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RESEARCH ARTICLE

Spatio-temporal variations in organic carbon density and carbon sequestration potential in the topsoil of Hebei Province, China

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Abstract

Reliable prediction of soil organic carbon (SOC) density and carbon sequestration potential (CSP) plays an important role in the atmospheric carbon dioxide budget. This study evaluated temporal and spatial variation of topsoil SOC density and CSP of 21 soil groups across Hebei Province, China, using data collected during the second national soil survey in the 1980s and during the recent soil inventory in 2010. The CSP can be estimated by the method that the saturated SOC content subtracts the actual SOC associated with clay and silt. Overall, the SOC density and CSP of most soil groups increased from the 1980s to 2010 and varied between different soil groups. Among all soil groups, Haplic phaeozems had the highest SOC density and Endogleyic solonchaks had the largest CSP. Areas of soil groups with the highest SOC density (90 to 120 t C ha^{-1}) and carbon sequestration (120 to 160 t C ha^{-1}) also increased over time. With regard to spatial distribution, the north of the province had higher SOC density but lower CSP than the south. With respect to land-use type, cultivated soils had lower SOC density but higher CSP than uncultivated soils. In addition, SOC density and CSP were influenced by soil physicochemical properties, climate and terrain and were most strongly correlated with soil humic acid concentration. The results suggest that soil groups (uncultivated soils) of higher SOC density have greater risk of carbon dioxide emission and that management should be aimed at maximizing carbon sequestration in soil groups (cultivated soils) with greater CSP. Furthermore, soils should be managed according to their spatial distributions of SOC density and carbon sequestration potential under different soil groups.

Keywords: carbon sequestration, SOC density, spatial variation, topsoil

1. Introduction

Terrestrial soil play an important role in the atmospheric carbon dioxide budget. Soils contain 1 500 Pg of organic carbon (Batjes 1996), which is 2.5 to 3 times the amount of organic carbon found in the global atmosphere or in terrestrial vegetation (Liu *et al.* 2006). The upper soil layer directly interacts with the atmosphere and is sensitive to land-use conversion, deforestation and human disturbances (Gao

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et al. 2008). Therefore, estimating the soil organic carbon (SOC) density and carbon sequestration potential (CSP) in topsoil is important for understanding the soil carbon dynamics in different soil groups and regions. Furthermore, these estimates will help establish better soil management practices to improve soil quality and mitigate the effects of global warming.

Recently, national- and regional-scale SOC density and carbon sequestration research has attracted considerable attention, particularly for agricultural soils (Jobbágy and Jackson 2000). Numerous studies have been conducted to estimate agricultural soil carbon sequestration potentials and explore management options to enhance carbon sequestration at national and regional levels (Vleeshouwers and Verhagen 2002; Marland *et al.* 2003; Dendoncker *et al.* 2004). In China, several studies have focused on SOC, including SOC analyses related to soil type and vegetation and preliminary assessments of the effects of cultivation and land use on SOC concentration (Chen *et al.* 2007; Yu *et al.* 2009; Fu *et al.* 2010).

Various methods have been developed to estimate SOC density and CSP (Xu *et al.* 2011; Olson *et al.* 2014a; Olson *et al.* 2014b). Traditionally, SOC density has been calculated from a given SOC content and bulk density (Wang S *et al.* 2004; Wang W *et al.* 2004), whereas the CSP has been calculated from carbon saturation levels associated with the contents of clay, silt and SOC (Hassink 1997; Angers *et al.* 2011). In recent decades, models have been developed to estimate SOC density and CSP. For example, the denitrification-decomposition (DNDC) model was employed to explore effective carbon sequestration options at regional and national scales using a regional mode (Li *et al.* 2004; Tang *et al.* 2006; Zhang *et al.* 2006). In addition, a site-level, process-based model has been linked with a geographic information system (GIS) to extrapolate point measurements at regional scales (Falloon *et al.* 2000; Zimmerman *et al.* 2004). However, soil carbon sequestration is a complex process that is influenced by many factors, such as organic carbon inputs from crop residues or organic manure applications, climatic factors, soil properties, original carbon level and soil type (Wang S *et al.* 2004; Wang W *et al.* 2004). These factors can result in uncertainties when performing estimations using simple scaled-up point measurements, which are used in the model.

In this study, we evaluated the SOC density and CSPs of soils from different groups in Hebei Province, China, based on historical and current basic soil data sets that were collected during the second national soil survey (Wei 1987) conducted in the 1980s and the most recent soil survey conducted in 2010. The objectives of this study were to: (1) estimate the temporal and spatial variations of the SOC density and CSP in topsoil in Hebei Province; and (2) identify the factors influencing potential variations in SOC density and carbon sequestration.

2. Materials and methods

2.1. Study area

This study was conducted in Hebei Province (36°–43°N, 113°–120°E) in northern China, which encompasses a total area of 190 000 km^2. Of this area, 40% consists of arable land. Elevations in Hebei Province range from >1 000 m in the highland north to <50 m in the lowland south, and the province borders the Taihang Mountains to the west and the Bohai Sea to the east. Furthermore, Hebei Province has a warm temperate continental monsoon climate with cold and dry winters and hot and humid summers. The average air temperatures in this region are –16 to –3°C in January and 20 to 27°C in July, and the annual precipitation ranges from 400 to 800 mm and are heavily concentrated during the summer. The abundant geographic and climatic variations in the region have created diverse soil properties, which make the province an ideal region for studying soil carbon storage in various soil groups. According to the soil classification system of the world reference base for soil resources (http://www.fao.org/docrep/003/y1899e/y1899e03.htm), the entire province has 21 dominant soil groups (Fig. 1), and the area of each soil group ranged from 9 to 51 000 km^2 (Table 1).

2.2. Data sources

We used relevant databases and maps from soil samples collected during the second national soil survey of China (Wei 1987) in the 1980s to evaluate historical soil carbon storage. The Hebei Province soil database contains information from 120 soil profiles that cover the 21 soil types found in the province (Zhong and Zhao 2001). And each site was a depositional site. The soil profile information includes the geographic location, soil depth, organic matter content, vegetation, land-use pattern and bulk density of the soil profiles. This information provides an important framework for analyzing the soil carbon storage of each soil group.

To evaluate the current soil carbon storage and compare it with historical values, 120 soil profiles from across Hebei Province were sampled again in 2010 according to the plot names in *Soil in Hebei* (Wei 1987). These sites were dispersed across the 21 soil groups and selected using a soil, land-use, geological, and geomorphological map (1:250 000). The northern portion of the province was more intensively sampled than the southern portion because of its diverse elevations and soil groups (Fig. 1). The geographical coordinates of the sampling locations were recorded