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Effects of tillage systems on soil organic carbon and total nitrogen in a double paddy cropping system in Southern China

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Soil organic carbon (SOC) and total nitrogen (TN) stocks in cropland soils play important roles in soil quality and climate change mitigation. Farming management have great impacts on SOC and TN dynamics, and thus affecting soil quality. The objective of this study was to assess the effect of tillage systems on the changes in SOC and TN pools under a double rice (*Oryza sativa* L.) cropping system in Southern China. A field experiment was conducted during 2005 in Ningxiang, Hunan Province. It comprised of four tillage treatments including no-till with residue retention (NT), rotary tillage with residue incorporation (RT), plow tillage with residue incorporation (PT), and plow tillage with residue removed (PT0). The results showed that NT increased soil bulk density (ρ_b) in the 0–20 cm soil layer. Adoption of NT increased the concentrations of SOC and TN at 0–5 cm depth but decreased the concentrations in deeper soil. The greatest SOC and TN concentrations were observed under RT at 5–10 cm depth and under PT at 10–20 cm depth. Tillage practice had small effect on the soil C:N ratio in the soil profile. Adoption of NT farming enhanced the SOC and TN stocks in the 0–10 cm layer, whereas PT increased SOC and TN stocks in the 0–50 cm profile. The stratification ratio (SR) of the SOC and TN concentrations were larger under NT compared with RT and PT. Thus, the adoption of short-term (7–8 years) NT practices is beneficial for the enhancement of SOC and TN stocks in the 0–10 cm soil profile, and rotational tillage may be an appropriate farming practice for paddy rice system.

1. Introduction

Climate change has become a challenging focus for researchers, farmers, and policy makers. The amounts of soil organic carbon (SOC) and total nitrogen (TN) are estimated to be ~1550 Pg (Lal, 2004) and ~137 Pg (Batjes, 2014) to 1 m depth in the global terrestrial environment, respectively. A small change in the size of the SOC and TN stocks could greatly alter the concentrations of greenhouse gases (GHG) (i.e., CO_2, CH_4, and N_2O) in the atmosphere, which could have a significant impact on global warming (Batjes, 2014; Wang et al., 1999) and affect soil quality through changes in the SOC and TN concentrations. Agriculture is one of the most important sources of total anthropogenic GHG emissions globally (Stocker et al., 2013), but suitable management can mitigate climate change by reducing GHG emissions and enhancing SOC and TN stocks. Adoption of the recommended management practices (RMPs) (e.g., conservation tillage, residue management) have a positive role in improving soil quality and mitigating climate change by SOC sequestration in soil and biota (Stavi and Lal, 2013). The SOC and TN stocks in agricultural ecosystems are more sensitive to anthropogenic activity with land use and farming management practices. However, little known about the size and variation of the SOC and TN stocks in the paddy ecosystem, especially in terms of their dynamic changes associated with soil management practices.

In general, intensive tillage in agricultural system can lead to a decline in SOC (Dalal and Mayer, 1986a; Lal, 2001) and TN (Dalal and Mayer, 1986b) concentrations due to destroying soil structure, exposing soil aggregate, and aggravating SOM decomposition. The adoption of no-till (NT) in many cropping systems can minimize the risks of SOC and TN depletion, thus leading to higher or similar levels of SOC and TN compared with plow tillage (PT). In general, the concentrations of SOC (Baker et al., 2007; Blanco-Canqui and Lal, 2008) and TN (Franzluebbers et al., 1994; López-Fando and Pardo, 2012; Lou et al., 2012) increases in the top soil layer under

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NT, but there may be either no significant differences or even some decrease compared with PT in the subsoil layers. Most previous studies indicate that the conversion of PT to NT system can increase the SOC stock (Mishra et al., 2010; West and Post, 2002), but some opposite trends have also been reported (Franzluebbers et al., 1994; Wander et al., 1998). Difference in SOC stock among the previous studies may be due to the variations in climate, soil type, tillage intensity, and durations. Similarly, NT can enhance the TN stock of the 0–30 cm soil profile (Lou et al., 2012; Mishra et al., 2010; Varvel and Wilhelm, 2011), but there may be no increase in comparison to PT (Du et al., 2010).

The C:N ratio is an important determinant of soil quality due to the close relationship between SOC and TN. Many factors influence the soil C:N ratio including climate, soil texture, vegetation types, land use, and management practices (Lou et al., 2012). Different tillage practices have a significant influence on the placement and distribution of crop residues within the plow layer. In comparison with PT, NT can increase the soil C:N ratio in the surface layer (0–5 cm) and decrease it in the 5–20 cm depth (Puget and Lal, 2005). In addition, the difference in the location of crop residues can result in a higher soil C:N ratio of the surface layer (0–5 cm) under NT than under PT (Lou et al., 2012).

Several studies indicate that NT can enhance the stratification of SOC and nutrients due to minimum soil disturbance and residue retention on the soil surface (Franzluebbers, 2002; Sá and Lal, 2009). A more homogeneous distribution of nutrients is observed under PT due to the incorporation of crop residues and fertilizers in the plow layer. The stratification ratio (SR) of SOC and TN can be used as an indicator to assess changes in soil quality by different tillage practices (Franzluebbers, 2002; Sá and Lal, 2009). In general, higher SR values indicate good soil quality, regardless of the soil and climatic conditions, and the SR of the SOC and TN stocks under NT are >2, but often <2 under PT (Franzluebbers, 2002). Most previous studies on the effect of tillage and residue management on SOC and TN stocks have been conducted in upland agro-ecosystems, and scientific information is scanty for paddy agro-ecosystems.

Rice (*Oryza sativa* L.) is one of the most important grain crops in China. Double-cropped rice, accounting for ~45% (~1.35×10^7 ha) of the total rice planting area and ~40% (~8×10^7 t) of the total rice production, is important to China's food security (Bai, 2013). However, paddy fields are a primary source of global CH_4 emissions, which are estimated at 493–723 Mt CO_2-eq. yr^{-1} in 2010 (FAOSTAT, 2013). The adoption of NT farming can significantly reduce CH_4 emissions from paddy fields for the entire rice growing season (Zhang et al., 2013). Meanwhile, paddy soils play a key role in the total carbon sequestration and account for approximately 40% of the total cropland SOC sequestration potential in China (Pan et al., 2004). Enhancement of the SOC and TN stocks of paddy soils can improve soil quality and mitigate global warming. Soil tillage and residue management affect the dynamics of SOC and TN direct and indirect effects on soil properties. Some studies have reported that NT practices can increase the SOC stock compared with PT in paddy agro-ecosystems (Sun et al., 2010; Xu et al., 2013), and the application of rice residues with inorganic fertilizer can enhance SOC sequestration in the double-rice cropping system in India (Bhattacharyya et al., 2012). To date, information about changes in SOC and TN stocks in paddy ecosystems is scanty in China. In addition, few studies have been conducted to assess the influence of tillage and residue management on SOC and TN stocks. Nonetheless, it is critical to validate, adapt and promote tillage systems in paddy ecosystems with a comprehensive knowledge of the SOC and TN dynamics. Therefore, the objectives of this study were (i) to assess the effects of different tillage systems on changes in the depth distribution, storage and stratification of SOC and TN in a double rice cropping system, and (ii) to identify suitable sustainable tillage systems for the double rice cropping system in Southern China.

2. Materials and methods

2.1. Site description

The field experiment was established in 2005 in Ningxiang County (28°07′N, 112°18′E, 36.1 m of altitude) in the Hunan province of Southern China. The region has a subtropical monsoonal humid climate with an average annual temperature of 16.8 °C. The highest mean monthly temperature (28.9 °C) is recorded in July, and the lowest mean monthly temperature (4.5 °C) is recorded in January. The annual precipitation and sunshine duration average 1360 mm and 1740 h, respectively. The average annual potential evapotranspiration is 1353.9 mm. The predominant soil at the experimental site is classified as Stagnic Anthrosols and is developed from the Quaternary red earth (Gong et al., 2007). Soil samples for 0–20 cm depth at the site were collected and tested prior to applying treatments, and the basic properties were 1.21 g cm^{-3} of bulk density (ρ_b), 34.9 g kg^{-1} of soil organic matter (SOM), 1.29 g kg^{-1} of total N (TN), 1.23 g kg^{-1} of total phosphorus, 17.63 g kg^{-1} of total potassium, 224 mg kg^{-1} of available N, 4.0 mg kg^{-1} of available phosphorus, 97 mg kg^{-1} of available potassium and pH (H_2O) of 6.3. The average temperature and precipitation in 2012 and 2013 are shown in Table 1. Double rice cropping, consisting of the early and late rice, is the principal cropping system in this region. Before transplanting of both the early and late season rice, rotary tillage has been the predominant tillage method since the late 1990s, and plow tillage with residue burning had been widely used before then. Rice residues were generally burned after harvest in both the early and late rice seasons. Both the early and late rice were transplanted by throwing the seedlings into standing water since 1996. Currently, rotary tillage for both the early and late rice seasons is the principal tillage system.

2.2. Experimental design and management

A detailed description of different tillage systems is necessary to compare the influence of tillage practices on environmental performance (Derpsch et al., 2014). Four tillage treatments were established in 2005, including no-till with residue retention (NT), rotary tillage with residue incorporation (RT), plow tillage with residue incorporation (PT), and plow tillage with residue removed (PT0). The dimensions of the plots were 8 × 8 m, and treatments were laid out in a randomized complete block design with three

Table 1
The average temperature and precipitation at the experimental site in 2012 and 2013.

Month	Temperature (°C)		Month	Precipitation (mm)	
	2012	2013		2012	2013
January	3.6	5.4	January	102.7	21.0
February	4.8	6.8	February	59.9	91.6
March	9.9	14.3	March	187.8	122.0
April	18.6	17.5	April	236.4	227.7
May	22.1	23.0	May	341.7	291.7
June	26.4	27.1	June	204.9	351.9
July	30.2	32.2	July	277.1	2.9
August	28.0	31.5	August	51.2	48.5
September	23.1	23.4	September	89.7	130.3
October	18.8	19.9	October	81.0	3.5
November	11.5	13.9	November	151.5	121.1
December	5.3	7.8	December	82.0	22.5
Average	16.9	18.6	Sum	1865.9	1434.7