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Effects of soil map scales on simulating soil organic carbon changes of upland soils in Eastern China

Liming Zhang[a,b,c], Yaling Liu[d], Xiaodi Li[a], Linbin Huang[a], Dongsheng Yu[e], Xuezheng Shi[e], Hanyue Chen[a], Shihe Xing[a,*]

[a] College of Resources and Environment, Fujian Agriculture and Forestry University, Fuzhou 350002, Fujian Province, China
[b] National Engineering Research Center of Juncao, Fujian Agriculture and Forestry University, Fuzhou 350002, Fujian Province, China
[c] University Key Lab of Soil Ecosystem Health and Regulation, Fujian Agriculture and Forestry University, Fuzhou 350002, Fujian Province, China
[d] Pacific Northwest National Laboratory, Joint Global Change Research Institute, University Research Court, College Park, MD 5825, USA
[e] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, Jiangsu Province, China

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ABSTRACT

Digital soil maps with different scales have been widely used to quantify soil organic carbon (SOC) dynamics in the upland-crop fields. However, most of the regional SOC modeling often uses soil maps with a fixed scale, thus how varying map scales influence modeled SOC dynamics has rarely been quantified. Different map scales have different levels of details in describing the soil properties (e.g., soil texture, SOC content, bulk density, and pH) for a specific area, with the high resolution map having finer spatial representation. In this study, six digital upland soil databases of the northern Jiangsu Province in Eastern China at scales of 1:50,000 (P5), 1:250,000 (P25), 1:500,000 (P50), 1:1,000,000 (P100), 1:4,000,000 (P400), and 1:10,000,000 (P1000) have been used to drive the DeNitrification-DeComposition (DNDC, version 9.5) model to quantify SOC changes for the period of 1980–2009. This suite of scales selections covers all basic soil map scales in China. Our simulations indicate that the regional total SOC changes from 1980 to 2009 in the top layer (0–50 cm) for upland soils using P5, P25, P50, P100, P400, and P1000 soil maps were 37.89, 34.91, 36.04, 37.05, 39.28 and 38.46 Tg C, respectively. Taking the regional total SOC changes based on the most detailed soil map, P5, as a reference, the relative deviation of those derived from the P25, P50, P100, P400, and P1000 were 7.86%, 4.86%, 2.21%, 3.67%, and 1.51%, respectively. Although the relative deviation of regional total SOC changes for most soil maps are low, disparities exist among SOC changes for different soil groups (i.e. 4.8 to 981%) and for administrative areas level (i.e. 0.32 to 151%). The results indicate that SOC estimates are significantly influenced by soil map scale. Lack of detailed soil information, like representation of many soil types and spatial variations in soil types, in coarse-scale maps result in the large uncertainties in the estimates of SOC changes. This study stresses the needs of detailed soil digital maps for accurate quantification of regional SOC changes.

1. Introduction

Soils play a pivotal role in the global carbon cycle because they store over 1550 Pg C of soil organic carbon (SOC) in the terrestrial ecosystem, with stocks about four times the biotic pool and three times the atmospheric pool (Batjes, 1996; Lal, 2004; Follett et al., 2010). Compared to natural ecosystems, the SOC storage in the global agroecosystem (140–170 Pg) is more profoundly affected by human activities (Buringh et al., 1984). Consequently, changes in regional SOC of cultivated land, and subsequent changes in atmospheric organic carbon may be much more substantial than natural changes (Poeplau and Don, 2015). Upland soil in China covers an area of 125 Mha (Xie et al., 2007), accounting for 76% of the total cultivated land (FAOSTAT, 2008). The SOC pool of upland soil in China is about 3.5 times larger than that of paddy fields (Xie et al., 2007). Moreover, the promotion of C sequestration in agricultural soils is recognized as one chance for achieving food security and mitigating atmospheric CO_2 (Stockmann et al., 2015). Subsequently, quantification of regional SOC changes in upland soil of China is crucial for mitigating carbon dioxide (CO_2) emissions.

Considering the complexity of carbon turnover processes in the upland-crop fields, process-based models are often used to quantify the SOC change at regional scales (Liski et al., 2005; Álvaro-Fuentes and Paustian, 2012; Gottschalk et al., 2012; Frank et al., 2015; Brilli et al.,

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[*] Corresponding author.
E-mail address: fafuxsh@126.com (S. Xing).

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2017). Soil database are essential to drive process-based models and predict critical processes of the biogeochemical cycle (Bossa et al., 2012). Recent years have seen studies on regional SOC quantification using a variety of models, such as DNDC (DeNitrification & DeComposition) model, CENTURY, RothC and EPIC (Environmental Policy Integrated Climate) model, together with different scales of soil databases (Ardö and Olsson, 2003; Tang et al., 2006; Cerri et al., 2007; Mondini et al., 2012; Black et al., 2014; Yigini and Panagos, 2016; Schillaci et al., 2017). However, the SOC estimates in these studies are often derived from a single or a narrow range of coarse scale soil databases (typically ranging from 1:1,000,000 to 1:14,000,000).

SOC dynamics are greatly affected by a number of spatially differentiated factors. Many studies have demonstrated that the spatial heterogeneity of soil properties (e.g. texture, SOC content, bulk density, and pH) is a major source of uncertainty for simulating SOC changes at regional scale with process-based models (Pathak et al., 2005; Grosz et al., 2017). Spatial variability of soil properties vary with map scales, which is expressed by map delineations and map unit composition (Heuvelink, 1998; Panagos et al., 2011). In general, soil types with small areas may merge into their neighboring soil types when the soil map changes from fine to coarse scales (Hennings, 2002; Häring et al., 2012; Pachepsky and Hill, 2017). Such a ‘scaling effect’ causes biases in the area and attribute of different soil types, consequently, it may lead to large bias in SOC estimates. For example, Zhang et al. (2016b) found that the relative deviations of DNDC estimates of SOC changes with various coarse soil maps ranged from 3.9% to 97% in Tai-Lake paddy soils of China, relative to the estimate with the 1:50,000 soil map. Moreover, the simulations with different soil map databases will generate different conclusions as to SOC balance in this region (Zhang et al., 2016b). Therefore, it is critical to identify an appropriate soil map scale for more accurate SOC simulation better simulates SOC change in paddy soil region of China.

Nonetheless, for uplands soil, which is quite different from paddy soils in their physical, chemical and biological properties owing to impacts of human management (Nishimura et al., 2008; Geisseler et al., 2017), the influence of modeled SOC changes stemmed from soil map scales is still unclear. This motivates us to fill this knowledge gap. Recently, a series of new soil maps with different spatial resolutions became available in Eastern China's upland-crop fields in northern Jiangsu Province (Li et al., 2016), which enables this work. This study quantifies the abovementioned influence, by using DeNitrification & DeComposition (DNDC) model and six soil databases at scales of 1:50,000 (P5), 1:250,000 (P25), 1:500,000 (P50), 1:1,000,000 (P100), 1:4,000,000 (P400), and 1:10,000,000 (P1000) for the northern Jiangsu Province. These scales include all basic national soil map scales in China. Quantification of this influence and identify the appropriate soil map scale(s) are critical for better understanding of SOC changes, and thus can be used to inform related agriculture production and climate mitigation policies.

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) is located in the lower reaches of the Huang-Huai-Hai plain of China, which produces 99.77 million Mg y^{-1} of grain and ~27.5% of the total crop production in China (Lei, 2006) (Fig. 1). It is characterized by a transitional climate zone from warm temperate to subtropical, with mean annual sunshine, mean annual precipitation, mean annual air temperature, and frost-free days of 2000 to 2600 h, 800 to 1200 mm, 13 to 16 °C, and 220 days, respectively. 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.

Approximately 85% of the total cropland area in this region is covered by upland soils according to the 1:50,000 digital soil map. It mainly consists of flat lands, with an elevation of 0 to 50 m. Upland soils in the region are derived mostly from fluvio-marine deposit, river alluvium, Yellow River flood alluvial, loess deposit and lacustrine deposit. According to the Genetic Soil Classification of China (GSCC) system (Huang et al., 2017), upland soils could be classified into 8 soil groups, 22 soil subgroups, 85 soil families and 338 soil species, which are represented in the 1:50,000 digital soil map. As discussed later in this work, the 8 soil groups include: Fluvo-aquic soil (Fluvisols), Saline soil (Chloridic Solonchaks), Brown soil (Haplic Luvisols), Lime concretion black soil (Eutric Acrisols), Cinnamon soil (Eutric Cambisols), Lithosols soil (Regosols/leptisols), Limestone soils (Regosols/leptisols), and Purplish soil (Cambisols) (Bockheim et al., 2012; Huang et al., 2017).

2.2. DNDC model and regional simulations

The DNDC (DeNitrification-DeComposition, version 9.5) model, developed by Li and his colleagues in the University of New Hampshire since 1992, is a process-based biogeochemistry model for simulating carbon and nitrogen (N) dynamics and greenhouse gas (GHG) emissions in agroecosystems (Gilhespy et al., 2014). The model consists of six interacting sub-models that describe the processes of soil climate, crop growth, decomposition, nitrification, denitrification and fermentation, respectively.

The sub-models include: (1) soil climate sub-model using air temperature, precipitation data, and soil physical properties to calculate soil temperature, moisture and redox potential (Eh) profiles and soil water fluxes through time; (2) nitrification sub-model calculating conversion of ammonium (NH_4^+) to nitrate (NO_3^-); (3) denitrification sub-model calculating hourly denitrification rates and N_2O, NO and N_2 production during periods when the soil Eh decreases due to irrigation, rainfall, soil freezing or flooding; (4) decomposition sub-model simulating decomposition of the SOC pools, i.e., calculating daily decomposition, nitrification, ammonia volatilization processes, and CO_2 production from soil microbial respiration; (5) plant growth sub-model calculating daily water and N uptake by plants, and plant growth; and (6) fermentation sub-model calculating daily methane (CH_4) production and oxidation (Gilhespy et al., 2014).

In this study, we use polygon that represents specific soil properties as the basic simulation unit (Molina-Herrera et al., 2017). Across the 6 simulations with the 6 sets of multi-scale soil maps, the model inputs (e.g., crops, agricultural management and climate) for all polygons within one county are the same, except for soil properties (e.g. texture, SOC content, bulk density, and pH) depending on soil map scale. The SOC simulation was conducted for the top 50 cm of soils (Gilhespy et al., 2014).

2.3. Data construction

To quantify SOC changes in northern Jiangsu Province, input data on climate, soil properties, and farming management regimes of cropping systems were collected, and all data were integrated into a GIS database. Below we describe how data were organized for the DNDC simulations.

2.3.1. Soil and climate data

In China, soil survey products (e.g., soil survey reports, soil maps) at different spatial scales (i.e., county, district, provincial, and national) from the Second National Soil Survey of China from 1980 to 1999 are the most important data sources for SOC change simulations (Zhi et al., 2014). Usually soil databases were compiled at six spatial scales for different administrative divisions, typical scales include county level of 1:50,000 (P5), district level of 1:250,000 (P25), province level of 1:500,000 (P50), and nation levels of 1:1,000,000 (P100), 1:4,000,000 (P400), and 1:10,000,000 (P1000) (Table 1). Correspondingly,