# Effects of tillage on soil nitrogen and its components from rice-wheat fields in subtropical regions of China

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**Abstract:** It is of great significance to explore the effects of different tillage practices on total nitrogen and its components in rice-wheat rotation farmland. The experiment was carried out in Jiangyan County, Jiangsu Province of China, and a total of four treatments were set up: minimum tillage (MT), rotary tillage (RT), conventional tillage (CT), and conventional tillage without straw retention (CT0). The total nitrogen (TN), light fraction nitrogen (LFN), heavy fraction nitrogen (HFN), particulate nitrogen (PN), and mineral-associated nitrogen (MN) in 0-20 cm soil were determined. The results show that MT increased TN concentration by2.26%-27.57% compared with the other treatments in 0-5 cm soil, but it lost this advantage in 5-10 cm and 10-20 cm soil. MT altered the concentration of LFN by 6.03%-95.86%, of HFN by 1.68%-20.75%, of PN by 12.58%-96.83%, and of MN by −1.73%-9.83% as compared to RT, CT, and CT0 in 0-5 cm soil, respectively. With the deepened of soil depth, the concentration of TN, LFN, HFN, PN, and MN decreased quickly in MT, which was lower than that in RT and CT at 10-20 cm soil depth. Straw return increased the concentration of TN and its components in 0-20 cm soil. The concentration of TN was extremely significantly positively correlated with that of LFN, HFN, PN, and MN ($p$<0.01). The variation of TN was significantly positively correlated with that of LFN, HFN, PN, and MN ($p$<0.01), and LFN showed the highest sensitivity to tillage practice. In general, minimum tillage combined with straw retention increased the concentration of soil TN and its components in topsoil. LFN was the best indicator to indicate the change in soil total nitrogen affected by tillage practice.

**Keywords:** rice-wheat rotation, soil active nitrogen components, light fraction nitrogen, heavy fraction nitrogen, particulate nitrogen, mineral-associated nitrogen

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## 1 Introduction

Nitrogen is a limiting factor of soil fertility and the mineral element with the largest demand for plant growth. It plays an important role in crop growth and physiological metabolism and attracted wide attention[1,2]. The improvement of the soil nitrogen pool can reduce the amount of nitrogen fertilizer application, increase the potential of soil nitrogen supply, and protect the environment from the negative effects of nitrogen loss[3]. Under different tillage practices, the intensities of soil disturbance and residue management were significantly different and resulted in changes in soil structure and physical and chemical properties, which in turn affected soil nitrogen storage[4,5]. Conservation tillage, represented by no-tillage, is considered to increase soil total nitrogen content due to reduced soil disturbance intensity combined with crop residues return. However, the nitrogen-enhancing effect of conservation tillage mainly appeared in 0-5 cm soil, and the effect in deep soils was controversial[5-7]. Xue et al.[8] obtained that no tillage decreased the concentrations of total nitrogen (TN) at the soil depth below 5 cm from a double rice cropping system in Southern China, while Lou et al.[9] reported that there was no significant effect of no tillage on soil nitrogen content at 5-100 cm soil depth in two maize fields in China, which may be due to specific research sites, climatic conditions, soil types, crop types, etc.

Although TN can be used to measure the amounts of soil nitrogen pools, it was not sensitive to management changes and cannot fully reflect the quality of the nitrogen pool. There were certain deficiencies when used to characterize changes in nitrogen pools[5]. In contrast, soil active nitrogen components were more sensitive to management changes and were an important indicator of changes in soil nitrogen pools[10-12]. Soil particulate fraction is mainly composed of partially degraded plant fragments, and the activity of particulate nitrogen (PN) is between active organic nitrogen and inert organic nitrogen[13]. PN is sensitive to management[14], which attracted extensive research because it is closely related to soil nitrogen supply capacity and nitrogen mineralization[11,15,16]. The light fraction of soil is mainly composed of newly synthesized organic substances such as microorganisms, polysaccharides in plants, and fungal hyphae. Light fraction nitrogen (LFN) has strong biological activity and is a source of mineralizable nitrogen in the soil. It plays a significant role in the nitrogen cycle and is extremely sensitive to management changes[12,17]. However, there are few reports on the effects of tillage practice on LFN. Heavy fraction nitrogen (HFN) is

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relatively stable in chemical properties and is sequestration of mineralizable nitrogen in the soil. Mineral-associated nitrogen (MN) is a stable component that determines the ability of nitrogen supplement from soil[2,13]. Further study of the distribution and changes of different nitrogen components in the soil can effectively evaluate the nitrogen supply capacity of the soil, and clarify the mechanisms of the soil nitrogen pool changes[2].

Rice-wheat rotation is the main cropping pattern in eastern China. The high dependence on nitrogen fertilizer input of intensive rice-wheat production has caused problems such as excessive chemical fertilizer input and decrease in soil quality in this area[18]. It is an important way to achieve sustainable agricultural development by constructing a reasonable farming system, improving the quality of soil nitrogen pool, and enhancing soil nitrogen supply capacity in this area. At present, studies in the rice-wheat system show that conservation tillage significantly increases the TN at 0-5 cm soil depth, and straw return is beneficial to increase the total nitrogen content at 0-20 cm soil depth[19-22], but studies on soil nitrogen components in this area are rarely reported. The distribution of nitrogen among different components and their response to tillage practices are still not clear. This study intended to clarify the distribution mechanism of soil nitrogen among different components and sensitivity of each nitrogen component to tillage by determining the distribution characteristics of soil TN, LFN, HFN, PN, and MN under different tillage practices, and analyzing the relationship between the concentration and variation of TN and nitrogen components. It will provide a theoretical basis for soil nitrogen pool management and establish a reasonable farming system in rice-wheat cropping system in eastern China.

## 2 Materials and methods

### 2.1 Experimental site

Field experiments were conducted in Jiangyan County (32°60′N, 120°14′E), Jiangsu Province of China from 2013. This area has a subtropical monsoon climate, with an annual average temperature of 14.5°C, annual accumulated temperature (≥0°C) of 5365.6°C and annual precipitation of 990 mm. The predominant soil is classified as a Stagnic Anthrosol[23]. Soil samples taken from 0-20 cm soil layer in 2013 have basic properties of 1.31 g/cm$^3$ bulk density, 21.06 g/kg SOC, 2.27 g/kg total nitrogen, 119.17 mg/kg available potassium, 49.74 mg/kg available phosphorus, and pH 7.24. The field experiment has a cropping system of winter wheat (mid-November to early June) and rice (mid-June to late October) double cropping.

### 2.2 Experimental design

The experiment include 4 treatments: (i) Minimum tillage with straw retention (MT); (ii) Rotary tillage with straw retention (RT); (iii) Conventional tillage with straw retention (CT); (iv) Conventional tillage without straw retention (CT0). Details of tillage procedures are listed in Table 1. Each treatment has a completely randomized block design with 3 repetitions. The film was covered on the ridge between different treatment plots as isolation measures. The area of each plot was 500 m$^2$ (25 by 20 m). In MT, RT and CT, the amount of wheat and rice residue applied was about 5200 kg/hm$^2$ and 9500 kg/hm$^2$ (fresh weight), respectively.

**Table 1 Field experimental treatments and tillage and straw management practices in the rice-wheat cropping system**

| Treatment | Tillage regime in the two-year circle | | | | Straw incorporation in each year | |
|---|---|---|---|---|---|---|
| | Wheat | Rice | Wheat | Rice | Wheat | Rice |
| MT | Shallow ploughing to a depth of 8 cm | No | No | No | Rice straw | Wheat straw |
| RT | Rotary to a depth of 11 cm | Rotary to a depth of 11 cm | Rotary to a depth of 11 cm | Rotary to a depth of 11 cm | Rice straw | Wheat straw |
| CT | Rotary to a depth of 11 cm | Plowing to a depth of 18 cm | Rotary to a depth of 11 cm | Plowing to a depth of 18 cm | Rice straw | Wheat straw |
| CT0 | Rotary to a depth of 11 cm | Plowing to a depth of 18 cm | Rotary to a depth of 11 cm | Plowing to a depth of 18 cm | No | No |

The wheat variety was ZHENGMAI 9 and the rice variety was NANJING 9108. Before wheat planting, 1500 kg/hm$^2$ of JIAOLE organic fertilizer (45% organic matter, 2.5% N, 2.5% K) and 375 kg/hm$^2$ of SAKEFU compound fertilizer (15% N, 15% P, 15% K) were applied as basal fertilizer, followed by 312 kg/hm$^2$ of urea (46% N) at the tillering stage and the elongation stage, respectively. The fertilizer operations before rice transplanting were the same as wheat, except that 250 kg/hm$^2$ of urea was applied every 10 d after rice transplanting. The amounts of fertilizer applied to all treatments were consistent.

### 2.3 Soil sampling and analysis

Soil samples were obtained from the 0-5 cm, 5-10 cm, and 10-20 cm soil after rice harvest in October 2016 and October 2017. TN content was determined by Sei-micro Kjeldahl method[24]. PN was determined using the 5 g/L sodium hexametaphosphate dispersion method[25], and MN was the difference between TN and PN. LFN was determined using the density grouping method[26], and HFN was the difference between TN and LFN.

The variation rate (%) was adopted for the sensitivity analysis of TN and its components to tillage, which was calculated using Equation (1)[27].

$$\text{Variation rate} = \frac{C_i - C_{i,CT0}}{C_{i,CT0}} \times 100\% \qquad (1)$$

where, variation rate is the variation rate of contents of TN or its components to a certain depth; $C_i$ is the concentration of TN at layer "$i$" ($i$=1, 2, and 3, represent 0-5, 5-10, and 20-30 cm, respectively); $C_{i,CT0}$ is the concentration of TN in CT0 at layer "$i$".

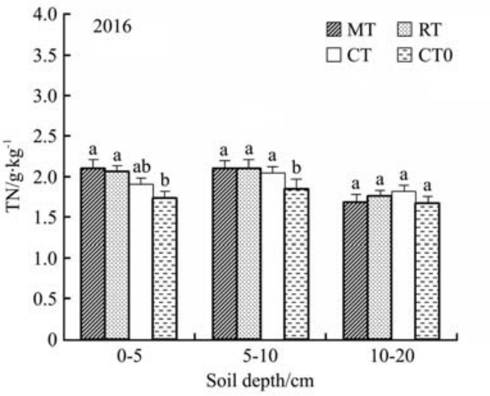
### 2.4 Statistical analyses

Statistical calculation and analysis were performed by Excel 2010 and SPSS 17.0. Least-significant difference (LSD) was applied to multiple comparisons. Pearson coefficient was used for correlation analysis.

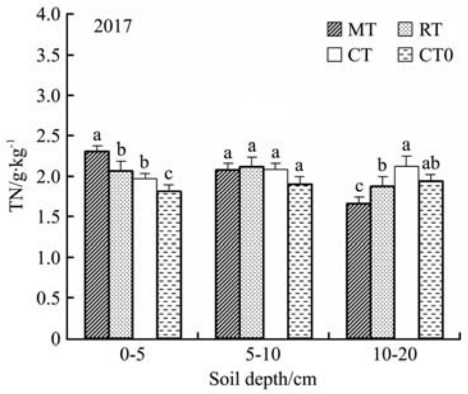
## 3 Results

### 3.1 Soil total nitrogen

In 2016, the TN concentration of MT gradually decreased with the deepening of the soil, while that of RT, CT, and CT0 showed a trend of rising first and then decreasing (Figure 1). The order of TN concentration of different treatments in different soil layers was as follows: MT>RT>CT>CT0 in 0-5 cm soil, MT=RT>CT>CT0 in 5-10 cm soil, CT0>RT>MT>CT0 in 10-20 cm soil. MT increased the TN concentration by 2.26%, 10.84% ($p$<0.05), and 21.92% ($p$<0.05) as compared with RT, CT, and CT0 in 0-5 cm soil respectively. The difference of TN concentration between MT, RT, and CT was not significant ($p$ >0.05) in 5-10 cm soil, but all of which were higher than ($p$<0.05) CT0. There were no significant differences of TN concentration between each treatment in 10-20 cm soil. In 2017, with the deepening of the soil layer, the TN concentration of MT decreased gradually, while that of RT increased first and then decreased, and that of CT and CT0 gradually increased. The TN concentration of MT was significantly higher than other treatments ($p$<0.05) in 0-5 cm soil, which were 11.94%, 17.03%, and 27.57% higher than RT, CT and CT0, respectively. The TN concentration in 5-10 cm soil followed by RT>CT>MT>CT0, no significant difference was found among treatments. CT had the highest TN concentration in 10-20 cm soil, which was 13.35% and 27.40% higher than RT and MT, respectively.




a. Distribution of TN in 2016



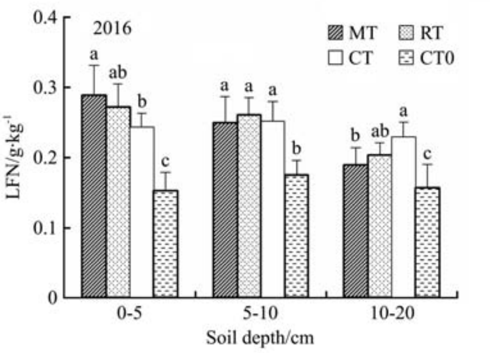

b. Distribution of TN in 2017

Note: MT, minimum tillage; RT, rotary tillage; CT, conventional tillage; CT0, conventional tillage without straw retention. Different letters over bars indicate a significant difference between tillage treatments at $p$<0.05. The same as below.

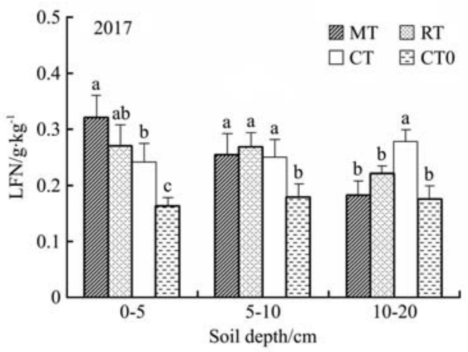
Figure 1 Depth distribution of soil total nitrogen (TN) concentrations under different tillage treatments

### 3.2 LFN and HFN and their distribution ratio

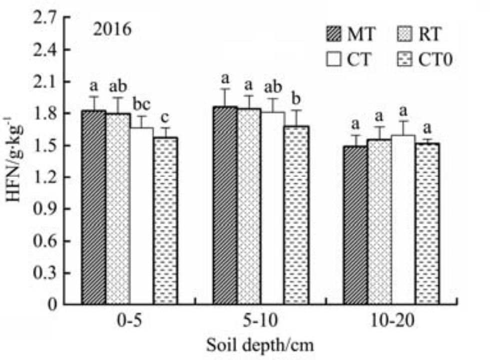
In 2016, as the depth of the soil layer deepened, the LFN concentration of MT and RT gradually decreased, while that of CT and CT0 increased first and then decreased (Figure 2). The LFN concentration in 0-5 cm soil was followed by MT>RT>CT>CT0, in which MT was 6.03%, 18.90% ($p$<0.05), and 88.21% ($p$<0.05) higher than RT, CT, and CT0, respectively. In 5-10 cm soil, the LFN concentration followed by RT>CT>MT>CT0, and RT increased it by 3.84%, 4.49% and 48.80% compared with CT, MT, and CT0, respectively. In 10-20 cm soil, the LFN concentration of CT was 13.05%, 21.09% ($p$<0.05) and 45.89% ($p$<0.05) higher than RT, MT, and CT0, respectively. In 2017, with the deepening of soil depth, the LFN concentration of MT and RT decreased gradually, while that of CT gradually increased, and that of CT0 increased first and then decreased. The difference in LFN between treatments was similar to that in 2016. Compared to RT, CT, and CT0, MT increased LFN concentration by 18.86%, 33.18%, and 95.86% in 0-5 cm soil, but this advantage did not exist in 5-10 and 10-20 cm soils. RT and CT had the highest LFN concentration in 5-10 cm and 10-20 cm soils, respectively.



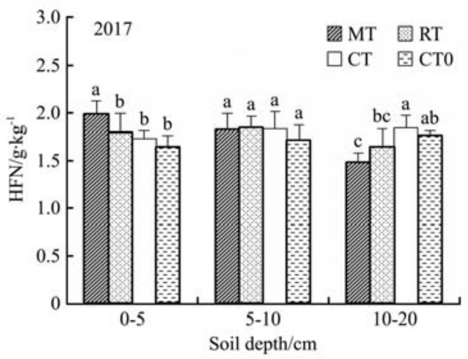

a. Concentrations of LFN in 2016




b. Concentrations of LFN in 2017




c. Concentrations of HFN in 2016




d. Concentrations of HFN in 2017

Figure 2 Concentrations of light fraction nitrogen (LFN) and heavy fraction nitrogen (HFN) in 0-20 cm soil under different tillage treatments

In 2016, with the deepening of the soil depth, the HFN concentration of each treatment showed a trend of rising first and then decreasing. The HFN concentration in 0-5 cm soil followed by MT>RT>CT>CT0, and MT increased it by 1.68%, 9.66% ($p$<0.05), and 15.47% ($p$<0.05) compared with RT, CT, and CT0, respectively. There was no significant difference in HFN concentration between treatments. In 2017, with the deepening of soil depth, the HFN concentration in MT gradually decreased, while in RT it increased first and then decreased, and in CT and CT0 it gradually increased. HFN concentration of MT in 0-5 cm soil was significantly higher than that of other treatments ($p$<0.05), which was 10.89%, 14.78%, and 20.75% higher than RT, CT, and CT0, respectively. There was no significant difference in the HFN concentration between treatments in 5-10 cm soil. In 10-20 cm soil profile, the HFN concentration followed CT>CT0>RT>MT.

As shown in Table 2, the distribution ratio of light fraction in each treatment was 1.29%-3.86% in 2016, 1.36%-3.97% in 2017, and that of LFN was 8.88%-13.70% in 2016 and 9.07%-13.94 in 2017. In the 0-5 cm soil, the LFN distribution ratio of MT was the highest, which was significantly higher than that of CT and CT0 ($p$<0.05). The interannual trends of the distribution ratio of LFN at 5-10 cm soil layer are different, followed by RT>CT> MT>CT0 in 2016, and RT>MT>CT>CT0 in 2017. The distribution ratio of LFN at 10-20 cm soil layer followed by CT>RT>MT>CT0.

**Table 2 Distribution ratios of soil total nitrogen components under different tillage treatments**

| Soil depth/cm | Treatments | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | LF/TF/% | LFN/TN/% | PF/TF/% | PN/TN/% | LF/TF/% | LFN/TN/% | PF/TF/% | PN/TN/% |
| 0-5 | MT | $3.86^{a}$ | $13.70^{a}$ | $46.92^{a}$ | $30.69^{a}$ | $3.97^{a}$ | $13.94^{a}$ | $47.70^{a}$ | $31.46^{a}$ |
| | RT | $3.12^{b}$ | $13.22^{ab}$ | $44.87^{ab}$ | $27.87^{ab}$ | $3.05^{b}$ | $13.13^{ab}$ | $44.01^{ab}$ | $27.61^{b}$ |
| | CT | $2.86^{b}$ | $12.77^{b}$ | $42.91^{bc}$ | $25.79^{b}$ | $2.40^{c}$ | $12.25^{b}$ | $43.26^{bc}$ | $24.21^{c}$ |
| | CT0 | $2.17^{c}$ | $8.88^{c}$ | $41.64^{c}$ | $21.54^{c}$ | $2.00^{d}$ | $9.08^{c}$ | $41.37^{c}$ | $20.39^{d}$ |
| 5-10 | MT | $2.41^{a}$ | $11.86^{a}$ | $43.16^{a}$ | $21.36^{b}$ | $2.44^{a}$ | $12.26^{a}$ | $43.40^{a}$ | $20.12^{c}$ |
| | RT | $2.22^{b}$ | $12.43^{a}$ | $42.41^{a}$ | $23.55^{a}$ | $2.20^{b}$ | $12.73^{a}$ | $42.38^{a}$ | $23.57^{b}$ |
| | CT | $2.29^{ab}$ | $12.26^{a}$ | $43.52^{a}$ | $24.58^{a}$ | $2.32^{ab}$ | $12.02^{a}$ | $43.63^{a}$ | $26.52^{a}$ |
| | CT0 | $1.71^{c}$ | $9.51^{b}$ | $37.88^{b}$ | $22.61^{ab}$ | $1.64^{c}$ | $9.51^{b}$ | $38.76^{b}$ | $21.72^{bc}$ |
| 10-20 | MT | $1.79^{b}$ | $11.24^{b}$ | $39.53^{a}$ | $21.27^{bc}$ | $1.84^{ab}$ | $10.98^{b}$ | $40.08^{a}$ | $18.31^{b}$ |
| | RT | $2.08^{a}$ | $11.52^{ab}$ | $39.43^{a}$ | $22.00^{b}$ | $2.00^{a}$ | $11.87^{ab}$ | $38.82^{ab}$ | $20.16^{b}$ |
| | CT | $1.71^{b}$ | $12.59^{a}$ | $40.16^{a}$ | $24.11^{a}$ | $1.78^{b}$ | $13.14^{a}$ | $39.40^{ab}$ | $25.83^{a}$ |
| | CT0 | $1.29^{c}$ | $9.39^{c}$ | $36.76^{b}$ | $19.62^{c}$ | $1.36^{c}$ | $9.07^{c}$ | $37.24^{b}$ | $19.62^{b}$ |

Note: LF: light fraction; TF: total fraction; LFN: light fraction nitrogen TN: total nitrogen; PF: particulate fraction; PN: particulate nitrogen; Different letters in the same row meant significant difference among tillage treatments at the same soil depth at 0.05 level (LSD test).

Correlation analysis showed (Table 3) that the Pearson correlation coefficients between LFN, HFN with TN were 0.886 and 0.986 ($p$<0.01), respectively, indicating that both can be used as indicators of TN changes, but The correlation between HFN and TN was higher than that of LFN.

**Table 3 Pearson correlation coefficients among contents of soil total nitrogen and its components**

| Indicator | TN | LFN | HFN | PN | MN |
|---|---|---|---|---|---|
| TN | 1 | | | | |
| LFN | 0.886** | 1 | | | |
| HFN | 0.986** | 0.798** | 1 | | |
| PN | 0.860** | 0.887** | 0.805** | 1 | |
| MN | 0.851** | 0.626** | 0.884** | 0.465* | 1 |

Note: * means significant correlation ($p$<0.05), ** means extremely significant correlation ($p$<0.01). The same as below.

### 3.3 PN and MN and their distribution ratios

With the deepening of soil depth, the PN concentration of MT and RT treatments gradually decreased, while that of CT and CT0 treatments increased first and then decreased (Figure 3). In 2016, the PN concentration at 0-5 cm soil layer followed by MT>RT>CT>CT0, and MT significantly increased by 12.58%, 31.91%, and 73.67% compared with RT, CT, and CT0, respectively ($p$<0.05). In 5-10 cm and 10-20 cm soil, PN concentration was followed by CT>RT>MT>CT0. In 2017, the trend of PN in 0-5 cm and 5-10 cm soil layers were the same as in 2016. The PN concentration of MT significantly increased by 27.54%, 52.06%, and 96.83% compared with RT, CT, and CT0 ($p$<0.05) in 0-5 cm soil. In 5-10cm soil, PN concentration of CT was 10.92%, 32.23%, and 34.10% higher than that of RT, MT, and CT0 ($p$<0.05), respectively. In 10-20 cm soil, PN concentration was followed by CT>CT0>RT>MT. The PN concentration of CT0 was significantly lower than CT in 0-5 cm, 5-10 cm, and 10-20 cm soil in both years.

The trends of MN concentration under each treatment with the deepening of the soil layer were similar to soil TN. In 2016, the MN concentration in 0-5 cm soil followed by RT>MT>CT>CT0, MT decreased the MN content by 1.73% compared with RT, but the differences among RT, MT, and CT were not significant. In 5-10 cm soil, the MN concentration was followed by MT>RT>CT>CT0, in which MT was 3.17%, 7.12%, and 16.05% higher than that of RT, CT, and CT0, respectively. In 10-20 cm soil, the difference of MN concentration among each treatment was not significant. In 2017, the MN concentration in 0-5 cm and 5-10 cm soil followed by MT>CT>RT>CT0. Compared to CT, RT, and CT0, MT increased the MN concentration by 5.84%, 5.98%, and 9.83% in 0-5 cm soil, and by 8.36%, 2.70%, and 11.73% in 5-10 cm soil, respectively. The MN concentration in 10-20 cm soil was followed CT>CT0>RT>MT, which of MT was significantly lower than that of CT and CT0.

As shown in Table 2, the distribution ratio of the particulate fraction was 36.76%-46.92% in 2016, and 37.24%-47.70% in 2017, while that of PN was 19.62%-30.69% in 2016, and 19.62%-31.46% in 2017. The distribution ratio of PN was the highest in MT at 0-5 cm soil depth, which was significantly higher than that in CT and CT0 in 2016, and all the other treatments in 2017 ($p$<0.05). The distribution ratio of PN followed CT>RT>CT0>MT in 5-10 cm soil in both years. AT 10-20 cm soil depth, the distribution ratio of PN followed CT>RT>MT>CT0 in 2016 and CT>RT>CT0>MT in 2017. Correlation analysis showed (Table 3) that the Pearson correlation coefficients between PN, MN with TN were 0.860 and 0.851 ($p$<0.01), indicating that both can be used as indicators to indicate TN changes. The correlation between PN and TN is higher than that of MN.

### 3.4 Variation of TN and its components

As shown in Table 4, the variation of TN and its components in 0-5 cm and 5-10 cm soil is positive, while in 10-20 cm soil, there are some negative values. Under all treatments, the variation of TN was from −14.38% to 27.57%, of LFN was from 0.60% to 95.86%, of HFN was from-16.18% to 20.75%, of PN was from −20.10% to 96.83%, and of MN was from −12.99% to16.05%. This indicates that the variation of LFN and PN at the 0-20 cm soil layer was higher than that of TN, HFN, and MN. Except for 0-5 cm in 2017, the LFN had a higher variation than PN, while the variation of HFN and MN was much lower. In 0-5 cm soil, MT had the highest variation of TN and its components, while in 10-20 cm CT had the highest. Correlation analysis showed that the variation of TN was significantly correlated with LFN, HFN, PN, and MN ($p$<0.01), and the correlation between TN and HFN was highest, which was 0.989 in 2016 and 0.987 in 2017, followed by LFN (2016) or PN (2017), then was MN.

**Table 4 Variation of TN, LFN, HFN, PN, and MN in different soil depths**

| Soil depth/cm | Treatment | 2016 | | | | | 2017 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TN/% | LFN/% | HFN/% | PN/% | MN/% | TN/% | LFN/% | HFN/% | PN/% | MN/% |
| 0-5 | MT | 21.92 | 88.21 | 15.47 | 73.67 | 7.71 | 27.57 | 95.86 | 20.75 | 96.83 | 9.83 |
| | RT | 19.23 | 77.50 | 13.55 | 54.27 | 9.61 | 13.97 | 64.78 | 8.90 | 54.33 | 3.63 |
| | CT | 10.00 | 58.30 | 5.30 | 31.66 | 4.05 | 9.01 | 47.06 | 5.21 | 29.45 | 3.77 |
| | CT0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5-10 | MT | 14.22 | 42.40 | 11.25 | 7.93 | 16.05 | 9.47 | 41.13 | 6.15 | 1.41 | 11.71 |
| | RT | 13.87 | 48.80 | 10.20 | 18.64 | 12.48 | 11.40 | 49.12 | 7.44 | 20.89 | 8.77 |
| | CT | 11.17 | 43.30 | 7.79 | 20.86 | 8.34 | 9.82 | 38.81 | 6.78 | 34.10 | 3.09 |
| | CT0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10-20 | MT | 0.60 | 20.48 | −1.46 | 9.08 | −1.47 | −14.38 | 3.65 | −16.18 | −20.10 | −12.99 |
| | RT | 5.17 | 29.05 | 2.70 | 17.95 | 2.05 | -3.77 | 25.94 | -6.73 | −1.12 | −4.41 |
| | CT | 8.75 | 45.89 | 4.90 | 33.65 | 2.67 | 9.08 | 58.02 | 4.19 | 43.60 | 0.65 |
| | CT0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Variation of TN | | | 0.951** | 0.989** | 0.837** | 0.802** | | 0.883** | 0.987** | 0.910** | 0.857** |

Note: The values in the last row of this table are the Pearson correlation coefficients among variation of soil TN and soil total nitrogen components.

## 4 Discussion

Soil TN content is comprehensively affected by external nitrogen input, crop root absorption, decomposition intensity, and leaching loss[2,28]. Many studies showed that conservation tillage, such as no-tillage, was conducive to increasing the TN content of surface soils, but there is no consensus on whether it will increase the TN content in deep soils[29]. Huang et al.[6] reported that the TN content of no-tillage was higher than that of traditional tillage in 0-5 cm soil, but in 5-10 cm soil it was lower. Pu et al.[13] pointed out that no-tillage increased the TN content in 0-5 cm and 5-10 cm soil, but decreased it in 10-20 cm and 20-30 cm soil. Zhang et al.[30] obtained that compared to rotary tillage, soil mineral N was increased by 22.1% under no-tillage at 0-10 cm soil depth from a rice-wheat cropping system. However, studies by Varvel and Wilhelm[31] have shown that no-tillage could increase the TN content in 0-150 cm soil profile compared to conventional tillage under long-term rainfed cropping systems. The results of this study indicated that in 2016, the TN concentration of MT in 0-5 cm and 5-10 cm soil was the highest, while in 10-20 cm soil it was lower than in other treatments, but there was no significant difference between MT, RT, and CT in each soil layer. In 2017, MT significantly increased the TN concentration in 0-5cm soil, while in 10-20 cm soil it significantly decreased the TN concentration compared to other treatments ($p$<0.05). MT had the highest TN concentration in 0-5 cm soil, mainly because straws distributed in the top soil increased the external nitrogen supply to soil, and its lower tillage intensity reduced the nitrogen decomposition. CT had the highest TN concentration at 10-20 cm soil depth, mainly due to its deeper tillage depth of 18cm, which promoted the mixing of 10-20 cm soil with straw and then increased the external nitrogen supply to this soil layer. CT increased The TN concentration by 8.75%-12.10% compared with CT0 in 0-5 cm, 5-10 cm, and 10-20 cm soil, indicating that straw return was conducive to increasing soil TN concentration[8,32].

Light fraction organic matter is a highly active organic matter in the soil, which is susceptible to external factors such as crops, the environment, and farming management, and can quickly reflect soil organic matter changes caused by tillage practice[33,34]. This study showed that the light fraction accounts for 1.36%-3.97% of the soil, and the ratio of LFN concentration to TN reaches 8.88%-13.94%, indicating that the nitrogen concentration in the light fraction was high. MT increased the LFN concentration in 0-5 cm soil, mainly because it reduced the soil tillage intensity and improves the amount of straw distributed in topsoil. Shu et al.[35] reported that the LFN concentration decreased with the increase in farming intensity. Studies also showed that conservation tillage reduced LFN concentration, but the effect may be related to the duration of different treatments in the experiment[2]. The LFN concentration of MT in this study in 10-20 cm soil was less than that of RT and CT, which was mainly due to the less straw distribution under MT than RT and CT in this soil layer. CT had the deepest soil depth of 18 cm, whose LFN concentration in 10-20 cm soil was the highest. The LFN concentration of CT was higher than that of CT0 in 0-5 cm, 5-10 cm, and 10-20 cm soil, indicating that straw return was beneficial to increase LFN concentration[36]. However, based on the 10 years of experiment, Dong et al.[37] reported that a single season of rice or wheat straw return was beneficial to increasing the LFN, but two seasons of rice and wheat straw return would lead to a decrease in the LFN. This may be because the measured LFN in his experiment was the nitrogen concentration in the light fraction, not the LFN concentration in the soil. Roscoe and Buurman[38] point out that HFN is a relatively stable nitrogen component and is less affected by farming methods[2]. This study indicated that the distribution characteristics of soil HFN among different soil layers were similar to that of soil TN. Since the HFN is a sink of soil mineralizable nitrogen, its concentration may mainly depend on the concentration of soil TN[2].

The activity of PN is between active organic nitrogen and inert organic nitrogen, and it responds quickly to tillage management[2,39]. Studies showed that conservation tillage reduced the soil disturbance intensity, and increased the straw distribution in the topsoil, which were helpful to increase the PN concentration in the topsoil[14,40]. However, the effects of tillage on PN concentration in deep soil were controversial. Pu et al.[13] reported that no-till was no longer an advantage for soil PN concentration in the soil below 10 cm from winter wheat- summer maize cropping system in north China. But the experiment of Sainju et al.[41], in dryland cropping system in eastern Montana, USA, obtained that the advantage of increasing PN concentration under no-tillage could reach 20 cm. The results showed that MT significantly increased soil PN concentration in 0-5 cm soils compared with RT and CT, but it decreased it in 5-20 cm soil. Soil particle fraction is a soil component with a particle size greater than 53 $\mu$m[2], which is vulnerable to soil management. Substances from decomposed straws such as humus and polysaccharides can promote the formation of aggregates and improve the protection of soil particulate nitrogen[42]. In this experiment, MT had the lowest soil disturbance intensity, and its straw was mainly distributed in the topsoil, resulting in the highest PN concentration in 0-5 cm soils. In 5-10 cm and 10-20 cm soil, the straw distribution of MT was less than that of RT and CT, which was the main reason for its less PN concentration than RT and CT. The PN concentration of CT was higher than that of CT0 in 0-20 cm soil, indicating that straw return was beneficial to increasing soil PN content[43]. MN was less affected by the tillage in this study, mainly because it is a stable nitrogen component[13].

Most studies have shown that soil TN concentration is significantly related to nitrogen component concentration such as LFN and PN, and active nitrogen components are a sensitive indicator of nitrogen affected by soil management[37,40]. This study showed that the concentration of TN was significantly correlated with that of LFN, HFN, PN, and MN ($p$<0.01), indicating that these four nitrogen components could be used as indicators of TN change. The variation of TN was significantly correlated with that of LFN, HFN, PN, and MN ($p$<0.01). The LFN and PN had the highest variation, and the variation of LFN was higher than that of PN except for in 0-5 cm soil in 2017, indicating that LFN was the best indicator of TN affected by the tillage practice in this study, followed by PN.

## 5 Conclusions

The different soil disturbance intensities and straw distributing depths under different tillage treatments affected the concentration of soil TN and its components. MT increased the TN and LFN, HFN, PN, and MN concentration in 0-5 cm soil (except for MN in 2016), and straw return was helpful to increase the TN and its components concentration in 0-20 cm soil. TN concentration was extremely significantly correlated with LFN, HFN, PN, and MN concentration, and the variation of TN is extremely significantly correlated with that of LFN, HFN, PN, and MN ($p$<0.01). Among the nitrogen components, LFN had the highest variation and showed the highest sensitivity to tillage practice, followed by PN. In all, minimum tillage combined with straw return could enhance the soil nitrogen pool in topsoil. By monitoring the changes in LFN concentration, it is possible to realize the impact of tillage practice on the nitrogen pool in time.

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