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Research Article

Long Term Dynamics of Cropland Use in Iowa State - Corn and Soybean Rotation

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Abstract

Rotation of corn and soybean is one of the common management practices of farmers in Iowa, United States (US). Over the last two decades, corn has been a popular feedstock used in biofuel production. In this study, we analyzed the interrelationship between land use and land cover change in Iowa, corn consumption in biofuel production, and corn prices over the years from 2002 - 2013. We used the land cover remote sensing datasets from the National Land Cover Database (NLCD) produced by United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) to analyze the long-term (2002 - 2013) land cover change in Iowa State. Results showed a shifting towards intensive corn rotations year after year prompted by a higher corn demand due to consumption of corn in biofuel production. Overall, throughout the study period corn-corn rotation has increased from about 20% for 2002 - 2003 to 28% for 2012 - 2013. However, percentage acreage for soybean-soybean rotation has gradually declined throughout the study period, suggesting increased in corn acreage had come from the declined soybean acreages. Our analysis also showed that the driving factor for continuous corn-corn rotation was the dramatic rise in price during the study period (corn-corn rotation and corn price and ethanol price; r^2 = 0.74 and 0.69). But soybean prices were determined by the demand supply gap resulted from land substitution effect (soybean substituted by corn). We also found that the indirect influencing factor for increased corn areas over the years was the corn use in ethanol production (corn price- corn use; r^2 = 0.76), which pushed the market price of the corn. Therefore, this study provided an overview of the scenario how use of corn in biofuel production have influenced the cropping pattern of farmers in Iowa.

Keywords: Corn; Crop Rotation; Ethanol Production; Market Price; Soybean

Introduction

Land use land cover change (LULCC) is one of the components that determine the global environment change because it alters the biophysical characteristics of earth`s surface such as land surface temperature, carbon-energy-water fluxes, carbon sequestration as well as other micrometeorological parameters. One of the most important driving factors inducing LULCC, not only in Iowa, but whole US Corn Belt is the demand of corn for biofuel production [1,2]. Both the tallgrass prairie and the mixed-grass prairie have been encroached extensively for the agriculture uses mostly for corn cultivation [3,4].

Exponentially increasing world population is imposing higher pressure on energy demands, and bioenergy has come out as a potential option to solve world energy crisis [5]. Bioethanol, extracted from corn sugar fermentation process is being popular all over the world including United States since last decade. Biofuel use, as an energy source, has generated voices both for and against it. Biofuels are produced from renewable feedstock and are considered not only sustainable than fossil fuels but also less polluting to environment owing to less carbon monoxide emission (US EPA 2010). However, significant potential negative impacts of biofuel production have been discussed. Searchinger., *et al.* [6] in his study found

that greenhouse gases were increased by the use of croplands for biofuels because of the land use change (conversion of forest and grassland into cropland). The next issue is the rise in price resulted from demand-supply imbalance of corn when diverted to biofuel which otherwise be used for human food and animal feed. Economic modelling of biofuel impact on corn price as a scenario, predicted corn price would likely to go up from 5-33% by 2015 [7]. US ethanol production reached to 40.88 billion liters in 2009 from 6.05 billion liters in 2000 (U.S. Department of Energy, 2010), while the US corn production increased from 250 million tons to 332 million tons over the same period (USDA, National Agricultural Statistics Service, 2010). Only in Iowa, 11873 million liters of ethanol production increased from 2000 to 2009, resulting into higher market price of corn [8]. About 20% of the increase in corn prices between 2007 and 2008 in US was solely due to ethanol demand (CBO, 2009) and International Food Policy Research Institute (IFPRI) reported 40% rise in corn prices between 2000 and 2007 was from the global ethanol demand (cited by CBO, 2010). This rises in price prompt farmers to go for corn-after corn in their farm to supply the rising biofuel driven corn market demand which otherwise would have been typical corn-soybean crop rotation practices of Midwestern US. Therefore, the hypothesis to be tested was that increase in corn expansion area was attributed from corn-corn rotation influenced by biofuel market over the years. More specifically this study addressed the questions: a) what is the driving factor for continuous corn? b) Is the relative price change due to the increased demand for corn? c) Is the amount of corn used in ethanol production determining the market prices for both soybean and corn? Finally, these set of questions provide an overview of the scenario how use of corn in biofuel production influence the cropping pattern of farmers in Iowa.

Data sources and Data analysis

Local or site specific changes can be monitored using aerial photographs [9] or field data while remote sensing has been widely used to monitor the changes over large area as well as considered very handy tool for inaccessible areas. Therefore, remotely sensed images have been used by several researchers in identifying changes occurred in various ecosystems ranging from aquatic, terrestrial, coastal, forest, urban and agriculture [10,11]. Yang and Lo (2002) extracted time series of Landsat MSS and TM images to study land use/cover change in Atlanta, Georgia metropolitan area over 25 years. Their results demonstrated that usefulness and accuracy of classification maps depends on resolution of remote sensing data, image processing skills and GIS techniques.

Similarly, Lambin., *et al.* [12] in their land cover change study found that people have significantly brought more land into agriculture. The results demonstrated that more than 50% land in Eastern Europe was covered by various crops. In the Western Corn Belt of USA, about 1.3 million acres of grassland were diverted to agriculture (soybean and corn) between 2006 and 2011 as well as conversion rate from soybean to corn areas were also significantly high [4]. The researchers used NASS CDL remote sensing data and concluded that dramatic conversion of natural ecosystems to cropland ecosystems was threatening to environment in context of climate change. NLCD [13] and MODIS data [14] have been widely used to study the trends of land cover change over the years, however, their precision and accuracy in determining the crop rotation varied depending upon the data sources used. Stern., *et al.* [8] studied the changes in crop rotation in Iowa State using the remote sensing data from USDA, NASS CDL product which is the same that we have used in our study. However, their study was focused at the state level and more on three year crop rotation while we have attempted to link the change in rotation with the biofuel production.

Like other Midwestern states, farmers cropping practice is to grow corn and soybean alternatingly year after year. The decisions of the farmers in choosing the type of crops results into the land cover change each year. Therefore, we used the land cover remote sensing datasets from the National Land Cover Database (NLCD) produced by United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) to analyze the long-term (2002 - 2013) land cover change in Iowa State. First step was to create land use classification for each year from 2002 - 2013 for all the possible land cover variables. Subsets for corn as well as soybean for each were derived using ArcGIS data management tools. These raster datasets were extracted using Inlist function tool under raster calculator. Then changes in respective crop area were observed year to year based on pixel counts. Determination of crop rotation for all the variables was found complex since it involved a large number of combinations and permutations. Therefore, this study analyzed only possible combinations of corn-and soybean rotations, i.e.:

i) Corn-corn (C-C)
ii) Soybean-corn (S-C)
iii) Corn-soybean (C-S)
iv) Soybean-soybean (S-S)

The layers for corn and soybean were combined for each year pair from 2002 - 2003 to 2012 - 2013. Before combining of crop layer the pixels values were reclassified in order to get the distinct addition output for four different rotations. This allowed us to calculate the number of pixels under corn to corn, corn changed to soybean, soybean changed to corn or soybean to soybean in consecutive years. Then, these pixels count of four categories were converted to areas. Finally, percentages of area for corn-corn and soybean-soybean rotation were computed.

Market price for corn and soybean was used from NASS website and its relationship was studied with the trends of corn-corn and soy-soy rotations over time. Similarly, percentage of corn-corn rotation from 2002/2003 to 2012/2013 was linearly regressed with the quantity of corn that was used in ethanol production. Corn used in ethanol production was computed empirically based on the relationship 25.4 kg of corn = 10.4 liters of ethanol (Iowa Renewable Fuels Association and USDA-NASS).

Results and Discussions

Increase or decrease in particular crop acreage depends on the decision of farmers whether to grow a particular crop on a farm in a given year. Farmers often made planting decisions based on market price of the crop resulting from demand and supply interaction. In Iowa, growing corn and soybean in alternating years on the same field is a common practice. However, results showed a shifting towards intensive corn rotations year after year prompted by a higher corn demand due to consumption of corn in biofuel production. Figure 1 showed the comparison of different four rotations (C-C, S-C, C-S, and S-S) for a two year period starting from 2000 to 2013. Among the four rotations the most significant changes was observed for C-C rotation over the study period. Also, pattern of S-C rotation was increased over the study period especially in the western part of the state whereas large changes in the C-C rotation were observed in central and north-eastern parts of the state. Since the change pattern cover only one year period rotation, area increase in corn-corn rotation was not clearly depicted in the figure for whole state. However, when 2012 - 2013 was compared to the 2002 - 2003 period, we found significant increased numbers of pixels for corn-corn rotation especially in north eastern and central parts of the state. The trend could be clearly visualized when zoomed in at county level. For example, high numbers of farmers at Hamilton County preferred corn after corn in 2012 - 2013 than that of in 2002 - 2003 rotations (Figure 2). Particularly, the north-eastern part of the county was almost covered by the red pixels indicating C-C rotations in 2013 which were very few in 2002. Overall, throughout the study period corn-corn rotation has increased from about 20% for 2002 - 2003 to 28% for 2012 - 2013 (Figure 3). However, percentage acreage for soybean-soybean rotation has gradually declined throughout the study period except 2008 and 2009. The decreased soybean acreage has been attributed to corn production.. Similar to our results most simulation studies also predicted increase in corn acreage as ethanol production increased. Under increasing ethanol production scenarios, studies predicted that increase in corn acreage would predominately would come from reducing soybean and wheat acreages, or from increasing cropland area converted from other land cover [6]. The ratio of corn to soybean areas provided an overview how the soybean acreages have contributed to the increased acreage of corn (Figure 4). There is an apparent trend in the ratio of corn to soybean production since 2002, most significantly trended up since 2007. The ratio ranges from 1.13 in 2005 to 1.61 in 2007. The overall (2002 - 2013) average corn-soybean ratio was 1.33 which increased to 1.44 for the period of 2007 - 2013. This means that on an average corn production was on average 66% of the size of soybean production and it has been increased to 72% during the later period (2007 - 2013). Understanding the trend of this ratio has importance because corn and soybeans are not only the major crops in Iowa but are also the crops that often compete for the same acre of land. Generally, corn-soybean rotation has been regarded as the best practice since soybean can replenish the soil nutrient pool by atmospheric nitrogen fixation. Therefore, expansion of corn acreage by reducing soybean acreage will result into increase in fertilizers cost as corn is nutrient intensive. The other ecological issues have been discussed by several studies due to conversion of grassland to corn production [3,4].

Though the state showed large increases in corn acreage with proportional decrease in soybean acreage, both corn and soybean prices went up from 85.8/ton to 244.8/ton for corn and 223.3/ton to 518.7/ton for soybean respectively from 2003 to 2013 (Figure 5). And, market price of soybean was always higher compared to corn in all years where the gap between the two prices increased more since 2007. This indicated that the increased in soybean market price outweighed the corn market price. This rise in the soybean price might have been resulted from the limited supply of soybean in the market. The basic assumption of high price of any crop would result into an increase of area of production was not true in this study. This is possibly due to the fact that farmers were less assured with the soybean price increase (limited supply) compared to the high demand of corn from the growing ethanol production. We observed the moderate correlation ($r^2 = 0.69$) of percentage of corn-corn rotation and the price of the ethanol during the study period (Figure 6). Observed changes in corn-soybean rotation pattern reflected relative crop prices during the study period. Our analysis showed that the driving factor for corn-corn rotation was the dramatic rise in price during the study period and positive correlation ($r^2 = 0.74$) was found between these two factors (corn-corn rotation and corn price).Thus, increased corn production was largely driven by the price of corn itself as well as the price of ethanol because about 69% and 74% of the variations observed in corn after corn rotation was explained by the corn market prices and ethanol market prices, respectively (Figure 6 and 7). However, despite the

Figure 1: One year land cover change for four rotations i) corn-corn (C-C) ii) soybean-corn (S-C) iii) corn-soybean (C-S) and iv) soybean-soybean (S-S) from 2002 - 2003 to 2012 - 2013

Figure 2: Comparison of change in crop rotation between 2002 - 2003 and 2012 - 2013, Hamilton County, Iowa State.

Figure 3: Trend of percentage of corn-corn rotation in Iowa State from 2002 - 2003 to 2012 - 2013. Change in area of corn-corn rotation for each year to that of four rotations is expressed as percentage.

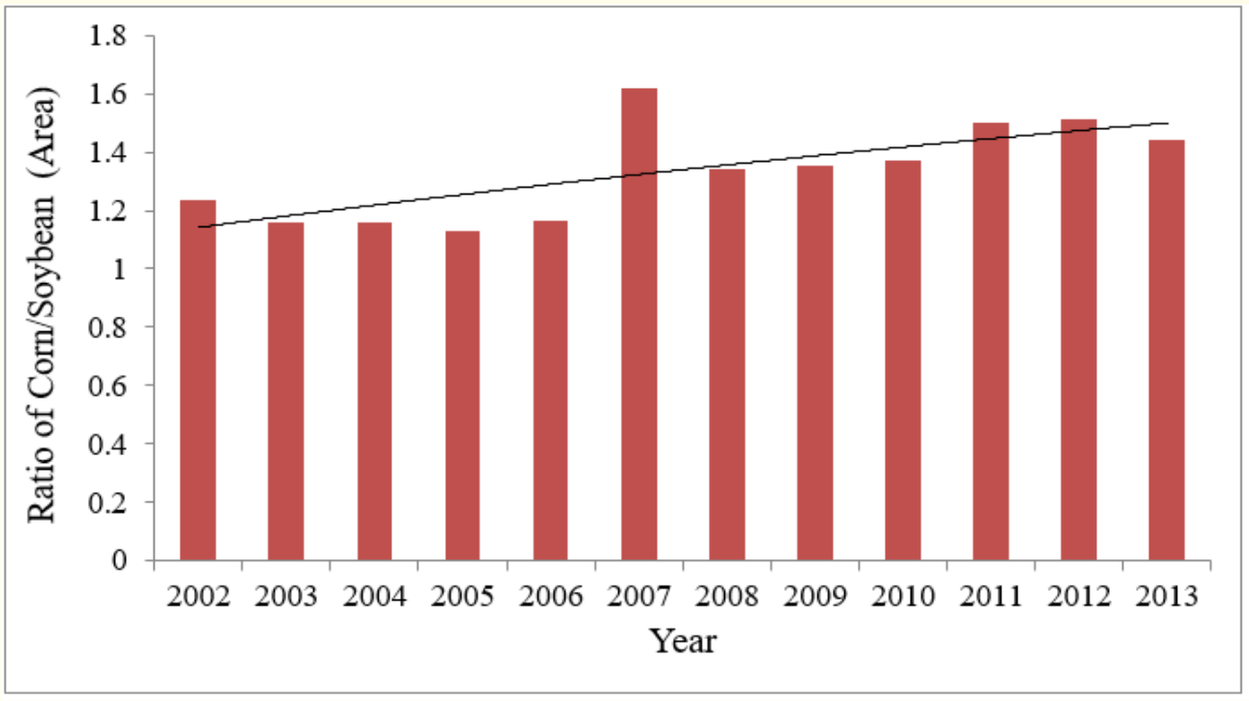

Figure 4: Yearly change in ratio (corn area/soybean area) in Iowa from 2002 - 2013.

rise in price for soybean we found negative correlation between soy-soy rotation and price. This is more likely because of lesser supply of soybean in market created higher demand resulting in its higher market price. This is the land substitution effect because of the fact that farmers planted more corn in place of soybean pushed by the increased corn consumption by ethanol manufacturers. In order to understand the market price trend of corn, we linearly regressed it with the quantity of corn that has been used for ethanol production. Iowa State consumed 52% more corn in ethanol production in 2013 than that of 2003.It was found the amount of corn that was allocated for biofuel production in Iowa State played a vital role in determining its market price (Figure 8). About 77% of the variability in corn prices was explained by the dependent factor (corn use in ethanol production), indicating corn-based ethanol production applying the grip on market price determination of the corn.

Figure 5: Average cash prices ($/ton) of corn and soybean in Iowa from 2002 - 3003 to 2012 - 2013.

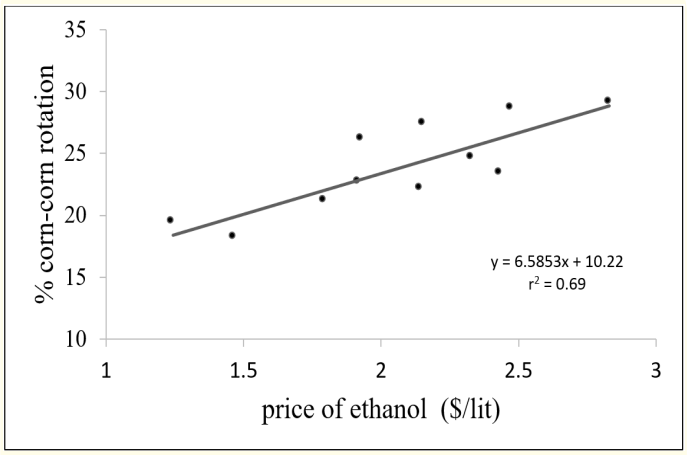

Figure 6: Relationship between percentage of corn-corn rotation and the market price of ethanol from 2002 - 2003 to 2012-2013 in Iowa.

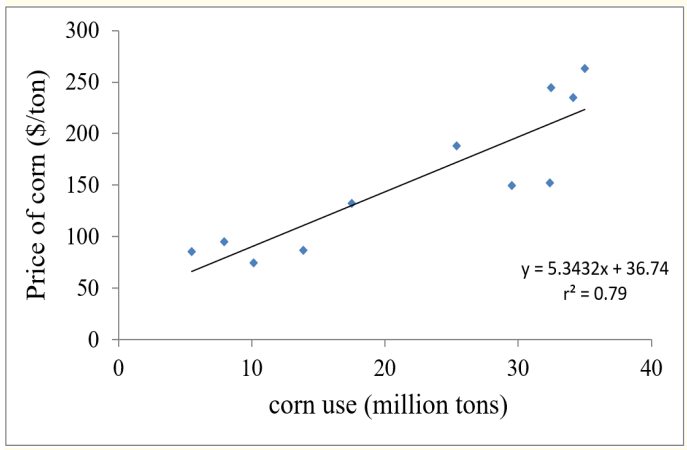

Figure 8: Relationship between the market price of the corn and the quantity of the corn used for ethanol production in a year in Iowa State.

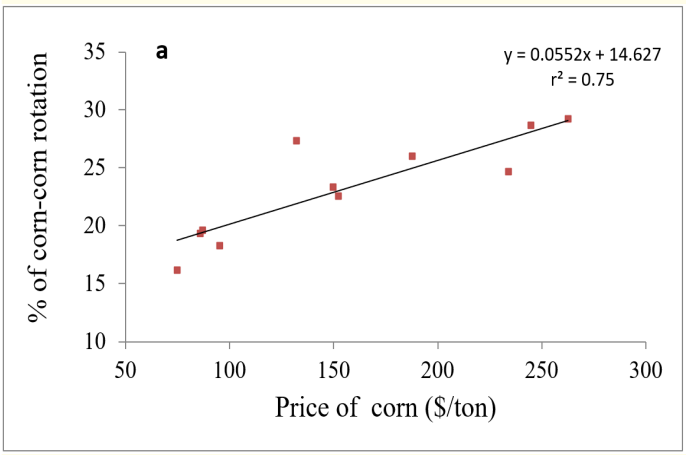

Figure 7: Linear correlation between percentage of corn-corn (left) and soybean-soybean (right) rotations and respective market price. A point represents one year value for % of rotation and market price for that year.

Conclusion

In Iowa State, the corn producing areas has been increasing over the years due to the incentives created because of higher market price of corn and higher ethanol prices. Generally, market price is the driving factors for the farmers to make decision on their land use and management. From our study we found that the indirect influencing factor for increased corn areas over the years was the corn use in ethanol production creating the demand-supply gap in the market pushing the price to the higher margin which in turn was an incentive for farmers to use continuous corn in their fields.

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