Catena 144 (2016) 102–108

Contents lists available at ScienceDirect

Catena

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

Spatial distribution of soil organic carbon in the Zoige alpine wetland, northeastern Qinghai–Tibet Plateau

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ARTICLE INFO

Article history:
Received 12 October 2015
Received in revised form 12 May 2016
Accepted 13 May 2016
Available online 21 May 2016

Keywords:
Soil organic carbon
Ecosystem services
Spatial scale
Carbon stock
Wetland
China

ABSTRACT

Regional-scale soil organic carbon (SOC) field investigations would significantly improve our understanding of national and global SOC sequestration and carbon (C) cycles. The Zoige wetland is the world's largest high-altitude wetland. It is located in northeastern Qinghai–Tibet Plateau. Although considered sensitive to global climate change, little is known of its wetland SOC stocks and spatial distribution patterns. Accordingly, we investigated SOC stocks and spatial distribution patterns in the uppermost 1 m soil layer in Ruoergai and Hongyuan counties in the Zoige wetland. We found that SOC decreased with increasing soil depth, which was highest in the topmost 0.3 m soil layer. Total nitrogen and water content were positively correlated to SOC content while bulk density was negatively correlated to SOC content in both wetland and grassland areas. Wetlands had a higher SOC density than grassland. In the uppermost 1 m of wetland soil, average SOC density was 69.5 kg C m^{-3}, greater by a factor of three compared to mean wetland SOC density in China and greater by a factor of six compared to the national average. SOC stock in the uppermost 1 m of wetland soils totaled 514 Tg C, of which 50% was stored in the topmost 0.3 m. This indicated that the two counties in the Zoige wetland stores from 8.3 to 10.2% of the total SOC in China in the topmost 1 m of wetland soils. This vast SOC pool and high SOC density requires sound land use practices to sustain and protect Zoige wetland ecosystem services and C stocks.

1. Introduction

Wetlands play an important role in the regulation of global climate change by sequestering and releasing a major proportion of atmospheric carbon (C) in the biosphere (Millennium Ecosystem Assessment, 2005). Previous studies reported that 12% of the world's total soil organic carbon (SOC) stocks are held in wetlands (Erwin, 2009; Mitra et al., 2005; IPCC, 1996; Sahagian and Melack, 1998), even though wetlands cover only 6% of global surface area (Lehner and Döll, 2004). Because of their anoxic, wet conditions, undisturbed wetlands often act as active C sinks, although also emitting greenhouse gasses (such as methane) into the atmosphere (Fung et al., 1991). Wetlands are an important component in the global C cycle, and their response to climate change will have important consequences for both ecosystem processes and global climate feedbacks (Erwin, 2009; Chen et al., 2013; Mitsch et al., 2013).

To make well-informed policy decisions that will preserve wetland C stocks in the face of global climate change, it is critical to estimate wetland SOC storage and spatial distribution (Vicari et al., 2011; Mitsch et al., 2013; DeLaune and White, 2011; Mitsch et al., 2010). The development and application of remote sensing, global positioning systems (GPS), and geographical information systems (GIS) have made spatial distribution estimations of wetland SOC feasible over large areas (Mitra et al., 2005; Bai et al., 2010; Zheng et al., 2013; Page et al., 2011; Joosten, 2009). However, despite the numerous studies that have been conducted on SOC stocks, such estimates have been highly variable. Previous estimates of the global wetland SOC stock have ranged from 202 to 535 Pg C (Mitra et al., 2005). For example, Post et al. (1982) reported that the total global wetland SOC stock was 202 Pg C, whereas Sjörs (1980) estimated it at 300 Pg C in the topmost 1 m of the soil layer. Based on the national 1:1 million scale soil database, Yu et al. (2007) estimated SOC stock in the uppermost 1 m of soil in China's wetlands at 12.2 Pg C, whereas Zheng et al. (2013) estimated a range from 5.0 to 6.2 Pg C and Niu et al. (2009) estimated a value of 3.7 Pg C. As these results indicate, wetland SOC stock estimate have been largely inconsistent on both global and national scales, indicating that more SOC stock and its spatial distribution estimates on a regional scale based on in situ data would significantly improve our understanding of SOC sequestration and C cycles on both national and global scales.

The Zoige Plateau is located in the northeastern region of the Qinghai–Tibet Plateau. Zoige wetland is the world's largest alpine peat wetland, having developed due to a combination of unique climatic (see

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http://dx.doi.org/10.1016/j.catena.2016.05.014
0341-8162/

Section 2.1), hydrological, topographical, and soil conditions (Xiang et al., 2009; Sun, 1992). The Zoige wetland is sensitive to climate change and human disturbances (Yang et al., 2014; Chen et al., 2014). In recent decades, for example, wetland area has shrunk by > 30% due to the influence of human activity in conjunction with climate change (Zhang et al., 2011; Xiang et al., 2009). A number of studies have investigated Zoige Plateau SOC stocks in peatlands and marshes (Cai, 2012; Sun, 1992; Chen et al., 2014; Q.F. Ma, 2013), characteristics of wetland SOC spatial distribution (Gao et al., 2006; Gao et al., 2007; Tian et al., 2003), and factors that influence wetland SOC (Yang et al., 2014; Luan et al., 2014; Cai et al., 2014; Huo et al., 2013). For example, Chen et al. (2014) estimated that the total peatland SOC stock in the Zoige Plateau was 0.48 Pg C. Q.F. Ma (2013) implied that the SOC pool in its marshes was 0.39 Pg C. By analyzing the spatial distribution of SOC in the topmost 0.3 m of the soil layer in Ruoergai and Hongyuan counties, Gao et al. (2007) found that the total SOC stock in the Black River basin was higher than in the White River basin. However, these previous studies focused on specific land cover types (such as peatland or marsh) or only considered the topmost 0.3 m of the soil layer. Therefore, little is known about the wetland SOC stocks and their spatial distributions in the uppermost 1 m of the soil layer on a regional scale.

The objectives of this study were to provide some of this missing data by (1) analyzing the vertical distribution of SOC in wetland soils, (2) studying the spatial distribution of SOC, and (3) estimating wetland SOC stocks in two counties that cover the majority of Zoige Plateau wetland area.

2. Methods

2.1. Study area

We selected Ruoergai and Hongyuan counties (from 31°51′N to 34°19′N and from 101°51′E to 103°39′E) as our study area (Fig. 1). Wetlands in these two counties cover greater than two-thirds of total wetland area on the Zoige Plateau (Bai et al., 2008), and, out of all counties in China, Ruoergai and Hongyuan have the highest peatland SOC stocks (X.M. Ma, 2013). Mean annual temperature in this region ranges from 0.7 °C to 1.1 °C, with monthly mean temperatures ranging from a minimum of −10.6 °C in January to a maximum of 10.8 °C in July. Annual precipitation averages 657 mm, 86% of which occurs between April and October (Xiang et al., 2009).

2.2. Methods

The land-cover map used in this study was based on the wetland distribution map by Niu et al. (2012) and the land-cover map of China (http://www.geodata.cn). The spatial resolution of both maps was 1 km. We assumed that land cover in a grid cell was wetland when at least one of the two maps used indicated wetland type in the grid cell. According to this assumption, total wetland area was 7390 km^2, accounting for 40% of the study area. After we confirmed wetland land cover, we assumed that land cover in a grid cell was grassland when the land-cover map of China indicated grassland type but the wetland distribution map did not indicated wetland type. Total grassland area was 9310 km^2, accounting for 50% of the study area. The remaining 10% of the study area was excluded from analysis. Finally, we generated a synthetic land-cover map at a 1-km resolution using three categories of land cover: wetland, grassland, or "other" (the latter category being excluded from analysis) (Fig. 1).

We randomly selected a total of 58 sample sites (Fig. 1) at 5 to 10 km intervals in accessible areas in the summer of 2013 to provide representative profiles (Brus and de Gruijter, 1997). We located sites in the field with two-dimensional positioning accuracy of 5 m using a hand-held GPS receiver (eTrex Vista HCx; Garmin, Olathe, JS, USA). We used a soil sampler (3 cm in diameter, 1 m in length) to determine soil profiles at a single sample location at each of the selected sites. For each site, we obtained ten samples in the topmost 1 m of soil: four samples at 5-cm intervals at the topmost 0.2 m of soil, two samples at 10-cm intervals in soil layers from 0.2 to 0.4 m, and four samples at 15-cm intervals in soil layers from 0.4 to 1.0 m. Sample sites were located in wetland (36 soil profiles or 360 samples) and grassland (22 soil profiles or 220 samples). After manually removing fresh roots and plant residues from samples, we air-dried samples at room temperature and then passed them through a 0.3-mm sieve after grinding. We then analyzed SOC and total nitrogen (TN) content.

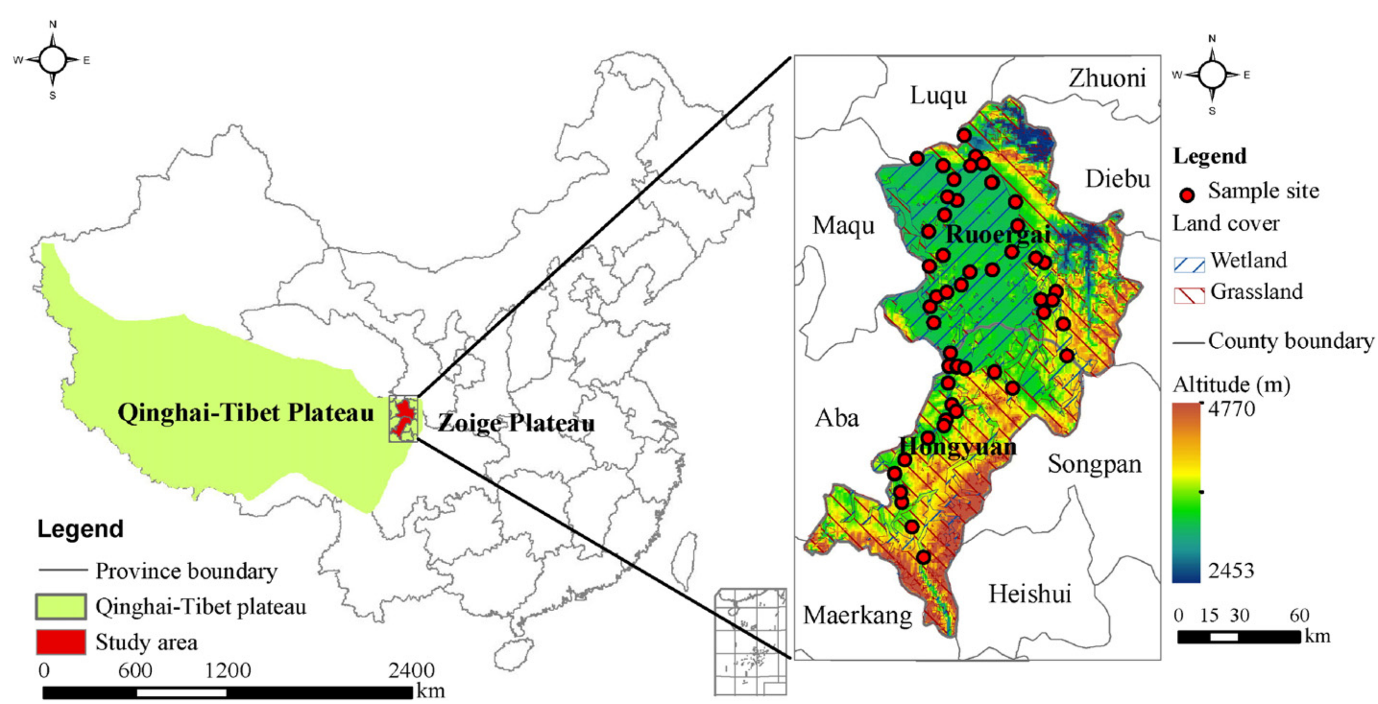

Fig. 1. Location of study area and sampling sites on the Zoige Plateau.