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Spatial and Temporal Analysis of Carbon Sequestrations in the Conterminous United States

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Abstract: This study develops geospatial analysis of terrestrial carbon exchange for the conterminous United State and estimates large-scale NEP (net ecosystem production) dynamic from 2008 to 2013. We apply land-use and land-cover data in order to coherently include cropland, forest, wetland and other ecologically active landscapes in the mapping. Our results show a distribution of high harvest carbon release in the Corn Belt states, in addition to hot spots around the US in areas like Southern California and Arizona. Harvest carbon is low in areas in the southern United States, and central/southern Appalachian Mountains. We identify NEP changes for coupled agricultural, forest and other high-carbon-uptake ecosystems systems, conversions to and from crop, and land in frequent conversion among forest, wetland, pasture and rangeland. Findings from this study will provide important information to support and promote the co-production of science and decision-making.

Key words: Spatial analysis, carbon sequestration, temporal change, net ecosystem productivity.

1. Introduction

The RFS (renewable fuel standard) Program is established by the Energy Policy Act of 2005 and expanded by the Energy Independence and Security Act of 2007 (EISA) [1]. The RFS program mandated increasing amounts of biofuel that must be blended with gasoline sold in the United States, targeting 36 billion gallons of renewable fuel ethanol-equivalent by 2022. The U.S. EPA (Environmental Protection Agency) administers the RFS Program and is required to assess its environmental and resource-conservation impacts. The US EPA report (2011) concluded that most of the environmental impacts from biofuels would likely result from the feedstock-production stage [2].

As carbon-based motor fuels derived from plant material or animal waste, biofuels are petroleum alternatives that can help reduce reliance on fossil fuels and address energy security. Biofuel use can result in less carbon accumulation in the atmosphere if the net rate of CO_2 uptake during the growth of their feedstocks is high enough to offset the CO_2 emissions from end-use fuel combustion after accounting for differences in production-related CO_2 emissions. To estimate the impacts of biofuel production, it is necessary to know how feedstocks are grown and where carbon emissions from land-cover conversion might take place. Holder et al. [3] developed a spatially explicit database for annual locations and quantities of corn grown for the years 2005-2010, focusing on the Great Plains and Midwest regions where most of the U.S. corn harvest is located. Zhoa et al. [4] presented a case study of carbon sources and sinks in Florida for 2001. They developed a spatial distribution in relation to vegetation carbon sinks from 2001 NLCD (National Land Cover Database) and concluded that net carbon sources are associated with urban and suburban densities.

Prior studies have investigated the effects of LUC (land-use change) associated with cropland expansion related to biofuel production. Lark et al. [5] performed a spatially-explicit analysis of net changes between

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cropland and non-cropland in the conterminous U.S. They conclude that 7.34 million acres of cropland expansion (0.16% of U.S. total area) occurred during 2008-2012 that is not suitable for cultivation. Qin et al. [6] report that corn, soybeans, and wheat are three major crops in the U.S., with about 220, 63, and 64 million tons per year (of the 1990s), respectively, and the largest carbon loss was observed when soybeans were replaced with biofuel crops. Corn is the most common crop planted directly on new land and the largest contributor to crop-driven direct land-use change [7].

Some studies [8-11] mention that, in general, newly converted croplands occurred mainly in the plains states. The distribution of corn and soybeans is similar, and is concentrated in the central and east coast of the U.S. However, the distribution pattern of wheat is concentrated in the central region and the northwest. Lave et al. [12] also describe that the majority of corn acreage is found in the Midwest and the primary feedstock for biofuel in the U.S. was corn grain. They report that the national average was 156 bushels per acre in 2010 and about 40 percent of corn yield was used to produce 13.2 billion gallons of ethanol. According to the IPCC [13], the conversion of undisturbed rangeland to the production of annual crops could in some case lead to large releases of carbons stored in the soil, as well as a loss of biodiversity.

As noted, many studies have been undertaken to assess the spatial distribution of land cover conversion. However, limited studies have been conducted monitoring cropland and carbon emission from land-cover conversion in the conterminous United States. Moreover, previous studies are not appropriately considered in the spatially explicit analysis for the relatively long term and most recent observation period. This research examines the geospatial analysis of land cover conversion and net carbon uptake on cropland in the conterminous United Sates during an updated period from 2008 to 2013. The objectives of this study are (1) to enhance assessments of carbon uptake and biofuel production in the conterminous United States and (2) to evaluate the spatially explicit effects of land-use dynamic using GIS applications.

2. Data Set and Methodology

Spatial data from the satellite-derived CDL (cropland data layer) were used to identify patterns of land cover for US cropland. CDL is provided by the NASS (National Agricultural Statistics Service) of the U.S. Department of Agriculture (USDA). We calculated “planted area” of the major crop types from the CDL using GIS applications (Fig. 1). The attribute table of CDL contains the number of pixels for every major crop. The planted area can be derived from counting pixels of a specific crop type and multiplying by the area represented by one pixel. The CDL has a spatial resolution of 56 meters, so that each pixel is an area of 3,136 square meters (56 meters × 56 meters, i.e. an area of 0.77 acre). For example, the 2008 CDL shows 279,208 pixels for corn in Alabama. Thus, we computed that corn has an area of 216,364 acres (279,208 pixels × 0.77 acres) in Alabama. We excluded the planted areas in Alaska and Hawaii to focus on the conterminous United States.

We also collected “yield per harvested acre” from Quick Stats 2.0. Quick Stats 2.0 is an interactive tool for accessing agricultural data developed by NASS, USDA. Production was computed by multiplying the yield per harvested area from Quick Stats 2.0 and the planted area from CDL. Since each county has different values for yield per harvested acre, we estimated independently for each county. If Quick Stats 2.0 did not have the values of yield per harvested acre for a specific state, the production was computed using the national average of the yield per harvested acre.

The key term for evaluating terrestrial carbon exchange is net ecosystem production (NEP), which represents the net flow of carbon from the atmosphere

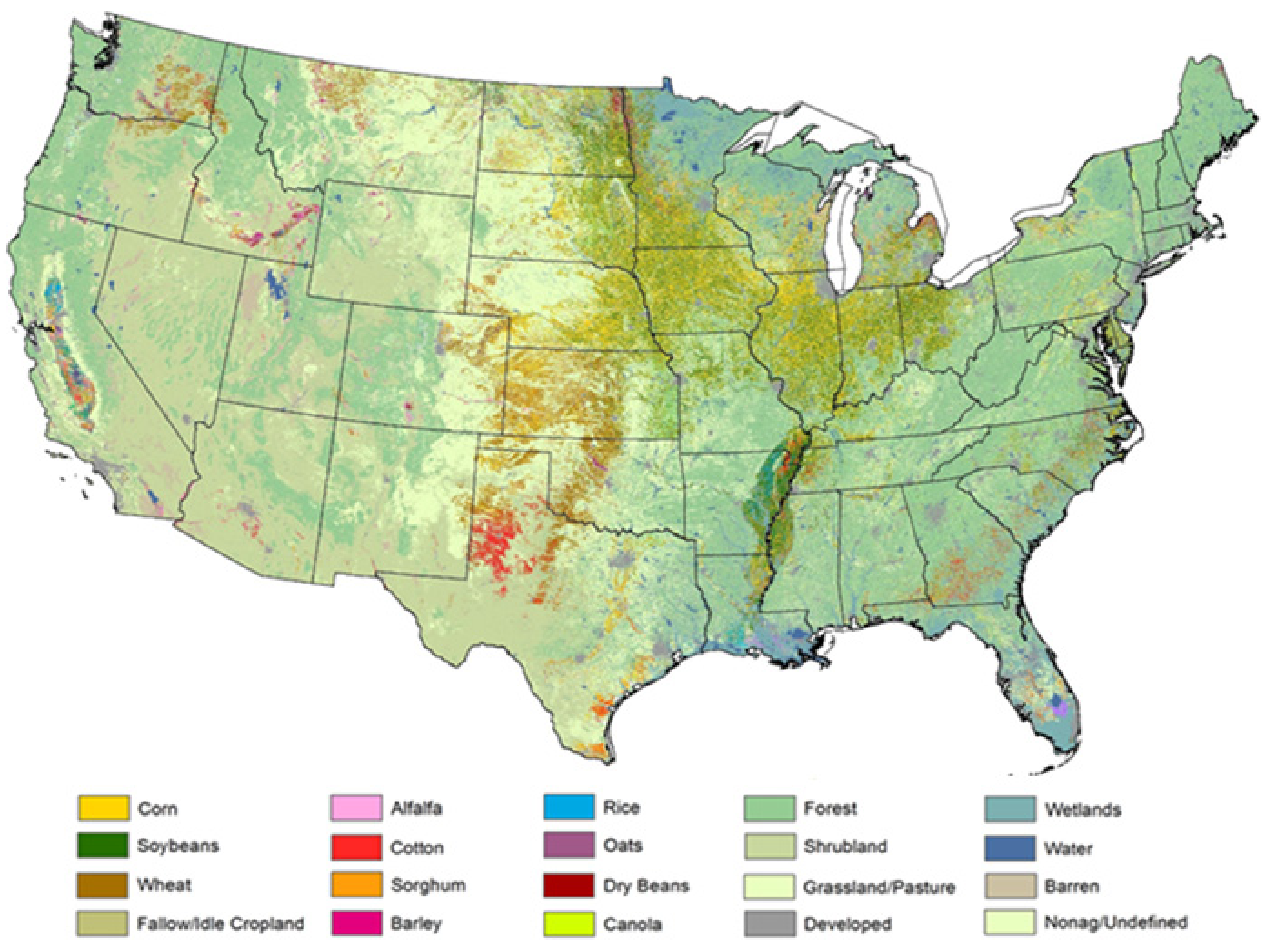


Fig. 1 The CDL map for 2013 in the conterminous United State.

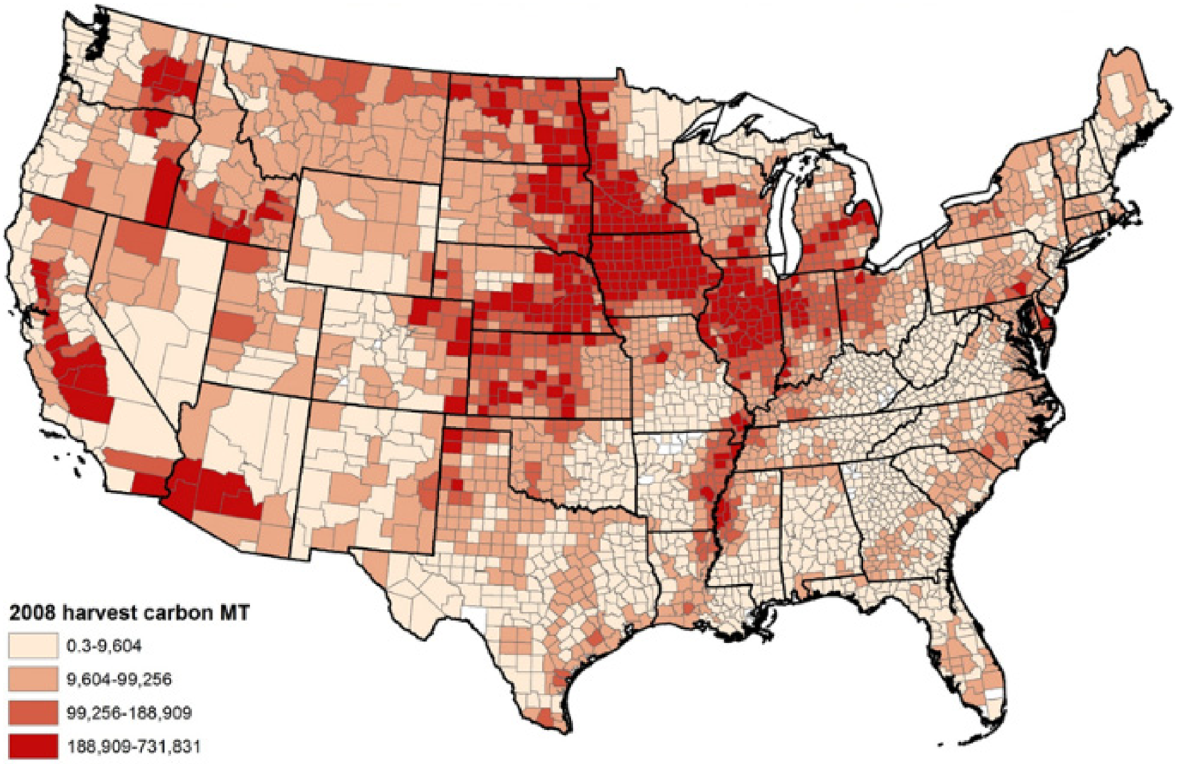
into the biosphere over a given area of land. It is the difference between net primary productivity (NPP) and heterotrophic respiration (R_h) and it shows net rate of carbon uptake in terrestrial ecosystems. For this study, the annual NEP of US cropland was estimated based on the mass of carbon in the annual crop harvest (H) [14]. We assume that the change in soil organic carbon (ΔSOC) can be treated as zero on annual cropland on average at national scale (see supplemental information). So annual changes in NEP are computed as:

$$\Delta NEP_t = \Sigma i \, (H_{it} - H_{it-1})$$

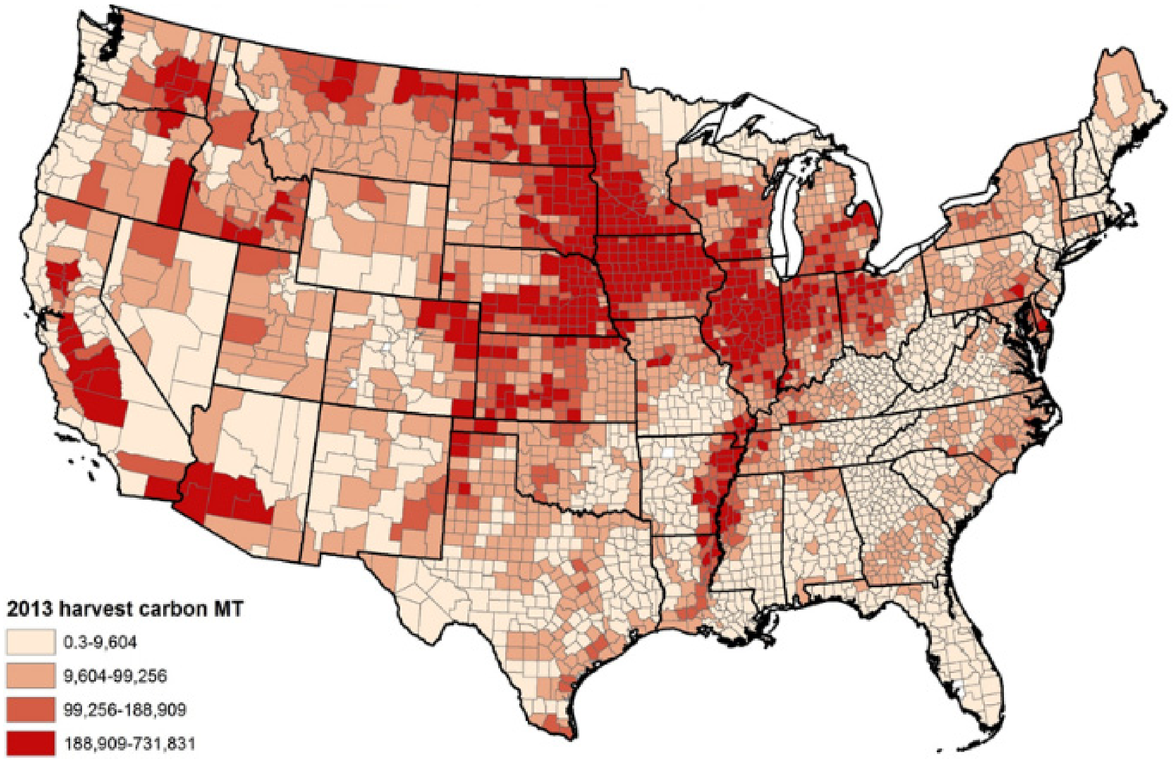
as a summation over crops (indexed by "i"), where H_it = carbon harvest of crop "i" at time "t" (a given year), and H_{it-1} = carbon harvest of crop "i" at time "t-1" (the prior year). Because harvest data reflect yield gains, any increase in CO_2 uptake due to agricultural intensification over the analysis period is reflected in these estimates of NEP. By definition, NEP estimate result consists of annual harvested carbon (H) and soil organic carbon change (ΔSOC) [14]. ΔSOC is regarded to be zero [15] and thus NEP estimate in this study is based on harvested carbon. NEP estimate for 2008 and 2013 is carried out using spatial data from geospatial cropland data layer (CDL) and statistical agricultural data from USDA Quick Stats 2.0.

3. Results and Discussion

In the 2008 map based on the CDL (Fig. 2a), we see a distribution of high harvest carbon release in the Corn Belt states including Iowa, Illinois, Nebraska, Minnesota, Kansas and Indiana, in addition to hot spots around the US in areas like Southern California, Arizona, Pennsylvania, Washington, and so on.



(a)



(b)

Fig. 2 Spatial distribution of NEP estimate: (a) 2008 and (b) 2013 in the conterminous United State (unit: MT, metric ton).

Table 1 Estimate of NEP and the difference between 2008 and 2013 (unit: Tg C, teragram carbon).

	2008	2009	2010	2011	2012	2013	Difference
Corn	110.54	119.12	119.68	120.78	107.05	133.58	23.04
Soybeans	28.80	33.23	33.94	31.93	30.47	34.09	5.28
Wheat	27.25	25.67	25.80	24.47	26.96	26.79	-0.45
Alfalfa	17.52	16.40	18.72	22.60	19.37	19.42	1.90
Cotton	1.29	1.22	1.69	1.96	1.89	1.46	0.17
Sorghum	3.88	4.19	3.98	2.78	3.31	4.60	0.72
Barley	1.70	1.59	1.34	1.23	1.82	1.87	0.17
Rice	3.28	4.03	4.20	3.26	3.38	3.21	-0.08
Sunflower	0.47	0.44	0.41	0.31	0.44	0.32	-0.15
Oranges	0.43	-	-	0.34	-	-	
Dry Beans	0.37	0.37	0.54	0.34	0.56	0.42	0.04
Oats	-	0.58	0.61	0.43	0.49	0.48	
Canola	-	-	0.56	-	0.59	0.55	
Peanuts	-	-	-	-	1.50	-	
Almonds	-	-	-	-	-	0.55	
Total	195.50	206.83	211.47	210.42	197.85	227.23	32.03

Harvest carbon was low in areas in the southern United States, and central/southern Appalachian Mountains. In 2013 (Fig. 2b), we see similar distributions of harvest carbon, with the greatest values centered around the historic Corn Belt states, and clusters of high harvest carbon values in areas of California, Arizona and Washington state. Again, low harvest carbon values were found in the southeast United States and lower Appalachian Mountain areas.

In 2008, total harvested carbon nationwide excluding Alaska and Hawaii was 195.50 Tg C, and increased to 227.33 Tg C in 2013 (Table 1). In both years, source of harvested carbon mainly comes from the Corn Belt such as Iowa, Illinois, Nebraska, Minnesota, Kansas and Indiana, whose total contribution of the nationwide harvested carbon is around 50%. From 2008 to 2013, largest source of harvested carbon comes from corn, followed by soybeans, wheat and alfalfa. Corn accounted for 57% of total harvest carbon in 2008, and its proportion increased to 59% in 2013. Corn is also the biggest contributor to harvested carbon increase from 2008 to 2013. It accounts for 72% of net harvested carbon increase, followed by soybeans accounting for 16%, and alfalfa for 6%. Wheat remained as the third biggest contributor to harvested carbon in 2013, however from 2008 to 2013 it is the only one that experiences a decrease in harvest in the four major crop types, and it also accounts for the largest decrease of all crop types.

From 2008 to 2013, change of harvested carbon (Fig. 3) was not unidirectional in all states. While the Corn Belt states experienced moderate fluctuation in harvested carbon, the largest increases occurred in Georgia, Alabama, Ohio and Tennessee, whereas the largest decreases occurred in Rhode Island, New Hampshire and Florida. None of the states experiencing large changes were within the Corn Belt region. The difference between harvest carbon values in 2013 and 2008 was mapped over the counties of the United States in order to determine change in harvest carbon values over time. From this map, we can see that major areas of harvest carbon increase on the margins of the Corn Belt states, as well as hot spots in southern California and southeast Washington states.

The trend on this map displays an increase in harvested carbon in counties on the margins of the Corn Belt States. This trend coincides with land conversion from previously non-cropland to cropland [16-18]. Conversion from non-cropland to cropland,

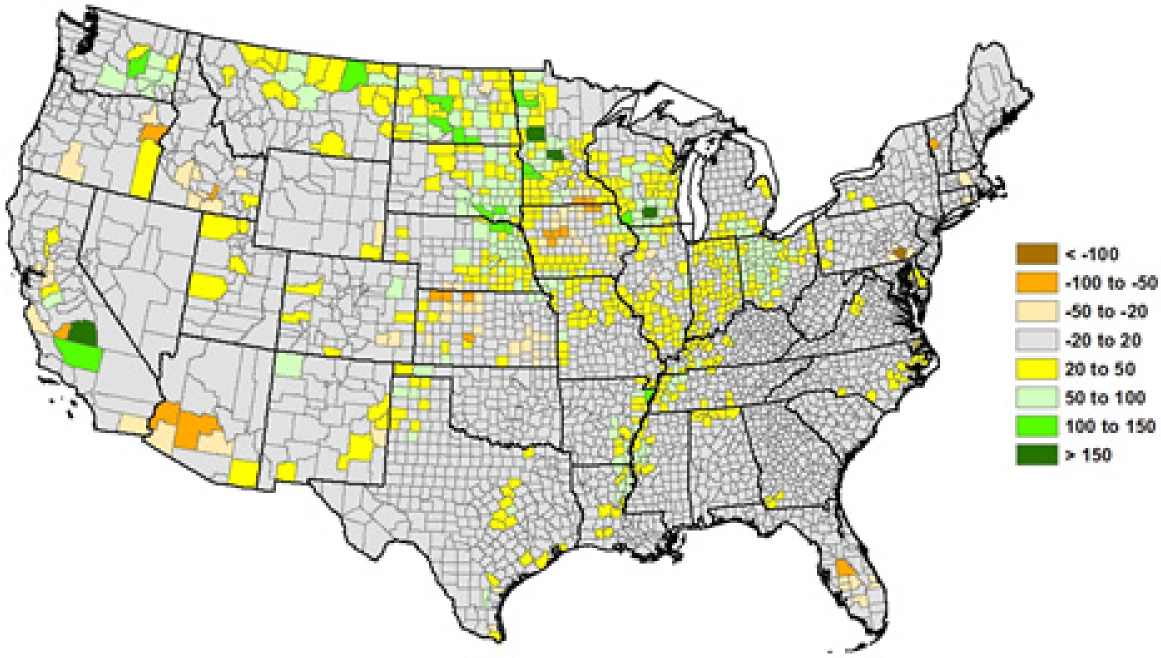


Fig. 3 Estimate of NEP difference between 2008 and 2013 in the conterminous United State (unit: Tg C, teragram carbon).

regardless of the crop type, causes a greater increase in harvested carbon in comparison to normal crop cycling as well as conversion between crop types. The counties experience decreases in harvest carbon, can be related to normal cycling of crop types. Different crop types have different harvest carbon contents, and in areas in the Corn Belt where crop cycling caused corn cropland in 2008 to be changed to other crop type coverage in 2013 would explain a natural decrease in harvest carbon content simply due to the type of crop cultivated.

Harvest carbon is low in the southeastern United States, because although the area is rich in vegetation, i.e. forest, grasslands, wetlands, but not necessarily the cropland that is represented in the CDL. Between 2008 and 2013, California faced issues with major drought, causing agricultural producers in Central Valley to shift from producing crops like corn, cotton and wheat, to more economically advantageous crops such as almonds, grapes and walnuts [19-21]. In Florida, many crops such as various citris crops and other vegetables like tomatoes are grown, but the amount of major crop types grown in this state is relatively low. Since this analysis is focused on major crop types making up 95% of agricultural production, it would not include the type of crops that are mainly grown in Florida, thus leading to seemingly low harvest carbon values [22, 23].

4. Conclusions

This study focused on measuring carbon sequestration associated with the croplands in the conterminous United States from 2008 to 2013. We developed quantitative methods of spatio-temporal analysis able to estimate the net ecosystem production (NEP) using GIS applications. NEP estimation enables us to evaluate the carbon removed from the land through harvests and provide the net rate of carbon uptake in terrestrial ecosystem. We found that harvested carbon nationwide was 195.50 Tg C, and increased to 227.30 Tg C in 2013. The source of harvested carbon mainly comes from the Corn Belt. Harvest carbon is low in the southeastern United States, because although the area is rich in vegetation. Corn accounted for 57% of harvest carbon in 2008, and its proportion increased to 59% in 2013. From

2008 to 2013, corn accounts for 72% of net harvested carbon increase, followed by soybeans accounting for 16%, and alfalfa for 6%. This research will enhance the assessments of carbon exchange and biofuel production in the conterminous United States. This study will also provide a spatio-temporal reference for analyzing the national-level Renewable Fuels Standard (RFS) over the period 2008-2013.

Acknowledgement

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