SPATIO-TEMPORAL ANALYSIS OF CROPLAND CHANGES IN US IN THE LAST DECADE

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ABSTRACT

Land use land cover changes (LULCC) are expected to occur due to population growth, climate change and bioenergy demand. It is imperative that we develop better data analysis and techniques to estimate these changes to better predict the consequences and impacts of such changes on the environment. In this study we analyze time series MODIS land cover data to estimate patterns of spatio-temporal cropland and grassland change by analyzing nine years of consistent land cover data. Our results show that the rate of displacement of cropland and grassland by each other declined for the first half of the last decade while it increased in the second half of the decade. Most of these changes were concentrated in the Great Plain regions and included states in the Corn Belt.

Index Terms— MODIS, Cropland, Grassland, Land use, Land Cover

1. INTRODUCTION

Global land cover change products are critical data inputs to help understand a variety of phenomenon, which include climate change and global environmental and population impacts [1-3]. In the past, land use land cover change (LULCC) was mainly caused by widespread deforestation to meet the food requirements of a growing global population [4,5]. However, more recently there has been apprehension that the mandate and demands of bioenergy will result in widespread direct and indirect LULCC. There are concerns that global adaptation of bioenergy will lead to widespread land use change due to conversion of forestland and grassland to cropland leading to significant greenhouse gas emissions [6, 7]. There have been no studies to determine the location of cropland changes spatially and correlating them to bioenergy demands mainly due to the lack of appropriate spatial data to estimate such changes. The lack of appropriate spatial data remains the biggest challenge in estimating land use changes due to growth of bioenergy. Existing data lack resolution, update frequency and appropriate classes to estimate land use changes due to growth of bioenergy. Researchers have recommended that spatially explicit land use land cover data with appropriate classes and characteristics is essential to confidently establish a causal relationship between land use change and bioenergy. According to a U.S. Department of Agriculture (USDA) [8] report, overall cropland area declined in the U.S. from 1950 to 2007, with a brief period of increase from 1964 to 1978. Total cropland used for crops decreased from 140 million ha to around 135 million ha from 1997 to 2007. Prior to 1950, most of the cropland expansion in the U.S. resulted from forest, steppes, and grassland conversion. It is estimated that the largest portion of cropland was created by clearing approximately 100 million ha of grassland in North America [5] in the historic past. Searchinger et al. [6] estimated that an additional 2.2 million ha of cropland would be needed in the US to meet the demand of ethanol corn by 2016. In this study we analyze the changes in spatio-temporal trend of cropland change in the conterminous US for the past decade using annual Moderate Resolution Imaging Spectroradiometer (MODIS) collection 5 land cover data (MCD12Q1). This analysis helps to understand how cropland pattern in the US changed over continuous space and time. It is important to analyze data over a continuous time period to accurately understand LULCC. Studies estimating change based on two time periods will not reveal the true pattern of LULCC as it is biased by the years chosen for analysis and can be influenced by other factors like temperature and rainfall patterns for those years. No previous studies have analyzed multi-year land cover data for the whole of the conterminous US to understand the pattern of cropland change in the US. Analysis of multi-year data will help to determine the trend of cropland change spatially as well as determine whether changes are permanent or random.

2. METHODOLOGY

MODIS data product MCD12Q1 available in HDF-EOS format was used in this study. The data was mosaiced and projected into Albers equal area projection, and clipped to the outline of the contiguous 48 states. The MCD12Q1 data contains 17 land cover classes but since the aim of this study was to study regional patterns of cropland change in the past decade, the data was reclassified into cropland, grassland and others. To reduce pixel-to-pixel errors in the MODIS data, the land cover data were aggregated by the dominant land cover class within a 10x10 (approximately 5x5 kilometers) non-overlapping window. The window also helped to remove noise and isolate misclassified pixels. Three change parameters were calculated for each non-overlapping block. These included areas of all the cropland which had changed in the past decade, areas of cropland
which were lost to grassland in the past decade and areas of cropland which were gained by replacing grassland in the past decade.

A total of three image files were produced as a result of this analysis, the first one was generated by calculating how many times had a cropland pixel changed in the total 9 years, i.e., if a majority pixel in the window changed every year it was assigned a value of 8, if it did not change at all it was assigned a value of 0. The second image was created based on the last occurrence of predominant cropland within a 10x10 window. If it changed in 2009 it was assigned a value of 8 and if it changed in 2002 it was assigned a value of 1, if the pixel did change at all it was assigned a value of 0. The third image represented the year when a pixel was first classified as cropland. All these analysis was performed using the python language and the Geospatial Data Abstraction Library (GDAL) while ArcMap software from ESRI was used to visualize the results and produce the maps.

3. RESULT

The total cropland displaced and added each year is shown in table 1. Overall a total of .13 million km$^2$ of cropland was lost from 2001 to 2009 in the conterminous US. A total of 0.38 million km$^2$ of cropland was replaced by grassland while a total of 0.24 million km$^2$ of grassland was replaced by cropland over the nine-year period. The spatial and temporal distribution of these changes is shown in figures 2, 3, and 4. The maximum displacement of grassland by cropland occurred in the year 2002 which included an area of around 70000 km$^2$ after which the displacement of grassland declined till 2007. Since 2007 increase in grassland displacement by cropland started to occur which continued to rise till 2009. A similar pattern of cropland displacement by grassland is also observed. Around 87000 km$^2$ of cropland was displaced in 2002 but total displacement continued to fall and reached its lowest level of around 40000 km$^2$ in 2005 after which again displacement of cropland continued to rise to around 60000 km$^2$ in 2009. Hence both grassland and cropland displacement continued to fall from 2001 to 2004-2005 and then both started to rise since then however the rate of cropland displacement by grassland was higher than the displacement of grassland by cropland. The rate of grassland displacement by cropland was around 5 % at the beginning of 2002 and dropped to less than 1 % in 2007 after which it rose to around 1.5 %. The rate of cropland displacement by grassland was around 6 % in 2002 and dropped to around 1.4 % in 2005 and then rose to over 4 % in 2009.

Looking at the spatial pattern of change it can be observed that most of the changes between cropland and grassland in the past decade have occurred in the Great Plains region (GPR). The GPR of the United States is a vast ecosystem that cuts through the central part of the nation, extending from Montana and North Dakota in the north to Texas and Louisiana in the south. It is predominately grassland and/or shrubland in the western and southern portions of the ecoregion, and cropland in the east, covering parts of 14 states [10]. In general, precipitation increases from west to east, and has historically contained the western edges of the Corn Belt, one of the most cropland intensive regions in the U.S. Land cover in the GPR has changed with fluctuating crop prices, market demands, and changing climatic patterns. Recent studies and data suggest land in parts of the Great Plains—previously converted from grassland to cropland—were converted back to grassland partly as a result of the conservation reserve program (CRP)[11]. The boundary of cropland-grassland in the Great Plains was the main region in the country where significant consistent trend of change between cropland and grassland could be found by the analysis while changes in other part of the country were mostly random and scattered. Since most of the changes seemed to occur at the boundary of grassland and cropland there is a possibility that due to confusion in classification of grassland and cropland some of the changes are not real but are a manifestation of classification errors due to differences in seasonal/annual moisture content or reflection differences. Even though total cropland was declining there were new areas in the Great Plains region where new cropland was being added every year however the percentage of new cropland being added has decreased over time from over 5 % in the beginning to less than a percent at the end of 2009. Most of the changes in cropland have been concentrated in the states of North Dakota, South Dakota, Nebraska and Kansas, which are part of the agriculturally intensive mid-western region of the US. This area is also part of what is referred to as the corn belt.

4. DISCUSSIONS AND CONCLUSION

From the analysis (figure 2,3,4) of the changes it can be seen that nationally there is a distinct patterns of cropland-grassland change, which has been concentrated in the GPR. Grassland displaced cropland from 2001-2005 after which cropland started displacing grassland in the same region. Though there is clear indication in the past five years that cropland has been displacing grassland the total quantity of cropland has been falling. This could be due to abandonment of existing cropland and increasing crop yields which required lesser area to meet the demands of required cropland. Given the increase in demand for bioenergy, an increase in agricultural land in the region has been predicted including reduction in CRP enrollment. This analysis shows that most of changes in cropland have been concentrated in the Great Plains region throughout the past decade. LULCCs often take place at edges, or frontiers, and the Great Plains ecoregion provides a good example of this. Land cover in the Great Plains has changed with fluctuating crop prices, market demands, and changing climatic patterns. Recent studies and data suggest land in parts of the Great Plains—previously converted from grassland to cropland—were converted back to grassland partly as a
result of the conservation reserve program [11]. Some of the conversions of grassland back to cropland have been due to expiring CRP contracts and flat CRP budgets in the past few years which support lesser enrollment. The spatial pattern and location of cropland change in the Great Plains region (Figure 5,7) suggest that recent bioenergy development primarily involved land that had been in rotation between cropland and grassland/pasture for decades. It is plausible therefore that most of the land use land cover change that occurred at the agriculture frontiers is also influenced by climatic conditions in addition to economic reasons. It is very difficult to directly identify a single phenomenon for causing land use land cover change in a region however there is a clear indication that in the early part of the decade the US was losing cropland and grassland which was mainly concentrated in the Great Plains region. Uncertainties associated with the data due to classification errors and errors in data acquisition will result in some spurious changes. MCD12Q1 has been shown to have an overall accuracy of about 75 % and the cropland class has a user accuracy of over 90 % [9]. These numbers are based on global estimates and may change at regional scales. However this product is the only available multi-year land cover data for estimating spatial change and is expected to give better results than previous versions or other national and global land cover products most of which are just available for a one or two time periods. There is a probability that classification errors due to confusion between cropland and the native grassland will introduce some amount of uncertainty in the results. Our statistical analysis showed that most of the resultant uncertainties lie within acceptable limits.

| Year | Cropland Lost (km²) | Cropland Gained (km²) | Net Change |
|------|---------------------|----------------------|------------|
| 2002 | 87900              | 71200                | -16700     |
| 2003 | 52300              | 45500                | -6800      |
| 2004 | 26900              | 29400                | 2500       |
| 2005 | 19600              | 29700                | 10100      |
| 2006 | 34500              | 19000                | -15500     |
| 2007 | 40100              | 13800                | -26300     |
| 2008 | 53400              | 14200                | -39200     |
| 2009 | 60500              | 19700                | -40800     |
| Total| 375200             | 242500               | -132700    |

Table 1. Gain and loss in cropland area 2002 to 2009

Figure 1. Graph showing the pattern of displacement of cropland by grassland and vice-versa from 2002 to 2009

Figure 2- Spatio-temporal change between grassland and cropland.

Figure 3- Displacement of cropland by grassland.
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