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Exploring the Relationship between Agricultural Intensification and Changes in Cropland Areas in the US

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Abstract: Rapid increase in human population, per capita food consumption (i.e., meat-intensive diet), and biofuel production further drives increasing demand for land. One critical solution is agricultural intensification of crop yield (i.e., crop production per unit area) improvement on the existing croplands. Therefore, the pressure to convert other land for food production can be reduced. Here, we used a panel data of the three most important crops (i.e., corn, soybean, and wheat) in the US Midwest to explore trends of change in agricultural yields and cropland areas at both county and crop levels during 1974-2008. We then utilized mapping to visualize and explicitly examine the spatial patterns of land-sparing and agricultural expansion. Finally, we related cropland area changes to changes in yield and other factors that may impact the contraction/expansion of cropland areas. We detected agricultural expansion with yield increases when considering all counties together. However, cropland area increases were less rapid than rises in crop production. Counties located at the southern periphery of the Corn Belt experienced land-sparing, whereas counties located at the western margin of the Corn Belt, that are more arid and potentially require higher input, exhibited highest agricultural expansion. Higher crop prices and USDA farm subsidies were associated with agricultural expansion.

Keywords: agricultural intensification; agricultural expansion; land-sparing; crop yield

1. Introduction

Global grain production tripled in the past 40 years from 1.8 to 5.4 billion tons (Burney et al., 2010; Foley et al., 2005; Matson et al., 1997; Tilman et al., 2002). Part of this production gain resulted from a 27% increase in global cropland areas through agricultural expansion, while much of it is through agricultural intensification (intensive use of the existing cropland areas through increased inputs and technological advancements) (Burney et al., 2010; Ceddia et al., 2014; Foley et al., 2005). However, contemporary agriculture raised serious environmental concerns including biodiversity loss, degradation of critical ecosystem services provided, and has become one of the greatest threats to the remaining natural ecosystems (Fischer et al., 2014; Foley et al., 2005; Maxwell et al., 2016; Tilman et al., 2002).

With the global population expected to reach 8.9 billion by 2050 (United Nations, 2013) and with a changing per capita global consumption to meat-intensive diets, as well as with an increasing demand for biofuels, world food demand is expected to more than double in that span (Bommarco et al., 2013; Foley et al., 2011; Rhys E. Green et al., 2005; Maxwell et al., 2016; Tilman et al., 2011, 2002). Therefore, large-scale biodiversity loss and environmental problems will likely be worse, especially in the context of global climate change (de Groot et al., 2012; Turner et al., 2007; Vitousek et al., 1997; Wright and Wimberly, 2013).

Given the increasing needs to balance food production and biodiversity conservation, continued agricultural intensification (i.e., produce more on less land) is often considered as a critical strategy (Bommarco et al., 2013; Cassman, 1999; Fischer et al., 2014; Foley et al., 2011; Phalan et al., 2016, 2011; Tilman et al., 2011; West et al., 2010). By concentrating production on some land, it helps to spare land for conservation benefits and restoration (Burney et al., 2010; Phalan et al., 2016). This is known as the land-sparing effect, which was supported by several agricultural and environmental scientists (Ausubel, 1996; Balmford et al., 2005; Borlaug, 2007; Cassman, 1999; Ewers et al., 2009; Phalan et al., 2016, 2011; Waggoner, 1995; Waggoner and Ausubel, 2001)

A competing argument states that agricultural intensification causes agricultural expansion rather than land-sparing (Angelsen, 1999; Brockett and Gottfried, 2002; Cassman, 1999; Ceddia et al., 2014; Garrett et al., 2013; Lambin and Meyfroidt, 2011; Matson and Vitousek, 2006; Rudel et al., 2009). The major thinking is that yield increase makes farming more profitable therefore farmers are more likely to cultivate more land (Lambin and Meyfroidt, 2011; Rudel et al., 2009). If demand for agricultural production is relatively elastic, it is still profitable for farmers to cultivate more land (Angelsen, 1999; Rudel et al., 2009). If food demand is relatively inelastic, crop price would drop, which can discourage farmers from farming (Borlaug, 2002; Rudel et al., 2009).

Whether yield increase has promoted agricultural expansion or land-sparing depends on a range of agricultural and economic factors (Waggoner and Ausubel, 2001), as well as government policies (Ceddia et al., 2014; Ewers et al., 2009). Conservation Reserve Program (CRP), designed to set aside highly erodible and environmentally sensitive acres of cropland from production into grasslands, may cause the decline in cropland areas (Rudel et al., 2009). The more land registered in the CRP program, the less land that is available for cultivation. Increases in global corn and soybean prices provide economic incentives for farmers to expand or transform land that they have under cultivation to corn or soybean plantations, leading to accelerated land conversions in the US Midwest (Johnston, 2014; Lin and Henry, 2016; Wright and Wimberly, 2013). USDA farm subsidy is another factor that was criticized to have promoted agricultural expansion (Ewers et al., 2009; US Government Accountability Office, 2007).

Agricultural intensification alone does not guarantee the long-term environmental sustainability, however, it is an essential step because cropland already accounts for about 20% of Earth's ice-free land (Ellis and Ramankutty, 2008; Rudel et al., 2009). Therefore, it is important to study the correlation between agricultural intensification and cropland areas to determine how yield changes impacted changes in cropland area. This study aims to: (1) explore the relationship of changes in cropland area to changes in yield by assessing historical records to see if land-sparing exists in the US under the context of agricultural intensification, (2) provide a spatial explicit assessment of agricultural expansion and land-sparing (if there is any) at the county-level and determine where expansion and intensification take place, and (3) relate cropland area changes to changes in yield and other factors that have confounding effects on cropland areas through multivariate analysis, as well as determine the direction and magnitude of their impacts.

2. Materials and Methods

2.1. Study area

Totaling 1,525,393 km^2, the U.S. Midwest Corn Belt is one of the nation's most productive region for farming and its agricultural productivity is integral to the U.S. economy (Carleton et al., 2001). The US agriculture economy is also critical for other countries that are also big agricultural exporters such as Argentina or Brazil (Trostle, 2008). All counties from the following nine states were selected: Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, and South Dakota. These were chosen for analysis since they are the nine leading states in the US in value of agricultural production (USDA NASS, 2014). For example, these nine states together account for more than 76% of the total crop production in the US.

Corn and soybeans are two of the most important crops in the world (Zhong et al., 2014). US is one of the world leading producers and exporters of corn and soybeans (US Department of Agriculture, 2009). Production of corn and soybeans are a major source of income for most of the farmers in the US Midwestern Corn Belt. Wheat ranks third among US field crops in both planted acreage and gross farm receipts (USDA Economic Research Service, 2013). Therefore, corn, soybeans, and wheat were included in this study.

2.2. Data analyses

Most studies of correlation between agricultural intensification and cropland area were based on data reported to the United Nations Food and Agricultural Organization, which were strongly criticized for containing inconsistencies among countries (Ewers et al., 2009). Here, we used the annual county crop data from the USDA National Agricultural Statistics Service (NASS), which provides statistically sound, reliable, and complete agricultural statistics for the US (USDA NASS, 2014).

Historical records of area planted to corn, soybean, and wheat during 1974-2008 at county level across all nine states were downloaded, along with crop yield and crop price received. Wheat data is systematically missing after 2008; treating wheat as zero would be problematic. Table 1 shows the description and data sources for variables that were included in the study. Specifically, trends in agricultural yields, crop prices, and cropland areas between 1974 and 2008 were identified. Then, bivariate regression analysis was used to examine relationships between changes in yield and changes in cropland area at the county level. Finally, multivariate regression analysis was used to relate changes in cropland areas to agricultural and economic factors, including changes in the yield, the amount of land enrolled in CRP, crop prices received by farmers, and the USDA farm subsidy payments.

2.2.1 Bivariate Regression Analysis of Yield-Cropland Area Changes

We combined the 1974 and 2008 values of yield and cropland area to calculate changes over time (Δ). We then fitted Ordinary Least Square (OLS) regression models with change in cropland area as the dependent variable and change in yield as the independent variable. The dependent variable was calculated using the log ratio value as $\Delta area = \log [area_{2008}/area_{1974}]$. The independent variable was calculated in the same fashion as $\Delta yield = \log [yield_{2008}/yield_{1974}]$. The relationship of yield-area changes was examined for each individual state using county-level data to see if there is a coincidence of increase in agricultural yield with decline or stasis in cropland area (land-sparing). We also plotted the yield-area changes between 1974 and 2008 by crops (i.e., corn, soybean, and wheat) to determine if there is any land-sparing effect at crop type level.

2.2.2 Multivariate Regression Analysis using Panel data statistical model

Panel data, also known as cross-sectional time-series data, is a dataset with the measurement of individual units i =1 … N observed across a certain time period t = 1 … T (Wooldridge, 2002). Here, a panel data of nine states, 846 counties, across 35 years (from 1974 to 2008) was used. To test whether a panel data is more appropriate over a pooled OLS regression, we examined the presence of heteroscedasticity using the Breusch-Pagan test (Breusch and Pagan, 1979; Cook and Weisberg, 1983). After running the OLS regression of area on the independent variables, we ran a Breusch-Pagan test and found a p-value of 0.000. Thus, we rejected the null hypothesis that there is no heteroscedasticity in the data. Therefore, we controlled for two possible types of biases related to heteroscedasticity: the omitted variable bias and standard error bias.

We then performed Hausman test (Hausman, 1978) to determine which model fits better between fixed-effects and random-effects models. We first used fixed-effects model to test our panel data and stored the estimated values. We later compared these values with the estimates from a random-effects model by running the Hausman command in Stata 13. The Hausman test resulted in a p-value of 0.000. Thus, we rejected the null hypothesis that a random-effects model is adequate for our data. Therefore, we adopted the time and place fixed-effects model instead of using pooled OLS regression or random-effects model.

Pooled regression assumes that each county in each year is weighted the same and there is no specific time or county effect (Baltagi, 2005; Vogelsang, 2012; Wooldridge, 2002). But the fact is that it is possible that a certain shock in a year, such as an extremely bad weather, could affect all states in a given year but not across all years. There may also exist some unobserved state characteristics contributing to the variations observed in different states but not over time (Barrett et al., 2006). It is impossible to control for all factors that affect outcomes in various states across different years, but year and state fixed-effects models can be used to overcome the above-mentioned unobserved variable biases (Steerneman, 1995; Vogelsang, 2012; Wooldridge, 2002). The year fixed-effects model is used to control for individual invariant factors, which are the same for all states or counties but vary across different years. The state fixed-effects controls for time invariant factors, which are the same for each state over years, but vary across states.

The following fixed-effects model, equation (1), is used to regress on cropland area with control variables, including crop yield, crop price received, the amount of land enrolled in CRP, and the USDA farm subsidies.

$$area_{it} = \alpha + \beta_1 yield_{it} + \beta_2 price_{it} + \beta_3 CRP_{it} + \beta_4 subsidies_{it} + \beta_5 county\_size_{it} + \mu_j + \lambda_t + \varepsilon_{it} \quad (1)$$

where the response variable $area_{it}$, cropland area, is the total cultivated area of all corn, soybean, and wheat combined in county i at year t. Key independent variable $yield_{it}$ is the crop yield in county i at year t. After Rudel et al. [24], yield was calculated by weighting land area for each crop. Crops with larger area would weight more in the average yield. For example, changes in the yield for corn (planted over large areas) affected trends in yield more than did changes in the yield for wheat (planted in a much smaller areas). Control variables $price_{it}$ is crop prices received by farmers in county i at year t, CRP_{it} is the amount of land enrolled under CRP program in county i at year t, and $subsidies_{it}$ is the USDA farm subsidy payments in county i at year t. μ_j is the state fixed-effects, which controls for state specific unobserved characteristics. Since counties vary in sizes from small to large, we also controlled for county size in the model. λ_t is the year fixed-effects, which controls for unobserved shocks that affect states in a given year. The standard error of the residuals ε_{it} is clustered at the state level. Clustered standard error by state relaxes the assumption that error term for all counties are independent to each other, and allows the standard error of residuals from the same state to vary among different states (Vogelsang, 2012). Spatial autocorrelation (test for spatial autocorrelation is shown in the Appendix, Fig. S1-3) among counties could be largely mitigated by clustered standard errors, which adjust standard errors in a manner that allows higher correlation for counties in the same state than counties in different states.

Furthermore, variables in equation (1) were standardized to mitigate the problem that the three crops investigated have different scales. Standardize variables also ease the interpretation of the regression results. For each crop, variables including cultivated area, crop yield, crop prices received by farmers, the amount of land enrolled in CRP, and the USDA farm subsidy payments, were calculated by creating a deviation from the mean value in each county across time series and scaled by its standard deviation, as shown in equation (2). Each variable was scaled to have a mean of zero and a standard deviation of one. The standardized variables (x_{dit}) were used to replace dependent and independent variables in equation (1). All statistical analyses were performed using the Stata software package (StataCorp.2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP, under Window 10 platform).

$$x_{dit} = \frac{x_{it} - \bar{x}_i}{\sigma_{x_i}} \qquad (2)$$

where x_{it} is the raw variable for each dependent and independent variable listed in equation (1) in county i at year t. $\bar{x}_i$ is the mean value of the variable for county i across all time period and σ_{x_i} is the standard deviation of the variable for county i.

After dropping missing values, the total number of observations was 27,057. The descriptive statistics for the raw variables were presented in the Appendix (Table S1).

3. Results

3.1. Bivariate analysis of changes in crop yields and cropland areas,1974-2008

In Table 2, we present values of yield and total cropland areas in both 1974 and 2008 for all nine US Midwestern states, as well as percent changes in yield, cropland area, and crop production. All nine states experienced simultaneous increases in both cropland areas and agricultural yields, suggesting certain degree of agricultural expansion over the 35-year period. Agricultural expansion was mainly concentrated in the states of South Dakota and Nebraska. South Dakota experienced the largest increases in both yield and cropland area by 176% (~2,938 kg/ha) and 68.5% (~2.058 million ha), respectively. In addition, total agricultural production in South Dakota has more than tripled (~18.3 million metric tons) over the same time span.

Bivariate analyses of yield-area changes of the nine states at the county-level revealed similar trends but with greater details (Fig. 1). Overall, no state exhibited statistically significant land-sparing effect, where there is simultaneous increase in crop yield and decline/no change in cropland area. The states of Kansas (coefficient = 0.63, $P < 0.01$) and Iowa (coefficient = 0.21, $P < 0.01$) showed a significant positive relationship between yield changes and area changes. There was weak evidence of land-sparing in

Minnesota and Indiana with respective regression coefficients of -0.8 and -0.02, although not statistically significant (P > 0.05). Even though 88% of counties (66 out of 75 counties) in Minnesota were located in the upper right quadrant (increases in both yield and area), the magnitude of cropland area increases was smaller than yield increases for the majority of the counties (Fig. 1).

Note that all nine states had a certain number of counties that experienced land-sparing where yield increase was concurrent with area decline/stasis (Fig. 1). For example, 53% of counties (51 out of 96 counties) in Missouri and 47% (46 out of 97 counties) in Kansas were located in bottom right quadrant (Fig. 1), indicating an apparent land-sparing among these counties. The states of Illinois (20 out of 98 counties) and Ohio (19 out of 76 counties) had the 2nd and 3rd largest number of counties that showed the signs of land-sparing. However, South Dakota and Nebraska had the least number of counties that underwent land-sparing (4 out of 62 and 11 out of 87 counties, respectively). In other words, South Dakota and Nebraska underwent the largest agricultural expansion among all nine states from 1974 to 2008.

When all counties were considered together, the relationship between change in cropland area and change in yield was significantly positive (coefficient = 0.29, P < 0.01; Fig. 2), indicating further agricultural expansion with yield improvements. Note that increases in cropland areas were less rapid than rises in total agricultural production between 1974 and 2008. Over the 35-year period, the total crop production in Missouri increased by 108% (~8.66 million metric tons) while the total cropland area grew by only 4.2% (~0.15 million ha); in Illinois, crop production grew by 142% (~38.58 million metric tons) from 1974 to 2008 and was at the expense of only 8.4% (~0.7 million ha) increase in the total cropland area (Table 2).

The yield-cropland area relationship was also examined across crops (i.e., corn, soybean, and wheat) (Table S2). Of all three crops considered, only wheat exhibited observable land-sparing effect. Wheat experienced the largest acreage loss totaling approximately 20 million ha while its yield increased by 72.6% over the 35-year period. Conversely, area planted to both corn and soybean experienced the concurrent increases in the yield and total acreage planted. In terms of total agricultural production, increase of soybean production was the largest (182%), increase of corn production was the second largest (149%), and wheat production increased by 34.9%.

We also plotted graphs of change in cropland area vs. change in yield for each of the three crops (Fig. S4-6). Contrary to what we observed from Table S2, yield-area change correlation was significantly positive for wheat (coefficient = 0.61, $P < 0.01$), indicating agricultural expansion under agricultural intensification from 1974 to 2008. 25% of all counties (118 out of 462 counties) that grew wheat experienced increase in area with yield increase (Fig. S6). The regression coefficient for corn is negative (-0.03) showing weak evidence for land sparing, although not statistically significant ($P > 0.05$); 290 out of 655 counties (44%) that grew corn from 1974 to 2008 had decline in total cropped area when yield increased (Fig. S4). As the second most important crop grown in the US Midwest, soybean has expanded to a great extent across all counties. There is a strong sign of agricultural expansion for soybean (coefficient = 1.31, $P < 0.01$); 88% of the counties (578 out of 659 counties) that grew soybean showed rises in both area and yield during the same time span (Fig. S5).

Even though the rate of increase in total cropland area was slow when compared with gain in the total agricultural production, the coincidence of increases in agricultural yield with declines or stasis in cropland area occurred rarely during 1974-2008 (Fig. 3). Following Rudel et al. (2009), we also compared annual values of crop yields, crop prices, and cropland areas between 1974 and 2008 to determine if there is any pattern on a year-by-year basis (Fig. 3). We found that the coincidence of agricultural intensification with declines in both crop price and total area cultivated only occurred between 1980 and 1985.

3.2. Spatial explicit analysis of yield and cropland area changes, 1974-2008

We visualized yield changes and cropland area changes across all counties over time by displaying log ratio values into different colors (Fig. S7). A log ratio value of zero means no change over time. A negative log ratio value means decline over time; whereas a positive log ratio value shows increase. Except for no data areas, crop yield experienced steady increases across all counties from 1974 to 2008 (Fig. S7 a). Counties located in the southern periphery of the Midwest Corn Belt are the ones experiencing less than 50% yield increase, such as southern Ohio, and western and southern Kansas. The majority of counties in the Midwest experienced moderate yield increase, ranging from two to three times. The highest yield increase occurred mostly in western periphery, South Dakota, in particular. Counties that had the highest land contraction overlapped mostly with counties that had the least yield increase (Fig. S7 b). Agricultural expansion occurred in the rest of the counties, with highest expansion in the peripheral US Midwest Corn Belt. Some counties in Nebraska, South Dakota, and Minnesota had area increased by six times as compared to those of 1974.

We overlaid the two layers (Fig. S7 a&b) together to visually identify where land-sparing and agricultural expansion occurred respectively (Fig. 4). Yield rarely decreased. Land-sparing did occur in some counties. Kansas had the highest number of counties that experienced land-sparing; Missouri ranked second. Overall, counties closer to the southern edge of the Midwestern Corn Belt states experienced land-sparing. Counties in the central and northern region of the Corn Belt went through moderate to high rates of agricultural expansion with intensified crop cultivation.

3.3. Multivariate analysis of yield-cropland area on a set of control variables, 1974-2008

The estimated coefficient of crop yield showed a significant positive correlation with cropland area, suggesting the existence of agricultural expansion ($p<0.01$, Table 3).

Specifically, when crop yield goes up one standard deviation (3,901 kg/ha), cropland area expands 0.4058 standard deviation (~16,681 ha). Contradictory to our expectation, there was no significant correlation between CRP area and cropland area ($p>0.05$). We also conducted a regression analysis of cropland area on the amount of CRP. The result showed a significant negative association between the two if ignoring the effect of uncontrolled variables on cropland area ($p<0.01$, Appendix Table S3).

The USDA farm subsidy exhibited a significant positive impact on cropland area: when the farm subsidy increases by one standard deviation (6.16 million dollars), the cropland area increases by 0.6222 standard deviation (~25,577 ha), correspondingly ($p<0.01$, Table 3). Although crop price had only a marginal effect at 10% significance level ($p<0.1$) on cropland area, the sign of coefficient is consistent with what we expected. When crop price rises by one standard deviation (US$3), the cropland area expands by 0.0593 standard deviation (~2,438 ha).

4. Discussion

We are entering a new era where our society needs to cope with not just feeding an increasing population, but also transportation. Agricultural intensification seems promising in that it concentrates all production on some lands, therefore sparing other lands for potential conservation uses (Borlaug 2002). A general trend of simultaneous increases in yield and cropland area was discovered across most of the counties in these nine US states during 1974-2008, indicating no overall land-sparing under agricultural intensification. This finding agrees with previous studies that supported further agricultural expansion under agricultural intensification. For example, Garrett et al. (2013) reported simultaneous increases in both soybean yield and soybean acreages in Brazil. Vosti et al. (2001) found a positive correlation between yield improvements and total cultivated area in the Brazilian Amazon. Similar results have been reported by West Africa (Ruf 2001) and Tanzania (Angelsen 1999). This pattern poses concerns on the ability of agricultural intensification to spare land. By implication, it is important to examine factors (i.e., agricultural, socio-economic, and government policies) that have contributed to agricultural expansion.

South Dakota had the majority (~94%) of counties with agricultural expansion and ranked 1st in terms of total gains in yield, cropland area, and agricultural production. It is a leading producer of ethanol fuel from corn, accounting for 10% of the total US ethanol production in 2011 (Renewable Fuels Association, 2014). In 2013, corn and soybean became the second and third largest land cover types in South Dakota as a result of land conversion from grassland (Lin, 2015).

Nebraska is another state that experienced the greatest expansion. Land uses in Nebraska were majorly shaped by farm policies and programs (such as Farm Bill 2002, which aimed to shift some payments to compensate farmers for producing certain crops), human population growth, as well as new energy demands (e.g., biofuels) (Hiller et al., 2009). It is the 2nd largest producer of biofuel in the US (Renewable Fuels Association, 2014). Corn was the second largest cover type and was the most important crop in Nebraska (Lin, 2015). Soybean is also an important crop in Nebraska with an increasing shift from other land uses (Hiller et al., 2009). This explains why there was a big increase in the total cropland area in Nebraska.

The rapid increase in corn prices has led to the expansion of corn, which, in turn led to reduced soybean production and increased soybean prices (Johnston, 2014; Lin and Henry, 2016; Tyner, 2008; Westcott, 2015). The westward expansion of cash crop cultivations (i.e., corn and soybean) into more arid western states potentially means higher agricultural input, in particular of irrigation (Wright and Wimberly, 2013). Some of the highest agricultural expansion in South Dakota was a result of land conversion from grasslands and wetlands that provide critical wildlife habitat and other ecosystem services, which can be disastrous for biodiversity and conservation (Johnston 2013).

Despite an overall pattern of agricultural expansion, we also discovered two interesting findings: 1, cropland area increased at a much lower rate than the total agricultural production did, indicating that increases in cropland area have not completely cancelled out the land-sparing effect; and 2, increases in yield and declines in cropland area did occur in some counties, especially the ones located at the southern edge of the Midwest Corn Belt such as Kansas and Missouri. Counties that had highest land contraction overlapped mostly with counties that had the least yield increase. Lower increase in the yield means lower profit for cultivation, therefore less attractive for farmers to further expand their land under cultivation.

Through multivariate analysis, we suggest that the uneven evidence of land-sparing/agricultural expansion at county level is a result of interplays among agricultural and economic factors, and government policies. CRP is the largest conservation program that was established officially through the 1985 Farm Bill. The implementation of CRP program has proved to enhance and benefit biodiversity in the US (Dale et al., 2010) because much of the land entering the CRP was land formerly being devoted to row crop production. The change in CRP land areas is subject to budget allocations from Congress and changes in agricultural commodity prices (Dale et al., 2010). If Congress cuts down budget allocated to CRP or if farmers choose to cultivate land instead of enrolling in CRP, total amount of land in CRP can be reduced. Farmers' decision to either idle or cultivate land is affected by the market prices of grain and fuel (Dale et al., 2010).

Significant loss of CRP acreages since 2007 indicates a larger weight of agricultural commodity prices in determining the trend of CRP amount. When crop prices are low, CRP can be very successful because it benefits both conservation and producers; however, when commodity prices are high, it will result in the wholesale loss of total CRP acreages as it is more economically profitable to cultivate land than re-enroll in the CRP program after the expiration of their CRP contracts (Westcott, 2015). Therefore, government policy should be designed to accommodate such problems. In other words, policy reform should be directed to emphasize the environmental benefits of CRP even when there are fluctuations in agricultural commodity market.

The U.S. farm subsidies were created to supplement farmers' income and ensure a steady supply of affordable food during hard times (Wilson, 2013). The positive effect of farm subsidies on agricultural expansion is consistent with previous studies, which have cited agricultural subsidy as a major factor that encourages conversion of grassland to cropland (US Government Accountability Office, 2007). Claassen et al. (2011) concluded that counties with high agricultural conversion rates tend to have higher government subsidies. Lubowski et al. (2008) studied the effects of different government policies and indicated that direct federal payments to producers resulted in an increase of land in crops by as much as 2% in 1997. Koo and Kennedy (2006) used model simulations and reached a conclusion that farm subsidies in the United States can override the classical economic constraints of demand and supply so that agricultural intensification stimulates over-production and hence total cultivated area. As suggested by Ewers et al. (2009), farm subsidies may distort land-sparing effect by promoting production of crops for uses other than feeding people. Therefore, the government farm subsidies program should be reformed to incorporate the conservation benefits of land-sparing effect.

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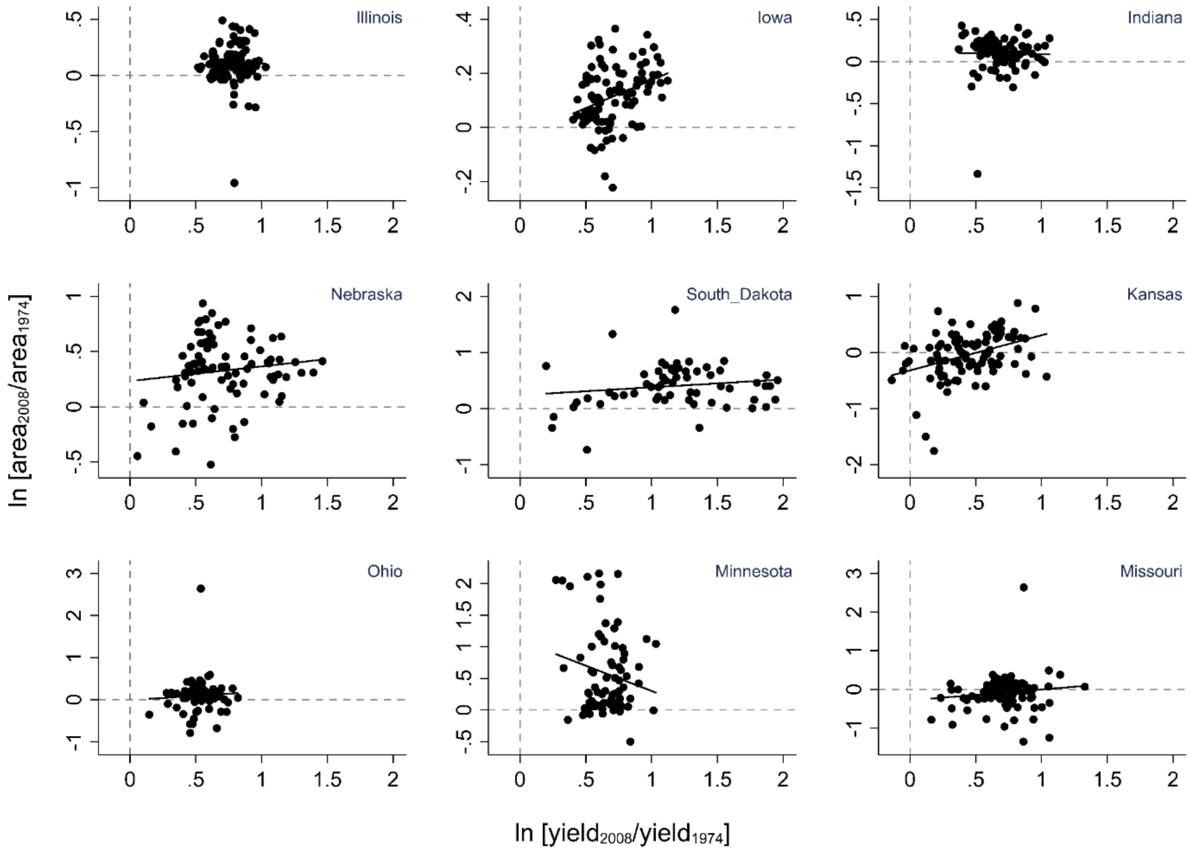

Fig.1 Cropland area changes in relation to yield changes of the three most important crops from 1974 to 2008. Results are plotted separately for each of the nine states. Each black dot represent a county in each state. Solid lines are the fitted line to the data. Dashed grey lines divide the graphs into four quadrants. Counties located in the bottom right quadrant indicate land-sparing effect, where there is a coincidence of yield increase and area decline.

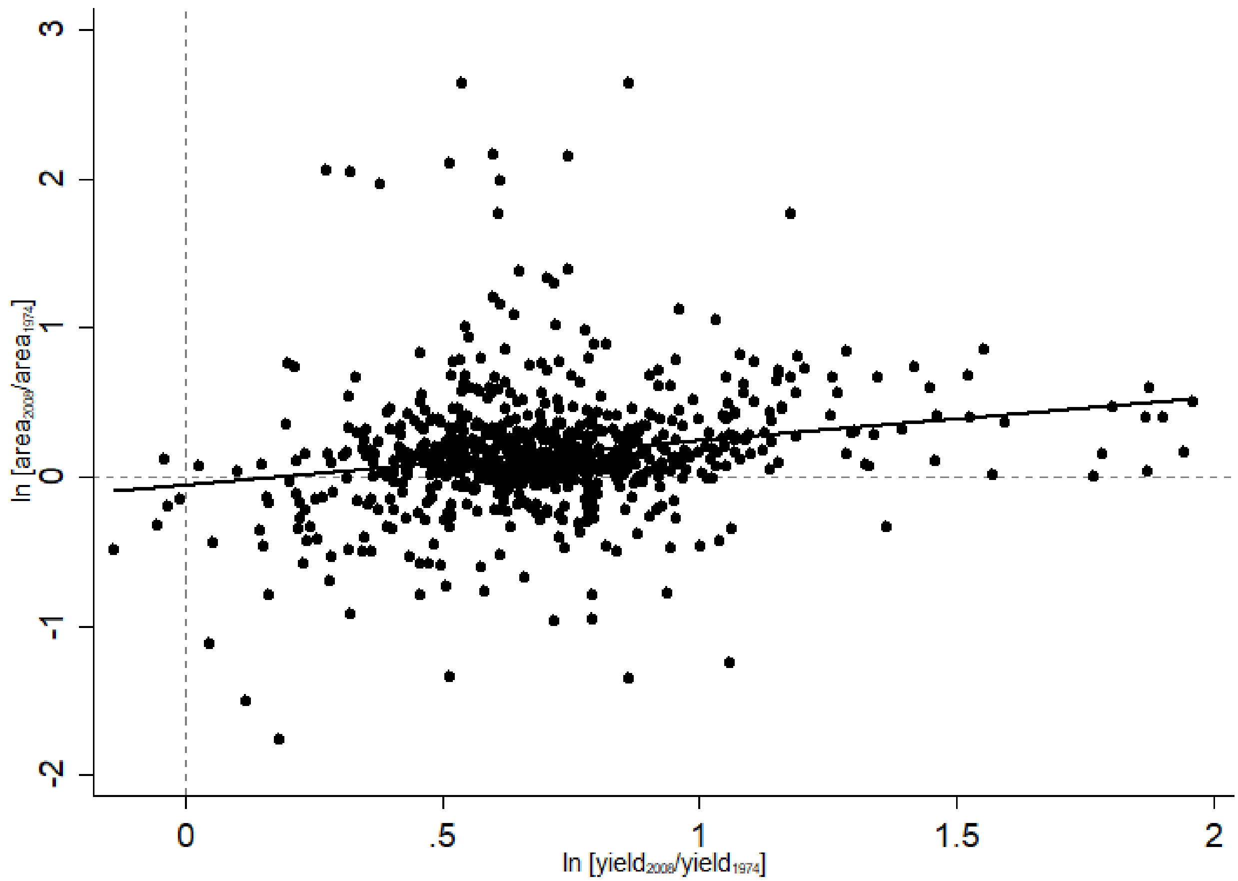

Fig.2 Bivariate relationship between cropland area changes and yield changes for the three most important crops during 1974- 2008 in all counties across all nine states plotted in one graph. Each black dot represents the value for a county. Solid lines are the fitted line to the data. Dashed grey lines divide the graphs into four quadrants. Counties located in the bottom right quadrant indicate land-sparing effect, where there is a coincidence of yield increase and area decline.

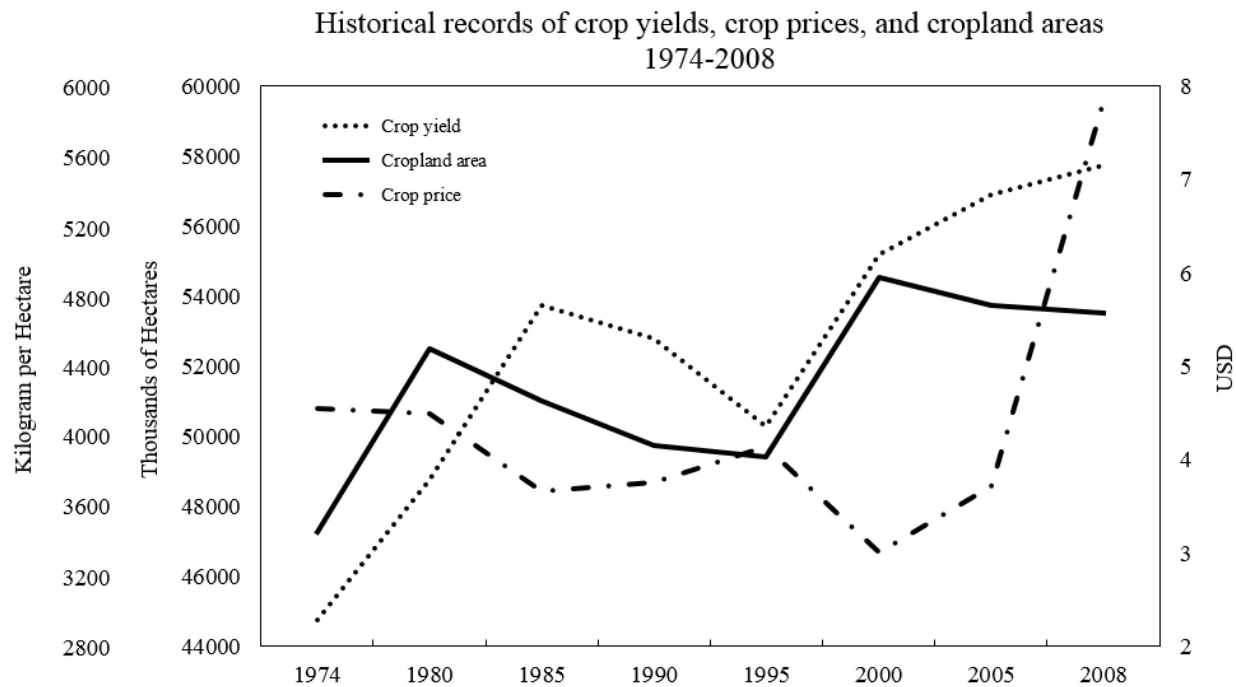

Fig.3 Crop yields, crop prices, and cropland areas for three major field crops (i.e. corn, soybeans, and wheat) in the US Midwest (including nine states in total) between 1974 and 2008. After Rudel et al. [24], the average for yield across the three Midwest crops was calculated by weighting land area for each crop. Crop with larger area would weight more in the average yield. For example, changes in the yield for corn (planted over large areas) affected trends in yield more than did changes in the yield for wheat (planted in a much smaller areas). Crop prices are in US$ per kilogram.

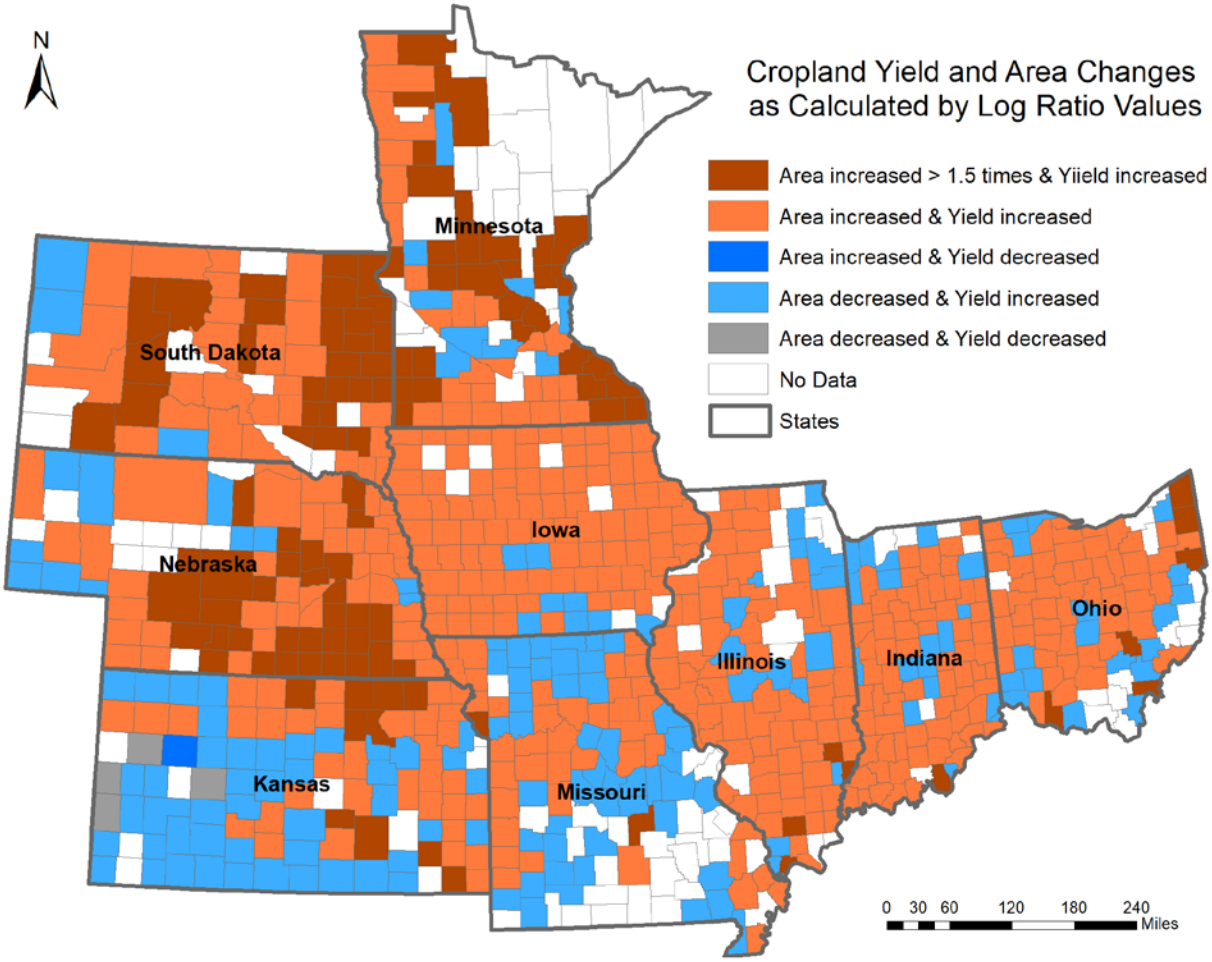

Fig.4 Spatial distribution of four possible combinations of cropland area change and yield change in nine US Midwest states during 1974-2008. Dark red represents counties with yield increase and more than 1.5 times area increase. Red represents counties with both area and yield increases. Green represents counties with yield increase but area decrease. Blue represents counties with area increase but yield decrease. Yellow represents counties with both area and yield decrease.

Table 1. Detailed descriptions and data sources of variables included in this study.

Variables	Description	Source
Cultivated area	Total areas cultivated for a particular crop at each county. In hectares.	U.S. Department of Agriculture National Agricultural Statistic Service (NASS). Accessed at: http://quickstats.nass.usda.gov/.
Crop yield	Crop production per unit area at each county. In kilogram per hectare (kg/ha).	U.S. Department of Agriculture National Agricultural Statistic Service (NASS). Accessed at: http://quickstats.nass.usda.gov/.
Crop price received	Crop price received by farmers at each county. In US$ per kilogram (US$/kg).	U.S. Department of Agriculture National Agricultural Statistic Service (NASS). Accessed at: http://quickstats.nass.usda.gov/.
Conservation Reserve Program (CRP)	Cumulative enrollment of land area under CRP at county level by fiscal year. In hectares (ha).	U.S. Department of Farm Service Agency (FSA). Accessed at: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp-st.
Agriculture subsidy	USDA subsidies for farms by category include conservation subsidies, disaster subsides, commodity subsidies, crop insurance premium subsidies. Here, agriculture subsidy is calculated by subtracting CRP payments from the reported total payments at county level. In US$.	Environmental Working Group (EWG) Farm Subsidies website. Accessed at: http://farm.ewg.org/index.php.

Table 2. Aggregated descriptive statistics for trends in yields (unit in kg/ha) and cropland areas (unit in thousands of hectares) of all three crops during 1974-2008 across states (data source: USDA NASS 2014).

States	Yield/land area 1974	Yield/land area 2008	% Change Yield/land area	% Change Crop production
Illinois	3,234/8,402	7,221/9,106	+123/+8.4	+142
Indiana	3,721/4,401	7,185/4,751	+93.1/+8.0	+108
Iowa	3,794/8,283	7,239/9,345	+90.8/+12.8	+115
Kansas	2,136/6,147	3,223/6,819	+50.9/+10.9	+67.4
Minnesota	1,351/5,544	3,095/6,748	+129/+21.7	+179
Missouri	2,214/3,606	4,431/3,756	+100/+4.2	+108
Nebraska	3,576/4,440	7,080/6,253	+98.0/+40.8	+179
Ohio	4,653/3,448	5,101/3,610	+9.63/+4.7	+14.8
South Dakota	1,667/3,005	4,605/5,063	+176/+68.5	+365

Table 3. Multivariate analysis of crop yield-cultivated area on a set of control variables. This table presents regression results for the following model:

$$area_{it} = \alpha + \beta_1 yield_{it} + \beta_2 price_{it} + \beta_3 CRP_{it} + \beta_4 subsidies_{it} + \beta_5 county\_size_{it} + \mu_j + \lambda_t + \varepsilon_{it}$$

All variables included were standardized to have mean zero and standard deviation one. The unit for each variable: hectare for cropland area, kilogram per hectare for crop yield, hectare for CRP area, US dollars for both USDA farm subsidies and crop price. This model used state fixed-effects (FE) with state clustered standard errors. The t-values, given in brackets, are based on standard errors that are clustered at the state level. ***, **, * denotes significance at the 0.01, 0.05, and 0.1 level, respectively.

Dependent variable: Cropland area	
Crop yield	0.4058***
	[7.551]
CRP area	0.0445
	[0.933]
USDA farm subsidies	0.6222***
	[14.349]
Crop price	0.0593*
	1.957]
County size	0.0850
	[0.886]
Year fixed effect	Yes
State fixed effect	Yes
Standard error clustered by state	Yes
Observations	27,057
R-squared	0.481