Changing agricultural land-use in the United States and its implications for ecosystem services

Jerome Dumortier

School of Public and Environmental Affairs
Indiana University – Purdue University Indianapolis
jdumorti@iupui.edu

Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association Annual Meeting, Boston, Massachusetts, July 31-August 2

Changing agricultural land-use in the United States and its implications for ecosystem services

Jerome Dumortier*

May 24, 2016

Abstract

Farmland in the United States has undergone significant transformation over the last decades. Productivity increases, the introduction of the Conservation Reserve Program (CRP), and the emergence of the biofuel industry have all contributed to significant land-use changes. The potential to produce cellulosic ethanol as well as climate change will continue to change the agricultural landscape. In this paper, we present preliminary results on the importance of the evolution of agricultural productivity in the future and how it changes the land-use allocation at the county level. In particular, we are interested in yield projections and their implications for ecosystem services. For this purpose, we use a simple optimization model predicting land-use at the county level for three crops and CRP land. Given differential yield increases varying by crop and county, the potential for land-sparing and distinct ecosystem services arises.

---

*Corresponding author: jdumorti@iupui.edu

1 Introduction

The agricultural sector contributes significantly to anthropogenic greenhouse gas (GHG) emissions but also offers substantial potential for climate change mitigation in the form of more efficient production techniques, conservation practices, and bioenergy. In 2014, the U.S. agricultural sector emitted 573.6 million metric tons of CO_2-equivalent (MMT CO_2-e) or 8.35% of total emissions in the United States (EPA, 2016). The majority of the agricultural emissions, i.e., 318.4 MMT CO_2-e or 55.5%, can be attributed to agricultural soil management such as fertilizer application and crop management. The remainder of the agricultural emissions are produced from livestock activities such as enteric fermentation and manure management. At the same time, 762.5 MMT CO_2-e were sequestered by land-use, land-use change, and forestry which represents 11.1% of U.S. emissions per year. Thus, the future dynamics of agricultural land-use play an important role for the U.S. GHG balance and the potential ecosystem services that can result.

Within this context of ecosystem services and reduction of GHG emissions, several relatively recent developments have impacted the agricultural landscape in the United States. First, the 1985 Farm Bill introduced the Conservation Reserve Program (CRP) that allows farmers to receive a government payment for taking marginal land, i.e., low yielding land, out of production. CRP land can serve as a carbon sink, buffer for wildlife habitat, wetland restoration, riparian buffers, and so on. In 2014, 25.4 million acres were enrolled in the program down from 36.7 million acres during the peak year 2007. The decrease in program enrollment is related to the second development that changed U.S. agriculture, i.e., the development of the biofuel industry. As of 2011, almost 40% of U.S. maize production was used to produce ethanol. The 10% blending limit[1] for motor fuel vehicles has been reached and a further increase in ethanol production will be governed by either an increase in conventional gasoline vehicles, by an increase in flex-fuel vehicles,[2] or by exports.

There are two future developments that potentially have a large impact on agricultural production in the United States, cellulosic biofuels and changes in climate. First, the production of cellulosic biofuels that is mandated by the 2007 Energy Independence and Security Act. Cellulosic

---

[1] Ethanol acts as a solvent and can cause damage to conventional gasoline engines if used in higher concentrations.

[2] Flex-fuel vehicles are able to use a significantly higher proportion of ethanol (up to 85% blending).

biofuels can be either produced from agricultural residues or from dedicated bioenergy crops such as switchgrass and miscanthus. The land-use change impact from cellulosic biofuels derived from agricultural residues is potentially small since the non-edible parts of corn, sorghum, and wheat are used for its production. If the price of biomass reaches a high enough level that makes the planting of dedicated bioenergy crops profitable, then the reduction in cropland will lead to a expansion elsewhere. Hellwinckel et al. (2015) argue that the enforcement of the Renewable Fuel Standard (RFS) will only minimally reduce CRP land since the majority of the mandate can be meet with crop residues. The production of cellulosic ethanol is very expensive due to its bulkiness that makes it relatively expensive to harvest and transport compared to its energy content. Despite the existence of a blending requirement for refiners, the EPA as the responsible institution to enforce the mandate chose to waive it over the last years.

The future evolution of climate, i.e., temperature and precipitation, will affect land allocation. B.Lobell et al. (2011) indicate that for the period 1980-2008, the net impact of climate on U.S. yields was positive (i.e., increase in yields) for wheat but negative for maize and soybeans. Schlenker and Roberts (2009) show that maize, soybeans, and cotton yields benefit from temperatures of 29°C, 30°C, and 32°C, respectively but decrease above those thresholds. Changes in rainfall and carbon dioxide levels may also have impacts. Attavanich et al. (2013) assess how climate change may affect grain flows in the U.S. due to changes in crop production patterns, river and lake water levels, and grain production in the rest of the world. They find that grain production will shift such that Pacific Northwest harbors gain importance at the expense of Mississippi river transportation. Besides changing transportation flows, the impact on crop production, land-use change, ecosystem services, rural welfare, GHG emissions play a vital role in future policy discussions. The future effect of climate change on agricultural yields has been analyzed but it is unclear how it will affect the agricultural landscape in the United States. The purpose of this paper is to present some preliminary results on the potential change in land allocation in the future based on a range of yield projections. Future differences in yield growth rate can affect where and how land is allocated. In particular, we are interested in the spatial shift of agricultural production under various yield assumptions and its effects on ecosystem services. At this point, we do not include

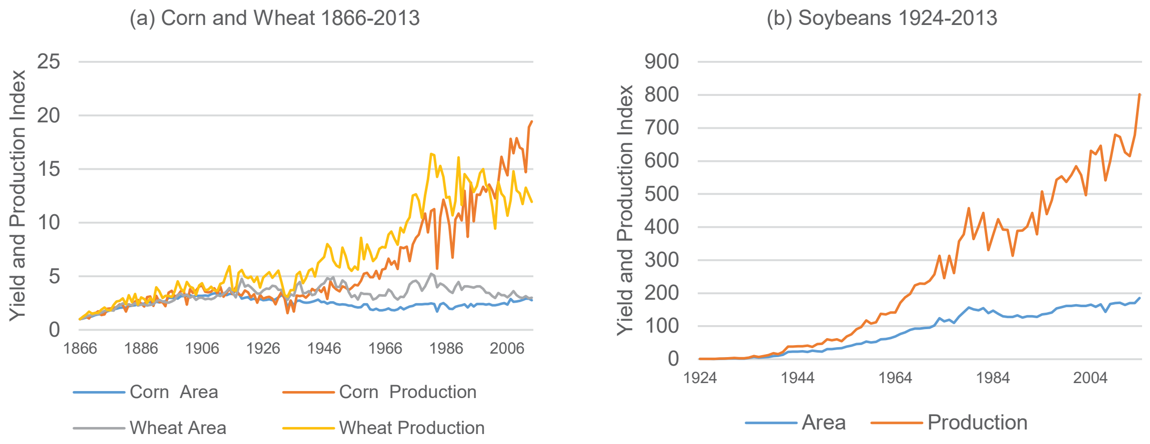

Figure 1: Panel (a) shows the index (with area and production set to 1 in 1866) of maize and wheat area and production for 1866-2013. Panel (b) shows the same information for soybeans for 1924-2013. Source: Adapted from Ausubel et al. (2013) and own calculations based on data from the National Agricultural Statistics Service.

yield fluctuations due to climate change but present results under linear as well as log-linear yield projections and how those rates affect cropland allocation and CRP land. Issues related to CRP and ecosystem services, biofuels, and climate change are all related to the fact that land as an input for production of food, feed, fuel and exports is fixed, i.e., activities on a unit of land are, in general, mutually exclusive.

Over the last decades, agricultural productivity has made tremendous progress in the United States (Wang et al., 2015). Total demand has been increasing mainly due to population growth and, in recent years, to the biofuel industry. At the same time, we see a significant increase in the yield of agricultural commodities in the United States. As shown in Figure 1, which illustrates the evolution of area and production for three major commodities (maize, soybean, and wheat) in the United States, the increase in production is mostly due to yield increases and not expansion of agricultural land. At the same time, the center of agricultural production has moved more in a north-west direction for maize and soybean, and to a lesser extend for wheat, as is illustrated in Figure 2. Economic theory suggests that if demand and supply, which are directly linked to the area harvested and the yield, increase at the same rate, we would expect prices to remain constant. If yield increases faster than crop demand, then the increase in supply leads to lower commodity

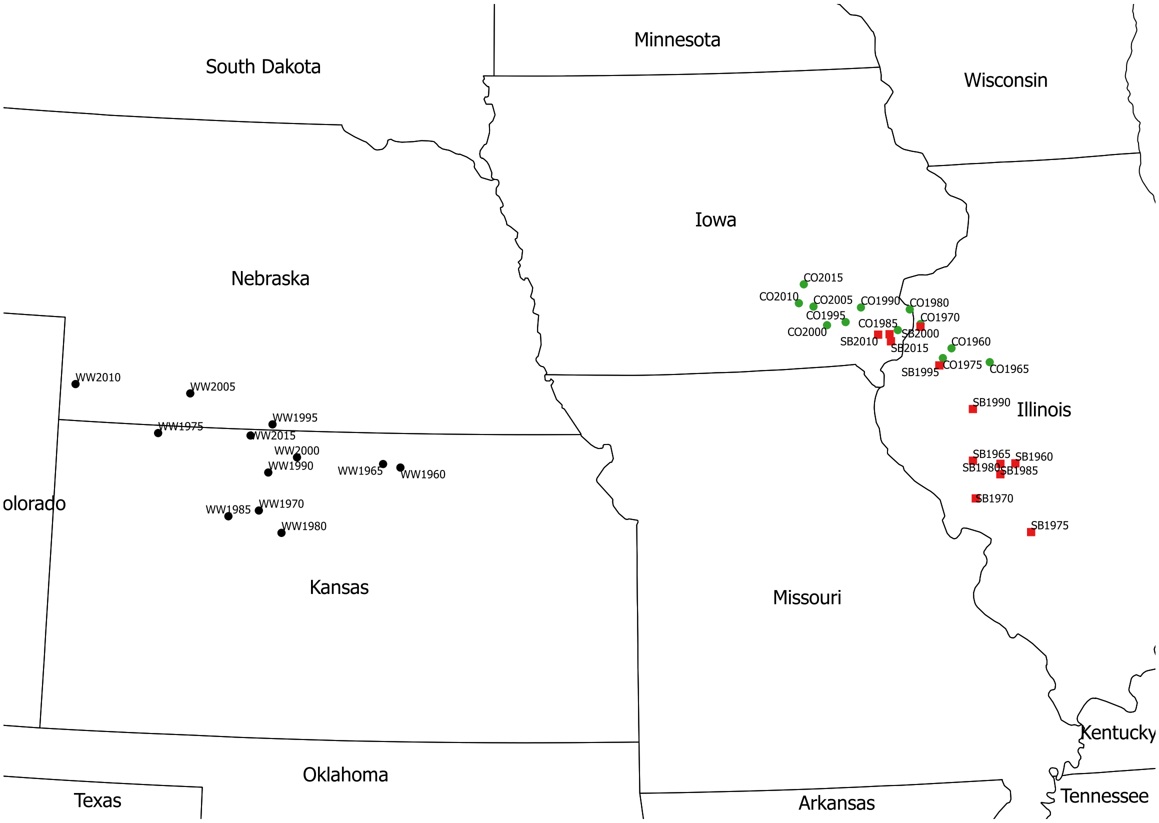

Figure 2: Production-weighted center of agricultural production for maize, soybeans, and wheat.

prices. Landowners would then have the incentive to switch land-use away from agriculture to an activity that yields a higher return. Landowners leaving agriculture reduces supply and leads ultimately to stable commodity prices in the long-run. The purpose of this paper is to identify the location of the cropland that is most likely coming out of production in the future and the potential uses the land will switch to. In particular, we are interested in identifying land that could provide ecosystem services and carbon sequestration (e.g., CRP land or forest) or could produce bioenergy crops. Previous literature has looked at the productivity growth, carbon policies, or afforestation policies (Dumortier, 2013) to induce the provision of ecosystem services. In this paper, we evaluate differences in yield growth to provide those services. We project how much and where land will be coming out of production in to the future under various scenarios. More importantly, the methods used in this paper can be applied to other countries as well. Ausubel et al. (2013) point out that the U.S. is not the only country where the trend of land-sparing can be observed. China, India, and the

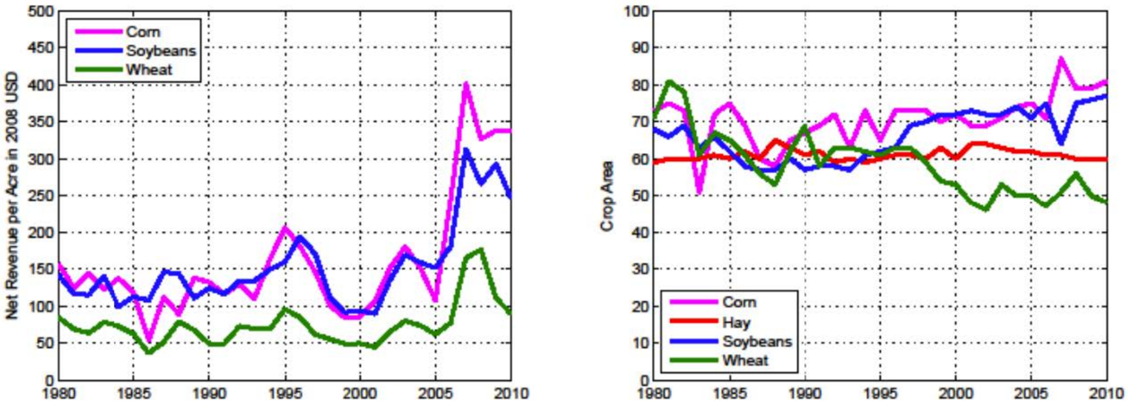

Figure 3: (Left Panel) Net return per acre in real terms for maize, soybean, and wheat. Stable returns prior to the increase in maize demand for ethanol. (Right Panel) Area (in million acres) for maize, hay, soybeans, and wheat. Source: Own calculation.

European Union are in a similar situation.

The concept of "land sparing" triggered by agricultural yield increase has been analyzed previously and leads to two opposing effects. In one case, less land is necessary for the same amount of production if yields increase (Ewers et al., 2009). Alternatively, higher yields make it more attractive to increase the amount of land in production (Rudel et al., 2009). The latter effect can be limited because commodity demand is downward-sloping, i.e., higher quantity results in lower prices, and hence, the amount of land that can be put in production is limited as well. Ausubel et al. (2013) point out that more hectares of maize were planted in the U.S. in 1925 than 2010. There are several indications that land-sparing occurs in the United States. First, according to the U.S. Department of Agriculture (USDA) Economic Research Service (ERS), cropland area in the U.S. peaked in 1969 with 472 million acres. In 2007, 408 million acres were in production which represents a decline of 14%. Even over the shorter period between 1982 and 2007, cropland area declined by 12%. The majority of the cropland decline occurred in the Northeast and the Southwest. In addition, the U.S. Department of Agriculture projects a decrease of cropland between 2013 and 2024 from 256 to 246 million acres for eight major commodities. NASS data show that the number of counties engaged in agricultural production has been declining between 1986 (year of the introduction of the CRP program) and 2013. In total, 416 counties that had more than

5,000 acres of cropland in 1986 dropped to zero in 2013. Figure 3 shows the evolution of per-acre net revenue/profit for maize, soybeans, and wheat. Before the biofuel boom in 2007, revenue remained relatively constant between 1980 and 2005. This supports our hypothesis that production grew more rapidly than demand, leading to landowners/farmers abandoning agricultural production due to declining commodity prices. Economic theory differentiates between declining prices in the short-run where high-cost farmers leave the agricultural sector and the long-run where stable prices are observed.

2 Methods

We follow the general approach outlined in Dumortier (2016). The harvested crop area and yield data are obtained from the USDA's National Agricultural Statistics Service (NASS). For now, we include three major food and feed commodities, i.e., maize, soybeans and wheat, as well as land in the Conservation Reserve Program in our analysis. The ERS provides data about the historical cost and returns for major commodities. Given the yield, area, commodity prices and production costs, we are able to calculate the average profitability of land in a given county while in agricultural production. The ERS also provides data about the average payments per county for land in the Conservation Reserve Program as well as the land area currently enrolled in the program. These data allow us to characterize the profit maximization problem of the land owner in county i and the current allocation that is assumed optimal. Our model is calibrated for the year 2022.

To calculate the demand in the United States, we rely on the demand equations provided by the Food and Agricultural Research Policy Institute (FAPRI) at the University of Missouri. The demand equations are used to project U.S. and export demand:

$$Q_j = \sum_{m=1}^{M} \left[\upsilon_{jm} \prod_{j=1}^{J} p_j^{\theta_{jm}} \right] + e \tag{1}$$

where Q_j is the quantity demanded for field crop j given prices p_j. For each crop, there are three demand sectors m: consumer/food, feed, and export. The demand parameters υ_{jm} and θ_{jm} represent the constants and the cross/own-price elasticities, respectively. There is a constant demand for corn ethanol that is represented by e. In this paper, we use two simple yield prediction equations. We will use a linear trend model (county subscript dropped for notational ease), i.e.,

$$\ln y_t = \beta_0 + \beta_1 t + \epsilon \tag{2}$$

and

$$y_t = \beta_0 + \beta_1 t + \epsilon \tag{3}$$

More evolved prediction models including climate variations will be presented in subsequent research. Given prices p_j, the return from agriculture in county i is written as

$$\pi_i^A(a_{ij}) = \max_{a_{ij}} \sum_{j=1}^{J} \left(p_j y_{ij} - \alpha_{ij}\right) a_{ij} - \sum_{j=1}^{J} \frac{\beta_{ij}}{2} a_{ij}^2 \tag{4}$$

where y_{ij} and a_{ij} denote the county specific crop yield and area, respectively. Note that the return from agriculture exhibits increasing marginal cost. This captures either the decrease of yields because marginal land with lower average yields is brought into production or the requirement of more fertilizer use for the same reason. In addition, increasing marginal cost guarantee a solution during the numerical maximization procedure. In addition to non-negativity constraints, equation (4) is subject to a binding land constraint because there is a maximum area available for crop production in each county. Setting up the Lagrangian and deriving the first order conditions are straightforward.

Agriculture is a perfectly competitive market and hence, all agents are price takers and do not take the effect of their acreage decision on output prices into account. In aggregate, however, the dynamics of the net revenue are endogenous to the model. If landowners decide to move from agriculture to forestry, less cropland is available for production, thus increasing the net returns and vice versa. Given the number of landowners that are in engaged in agriculture production and demand parameters, we can calculate the equilibrium prices over the projection period using linear programming. It is important to have national coverage in our model because the decline in cropland is ultimately driven by the possibility of declining commodity prices. Those prices are set at the national level and each landowner/farmer is affected by the national prices. In the simulation part of our model, we solve for prices of the major commodities that clear the market over time by allowing unprofitable land to withdraw from production.

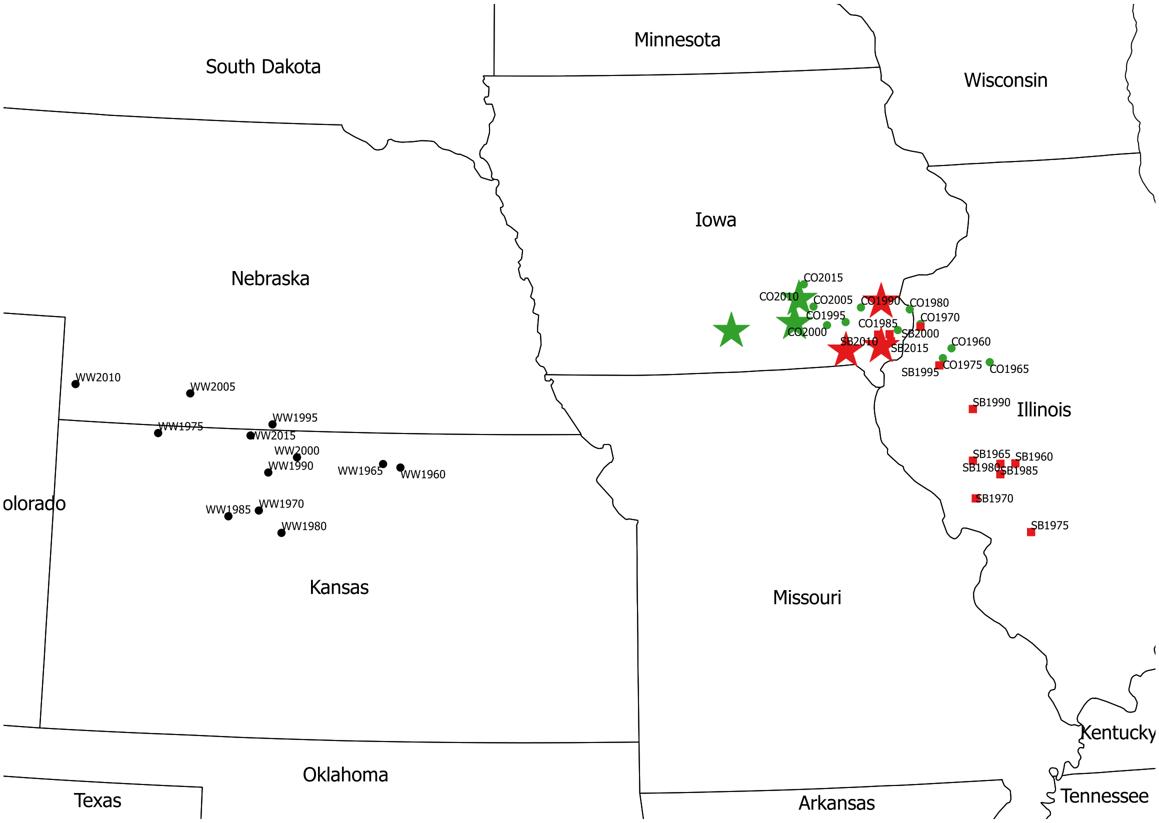

Figure 4: New production-weighted centers of agricultural production for maize (green stars) and soybeans (red stars) under the baseline and two scenarios.

3 Results

We run two different scenarios in addition to the baseline. The entire model is calibrated for the year 2022. In the baseline, we use the projections from FAPRI's Farm Cost and Return Tool for corn and soybeans. In a first scenario, we use the logarithmic yield projection from equation (2) which is then replaced by the linear projection, i.e., equation (3), in a second scenario. Figure 4 show the new production-weighted centers for maize and soybeans based on the baseline and the three scenarios. Given the linear and log-linear predictions, we continue to see a shift of agricultural production in a northwest direction. Figure 5 illustrates the difference in CRP land allocation between the baseline and the linear (S2) and log-linear (S3) scenario. Note that the linear prediction leads to more land in CRP in Iowa and Illinois which is caused by higher yields.

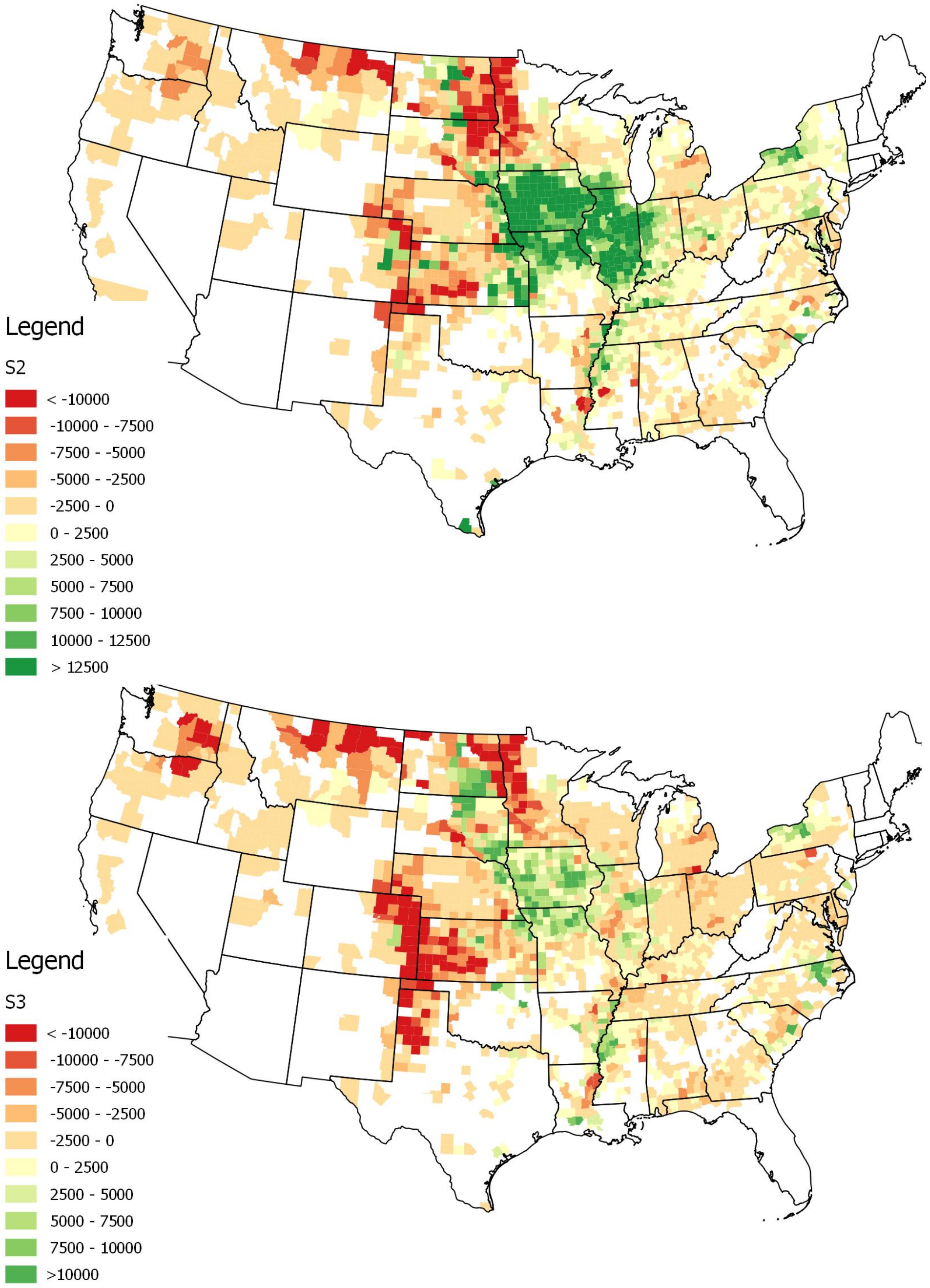

Figure 5: Production-weighted center of agricultural production for maize, soybeans, and wheat.

Since the demand is downward sloping, higher yields do not necessarily lead to more land since this results in a decrease in commodity price.

The difference between the baseline and the log-linear yield trend amounts to an additional 3.98 million ha and the for the linear trend, a reduction of 1.42 million ha is observed compared to the baseline. These preliminary results indicate how differences in yield growth changes the allocation of land with respect to CRP. Since carbon sequestration rates different for different parts of the country, policies, e.g., higher CRP rental rates, might be necessary to foster ecosystem services.

4 Discussion and Conclusion

The insights gained from this project will be used to analyze carbon sequestration in the United States in more detail. In the future, we will calibrate the model to include changes in climate as well as various yield growth functions to determine the effects on land allocation. Recently abandoned agricultural fields tend to be carbon sources; as succession occurs, the ecosystem typically switches from a source to a long-term sink, with the magnitude of the sink depending strongly on species composition and the historic management and disturbance regime.

The effects of different yield evolutions are potentially significant and impact ecosystem services as well as the GHG inventory. From a policy perspective, this could impact the allocation of conservation resources and/or farm subsidies. Future work needs to expand in at least three dimensions. First, yield projections need to be calibrated more precisely. Second, exogenous variables such as precipitation and temperature need to be includes. And lastly, the number of agricultural commodities needs to be increased.

References

Attavanich, W., McCarl, B. A., Ahmedov, Z., Fuller, S. W., Vedenov, D. V., 2013. Effects of climate change on US grain transport. Nature Climate Change 3, 638–643.

Ausubel, J. H., Wernick, I. K., Waggoner, P. E., 2013. Peak farmland and the prospect for land sparing. Population and Development Review 38 (Supplement), 221–242.

B.Lobell, D., Schlenker, W., Costa-Roberts, J., 2011. Climate trends and global crop production since 1980. Science 333 (6042), 616–620.

Dumortier, J., 2013. The effects of uncertainty under a cap-and-trade policy on afforestation in the United States. Environmental Research Letters 8, 044020.

Dumortier, J., 2016. Impact of agronomic uncertainty in biomass production and endogenous commodity prices on cellulosic biofuel feedstock composition. Global Change Biology Bioenergy 8 (1), 35–50.

EPA, 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. Tech. Rep. EPA 430-R-16-002, U.S. Environmental Protection Agency.

Ewers, R. M., Scharlemann, J. P., Balmford, A., Green, R. E., 2009. Do increases in agricultural yield spare land for nature? Global Change Biology 15 (7), 1716–1726.

Hellwinckel, C., Clark, C., Langholtz, M., Eaton, L., 2015. Simulated impact of the renewable fuels standard on US Conservation Reserve Program enrollment and conversion. Global Change Biology Bioenergy 8 (1), 245–256.

Rudel, T. K., Schneider, L., Uriarte, M., II, B. T., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E. F., Birkenholtz, T., Baptista, S., Grau, R., 2009. Agricultural intensification and changes in cultivated areas, 19702005. Proceedings of the National Academy of Sciences 106 (9), 2067520680.

Schlenker, W., Roberts, M. J., 2009. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences 106 (37), 15594–15598.

Wang, S. L., Heisey, P., Schimmelpfennig, D., , Ball, E., 2015. Agricultural productivity growth in the United States: Measurement, trends, and drivers. Economic Research Report ERR 189, U.S. Department of Agriculture, Economic Research Service.