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Tillage effects on labile pools of soil organic nitrogen in a semi-humid climate of Argentina: A long-term field study

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ABSTRACT

Tillage systems strongly affect nitrogen (N) mineralization. However, there is still only limited information on the relationship between N in labile soil organic matter (SOM) fractions and crop N uptake under different tillage systems in areas with poor water availability. This study discusses the long-term effect of two tillage systems on i) the N-content in labile organic matter fractions and their relationship with the N mineralization potential at three depths (0–5; 0–10 and 0–20 cm), ii) the factors that affect the N mineralization potential, and iii) the relationship between potentially mineralizable N (N_0) and crop N uptake in a semi-humid climate. In a long-term experiment, a Typic Argiudoll was sampled under two contrasting tillage systems: no-tillage (NT) and conventional tillage (CT). The soil sampling was performed over four years of the crop sequence (2003, 2009, 2010 and 2011) when the plots were sown with winter wheat (*Triticum aestivum* L.). They were analyzed for N_0 in the form of anaerobic N, soil organic nitrogen (SON), physically separated SOM fractions and crop N uptake. Higher values of SON and labile soil N fractions were observed under NT at all three depths. Significant differences in N_0 were found between the tillage systems, with greater values under NT. Significant ($P < 0.05$) and positive correlations between N_0 and fine particulate organic carbon (fPOM-C) ($r \geq 0.66$) were found in CT and in NT at the three depths, whereas highly significant ($P < 0.001$) and negative relationships between N_0 and fine particulate organic N (fPOM-N) ($r \geq -0.83$) were found under both tillage systems at 0–5 and 0–10 cm. The most pronounced difference in these relationships between tillage systems was observed at the 0–5 cm soil depth. Significant correlations of N_0 with residue input from previous crops and the fallow period were observed under both tillage systems and for all three depths. Regarding the relationships between N_0 and wheat N uptake, no significant correlations were found for any tillage system or depth. Soil organic N fractions were shown to be strongly influenced by the residue input from the previous crop and by variable weather conditions during the fallow period. The higher content of SON fractions under NT was associated with a higher N mineralization potential, however, it did not result in increased N availability and N uptake by wheat, because of climatic conditions during the crop growing season.

1. Introduction

Nitrogen (N) is a major yield-limiting nutrient in agricultural areas worldwide (Fageria and Baligar, 2005). Enhanced N-use efficiency is fundamental (Sainz Rozas et al., 2011), due to the high cost of N-fertilizers. Tillage systems affect N mineralization and concentration in the soil through short- and long-term effects on physical, chemical, and biological properties of the soil (Sharifi

Abbreviations: NT, no-tillage; CT, conventional tillage; N, nitrogen; N_0, potentially mineralizable N; Nan, anaerobic nitrogen; SOM, soil organic matter; POM, particulate organic matter; POM-C, particulate organic carbon; SOC, soil organic carbon; SON, soil organic nitrogen; CN, carbon-nitrogen ratio in whole soil; cPOM-C, coarse particulate organic carbon; cPOM-N, coarse particulate organic nitrogen; fPOM-C, fine particulate organic carbon; fPOM-N, fine particulate organic nitrogen; cPOM-CN, carbon-nitrogen ratio of the coarse particulate organic matter; fPOM-CN, carbon-nitrogen ratio of the fine particulate organic matter; NH_4-N, ammonium N; NO_3-N, nitrate N; Pe, extractable phosphorus; BD, bulk density; Z22, wheat tillering stage; CWR, crop water requirement.

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et al., 2008). Conventional tillage (CT) favors residue and soil organic matter (SOM) decomposition through disruption of the soil aggregates which enhance aeration and distribute carbon (C) sources more uniformly. Tillage exposes the protected organic compounds to the action of microorganisms and thus hastens C and N cycling (Mikha and Rice, 2004). Also, incorporation of crop residues results in faster turnover rates (St. Luce et al., 2011). In contrast, no-tillage (NT) promotes SOM stratification, with a higher concentration at the soil surface where residues accumulate over time (Ferreira et al., 2013). This SOM increase under NT is closely related to crop production (Diovisalvi et al., 2008), and the N released from residues depends on its N content and C:N ratio (Vigil and Kissel, 1991).

The Pampas region in Argentina is known as one of the most important grain-producing areas in the world (Satorre and Slafer, 1999), the main crops being wheat (*Triticum aestivum* L.), maize (*Zea mais* L.) and soybean (*Glycine max* L. Merr) (Reussi Calvo et al., 2013). This region includes a temperate zone known as the Humid Pampas which extends to the semi-humid zone, where rainfall is scarce and the climate is more seasonally variable. Wheat is the basic crop in production systems across a wide region of the southwestern Pampas in Argentina (Martínez et al., 2015, 2016). Considering that the wheat yield is strongly influenced by the weather conditions and soil properties, it is essential to maximize both N and water use efficiency (Galantini et al., 2004). In addition, the response to N-fertilizer application depends on the amount and distribution of rainfall in areas with low water availability (Martínez et al., 2015, 2016).

To determine optimal N-fertilization rates it is necessary to consider both the inorganic N accumulated during the fallow period and the soil organic N (SON) that is mineralized during the growing season (Sainz Rozas et al., 2011). Most estimates of soil N mineralization are based on long-term aerobic incubation (Stanford and Smith, 1972). This method determines the soil labile N fraction that can be converted to mineral forms, which is known as potentially mineralizable N (N_0). This pool can also be estimated through tests performed in the field (Bundy and Meisinger, 1994) or in laboratories by anaerobic incubation (Waring and Bremner, 1964). The anaerobic N (Nan) consists of ammonium N (NH_4-N) released by microorganisms that are killed under anoxic conditions in a soil-water slurry incubated for 7 to 14 days. The Nan was considered to be the most useful indicator of soil quality in semi-arid regions (Keeney, 1982); other authors (Bushong et al., 2007; Soon et al., 2007) have argued that Nan is the best biological indicator of N_0. Also, Reussi Calvo et al. (2013) proposed that the use of Nan to estimate N-supply through mineralization would help to better assess N-availability.

Soil organic matter and its labile fraction –particulate organic matter (POM)- are considered important factors in regulating N-dynamics (Fabrizzi et al., 2003; Gregorich et al., 2006; Cozzoli et al., 2010) in view of their key role in N-mineralization (Gómez-Rey et al., 2012) and N-availability to crops (Wander, 2004). The POM may provide more accurate information on N-mineralization as it contains easily mineralizable N-fractions. This fraction represents the mineralizable pool and it can easily predict the N-mineralization capacity (Fabrizzi et al., 2003). Haynes (2005) reported that POM is an important labile N-pool in several soils; whereas Boone (1994) found that POM contributed as little as 2–13% mineralized N. According to Galantini and Suñer (2008), the N in POM is not always directly related to mineralized N, but it may be used for N estimation. Decomposition of this labile fraction is heavily dependent on residue input and weather conditions (Galantini et al., 2014), which vary significantly between years in semi-humid areas.

In order to assess the effect of tillage systems on N-dynamics and N-availability to the crop it is important to obtain information from long-term experiments in areas with low water availability. Sharifi et al. (2008) suggested that the effect of tillage systems on active organic N might vary with the specific soil and weather conditions. In Argentina, NT systems were implemented about 40 years ago; however, few comparative studies are old enough to evaluate long-term effects, especially in Mollisols of semi-humid areas. Moraes Sá (2003) reported that conversion of CT to NT could stabilize after 20 years, which highlights the importance of long-term experiments. In Argentina, a few studies have been conducted on the relationship between N mineralization and the labile C and N fractions in the humid Pampa (Fabrizzi et al., 2003; Diovisalvi et al., 2008; Domínguez et al., 2009); however, little is known about the relationship between N in labile SOM fractions and crop N uptake under different tillage systems in areas with poor water availability. In semi-humid areas, rainfall variability leads to annual variation in the biomass production, residue input and soil conditions as a result of the biological transformation of labile organic fractions. We hypothesized that the long-term increase of labile SON fractions is more pronounced under NT than under CT, thus enhancing the N mineralization potential and uptake by wheat crops. However, the differences in these fractions caused by the tillage system depend on a comparison at different soil depths.

This study discusses the long-term effect of two tillage systems on i) the N content in the labile organic matter fractions and their relationship with N mineralization potential at three depths (0–5; 0–10 and 0–20 cm), ii) the factors that affect the N mineralization potential, and iii) the relationship between crop N uptake and N_0 in a semi-humid climate.

2. Materials and methods

2.1. Study site

The study was conducted at the experimental site at Hogar Funke (38° 07′ 06" S – 62° 02′ 17" W) in southwestern Buenos Aires province, Argentina (Fig. 1). The soil is classified as a Typic Argiudoll, of over 2 m in depth with a loamy texture in the A horizon and clayey-loamy in the B_2 horizon. According to Thornthwaite, the climate is classified as semi-humid. The rainfall gradient determines an udic soil moisture regime with irregular distribution (Soil Survey Staff, 2010), the rainy seasons being in autumn (March–April) and spring (September–October). The mean annual temperature in this area is 15 °C and the annual precipitation is 735 mm (1887–2012).

A long-term experiment was initiated in 1986 to compare two tillage systems: conventional tillage (CT) and no-tillage (NT). Prior to the establishment of the trial, the site had been cropped under CT for more than 30 years. The CT management was based on two disk operations to mix the residues with the soil: one in the early summer fallow to 15 cm in depth and another before sowing to 10 cm. Meanwhile, NT was characterized by the absence of tillage with over 30% residues covering the soil surface at all times. Under this system, a direct seed drill (John Deere 750 drill, John Deere Argentina S.A.) was used to sow directly into the standing residues of the previous crop. A herbicide (2 L ha^{-1} of glyphosate) was applied for weed control. The plots were fertilized with 10 kg P ha^{-1} $year^{-1}$ as diammonium phosphate (18-46-0) at seeding under both tillage systems. The experiment was designed using a randomized complete block with three replicates. The treatment plot size was 660 m^2 (33 m × 20 m).

In the years when the plots were sown with winter wheat the soils were sampled at tillering (Z22, Zadoks et al., 1974), as recommended by El-Harris et al. (1983) for studying the N mineralization potential. The full crop sequence and the fallow period differed according to the tillage system and year, as detailed in Table 1. The fallow period was variable for each year and tillage