Ecological Engineering 106 (2017) 24–34

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Carbon and nitrogen mineralization kinetics as affected by tillage systems in a calcareous loam soil

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ARTICLE INFO

Article history:
Received 20 July 2016
Received in revised form 11 May 2017
Accepted 17 May 2017

Keywords:
C sequestration
Microbial activity
Soil management
Soil quality
Calcixerepts

ABSTRACT

Tillage systems may affect soil carbon (C) and nitrogen (N) kinetics. However, the effects of tillage on C and N kinetics have not yet been studied for the major calcareous soils (Calcixerepts) from Iran. The aim of this study was to assess the effect of four tillage systems on soil C and N mineralization kinetics in a semi-arid loam soil after six years of two conventional tillage (CT) systems (moldboard plow, MP and disk plow, DP) and two reduced tillage (RT) systems (chisel plow, CP and rotary plow, RP) under similar plant residue inputs and cover crops in Shahrekord, Central Iran. We tested the hypothesis that soil C and N mineralization kinetic parameters are higher in RT than CT systems because of differential soil disturbance and mixing. Tillage systems were established in 2005 and, an experiment was arranged in a randomized complete block design with each tillage system replicated three times and sampled over three years (2008, 2009 and 2011). Soil samples (0–20 cm) were incubated (at 25 °C for 11 weeks) to measure the cumulative C and N mineralization throughout the incubation and to estimate the potentially mineralizable C (Co) and N (No), and the rate constants for labile C (k_C) and N (k_N) using the first-order kinetic single model. Soil C, N and particulate organic matter (POM) remained unaffected by tillage systems and thus these properties are not a sensitive indicator of changes in soil C and N contents. The cumulative C and N mineralization; and Co indicated the effect of tillage systems over the period of study. RT systems had lower soil cumulative C mineralization (20%), Co (17%) and k_C (10%) than CT systems. The cumulative N mineralization was also lower (23%) in RT (20.7-34.3 mg kg^{-1}) than CT (28.1-42.2 mg kg^{-1}), while No tended to increase only in RP (231 mg kg^{-1}) when compared with other tillage systems (151–177 mg kg^{-1}). The k_N was generally lower (33%) in RT (0.017 $week^{-1}$) than CT (0.024 $week^{-1}$). The initial potential rates of C (Co × k_C) or N (No × k_N) mineralization tended to be lower in RT and were found to be more suitable indicators to differentiate tillage effects. Differences in C and N mineralization among tillage systems were much larger in 2011 than 2008. The data rejected our hypothesis with regard to higher C and N mineralization kinetic parameters in RT systems with less soil disturbance. In conclusion, when crop residue is maintained, RT systems can protect the labile C pools and decrease the incorporation of crop residues into the soil matrix with a lower supply of mineralizable organic C and N for microbes under the studied environmental settings. Our findings indicate that soil C and N kinetic parameters might be a more sensitive indicator of tillage effects on C and N turnover than the whole soil organic matter (SOM) and POM fraction, with a potential consequence for the soil CO_2 emissions and N transformation rates.

1. Introduction

Soil fertility and crop productivity in arid and semi-arid areas are low, owing to inadequate soil organic matter (SOM) and plant-available nutrients, poor soil structure and low water availability (Raiesi, 2006; Moreno et al., 2006; Zarea, 2011). In addition to low net primary production and high SOM decomposition rates (Zarea, 2011), intensive tillage and cropping practices, when combined with removal of crop residues also decrease SOM concentration and aggregate stability and consequently the soil quality and fertility in semi-arid agroecosystems (Moreno et al., 2006; Madejón et al., 2007). Hence, identification of key and sensitive soil properties as early warnings is essential for monitoring soil degradation by intensive tillage and possible ecological restoration of soils in these regions of the world.

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http://dx.doi.org/10.1016/j.ecoleng.2017.05.023
0925-8574/

Although the concentration of bulk SOM is an important indicator of soil quality for assessing tillage effects on soil fertility and productivity, the biologically active carbon (C) and nitrogen (N) fractions such as potentially mineralizable C and N as well as the cycling of N and C in soils are more sensitive to tillage and cropping practices than the whole SOM (Carter and Rennie, 1982; Simard et al., 1994; Balota et al., 2004). Mineralization of soil C and N is an indicator of microbial activity, and C and N cycling in the soil (Gregorich et al., 1997; Filip, 2002). Soil C and N mineralization is closely related to the size and composition of the microbial community, litter quality and quantity as well as other parameters including soil moisture, temperature, substrate placement and mixing (Beare et al., 1992; Gregorich et al., 1994; Gregorich et al., 1997), which are strongly affected by tillage systems (Franzluebbers and Arshad, 1997; Mikha et al., 2006; Sharifi et al., 2008; Laudicina et al., 2011; Guo et al., 2015).

Tillage systems modified C and N mineralization turnover in both short-term (Simard et al., 1994) and long-term (Carter and Rennie, 1982; Alvarez et al., 1995; Balota et al., 2004) experiments, as a consequence of their effect on the quantity and quality of organic residues, SOM concentration and availability, soil microbial biomass and activity, soil aggregation and environmental conditions. For example, excessive tillage can stimulate soil microbial activity and respiration (CO_2 release) mainly due to greater aeration and exposure of SOM to decomposing microorganisms (Kristensen et al., 2003; Bini et al., 2014), with an important consequence for both C and N cycling in the soil. However, different effects of tillage systems on SOM mineralization, and more generally on soil microbial activity, were observed in previous studies; with decreased (Laudicina et al., 2011; Bini et al., 2014), increased (Balota et al., 2004; Sharifi et al., 2008; Mikha et al., 2006; Wang et al., 2011) or no clear effect (Simard et al., 1994; Wright et al., 2005; Kristensen et al., 2003; Sharifi et al., 2008; Mijangos and Garbisu, 2010; Bini et al., 2014) on soil microbial respiration and N release rates in different conservation tillage (*i.e.*, minimum, reduced and no-tillage) systems.

The mathematical description of C and N mineralization kinetics is an interesting procedure to characterize SOM pools, predict the ability of soils to supply potentially mineralizable N and, more generally, estimate SOM balance (Campbell et al., 1991; Dou et al., 1996; Wang et al., 2003). Furthermore, potentially mineralizable organic C (Co) and N (No) are the labile components of SOM with a key role in short-term C and N turnover (Campbell et al., 1991; Saviozzi et al., 1993). However, the use of C and N mineralization kinetics as a tool to underscore and measure the effects of different tillage and management systems on soil C and N release is limited (Campbell et al., 1991; Saviozzi et al., 1993; Franzluebbers and Arshad, 1997; Liebig et al., 2004). Doran (1987) and Liebig et al. (2004) reported that the concentration of No in the top 7.5 cm layer was greater in conservation tillage than conventional tillage (CT) systems. Higher potentially mineralizable N and microbial biomass in conservation tillage was reported by other researchers (Carter and Rennie, 1982; Franzluebbers and Arshad, 1997) because of crop residue accumulation on the soil surface. In some studies, the positive effect of conservation tillage systems on C and N mineralization as well as their kinetic parameters was restricted only to the topsoil layer (Carter and Rennie, 1982; Doran, 1987; Alvarez et al., 1995; Liebig et al., 2004; Wright et al., 2005). In contrast, soil No was not affected by tillage systems in the 0–16 or 0–20 cm layers under temperate and humid climates in northern Spain (Mijangos and Garbisu, 2010).

Despite the inconsistent effect of tillage systems on SOM dynamics and turnover, there is still a great gap in our knowledge about changes in C and N cycling as well as the concentration of active SOM pools in conservation tillage systems. This is largely due to differences in climate, management history, soil type or the type, depth and frequency of tillage operations. In addition, there are no available data on the effect of tillage intensity and systems on C and N mineralization kinetics for the predominant calcareous soils (Calcixerepts) with low C concentration under semi-arid conditions in Central Iran. The main aim of this study was to quantify changes in soil C and N mineralization kinetic parameters (*i.e.,* potentially mineralizable C and N as active fractions of soil organic C and N) in reduced tillage (RT) systems by chisel and rotary plows compared with CT systems by moldboard and disk plows under similar plant residue inputs and cover crops, using a first-order kinetic model, in a Calcixerepts soil from Central Iran. It is hypothesized that soil C and N mineralization kinetic parameters (*i.e.,* potentially mineralizable C and N, and mineralization rate constants) are higher in RT than CT systems due to differential soil disturbance and mixing of soil and residue.

2. Materials and methods

2.1. Site and experiment description

The experiment was established in 2005 at the Agricultural Research Station of Shahrekord University, Iran. Further information on the study location and a detailed description of the experimental set-up and treatments were provided by Kabiri (2014). The soil type is a Haplic Calcisols (FAO) or mesic Typic Calcixerepts (Soil Survey Staff, 2010) with a loamy texture (sand 290, silt 450 and clay 260 $g\,kg^{-1}$) (Kabiri, 2014). Three composite soil samples were collected randomly from the 0–20 cm depth to quantify the initial soil properties before tillage operations. The concentration of SOM was low (5.84 g organic C kg^{-1} and 0.49 g total N kg^{-1}) and the experimental site had not been cultivated for 5 years before the start of the experiment. Other soil characteristics were: pH 7.95, electrical conductivity 0.40 $dS\,m^{-1}$, $CaCO_3$ 350 $g\,kg^{-1}$, available phosphorus 12.2 $g\,kg^{-1}$ and available potassium 207 $g\,kg^{-1}$ (Kabiri et al., 2015). The experiment was organized in a randomized complete block design with four tillage systems and three sampling years (2008, 2009 and 2011). The tillage systems consisted of (1) moldboard plowing (MP, 18 cm tillage depth); (2) disk plowing (DP, 17 cm tillage depth); (3) chisel plowing (CP, 14 cm tillage depth) and (4) rotary plowing (RP, 10 cm tillage depth). Both MP and DP are inversion tillage systems and thus are considered as conventional tillage (CT), while CP and RP can be described as non-inversion systems and thus are considered as RT. Each tillage system was replicated three times (three blocks) using 4 m × 50 m plots. Clover (*Trifolium pratense* L.) and winter barely (*Hordeum vulgare* L.) were sown and rotated on an annual basis. The barley top residues (*ca.* 25–35%) were left and added to the soil surface after harvest in all the tillage systems. The clover residues were not harvested and fully added as green manure to the soil surface during tillage operations. Other agricultural management and practices were similar to those practiced by local farmers (Table 1).

2.2. Soil sampling and preparation

Composite soil samples were obtained in September–October 2008, 2009 and 2011 before tillage operations, using a flat-bladed stainless steel shovel. In each replicated plot, three individual soil samples (2 kg) at the 0–20 cm depth were collected and homogenized to make a composite sample (ca. 1 kg) for each replicate. Field-moist soil samples were crushed and sieved through a 2-mm screen to remove large plant material and stone fragments, and split into portions for analysis of C and N mineralization. Soil samples were kept in perforated plastic bags at 4 °C. Before measuring net C and N mineralization, field-moist samples were moistened to 70% water holding capacity (WHC) and pre-incubated in the dark