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Effects of straw return and regional factors on spatio-temporal variability of soil organic matter in a high-yielding area of northern China

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ABSTRACT

Understanding the effects of straw return and regional factors on changes of soil organic matter (SOM) is helpful for improving soil quality and sustaining high crop productivity in intensive agro-ecosystems. This study focuses on the changes in SOM of agricultural soils in a high yielding area of Huantai County, northern China, for which data are available for 1982, 1996 and 2011. The spatio-temporal patterns of SOM, and the factors that influence them, were analyzed before and after widespread implementation of straw retention practices in large areas. The results showed that the average SOM contents in the cultivated layer were 13.24, 15.06 and 18.73 g kg^{-1} in 1982, 1996 and 2011, respectively. The rate of increase in SOM contents during 1996–2011 was approximately twice that of 1982–1996. Semivariogram analysis results showed that the spatial correlation distances of SOM in 1982 and 1996 were 8.78 km and 4.02 km, respectively, while the pattern was a pure nugget effect in 2011, reflecting that the influence of human activities on SOM content increased over time. During 1982–1996 straw retention practices had not been implemented in large areas and the increase of average SOM content was relatively small, and even declined in some sub-regions. In contrast, the average SOM content of the entire county generally increased from 1996 to 2011 after straw return was implemented in large areas. The effects of topography on SOM distribution can be ignored because the county is relatively flat. From 1982 to 1996 regional factors such as soil type and soil texture had moderate impacts on SOM distribution. From 1996 to 2011 increased straw return resulted in substantially increased SOM, while the effects of soil type and soil texture were weakened. Straw return increased carbon sequestration in an intensive agro-ecosystem in this region and should be recommended as a long-term management practice to improve soil fertility and sustain high crop yields, as well as to store carbon and reduce greenhouse gas emissions.

1. Introduction

There is an enormous carbon (C) reserve in soil in the form of soil organic matter (SOM) that stores at least three times as much C as either the atmosphere or living plants (Lal, 2004; Schmidt et al., 2011), and is a significant part of the global terrestrial C pool (Mariam et al., 2007). Maintenance of SOM content provides an important opportunity for mitigation of greenhouse gas emissions by C sequestration. Increasing SOM content can also have positive effects on nutrient release and immobilization in soils (Yu et al., 2006), regulating soil porosity and structure (John et al., 2005), increasing soil permeability and reducing erosion (Carter, 2002), and improving soil biological activity (Liu et al., 2010). Agricultural practices to increase SOM contents include no-till farming with crop residue retention, incorporation of forages in the rotation, maintenance of positive nutrient balance, application of manure and other biosolids, conversion of agriculturally marginal soils to perennial land use, and restoration of degraded soils and wetlands (Whitbread et al., 2003; Su et al., 2006; Lal, 2007).

China's arable areas account for 7% of the world's total cultivated land and play an important role in global C sequestration (Yan et al., 2007). The North China Plain (NCP) has about 18 million ha of farmland and is China's main grain production area contributing about 30% of total national food production. The region has an intensive cropping system with winter wheat and summer maize every year. Some studies have investigated the long-term effects of irrigation, fertilization, tillage and residue management on the SOM accumulation process in the NCP. Liu et al. (2010) found that returning straw and adding farmyard manure can significantly increase SOM levels compared with the application of chemical

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fertilizer only. Results from long-term experiments at five research stations across the NCP, at Quzhou, Wuqiao, Dongbeiwang, Luancheng, and Hengshui, showed that agricultural practices such as optimal irrigation and fertilization, larger fertilization rates, residue return and rotary tillage have had significant impacts on SOM storage over the last two to three decades (Zhao et al., 2013a). In this regard, the application of the EPIC model (Williams, 1995) to data from the experimental stations indicated that optimal irrigation and fertilization, reduced tillage and residue return were all effective strategies for improving SOM content and storage in the NCP (Zhao et al., 2013b). However, these studies were conducted at field scale and the results are generally site specific. Regional factors affecting SOM accumulation, such as soil type, soil texture topography, and land use conversion, all vary at different experimental sites (Mclauchlan, 2006; Kong et al., 2006; Wang et al., 2012), which are not fully described by EPIC or other models. In addition, some studies found that long-term mineral fertilizer inputs may promote or impede SOM accumulation (Yang et al., 2003; Gong et al., 2009; Niu et al., 2011). Therefore previous plot-scale studies have limited value for determining the impacts of agricultural management on SOM of the NCP at the regional scale. Determination of the spatial variation of SOM at regional scale, and its changes over time, are important for estimating changes in soil C sequestration in the main grain production areas of China.

Huantai County is a typical high-yielding area in the NCP. Agriculture in this county is dominated by a rotation of winter wheat and summer maize that accounts for 87% of all crops planted in recent decades (Liu et al., 2005), and there have been distinct changes to straw management practices over the last two to three decades. From the early 1980s to the middle 1990s high grain production relied on sufficient to excessive amounts of fertilizer applications (Liu et al., 2005). Most of the straw produced was burnt in the field or used as domestic fuel by local farmers (Zhang et al., 2008). This led to atmospheric pollution, greenhouse gas emissions (CO_2) and soil nutrient depletion when straw was removed from farmland. Under this production pattern 14,218 kg CO_2 ha^{-1} was emitted yearly (Shi, 2013). With the promotion of the use of combine harvesters and field straw choppers around the mid-1990s straw management was transformed within the county leading to crop residue retention and the improvement of soil fertility (Zhang et al., 2008). However, the impacts of the changes in practices on SOM accumulation not yet been quantified.

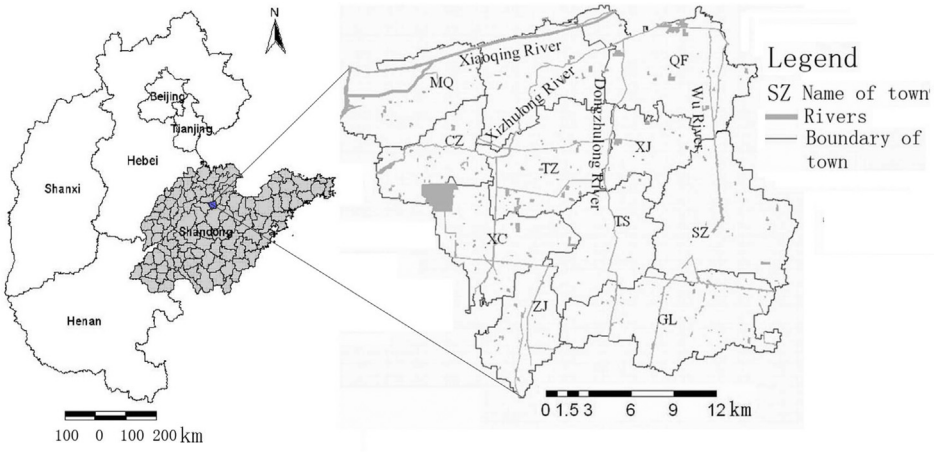
The objectives of this study are to determine the changes of SOM in space and time when significant changes in straw retention were introduced, and to explore the effects of straw retention and regional factors on spatio-temporal variation of SOM. The results should lead to the promotion of practices that improve soil fertility and to improve understanding of C sequestration in the NCP.

2. Materials and methods

2.1. Study area

The study was conducted in Huantai County in the southeastern NCP, downstream of the Yellow River, on the south bank of the Xiaoqing River, and administratively attached to Zibo city in Shandong Province. The county is located at 36°51′50″–37°06′00″N and 117°50′00″–118°10′40″E, with an area of 509.5 km^2 (Fig. 1). The study area covers a transient zone from the alluvial plain in central Shandong to the Yellow River plain in the north. The topography slopes slightly from the southwest to northeast with relative elevations of 6.5–29.5 m. The county is relatively flat with gradient ratios of 1/800–1/3500 (Liu et al., 2005). According to the Köeppen classification, the climate of the region is classified as Dwa temperate, which is characterized by dry and cold winters and hot and moist summers. The groundwater depth is 7–24 m. The annual mean hours of sunshine is 2833 h, and the annual mean temperature is 11.8–12.9 °C. The mean annual precipitation is 600 mm with an uneven temporal distribution, 70% of which is concentrated from June to September each year. The annual mean frost-free period is 198 days from late spring to late autumn.

According to the second National Soil Survey (NSS, 1995), textures of soils of Huantai County include sandy loam, light loam, middle loam, heavy loam and light clay according to the Kachinsky classification system (Fig. 2). Among the five textural types, middle loam has the largest area and is distributed throughout the county, especially in the central and southern areas where it accounts for 86.8% of the total area. Sandy loam has the smallest area, accounting for only 0.1% of the total area, and is distributed in the northeast. Heavy loam is distributed in the northwest of the county. Light clay is concentrated in the border area of Chenzhuang and Xincheng towns, only accounting for 1.39% of the total area. Light loam is distributed in the other areas of the county and accounts for 11.5% of the total area.



Abbreviations: CZ: Chengzhuang town; GL: Guoli town; JJ: Jingjia town; MQ: Maqiao town; QF: Qifeng town; TS: Tangshan town; XC: Xingcheng town; XJ: Xingjia town; ZJ: Zhoujia town

Fig. 1. Schematic diagram of the geographical position of Huantai County.