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Effects of land use change on soil carbon cycle in process of urbanization in China

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Abstract: Urbanization is a target and result of economic development in China. Urbanization has changed the type of urban land use, and also affected the soil carbon cycle of urban ecosystem. In this paper, the land use change characteristics and soil carbon content in different land use types of urban ecosystem in the process of urbanization were reviewed, as well as the influence of urbanization on soil carbon characteristics, and the main factors affecting the carbon storage in urban surface soil. Finally, the future research direction of soil carbon cycle in urban ecosystem was discussed, and some countermeasures and suggestions were put forward to ensure soil carbon balance.

Introduction

Urbanization is a prominent phenomenon in contemporary China. Urbanization contains two aspects of contents, i.e. the transformation from rural areas to urban areas and the expansion of the existing urban areas. Urbanization in this paper mainly refers to the latter, and only the large cities' urbanization was reviewed and discussed [1-2]. Urbanization has changed the structure and function of urban ecosystem, and also changed the land cover type in cities and its surrounding areas [3-4].

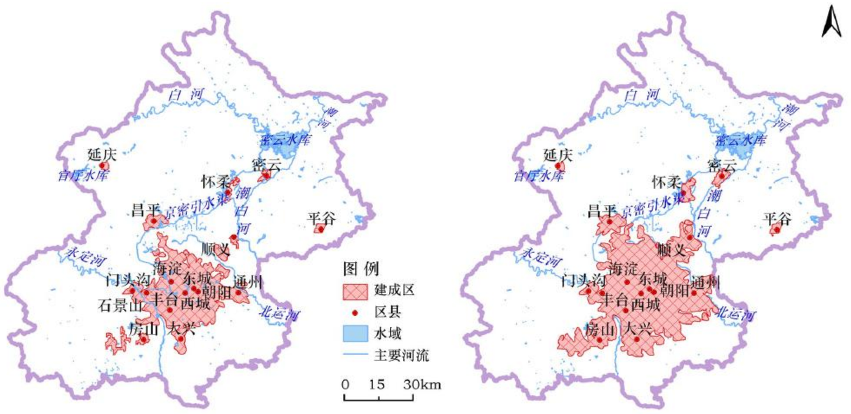
The city area is strongly influenced by human activities [5-8], and the land use patterns show a high spatial and temporal variability, which directly changes the process of regional natural carbon cycle, and indirectly changes regional anthropogenic carbon emissions. Therefore, the study of soil carbon cycling in urban area has greater uncertainty and challenge [9-14].

There are relatively many studies on land use change in the process of urbanization. In addition to field sampling and model calculation, more and more "3S" technologies have been applied [15-21]. In these studies, the issue on how does the soil carbon cycle respond to the strong land use change in the process of urbanization is included [22-24]. This paper reviewed the influence of land use change on soil carbon cycle in China's urbanization process, aiming to provide reference for the study of carbon cycle in urban ecosystem.

The characteristics of land use change in process of urbanization

As the rural population gathers to the city, the scale of city continues to expand, and the city construction land, roads and other land area expand; and land use change is one of the external performances in the process of urbanization, which is strong and direct. In this process, the main feature of land cover change is the rapid expansion of construction land, which results in the decrease of forest land, arable land, garden plots and other areas, and the fragmentation of landscape [25].

The study found that during the years of 1992-2008, there was 792.69 km^2 farmland changed to construction land in Beijing [26], urban construction land expanded with a decentralized group mode along the Ring Road (i.e. the main urban road with a circular shape in Beijing, e.g. the 2nd Ring Road) outward, and a lot of cultivated lands were occupied [27]; in 2004-2013, the traffic land, and town and village and industrial land in Beijing City increased with an average annual growth rate of 8.089% and 1.29%, respectively, and the arable land decreased with an average annual reduction rate of 0.73% [28]. In addition, as the figure showed, the built-up area in Beijing expanded from 1253 km^2 in the year of 2000 to 2348 km^2 in 2010 [29].



a. In the year of 2000 b. In the year of 2010

Figure Morphological changes of city space in Beijing from 2000 to 2010 [29]

In the process of urbanization, land use change also presents a feature of periodical change. Taking Shanghai as an example, as shown in the table [30], in the 3 periods, i.e. 1994-2000, 2000-2003 and 2003-2006, the farmland area in Shanghai continued to decrease; due to the acceleration of the process of urbanization further in 2000-2003, the annual average farmland reduced most significantly, and then the decrease trend slowed down obviously after 2003; the green area continued to increase, and the increase rate increased during the 2000-2003 period, followed by the slowing down of the growth rate; the industrial land, road traffic land and residential land were increasing consistently, and the growth rate continued to increase [30]. The built-up area of Shanghai in 1987-2008 grew at an average annual rate of 6.84%, with an increase of 702 km^2 by the year of 2008, and cultivated land area decreased with an average annual rate of 2.34% [26].

Table Statistics of annual area change of main land use types in Shanghai [30] (Unit: hm^2/a)

Land use type	Years of 1994-2000	Years of 2000-2003	Years of 2003-2006
Farmland	-4624.92	-13418.86	-8667.21
Green area	421.94	1927.43	326.15
Industrial land	886.66	2939.74	5290.57
Road and traffic land	924.25	1212.88	2775.02
Residential land	459.38	1891.49	2516.8

Note: minus indicates decrease

Soil carbon content of different land use types in urban ecosystem

In a typical urbanization area in the northwest suburbs of Beijing, the content of total carbon in soil changed between 0.918% and 2.546%, the content of total carbon in urban forest land, artificial grassland and mountain forest land was relatively high, and that in bare land was the minimum, but the difference was not very significant [14]. The average soil organic carbon content at 0-30 cm depth was 0.72-40.52 g/kg for different land use types in Shenzhen City, of which the mangrove was the highest, followed by the wetland and woodland; the soil organic carbon density ranged from 0.27 to 13.36 kg/m^2, and the construction and idle land showed a very low content and density of soil organic carbon [31]. The surface soil carbon density of the new development zone (1.87 kg/m^2) was significantly lower than that of the old urban area (3.12 kg/m^2) in Chongqing City; the soil carbon density of the regions with the slope of 2-6° (3.36 kg/m^2) and above 25° (3.20 kg/m^2) was relatively higher; among different green areas, the soil carbon density of green space of park and garden was the highest (3.63 kg/m^2), while the lowest value occurred in green area along roadside (2 kg/m^2) [32]. The carbon sequestration capacity in paddy field was the highest among different land use patterns in Shanghai area, with the soil carbon density of 3.859 kg/m^2, the minimum was 1.379 kg/m^2 occurring in the intertidal zone, and the order for the soil carbon density of several other land use patterns was: dry land > forest land > abandoned land > city lawn > garden plot [30].

The influence of urbanization on soil carbon characteristics

For the functional areas with different degrees of urbanization in Beijing, the soil organic carbon content was relatively high in the new urban development zone and the ecological conservation area with relatively low degree of urbanization, and was low in the capital core functional area and the city functional expansion area, which has a relative high degree of urbanization and stronger human disturbance. And the development speed of urbanization was approximately negatively correlated with the organic carbon content and carbon-nitrogen ratio [33]. During the rapid urbanization process in 1987-2007, the vegetation and soil carbon storage in Shanghai City decreased from 4.1×10^7 to 3.2×10^7 t, the total reserves decreased by 0.9×10^7 t, and the negative effect of urbanization level on carbon reserves was significant [34]; the surface soil organic carbon loss was about 4.23×10^6 t, and the soil organic carbon loss per unit area was even larger in the expansion area within the period of 1999-2007 [35]. Shenzhen is one of the cities with the fastest urbanization in China; in the initial stage, accelerated stage and stable stage in the urbanization process, the carbon storage in urban ecosystem roughly corresponded to the high carbon storage period mainly owing to natural vegetation and agricultural land, the rapid decrease period of carbon storage due to the rapid expansion of construction land, and the carbon reserves gradual recovery period [25]. During the years of 1998-2005, the urbanization process in Zhengzhou eroded the suburban green space, resulting in a rapid decline in the carbon storage capacity of the agricultural ecosystem in the suburbs [36].

Generally speaking, in the urbanization process, there will be a lot of farmland occupied and then transformed into construction land, road land, and so on. Original accumulation way of soil organic carbon is cut off, so the surface soil organic carbon density and storage will be significantly reduced, which is a typical characteristic of urbanization process. The urbanization process of different typical cities has changed the land use pattern, and also changed the surface soil properties, thus changing the characteristics of soil carbon.

Main influencing factors of urban surface soil carbon storage

The carbon storage and its spatial distribution of urban surface soil are affected by soil physical and chemical properties, environmental factors and human factors [37]. Soil physicochemical properties include soil nitrogen content, pH value, bulk density, and so on; environmental factors include the distance from city center, greenbelt type, urban and suburban difference, urban expansion period and slope; among the effects of human activities, the good management and protection, and the arbor-shrub-grass composite configuration are conducive to carbon accumulated [32,37]. The research found that the organic carbon, inorganic carbon and total carbon content in the soil of typical green area in Beijing had the significant positive correlation with the built time of green area; the holding rates of 3 kinds of carbon in green space of residential area were respectively 46, 19 and 65 $g/(m^2\cdot a)$, showing a trend of increasing linearly with the built time, but the soil carbon accumulation in park green space was influenced greatly and relatively low due to human disturbance, such as landscape transformation [37].

In the process of urbanization, land use changes significantly, which then affects the surface carbon cycle process. This relationship can be showed from the 2 aspects: on one hand, some processes, including non-agricultural conversion of land use, land development, and land use intensification, will increase the disturbance of the soil carbon pool, accelerate the decomposition of soil carbon, and increase carbon emissions; on the other hand, the land use change, such as afforestation, returning farmland to forests and grassland, and disintensification of agricultural land use, can reduce carbon emissions and increase carbon sequestration [38].

Suggestions and perspectives

In the context of global change, with the economic development, urbanization has become one of the most important social and economic phenomena in the world. The development of urbanization is one of the goals of economic development in China, and the urbanization has resulted in a reduction in carbon density and storage of urban ecosystem, but through appropriate vegetation and soil carbon management measures, the carbon pool in urban ecosystem can be recovered gradually [25]. Reasonable land management measures can improve soil carbon sequestration potential. The research shows that increasing the application of green manure, increasing the proportion of straw incorporated, and combining the application of organic fertilizer and chemical fertilizer, can make the carbon-fixed potential of farmland soil increase obviously; afforestation has an obvious effect on forest vegetation and soil carbon sequestration; strengthening the construction of urban green space, and improving the management level of urban green space, also play an important role in increasing soil carbon sequestration in cities [30].

In the present study, there is lack of dynamic data of soil carbon density with time change under different land use types in the process of urbanization [39]. For the research method, either model estimation or remote sensing estimation, field sampling, there are large uncertainties [40-41]. In addition, it is still difficult to quantitatively determine the different factors that affect the carbon dynamics of urban ecological system and their interaction [42].

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