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Quantifying the impacts of agricultural management and climate change on soil organic carbon changes in the uplands of Eastern China

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ABSTRACT

In order to implement optimal farming practices for increasing soil organic carbon (SOC) in agro-ecosystems, there is a need for understanding how management practices and climate change alter SOC levels. This study quantified the influence of agricultural management practices and climatic factors on SOC changes in Eastern China's upland-crop fields in northern Jiangsu Province for the period of 2010–2039, by using the DeNitrification-DeComposition (DNDC, version 9.5) model. We utilized the currently most detailed soil database, which is at a scale of 1:50,000, containing 17,024 soil polygons derived from 983 upland soil profiles. Across all the examined scenarios of agricultural management practices, our results show that the carbon sequestration potential in the upper layer soil (0–50 cm) of the study area varied from 6.93 to 155.11 Tg C during 2010–2039, with an average rate of 59 to 1317 kg C ha^{-1} $year^{-1}$. As a promising alternative, the combined scenario of crop residue return rate of 50% and farmyard manure incorporation rate of 50% is recommended for agricultural management practice in this region. Meanwhile, climate conditions play a significant role in the annual SOC changes as well. Air temperature increase of 2–4 °C leads to 3.41–7.51 Tg C decrease in SOC under conventional management for the entire study region. Decreasing or increasing precipitation by 20% would increase 0.57 Tg C or decrease 1.09 Tg C under the conventional management scenario, respectively. Additionally, among all the soil groups, the fluvo-aquic soils have the highest C sequestration rate in most scenarios. Our findings could be used to inform optimal agricultural management toward climate mitigation.

1. Introduction

Soil organic carbon (SOC) is one of the important carbon pool which is about 4.5 and 3 times greater than biotic and atmospheric carbon pools, respectively (Lal, 2004; Follett, 2010; Aguilera et al., 2013). Thus, the changes of SOC have profound implications for the global carbon cycling. Agro-ecosystems, accounting for approximately 10% of the world's land area, are among the most sensitive ecosystems to the future climatic change owing to human activity (Smit and Skinner, 2002). Cultivation of natural ecosystems has invariably been accompanied by a substantial decline of SOC, and the historical loss of original SOC pool is estimated to be 55 Pg C (IPCC, 1995). Loss of SOC from cultivated soils not only reduces soil fertility but also increases greenhouse gas emissions in the terrestrial ecosystem. Thus, adoption of reasonable management practices on agricultural soils could reduce greenhouse gas emission while having positive impacts on soil fertility (Singh and Lal, 2005). Additionally, climatic variables such as air temperature and precipitation can affect crops biomass in agro-ecosystem (Grace et al., 2006). These changes may affect the SOC pool due to the changes in biomass input to the soil (Smit and Skinner, 2002).

Upland is the dominant agricultural land use type in China, which is about 3.7 times larger than that of paddy field areas (Li et al., 2010). Upland soil in northern Jiangsu Province is located in the lower reaches of the Huang-Huai-Hai plain where ~27.5% of the total crop production in China is produced (Lei et al., 2006). It is considered to be a representative grain production region in China because of the long history of cultivation (Yang et al., 2009). Consequently, an accurate estimation of SOC variations for upland soil at this region is important for quantifying national C balances and assessing the feedbacks of terrestrial ecosystems to climate change.

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However, SOC dynamics in agro-ecosystems are affected by complex interactions of agricultural management practices and climate conditions, which hinder our understanding of the major drivers (Wang et al., 2014). Process-based models provide an opportunity to estimate the influences of future climate change and different management practices on SOC change in agroecosystems (Álvaro-Fuentes et al., 2012; Yu et al., 2013). Recently, the DeNitrification–DeComposition (DNDC) model have been widely used to quantify the interaction effects between soil management, crop, and climate through coupling of the SOC turnover mechanisms in the terrestrial ecosystem (Giltrap et al., 2010; Smith et al., 2010; Xu et al., 2013). During the past thirty years, the DNDC model has been applied for study of carbon and nitrogen cycles over 20 countries including China with encouraging results (Qiu et al., 2005; Li et al., 2011).

Recently, a new soil database for this study region with improved spatial resolution (1:50,000 scale) was established (Zhang et al., 2016), which enabled the examination of optimal agricultural management practices favoring C sequestration through model simulations at a finer scale, and consequently with higher confidence. This motivated this work. The specific objectives of this study were to (1) quantify the influences of agricultural management practices and climate change on soil carbon sequestration in northern Jiangsu Province over the next 30 years; (2) identify the best management practices for carbon sequestration.

2. Materials and methods

2.1. Study area

The upland soil region of northern Jiangsu Province (116°21′–120°54′E, 32°43′–35°07′ N) encompasses five cities of Xuzhou, Yancheng, Lianyungang, Huaian and Suqian, and covers a total area of 52,300 km^2 (Fig. 1) (Yang et al., 2009). This region is located in a climate transitional zone from warm temperate to subtropical. Precipitation is 800–1200 mm, with a mean annual temperature of 13–16 °C, annual sunshine of 2000–2600 h, and frost-free days of about 220 days. The upland soils cover about 85% of the cropland area (Yang et al., 2009). Most of the croplands are cultivated with summer-maize and winter-wheat double cropping rotation systems.

Upland soils in northern Jiangsu Province are derived mostly from river alluvium,Yellow River flood alluvial, lacustrine deposit, loess deposits and fluvio-marine deposit. They can be classified into eight upland soil groups based on the World Reference Base Soil Taxonomy (WRB) (Shi et al., 2010): Fluvo-aquic soil (Fluvisols), Lime concretion black soil (Eutric Acrisols), Cinnamon soil (Eutric Cambisols), Limestone soils (Regosols/leptisols), Saline soil (Chloridic Solonchaks), Lithosols soil (Regosols/leptisols), Brown soil (Haplic Luvisols) and Purplish soil (Cambisols).

2.2. Model description and regional simulations

The DNDC (DeNitrification-DeComposition, version 9.5) model is developed by integrating a relatively complete set of geochemical and biochemical reactions commonly occurring in the agricultural systems, which govern transport and transformation of C and N in the plant-soil-climate systems (Li et al., 2011). DNDC consists of six interacting submodels that describe the plant growth, soil climate, fermentation, decomposition, nitrification, and denitrification, to predict dynamics of SOC change (Li, 2000, 2007a). A detailed description about model mechanisms and concepts can be found in Giltrap et al. (2010).

The DNDC model uses counties as the default simulation unit at the regional scale (Li et al., 2004), which could cause great uncertainties due to the ignorance of nonlinear impacts of soil heterogeneity within a county (Zhang et al., 2014). However, here we use polygon that represents polygon-specific soil characteristics across each county as the basic simulation unit (Zhang et al., 2016). The SOC estimates are for the upper layer 0–50 cm soils. Our model has been validated with 9-years observations from a field site in the study area. The validation results showed that the model performance were promising. Detailed results of the DNDC model validation in this region were discussed in Zhang et al. (2016).

2.3. Data

To apply DNDC to the upland-crop fields in northern Jiangsu Province, we collected all the input information including soil properties, climate, and agricultural management practices for the study area.

2.3.1. Soil databases

A polygon-based soil database of 1:50,000 was constructed to support the regional simulations with the DNDC model, which currently is the most detailed soil database for the upland soil region of China (Zhang et al., 2016). This dataset contained 17,024 polygons, and it was produced by digitizing and recompiling the 29 county-level 1:50,000 field maps. The soil attributes are derived from the representative 983 upland soil profiles collected during the 2nd National Soil Survey of China from the 1980s to 1990s (Shi et al., 2006). Soil polygons were delineated by using the Pedological Knowledge Based (PKB) method based on Genetic Soil Classification of China (GSCC) system (Zhao et al., 2006). This database included profile code, soil name, thickness

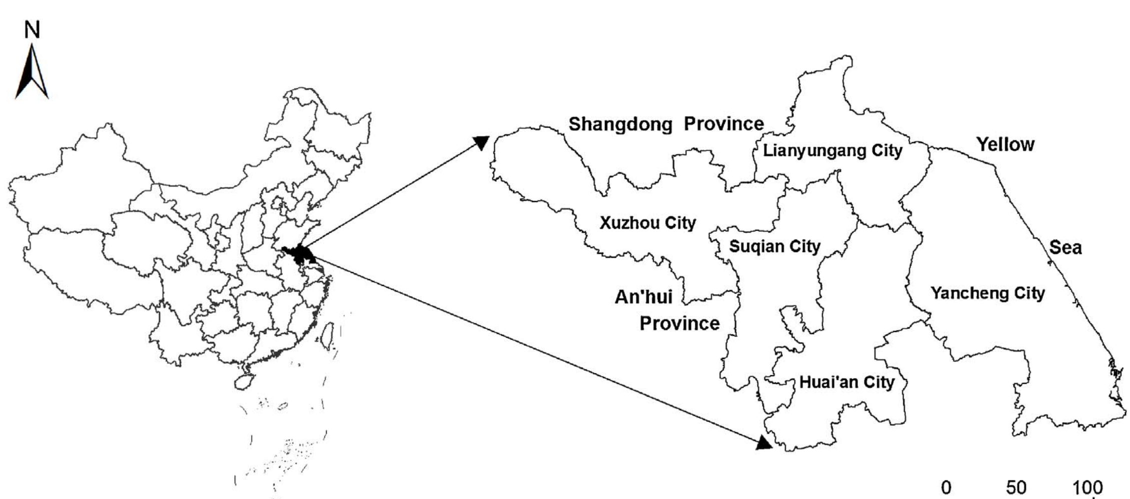

Fig. 1. Geographical location of the northern Jiangsu Province in China.