Agriculture, Ecosystems and Environment 222 (2016) 13–22

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Uncertainty of organic carbon dynamics in Tai-Lake paddy soils of China depends on the scale of soil maps

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ARTICLE INFO

Article history:
Received 17 July 2015
Received in revised form 26 January 2016
Accepted 29 January 2016
Available online 12 February 2016

Keywords:
Tai-Lake region
Mapping scale
DNDC (DeNitrification and DeComposition)
Soil organic carbon (SOC)
Paddy soil

ABSTRACT

Agro-ecosystem models have been widely used to quantify soil organic carbon (SOC) dynamics based on digital soil maps. However, most of the studies use soil data of single or limited choices of map scales, thus the influence of map scales on SOC dynamics has rarely been quantified. In this study, six digital paddy soils databases of the Tai-Lake region in China at scales of 1:50,000 (P005), 1:200,000 (P02), 1:500,000 (P05), 1:1,000,000 (P1), 1:4,000,000 (P4), and 1:14,000,000 (P14) were used to drive the DNDC (DeNitrification & DeComposition) model to quantify SOC dynamics for the period of 2001–2019. Model simulations show that the total SOC changes from 2001 to 2019 in the top layer (0–30 cm) of paddy soils using P005, P02, P05, P1, P4, and P14 soil maps would be 3.44, 3.71, 1.41, 2.01, 3.57 and 0.10 Tg C, respectively. The simulated SOC dynamics are significantly influenced by map scales. Taking the total SOC changes based on the most detailed soil map, P005, as a reference, the relative deviation of P02, P05, P1, P4, and P14 were 7.9%, 58.9%, 41.6%, 3.9%, and 97.0%, respectively. Such differences are primarily attributed to missing soil types and spatial variations in soil types in coarse-scale maps. Although the relative deviation of P4 soil map for the entire Tai-Lake region is the lowest, substantial differences (i.e., 22–1010%) exist at soil subgroups level. Overall, soil map scale of P02 provides best accuracy for quantifying SOC dynamics of paddy soils in the study region. Considering the soil data availability of entire China, P1 soil map is also recommended. This study suggested how to select an appropriate scale of input soil data for modeling the carbon cycle of agro-ecosystems.

1. Introduction

Soil plays an important role in the global carbon cycle and contains more carbon than the atmosphere and vegetation combined (Eswaran et al., 1993). It is thus of importance to quantifying the soil organic carbon (SOC) dynamics and their feedback on global climate change (Marques-Lopez et al., 2009). As an important component of the global soil system, SOC dynamics in agricultural soils is crucial for estimating soil fertility and managing crop production (Shi et al., 2010). Loss of SOC from agricultural soils not only diminishes soil sustainability but also elevates CO_2 emissions from terrestrial ecosystems (Lal, 2004). In particular, paddy rice area in China ranks the second largest agricultural area in the world, spanning temperate, subtropical and tropical zones (Liu et al., 2006). The total area of paddy soils in China is 45.7 Mha, accounting for 34% of the total cultivated land (Liu et al., 2006; Xu et al., 2012). Accurate quantification of the SOC change in paddy soils shall thus significantly help to improve current understanding of global carbon cycle.

Process-based agro-ecosystem models are useful tools for quantifying SOC dynamics in soils at regional scales (Paustian et al., 1992; Bricklemyer et al., 2007; Wang et al., 2011). Soil databases at different spatial resolutions have been used in existing studies. For example, Ardö and Olsson (2003) assessed SOC dynamics during the period 1900–2100 in the province of Northern Kordofan in semi-arid Sudan using 1:5,000,000 FAO/UNESCO data and CENTURY model. Tang et al. (2006) simulated SOC changes in croplands of China in 1998 using the 1:14,000,000 soil database

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http://dx.doi.org/10.1016/j.agee.2016.01.049
0167-8809/

and DNDC (DeNitrification & DeComposition) model. Cerri et al. (2007) used CENTURY, RothC, the Intergovernmental Panel on Climate Change (IPCC) model, and 1:5,000,000 SOTER data to estimate SOC changes for the years 2000–2030 in the Brazilian Amazon. Xu et al. (2013) used DNDC model and three digital soil maps with scales of 1:1,000,000, 1:4,000,000, and 1:14,000,000 to estimate SOC stocks of paddy soils from 1980 to 2008 in China. Qin et al. (2013) used two statistical models and a 1:1,000,000 digital soil map to estimate SOC sequestration potentials in croplands of China. Wang et al. (2015) used DNDC model and 1:50,000 digital soil map to estimate the SOC balance between impacts arise from rising temperatures and elevated atmospheric CO_2 in the Tai-Lake region of China. However, these SOC estimates were often made using a single or a narrow range of scales of soil databases for a specific agriculture region.

Spatial variability of soil properties is expressed by map delineations and map unit composition, which varies with map scales (Heuvelink, 1998). Spatial soil processing methods affect the accuracy for the simulation of the spatial distribution of soil properties (Shi et al., 2009, 2011, 2012; Emadi and Baghernejad, 2014; Arslan and Turan, 2015). The ability to represent the soil properties differs significantly at different mapping scales (Zhao et al., 2006). Many datasets were mapped at scales appropriate to maintain details in soil properties for SOC estimation in a designated agricultural region. Studies demonstrated that the spatial heterogeneity of soil properties (e.g., texture, SOC content, bulk density, and pH) is the major source of uncertainty in simulating SOC dynamics under specific agricultural management conditions at regional scales (Li et al., 2004; Pathak et al., 2005). As such, the choice of soil map scales used in the estimation of regional SOC may lead to large uncertainties (Zhao et al., 2006). To date, there is still a lack of research to quantify the effects of map scales on SOC dynamics simulation in agro-ecosystems.

This study uses six soil databases at scales of 1:50,000 (P005), 1:200,000 (P02), 1:500,000 (P05), 1:1,000,000 (P1), 1:4,000,000 (P4), and 1:14,000,000 (P14) to drive the DeNitrification & DeComposition (DNDC) model for quantifying SOC dynamics in the rice-dominated Tai-Lake region. These scales involve all basic national map scales of soil data in China. We aim to: (1) simulate the total SOC changes in the study area for 19 years based on the six soil database, (2) analyze the uncertainties in the simulated SOC dynamics from each soil database in rice field ecosystems, and (3) determine the appropriate scales of soil data for simulating SOC dynamics of higher accuracy in the paddy region of China.

2. Materials and methods

2.1. Study area

Tai-Lake region (118°50′–121°54′E, 29°56′–32°16′N) located in the middle of the Yangtze River paddy soil region of China includes the entire Shanghai City and a part of Jiangsu and Zhejiang provinces, with total area of 36,500 km^2 (Fig. 1) (Li, 1992). It features a warm and moist climate and with annual rainfall of 1100–1400 mm and annual mean temperature of 16 °C. This region is one of the oldest agricultural regions in China, which has a long history of rice cultivation for more than 7000 years. The Tai-Lake region is considered to be the most typical rice production area under intensified agricultural management in China.

Approximately 66% of the total land area is covered with paddy soils (Zhang et al., 2012). Paddy soils in the region are derived mostly from alluvium, loess, and lacustrine deposits. According to the Genetic Soil Classification of China (GSCC) system, soils could be classified into 6 paddy soil subgroups, 137 soil families and 622 soil species in the 1:50,000 map. The six GSCC subgroups according to the U.S. Soil Taxonomy (ST) are Submergenic (Typic Endoaquepts), Gleyed (Typic Endoaquepts), Degleyed (Typic Endoaquepts), Hydromorphic (Typic Epiaquepts), Percogenic (Typic Epiaquepts), and Bleached (Typic Epiaquepts) (Shi et al., 2006; Soil Survey Staff in USDA, 2010). Its main croplands are managed with rice and winter-wheat rotation systems (Xu et al., 1980).

2.2. DNDC model and regional simulations

DNDC is a process-orientated model that simulates crop yield, C sequestration, nitrate leaching loss, and emissions of C and N gases in agro-ecosystems (Li et al., 2004; Li, 2007a). It has six sub-models to estimate soil climate, plant growth, decomposition, nitrification, denitrification and fermentation. The model has been tested and optimized against numerous field observations with regard to SOC dynamics across various agro-ecosystems in Asia (Tang et al., 2006; Xu et al., 2012), Europe (Abdalla et al., 2011), and America (Tonitto et al., 2007). DNDC model has also been applied to simulate biogeochemical processes occurring in rice paddies (Cai et al., 2003; Li et al., 2004; Zhang et al., 2006, 2014; Giltrap et al., 2010; Xu et al., 2012).

DNDC uses counties as basic simulation unit (Li et al., 2004). Thus the model estimates may be biased by ignoring the spatial heterogeneity of soil within a simulation unit (Zhang et al., 2014).

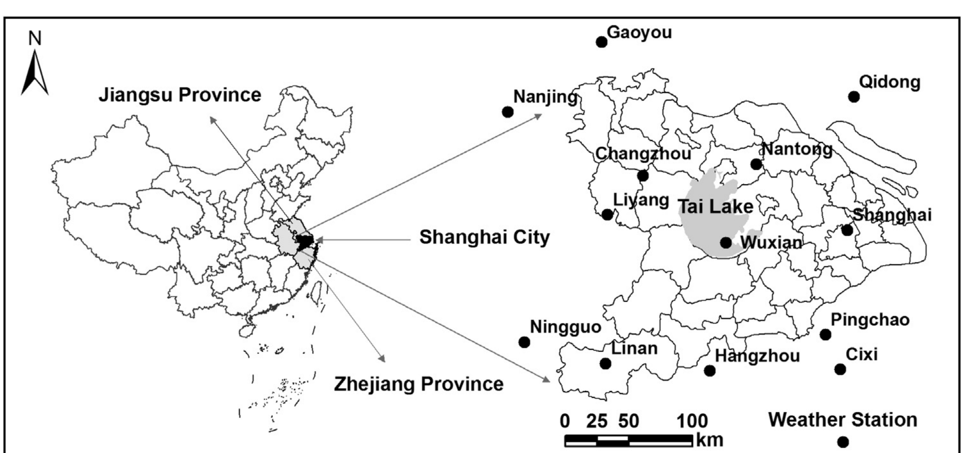

Fig. 1. Geographical location of the study area in China.