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Profile Distribution and Storage of Soil Organic Carbon and Total Nitrogen under Conservation Tillage in Northwest Liaoning, China

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ABSTRACT

To evaluate the effect of conservation tillage for 6 years on soil organic carbon (SOC) and total nitrogen (TN), the profile distribution and storage of SOC and TN were compared between conventional tillage (CT) and no-tillage (NT). Soil samples were taken to 1 m depth (0–5, 5–15, 15–30, 30–50, 50–75 and 75–100 cm) from the CT and NT fields in Northwest Liaoning, China. The results showed that there were similar variation trends in the profile distribution and storage of SOC and TN. Significant depth effects on SOC and TN were observed in this investigation. A higher tillage effect was found on SOC than on TN. The concentration of SOC was significantly correlated with that of TN in the CT and NT fields. C/N ratios significantly declined with increasing soil depth. No-tillage significantly increased the SOC storage at the 0-15 cm depth. No significant differences in the SOC and TN storage were found at the 0-100 cm depth. Soil depth was a key factor in evaluating SOC and TN storage in the conservation tillage system.

Key words: Conventional tillage, No-tillage, soil depth, soil organic carbon, total nitrogen

Introduction

Conservation tillage including minimum and no-tillage has been a major component of many agricultural systems and has been practiced for many years in China. It is generally believed that conservation tillage lowers fuel consumption and labor inputs, decreases traffic, increases water storage and water-use efficiency, and reduces soil erosion (Hussain et al., 1998; Islam and Weil, 2000). Application of conservation tillage has also been shown to make an important contribution to improve soil properties (Fabrizzi et al., 2005).

Soil carbon and nitrogen accumulation is of key importance to mitigate the potential greenhouse effect and improve soil quality and productivity (Lal et al., 2004; Venterea et al., 2006). To a great degree, the storage capacity of carbon and nitrogen in soil was influenced by tillage management practices. Some studies on the effect of conservation tillage on soil organic carbon and nitrogen storage were conducted. However, the viewpoints on it were controversial in previous studies. It is widely believed that soil disturbance by tillage was a primary cause of the historical loss of soil organic carbon in North America, and the substantial soil organic carbon sequestration can be accomplished by conservation tillage (Baker et al., 2007). The study of Bayer et al. (2006) in subtropical Brazilian soils showed that the adoption of no-till management had lead to soil organic carbon accumulation rates of 0.19–0.81 Mg ha⁻¹ year⁻¹ in the 0–20 cm layer. Allmaras et al. (2000) reported that conservation tillage increased soil organic C and N content of the surface soil after being practiced for extended periods of time. In the studies of Gál et al. (2007), no-tillage also resulted in more organic carbon

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and nitrogen accumulation than moldboard plow in the surface 15 cm. However, Powelson and Jenkinson (1981) found no significant differences in organic C and total N between no-tillage and moldboard plow in experiments conducted for 5 to 10 yr. The study of Diaz-Zorita et al. (2004) in Kentucky also proved no significant differences in organic C and total N contents between no-tillage and intermittently chisel-plowed soils 8 to 20 months after plowing.

In addition, most previous studies regarding tillage system effects on soil organic carbon and nitrogen were limited because these studies only focused on the “plow layer” (0–30 cm depth) and did not account for potential changes at deeper depths (Lal et al., 1994; West and Post, 2002; Zhang et al., 2009). Ignoring the subsoil can underestimate the real soil potential to release or sequester C and N although depletion and accumulation are more intense in the top layers (Mikhailova et al., 2000). It was necessary to consider deeper soil layers in the assessment of tillage management impact on soil organic C and N, and one meter depth is usually accepted to be sufficient for C and N budget studies in most soils of the world (Diekow et al., 2005).

Therefore, this study was designed to collect soil sampling in 6 soil layers throughout 100 cm soil depth under conventional tillage and no-tillage systems. The objectives of our study were to investigate the profile distribution of soil organic carbon and total nitrogen under conventional tillage and no-tillage, and to evaluate the effect of no-tillage for 6 years on soil organic carbon and total nitrogen storage.

Materials and methods

Study site

This study was conducted at Zhangwu county, Northwest Liaoning province, China (42°32’ N, 122°20’ E). The experiment site is located in a continental temperate monsoon zone. The annual temperature averages 7.2 °C, mean annual precipitation is 510 mm and the non-frost period is 152 days. The test soil is classified as a cinnamon soil.

Soil sampling and analysis

Before October 2002, all land was maize field in a conventional tillage (CT) system, which did not receive residues from the previous crop. After October 2002, part of the land was converted to conservation tillage, i.e., no-tillage (NT) (a kind of typical conservation tillage practice in Zhangwu). Maize (Zea mays) was planted in the CT and NT fields. The soil in the CT field was ploughed to a depth of 25 cm by means of a two-share mouldboard plow. The NT field with straw mulching has not been tilled at all for 6 years. Four replicate profiles for each field were sampled to a depth of 100 cm and subdivided into layers of 0–5, 5–15, 15–30, 30–50, 50–75 and 75–100 cm by a hand auger (6.7 cm diameter) after maize harvest on October 12, 2008. The bulk density (BD) samples were collected by a double-cylinder metal sampler (thin walled metal cylinder with a volume of 100 cm³), and were determined by dry soil mass oven-dried at 105 °C. Soil organic carbon (SOC) and total nitrogen (TN) was determined by Elementar (Vario ELIII, Germany).

Statistical analysis

The significance of soil depth and tillage effect on soil bulk density, organic carbon and total nitrogen was tested by one-way analysis of variance (ANOVA). Pearson correlation coefficients were used to evaluate relationships between the corresponding variables. For all tests, statistically significant differences were assigned to P < 0.05. All statistical analyses were performed by SPSS software package.

Soil organic carbon and total nitrogen storage were calculated by the following formula.

$$\text{SOC}_{\text{TN}} = \frac{n}{\sum_{i=1}^{n} (C_i/N_i \times q_i \times T_i) \times 10^{-1}}$$

Where SOC/TN, is soil organic carbon/ total nitrogen storage (Mg C/ha) at a given depths, C/N, is organic carbon/total nitrogen concentration (g C/kg) of layer i, \(q\) is soil bulk density (g/cm³) of layer i, \(T_i\) is the thickness (cm) of layer i, and n is the number of layers (Jiang et al., 2005).
Results and Discussion

Soil bulk density

The lowest values of BD in the CT and NT fields all appeared at the 0–5 cm depth (Table 1). Significant difference in the values of BD among soil depths was observed in the CT field (P < 0.01), but not in the NT field. BD was not influenced by tillage management in this study.

Table 1: Variation of bulk density (BD), soil organic carbon (SOC) and total nitrogen (TN) under CT and NT fields to 100 cm depth

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>BD (g/cm³)</th>
<th>SOC (g/kg)</th>
<th>TN (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>NT</td>
<td>CT</td>
</tr>
<tr>
<td>0-5 cm</td>
<td>1.36±0.04bA</td>
<td>1.39±0.10aA</td>
<td>10.13±0.30aB</td>
</tr>
<tr>
<td>5-15 cm</td>
<td>1.46±0.02aA</td>
<td>1.47±0.09aA</td>
<td>9.55±0.40aA</td>
</tr>
<tr>
<td>15-30 cm</td>
<td>1.48±0.03aA</td>
<td>1.46±0.02aA</td>
<td>8.72±0.57aA</td>
</tr>
<tr>
<td>30-50 cm</td>
<td>1.47±0.04A</td>
<td>1.50±0.07aA</td>
<td>8.12±0.29bA</td>
</tr>
<tr>
<td>50-75 cm</td>
<td>1.44±0.02aA</td>
<td>1.46±0.08aA</td>
<td>6.40±0.56cA</td>
</tr>
<tr>
<td>75-100 cm</td>
<td>1.40±0.03aA</td>
<td>1.44±0.04aA</td>
<td>3.92±0.43dA</td>
</tr>
</tbody>
</table>

Significant differences (P < 0.05) among soil depths were indicated with small letters in the rows; significant differences (P < 0.05) between CT and NT were indicated with capital letters in the lines.

SOC and TN concentrations

There were similar variation trends between soil organic carbon and total nitrogen (Table 1). The values of SOC and TN were all significantly different among different soil depths in both the CT and the NT fields (P < 0.01). The concentrations of SOC and TN decreased with increasing soil depth. The correlation analysis showed that negative relationships were found between soil depth and SOC in the CT and NT fields (Figure 1). Significant correlations were also observed between soil depth and TN in the both fields (Figure 1).

![Fig. 1: Concentrations of SOC and TN at different depths under CT and NT fields](image)

The SOC concentration was greater in the NT field than in the CT field throughout the 100 cm depth and significant difference was observed only at the 0–5 cm depth (P < 0.01). The differences in the SOC concentration between the NT and the CT field reduced sharply with depth. The TN concentration in the profile of 0–50 cm was higher in the NT field than in the CT field. Significant difference was observed only at the 5–15 cm depth between the NT and the CT field (P < 0.05) and no significant tillage effect on TN concentration was detected in other soil layers.

Correlation of SOC with TN in the CT and NT fields were shown in Figure 2. Linear regressions indicated that SOC was positively correlated with TN in the CT and NT fields (P < 0.01).

C/N ratios

C/N ratios in the CT and NT fields ranged from 8.4 to 10.7 (Figure 3). The highest values of C/N ratio appeared at the 0–5 cm depth in the NT field and at the 5–15 cm depth in the CT field, respectively. In general, C/N ratios decreased with increasing soil depth. Both in the CT and NT fields, significant differences in the values of C/N ratio were observed among different soil depths. No significant tillage effects on the values of C/N ratio were found throughout the 100 cm depth.
Fig. 2: Correlation of SOC with TN under CT and NT fields

Fig. 3: C/N ratios at different depths under CT and NT fields

Fig. 4: SOC and TN storages under CT and NT fields

SOC and TN storage

The SOC and TN storages under CT and NT fields were shown in Figure 4. Significant differences in the SOC and TN storages in the CT and NT fields were observed among different depths (P < 0.01).

At the 0–5 and 0–15 cm depths, the SOC storage was significantly higher in the NT field than in the CT field (P < 0.01). The SOC storage was higher in the NT field than in the CT field at
other soil layers. However, at the 0–30, 0–50, 0–75 and 0–100 cm depths, no significant tillage effects on the SOC storage were detected. No significant tillage effects on the TN storage were also found throughout the 100 cm depth.

**Discussion**

In our study, no significant differences in the values of soil bulk density were observed between the both tillage fields. The result was not consistent with the study of Gál et al. (2007) on long-term (28 years) tillage system, who proved that bulk density was affected by tillage in the upper 30 cm, with significantly higher values occurring for no-till than for plow. Data from the work of So et al. (2009) also showed that after 14 years, the no-till surface soil has a significantly lower bulk density than the conventional tillage surface soil. The relative soil bulk density changes also depend upon the length of time in the no-till system (Kladivko and Larney, 1989), and the short-term no-tillage with 6 years in our study had not a significant effect on bulk density compared to conventional tillage.

Significant variations in the concentrations of SOC and TN among different soil depths were observed in both the CT and the NT fields. Repeated cultivation, traffic and associated loading in the CT field and crop residue accumulation in surface soil of the NT field all tended to give rise to differences in the concentration of SOC and TN among different soil depths (Soane and van Oudwerkerk, 1994; Halvorson et al., 2002). Significant tillage effects on the concentration of SOC and TN only appeared above 15 cm soil depth. Pierce et al. (1994) reported that plowing significantly reduced soil organic C and total N in the surface 20 cm and differences in C and N contents between the plowed and no-till were small and significant only at the 0–5 cm depth interval after plowing for 4 to 5 years.

C/N ratios were affected by soil depth effect, but not by tillage effect. The results were similar with those of Diekow et al. (2005) and Sá et al. (2001). They found there was no clear evidence that cropping systems had some influence on the C/N ratio even though they did affect the absolute amounts of C and N, and C/N ratio decreased from the top layer and significant changes occurred within the soil profile. Either in the CT or in the NT field, soil organic carbon was significantly correlated with total nitrogen. Significant correlation could be explained that soil organic material contributed to the pool of total and potentially mineralizable N, and further influenced their retention and supply capacity in soil (Wang et al., 2001).

Carbon and nitrogen storage in soil ecosystems have been studied widely because they are important for soil productivity (Warkeintin, 1995). No-till systems, which maintain high surface soil coverage, have resulted in significant change in soil properties, especially in the upper few centimeters (Anikwe and Ubochi, 2007). We also found that no-tillage significantly increased the SOC storage at 0–15 cm depth. At 0–100 cm depth, SOC storage increased in the NT field compared to the CT field, but the difference was not significant. McCarty et al. (1998) indicated that soil organic carbon accumulation in short-term (3–5 years) no-till field was limited to surface soil (<10 cm). According to West and Post (2002), soil C sequestration rates, with a change to no-till practices, have a delayed response and reach peak sequestration rates in 5 to 10 yr. No-till practices with 6 years in our study did not significantly increased SOC storage throughout 100 cm soil depth. Therefore, it was necessary to take into account the whole soil profile when we assessed soil management effects on soil organic carbon accumulation (Diekow et al., 2005). No significant differences in the TN storage throughout a 100 cm depth were observed between the CT and NT fields. The results are similar to those of Angers et al. (1997) in eastern Canada, who found no significant tillage effect on total nitrogen storage to a 60 cm depth. We can conclude that tillage effect on soil organic carbon was greater than total nitrogen.

**Conclusions**

The depth of soil profile was critical to the assessment of C and N storage in tillage systems. No significant storage was found under the NT system compared with the CT system when the entire sampled depth was considered. Soil depth effect on the concentration of SOC and TN was similar and tillage effect was greater on SOC than on TN. The relative no-till advantage declined sharply with depth. The significant changes in SOC and TN storage took place at the surface soil (0–15 cm layer) in a 6 years no-till system. The length of tillage time was determining factor for the storage of SOC and TN. Future research on the mid- and long-term effects of conservation tillage on SOC and TN storage was necessary.
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References


