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Effects of long-term no tillage treatment on gross soil N transformations in black soil in Northeast China

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A R T I C L E   I N F O

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A B S T R A C T

No tillage (NT) is a common conservation tillage practice used to enhance soil C sequestration. However, to date, the understanding regarding the impact of NT on soil nitrogen (N) transformations remains limited. Here, we used ^{15}N tracing to investigate the effects of 14 years of NT on the gross N transformation rates in black soil in China. We also evaluated the risk of N loss from soil in NT systems compared to that treated with conventional tillage (CT). The gross N mineralization rates in the top 5 cm of NT-treated soil was more than three times higher than the rates in the 5–15 cm layer ($P < 0.01$), which was significantly higher than those in the same layer of CT soils ($P < 0.05$). However, the total gross NH_4^+ immobilization rates were almost negligible in NT soil than in CT soil, which led to significantly higher net mineralization rates. The highest gross autotrophic nitrification rates were observed in the top 5 cm of NT soil, which was significantly higher than those in CT ($P < 0.05$). Heterotrophic nitrification rates were very low in NT soil, and ranged from 0.02–0.11 mg N·kg^{-1} d^{-1}, which were significantly lower than those in CT (average rate of 0.80 mg N·kg^{-1} d^{-1}). The ratio of autotrophic nitrification to NH_4^+ immobilization, and the N_2O emission rate were significantly higher in NT than in CT. Soil N_2O emission rates were positively correlated with autotrophic nitrification rates. Thus, long-term NT treatment was more likely than CT treatment to increase the risk of NO_3^- leaching and N_2O emission.

1. Introduction

No tillage (NT) is a conservation tillage practice that has been proposed in many countries to increase carbon sequestration (Franzluebbers et al., 1994; Blanco-Canqui and Lal, 2008). However, the understanding regarding the impact of NT on soil nitrogen (N) transformation remains limited. Previous studies investigating the effects of NT on soil N transformations have primarily focused on net N transformations (e.g. net mineralization and net nitrification) (Franzluebbers et al., 1994; Hart et al., 1994; McCarty et al., 1995). Net N transformation rates can provide an index of plant-available N and N leaching; these values cannot provide any insights into the individual processes inherent in cycling among N pools. Determining the gross N transformation rates by ^{15}N tracing can help identify individual N turnover processes and provide a better understanding on the soil N cycling processes and mechanisms (Zhang et al., 2012a; Lang et al., 2016). To date, only few studies have investigated the effects of long-term conservation tillage on gross N transformation rates in soil (Gómez-Rey et al., 2012; Dong et al., 2012). Some individual N transformation processes (such as dissimilatory NO_3^- reduction to NH_4^+, oxidation of N_{rec} to NO_3^-, and mineralization of N_{lab} to NH_4^+) under NT treatment have not been reported. Therefore, we carried out a laboratory ^{15}N tracing study to investigate the effects of long-term NT treatment on gross N transformation rates in soil and to evaluate the impact of NT for N conservation in black soil in Northeast China.

Abbreviations: BD, Bulk density; CT, Conventional tillage; NT, No tillage; SOC, Soil organic carbon; SOM, Soil organic matter; TN, Total nitrogen; WFPS, Water-filled pore space; WHC, Water-holding capacity

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2. Materials and methods

2.1. Experimental site

The experimental site was located in the Experimental Station (44°12′N, 125°33′E) of the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, in Jilin province, China, which is characterized by a typical temperate continental monsoon climate. The average annual potential evapotranspiration is 1009 mm (1971–2000), and it markedly exceeds annual precipitation (520 mm). The soil, which is derived from loamy loess soil, is classified as a black soil according to the Chinese soil classification system (equivalent to Hapudoll, USDA Soil Taxonomy) with a clay loam texture (39.5% sand, 24.5% silt, and 36% clay). Before the tillage trials were initiated, the experimental site had been continuously cropped with maize (*Zea mays* L.) under conventional tillage (CT) conditions for > 20 years (Liang et al., 2007).

2.2. Experimental design and management practices

The long-term tillage experiment was established as a split-plot design with four replicates in autumn 2001. Each main plot (10.4 × 20 m^2) was split into two 5.2 × 20 m^2 sub-plots. NT and CT were the two tillage treatments applied at the main plot level, and maize-soybean (*Glycine* max Merr.) rotation were applied at the sub-plot level with both crops planted in each whole plot every year (Fig. 1).

NT soils were not disturbed except during planting using a no-till planter (KINZE 3000, USA). Management of CT-treated soils included mouldboard ploughing (approximately 20 cm deep) after maize harvest in the fall, followed by disking (7.5–10 cm depth) and harrowing for secondary seedbed preparation in the spring. The crops were planted in May and harvested in September. After the manual harvest, maize stalks in the NT plots were manually cut into 30-cm pieces leaving a 30- to 35-cm stubble, and then laid on the soil surface. All aboveground maize residues were removed from the CT plots before fall ploughing.

2.3. Laboratory ^{15}N tracing experiment

For the ^{15}N tracing assay, soil samples were collected in October 2015, i.e., during year 14 of the experiment (from three of the four field replicates) from the maize planting sub-plot of each tillage system after harvest. Seven core samples were taken from each plot. Each core sample was separated into two segments (0–5 and 5–15 cm) according to the vertical distribution of the soil organic carbon (SOC) and total nitrogen (TN) contents, and the seven core sample segments for each depth per plot were combined into a single composite sample.

Two ^{15}N-labelling treatments with three replicates and three sampling points were conducted for each field plot. A total of 216 (36 flasks per field plot, and 18 per depth) 250-mL Erlenmeyer flasks were prepared with 20 g of fresh soil (oven-dried basis). After pre-incubation for 24 h, 2 mL of $^{15}NH_4NO_3$ (9.38 at% ^{15}N excess in ammonium) or $NH_4{}^{15}NO_3$ (9.74 at% ^{15}N excess in nitrate) were added to each flask at the rate of 20 mg $NH_4{}^+$-N·kg^{-1} soil, and 20 mg $NO_3{}^-$-N·kg^{-1} soil, which was equivalent to 82 kg N ha^{-1}. The soil samples were then adjusted to obtain a water-holding capacity (WHC) of 60% and incubated at 25 °C for 72 h. At 0.5, 24, and 72 h after NH_4NO_3 addition, the soils were extracted with 2 M KCl solution for 1 h in a 1:5 soil-solution ratio (Zhang et al., 2013), to determine the concentrations and ^{15}N enrichments of the $NH_4{}^+$ and $NO_3{}^-$.

Further, N_2O emissions were measured on 0, 1, 2 and 3 days after unlabelled NH_4NO_3 addition in another set of Erlenmeyer flasks. Each time, the flasks were sealed for 5 h with rubber stoppers and 20 mL of headspace gas before and after sealing and were sampled with a syringe. The N_2O concentrations were studied using a gas chromatograph (Agilent 7890, Santa Clara, CA, USA).

2.4. ^{15}N tracing model

We used a numerical ^{15}N tracing model to quantify the simultaneously occurring gross N transformations in soil (Müller et al., 2007). The model considered five N pools and the following ten N transformation processes including: (1) mineralization of N_{lab} to $NH_4{}^+$ (M_{Nlab}), (2) mineralization of N_{rec} to $NH_4{}^+$ (M_{Nrec}), (3) immobilization of $NH_4{}^+$ to N_{lab} ($I_{NH4\text{-}Nlab}$), (4) immobilization of $NH_4{}^+$ to N_{rec} ($I_{NH4\text{-}Nrec}$), (5) oxidation of $NH_4{}^+$ to $NO_3{}^-$ (O_{NH4}, autotrophic nitrification), (6) oxidation of N_{rec} to $NO_3{}^-$ (O_{Nrec}, heterotrophic nitrification), (7) immobilization of $NO_3{}^-$ to N_{rec} (I_{NO3}), (8) dissimilatory $NO_3{}^-$ reduction to $NH_4{}^+$ (D_{NO3}), (9) adsorption of $NH_4{}^+$ on cation exchange sites (A_{NH4}), and (10) release of $NH_4{}^+{}_{ads}$ (R_{NH4}). The N_{lab} pool was assumed for 1% of the total organic N pool according to the results reported in a previous study for cultivated black soil (Chen et al., 2015). For further details on the model, see Müller et al. (2007).

2.5. Calculations and statistical analyses

All statistical analyses were performed with SAS 9.2 (SAS Institute Inc., USA). The effects of tillage practice and soil layers on the measured soil properties, gross N transformation rates, and N_2O emissions were analysed using analysis of variance. Mean comparisons of the different treatment approaches were made using the least significant difference test, and a *P* value of < 0.05 was considered statistically significant. Correlation analyses were used to examine the relationship among gross N transformation rates and N_2O emission. The total N mineralization and immobilization rates were calculated as follows:

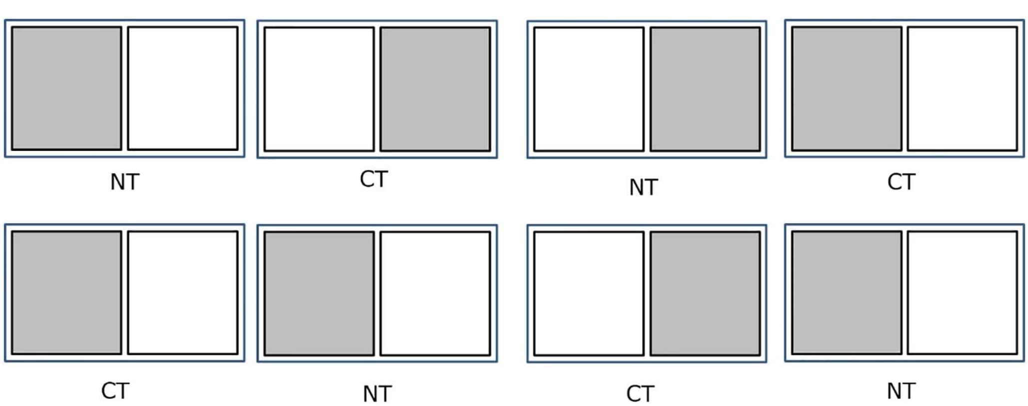

Fig. 1. Diagram of the tillage experiment plots. NT (no tillage) and CT (conventional tillage) under the main plot refer to the tillage treatment of the plot. Grey sub-plots represent sub-plots with maize planted in odd years and soybean in even years. For sub-plots indicated in white, the reverse was carried out.