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Tillage effects on phosphorus composition and phosphatase activities in soil aggregates

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ABSTRACT

Phosphorus (P) and phosphatase activities in soil aggregates affected by tillage under cold monsoon climate remain poorly understood. Based on the hypothesis that the distribution of P composition and phosphatase activities in soil aggregates should be affected by different tillage practices, a field experiment was conducted to study the effects of moldboard plow (MP), ridge tillage (RT), and no-tillage (NT) on the distribution of soil P composition determined by ^{31}P nuclear magnetic resonance (NMR) and phosphatase activities in different size fractions of soil aggregates (>2, 1–2, 0.25–1, and <0.25 mm) at the 0 to 20 cm depth in northeastern China. NT treatment had significantly higher organic P proportion in total P and larger proportions of monoesters and diesters in extracted total P than the MP treatment, whereas the MP treatment showed higher concentrations of total P, organic P, plant available P, NaOH-EDTA extracted total P, orthophosphate and monoesters. Soil alkaline phosphatase (AlP) and phosphodiesterase (PD) activities under NT were significantly higher than those under MP, and the responses of AlP in 0.25–1 mm size fraction and PD in <0.25 mm size fraction were more sensitive to tillage treatments. Overall, although NT facilitated more P stored in the organic P form and increased phosphatase activities, soil with NT had lower total and plant available P compared to traditional MP treatment and therefore, MP may be the right practice to conserve soil P under cold monsoon climate.

1. Introduction

Tillage can affect the mineralization and decomposition of soil organic matter (SOM) by changing the physical and chemical properties of soils and altering the diversity and activity of the soil microbial community and enzymes, which in turn affects the concentration and composition of soil P (Redel et al., 2011; Selles et al., 1997; Wang et al., 2011). In temperate and tropical soils, numerous studies demonstrated that no-tillage (NT) increased the concentrations of total P, organic P, and plant available P compared with conventional tillage (CT) (López-Fando et al., 2007; Qin et al., 2010; Saavedra et al., 2007). In colder climates, the studies about the effect of tillage on soil P mostly concentrated on its runoff losses (Hansen et al., 2000; Tiessen et al., 2010).

Soil aggregates have been considered as the basic units of soil structure (Lynch and Bragg, 1985). Different aggregate size fractions have diverse effects on maintaining and supplying soil nutrients (Chen et al., 1994), and their stability as an indicator of vital soil functions can be used to assess soil quality (Seybold and Herrick, 2001). Previous studies have shown that tillage can speed microbial decomposition of fungal hyphae, roots, and other organic materials that bind microaggregates together to form macroaggregates (Tisdall and Oades, 1982) and can thereby affect the size distribution and stability of aggregates (Green et al., 2005; Helgason et al., 2010; Hernandez-Hernandez and Lopez-Hernandez, 2002). NT and ridge tillage (RT) soils exhibited higher amounts of >0.25 mm macroaggregates and greater aggregate stability compared to moldboard plow (MP) soils (Chung et al., 2008; Yang and Wander, 1998).

Moreover, aggregate size fractions can also influence the concentration of P by acting on sorption and desorption of soil P (Linquist et al., 1997; Wang et al., 2001). Therefore, the distribution of P in different aggregate size fractions can be influenced by tillage directly through its effects on sorption and desorption of soil P by aggregates. The various P forms in soil aggregates affected by tillage, including total P, extractable P, and bound P, were extensively studied (Elliott, 1986; He et al., 1995; Maguire et al., 1998; Messiga et al., 2011; Urioste et al., 2006; Wright, 2009). In addition, the organic carbon and microbial biomass in soil aggregates affected by tillage were also investigated by some researchers (Liang et al., 2007; Zhang et al., 2012). However, the information about using ^{31}P nuclear magnetic resonance (NMR) spectroscopy technique to study the effect of tillage on soil P composition in aggregates is still rare. The different P compounds in soil had variable abilities to provide P nutrient to crops (Doolette and Smernik, 2011), and the P compounds in soil could be identified successfully with ^{31}P NMR spectroscopy when the soils were extracted with a NaOH-EDTA solution (Cade-Menun and Preston, 1996; Condron et al., 1990; Redel et al., 2011).

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Soil phosphatases such as phosphomonoesterase (AcP and AlP), phosphodiesterase (PD) and inorganic pyrophosphatase (IPP) play critical roles in organic and condensed P hydrolysis and the plant available P supply to crops (Fox and Comerford, 1992; Tabatabai, 1994; Tarafdar and Jungk, 1987). Previous studies showed that the NT treatment increased phosphatase activities compared with the CT treatment in the surface soil (Deng and Tabatabai, 1997; Dick, 1984; Wang et al., 2011). The distribution of microorganisms (e.g., fungi, bacteria) differs among different soil aggregate size fractions (Gupta and Germida, 1988), and phosphatases may totally or partly derive from microorganisms (Tabatabai, 1994; Turner and Haygarth, 2005). Therefore, the activities of phosphatases among different aggregate size fractions can also be affected by tillage (Qin et al., 2010). Gupta and Germida (1988) showed that macroaggregates contained higher acid phosphatase activity than the corresponding microaggregates in both native and cultivated soils after 69 years of cultivation. Although the effect of tillage on phosphatase activities in aggregates was studied, previous researches mainly involved individual phosphatase (e.g., phosphomonoesterase) (Gupta and Germida, 1988; Kandeler et al., 1999; Marx et al., 2005; Mendes et al., 2003). Little is known about the effect of tillage on phosphodiesterase and inorganic pyrophosphatase activities in aggregates.

In northeastern China agroecosystems, MP has been the common practice for many years. Intensive tillage management without a cover of crop residues has caused a significant loss of SOM and serious soil degradation, and has threatened sustainable crop production and even national food security (Liu et al., 2010). To effectively stop and reverse the adverse trend, NT and RT practices have been proposed as an alternative agriculture option. In this study site, previous research has mainly focused on the effect of tillage on soil SOC in aggregates (Liang et al., 2011; Zhang et al., 2013). There have been few studies about the effects of various tillage practices on soil P in aggregates. Thus, the objectives of this study were to determine the effects of moldboard plow (MP), ridge tillage (RT), and no-tillage (NT) on (a) the distribution of P as well as P composition in aggregates and on (b) the relative phosphatase activities in different aggregate size fractions at the 0 to 20 cm depth in northeastern China.

2. Materials and methods

2.1. Site description

The tillage experiment was initiated in fall 2001 at the experimental station (44°12′N, 125°33′E) of the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences. The station is located in Dehui County, Jilin Province in the northeastern part of China, which has a continental monsoon climate. The mean annual temperature was 4.4 °C, and the mean annual precipitation varied from 500 to 600 mm with most of it occurring in June, July, and August. The type of soil used in this study was a clay loam soil, and it is classified as a phaeozem (FAO, 1998). The initial soil in this study site was slightly acidic with average pH of 6.5 (Liang et al., 2007) and has decreased to 5.7, 5.5, and 5.6 in MP, RT, and NT soils, respectively. Before the establishment of this tillage experiment, the field had undergone more than ten years of conventional tillage management for continuous maize cultivation (Liang et al., 2007).

The tillage experiment consisted of moldboard plow (MP), ridge tillage (RT), and no-tillage (NT) and was arranged in a randomized complete block design with four replicates. Each tillage plot was 5.2 m × 20 m and had a maize–soybean rotation with both crops present in each year. The MP treatment included one fall moldboard plowing (approximately 20 cm deep) after the crop harvest and spring disking (7.5 to 10 cm deep) before planting. The RT treatment included ridging in June for maize and soybean, chopping the crop stalk/roots in the fall (approximately 1/3 row width) and spring planting with a no-till planter. The NT treatment did not disturb the soil except for planting. All the treatments used a KINZE-3000 NT planter (Williamsburg, Iowa, USA) for the spring planting. Except for the plots under the MP treatment, all crop residues were retained on the soil surface directly after harvesting. Each year, 100 kg N ha^{-1}, 45.5 kg P ha^{-1}, and 78 kg K ha^{-1} were applied to maize as basal fertilizer. An additional 50 kg N ha^{-1} was applied as a top dressing at the V-6 stage (40 days after planting). For soybean, all fertilizers were applied as basal fertilizer, including 40 kg N ha^{-1}, 60 kg P ha^{-1}, and 80 kg K ha^{-1}. The basal fertilizers were applied simultaneously during the planting using the banding attachment on the KINZE-3000 NT planter (Williamsburg, Iowa, USA).

2.2. Soil sampling

Soil sampling was carried out in April 2010 after the snow melted. In the central rows of each tillage plot, three undisturbed soil samples were random taken from 0 to 20 cm (≈2000 cm^3) after the soil floor materials were removed. Then, the undisturbed soil samples were placed in hard plastic containers to maintain their primary structures. After transportation to the laboratory, the three undisturbed soil samples were composited for soil aggregate fractionation.

To acquire the aggregate-size fractions, the soils were sieved according to the methods described by Schutter and Dick (2002) and Sainju et al. (2003). After sampling, large soil clods were gently broken by hand, and then soils were laid out on brown paper to dry slowly for several days. This process was conducted at 4 °C to minimize the impact of air drying on the microbial communities and activities (Schutter and Dick, 2002) until a gravimetric water content of approximately 80 g kg^{-1} soil was reached so that dry sieving method could be effectively implemented at this moisture level.

The soil was fractionated into aggregates by a dry-sieving method because dry-sieving the soil would disrupt the physical habitat of microbial communities to lesser degrees than wet-sieving would (Schutter and Dick, 2002). Before sieving, visible plant residues were removed, and then, cold air-dried soils were passed through a 5-mm sieve, and large particles retained in the sieve were gently crushed by hand to pass through it. The particles that did not pass through the 5-mm sieve contained mostly stone and plant fragments and were discarded (Sainju et al., 2003). Fractionation was achieved by placing 100 g of cold air-dried, sieved soils (<5 mm) on nested sieves mounted on Retsch AS200 Control (Retsch Technology, Düsseldorf, Germany). The sieves were mechanically shaken (amplitude 1.5 mm) for 2 min to separate the soil into the following aggregate-size classes: >2 (large macroaggregates), 1–2, 0.25–1 (small macroaggregates), and <0.25 mm (microaggregates, silt + clay size fraction). Preliminary experiments showed that shaking for 2 min at 1.5 mm amplitude was adequate for separating the soil aggregates without causing the mechanical destruction of large aggregates (data not shown).

The fractionated samples were later combined to make composite samples for each aggregate-size class. The aggregate distribution was determined by weighing soil from each aggregate size class. The bulk soil and all the soil aggregate samples were stored in polyethylene bags at 4 °C until they were analyzed for their chemical and biological properties.

2.3. Soil P analysis

With the exception of samples for total P analysis, which required the samples to go through a 100-mesh (0.15 mm) sieve, the bulk soil and all the aggregate samples were air-dried, sieved (<2 mm), and stored at ambient laboratory temperature before other P analysis. The plant available P was determined by the molybdenum blue colorimetric method (Murphy and Riley, 1962) after extraction by 0.5 M $NaHCO_3$ (Olsen et al., 1954). The total P was determined by the same method following perchloric acid ($HClO_4$) digestion (Kuo, 1996). The inorganic P was extracted with 0.5 M H_2SO_4 (1:25 soil-to-solution ratio for 16 h) and measured by the method of Kuo (1996). The organic P was