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Net nitrogen mineralization enhanced with the addition of nitrogen-rich particulate organic matter

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ABSTRACT

Particulate organic matter (POM) is a labile fraction of soil organic matter (SOM) that can contribute to nitrogen (N) mineralization. We added native and non-native POM to soils with contrasting properties and assessed net N mineralization during a 28 days incubation study. Soils (0–15 cm depth) for this study were a clay soil with a 3-year history of corn (*Zea mays* L.), a loam soil with a 2-year history of alfalfa (*Medicago sativa* L.) and sandy–loam and silty–clay–loam soils that were cropped in the previous 5 years with a corn-soybean (*Glycine max* L.) — corn–forage–forage [45% alfalfa + 55% timothy (*Phleum pratense* L.)] and corn–soybean–forage–forage–forage rotation, respectively. The POM was separated by size fractionation (>53 μm) from coarsely sieved (>6 mm) soil. The N concentration in POM followed the order loam > silty–clay–loam > clay > sandy–loam, whereas the acid unhydrolyzable fraction, a proxy for the lignin concentration, was the reverse. Compared to soil only, addition of N-rich POM from the loam soil increased net N mineralization in the clay soil and gave similar net N mineralization in the other soils, while addition of N-poor POM from the sandy–loam soil resulted in lower net N mineralization in the loam and silty–clay–loam soils. Multiple stepwise regression analysis showed that net N mineralized due to POM addition was related to the N concentration in the POM (partial $R^2 = 0.54$) and the initial soil mineral N concentration (partial $R^2 = 0.33$), suggesting that N mineralized from POM was related more to POM chemical composition than soil properties. We propose that information on POM chemistry in conjunction with soil mineral N concentration and texture could be useful for constructing N mineralization prediction models to improve N fertilizer management in agricultural soils.

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1. Introduction

Particulate organic matter (POM) is widely recognized as a labile fraction of soil organic matter (SOM) that is actively involved in N cycling in agricultural soils (Haynes, 2005; Gosling et al., 2013). The POM fraction is composed of partially decomposed plant residues and may account for as much as 60% (average of 14%) of total soil N (Gregorich et al., 2006). The POM is a site of intense microbial and enzymatic activity because it serves as a readily decomposable substrate for soil microorganisms (Magid and Kjærgaard, 2001). Some studies indicate that the contribution of POM to total soil N mineralization is proportional to the POM content of SOM (Yakovchenko et al., 1998; Whalen et al., 2000). Other studies indicate that POM may cause N immobilization because it is physically stabilized within aggregates (Cambardella and Elliott, 1994), or because it has a wider C/N ratio than soil (Gregorich et al., 2006). Parfitt and Salt (2001) reported that net N mineralization from POM differed with land management, with greater N mineralization under corn (*Zea mays* L.) than pasture that was attributed to the greater C/N ratio of POM under pasture than corn. Research on POM chemistry is needed to understand its relative contribution to N mineralization, which may enhance our knowledge of soil N cycling.

Cropping practices influence both the quality and the quantity of unharvested residues that are returned to agricultural soils. Thus they directly impact POM characteristics, such as its biodegradability and the proportion of total soil N present in the POM fraction (Cambardella and Elliott, 1992; Haynes, 2005). For example, Spargo et al. (2011) explained that the greater N concentration in the POM and the lower POM C/N ratio in soil under crop rotations with a greater frequency of legumes [alfalfa (*Medicago sativa* L.)] than grains (corn) was due in part to the greater quantities of N-rich residues returned to the soil from legumes. Crop residues with high N concentrations, low C/N ratios and low lignin concentrations such as those derived from legumes tend to decompose faster (Chivenge et al., 2011; Yanni et al., 2011), such that legume residues enter the POM pool and are then

Abbreviations: C–S–C–F–F, corn–soybean–corn–forage–forage rotation; C–S–F–F–F, corn–soybean–forage–forage–forage rotation; MIR, mid infrared reflectance spectroscopy; NIR, near infrared reflectance spectroscopy; POM, particulate organic matter; SOM, soil organic matter.

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transformed to soluble substrates, including mineral N, more quickly than non-legume residues, regardless of soil texture. In soils incubated with ^{15}N labelled faba bean (*Vicia faba* L.) and wheat (*Triticum aestivum* L.) residues, St. Luce et al. (2014a) found a greater ^{15}N concentration in POM in faba bean-amended soils than wheat-amended soils.

The breakdown of crop residues, leading to the formation of POM and its subsequent transformation into soluble organic matter, is mediated by soil microorganisms (Cotrufo et al., 2013). Hence, the extent to which POM contributes to N mineralization may depend on soil properties such as texture, mineral N concentration, pH and the quantity and quality of the POM due to their influence on microbial accessibility, microbial community structure and decomposition rates (Marschner et al., 1999, 2001; Murphy et al., 2011; Shen et al., 2013). Soils with high clay contents protect crop residues and POM from decomposition (Six et al., 2002; Cotrufo et al., 2013). Nitrogen transformation rates of added organic N sources are generally faster in coarse- than fine-textured soils (St. Luce et al., 2014a), because of. the lower degree of SOM physical stabilization in coarse- than fine-textured soils (Six et al., 2002; Cotrufo et al., 2013), rather than the fact that POM accounts for a larger proportion of total soil N in coarse- than fine-textured soils (Gregorich et al., 2006).

There is scant information on how POM derived from agricultural soils with different cropping history and texture affects N mineralization. Previous studies focused on either one site with uniform soil texture and agricultural management (Yakovchenko et al., 1998), on the impact of disturbance in agricultural and forest soils (Whalen et al., 2000), or on forest soils only (Boone, 1994). This study sought to examine the contribution of POM to N mineralization, as a function of POM chemical characteristics, using POM that came from four agricultural fields with different cropping systems and soil textures. To our knowledge, this is the first study in which native and non-native POM were added to soils to examine the effect of POM on net N mineralization. Our hypotheses were that (i) net N mineralization from added POM would be greater for POMs with higher N and lower lignin concentrations, regardless of soil texture and (ii) the contribution of POM to net N mineralization would be more strongly related to POM chemistry, such as N and lignin concentration, than soil properties.

2. Materials and methods

2.1. Soils

Composite soil samples, hereafter referred to as soil, were collected from the upper layers (0–15 cm) from four fields in spring 2011. Two fields were located at Agriculture and Agri-Food Canada's Harlaka Research Farm (46° 47′N, 71°08′W) and the other two fields were located at a farm in St-Nicolas (46° 41′N, 71°28′W), both near Quebec City, Canada. At the Harlaka site, a Kamouraska clay (fine, mixed, frigid, Typic Humaquept) soil was collected from a field that was under corn since 2008, while a St-André loam (loamy, mixed, frigid, Dystrochrept) was collected from a field under alfalfa since 2009. At the St-Nicolas site, a St-Antoine sandy-loam (loamy, mixed, frigid, Dystrochrept) was collected from a field where the preceding crops were corn in 2006 and 2008, soybean (*Glycine max* L.) in 2007 and pasture [45% alfalfa/55% timothy (*Phleum pratense* L.)] in 2009 and 2010. The other soil from St-Nicolas, a Tilly silty–clay–loam (fine, mixed, frigid, Typic Dystrochrept), was collected from a field where the preceding crops were corn in 2006, soybean in 2007 and pasture (45% alfalfa/55% timothy) in 2008, 2009 and 2010. Field moist soil samples were frozen (−20 °C) for about 1 year. At the beginning of the experiment, the soil samples were thawed and large plant materials were removed manually before passing through a 6-mm sieve. The soils were air-dried and a subsample was ground to pass through a 2-mm sieve. Soil chemical and physical properties at each site are given in Table 1.

2.2. POM fractionation

The POM was separated by size fractionation following the procedure of Gregorich and Beare (2008). Briefly, 100 g of coarsely sieved (>6 mm) air-dried soil was dispersed by shaking in 400 mL of deionized water with 40 glass beads (6 mm) for 16 h. The dispersed soil was passed through a 53 μm sieve. The retained sand and macroorganic matter were dried at 50 °C and weighed. This procedure was repeated with additional soil until sufficient POM was obtained. The POM and a sub-sample of the air-dried soil were ground using a mortar and pestle to pass through a 250 μm sieve.

2.3. POM and soil characteristics

To characterize the POM and soil, all analyses were done in triplicate. Total N and organic C concentrations of the POM and soil samples were determined by dry combustion using an Elementar CN Analyzer (Elementar Analysensysteme GmbH, Hanua, Germany). Total C was considered to represent organic C since no carbonates were detected upon treatment with 6% (w/v) H_2SO_3 solution. The N concentration of the POM was expressed as mg N g^{-1} POM. The POM C/N ratio was also used as a quality indicator. The acid unhydrolyzable fraction, a proxy for lignin concentration of the POM (mg g^{-1} POM), was determined using the acid detergent fiber method (Goering and Van Soest, 1970). Hereafter, lignin and not acid unhydrolyzable fraction is used.

Near infrared reflectance spectroscopy (NIR) was also used to indirectly assess the chemical composition of the POM samples. The NIR spectral region is typically weak and is characterized by overtones and/or combinations of fundamental vibrations which occur in the mid infrared (MIR) region. Nevertheless, the NIR region contains useful information on organic constituents in soils (Stenberg et al., 2010). Certain wavelengths in the NIR region were shown to correlate with some biochemical components of SOM, including carbohydrates and protein, mostly due to their corresponding assignments on the MIR wavebands (Stenberg et al., 2010; Cécillon et al., 2012; Forouzangohar et al., 2013). In addition, NIR was also used to identify and discriminate between soils and SOM (Ben-Dor et al., 1997; Ertlen et al., 2010; Hedde

Table 1
Soil characteristics at the four agricultural fields used in the experiment.

Soil texture	Crop	pH[a]	Sand[b]	Silt[b]	Clay[b]	Mineral N[c]	Total N[d]	Organic C[d]	C/N
			g kg^{-1} soil			mg kg^{-1} soil	g kg^{-1} soil		
Clay	Corn	5.52	302	292	406	11.6	3.2	35	11
Loam	Alfalfa	5.41	435	363	202	24.0	3.5	37	11
Sandy-loam	C–S–C–F–F[e]	6.23	683	164	152	20.6	2.3	25	11
Silty–clay–loam	C–S–F–F–F[f]	5.77	187	428	385	20.5	2.9	28	10

[a] pH in water (1:2 soil:water slurry) (Hendershot et al., 2008).
[b] particle size by hydrometer method (Kroetsch and Wang, 2008).
[c] Initial soil mineral N concentration (NH_4–N + NO_3–N) in 2 M KCl (Maynard et al., 2008).
[d] Total N and organic C determined by dry combustion.
[e] C–S–C–P–P, corn–soybean–corn–forage–forage rotation.
[f] C–S–F–F–F, corn–soybean–forage–forage–forage rotation.

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