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Carbon sequestration in the uplands of Eastern China: An analysis with high-resolution model simulations

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ABSTRACT

Using the DeNitrification-DeComposition (DNDC, version 9.5) model, we investigated the soil organic carbon (SOC) changes from 1980 to 2009 in Eastern China's upland-crop fields in northern Jiangsu Province. A currently most detailed high-resolution soil database, containing 17,024 polygons at a scale of 1:50,000, derived from 983 unique upland soil profiles, was used. A coarser county-level soil database was also used for a pair-wise simulation for comparison. We found that SOC changes modeled with the county-level soil database differ significantly from those with high-resolution soil data, with the deviation ranging from −64% to 8.0% in different counties. This implies that coarse soil data may lead to large biases in SOC simulation. With the high-resolution database, the model estimates a SOC increase of 37.89 Tg C in the top soils (0–50 cm) over the study area of 3.93 Mha for the past three decades, with an average rate of 322 kg C ha^{-1} year^{-1}. The SOC accumulation in the study region accounts for 10.2% of annual national carbon sequestration of upland soils, compared with the fraction of 3.7% in the total upland area of China. This underscores its significance to national climate mitigation. The annual SOC change varied between 61 to 519 kg C ha^{-1} year^{-1}, mainly driven by the variations in N-fertilizer and manure applications. This study highlights the significance of high-resolution soil databases in quantifying SOC changes. Our high-resolution estimates of SOC will support farming and carbon management in this region.

1. Introduction

Soils play a pivotal role in global carbon (C) budget because they store over 1550 Pg of soil organic carbon (SOC) in the terrestrial ecosystem, which is 2–3 times larger than that in the atmospheric pool with 750 Pg and biotic pool with 500–600 Pg (Batjes, 1996). The SOC storage in the global agroecosystem (140–170 Pg) accounts for ~10% of the total terrestrial SOC storage and plays a significant role in adopting appropriate soil conservation measures and greenhouse gas mitigation strategies (Buringh, 1984). Therefore, quantification of regional SOC changes in agroecosystem is crucial for assessing and mitigating global climate change (Li et al., 2011).

Nationwide, China possesses ~140 million ha of agricultural lands, including 110 Mha of upland-crop fields and 30 Mha of paddy rice fields (Li et al., 2010). The SOC pool of upland soil is about 3.5 times larger than that of paddy fields (Wang et al., 2011a). Upland soil thus plays an important role in sequestrating carbon and mitigating climate change, because of its vast area and tremendous amount of SOC. Winter wheat-maize rotation is one of the most popular cropping systems in upland soil of China, which is widely distributed across wide ranges of climatic zones and geographic regions. Among these regions, the Huang-Huai-Hai region is the most important one, providing 99.77 million tons of grain and ~27.5% of the total crop production in China (Lei et al., 2006). The upland soil region of northern Jiangsu Province is located in the lower reaches of the Huang-Huai-Hai region of China. It is considered to be a typical area of winter wheat-maize rotation because of the long history of cultivation and intensified agricultural management (Yang et al., 2009). Accurate estimation of SOC dynamics for upland soils in the northern Jiangsu Province

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is therefore vital in understanding the contribution of the Huang-Huai-Hai region in the national carbon inventory.

Due to the complexity of carbon turnover processes and the dynamic response of carbon to environmental conditions, process-based models are extensively used to simulate the dynamics of SOC in agricultural system (Paustian and Álvaro-Fuentes, 2011; Gottschalk et al., 2012; Goglio et al., 2014). The DeNitrification-DeComposition (DNDC) model is one of the most widely accepted agroecosystem model in the world (Gilhespy et al., 2014). Encouraging performances of the DNDC model have been demonstrated at the plot scale through long-term applications in Asia (Wang et al., 2008), America (Tonitto et al., 2007) and Europe (Abdalla et al., 2011). It has also been used to upscale estimates of SOC changes from local sites to regional scales. However, most of these studies were conducted with county- or town-based soil databases that were characterized with relatively coarse resolution (e.g., 1:14,000,000 soil map was widely used for the simulations in China) or large spatial simulation units with a resolution about 0.5° × 0.5° (Li, 2000; Pathak et al., 2005; Tang et al., 2006; Gao et al., 2014). Large uncertainties may exist in these simulations, as areal averaging of soil properties for each county/town ignores the impacts of soil heterogeneity within a county (Pathak et al., 2005; Giltrap et al., 2010; Xu et al., 2013). Another drawback of the county scale model simulations is that soil type-specific crop management practices cannot be identified because the coarse soil database is unable to differentiate soil types (Zhang et al., 2009). With high spatial heterogeneity, the qualities of soil data (e.g. resolution) critically determine the accuracies of regional model results (Kersebaum et al., 2007). Thus, the model results driven by coarse soil data may fail to efficiently inform the field management strategies that aim at SOC increase. Therefore, improving the accuracy of soil information and resolution of simulation unit are essential for enhancing the accuracy of SOC simulations with process-based models (e.g. DNDC) at regional scale.

Driven by the needs of decreasing model uncertainty derived from input soil database, the primary objective of this study is to improve the accuracy of model estimate and analyze the annual-, and total SOC changes in upland soils of the northern Jiangsu Province from 1980 to 2009. To that end, we conducted a pair-wise experiment with two sets of DNDC model simulations to investigate the soil-induced model uncertainties: one used the county-based soil database and the other one used the high-resolution polygon-based 1:50,000 soil database (hereafter referred to as county- and polygon-based database, respectively). The goal of the pair-wise simulations was to examine how far the results from the coarse soil data deviate from those of the fine one – the uncertainty induced from difference in simulation unit and representation of soil heterogeneity. Next, the set of more desirable simulation with high-resolution soil data was then used to analyze the SOC changes for this region. Strategies for improving the biogeochemical model application at the regional scale were also discussed.

2. Materials and methods

2.1. Study area

The study area, an upland soil region of northern Jiangsu Province (116°21′–120°54′E, 32°43′–35°07′ N), is located in the lower reaches of the Huang-Huai-Hai plain of China. This region includes five cities of Xuzhou, Lianyungang, Suqian, Yancheng and Huaian, and encompasses 29 counties. It covers a total area of 52,300 km^2 (Fig. 1) (Yang et al., 2009). It is located in a climate transitional zone from warm temperate to subtropical, with annual rainfall of 800–1200 mm, mean temperature of 13–16 °C, and average annual sunshine of 2000–2600 h. The frost-free period is about 220 days. The study area is one of the oldest agricultural regions in China, and upland soils cover about 85% of the cropland area – 3.93 Mha (Yang et al., 2009). Most cropland in the region is managed as a summer maize- winter wheat rotation. Maize is planted in June and harvested in September and wheat is planted in October and harvested in June of the next year. The upland soils are derived mostly from Yellow River flood alluvial, river alluvium, lacustrine deposit, fluvio-marine deposit and loess deposits.

2.2. Description of the DNDC model

The DNDC (DeNitrification-DeComposition) model version 9.5 is a biogeochemical model of the plant–soil system that simulates carbon-nitrogen dynamics and greenhouse gas (GHG) emissions in agroecosystems. It integrates crop growth and soil

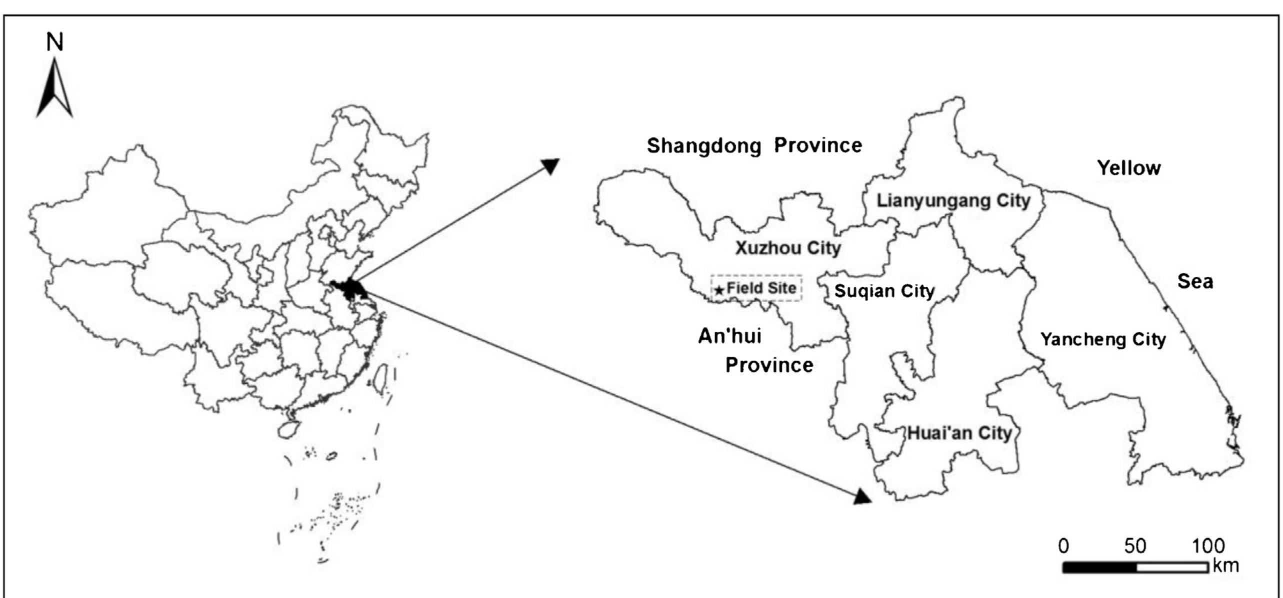

Fig. 1. Geographical location of the study area in China.