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What should we do in the Context of Land Use Change Occurring Frequently in China?

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Abstract

China's effort to mitigate soil organic carbon (SOC) loss caused by rapid land use changes over the last two decades faces great challenges. Generally, land use change projects in China have been performed without considering the mechanisms involved in the link between land use change and SOC dynamic. Such situation will likely increase the climatic and environmental risks brought by land use changes. In this paper, we illustrate why most studies over the past several decades in China have been unable to provide significant guiding information for what kind of land use can be adopted to benefit the climate and ecological environments. In addition, we recommend the combination of soil organic matter fractionation with radiocarbon assessment, which researchers are working on to better predict the dynamic trends of SOC under land use change, and present several proposals in regard to how to sequester more carbon in soils after land use change.

Keywords: Land use change; Radiocarbon; Fractionation of soil organic matter; Soil carbon sequestration

Land Use Change and SOC Dynamics

Globally, soils store more than twice the amounts of carbon present in atmospheric CO_2. SOC stock is determined by the balance of net carbon inputs to the soil (as organic matter) and net carbon losses from the soil (as CO_2, dissolved organic carbon, and the loss through erosion). Land use change is identified as the main driving for the balance between carbon inputs and losses in soil [1,2]. Therefore, changes in land use and land management are important causes of SOC store variation; such variation could lead to a marked climate change because altering in climate patterns is associated with atmospheric CO_2 concentration [3]. Approximately 545Gt of carbon have been released in the atmosphere by land use change and the use of fossil fuels, which resulted in an increase in the atmospheric CO_2 concentration from the range of 275ppm to 281ppm in 1750 to 390 ppm in 2011 [4] and 400ppm in 2013 [5].

Significant changes of land use have occurred in China over the last two decades [6]. The cropland area decreased in the south and increased in the north; however, the total area remained almost unchanged. The reclaimed cropland was shifted from the northeast to the northwest. The built-up lands expanded rapidly and were mainly distributed in the east. Moreover, these lands gradually spread out to Central and Western China. Woodland decreased initially and increased eventually; however, desert area showed the opposite result. Grassland continued to decrease. These changes have greatly affected the ecosystem carbon processes, particularly the exchanges of carbon between the atmosphere and terrestrial carbon pools; they have also affected vegetation cover, photosynthesis, biodiversity, nitrogen utilization, and soil organic matter composition [7,8]. All of which are associated with global carbon cycling, which consequently affects climate change. Inappropriate land use and management in China have exacerbated approximately 8Gt to 14Gt of carbon depletion in soils, and 50% to 60% of these carbon emissions can be restored by restoring degraded soil and ecosystem [9,10]. Thus, understanding how land use and management affect SOC sequestration for sustainable development of China while improving soil and ecosystem resilience is an urgent demand.

Barriers to the Implementation of Land Use Change in China in view of SOC Dynamic Mechanisms

Land use changes over the recent decades in China were primarily driven by national land policy

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and development programs, economic growth, and agricultural expansion. Such situation will likely increase the climatic and environmental risks of land use change, which will ultimately affect the climate and environment adversely. In China, a close relationship between land use and SOC dynamics have been reported in several studies [7,11-16], which may be able to provide some significant guiding information for what kind of land use would be beneficial for climate and ecological environments. However, in order to better implement land use change in view of SOC dynamic mechanisms, a process-based understanding in relation to the mechanisms involved in the link between land use change and SOC dynamic may be still needed, and several issues must be taken into account as follow: (1) Most previous studies only focused on the SOC content and storage change under land use change. In addition, they only emphasized on the short-term processes that dominate carbon balance at the point or soil profile scale; whereas other processes that dominate over longer timescales and larger spatial scales may actually be more important in determining the carbon balance of soils under land use change [17]. (2) Soil organic matter comprises a vast range of different functional pools with a turnover time in soil that ranges from less than one year to thousands of years. However, soil organic matter in most previous studies was treated as a homogeneous pool with a single turnover time; this condition may overestimate SOC response on long-term scales [18]. (3) The most common approaches used to evaluate the dynamics of SOC in previous studies include the first-order kinetic equation fitting method [19], natural abundance 13C labeling tracer method [20], and soil respiration measurement method [21]. Although these approaches have provided a number of important insights into SOC dynamics, they cannot be used in all ecosystems and cannot be reliably applied to study SOC dynamics on extremely long timescales.

Recommendations

Application of the underutilized radiocarbon tool in China must be developed

To cope with the problem of high environmental risks caused by land use change and to provide highly valuable information to predicate the feasibility of land use change, systematic identification of the mechanisms involved in SOC dynamics at long-term scales under land use change in China should be addressed immediately. Natural abundance radiocarbon analysis is one of the methods used to study SOC dynamics on decadal to millennial timescales; in addition, this approach provides a means to directly test the SOC dynamics models under land use change [17]. The combination of soil organic matter fractionation with radiocarbon assessment is a useful means to study the age of organic matter that is associated with specific mineral phases or soil structural components [22]. Such combination can also help to reconstruct the pathways and timescales of soil organic matter transformation under land use change. Therefore, future studies in China should focus on this approach.

However, the adoption of radiocarbon analysis based on soil organic matter fractions in China is challenging because of several reasons. (1) The major challenge is not to failure to identify a single, universal method to separate organic matter into pools that cycle with different intrinsic timescales in all soil types, but the goal to understand what information can be obtained from each method for the scientific questions, because the numerous methods that are available for SOC fractionation [23-26] can only provide limited success, e.g. low-density or large-size fractions of soil organic matter can contain a component of distinct chemical properties and dynamics; in addition, the oldest chemically isolated fractions may also contain material with younger organic matter. (2) Since 2000s, accelerator mass spectrometry (AMS) has been employed to measure radiocarbon in China because this technique requires only a fairly small sample that is 10,000–100,000 times less than that of decay counting and only requires minutes for one sample. However, only three laboratories in China have AMS machines because of inadequate funding to scientific research, which is not the case in many developed countries. In addition, only a small number of researchers are focusing on the natural abundance radiocarbon analysis. Moreover, most samples for radiocarbon measurements in these laboratories are associated with archaeology, paleontology, history, and geochemistry [27]. Such situation results in the inability to meet the demand for a considerable number of soil samples for the study of SOC dynamic because of the number does not correspond to the extremely large land area and the various land use change in China. Hence, to meet the increasing demand for radiocarbon analyses of soil samples, China has to install more AMS machines or strengthen international cooperation with other countries with more AMS laboratories for radiocarbon measurements. (3) Currently, an increase in the demand to process small-mass samples for AMS radiocarbon measurements has been reported, especially when radiocarbon concentration of operationally isolated fractions or biomarkers of soil with very low carbon content is measured. Although several radiocarbon AMS laboratories worldwide have been working on reduction of the required sample size down to a few micrograms carbon [28-31], the ongoing goal in AMS toward small sample size in China presents challenges in both AMS data acquisition and the methods of small-mass graphite preparation. In China, both hardware improvements of radiocarbon AMS machines and the development of a dedicated graphitization system should be achieved to produce a high-quality target that can guarantees an accurate radiocarbon analysis for small amount of sample material. These processes eventually lead to significant reduction of the sample size below 0.1mg carbon.

Effective measures to sequester SOC after land use change must be adopted

Forecast of the SOC dynamics before the implementation of a land use change project is necessary; however, this approach does not suggest that the Chinese government does not work on the soils or lands, whose use patterns have been changed. According to nationwide multiple-target regional geochemical survey, the SOC density in China averages 48.8 t C/ha, which is lower than 50.3 t C/ha of the United States and 70.8 t C/ha of European Union. This finding indicates great potential of soil carbon sequestration in China. Hence, to encourage and support the development of efficient ways to increase carbon sequestration in soil is a no-time-to-delay task for the Chinese government. In Northern China, especially in northeast area, where most crops straw is not returned to soil as carbon inputs, the storage of organic carbon in cultivated soil is lower than 50% than that of primitive soil without cultivation. Therefore, the amount of organic carbon in farmland soils can be significantly increased by mere adaptation of the measure of returning crops straw to soil. Given that the storage of soil organic matter in China can be increased by 30% to 40% within 30 years, the increased organic carbon sequestered in cultivated soil will still reach one billion tons. This value equals the sum of those in the United States and Canada. If cultivated land is combined with barren land and pasture land, a greater potential of the soil sequestering organic carbon is expected to mitigate atmospheric

CO2 in China than that in Northern America. Interestingly, in most dryland agriculture and forestry areas in China, rainfall may limit the amount of organic carbon that can be added into the soil. However, sometimes, plant nutrition sets the limit.

Sequestration of organic carbon in soils using relatively inefficient and more resistant material, such as biochar or fly ash, has been suggested [32]. In China, substantial works on biochar and fly ash are currently available [33-38], this will certainly provide significant guiding information for farmers to sequester carbon in soils by using biochar and fly ash as soil ameliorant or fertilize. According to an estimation of Woolf [39], if all of the crop residues in the world were converted into biochar, approximately 1Gt of carbon would be sequestered. Biochar technology can be estimated to store approximately 2.2Gt of carbon annually worldwide by 2050 [40]. The potential of biochar to sequester carbon in soils may vary depending on biochar characteristics, inherent soil propertied, and climate conditions [41,42], these factors must be taken into account when using biochar.

In addition, increasing the amount of attainable SOC stored below a depth of 1m is a good strategy. At this depth, SOC may be kept for long in stable forms, by selecting plant species that can provide a greater amount of roots in the subsoil to increase the amount of SOC that may dissolve and move down [43].

Although several approaches have been proposed to increase SOC stocks, the energy and carbon costs associated with achieving attainable organic soil carbon levels must be counted in any carbon budget. The net benefits of carbon sequestration in soils may not be as large as first expected and some processes that increase carbon sequestration may have adverse environmental effects, particularly on biodiversity and ecosystems. In fact, decisions on how to manage SOC in China remain uncertain. Therefore, more effort is needed to detect long-term dynamic of SOC under land use change in China.

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