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Estimation of soil organic carbon reservoir in China

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Estimation of soil organic carbon reservoir in China WANG Shao-qiang1, ZHOU Cheng-hu1, LI Ke-rang1, ZHU Song-li2, HUANG Fang-hong1 (1.The State Key Laboratory of Resources and Environment Information System, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China; 2. Institute of Environment Science, Beijing Normal University, Beijing 100875, China) Introduction Research on global change has aroused many scientists’ attention to the balance, storage and spatial distribution of carbon in the terrestrial ecosystem. The carbon stored in soil is 2.5-3 times as much as that stored in plants[1,2], so the distribution and conversion of carbon in humus has become one of the global research foci on organic carbon at present[3]. Organic carbon and nitrogen contents in soils are not only important components of soils but also the most important ecological factors in global biogeochemical cycle, so attention has also been given to it in many subjects such as ecology, geography and pedology. In addition, it has become one of the important contents for global change study[4]. Scientists have long been involved in calculating the global and some regional soil organic carbon reservoirs. For example, the estimation of global soil organic carbon storage is about 13953×108 tC[5], the soil organic carbon reservoir is about 1800×108 tC in China[6], which can play a more important role in global carbon cycle and global climate change. Many researches showed that soil organic carbon exchanging with atmosphere constitutes about two-thirds of the carbon storage in terrestrial ecosystem. Enormous storage and long existence make soil become a reservoir which absorbs carbon emitted by human activities[5], so soil is not only a carbon sink but also a carbon source. At present, the uncertainty on understanding the global carbon cycle is mainly about spatial distribution and dynamics of soil organic carbon[7]. To accelerate the emission of soil organic carbon to atmosphere is one reaction to the global warming, which will accelerate the rise of atmospheric CO2 concentration, further intensifying the tendency of global warming[8]. Moreover, the land use/land cover change can not only directly affect the content and distribution of soil organic carbon, but can also be indirectly affected by impacting factors of soil organic carbon formation and transition[3]. So precise estimation of the effects of soil organic carbon reservoir and land-use/land-cover change on carbon balance in terrestrial ecosystem constitutes the foci of research on global change and terrestrial carbon cycle. In China, scientists have already launched studies on s oil organic carbon cycle. Li et al.[10] used double component model to simulate the soil organic carbon dynamics after changing land-use pattern in hilly red earth region of subtropical China. Wang et al.[3] researched the impact of human activities on the distribution of soil organic carbon in temperate grassland in Xilin Gol League, Inner Mongolia. Li[11] reviewed research results and recent advances in the studies of long-term effect of land-use change including grassland reclamation and overgrazing on soil carbon storage in grassland ecosystem. Wu et al.[12,13] and Li[14] researched the soil carbon storage of tropical forests in Jianfengling. They found that the high soil carbon storage in tropical forest is closely related to the productivity of plant, the activity of microorganism and climate conditions. Wang[15] studied and found that carbon may increase greatly by using organic fertilizer and during a period, the change of temperature is also an important factor causing fluctuation of soil organic carbon. Researches on soil organic carbon are mainly conducted in connection with specific regions and ecosystems[3,4,10-19]. Although researches have been carried out on the respiration of soil and carbon emission to the atmosphere, the estimation of terrestrial soil organic reservoir is still very limited in China. Hence the contribution of soil to the global carbon cycle have not been fully recognized. At present, land erosion and degradation caused by various reasons, such as deforestation, soil erosion, desertification and overgrazing, made vegetation biomass and soil organic carbon decrease which resulted in more carbon emission to the atmosphere and increase in concentration of carbon dioxide. Then, the tendency of global warming and the concerned climate change became stronger. This paper uses measured data and the technique of geographical information system to calculate the terrestrial soil organic carbon reservoir, tries to analyze the spatial distribution characteristics of soil carbon reservoir and discusses the role of soil organic carbon reservoir on the global change. 2 Materials and method 2.1 Materials Materials of the second national soil survey include records of 2,473 typical soil profiles[20, 21] and their geographic location, soil depth, organic content, bulk density, area, principal properties, physio-chemical analytical data, etc. (Figure 1). There are many types of soils in China, for example, the phospho-calcic soils on South China Sea Islands, the tropical latosols in South China, the brown coniferous forest soils of cold temperate Northeast China, the coastal solonchaks of coastal plain in East China, the felty soils and the frigid frozen soils in the Tibetan Plateau and the various kinds of desert soils and so on. Among all area of soil types in China, to calculate more precisely, this paper removed the area of waters, glaciers, perennial firn, bare rock and gravel hills, then the total soil area is about 877.63×106 hm2 (excluding the area of Taiwan which is about 23.95×106 hm2), only 91.39% of the total land area in China[20]. Figure 1 Location of sampled soil profiles in this study 2.2 Method Many scientists have started the study of soil carbon cycle[1,5,6,7,9] since 1979. They mainly estimated the soil organic carbon according to soil carbon density and soil area[5,6,9,22]. In this research we respectively adopted physio-chemical properties of every soil stratum from 2473 soil profiles. The corresponding carbon content of soil is estimated by utilizing conversion coefficient 0.58 used in calculations by Fang[6]. First, we calculated the carbon content of every stratum of different soil horizons in the same soil subtypes. Then, we took soil stratum depth as weight coefficient to acquire the average physio-chemical properties of various kinds of soil horizons. Finally, we got the average depth, organic content, bulk density and carbon density of different soil subtypes through area averaging (Figure 2). Figure 2 Flow diagram of soil carbon density calculation The total carbon quantity of different types of soils can be calculated by the following expression: where, j is soil type, Cj is carbon storage of j soil type, Sj is distribution area of j soil type, Hj is average depth of j soil type, Oj is average organic content of j soil type, and Wj is average bulk density of j soil type. 3 Results and discussion 3.1 Spatial distribution characteristics of soil organic carbon storage in China The result of calculation shows that the average bulk density of soil is 1.30g/cm3 in China, the average depth of soil profiles is 87cm, the average soil organic content is 1.78%, and the average soil carbon density is 10.53kgC/m2. According to the soil area of 877.63×106hm2, the total soil carbon storage is about 924.18×108t in China. Figure 3 The distribution map of soil carbon densities in China We can see the spatial distribution of soil carbon density in China from Figure 3. It shows that the soil carbon densities of forest soils and alpine soils are very high. For example, soil carbon densities of brown coniferous forest soils, dark-brown earths and gray forest soils, which are distributed in Northeast China, and bog soils, felty soils (alpine meadow soils) and frigid calcic soils (alpine steppe soils), which are distributed in northeast and southeast of the Tibetan Plateau, are much higher than that of other regions. In Northeast China, the vegetation is flourish and the climate is wetness. The organisms entering into soils are mainly in the form of deadwood and defoliation, so the accumulated process of humus is quite apparent in soil surface layer. With the lower average temperature and presence of backwater on soil surface, organisms decompose slowly and make soil fertile. In southeast Tibet and west Sichuan Province, the terrain is mainly gentle hillside, ancient till platform, glacio-fluvial deposits and so on. The climate is frigid and humid and surface vegetation is short but flourishes, so organisms decompose very slowly. Moreo ver, layers of sward and humus are well developed, facilitating strong accumulated process of turf organisms. The region is an important natural pasture. Besides the effects of climate, terrain, soil parent materials, rock and vegetation, human activities impact the soil organic content through cultivation, fertilization and other agricultural measures. The soil organic content decreases in Loess Plateau and Huang-Huai-Hai Plain with a long cultivation history. However, paddy soils long time submerged in water are in favor of accumulating organism because of deoxidization environment reducing mineralization rate. 3.2 Horizontal zonal distribution character of soil carbon density The distribution of soil horizontal zonality is that soil types and soil formation characteristics coinciding with zonality of large climate zone and biology, so the distribution of soil carbon density also coincides with horizontal zonality of soil and vegetation. In order to analyze the spatial distribution characteristics of soil carbon density in China, the paper made three profile lines of soil carbon densities respectively in eastern, northern and western China by using ArcView GIS software (Figure 4). In eastern China, with the descending of quantity of heat from south to north, vegetation types are tropical rainforest, monsoon rainforest, evergreen broad-leaved forest, mixed broad-leaved deciduous and evergreen forest, broad-leaved deciduous forest, deciduous broad-leaved and coniferous mixed forest and cold-temperate needle-leaved deciduous forest. Corresponding soil types are latosols, latosolic red earths, red earths and yellow earths, yellow-brown earths and yellow-cinnamon soils, brown earths, dark-brown earths, and their carbon densities increase gradually (Table 1 and Figure 5a). Generally speaking, a tendency is indicated that soil carbon density increases with the increase of latitude in eastern China. With decreasing of moisture from east to west in northern China, we can see dark-brown earths of humid temperate forest, black soils, gray forest soils, chernozems, dark castanozems, castanozems, and light castanozems with thin surface accumulation and brown caliche soils where vegetation is short and sparse. When entering desert environment further west, it is even drier with scarce rain and even lower vegetation coverage. There are gray desert soils and gray-brown desert soils with carbon densities decreasing step by step (Table 2 and Figure 5b), that is soil carbon density tends to reduce along with decrease of longitude in northern China. In western China, with the decreasing temperature from north to south, vegetation changes from needle-leaved deciduous forest in cold-temperate and temperate steppe to temperate deciduous dwarf semi-shrubby desert, temperate shrubby and semi-shrubby desert, temperate alpine desert with creeping or matted drawf semi-shrubs, alpine steppe in temperate or subtropical zone, temperate meadow, alpine and subapline meadow. Correspondingly, the soil types are grey forest soils, aeolian soils, grey desert soils, grey-brown desert soils, sierozems, frigid calcic soils, cold brown calcic soils, dark felty soils and cold calcic soils. The carbon density of these soils increases gradually with the changing sequence (Table 3 and Figure 5c), showing a general tendency of soil carbon density increase with the decrease of latitude in western China. 3.3 Spatial characteristics of transitional zone The horizontal distribution of soil carbon density is not simply to arrange according to longitude and latitude in China. There is a little deflexion. Seeing from Figure 3, there is a transitional zone between central and western China, which parallels with the population border of Tengchong-Heihe. The transitional zone is located between second terrace and third terrace in topography. The difference of soil carbon density is very large in two sides of the transitional zone because of the comprehensive formed results of large terrain and monsoon characteristics in China[20]. The transitional zone in central China is an economically poor and environmentally critical region (Figure 6). The zone which is approximately located in northeast and southwest is also the typical region experiencing land degradation and the most severe contradiction between human and environment[23]. The transitional zone takes second terrace as the main body. Areas in third terrace are mainly located in western part of Northeast China Plain to east Da Hinggan Mountains including Songnen Sandy Lands and Horqin Sandy Lands. Areas in second terrace include Liaoxi hills, hills in east Xiao Hinggan Mountains, hills in north Hebei Province, Loess Plateau, Qinling Mountains, Daba Mountains and Hengduan Mountains and large part of Yunnan-Guizhou Plateau, which covers an area of about more than $200\times10^4 km^2$[23]. From northeast to southwest, natural vegetations are temperate forest, forest steppe, mountain forest and montane shrubs that original forests were destroyed seriously and climate change is very obvious. Due to human activities and natural factors, eco-environment of the transitional zone has become more deteriorated and erosion of soil and water is more serious. So the soil organic content is decreasing. Seeing from Figures 3, 6 and Table 4 soil organic content varies with different kinds of vegetation and soil types in transitional zone. The soil carbon density is high in northeastern regions due to high vegetation cover rate and decreases by and by towards southeastern region, especially in hilly and eroded areas of Liaoxi, north Hebei, north Shanxi. The soil carbon density increases in southeastern regions such as Qinling-Daba Mountains and Hengduan Mountains. It shows that difference in soil carbon storage is large in transitional zone, relating with natural environment and human role[23]. Figure 6 The transitional zone (left after Zhou et al., 1998) and soil carbon density of transitional zone from Northeast to Southwest of China (right) 3.4 The global position of Chinese soil carbo n reservoir The area of aeolian soils is 67.56×106hm2, about 7.70% of the nation´s statistical area, but its carbon density is only 2.54kgC/m2, so its carbon storage is only 17.146×108t, or about 1.89% of the total soil carbon reservoir in China. The total area of those soil types with carbon densities under average level of 10.53 kgC/m2 is about 571.713×106hm2, or 65.10% of the nation´s statistical area, but their carbon storage is only 320.09×108t, or 34.60% of the total soil carbon reservoir. Viewing from other side, this shows that many soil types have low soil organic content in vast areas, so the total soil carbon storage is small. There are two factors for the low soil carbon storage in China. One is that the forest coverage in China is lower than the average level in the world. The other is that areas of steppe and sands are very large in China with sparse vegetation and lower soil organic content. Table 5 lists the estimations of the global carbon reservoirs. If we take 13,732×108 t, the median of all soil carbon storage in Table 5, as the global average soil carbon storage, then China's soil carbon storage is about 6.73 % of the global soil carbon reservoir. However, the terrestrial area in China is only 6.4 % of the global terrestrial area[6]. It indicates that the soil carbon storage in China occupies a slightly higher percentage in the global soil carbon reservoir. The international calculation method of soil organic carbon reservoir is traditionally based on organic content of 1 m soil depth[5,22,24]. However, this paper adopted the measured soil depth to calculate the soil organic content. Not only measured soil depth is different, but also the organic content in soil strata of different depths is different and most of the soil depth is less than 1m. In fact, many soils are very deep, furthermore, the core stratum of soil has a lot of organic carbon and inorganic carbon, so the soil carbon storage should be much higher in China. The role of soil circle in global change is to impact soil, environment and climate changes through exchanging matter and energy between soil circle, biosphere and atmosphere, which has remarkable effect on global warming[27]. Soil degradation, resulting from many kinds of reasons, can make soil organism reduce and cause more carbon emitting to atmosphere. This leads to the increasing of atmosphere CO_2 concentration and further enhances the tendency of global change and relative climate change. It requires us to strengthen the research of carbon storage and flow and their relationship to water, soil and land management[28]. Not only vegetation biomass of forest is about 86 % of the global vegetation, but also soil organic carbon of forest is about 73 % of the global soil carbon storage[29]. So deforestation not only leads to emission of carbon from vegetation litter, but also makes vegetation free from protection. Then the humus that enters into soil would be much lower and the accumulation of soil organic matter reduces and soil carbon density decreases. We should increase carbon storage in vegetation and soil by protecting forest and expanding forest area. Land-use changes, especially changes due to deforestation, cause the loss of soil organic carbon by over 20 % - 50 % of the average level[24]. Houghton et al. initially estimated a release of 1800×108 t for the period 1860-1980 from global vegetation and soil to the atmosphere due to human activities[30]. The average release of the 1980s is estimated by Houghton to have been 1.6±0.7×109 t/y[31]. So we should fertilize much more to soils by combining the effects of CO_2 fertilization and resisting evaporation based on the probability of increasing soil carbon storage at present[24]. 3.5 Uncertainties This study is based on soil sample data derived from different previous study projects, which may adopt different criteria for soil classification, mapping scales, and degree of representatives of soil profiles, so that the measured soil property data might be inconsistent. The lack of standardized sampling methods may also contribute to this inconsistency. Furthermore, the lack of sufficient data on bulk density of soil horizons, climate and land-use/land-cover change also limits the accuracy of the results. It is obvious that there is still a large room to further develop our methodology to derive more accurate and realistic carbon estimation. Nevertheless, this study has presented a largely improved result by considering the variations of different soil types, soil depths, soil horizons and their corresponding soil organic matter content, which are based on a large number of sampled soil profiles all over the country. 4 Conclusion This paper indicates that the total soil organic storage is about 924.18×108 t in China according to the nation´s statistical area of 877.63×106 hm2. The spatial distribution characteristics of soil organic carbon in China is that the carbon storage increases when the latitude increases in eastern China and the carbon storage decreases when longitude reduces in northern China. There is a transitional zone that carbon storage varies greatly. Moreover, there is an increasing tendency of carbon density with latitude decreasing in western China. Soil circle is of great significance to global change[27], but the variability is very large about soil spatial distribution throughout the country. Because the structure of soil is in homogeneous with many uncertainties, it can also result in certain mistakes in estimating soil carbon reservoir. So it is necessary to farther resolve soil respiration and organic matter conversion and other related questions, build uniform and normal methods of measurement and sampling to resolve uncertainty on estimating soil organic carbon. Establishing a global database on soil profile samples would certainly help to produce more realistic and representative analytical results in soil carbon studies. Further research is also proposed to enhance GIS application methods so that the scientific findings and theo

retical models on soil carbon circulation can be adopted to simulate the spatial distribution of soil carbon reservoir, the relationships between soil, vegetation and atmosphere, and the potential impact on the global climate change. References

关键词： terrestrial ecosystem; global change; soil carbon reservoir; carbon cycle

