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Carbon and nitrogen mineralization during decomposition of crop residues in a calcareous soil

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ABSTRACT

The present work was aimed at evaluating, under laboratory conditions, the medium-term influence of pepper residues applied at different rates (2, 3 and 5 g kg^{-1}) on carbon and nitrogen cycles in an agricultural soil. The cumulative quantities of CO_2–C that evolved from the pepper residue mineralization were fitted to a first-order kinetic model. These values are equivalent to ~30% of the organic carbon added for all doses, with similar mineralization constant rate (~0.09 $days^{-1}$). Net ammonification followed the same pattern in all doses indicating a net loss of NH_4^+–N by nitrification or immobilization. Net nitrification followed a different pattern depending on the dose. Final positive values were observed for the two highest doses, but when 2 g kg^{-1} was applied, net nitrification was always negative, suggesting net immobilization of N. The net N mineralization was −3.1, 13.7 and 56.7 mg kg^{-1} for doses 2, 3 and 5 g kg^{-1}, respectively. Thus, the addition of pepper residues at low doses produced a net N immobilization in soil. This trend may indicate that N is likely a limiting factor for microbial growth. The activities of soil enzymes involved in C and N cycles responded differently according to the dose, indicating that only the highest dose would increase the capacity of soil to perform useful ecosystem functions. These results highlight the importance of dose when applying pepper residues, since doses <5 g kg^{-1} do not easily release available N for plant growth in the loamy calcareous soil used for this experiment.

1. Introduction

The decline in soil organic matter (SOM) in many Mediterranean semiarid agricultural zones is associated with a decrease in soil fertility. This SOM depletion associated with the intensification of agriculture is considered one of the foremost environmental threats in the EU (Marmo, 2008). This intensification has also led to over-application of inorganic fertilizers turning this practice into an important focus of contamination (Bumb and Baanante, 1996). Thus, it is essential to find appropriate crop management to reduce the inorganic fertilization and increase soil quality. The use of organic residues as soil fertilizers has been proposed as a sustainable strategy to achieve this aims (Eghball, 2001). Nonetheless, better knowledge about carbon and nitrogen mineralization dynamics of residues is essential to quantify the potential benefits of residue management on soil quality and fertility.

Organic residues often exhibit different physicochemical properties and therefore they affect the soil ecosystem in different ways. Thus, the study of their impact on soil is essential to benefit from their potential as amendments and to avoid adverse environmental effects (Cayuela et al., 2009). Organic matter mineralization processes are of great importance in maintaining soil quality and fertility, and hence agricultural sustainability. An extensive amount of research has been done on the investigation of crop residues as an organic amendment such as wheat, mungbean, maize, rape, olive tree pruning, almond nut skin, and straw (Barzegar et al., 2002; Cayuela et al., 2009; Trinsoutrot et al., 2000); however little information about the use of greenhouse crop residues as organic amendments is available. Studies demonstrated that biochemical composition (C:N ratio, hemicellulose, lignin…), rates, and the size of crop residues affect C and N decomposition rates (Barzegar et al., 2002; Raiesi, 2006). Biochemical composition, and particularly the soluble C content, determines the initial rate of residue decomposition (Hadas et al., 2004), whereas the lignin content controls the medium to long-term fate of added C (Trinsoutrot et al., 2000).

Previous studies have indicated that organic residue management affected microbial population and activity (Cayuela et al., 2009; Guerrero et al., 2007; Raiesi, 2006). Soil microbial populations and enzymes are crucial in the degradation of SOM and cycling of nutrients

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and, therefore, can be used as sensitive indicators to reflect the effects of land management practices on soil quality (Bandick and Dick, 1999). The enzyme activities are directly involved in the transformation of complex carbon forms of organic matter to readily available nutrients for the plants, determining the pattern of most of the chemical transformations in soil (Stryer, 1995). Changes in microbiological indicators may decrease or increase C and N dynamics and have an influence on nutrient uptake by plants. In fact, the synchronization of N supply with plant demand is important for both environmental and agronomic reasons.

The present work was aimed at evaluating, under laboratory conditions, the medium-term influence of pepper residues applied at different rates on carbon and nitrogen cycles in an agricultural soil. This type of research is needed to understand and explore soil organic matter enrichment and nutrient availability under controlled conditions and provide scientifically based information to support decision regarding crop residue management and its agronomic importance.

2. Materials and methods

2.1. Soil and crop residue used

The soil used was collected from the top 30-cm Ap horizon from an agricultural land in Murcia Region, SE Spain (UTM: 4191030N, 68625016E). The climate of the area is semiarid Mediterranean, with a mean annual temperature of 17 °C and a mean annual rainfall of 300 mm. The soil is a Typic Petrocalcid (Soil Survey Staff, 2006) with loam texture. Some of the soil characteristics are shown in Table 1. The soil was air dried and sieved <2 mm.

The crop residue consisted of a dehydrated and crushed mix of stems, leaves and pepper fruits which do not meet the standards for commercial use from pepper plants (*Capsicum annuum*). Pepper plants were collected after harvesting from a greenhouse. The residue was dried at 55 °C (high temperature can favor the loss of volatile compounds) until constant weight. Then it was ground to homogenize to powder size before application.

2.2. Soil incubation

Potential C and N mineralization was studied in a laboratory incubation experiment in dark, at constant humidity (55% of soil holding water capacity) and temperature (25 °C), under aerobic conditions for 155 days. The residues were thoroughly mixed at three different doses: 2 g kg^{-1} soil (D1), 3 g kg^{-1} soil (D2) and 5 g kg^{-1} soil (D3) dry weight basis, with soil samples. These rates correspond to 170 (D1), 255 (D2) and 383 (D3) kg N ha^{-1}. The application rate corresponding to D2 was the N recommended by the local law (BORM 287, 2007) for broccoli crop, which is widely grown in the area and in which we can apply the pepper residues while the application rates 1 and 3 were 1.5 times smaller and greater, respectively, than the recommended N level. Untreated soil was also included as the control (CT). For C mineralization, 10 g of amended soil was placed in 0.5 L polyethylene jars containing alkali traps (0.2 M NaOH) to determine CO_2 emissions at 1, 6, 10, 15, 23, 34, 45, 59, 76, 94, 114, 133 and 155 days of incubation. Three jars without soil or plant residue were considered as blanks. For N mineralization, 150 g of amended soil was placed in 0.5 L polyethylene jars with thin plastic film perforated to ensure gas exchange. Soils were sampled to monitor the evolution of NH_4^+–N and NO_3^-–N at 0, 4, 7, 15, 24, 30, 42, 63, 83, 126 and 155 days of incubation. Each treatment was replicated three times, and moisture levels were gravimetrically maintained every 3 days using deionised water.

Soil organic C, total N, soluble C, microbial biomass C and the enzyme activities β-galactosidase, β-glucosidase, arylesterase, urease and protease were determined at the beginning and at the end of the incubation.

Table 1
Main properties of soil used for incubation experiment. Values are the mean ± standard deviation (n = 3).

Soil properties	
Sand (g kg^{-1})	407 ± 25
Silt (g kg^{-1})	356 ± 24
Clay (g kg^{-1})	237 ± 27
Textural class	Loam
pH	7.81 ± 0.15
Electrical conductivity (μs cm^{-1})	921 ± 171
$CaCO_3$ (g kg^{-1})	584 ± 32
Soil organic carbon (Corg) (g kg^{-1})	19.3 ± 2.4
Total nitrogen (TN) (g kg^{-1})	1.52 ± 0.13
NH_4^+–N (mg kg^{-1})	20.9 ± 4.1
NO_3^-–N (mg kg^{-1})	78.5 ± 3.9

2.3. Analytical methods

Characteristics of pepper residues are shown in Table 2. The pepper residues were dried, ground and analyzed for total nitrogen (TN) according to the Kjeldahl method (Hoeger, 1998) and total organic carbon (TOC) (Golueke, 1977). P, Ca, Mg, Na, K, Fe, Mn, Cu and Zn were analyzed after incineration at 500 °C and redilution using 6 N HNO_3, by ICP-MS (7500 CE, Agilent). Cellulose was determined by Brendel et al. (2000). Lignin was determined after a two stage sulphuric acid hydrolysis (Hatfield et al. 1994). Water soluble organic carbon (WSOC) was extracted in water (1:500 w/v) and determined UV–persulfate digestion (Teledyne-Tekmar Phoenix 8000).

Soil pH and electrical conductivity (EC) were measured in deionised water (1:1 and 1:5 w/v, respectively). Particle size distribution was determined using the Robinson pipette method and textural class defined according to Soil Survey Staff (2006). Soil organic carbon (Corg) was analyzed with dichromate oxidation technique (Walkley and Black, 1934), while total nitrogen (TN) was determined using the Kjeldahl digestion method (Hoeger, 1998). For equivalent calcium carbonate the volumetric method (Bernard calcimeter) was used. The concentrations of NH_4^+–N and NO_3^-–N were determined by UV–visible spectrophotometry in a 2 M KCl extract (1:10 w/v) (Kandeler et al., 1999). The total inorganic-N (IN) is the sum of NO_3^-–N and NH_4^+–N. CO_2 emissions were measured by titration of the unreacted NaOH with standardized 0.1 M HCl to phenolphthalein end point (Anderson, 1982). The microbial biomass carbon (MBC) was determined using the chloroform fumigation-extraction method proposed by Vance et al. (1987). The non-fumigated fraction was considered as soluble carbon (Csol). The arylesterase activity was quantified following the method of Zornoza et al. (2009). β-Glucosidase and β-galactosidase activities were measured according to Tabatabai (1982) and Eivazi and Tabatabai (1988), respectively. Urease activity was determined according to Nannipieri et al. (1978). Protease activity was analyzed following the method of Bonmatí et al. (1988).

Table 2
Main chemical properties of pepper residues used for incubation with soil. Values are the mean ± standard deviation (n = 5).

Properties[a]	
TN (g kg^{-1})	22.9 ± 2.9
TOC (g kg^{-1})	438 ± 13
C/N	19 ± 2
P (g kg^{-1})	6.02 ± 0.37
Ca (g kg^{-1})	23.9 ± 6.2
Mg (g kg^{-1})	7.23 ± 1.33
Na (g kg^{-1})	1.89 ± 0.22
K (g kg^{-1})	40.7 ± 3.2
Cu (mg kg^{-1})	12.5 ± 1.0
Zn (mg kg^{-1})	77.6 ± 11.8
Fe (mg kg^{-1})	184 ± 58
Mn (mg kg^{-1})	87.4 ± 18.8
Cellulose (g kg^{-1})	200 ± 1
Lignin (g kg^{-1})	179 ± 5
WSOC (g kg^{-1})	34 ± 3

[a] TN: total nitrogen; TOC: total organic carbon; WSOC: water soluble organic carbon.