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Long term nitrogen fertilization: Soil property changes in an Argentinean Pampas soil under no tillage

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ABSTRACT

The main objective of nitrogen (N) fertilization is to achieve high yields and/or to increase grain quality. However, nutrient application may affect soil processes and cycles. These could involve increases in crop residues return to soil, changes in soil organic matter dynamic, NO_3^--N content and pH decrease. The aim of this study was to determine the effect of N application on: crop residue input, soil organic carbon (SOC) and N (SON), their particulate (POC and PON) and mineral associated (AOC and AON) fractions, mineralizable N (anaerobic incubations, AN), and pH on a Molisoll of the southern Buenos Aires Province under no tillage (NT). A long-term crop rotation experiment has been conducted between 2001 and 2008 on a complex of Typic Argiudoll and Petrocalcic Paleudoll soils at Balcarce, Argentina (37°45′S, 58°18′W). Three N rates (N0, N1 and N2) were evaluated, with an average N input of 0, 57 and 105 kg ha^{-1} year^{-1}, respectively. Crop sequence was integrated by maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.) and wheat (*Triticum aestivum* L.)/soybean double crop. Soil sampling was done in 2008, previous to maize planting.

Nitrogen fertilization increased carbon (C) return to soil during 2001–2008 (11.1 and 18.7% for N1 and N2 respect to N0) but no differences in SOC, SON, AOC, and AON were observed among N rates in 0–5 and 0–20 cm depth. It was only found more PON in N1 and a slight tendency to increased POC (3% and 13% for N1 and N2 respect to N0) in 0–5 cm depth. At the same time, NO_3^--N content in 0–60 cm depth was similar among N rates (89.6 ± 8.4, 88.6 ± 6.4, and 81.6 ± 10.3 kg N ha^{-1} for N0, N1, and N2, respectively). By contrast, it was determined soil acidification (5.8 ± 0.3, 5.5 ± 0.2, and 5.3 ± 0.2 for N0, N1, and N2, respectively) and AN reductions in 0–5 cm depth as N rate increased, (76.1 ± 3.2; 74.9 ± 6.3 and 57.9 ± 3.5 for N0, N1 and N2 respectively). The high frequency of soybean in the rotation could have prevented higher increases in C return to soil and, as a consequence, mitigated the changes in related soil properties. In addition, the absence of N application to soybean also could have prevented enhances in soil acidification and AN depletion.

1. Introduction

The main objective of crop fertilization is to achieve high yields and/or increased grain quality (Mosier et al., 2009). However, nutrient application may affect soil processes and cycles (Russell et al., 2006). Nitrogen (N) is the main nutrient limiting crop growth and yield in the world (Huber and Thompson, 2007) and in the southeastern Buenos Aires Province (Argentina) in particular (Echeverría and Sainz Rozas, 2005). Crop response to N fertilization involves increases in CO_2 fixation and, as a consequence, in aboveground and root biomass production (Tognetti et al., 2005). This increase leads to more crop residue return to soil (Studdert and Echeverría, 2000; Wilts et al., 2004) which, in temperate agroecosystems, is considered the main factor controlling soil organic matter (SOM) dynamics (Stevenson and Cole, 1999). Therefore, several reports exist about rates and quantity of SOM change due to N fertilization, depending on N rates, crop rotation, environment and soil type evaluated (Álvarez, 2005).

It is widely assumed that agriculture, particularly under conventional tillage (CT) leads to depletions of SOM content. Therefore, N fertilization is often recommended to increase SOM, or to reduce loss rates (Studdert and Echeverría, 2000). Liebig et al. (2002) reported that fertilization with 180 and 90 kg N ha^{-1} increased soil carbon (C) sequestration in 1.4 Mg ha^{-1} and

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1.0 Mg ha^{-1}, respectively, in comparison with the unfertilized plot. Nevertheless, both treatments showed SOM depletion in 0–7.6 cm depth respect to the level determined 26 years before. In the southeastern Buenos Aires Province, Fabrizzi et al. (2003) observed that in a degraded soil, N fertilization increased SOM content with respect to the unfertilized treatment, whereas the same treatment applied to a non-degraded soil did not cause differences. Contrarily, Khan et al. (2007) documented opposite trends for a wide variety of geographic regions, cropping systems, and tillage practices: mineral N application, at higher rates than those used currently in Argentina, enhanced microbial decomposition of SOM and reduced soil organic carbon (SOC) content in relation to the unfertilized plots.

Most agricultural soils in the world and particularly in Argentina have net negative charge, which limits NO_3^- adsorption and increased leaching probability (McNeill and Unkovich, 2007). As a consequence, crop N uptake and microbial immobilization is considered the main N retention process in soils (Halvorson et al., 2002; Eriksen, 2008). Therefore, Halvorson et al. (1999) observed a positive relationship between the amount of N in residues and total N in 7.5 cm top-soil after applying N to crops during 10 years. However, as Khan et al. (2007) reported for SOC, Mulvaney et al. (2009) observed that N fertilization caused soil organic N (SON) depletions due to the increase in microbial activity.

Changes in SON caused by N fertilization may affect soil N potential mineralization (N_0), which plays a critical role in N supply to crops. This parameter can be estimated by the amount of N-NH_4^+ produced by short term anaerobic incubations (AN), which has been demonstrated to be sensitive to the effect of tillage, liming, fertilization and crop sequences (Soon et al., 2007). In the southeastern Buenos Aires Province, Diovisalvi et al. (2008) reported that after 10 years, crop N fertilization caused no change in SON in 0–5 cm and 0–20 cm depths. As a consequence, it was observed no difference in AN. On the contrary, Domínguez et al. (2009) and Genovese et al. (2009) reported AN depletions after seven and twelve years of N fertilization in the same region, respectively.

Soil acidification is a negative aspect of applying ammonium N forms. This process can produce detrimental conditions for microorganism development, altering C and nutrient cycling (Kemmitt et al., 2006). Soil acidity also affects crops, reducing their biomass production and grain yield (Zhao et al., 2010).

Soil organic matter dynamics is highly modified by tillage systems (Six et al., 1999). No-tillage (NT) generally leads to an increase of SOM content compared with CT that is more evident in the upper layers of the profile (Kern and Johnson, 1993; West and Post, 2002). As a consequence, some authors reported that SOM changes due to N fertilization were more pronounced in the first layer of soil (Fabrizzi et al., 2003; Domínguez et al., 2009). Acidification of soil surface has also been more intense in NT than in CT when N was broadcast-applied (Eckert, 1985).

Traditionally, agricultural systems in the southeastern Buenos Aires Province (Argentina) comprised aggressive tillage that reduced SOM levels. Nowadays, most of these systems have adopted NT to mitigate soil degradation. In spite of that, soybean cultivation has dramatically increased, and this contributed to increase SOM losses (Studdert and Echeverría, 2000). In this context, best management practices that involve adequate nutrient applications are auspicious to maintain or improve soil quality.

The aims of this study were to evaluate the long term effect of N fertilization on crop biomass production, and some selected soil properties (BD, pH, AN, and SOC, SON, and their fractions) of a Mollisol of the southern Buenos Aires Province (Argentina) under NT. We hypothesized that long-term N crop fertilization (1) increases POC and PON and AN, (2) reduces pH and (3) does not affect BD and NO_3^--N content.

2. Materials and methods

2.1. Experimental site

A long-term crop rotation experiment has been conducted between 2001 and 2008 at the *Unidad Integrada Balcarce*, at Balcarce, Buenos Aires Province, Argentina (37°45′S, 58°18′W, 138 m above sea level). The soil of the experimental site is a complex of Mar del Plata series (fine, mixed, thermic Typic Argiudoll) and Balcarce series (fine, mixed, thermic Petrocalcic Paleudoll) with less than 2% slope (no erosion). The petrocalcic horizon of the Balcarce soil series is below 0.7 m. The soil has a loam texture at the surface layer (0–20 cm depth), with an average size-particle distribution of 23% clay, 36% silt and 41% sand. The subsurface layer (25–110 cm depth) has clay-loam texture. Prior to the establishment of the experiment, the site had been under cropping with CT for more than 25 years. Tillage comprised moldboard plowing, disking and field cultivation with the least tillage operations necessary to get an appropriate seedbed. In 2001, at the beginning of the study, soil pH in the 0–20 cm depth was 5.5 and SOC and P-Bray were 25.4 g kg^{-1} and 28.7 mg kg^{-1}, respectively.

2.2. Experiment design

In the southern Buenos Aires Province, the typical rotation cycle is maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.) and wheat (*Triticum aestivum* L.)/soybean double crop. For maize and soybean, the optimal sowing dates are during October and November respectively, and the harvest period starts during April–May for both crops. Wheat is planted in June–July and harvested at the end of December or early January. Double cropped soybean is sown immediately after wheat harvest and is harvested during May. Crop sequence during the first rotation cycle was: maize (sown in year 2001), soybean (2002) and wheat/soybean double crop (2003); the second cycle was integrated by wheat/soybean (2004), maize (2005) and soybean (2006). In 2007 wheat/soybean double crop was sown, corresponding to the third rotation cycle.

Three different N rate treatments (N0, N1, and N2), applied to cereal crops, were evaluated. Treatment N1 (70 kg N ha^{-1}) was defined in correspondence to the most usual rates applied for farmers in the region to wheat and maize and was. Treatment N2 (140 kg N ha^{-1}) was established in order to achieve maximum yields. In the maize sown in 2005 the N rates increased (116 kg N ha^{-1} and 176 kg N ha^{-1} for N1 and N2 respectively). In addition, N0 was used as a check, without N fertilization. Urea (46–0–0) was the N source. Soybean was inoculated with *Bradyrhizobium japonicum* before sowing. The experimental design was in randomized complete blocks with four repetitions. The dimensions of the experimental units were 12 × 5 m. Phosphorus (P) and sulfur (S) were applied to all treatments as triple superphosphate (0–46–0) and gypsum ($SO_4Ca \cdot 2H_2O$, 16% S, 20% Ca), respectively.

High potential varieties and hybrids, widely spread in the southeastern Buenos Aires Province, were used. Crops were sown under NT, in optimal dates for the region and were kept free of weeds, pests and diseases. The numbers of plants established per m^2 were 8, 25, 300 and 35 for maize, soybean, wheat and double cropped soybean. Nitrogen was broadcast-applied at Zadoks 22 (Zadoks et al., 1974) in wheat, and V6 (Ritchie and Hanway, 1982) in maize. Phosphorus and S were also surface-broadcasted annually, previous to crop sown, applying 20 kg P ha^{-1} year^{-1} and 15 kg S ha^{-1} year^{-1}.

At physiological maturity, defined in Zadoks 90 (Zadoks et al., 1974) for wheat, R6 (Ritchie and Hanway, 1982) for maize, and R8 (Fehr and Caviness, 1977) for soybean, crops were harvested by collecting material from a surface of 8 m^2 per plot. Crops residues were returned to soil.