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Land use structure optimization based on carbon storage in several regional terrestrial ecosystems across China

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ABSTRACT

Land use change is a main driver of carbon storage in terrestrial ecosystems. Based on land use data, research results related to carbon densities in vegetation and soil as well as government policies related to development in different regions of China, this paper optimized land use structure in 2020 for different regions with the goal of increasing terrestrial ecosystem carbon storage. We defined seven types of land use: (1) cultivated land, (2) garden land, (3) woodland, (4) pasture land, (5) other agricultural land, (6) urbanized land, and (7) a mixture of other land which we call mixed land which included open water, swamps, glaciers and other land as defined below. We found: (1) For most eastern regions, woodland has the highest carbon (C) densities while C densities of pasture land and cultivated land did not differ widely. Both have C densities higher than urbanized land while urbanized land has higher carbon densities than the areas placed in the mixed land type. (2) Under an optimized land use structure projected for 2020, the area of cultivated land will decrease compared with 2005 for most regions. The areas of garden land, pasture land and other agricultural land are much smaller compared with the mixed land use type, and the changes there are not obvious and their contributions to increased carbon storage are not significant. The area of woodland will increase the most obviously and it will contribute the most to increased carbon storage. The increasing urbanization of land and the decreasing trend of other land types make it difficult to change carbon storage patterns since the Chinese economy is expanding rapidly. (3) The optimized land use structure presented here will have effects on the entire country though with regional differences. Some inland regions will always have a larger potential to increase carbon storage than other areas because the potentialities in some coastal regions are limited by social and economic development.

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1. Introduction

Changes in how and where carbon is stored in terrestrial ecosystems are very important to global carbon circulation and global warming (IPCC, 2000). Batjes (1996) reported total global carbon storage in terrestrial ecosystems can reach to 2000–2500 Pg (1 Pg = 10^{15} g), which includes 500–600 Pg from global vegetation and 1500–1900 Pg from the upper 1 m of soil. Terrestrial ecosystems absorbed 0.9 Pg/a carbon which accounted for 12.5% of carbon emissions from energy consumption and cement production during 2000–2005 (Lal, 1999). Land use change caused by human activities is a main driver to terrestrial ecosystem carbon storage (Su et al., 2006; Jiao et al., 2010). First, it can change the vegetation cover which can directly influence vegetation biomass. For example, the changes from woodland to other land types, and especially the changes to urbanized land, will greatly reduce vegetation biomass and will release carbon into the atmosphere (Fang et al., 2007; Houghton, 2008; Bailis and McCarthy, 2011), while changes from other land use types to woodlands can always increase its vegetation biomass and carbon storage (Zhao et al., 2011; Chuai et al., 2011a,b, 2012). Second, land use changes also have a profound influence on soil organic carbon (Bushchbacher et al., 1988; Fu et al., 1999a,b; Solomon et al., 2000; Kong et al., 2009; Jaiarree et al., 2011). Soils can be a source or sink for atmospheric carbon depending on land use and management techniques (Lal, 2002; Umakant et al., 2010). Barnett et al. (2005) reported that, in the past 20 years, about one fourth of anthropogenic carbon dioxide emissions are caused by land use changes, especially deforestation, and the rest is caused by fossil fuel burning. Long-term experimental studies have confirmed soil organic carbon is highly sensitive to land use changes since native ecosystems, such as forest or grassland, become agricultural systems, resulting in the loss of organic carbon (Paul et al., 1997). With the development of urbanization, more and more farmland, woodland and grassland has been converted to urbanized land; this results in the land area being converted from carbon sink to carbon source, as a large amount of carbon is released from these disturbed terrestrial ecosystems into atmosphere (Deng et al., 2009). If one compares emissions from the combustion of fossil fuels with changes in emissions resulting from land use change, the mechanisms involved in carbon emissions caused by land use change are more complex and poorly known. The impact on carbon balance caused by land use and land cover change in terrestrial ecosystems has become the focus of global change research in recent decades (Houghton, 2002, 2003).

In response to global climate change, many plans have been made to reduce carbon emissions around the world (Wang et al., 2010), such as the use of biofuels, carbon capture and storage planning for energy use in industrial areas (Fargione et al., 2008; Searchinger et al., 2008; Tilman et al., 2009; Melillo et al., 2009; Service, 2009) and the plan to reduce carbon emissions from deforestation and degradation (REDD) made by agriculture and forestry departments (Chu, 2009; Haszeldine, 2009). Most of these plans face considerable difficulties created by a technological problems as well as the business and politics of energy use (Stuart, 2009), so reductions in carbon emissions are often difficult to achieve. Using current technology, enhancing the function of land-based carbon sinks through adjusting land use patterns and management seems to be an effective plan which can be used to increase carbon storage in terrestrial ecosystems (IPCC, 2005; Yu and Wu, 2011). Research related to land use structure optimization based on low carbon emissions is still in its infancy, although some scholars have made tentative studies in local areas. Zhong et al. (2006) optimized land use readjustment to reduce carbon storage loss in Cuiyuan Village in Hubei province, China. Tang et al. (2009) optimized land use structure in Tongyu County, Jilin Province, China to maximize carbon storage in terrestrial ecosystems, and found the plan effective in reducing carbon emissions. Yu and Wu (2011) designed the Land Use Structure Optimization of Low-carbon Dynamic Control Model in a study of Taixing City, Jiangsu Province, China and found it can meet the requirements of maximizing the efficiency of land resource allocation and sustainable development. Since China faces great pressure to reduce its portion of the world's carbon emission (Chuai et al., 2012), making low-carbon land use structure optimization plans for different regions of China seems very necessary and meaningful.

We used land use data and data related to carbon densities of vegetation along with soil organic carbon data from the top 1 m of soil as well as developmental policies of different regions in China to study the carbon densities for different land use types and establish a land use structure optimization model for different regions of China.

2. Methods

2.1. *Data sources*

Data used in this paper includes a China land use type map from the 1980s, a provincial administrative zoning map produced by Chinese government, provincial land use structure data from 2005, planned provincial land use for 2020, and a map of vegetation density and soil organic carbon density.

The 1 km × 1 km grid land use map of China from the 1980s was obtained from the Modis image of Landsat TM (Lai, 2009). The Chinese provincial administrative zoning map was provided by the National Geomatics Center of China. Land use structure data in 2005 and the planned provincial land use for 2020 were provided by the China Land Surveying and Planning Institute. This paper did not include data from Taiwan, Hong Kong and the Macao Special Administrative Regions because of a lack of data from these areas.

Carbon densities of different vegetation types were obtained using mean values from existing research in China. Many scholars have conducted research related to vegetation carbon densities in different regions of China. Lai (2009) collected data from more than 800 related research projects in recent years which can cover almost all kinds of vegetation found in China. Mean carbon densities of 50 different vegetation types have been summarized. Using comprehensive analysis (Lai, 2009) and the China Vegetation Map compiled in the 1980s, we produced distribution maps