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Nitrogen and carbon mineralization in soils amended with biofumigant or non-biofumigant plant materials

Rosa Marchetti[a,*], Luca Lazzeri[b], Lorenzo D'Avino[c], Gilda Ponzoni[a]

[a] *Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Unità di ricerca per la suinicoltura (CRA-SUI), Via Beccastecca 345, 41018 San Cesario sul Panaro, Modena, Italy,*

[b] *Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Centro di ricerca per le colture industriali (CRA-CIN), Via di Corticella, 133, 40128, Bologna, Italy*

[c] *Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Centro di ricerca per l'agrobiologia e la pedologia (CRA-ABP), via di Lanciola 12/A, 50125 Cascine del Riccio, Firenze, Italy*

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ABSTRACT

Biofumigant plant materials from Brassicaceae are rich in nutrients and could represent an interesting source of organic nitrogen for crops, when used as soil amendments. In this study, we evaluated in two laboratory experiments the nitrogen and carbon mineralization in soil amended with glucosinolate-containing (*Brassica carinata* defatted seed meals and *Brassica juncea* green manure) or non-containing (carinata crop residues, and sunflower) plant materials. In the first experiment, two soils of contrasting texture (a loam and a silty clay) were amended with carinata defatted seed meals, *B. juncea* green manure, carinata crop residues and un-amended control. In the second experiment, a loam soil amended with carinata and sunflower defatted seed meals obtained by mechanical and solvent extraction were compared. The amount of mineralized nitrogen at the end of a 3-month incubation period was on average 56.6% of the added nitrogen in soil amended with carinata seed meals, and 39% in soil amended with *B. juncea* green manure, whereas nitrogen immobilization occurred in soil amended with carinata crop residues. Inorganic nitrogen release was faster in soil amended with carinata defatted seed meals. These results were related to carbon to nitrogen ratio in the plant materials. The soil type did not affect N mineralization of the amendments. No negative effect on mineralization could be attributed to the presence of glucosinolates or to the oil extraction method. Biofumigant defatted seed meals from carinata, used as soil amendments, release interesting inorganic-nitrogen amounts into soil and could therefore substitute chemical nitrogen fertilizers for crop nutrition.

1. Introduction

Green manure of Brassicaceae containing glucosinolates is able to play a biofumigant effect in soil and has been utilized for the biological control of some soilborne plant pests and nematodes (Matthiessen and Kirkegaard, 2006; Curto et al., 2008; Larkin and Griffin, 2007). It represents a natural alternative approach to the use of chemical fumigants, such as metam sodium (Pinkerton et al., 2000; Rowe and Powelson, 2002; McGuire, 2004) or methyl bromide (Lazzeri et al., 2004; Mattner et al., 2008), which entered in phase-out several years ago. The utilization of biofumigant green manure crops can be partially or totally replaced by glucosinolate-containing defatted seed meals (DSMs) (Handiseni et al., 2013), that are by-products of Brassicaceae seed defatting and biodiesel industry. Defatted seed meals can be more easily managed than green manure in field applications, because they are less subject to constraints in timing of incorporation into soil and the amounts to be incorporated can be quantified more easily.

The decline in soil organic matter in many Mediterranean semi-arid agricultural areas is associated with a decrease in soil fertility (Moreno-Cornejo et al., 2014). Whether acting as biofumigants or not, DSMs as well as green manure may improve soil fertility (Moore, 2011; Mohammadi and Rokhzadi, 2012) through incorporation of large organic matter amounts potentially suitable as nutrient sources for crops (Kumar and Goh, 2000; Thorup-Kristensen et al., 2003).

Organic carbon (C) and organic nitrogen (N) mineralization are tightly linked processes. While the influence of crop residue char-

Abbreviations: DSMs, defatted seed meals.

* Corresponding author. Tel.: +39 059926268; fax: +39 059928371.
E-mail addresses: rosa.marchetti@entecra.it (R. Marchetti), luca.lazzeri@entecra.it (L. Lazzeri).

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Table 1
Selected chemical characteristics (mean ± standard deviation) of the plant materials used in the experiments. DM: dry matter; FW: fresh weight.

Parameter	*Brassica juncea* green manure	Carinata defatted seed meals	Carinata crop residues	Sunflower defatted seed meals	
		(Mechanical pressing)		(Mechanical pressing/hexane)	(Mechanical pressing)
Moisture, % FW	75.2 ± 1.8	6.6 ± 1.5	6.6 ± 0.8	7.7 ± 1.2	8.3 ± 0.4
Total C, % DM	43.4 ± 0.4	47.9 ± 0.1	47.0 ± 0.3	47.5 ± 0.4	42.7 ± 0.3
Kjeldahl N, % DM	2.5 ± 0.2	6.1 ± 0.8	0.6 ± 0.2	5.4 ± 0.3	4.7 ± 0.4
Ashes, % DM	9.9 ± 1.6	6.6 ± 0.3	7.5 ± 0.9	6.9 ± 0.4	6.4 ± 0.2
C/N	17.5	7.9	75.7	8.9	9.1
Oil, % DM	Tr	10.8 ± 0.1	Tr	0.8 ± 0.1	12.8 ± 0.2
Glucosinolates, μmol g^{-1} DM	10.7 ± 0.6	90.3 ± 2.0	Tr	Absent	Absent

Tr = traces.

acteristics on rate and extent of soil inorganic N availability and CO_2–C release is well known (Mary et al., 1996; Trinsoutrot et al., 2000), information on the influence of biochemical composition, and particularly glucosinolate effect, on N and C mineralization of Brassicaceae defatted seed meals is still scarce.

Fresh organic matter decomposition also depends on the soil type. In particular, the soil pore size distribution influences the accessibility of organic substrates to soil organisms (Hassink, 1992). Thomsen et al. (1999) found a high correlation between CO_2 release from crop residue decomposition and water retained in soil pores with diameters >0.2 μm. Little is known on C and N mineralization patterns of different DSMs when incorporated into soils with different texture.

The most critical point in the management of organic amendments as N sources is the difficulty to predict the right time for their incorporation into soil, depending on the pattern of N release (Mohanty et al., 2011). Green manure from leguminous crops releases N early after incorporation, and high amounts of clover N are generally mineralised within a month (Båth, 2000) whereas, on the contrary, crop residues may reduce soil inorganic N availability, due to N immobilization in microbial biomass. Knowledge on C and N mineralization dynamics in soils amended with glucosinolate-containing plants or DSMs is not yet well established. Improvement in this knowledge should help in estimating the most suitable incorporation time, in tune with the nutrition needs of the crops.

The organic C and N mineralization in soil is carried out by several groups of microorganisms. The effect of glucosinolate-containing plant materials on their activities has been the subject of debate. Glucosinolates are responsible for allelochemical effects (Brown and Morra, 1997), even if their toxicity varies with the type of degradation product and the type of organism involved (Brown et al., 1991; Scott and Knudsen, 1999; Bending and Lincoln, 2000; Reardon et al., 2013). A better understanding of the relationship between type of amendment and type of involved organisms could help to explain these seemingly contradictory results.

The overall objective of this study was to evaluate the fertilizing contribution of biofumigant DSMs in terms of available N for crops. Nitrogen and C mineralization in soil amended with carinata DSMs was compared with that in soil amended with other plant materials usable as soil amendments: *B. juncea* green manure and carinata crop residues. Glucosinolate-containing *B. juncea* was chosen because it is recognized as the most effective species in biofumigant green manuring (Lazzeri et al., 2003), whereas carinata crop residues were included because, though deriving from a biofumigant crop, are nearly glucosinolate-free, and may be assimilated to crop residues commonly used as soil amendments. Two soils of contrasting texture, a loam and a silty clay, were included in the evaluation to investigate the response variability due to soil textural class. The variability in DSMs N and C mineralization due to different glucosinolate and oil content was also tested by comparing carinata glucosinolate-containing and sunflower glucosinolate-non containing DSMs obtained with different oil extraction technologies.

2. Materials and methods

2.1. Plant materials and soils

Three types of DSMs were tested (Table 1): a meal obtained from seeds of *Brassica carinata* A. Brown (common names: carinata, Ethiopian mustard) and two DSMs from *Helianthus annuus* L. (sunflower). The carinata DSMs were obtained by mechanical oil extraction after a patented procedure aimed at optimizing isothiocyanate release over time (Lazzeri et al., 2010; Lazzeri et al., 2011), and purchased from Agrium Italia S.p.A. (Livorno, Italy). The sunflower DSMs were obtained by pressing extraction at the Scaramagli plant in Ferrara, Italy, or by pressing/hexane extraction at Italcol S.p.A. (Castelfiorentino, Firenze, Italy).

B. juncea L. Czern. sel. ISCI99 (common name: Indian mustard) and carinata crops were grown in small plots at the CRA-CIN experimental farm of Budrio (Bologna, Italy; 44° 32′ 13″ N, 11° 29′ 40″ E, altitude 29 m. asl). At full flowering time, *B. juncea* plants were harvested, immediately taken to the laboratory and finely cut in a grinder mill just before incorporation into soil. Carinata seeds were harvested at seed technological maturity. After seed removal, crop residues were dried at 65 °C and milled at 1 mm. Selected analytical parameters for characterization of the plant materials are reported in Table 1.

Soil samples were collected in the top 0.2-m soil profile, at Bovolone, Verona (BV soil), San Cesario sul Panaro, Modena (SCe soil), and Pisa (PI soil). These sampling sites are located in experimental farms of selected CRA research centers (BV and SCe soils, in the Po Valley) and of Pisa University (PI soil, in Tuscany). Selected soil characteristics are reported in Table 2.

2.2. Experimental design and microcosm incubations

Mineralized N and C were measured in 2 laboratory experiments, organized in randomized complete block designs with 3 (Exp. I) or 4 (Exp. II) replications.

Experiment I (Exp. I). Mineralized N and C were measured in a loam (BV) and a silty clay (SCe) soil amended with carinata DSMs, *B. juncea* green manure and carinata crop residues. The amounts of amendments corresponding to those adopted in the current field practice were incorporated into soil (Table 3).

Experiment II (Exp. II). Mineralized N and C were measured in a loam soil (PI) amended with carinata DSMs in comparison with sunflower DSMs produced by mechanical pressing or mechanical pressing/hexane extraction. In this experiment, the comparison was based on the same amount of incorporated N (100 kg N ha^{-1}). The incorporation of fresh organic matter into moist soil on a volume basis (gram fresh weight L^{-1} moist soil) entailed the supply of