Effects of Tillage Systems on Labile Fractions of Soil Organic Nitrogen of a Freeze-Thaw Agricultural Area in Northeast China

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Abstract: The impact of tillage systems is obvious in the nitrogen mineralization. Few studies have focused on the relationship between labile fraction of soil organic nitrogen (SON) and crop nitrogen absorption under different tillage systems in freeze-thaw agricultural area. In this study, the effects of conventional tillage (CT) and no-tillage (NT) on the labile fractions of soil organic nitrogen and the relationships with the potentially mineralizable nitrogen (N0) at different soil depths in seeding, jointing, filling and maturity seasons over four years (2010, 2011, 2015 and 2016) were explored. It has been demonstrated that the labile fractions of SON and N0 in NT were higher than in CT at 0-5, 0-10 and 0-20cm. N0 was positively and highly related to the medium particulate organic carbon (mPOM-C) (P<0.01) under CT and NT, whereas highly significant and negative correlations (P<0.01) between N0 and medium particulate organic nitrogen (mPOM-N) were detected under both tillage systems at 0-5 and 0-10cm. The difference in these correlations between tillage systems had been found to be the most notable at the 0-5cm depth. The higher SON fractions content would contribute to the nitrogen mineralization potential because of freeze-thaw conditions during the crop growing season.

1. Introduction

Soil nitrogen is a crucial nutrient indicator to measure soil fertility and quality, which is primary for agricultural sustainability and environmental stability [1]. Anthropogenic activities had induced a doubling of nitrogen deposition for terrestrial ecosystem over the last 100 years, and the deposition is estimated to reach 200 TgN/a [2]. Increase use of N efficiency is essential because of the high-cost nitrogen fertilizer [3]. Tillage systems have impacts on soil physical, chemical and biological properties and affect soil nitrogen mineralization [4]. Conventional tillage (CT) promotes the decomposition of soil organic and residue through soil aggregates disruption, and then enhances the soil aeration and distribute carbon source more evenly [1]. Tillage accelerates the microbial action on the protected organic compounds which hasten carbon and nitrogen cycling [5]. On the contrary, no-tillage (NT) results in a higher concentration of residues accumulation at the soil surface and promotes soil organic matter (SOM) stratification [6].

Sanjiang Plain in northeastern China is known as one of the freeze-thaw agricultural areas in the world [7], the main crops being maize, rice and soybean. This region has cold and long winters known...
as the 1.1~2.0m frozen soil depth, where the long period of soil freezing (100~150 days) and the rainfall are conducive to the soil organic matter (SOM) accumulation. Maize is the basic food product across a wide agricultural area of the northeastern China [7]. The response to nitrogen fertilizer application is affected by the amount of rainfall in region with long frozen time [8]. Therefore, it is necessary to consider the accumulated inorganic nitrogen during the fallow period and the mineralized soil organic nitrogen during the growing season to determine the optimum fertilizing quantity [9].

SOM and the particulate organic matter (POM) (the labile fraction of SOM) are considered to be the crucial factors in exploiting nitrogen dynamics in view of their significant actions on nitrogen mineralization and availability to crops [10]. The POM contains easily mineralizable nitrogen fractions so that it can give more accurate information on nitrogen mineralization. These fractions are typically used to predict the nitrogen mineralization ability [11]. POM is regarded as the considerable labile nitrogen pool in several types of soils [12]; whereas a few studies had indicated that POM contributed no more than 2% to 13% mineralized nitrogen [13]. The relationship between the nitrogen in POM and the mineralized nitrogen has not been determined, but the nitrogen in POM is available for nitrogen estimation. The labile fraction decomposition is heavily relying on weather conditions and residue input in different areas [14].

This study discusses the effects of two tillage systems (CT and NT) on the relationship between the labile fractions content of organic nitrogen and nitrogen mineralization potential at different soil depths; the factors affecting the nitrogen mineralization potential were also explored in a freeze-thaw area.

2. Materials and methods

2.1 Study site and soil samples collection

The study area locates in the Sanjiang Plain of northeast China, lies between 47°18’ and 47°27’50’ North and 133°50’ and 134°33’ East. This region is a freeze-thaw agricultural region because of its long freezing period with several months and the abundant per-capita arable land area. The average temperature and frozen soil depth were 2.94 °C and 1.4m [15]. The experiment was determined by the randomized blocks design of three replications. In the plots where were sown with maize the soils samples were collected at growing period as recommended to study the nitrogen mineralization potential [16]. Soil samples were collected in different crop seasons (seeding, jointing, filling and maturity) in 2010, 2011, 2015 and 2016. The details of the soil physical and chemical properties of the sites were shown in Table 1.

**Table 1.** Physical and chemical properties of soil (mean±standard deviation) at the initial stage of the study (year 2010).

| Depth (cm) | Cropping types | SOM (g kg⁻¹) | SON (g kg⁻¹) | TN (g kg⁻¹) | Pe (mg kg⁻¹) | pH | BD (g cm⁻³) |
|-----------|----------------|--------------|--------------|-------------|--------------|-----|-------------|
| 0-20 m    | NT             | 49.27±10.00aA | 2.29±0.45aA  | 3.12±0.71aA | 13.03±1.02aA | 5.71±0.39aA | 1.44±0.21aA |
|           | CT             | 45.88±11.15bB| 2.14±0.59aA  | 2.92±0.77aB | 10.80±1.10bA | 6.03±0.25aA | 1.39±0.15aB |
| 20-40 m   | NT             | 27.41±7.31aA  | 1.14±0.41aA  | 1.53±0.58bA | 7.48±0.74aB  | 6.02±0.24aA | 1.74±0.29aA |
|           | CT             | 20.91±7.69bB  | 0.86±0.31aB  | 1.31±0.55bB | 6.76±0.56bB  | 6.05±0.30aA | 1.68±0.22aB |

Lowercase letters indicate the difference between tillage systems; capital letters indicate the difference between soil depths (α=0.05)

NT, no-tillage; CT, conventional tillage; SOM, soil organic matter; SON, soil organic nitrogen; TN, soil total nitrogen; Pe, soil extractable phosphorus; BD, bulk density.

2.2 Statistic analysis

All difference analysis of different years or tillage system results was performed by a two-way ANOVA. If there are significant differences (P<0.05) between treatments means, the least significant difference test was adopted to compare the main effects. The relationships of N₀ with soil nitrogen
organic fraction and other factors were evaluated by the Person’s correlation analysis. The statistical analysis was conducted with SPSS21.0 software.

3. Results

3.1 Crop production and nitrogen uptake

As shown in Figure 1, grain and straw aerial biomass yields were consistently lower under CT than under NT, which indicated the extremely significant differences between tillage systems for 2010, 2011 and 2016 (P<0.01) except for 2015 (P<0.05). In general, maize grain aerial biomass yields in NT were 1.3 times in CT and presented the favorable stability because of the lower variation coefficients (CV) over the different years.

![Figure 1. Grain and Straw aerial biomass yield under conventional tillage (CT) and no-tillage (NT) systems in the sampling years. Different letters indicated there are significantly differences between tillage systems for each year (P<0.05).](image)

There are striking differences for crop nitrogen uptake between tillage systems over the years (P<0.01) (Figure 2), therefore the impact of tillage systems on nitrogen uptake was observed separately in each sampling year. A significant difference was observed in nitrogen uptake between crop grain and straw under CT in 2015 (P<0.01), and highly remarkable differences (P<0.001) were found of two tillage systems in the sampling years.

![Figure 2. Maize nitrogen uptake under conventional tillage (CT) and no-tillage (NT) systems in the sampling years. Different letters indicated there are significantly differences between tillage systems for each year (P<0.01).](image)
3.2 Difference of soil organic nitrogen (SON) fractions between tillage systems

There were obvious differences (P<0.05) in SON content between tillage systems over the years at 0-5, 0-10 and 0-20cm (Figure 3). In particular, the strikingly differences (P<0.001) were detected in 2010, 2011 and 2016 between two tillage systems at different depths except for 2015. The average SON values under NT were over 50% higher as compared to CT at 0-5cm, even more than twice in 2011. Analogous patterns were detected at 0-10cm and 0-20cm, but to a lesser extent (6.57-43.44%).

![Figure 3. Soil organic nitrogen (SON) contents by tillage system and years at different depths. Different lowercase letters indicated that there are significantly differences between conventional tillage (CT) and no-tillage (NT) systems for each year (P<0.05); different capital letters showed that there are significantly differences among the sampling years (P<0.05).](image)

The average contents of coarse particulate organic nitrogen (cPOM-N) and medium particulate organic nitrogen (mPOM-N) were larger under NT than CT among soil depths and years; and there were highly significant differences (P<0.001) between tillage systems over years (Table 2).

| Table 2. Particulate organic matter nitrogen (POM) contents by tillage system and years at different depths (mean±standard deviation) |
|---|---|---|---|
| SON fraction | Tillage system | Year | Soil depth |
| | | | 0-5cm | 0-10cm | 0-20cm |
| cPOM-N (mg ha⁻¹) | Conventional tillage (CT) | 2010 | 0.052±0.006aB | 0.095±0.010aA | 0.118±0.013aA |
| | | 2011 | 0.040±0.007aA | 0.088±0.010aA | 0.127±0.011aA |
| | | 2015 | 0.054±0.006aB | 0.101±0.011aA | 0.148±0.009aA |
| | | 2016 | 0.061±0.007aB | 0.097±0.011aA | 0.139±0.011aA |
| | Non-tillage (NT) | 2010 | 0.078±0.007bB | 0.115±0.010bA | 0.162±0.009bA |
| | | 2011 | 0.092±0.010cB | 0.129±0.014cA | 0.152±0.010cA |
| | | 2015 | 0.103±0.011cB | 0.138±0.007cA | 0.158±0.011cA |
| | | 2016 | 0.071±0.007bA | 0.133±0.010bA | 0.151±0.010bA |
| mPOM-N (mg ha⁻¹) | Conventional tillage (CT) | 2010 | 0.069±0.008aB | 0.187±0.009aA | 0.517±0.014aB |
| | | 2011 | 0.171±0.009aD | 0.379±0.011aD | 0.762±0.012aD |
| | | 2015 | 0.153±0.007aC | 0.333±0.012aC | 0.605±0.010aC |
| | | 2016 | 0.105±0.008aB | 0.225±0.012aB | 0.419±0.010aA |
| | No-tillage (NT) | 2010 | 0.129±0.009bA | 0.297±0.011bA | 0.584±0.010bA |
| | | 2011 | 0.274±0.009bD | 0.508±0.009bC | 1.012±0.014bD |
| | | 2015 | 0.257±0.011bC | 0.514±0.008bD | 0.825±0.010bC |
| | | 2016 | 0.168±0.008bB | 0.323±0.012bB | 0.699±0.015bB |
Different lowercase letters indicated that there are significantly differences between tillage systems (P<0.05); different capital letters showed that there are significantly differences among the sampling years (P<0.05).

3.3 Potentially mineralizable nitrogen

The potentially mineralizable nitrogen (N$_0$) stock was lower in CT than in NT (P<0.001) for different depths across the sampling years (Figure 4). Estimates of the average N$_0$ values under NT were 46.9% greater than under CT at 0-5cm, and similar relationships were found at 0-10cm and 0-20cm with 35.0% and 33.8%. Highly significant differences (P<0.001) in N$_0$ were detected between the sampling years for NT, where 2010>2016>2015>2011 at 0-10cm. There were significant differences (P<0.05) between years for CT at three depths.

![Figure 4. Potentially mineralizable nitrogen (N$_0$) contents by tillage system and years at different depths. Different lowercase letters indicated that there are significantly differences between conventional tillage (CT) and no-tillage (NT) systems for each year (P<0.001); different capital letters showed that there are significantly differences among the sampling years (P<0.05).](image)

The proportion of SON that represents the potentially mineralizable nitrogen (N$_0$) indicated the active nitrogen fraction of SOM-performed obvious difference (P<0.05) for both tillage systems for the sampling years (Table 3). Also, obvious differences between tillage systems were observed at 0-20cm in 2011, 2015 and 2016, at 0-10cm in 2011 and 2015 (P<0.01).

| Tillage system     | Years | Soil depth   |         |         |
|--------------------|-------|--------------|---------|---------|
|                    |       | 0-5cm        | 0-10cm  | 0-20cm  |
| Conventional       | 2010  | 1.67±0.34aA  | 2.02±0.32aA | 2.54±0.15bA |
| tillage (CT)       | 2011  | 1.95±0.34aB  | 2.68±0.45aB | 2.99±0.28aA |
|                    | 2015  | 2.30±0.41aB  | 3.22±0.34bC | 3.97±0.22bB |
|                    | 2016  | 1.52±0.25aA  | 2.41±0.30aB | 3.78±0.24bB |
| No-tillage (NT)    | 2010  | 1.65±0.27aA  | 2.04±0.17aA | 2.20±0.10aA |
|                    | 2011  | 2.99±0.44bC  | 3.42±0.29bC | 3.00±0.258aB |
|                    | 2015  | 2.52±0.23aB  | 2.56±0.30aB | 3.44±0.23aC |
|                    | 2016  | 1.69±0.25aA  | 2.41±0.21aB | 3.18±0.14aB |
Different lowercase letters indicated that there are significantly differences between tillage systems (P<0.05); different capital letters showed that there are significantly differences among the sampling years (P<0.05).

4. Discussion
The result of higher crop under NT was consistent with the research result of Zheng et al. [17], in which different tillage systems were compared by a field experiment in the freeze-thaw condition region. These differences between tillage systems were caused by higher water use efficiency under NT owing to the water-stop sheet formed by the seasonal frozen soil [18]. Simultaneously, the similar crop yields were found for CT and NT under no freeze-thaw conditions [19]. For the sampling years, no correlations were found between the aerial biomass and crop nitrogen uptake. There was no relationship between nitrogen accumulation and higher grain yields under the freezing-thawing condition. This result can be assumed that crop nitrogen uptake will assist in evaluating nitrogen mineralization instead of aerial biomass and grain yield by the freeze-thaw action. Also, previous research had shown that nitrogen uptake is a proper criterion to study the plant N-availability [20].

As hypothesized, the results indicated that soil labile nitrogen fractions and potentially mineralizable nitrogen (N₀) values were higher under NT than CT. However, these higher N₀ values in NT were observed at three soil depths. These results suggest that there is no difference in the effect of tillage on labile fractions of nitrogen among the different depths (0-5, 0-10 and 0-20cm). One possible reason could be the degradation induced by the agricultural reclamation and the soil erosion in study region. It had been found that a higher content of SON and labile nitrogen fractions at various depths by contrasting tillage systems might be attributed to soil degradation caused mainly by erosion under continuous grain cropping for several years [21], which is comparable to this study.

As was mentioned by several authors, the variation trends of N₀ were similar to SON and particulate organic nitrogen fractions according to the tillage systems at all depths, which would suggest that N₀ could be heavily reliant on the labile nitrogen fractions [22]. Furthermore, significant differences were observed across the years of study by the tillage system for all depths evaluated, however, significant differences were found between the years at 0-20 cm under NT. These differences according to the tillage system may be as a result of the differential residue contribution by years, which is primarily affected by the variability in the climatic conditions. N₀ is closely correlated with the weather conditions as reported in previous studies [23].

5. Conclusions
There was a positive relationship between SON fractions contents and the mineralization potential due to freeze-thaw conditions. The N₀ could be confirmed to be positively influenced by the POM-C quantity and quality for any tillage system. N₀ was positively and highly related to the medium particulate organic carbon (mPOM-C) (P<0.01) under CT and NT. The higher SON fractions content would contribute to the nitrogen mineralization potential because of freeze-thaw conditions during the crop growing season.

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