Agriculture, Ecosystems and Environment 222 (2016) 125–132

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Size and dynamics of soil organic carbon stock in cropland of the Eastern Qinghai-Tibetan Plateau

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ARTICLE INFO

Article history:
Received 7 April 2015
Received in revised form 19 November 2015
Accepted 23 November 2015
Available online 17 February 2016

Keywords:
Qinghai-Tibetan Plateau
Straw return
Soil organic carbon pool
Soil quality
Soil productivity

ABSTRACT

Estimating the size and changes in cropland soil organic carbon (SOC) stock in the Qinghai-Tibetan Plateau is important for the improvement of soil quality and mitigation of greenhouse gas emissions in this region. In this study, we investigated the dynamics of SOC concentrations, SOC density (SOCD), and SOC stock in cropland topsoil (0–20 cm) in the eastern Qinghai Province from the 1980s (1980–1989) to recent years (2000–2014). We conducted a long-term fertilization field experiment initiated in 1992 in eastern agricultural region of the Plateau, and used additional data of Qinghai section collected in 1980s by the Second State Soil Survey of China (SSSSC), observational data obtained from field studies in the area from 2006 to 2007. The results showed that the average SOC concentration during 2006–2007 increased by 16.0% compared to that in the 1980s, and increased by 11.9–24.1% in the treatments of the long-term field experiment in 2014 compared to that in 1992. Up until the 1980s, 21.9 Tg SOC was stored in 711751.6 ha of topsoil throughout the entire cropland region. The average SOCD in Huangzhong County during 2006–2007 was 35.4 Mg ha^{-1}, 9.7% higher than that during 1980–1989 (32.3 Mg ha^{-1}). The annual rate of increase in SOCD ranged from 0.10 to 0.41 Mg ha^{-1} yr^{-1}in the long-term chemical fertilization treatments and from 0.22 to 0.85 Mg ha^{-1} yr^{-1}in the combined long-term straw return and chemical fertilization treatments. The order of the soil types in the region with respect to mean SOC concentration was Chernozems > Gleysols > Anthrosols > Luvisols > Cambisols > Kastanozems > Calcisols. The long-term field experiment verified the increase of SOC stock per unit area in the whole region. Organic fertilization, especially straw return and chemical fertilization and other management strategies such as conservation tillage, contributed to the increase of the SOC stock. This study provides an understanding of SOC size and dynamics in cropland of Qinghai-Tibetan Plateau and highlights the importance of protecting cropland and using straw return to improve management practices and increase the SOC stock in cropland of the plateau.

1. Introduction

The Qinghai-Tibetan Plateau, long known as the roof of the world or the world's third pole, has a unique and fragile ecosystem (Yu and Lv, 2011), significantly high topography, and a cool, arid climate. This area is imperative to China's, and even Asia's ecological safety (Sun et al., 2012; Wang et al., 2008) because of its role as a sensor, signal, and amplifier of climate change in the Northern Hemispheric. The plateau has a strong influence on the global climate and environmental change (Mo et al., 2004), and the development of the environment and society in this region has received global attention. Ago-ecosystems, which greatly contribute to local economic development, are important in this region. However, in recent decades, the environmental impacts of agricultural production, such as soil degradation, impoverishment, and desertification (Wang et al., 2005) have led to local food security issues (Wen, 2002). Thus, it is urgent to improve the cropland soil quality and agricultural production in this region.

Soil organic carbon (SOC) is not only a key indicator of soil health(Lal, 2004, 2011; Tang et al., 2010) and the main indicator of soil quality (Ghosh et al., 2012; Dexter et al., 2008; Zhang et al., 2012; Post et al., 1982), but also a natural, effective, and environmental-friendly approach to compensate atmospheric CO_2 emissions (Gelaw et al., 2014; Lal, 2004; Davidson et al., 2000), which has become a strategy for mitigating climate change (Chen et al., 2009; Lal et al., 2007; Sundermeier et al., 2005). Therefore, research in SOC stock has become a widely studied topic in recent years.

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http://dx.doi.org/10.1016/j.agee.2015.11.028
0167-8809/

Estimations of SOC stock and its dynamics are main focuses of research on agricultural SOC sequestration. Scientists have estimated that 1100–1600 Pg C is sequestered in soils worldwide (Izaurralde et al., 2000) and the global SOC sequestration potential is 0.4–1.2 Pg yr^{-1} (Lal, 2004, 2008). Based on averaged SOC and bulk density calculations, Fang et al. (1996) reported that 185.7 Pg C are sequestered in the top 86.2 cm of China's terrestrial ecosystematic soil (not including Taiwan) and 38.4 Pg C are stored in the top 72 cm over an area of 2.0×10^8 ha in the Qinghai-Tibetan Plateau. On the basis of data from the Second State Soil Survey of China (SSSSC), Xie et al. (2007) estimated the SOC stock in China's paddy, upland, forest, and grassland soils in the 1980s to be 89.6 Pg on 8.7×10^8 ha of land over the whole soil profile. Moreover, Liang et al. (2010) evaluated the SOC storage potential in the top 1 m of Chinese cropland soil as 668 Tg. Using the DNDC model, Tang et al. (2010) estimated the SOC stock on 1.2×10^8 ha of Chinese cropland to be 5.0 Pg and measured an average SOCD of 42.0 Mg ha^{-1}. Yu et al. (2013) applied the Agro-C model and find that, from 1980 to 2009, the SOC in 81% of China's cropland increased and 730 Tg C was sequestered in the 0–30 cm soil layer of 1.3×10^8 ha of land. According to monitoring data from long-term field experiments in China, Pan et al. (2010) observed that the SOC pool increased in China's cropland from 1985–2006.

The SOC stock is affected by complex factors such as climate, soil properties, land utilization, and crop management. Chen et al. (2014) observed that moisture levels significantly affected the carbon mineralization rates and microbial attributes (e.g., microbial biomass C and population size) in straw-amended soils. Li and Shao (2014) found that clay and silt particles were the major determinants of SOC in an arid region of northwestern China. Plaza-Bonilla et al. (2014) recognized that SOC in the form of particulate organic carbon is most sensitive to agricultural management and consequently affects SOC sequestration. Other studies have shown that modified cultivation methods such as no-tillage and agro-forestry increased the SOC concentration compared with conventional cultivation practices (Larsen et al., 2014; Dimassi et al., 2014; Sierra et al., 2013). Many studies have suggested that inorganic and organic fertilization, including straw return, greatly increase SOC stocks (Bhattacharyya et al., 2010; Ghosh et al., 2012; Powlson et al., 2011; Yan and Gong, 2010), and a combination of organic and inorganic fertilization results in a greater increase in the carbon pool than chemical fertilization alone (Brar et al., 2013).

The above-mentioned studies have greatly contributed to research on SOC sequestration and provide valuable methodology and theoretic references for future work. However, the results of studies related to Qinghai or the Qinghai-Tibetan Plateau were not consistent with respect to SOC stock, trends, and sequestration potential. For example, some studies reported that the SOC content or potential stock of cropland soil in Qinghai has declined (Liang et al., 2010; Zhong et al., 2012); however, Huang and Sun (2006) and Xie et al. (2007) reported an increase. Furthermore, studies in the Qinghai-Tibetan Plateau have mainly focused on grassland ecosystems (Li et al., 2010; Wang et al., 2002; Zhu et al., 2013), and cropland SOC dynamics and pools have seldom been investigated. Thus, cropland SOC pool and its changes due to the Plateau's unique climate and current production management should be better understood. In this study, data collected during the 1980s by the SSSSC, experimental data from a long-term experiment initiated in 1992, and observational data from field surveys in this area conducted in 2006–2007 were used to investigate the evolution of the cropland SOC pool and understand whether cropland soil in this region is sink or source of atmospheric CO_2. The results will provide suggestions for the improvement of soil quality, agricultural environmental protection, and sustainable production in this region. The detailed objectives of this study were to: (1) investigate the size and dynamics of SOC pool in the study area and (2) analyze the effect of long-term chemical fertilization and straw return on the SOC pool.

2. Materials and methods

2.1. Description of the study area

Qinghai Province, the second largest province in the Qinghai-Tibetan Plateau, lies in the eastern region of the Plateau. Its eastern agricultural area (35°50′46″N–37°08′35″N, 101°13′37″E–102°45′2″E), which is an agro-pastoral transitional zone between the Loess Plateau and the Qinghai-Tibetan Plateau, occupies 80.9% (410000 ha) of the total provincial arable land (507000 ha) (Qinghai Statistic Annual book, 2013) and is the main food production area in the plateau. Historically, the crop rotation system in this area has been one crop per year due to the cold climate (annual average temperature is 6 °C). In addition, in recent decades, extensive agricultural management practices such as unregulated chemical fertilization and inadequate organic fertilizer input, have led to low levels of productivity. Therefore, it is imperative to improve the farmland soil quality in this region.

2.2. Data collection: 1980s and 2006–2007

Data for the calculation of SOCD and SOC stock in the eastern Qinghai Province in the 1980s were obtained from the Second State Soil Survey of China (SSSSC), which was conducted from 1980 to 1989. The study area was restricted to eastern typical croplands, where there was a long history of cultivation and large arable land. The region included nine counties and one city: Xining City, Huangzhong County, Huangyuan County, Datong County, Pingan County, Ledou County, Huzhu County, Minhe County, Hualong County, and Xunhua County. The soil types included Kastanozems, Chernozems, Calcisols, Cambisols, Gleysols, Luvisols, and Anthrosols. The soils were distributed over three topographies: river basin (height of 1700–2700 m), middle hill (height of 1800–2800 m), and high mountain (height of 2400–3000 m) (Qinghai Soil, 1997). The soil data were published in a monograph on Qinghai Soil (1997) and in a series of original monographs of every county/city. A total of 316 farmland soil profiles, including seven soil types, were sampled and determined in the early 1980s. The available soil information includes geological location, area, soil depth, parent material, and physico-chemical properties (e.g., organic carbon concentration, pH, CEC, total and available N, P, K concentration). However, for many soil profiles, the soil bulk density was not provided.

To obtain recent data, topsoil (0–20 cm layer) SOC concentration dataset was collected from field tests and observations conducted by the Academy of Agriculture and Forestry Sciences, Qinghai University from 2006 to 2007 in Huangzhong County, where there is the largest arable land of the nine counties and one city, and the cropland is typical of soil types and agricultural management in the eastern agricultural region of Qinghai. Topsoil organic carbon concentration of 421 soil samples collected in as much as possible the same locations as those studied by the SSSSC, were used to estimate changes in SOC. The soil bulk density was not determined from 2006 to 2007.

2.3. Long-term experimental design

The long-term experiment was initiated in 1992 at the experimental base of the Qinghai Academy of Agriculture and Forest (101°49′17″E, 36°34′03″N, and altitude of 2360 m). This region has a semi-arid, continental climate. The average annual rainfall is 413.6 mm, the average annual evaporation is 1180.9 mm,