software (SAS®, Version9.2) we calculated total lands in continuous crop, plus half of any rotation crops. If needed the potential acreage selected for conversion was iteratively adjusted until the total acreage came close to the CARD predictions for corn acreage without loss of more than the 5-10% expected soybean. However, since the CARD wheat acreage was under-represented in 2001 as compared to the BY 2001 we did not try to match the total wheat acreage for 2020 CARD. Instead we used the percent of total change. To do this we shifted part of the undefined crop class into wheat for 2020 where wheat yield was highest. Five states had increased wheat acreage in 2020 CARD, these included Illinois, Iowa, Missouri, Michigan, and Wisconsin (Table 2).

The method we used to shift land cover to meet biofuel targets did not require an increase in land consumption external to already cropped acreage (i.e. forest, pasture). We were able to meet projected 2020 corn acreage from the CARD econometric model by shifting cropping practice out of rotation or other crop types to meet demand. The assumptions we used to develop the BT 2020 land cover do not completely capture specific farmer choices taking place at a local scale. For example, we know from regional experts that many farmers previously enrolled in Conservation Reserve Lands (CRP) have recently withdrawn their lands from the Farm Services Association (FSA) programs and returned them to wheat. However, the assumption in the baseline CARD model output was that the total acres held constant from 2010 to 2020 so only the small changes which occur between 2001 and 2010 are reflected in Table 2. As a result of the lack the CARD assumptions for CRP acres we chose to exclude CRP from our biofuel target scenario. Therefore, the final land cover data should be viewed as representing major changes to large cash crops within the 12 state region of the Midwest as a result of biofuel demand.

Corn yield adjustment coefficients

To calculate future corn production it was necessary to adjust the crop yield estimates from SSURGO and NASS county yield data. The time frame for the SSURGO-based yields was generally earlier (2001) than that of the NASS (2004-2007) county/district yields. Therefore we employed a second yield adjustment coefficient where SSURGO was unavailable. To construct these coefficients we used the CARD econometric sector model year-by-year state average harvested corn yield estimates to the year 2020. We used the 2001 CARD as the base year for SSURGO and 2007 for the NASS data to calculate the absolute difference over time in projected corn yield between the respective base years and the year 2020. We then applied the coefficients to the 2001 yield data to determine future corn yields for the BT 2020 landscape.

Results

As a result of the methods we used to redistribute agriculture across the Midwest landscape to meet future demand for biofuel, several states saw watersheds with a greater than 50% increase in continuous corn planting (Figure 2A). The CARD model indicated that the Iowa and Illinois would see the greatest increase in corn planting with close to four million more acres in each state (Table 1). In Illinois the most productive soils were located in the northern watersheds so our method of spatially allocating the crops resulted in more continuous corn planting in the top half of the state. In Iowa the distribution was spread across the middle of the state. For these two states the vast majority of corn-soybean rotation was shifted into continuous corn to meet the expected target corn production (Figure 3). The states of Nebraska, Minnesota, and the Dakotas had the next greatest change in continuous corn planting, between two and three million acres. In Nebraska the method for selection we implemented placed most of the change from rotation to continuous corn planting within the watersheds south of the Platte River where the fertile loess soils were located. In Minnesota and the Dakotas the changes were distributed across more watersheds having between 16 and 50% shifts to continuous corn cropping (Figure 2A). As in Nebraska, the majority of the watersheds with having the larger shifts to continuous corn were located in the more fertile river outwash areas near major rivers. Across all the Midwest states a total of 40 million acres of farmland was converted to continuous corn with almost 15 million of the acres coming from a other rotational practice including corn.

However, not all of the increased corn production was met by changing to continuous corn planting. In eastern Dakota and western Minnesota increases in corn production were achieved by shifting farming practices from a rotation that previously did not have corn as part of the crop rotation to one that did. The result was increased acres of wheat- corn rotation that reached up to 75% in of a number of watersheds (Figure 2B). To meet the slight increase in soybean production for 2020 in North Dakota and to compensate for loss of soybean production as a result of conversion to corn in the states of South Dakota and Michigan we shifted a number of the wheat fields into rotation with soybeans. The greatest shift to soybean rotation (without corn) within a watershed was 90% (Figure 2C). Other changes were less dramatic with most watersheds having less than 15% shift to soybean rotation.

After creating the BT 2020 land cover we compared expected change in corn acreage predicted by the CARD econometric model with the final acreage in the 2020 scenario that we developed for the Midwest (Table 1). While we used the CARD acreage as a starting point for the disaggregation into the final 30 meter grid, we did not expect complete agreement for each state after we applied our methods for spatially allocating the crops to the landscape. We found that our methods resulted in the BT 2020 land cover having greater acreage in the Corn Belt states particularly in the states of Iowa and Ohio, while the Lake states and the Northern Plains states had slightly less than the CARD model projections. As soil fertility was the main selection criteria, states such as Iowa and Ohio had a slightly greater conversion to continuous corn which offset the production in the drier northern states. Despite the state to state differences the overall corn acreage in the Midwest BT 2020 was within 1% of that predicted by the CARD model.

Applying the yield adjustment coefficients to the landscape scenarios resulted in variability in yields within and between regions (Table 3). Yields increased between 30 and 60 bushels per acre between BY 2001 and the BT 2020. In the Corn Belt our coefficient derived corn yields were roughly equivalent to the CARD model values. However, in the Central and North plains our average yields were lower by around 10 bushels than the CARD model yields. There was a general east to west gradient in average watershed yields with the colder drier areas of North Dakota where little corn is grown having the lowest overall values (Figure 4). The highest BT 2020 yields were concentrated in central Iowa and Illinois where many watersheds had yields ranging between 100 and 200 bushels per acre (Figure 4).

With the increased continuous corn planting, higher yields, and expansion of corn into new areas most states in the Midwest came close to doubling the total corn grain production (Table 3). We found that the changes in corn grain production within the 12-digit watersheds reflected a combination of shifts in cropping practices in combination with the slight increases in yield. In the Northern Prairie region the addition of more corn into the rotation increased grain production in the eastern watersheds of North and South Dakota. In the Northern Plains watersheds to the south of the Platte River stand out with total grain production increases reaching over 1 million bushels in some watersheds. According to the CARD model the greatest increases in production are expected to occur in the Corn Belt. In the states of Illinois and Iowa we were able to reach the doubling of corn grain production with high rates of continuous corn planting and a 60 bushel per acre increase in yield.

In addition to changes to future cropping practices we also were able to represent farm land loss from urban growth by including the ICLUS baseline data. The ICLUS demographic and spatial allocation models expanded suburban growth around major city centers were the growth radiated out into land that in BY 2001 were being used for agriculture. After applying the new urban to the landscape we found that all 12 states had several watersheds where urban growth resulted in lost agriculture lands (Figure 5). In states like Iowa, Missouri, and Minnesota bedroom communities were predicted to expand near larger metropolitan areas. The suburban growth in these three states consumed farmland resulting in the loss of 2.47 million acres of previously cropped fields. The expected growth around the larger cities like Chicago resulted in loss that expanded into not only northeast Illinois but also neighboring states of Wisconsin and Indiana. The western Dakotas and Nebraska have fewer large cities and in many locations population is actually in decline, therefore watersheds in these areas showed the least amount of farmland loss. We determined that urban growth could result in a loss of over 7 million acres of productive farmland in the BT 2020 Midwest landscape. The urban projections from ICLUS do not represent specific situations at a local scale where protection ordinances restrict conversion of agriculture lands but more the potential loss given expected population growth across the Midwest.

Discussion

The desire to move toward energy independence on foreign oil in the United States has led to a search for alternative sources of renewable energy. Current conventional biofuels are predominantly corn-based ethanol, thus the requirements for ramping up production of corn production to allow time for new the technologies to emerge which can better process advanced biofuels. The government mandates for ethanol spurred a rapid inflation of corn prices reaching a peak in 2008 (Fortenbery and Park, 2008). These increases in price have had a beneficial effect on the income and wellbeing of farmers (Larson et al. 2010). Consequently a large number of farmers, wanting to capitalize on the market, shifted their lands into corn production. Fargione et al. (2009) provide a graph of this relationship between ethanol production and corn planting showing the sudden spike that occurred after 2005. Increased corn planting is expected to continue into the future to meet the desired production of 36 million gallons of ethanol by 2022. Previous studies have used much larger scales (7 to 10 km) land cover and use datasets to assess impacts from biofuel production (Costello et al. 2009, Donner and Kucharik 2007). These studies, while first to wave the red flag relating issues of increased nitrogen inputs to the rivers of the Midwest miss finer scale variability in cropping practices that could change overall loads. As a result of the large scale these studies use other data such as the county level agriculture information to apportion total agriculture within the landscape. To the best our knowledge there have been only two studies, technical reports, which have produced finer scale landcover that includes crop rotational practice (Stern et al, 2008 and Santhi et al 2008).

In this study we demonstrated a method for combining economic model outputs with geographic data in order to create a detailed future landscape scenario based on increased biofuel feedstock production. We use the economically based prediction of future acres, crop rotation, and soil productivity to spatially allocate the shifts in cropping practices would occur across the Midwest. Our disaggregation method resulted in substantial agreement between the predicted future acreage by the econometric model and the developed GIS landscape. To create our landscape it was necessary to make some assumption based on current trends and current refinery technology. We assumed that the majority of the mandated ethanol production would initially come from corn grain. The second assumption we made was that the conversion to continuous corn would occur first on the most fertile soils. Lastly we assumed that shifting crop rotational practices on currently farmed fields would occur before any shifts to CRP or pastureland occurred. Based on these assumptions and our final BT 2020 landcover we found that the Upper Mississippi watersheds might expect see the largest shifts to continuous corn planting and grain production in the next 10 years. States having the highest percent increase were Iowa and Illinois. The soils of these states are predominantly silt loams derived from glacial till. Despite decades farming the soil continues to support high yields do to the rich soils and continued use of industrial fertilizer (Foley et al. 2004). Other areas that should see an increase in conversion to continuous corn are Nebraska south of the Plate River and watersheds scattered throughout Ohio and Indiana. The remaining states, such as North and South Dakota, might expect increased corn production as a result of incorporating corn into rotational planting practices rather than continuous corn. Larson et al. 2010 found a similar shift of crops like soybean and cotton out of the midcontinent in order to accommodate increased corn production.

It is impossible to predict the exact amount of change in yield that will occur in the future. Changes in climate and farming practices along with advances in genetic modification for crops will result in some variability across the Midwest. However, past trends suggest that we can expect at least some improvement in yields in the future (Tannura et al., 2008). In our study we used a crop yield adjustment coefficient to account for increases in future corn production across the Midwest. The yield coefficient resulted in pushing the bushel per acre production close to 200 in the highly productive Corn Belt states and Lake States (Table 3). By applying the increased levels of corn production to land classified as corn or corn rotation in the BT 2020 landscape we were able to come within 2% of predicted total corn grain production predicted by the CARD model for the Midwest on currently farmed or fallow fields.

The changes in land use by farmers combined with continued urban growth are expected to alter the environment and production of ecosystem services (Dale et al. 2010). The continued loss of productive farmlands to urban growth has the potential to compound these problems by forcing corn feedstock production for ethanol onto fewer hectares of land or pushing it into lower quality lands. Not surprisingly many environmental groups and government agencies have expressed concern that a focus on corn based biofuels will further degrade surface and ground water across the Midwest and exacerbate the hypoxia issue in the Gulf Coast (Dale et al., 2010)

The ecosystem services with the strongest link to continuous cropping of corn include soil productivity, water quality, water quantity, and air quality (Searchinger et al. 2008, Landis et al. 2008, Jordon et al. 2007). To determine the sustainability biofuel driven land use practices including the trade-offs among these ecosystem services we must first have information about the spatial distribution and intensity of the changes involved.

The higher demand to support productivity levels reaching into the billions of bushels of corn will likely deplete soil resources across the Midwest. The resulting loss of soil productivity from extensive corn planting and loss of residue has been shown to lead to decreased yield (Banco-Canqui et al., 2006). Once refineries are in place to process corn stover those farmslands in close proximity could see 75% removal of residue from the fields, which would further increase soil erosion (Graham et al., 2007, Perlack et al., 2005). From 1987 to 2007 application rates have increased by close to a million tons across the United States (IPIN, 2010). Some of this increase has been offset by N removal via fixation by legumes, higher density planting, and retention in the grain. However, continuous corn planting will remove legumes as part of the rotation in many areas of the Midwest thus resulting in a loss of any nitrogen fixing benefits. Maintaining soil productivity will likely require farmers to increase fertilizer applications (Larson et al. 2010). Without greater conservation practices the increased fertilizer expected to increase loads to streams and gases to the atmosphere degrading both water and air quality. Planting millions of hectares of continuous corn fields also lends itself to increases in the spread of harmful pests potentially leading to increased pesticide use (Weiss, 2002).

In the Midwest corn production is a major economic good to the farmers but as demonstrated by several studies (Alexander et al. 2008, Gassman et al. 2006,) it is also strongly correlated with increase degradation of a number of ecosystem services. The tradeoffs could be evaluated using our BT 2020 scenario and compared to the BY 2001 for the Midwest region. An additional trade off to evaluate might be between urban growth and lost farmland. Using the total acres replaced with urban in the BT 2020 as a quick estimate we calculated a decrease of over 1 billion bushels of corn for the Midwest or 4 billion dollars assuming a price per bushel of four dollars. Future research might include an evaluation how the agriculture losses stacks up in relation to economic benefits from urban growth at the local and regional level.

By linking agricultural landcover types to rotational practices, fertilizer and pesticide application rates, and yield in the final 2020 dataset we can estimate ecological response functions related to nutrient and pesticide loading and retention rates at fine scale using accumulation models. Recently the USDA Conservation Effects Assessment Project (CEAP; USDA 2010) has evaluated the benefits of conservation management in the Upper Mississippi River Basin. Their study showed significant decreases in sediment, nutrient and pesticide problems when conservation practices were combined and targeted to critical areas. With very little effort our BT 2020 dataset could be used to proactively select locations that would help sustain water quality in the future with the implementation of conservation enhancements. In this study we demonstrated a method that can effectively be used to develop a detailed future scenario from economic model output. Understanding where changes are likely to take place on the landscape will enable the implementation of proactive measures such as those taken by the CEAP program to maintain sustainable production for both food and fuel into the future.

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References

Alexander, R.B., Smith, R.A., Schwarz, G.E., Boyer, E.W., Nolan, J.V., and Brakebill, J.W.. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environmental Science and Technology 42(3):822-830.

Banco-Canqui, H., R. Lal, W.M. Post and L.B. Owens. 2006 Changes in long-term no-till corn growth and yield under different rates of stover mulch. American Society of Agronomy 98:1128-1136.

Costello, C, W.M. Griffin, A.E. Landis, and H.S. Matthews. 2009. Impact of biofuel crop production on the formation of hypoxia in the Gulf of Mexico. Environmental Science and Technology. 43:7985-7991.

Dale, VH, Fargione, J, Kline, K, Wiens, J. 2010. Biofuels: Implications for Land Use and Biodiversity. Biofuels and Sustainability report of the Ecological Society of America (http://www.esa.org/biofuelsreports).

Donner, S.D., and C.J. Kucharik. 2008. Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi river. Proceedings of the National Academy of Sciences. 105: 4513-4518.

Energy Independence and Security Act 2007. Title II-Energy security through increased production of biofuels, Subtitle A – Renewable fuel standard.

FAPRI (Food and Agricultural Policy Research Institute). "Baseline Briefing Book." FAPRI-MU Report #03-08, University of Missouri, Columbia, March 2008.

Fargione J.E., T. R. Cooper, D.J. Flashpohler, J. Hill, C. Lehman, T. Mccoy, S. Mcleod, E. J. Nelson, K. S. Oberhauser, and D. Tilman 2009. Bioenergy and Wildlife: Threats and Opportunities for Grassland Conservation. Bioscience 59 767-777

Federal Register, Friday, March 26, 2010. Rules and regulations 14681. Vol 75. No. 58.

Foley, J. A., C.J. Kucharik, T.E. Twine, and M.T. Coe 2004. Land use, land cover, and climate change across the Mississippi basin: Impacts on selected land and water resources. *In:* Ecosystems and Land Use Change. DeFries, R., Asner, G., and Houghton, R. (eds). American Geophysical Union, Geophysical Monograph Series Vol. 153, 344 pp. Washington, D.C.

Fortenbery, T.R. and H. Park, 2008. Effect of Ethanol Production on the U.S. National Corn Price. Staff Paper No. 523. Department of Agricultural and Applied Economics, University of Wisconsin-Madison.

Gassman, P.W., Secchi, S., and Jha, M. 2006. Upper Mississippi river basin modeling system Part1: SWAT input data requirements and issues. Coastal Hydrology and Processes (ed. By V.P.

Singh and Y. J. Xu) pp 103-115. 2006 Water Resources Publications, LLC, Highlands Ranch, CO, USA.

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. 2007. Currt and potential U.S. corn stover supplies. Agronomy Journal. 99:1-11.

Homer C., Huang C.,Yang L, Wylie, B. and Coan M. 2004. Development of a 2001 National Land-cover Database for the United States. Photogrammetric Engineering and Remote Sensing 70:829-840.

IPIN, International Plant Nutrition Institute, 2010. A preliminary nutrient use geographic Information System (NuGIS) for the U.S. IPNI Publication No. 30-3270. Reference No. 09130. Norcross, GA.

Larson, J.A., B.C. English, D.G. De La Torre Ugarte, R. J. Menard, C.M. Hellwinckel, and T.O. West. 2010. Economic and environmental impacts of the corn grain ethanol industry on the United States agricultural sector. Journal of Soil and Water Conservation. 65:267-279.

McGie, R.G. 1996. Creation of a comprehensive managed areas database for the coterminous United States. Summary project technical report NASA-NAGW-1743. Remote Sensing Research Unit, University of California, Santa Barbara).

Mehaffey, M.H., R. VanRemortel, E.Smith, and R. Bruins. In press 2011. Developing a dataset to assess ecosystem services in the Midwest, United States. International Journal of Geographic Information Services. Vol 25.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77(1):118-125.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. DOE/GO-102995-2135 ORNL/TM-2005/66

Renewable Fuels Association 2010. Biorefinery locations. Available online at http://www.ethanolrfa.org/ [Accessed February 15, 2010]

Santhi, C., P.W. Gassman, S. Secchi, and R. Srinivasan. 2008. Comparison of land use area estimates from three different data sources for the Upper Mississippi river basin. Center for Agriculture and Rural Development Technical Report 08-TR 48.

Stern, A.J., P. Doraiswamy, and B. Akhmedov 2008. Crop rotation changes in Iowa due to ethanol production. Proceedings of the International Geoscience and Remote Sensing Symposium, July 6-11, 2008. Boston, MA. V-200-03

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong. A. Elobeid, J. Fabiosa, S.Tokgoz, D. Hayes, and Tun-Hsiang Yu 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gasses through Emissions from Land Use Change. Science, 08/02/2008, pp. 1238-1240.

Secchi, S., P.W. Gassman, J.R. Williams, B.A. Babcock. 2009. Corn-based production and environmental quality: A case of Iowa and the Conservation Reserve Program. Environmental Management. 44:732-744.

Tannura, M. A., S. H. Irwin, and D. L. Good. "Weather, Technology, and Corn and Soybean Yields in the U.S. Corn Belt." Marketing and Outlook Research Report 2008-01, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, February 2008. Available at [http://www.farmdoc.uiuc.edu/marketing/morr/morr_archive.html]

Tokgoz, S., A. Elobeid, J.F. Fabiosa, D.J. Hayes, B.A. Babcock, T-H. Yu, F. Dong, C.E. Hart, and J.C. Beghin. "Emerging Biofuels: Outlook of Effects on U.S. Grain, Oilseed, and Livestock Markets." CARD Staff Report 07-SR 101, Center for Agricultural and Rural Development, Iowa State University, July 2007 (Revised). Available online at http://www.card.iastate.edu/publications/synopsis.aspx?id=1050.

United States Department of Agriculture (USDA) 2010. Assessment of the effects of conservation practices on cultivated cropland in the Upper Mississippi River Basin. Final Draft Report.

United States Department of Agriculture, 2010. Soil Survey Staff, Natural Resources Conservation Service, Soil Survey Geographic (SSURGO) Database for [Survey Area, State]. Available online at http://soildatamart.nrcs.usda.gov. [Accessed May15, 2010].

United States Department of Agriculture 2004-2007. National Agriculture Statistics Service, Crop Yields for Corn, Soybean, Wheat, Hay. Available at http://www.nass.usda.gov/Data_and_Statistics/County_Data_Files/ [Accessed June 21, 2010]

United States Department of Interior, Geological Survey, 2007. The National Map LANDFIRE: LANDFIRE National Existing Vegetation Type layer. Available online at http://gisdata.usgs.net/website/landfire/ [Accessed February 8, 2010].

United States Environmental Protection Agency. 2008. Preliminary steps towards integrating climate and land use: the development of integrated climate and land use scenarios. Global Change Research Program, National Center for Environmental Assessment, Washington, DC; EPA/600/R-08/076A. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

United States Environmental Protection Agency (EPA) 2010. National Renewable Fuel Standard Program for 2010 and Beyond. Office of Transportation and Air Quality EPA-420-F-10-007.

Weiss, M.J. 2002 Monocultures and pests. *In* Encyclopedia of Pest Management (Print), Edited by David Pimentel CRC Press 2002. Published by Taylor and Francis Group, Boca Raton, Florida USA.

Table 1. Comparison of planted acres of corn from the Center for Agriculture and Rural Development (CARD) model and planted acres of corn and corn rotation in the Midwest base year (BY 2001) and biofuel target (BT 2020) landcover data.

	CARD			Midwest Landcover Data		
	BY 2001	BT 2020	Change	BY 2001	BT 2020	Change
	Millions of Acres					
Corn Belt	35.6	46.6	11.05	35.83	50.30	14.47
Illinois	11.2	14.91	3.71	11.28	14.85	3.57
Indiana	5.7	7.3	1.6	6.21	7.74	1.53
Iowa	12.3	16.32	4.02	12.44	18.68	6.24
Missouri	2.85	3.86	1.01	2.77	3.85	1.08
Ohio	3.55	4.23	0.68	3.13	5.18	2.05
Central Plains	11.95	15.97	4.02	11.27	15.32	4.05
Kansas	3.45	4.96	1.51	3.30	4.80	1.50
Nebraska	8.5	10.71	2.21	7.97	10.52	2.55
Lake States	12.9	18.11	5.21	14.44	17.94	3.50
Michigan	2.2	3.05	0.85	2.58	2.82	0.24
Minnesota	7.2	10.12	2.92	7.59	10.32	2.73
Wisconsin	3.5	4.94	1.44	4.27	4.80	0.53
Northern Plains	5.38	10.18	4.8	7.01	10.26	3.25
North Dakota	1.08	3.91	2.83	2.35	4.22	1.87
South Dakota	4.3	6.27	1.97	4.66	6.04	1.38

Table 2. Change in planted acres of corn, soybean and wheat between base year (BY 2001) and biofuel target (BT 2020) from the Center for Agriculture and Rural Development (CARD) model.

	Wheat			Soybean			CRP		
	BY 2001	BT 2020	Change	BY 2001	BT 2020	Change	BY 2001	BT 2020	Change
	Millions of Acres								
Corn Belt	3.69	3.42	-0.27	36.3	26.9	-9.4	4.34	4.35	0.01
Illinois	0.95	1.08	0.13	10.5	7.29	-3.21	0.78	0.89	0.11
Indiana	0.55	0.47	-0.08	5.5	4.2	-1.3	0.27	0.26	-0.01
Iowa	0.02	0.04	0.02	10.7	7.46	-3.24	1.59	1.61	0.12
Missouri	1.05	1.06	0.01	5.15	4.3	-0.85	1.43	1.3	-0.13
Ohio	1.12	0.76	-0.36	4.45	3.64	-0.81	0.28	0.3	0.02
Central Plains	11.55	10.74	-0.81	7.15	7.19	0.04	3.57	3.75	0.18
Kansas	9.8	9.03	-0.77	2.85	3.09	0.24	2.52	2.66	0.14
Nebraska	1.75	1.71	-0.04	4.3	4.1	-0.2	1.05	1.09	0.04
Lake States	2.57	2.11	-0.46	10.9	8.25	-2.65	2.33	2.23	-0.1
Michigan	0.52	0.62	0.1	2.05	1.49	-0.56	0.28	0.23	-0.05
Minnesota	1.87	1.2	-0.67	7.3	5.55	-1.75	1.46	1.5	0.04
Wisconsin	0.18	0.29	0.11	1.55	1.21	-0.34	0.59	0.5	-0.09
Northern Plains	12.48	9.8	-2.68	6.3	8.38	2.08	4.49	4.03	-0.46
North Dakota	9.45	6.97	-2.48	1.9	4.26	2.36	3.16	2.76	-0.4
South Dakota	3.03	2.83	-0.2	4.4	4.12	-0.28	1.33	1.27	-0.06

Table 3. Total corn grain production and yields from the Midwest base year (BY 2001) and biofuel target (BT 2020) landcover, the Center for Agriculture and Rural Development (CARD) model and the National Agriculture Statistics Service (NASS).

Regions		Total Corn Grain Production		Corn Yield	
		BY 2001	BT 2020	BY 2001	BT 2020
Corn Belt	States	Million Bushels	Million Bushels	Bushels/ Acre	Bushels/ Acre
	IL	1,654	3,044	147	216
	IN	725	1,292	112	177
	IA	2,017	4,209	159	234
	MO	383	676	135	188
	OH	376	870	116	173
Total/Avg		5,155	10,091	134	198
CARD Total		5,088	9230	147	193
NASS Total		4981	6418*	145	171*
Lake States					
	MI	286	460	111	157
	MN	1,029	2,023	133	195
	WI	463	775	107	166
Total		1,778	3,258	117	173
CARD Total		1,569	3,142	138	180
NASS Total		1336	2001	121	158
Central Plains					
	KS	317	577	100	135
	NE	857	1,393	135	161
Total		1,174	1,970	118	148
CARD Total		1,571	2,922	127	167
NASS Total		1526	2173	137	167
Northern Plains					
	ND	200	522	77	149
	SD	327	623	68	113
Total		527	1,145	73	131
CARD Total		540	1,507	112	150
NASS Total		787	907	112	133

* = NASS total production and yield data as of 2009

Figures

Figure 1. The Mississippi/Atchafalaya drainage basins and the 12 states of the Midwest study area (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)).

Figure 2. Percent change in **A**) monoculture corn, **B**) corn as part of rotational cropping and **C**) soybean as part of (non-corn) rotational cropping between 2001 base year (BY) and 2020 biofuel target (BT) within the 12-digit hydrologic units of the Midwest.

Figure 3. A close up view of the cropping changes between our 2001 base year (BY) **A**) and 2020 biofuel target (BT) **B**) landscape. Cropping changes are due to shifts in corn production as a result of biofuel demand.

Figure 4. Average bushel per acre for 2020 biofuel target (BT) within the 12-digit hydrologic units of the Midwest.

Figure 5. Change in total acres of farmland as a result of urban growth between 2001 base year (BY) and 2020 biofuel target (BT) within the 12-digit hydrologic units of the Midwest.

1

Figure 1.

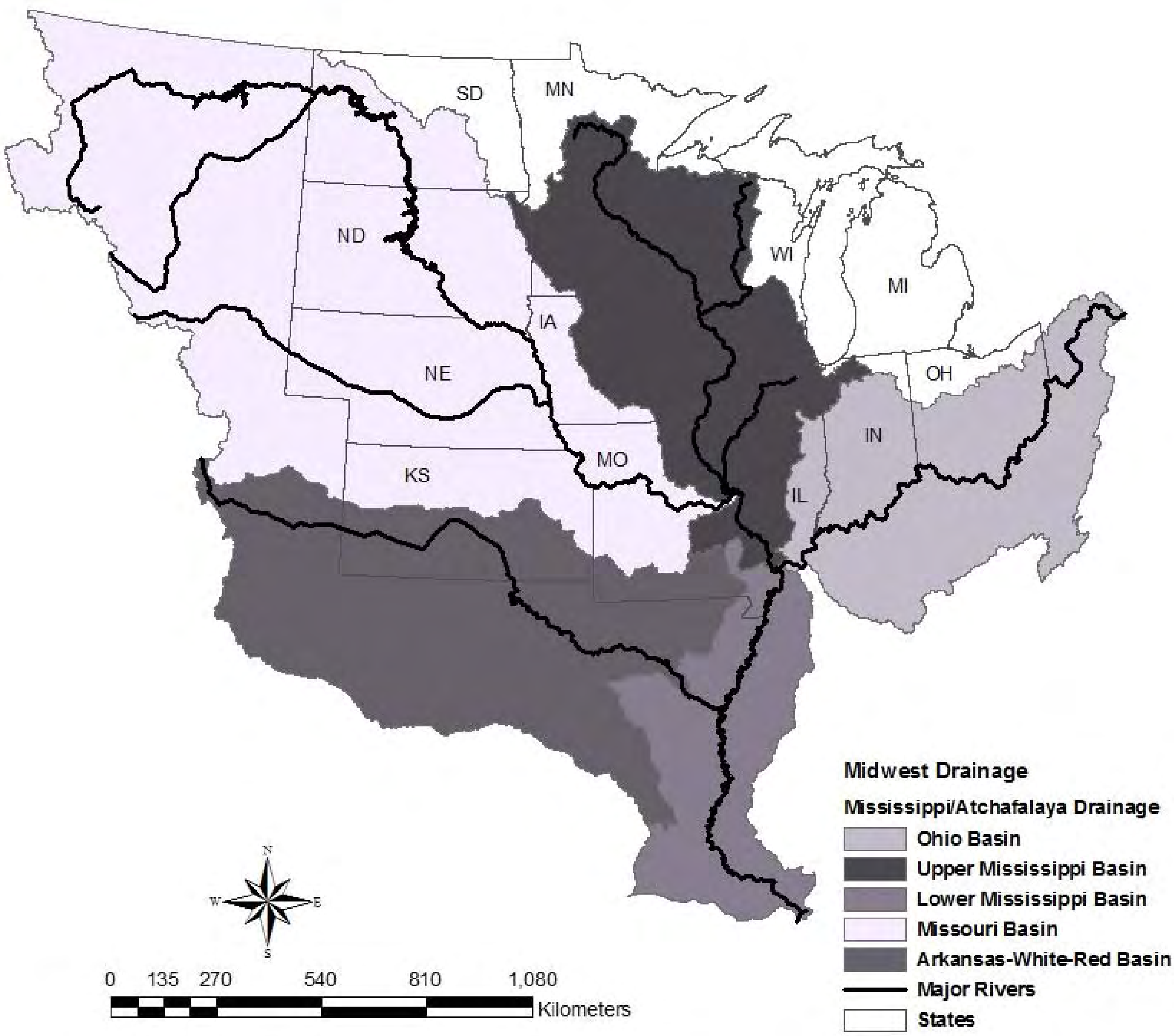
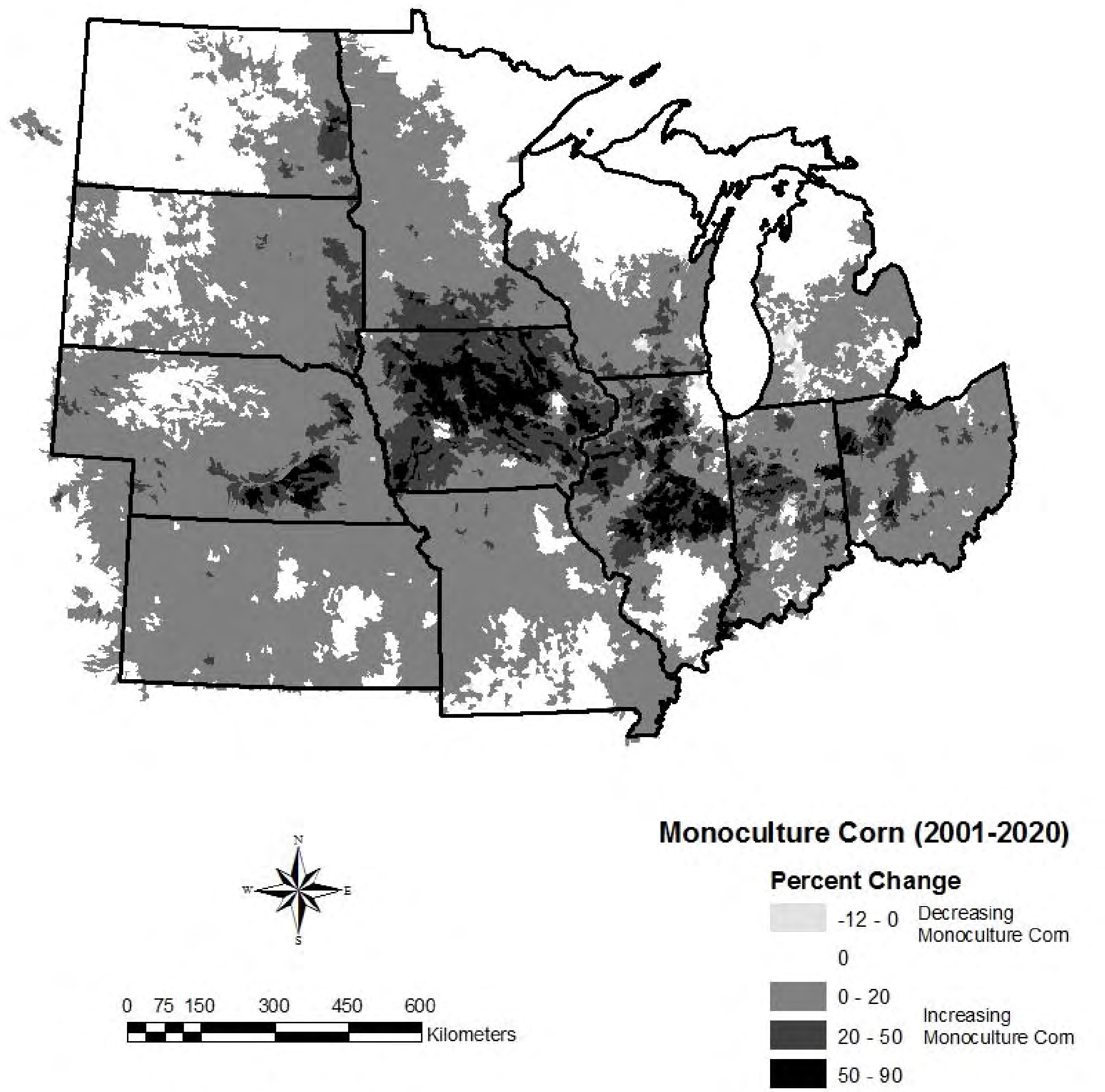
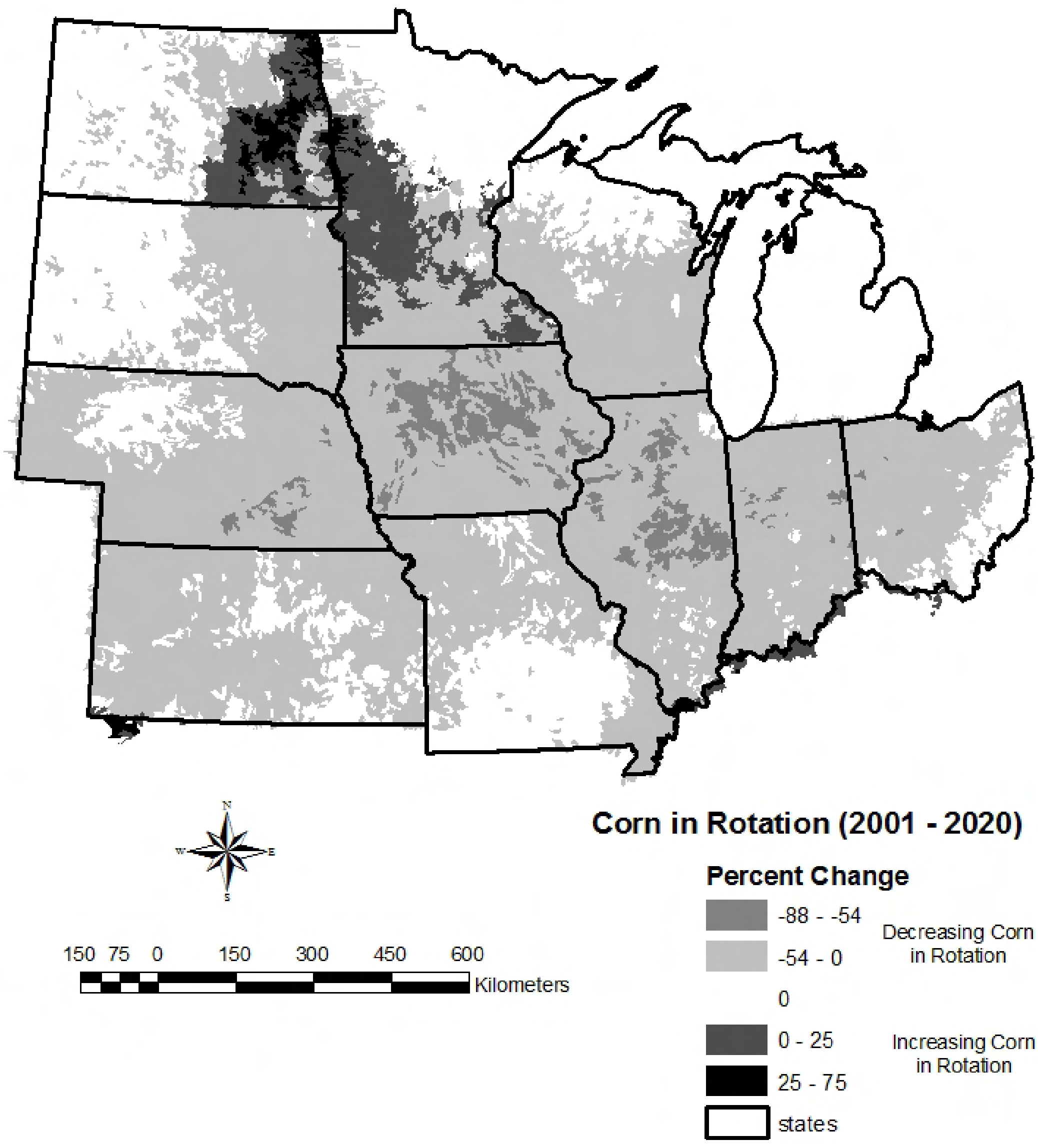

SD
MN
ND
WI
MI
IA
NE
OH
IN
MO
KS
IL
Midwest Drainage
Mississippi/Atchafalaya Drainage
Ohio Basin
Upper Mississippi Basin
Lower Mississippi Basin
Missouri Basin
Arkansas-White-Red Basin
Major Rivers
States
N
W
E
S
0 135 270 540 810 1,080
Kilometers

Figure 2A.


Monoculture Corn (2001-2020)
Percent Change
-12 - 0
Decreasing Monoculture Corn
0
0 - 20
20 - 50
Increasing Monoculture Corn
50 - 90
N
W
E
S
0 75 150 300 450 600
Kilometers

1 Figure 2B.



Corn in Rotation (2001 - 2020)
Percent Change
-88 - -54
-54 - 0
Decreasing Corn in Rotation
0
0 - 25
25 - 75
Increasing Corn in Rotation
states
150 75 0 150 300 450 600
Kilometers
N
S
E
W

Figure 2C.

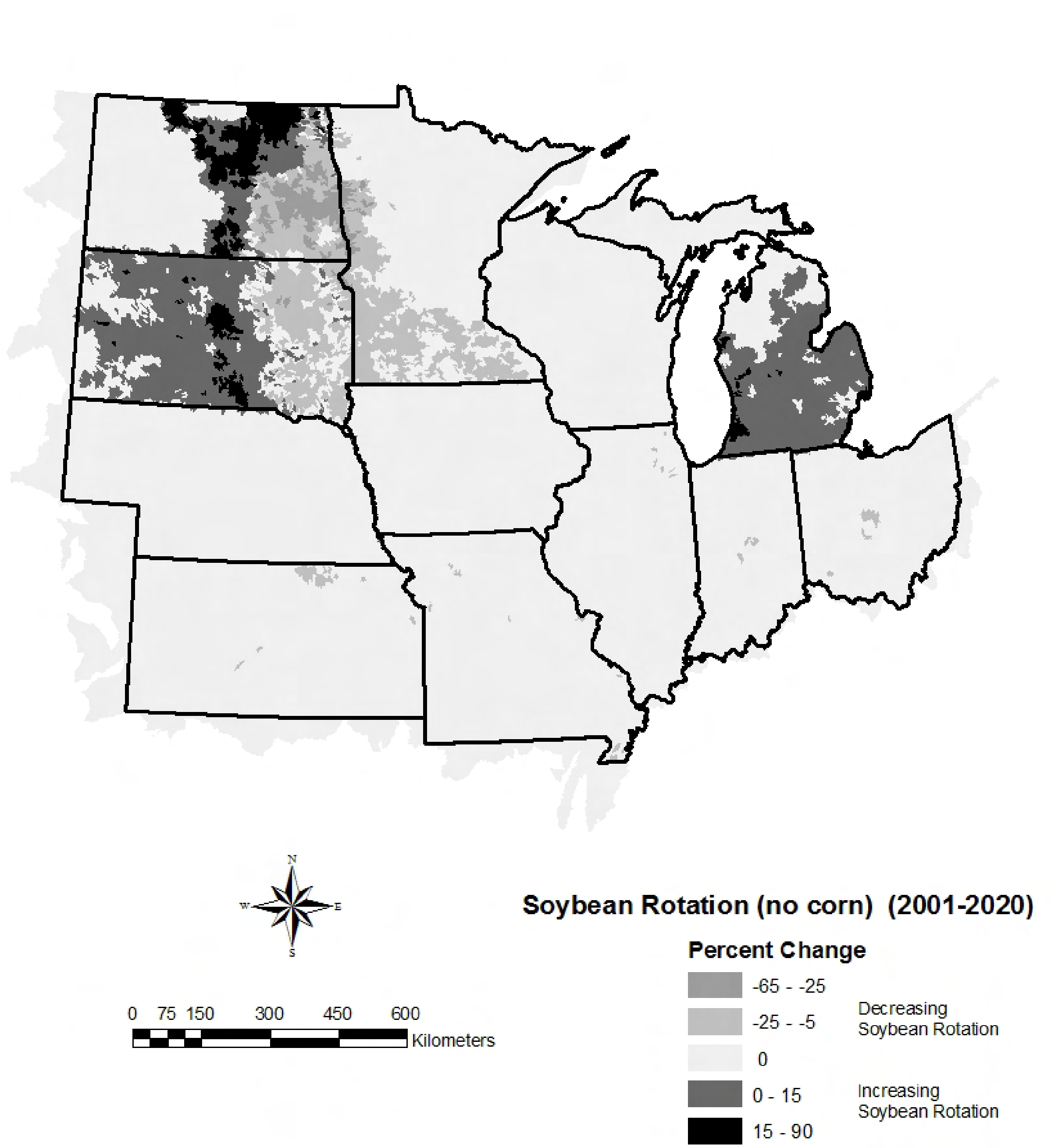

N
W
E
S
0 75 150 300 450 600
Kilometers
Soybean Rotation (no corn) (2001-2020)
Percent Change
-65 - -25
-25 - -5
0
0 - 15
15 - 90
Decreasing Soybean Rotation
Increasing Soybean Rotation

Figure 3.

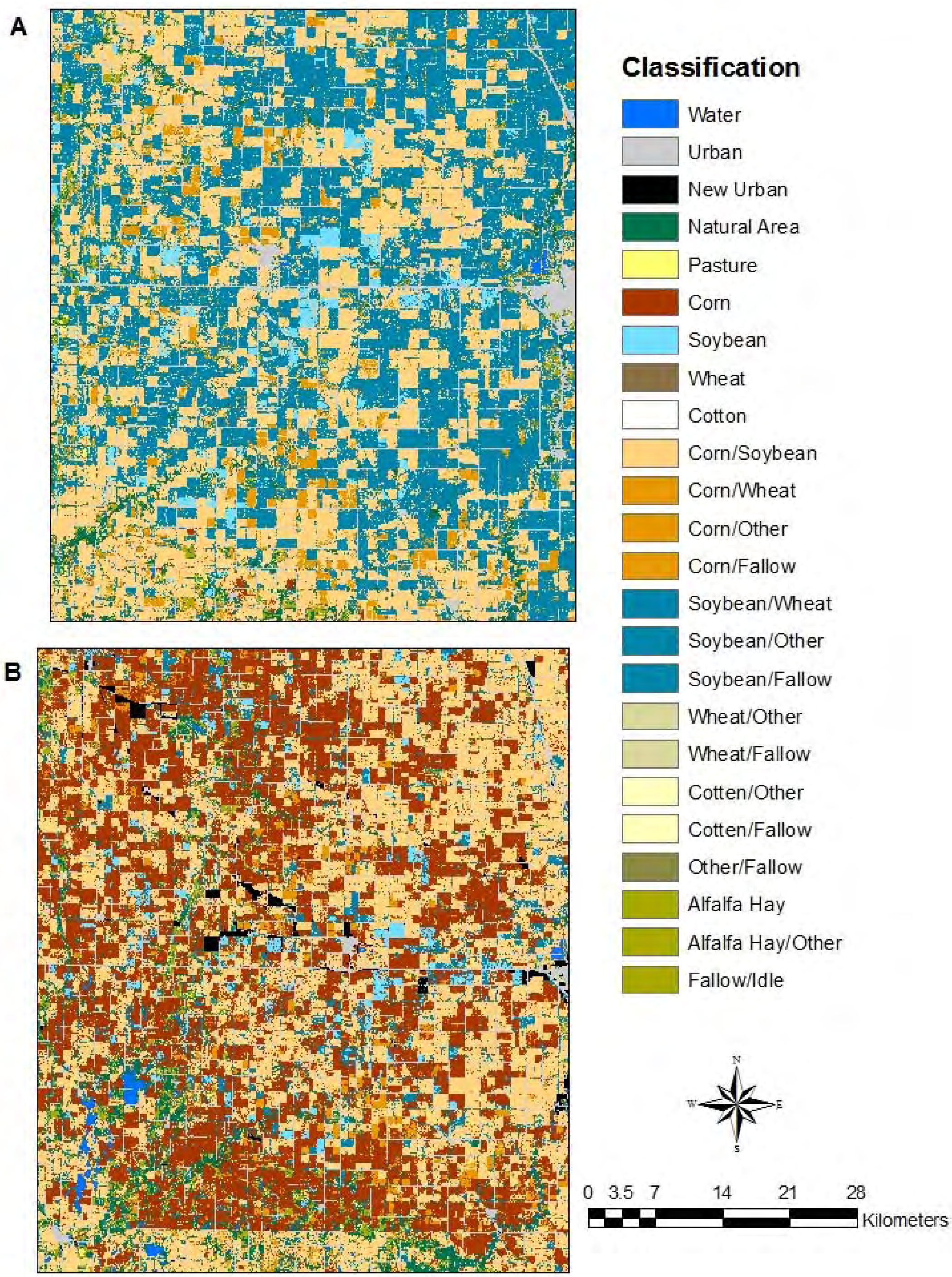

A
B
Classification
Water
Urban
New Urban
Natural Area
Pasture
Corn
Soybean
Wheat
Cotton
Corn/Soybean
Corn/Wheat
Corn/Other
Corn/Fallow
Soybean/Wheat
Soybean/Other
Soybean/Fallow
Wheat/Other
Wheat/Fallow
Cotten/Other
Cotten/Fallow
Other/Fallow
Alfalfa Hay
Alfalfa Hay/Other
Fallow/Idle
N
W
E
S
0 3.5 7 14 21 28
Kilometers

Figure 4.

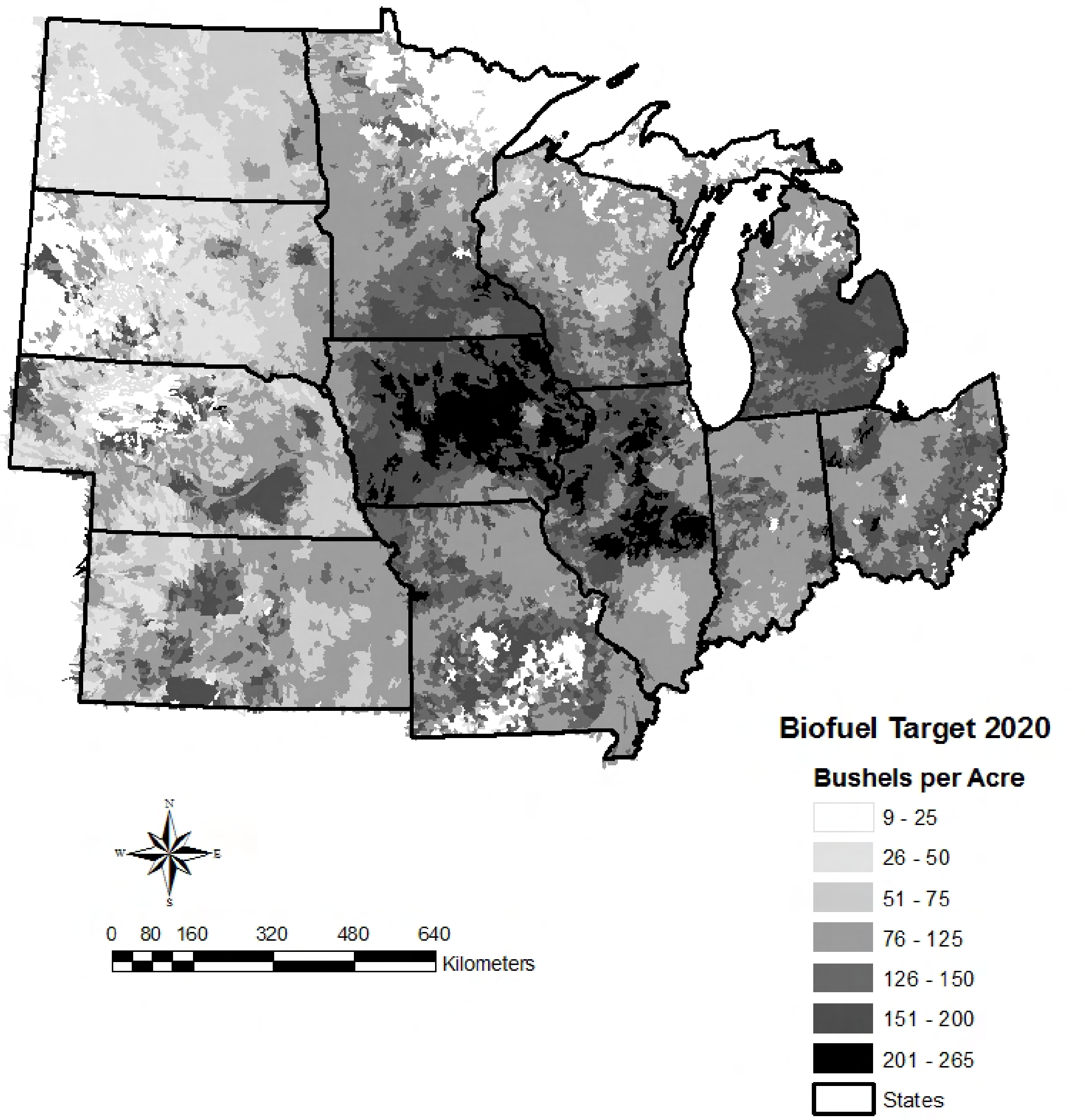
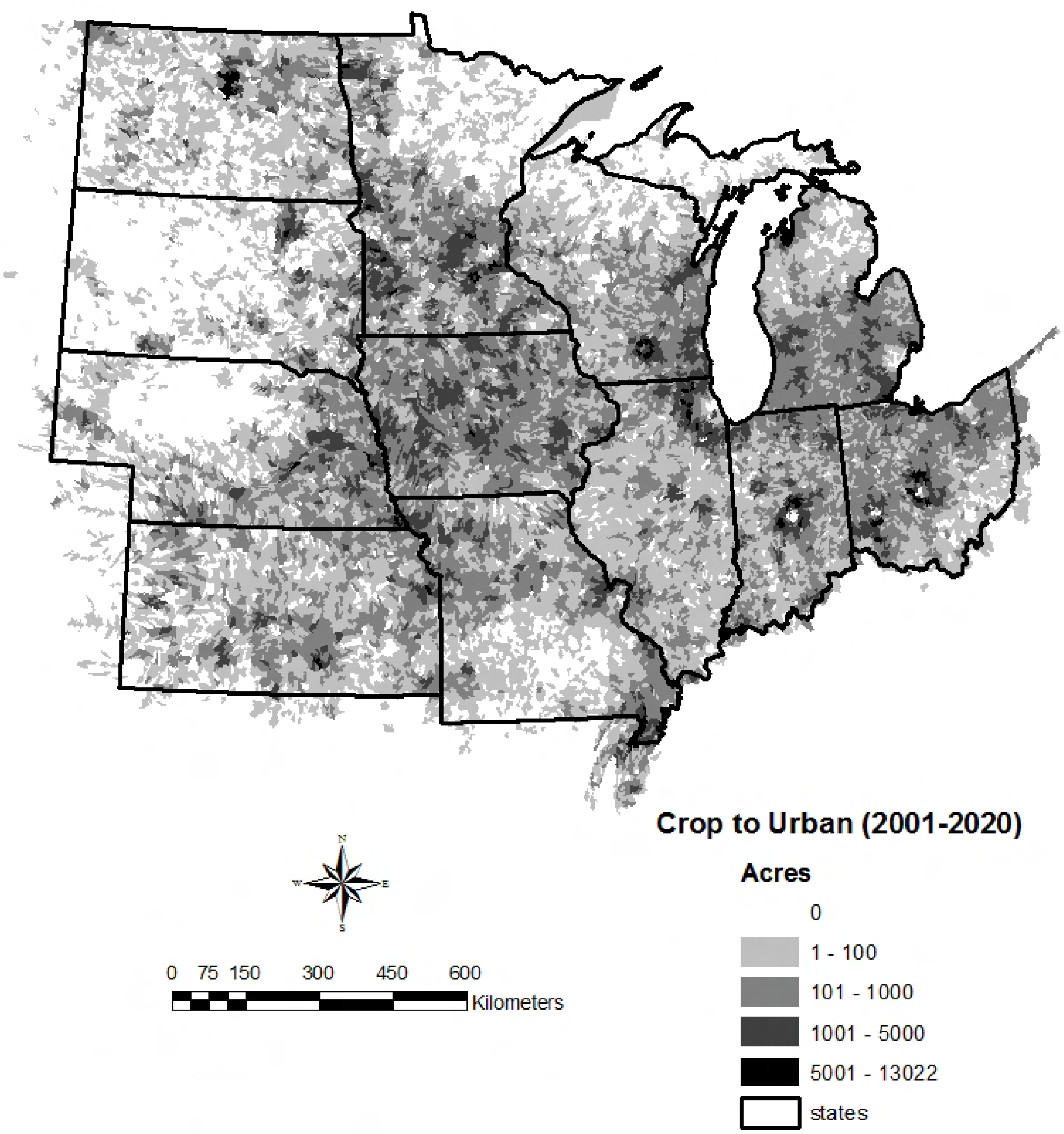

Biofuel Target 2020
Bushels per Acre
9 - 25
26 - 50
51 - 75
76 - 125
126 - 150
151 - 200
201 - 265
States
0 80 160 320 480 640
Kilometers

Figure 5.


Crop to Urban (2001-2020)
Acres
0
1 - 100
101 - 1000
1001 - 5000
5001 - 13022
states
0 75 150 300 450 600
Kilometers
N
W
E
S