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Nitrogen Mineralization from Organic Amendments Predicted by Laboratory and Field Incubations

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ABSTRACT

Reliable methods to estimate nitrogen (N) mineralization from organic amendments are needed to improve the fertilization recommendations for organic horticultural crops. With this aim, N mineralization from farmyard manure compost (FYMC), commercial organic fertilizer (COF) based on materials that are prompt to rapid N mineralization and green manure was determined in field situation where environmental factors affect mineralization rates and under controlled laboratory conditions that may not reflect conditions in the field. The ability of field and laboratory incubations to predict N mineralization was estimated during a field organic crop rotation set up with a cover crop of rye and vetch, followed by Portuguese cabbage and carrot. The relationship between mineralized N in field incubation and crop N accumulation suggests that field incubation is effective to predict N mineralization from FYMC, COF and green manure. However, the pattern of N mineralization from FYMC and green manure was different in field and laboratory incubation conditions as opposed to N mineralization from COF that was similar in both incubations.

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Introduction

Organic farmers need information about organic fertilization practices such as green manuring and the use of composts and other organic amendments to sustain soil fertility and increase crop yields. Compost is the main source of organic matter (OM) and N supply for organic farming (Raviv et al. 2004) but frequently has low organic N content and a slow rate of mineralization (Cordovil et al. 2005). Nevertheless, the composting process yields a sanitized and stabilized organic material containing humic substances that contribute to the long-term mineralization, acting as a slow-release source of N (Hartl and Erhart 2005). In contrast to the small amount of mineralized N from mature composts in the short-term, commercial organic fertilizers which have higher contents of total N and labile N show larger available N contents and are often recommended in situations of high crop N demand (Brito et al. 2016). Green manures are cover crops incorporated into the soil that may contribute to the fertilization of the subsequent crop through the mineralization of the cover crop biomass (Salmeron, Isla, and Cavero 2011). After incorporation of fresh crops into the soil as green manure, soil microbial biomass increase because of the incorporation of easily degradable materials (Elfstrand, Bath, and Martensson 2007) and may lead to an increase in soil fertility (Kautz, Wirth, and Ellmer 2004). The enhancement of microbial activity also can promote the N mineralization of indigenous soil organic matter by the priming effect (Zhou et al. 2012).

Composts and green manures increase the soil organic matter pool of the soil. However, there is a need to predict the amount of mineralized N and the pattern of N release from the organic

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amendments incorporated into the soil, to find the optimal rate and best time for fertilizer application to match nutrient supply with plant demand (Brito 2001).

Methods to estimate N mineralization from organic amendments using aerobic incubation under controlled temperature and water conditions in the laboratory are the most widely used (Zinati, Christenson, and Harris 2007). However, conflicting results have been reported because of changes of physical and chemical characteristics of the samples from sample perturbations during storing, mixing, and sieving (Arnold, Corre, and Veldkamp 2008; Makarov et al. 2017; Risch et al. 2019). In addition to sample manipulation, temperature and soil water conditions are different in the field than in laboratory incubation (Hanselman, Graetz, and Obreza 2004; Lomander, Katterer, and Andren 1998). Field incubations including polyethylene bags (Eno 1960), PVC cores (Raison, Connell, and Khanna 1987), or the addition of acetylene to prevent N losses through denitrification (Hatch, Jarvis, and Philips 1990) were used to estimate N mineralization under temperature and moisture conditions that exist in undisturbed soil. Although field incubations showed limitations associated with disturbance of soil and isolation of the soil from natural drying-wetting cycles during sampling and incubation (Hatch, Jarvis, and Philips 1990), the buried bag technique prevents leaching losses and provides an accurate estimation of N mineralization. It is also helpful to validate the N mineralization models obtained from laboratory studies (Monaco et al. 2010; Sierra 1997; Wienhold 2007).

Nitrogen mineralization from organic amendments determined in laboratory and field incubations are not consistent because of differences in the applied methodology and environmental conditions (Arnold, Corre, and Veldkamp 2008; Hanselman, Graetz, and Obreza 2004). Laboratory methods are difficult to extrapolate to field conditions because the amount of mineralized N depends on the method used to handle and to store the samples and the models need to be calibrated on site (Benbi and Richter 2002). In this context, information about N mineralization dynamics in the field is crucial to determine the amount of N that is available to the crops, and to improve fertilizer recommendations for organic farming. We hypothesized that N mineralization from organic amendments whose chemical characteristics promote N mineralization (low C/N ratio and high amounts of soluble C and N), can be estimated by laboratory incubation. On the contrary, we hypothesized that N mineralization from the organic amendments whose chemical characteristics do not promote N mineralization would be difficult to predict under controlled laboratory conditions because their mineralization depends heavily on biological community. Therefore, the objectives of this study were: (i) to estimate N availability from farmyard manure compost (FYMC), immature commercial organic fertilizer (COF), and rye consociated with vetch as green manure according to their chemical characteristics in field and laboratory incubations; and (ii) to assess the ability of these incubations to predict the pattern of N release from these organic amendments during a field organic crop rotation.

Materials and methods

Study site description

The field experiment was carried out in a sandy loamy Dystric Cambisol (IUSS, 2006) located at the NW of Portugal, in Fafe (41° 12′ N and 8° 20′ W), approximately at 300 m altitude. The soil was of granite origin with 784 g kg^{-1} sand, 163 g kg^{-1} lime and 52 g kg^{-1} clay and a bulk density of 1.04. The soil reaction was acidic with a pH (H_2O) value of 4.9; consequently, dolomite lime was applied at 5 t ha^{-1} of $CaCO_3$ equivalent. The soil electrical conductivity was 0.03 dS m^{-1}; the total N content was 1.9 g kg^{-1}, and the soil organic C content was 29 g kg^{-1}.

The experiment was set up in 2014 with a cover crop of rye (*Secale cereale* L.) consociated with vetch (*Vicia sativa* L. cv. Barril) grown over the autumn and winter, for green manure, followed by Portuguese cabbage (*Brassica oleracea* var. tronchuda cv. Penca da Póvoa) from April to June and carrot (*Dacus carota L.* cv. *Jarana* F1) from June to October. The horticultural crops were irrigated

with a system of mini-sprinklers (200 Lh^{-1}) placed at a distance of 6.5 m between them so that the water content in the soil was not limiting for plant growth. Hoe blade weeding was carried out frequently to avoid weed competition.

Soil and air temperature were registered automatically with two thermistors, one buried in the soil at 10cm depth and another below a reflector board at 30cm height. The temperature was registered every hour with a DL2 Data Logger (Delta-T Devices, Cambridge, United Kingdom) and the average daily air and soil temperatures were calculated.

Experimental treatments

The experimental crop rotation was set up as a randomized complete block design with four blocks to quantify crop N accumulation and N mineralization determined by laboratory and field incubations. The experimental site with 240 m^2 was divided in 16 plots of 15 m^2 each. The treatments included: (i) 22 t ha^{-1} green manure (GM); (ii) GM with 40 t ha^{-1} FYMC (C40); (iii) GM with 2 t ha^{-1} COF (CF2) and (iv) a reference treatment without fertilizers (T0). The FYMC, COF, and green manure characteristics are shown in Table 1.

Farmyard manure compost

Composting piles were prepared outdoor with cow manure and wheat straw as bedding material accumulated for one year in the cattle shed. The feedstock was composted for approximately 7 months and manually turned twice at 2 and 4 months after the start of composting. The FYMC was matured as indicated by the concentration of NH_4^+-N (81 mg kg^{-1}) below the maximum recommended value (400 mg kg^{-1} DM) for mature composts by Zucconi and de Bertoldi (1987) and by the rate NH_4^+-N/NO_3^-N (0.06) which was below to the suggested upper limit value of 1 for matured composts by Larney and Hao (2007).

Commercial organic fertilizer

The commercial organic fertilizer traded by (Crimolara, Lisboa, Portugal) certified for organic agriculture was based on granulated poultry manure, beet molasses and feathers. In contrast, the COF was not matured as indicated by the concentration of NH_4^+-N (5309 mg kg^{-1}) far above the maximum recommended value (400 mg kg^{-1} DM).

Field incubation

The field incubation was set up as a plant growing experiment during the Spring-Summer growing season immediately after the incorporation of the organic amendments previously to planting the

Table 1. Dry matter content (DM) and chemical characteristics of farmyard manure compost (FYMC), commercial organic fertilizer (COF), or green manure (mean, standard deviation).

Characteristic	Unit	FYMC	COF	Green manure
DM	(%)	24.7	90.5	20.1
pH		7.9 ± 0.02	6.9 ± 0.01	
EC	(dS m^{-1})	5.2 ± 0.8	6.9 ± 0.2	
C	(g kg^{-1})	313 ± 37	423 ± 5	399 ± 22
N total	(g kg^{-1})	25.4 ± 1.5	99.6 ± 5.0	20.6 ± 1.7
C/N		12 ± 1.7	4.3 ± 0.2	20 ± 3.0
Soluble C	(g kg^{-1})	7.8 ± 0.5	52.2 ± 1.3	70.4 ± 1.5
Soluble N	(g kg^{-1})	1.2 ± 0.2	21.2 ± 0.3	6.1 ± 0.2
NH_4^+-N	(mg kg^{-1})	81 ± 9	5309 ± 150	
NO_3^-N	(mg kg^{-1})	1334 ± 30	135 ± 9	
P	(g kg^{-1})	5.8 ± 0.3	12.8 ± 0.6	3.9 ± 1.1
K	(g kg^{-1})	29 ± 2.2	25.8 ± 9.5	23.6 ± 3.6

Nutrient concentrations are expressed on a dry matter basis

Portuguese cabbage, based on the methodology described by Raison, Connell, and Khanna (1987). The soil samples were collected every 14 days during the incubation experiment except for the first period that was of 7 days. Simultaneously, four plants from each replicate were harvested for analysis to quantify crop total N content. At the start of each incubation period, five pairs of samples were collected randomly from each plot using PVC cores to avoid soil disturbance. The cores had a length of 15 cm, 4 cm diameter, and six holes with 6 mm of diameter to allow aeration. One sample from each pair was frozen, and the remaining five samples were enclosed in micro-perforated polyethylene bags and buried at 20 cm depth. Net N mineralization was calculated by the difference between the amount of inorganic N (NH_4^+-N + NO_3^-N) in incubated and frozen samples. The accumulated mineralized N during incubation was calculated by the sum of N mineralized during each period of incubation and provided the estimate of total mineralized N in the tilled layer. Nitrogen mineralized from the FYMC and COF (mg kg^{-1} soil) was estimated by the difference between mineralized N (mg kg^{-1} soil) in treatments C40 and CF2 and mineralized N (mg kg^{-1} soil) in treatment GM. The green manure mineralized N was calculated by the difference between mineralized N (mg kg^{-1} soil) in treatments GM and T0. Nitrogen mineralization (g kg^{-1} initial N) from these soil amendments was calculated by the ratio between accumulated mineralized N (mg kg^{-1} soil) from FYMC, COF or green manure during the incubation period and the total amount of N_{org} applied (g kg^{-1} soil) (equation 1).

$$\mathrm{Nm} = \sum_{i=1}^{13} Nti/\mathrm{N_{org}} \quad (1)$$

Where Nm is N mineralization from soil amendments (g kg^{-1} initial N); Nti is mineralized N during each period (i) of incubation (mg kg^{-1} soil); N_{org} is the total amount of organic N applied (g kg^{-1} soil).

Laboratory incubation

The soil was pre-incubated at 25°C for 15 days, in the dark, prior to laboratory incubation procedures. The laboratory incubation was set up with samples of 60 g of soil (dry weight basis) prepared according to the experimental treatments incorporated into the soil in the field experiment. The fertilized treatments included: (i) FYMC; (ii) COF; (iii) green manure; (iv) FYMC with green manure; (v) COF with green manure and (vi) a reference treatment. The FYMC was applied at 7.5 g DM kg^{-1}; the COF was applied at the rate of 1.4 g DM kg^{-1} and green manure was applied at the rate of 3.3 g kg^{-1}. Before the experiment, soil moisture was adjusted to 70% of soil water-holding capacity by adding water gradually and then thoroughly stir the mixture

The soil samples of each treatment (4 replications) were placed in plastic containers and put into 1-L glass jars. These subsamples were removed from the glass jars for N mineral analyzes after 1, 3, 7, 10, 14, 21, 35, 56, 84, 112 and 168 days and replaced by the subsamples stored in plastic containers in the beginning of the incubation. The plastic containers and the jars sealed with air-tight glass lids were incubated for 168 days at 25°C. The plastic containers were weighted every 15 days to adjust water content. The glass jars contained a vessel with 20 ml of NaOH (1M) solution to trap evolved CO_2 and a vessel with 40 ml of distilled water to avoid desiccation. After 1, 2, 3, 5, 7, 10, 14, 21, 28, 35, 42, 49, 56, 70, 84, 98, 112, 126, 140, 154, 168 days, the vessels with NaOH solution were removed, and the trapped CO_2 was determined with an elemental analyzer with near-infrared detector (NIRD) Formacs^{HT} Analyzer (Skalar, Breda, The Netherlands) and replaced with fresh NaOH (Gardner et al. 2013) The apparent loss of added organic materials C was estimated by subtracting total CO_2-C released in a given treatment from that measured in the reference treatment. The accumulated mineralized N was calculated for 168 days (crop growth period).

Analytical methods

The horticultural crop sampling was based on four plants of each replicate treatment. Crop samples were dried at 65°C until constant weight, milled using a 2-mm sieve and subsequently

used to determine total N content. The FYMC, COF, and green manure samples were frozen and, subsequently, freeze-dried to reduce water content. Dry matter content (DM), pH, and electrical conductivity (EC) were determined by standard procedures (CEN, 1999). Total C was determined by near-infrared detector in an elemental analyzer (Primacs$^{SNC-100}$ Analyzer, Skalar, Breda, The Netherlands) after combustion at 950°C (Temminghoff and Houba 2004). Total N and P was measured by molecular spectrophotometry (San^{Plus} System, Skalar, Breda, The Netherlands) and K was quantified by flame photometry (PFP7 Flame Photometer, Jenway, Stadfforshire, UK) after digestion with sulfuric acid (Temminghoff and Houba 2004). Mineral N was extracted from 6 g fresh samples of soil, FYMC and COF samples using KCl 1:5 solution ratio and NH_4^+-N and NO_3^-N contents were determined by molecular absorption spectrophotometry with a segmented flow analyzer system (San^{Plus} System, Skalar, Breda, The Netherlands) (Houba et al. 1989) For green manure, FYMC, and COF, soluble C and N were extracted from 4 g dry samples with 0.01 M $CaCl_2$ at a ratio of 1:20 and determined by near-infrared detector and chemiluminescence, respectively, in an elemental analyzer (Formacs^{HT} Analyzer, Skalar, Breda, The Netherlands) after combustion at 950°C (Boon et al. 2014).

Statistical analysis and kinetic model

The first-order kinetic model with one mineralization pool (Bonde and Lindberg 1988) was fitted for both incubations to N mineralization from FYMC, COF, and green manure (equation 2).

$$Nm = N_0\left[1 - \exp\left(-k_1 t - k_2 t^2\right)\right] \quad (2)$$

Where Nm is estimated N mineralization (g kg^{-1} of initial N) at time t (days after incorporation of FYMC, COF or green manure); k_1 and k_2 are mineralization constant rates (the quotient $-k_1/k_2$ defines the immobilization time period); and the amount of potentially organic mineralizable N pool is given by N_0 (g kg^{-1} of initial N).

Model equations were fitted by the non-linear least-square curve-fitting technique (Marquardt–Levenberg algorithm), to minimize the sum of the squared differences between the observed and predicted values of the dependent variable. Analyses of variance (ANOVA) were performed to calculate equations F values to test the dependence of mineralization on incubation time. The Pearson correlation coefficient was used to validate the equations and to assess the strength of the linear association between N accumulated by the crops and the accumulated mineralized N. All statistical calculations were performed using SPSS v. 17.0 for windows (SPSS Inc. Chicago, USA) (Suárez et al. 2011).

Results and discussion

Nitrogen mineralization

Nitrogen mineralization depends on the activity of microorganisms, which is closely associated to temperature and soil water. Soil temperature in the laboratory was constant (25°C) whereas, soil daily temperature in the field fluctuated from 9.7°C to 23.9°C during the growth period of the vegetable crops. The field average soil temperature during the growth period of cabbage (from 22nd April to 17th June) and carrot (from 22nd June to 1st October) was 15.4°C and 19.4°C, respectively. Soil water content in laboratory incubation was approximately constant (70% water holding capacity), while the overall average soil water holding capacity (WHC) during the growth period of cabbage and carrot was 78%. The minimum and maximum WHC ranged between 56% and 95% in the field incubation (Figure 1).

Nitrogen mineralization was expected to increase in warmer laboratory conditions compared to field incubation (Wang et al. 2006), but this did not happen for FYMC, COF and, green manure (Table 2). Actually, soil biological activity promotes N mineralization over a large range of soil temperature and soil water contents (Borowik and Wyszkowska 2016a, 2016b). The maximum

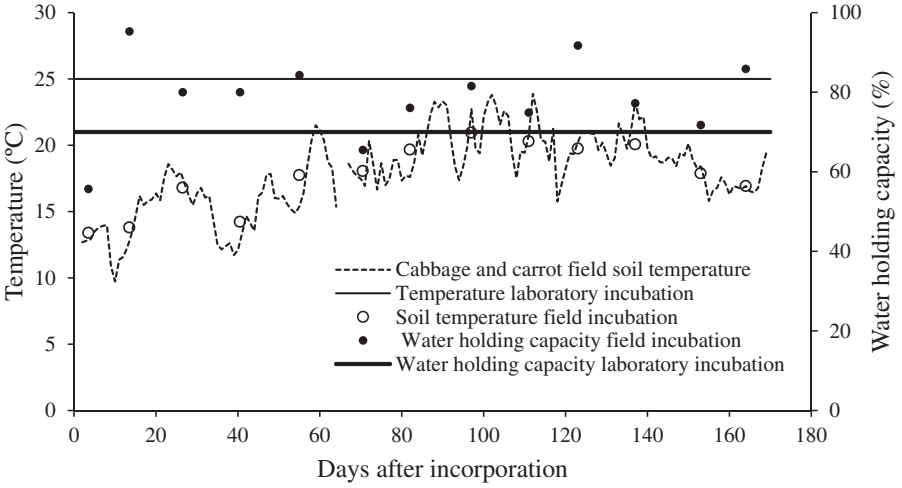

Figure 1. Soil daily mean temperature during the growth period of cabbage and carrot, average soil temperature and water holding capacity (WHC, %) for each incubation period in field incubation, temperature and WHC (%) in laboratory incubation.

Table 2. Nitrogen mineralization (g kg^{-1} of initial N) equations, F values and determination coefficients (R^2); N_{org} applied (g kg^{-1} soil) and estimated N mineralization (g kg^{-1} initial N) during 168 days, for farmyard manure compost (FYMC), commercial organic fertilizer (COF) and green manure during field and laboratory incubation. ** $p < .01$ *** $p < .001$.

Organic amendments	Model equation	N_{org} applied (g kg^{-1} soil)	N mineralization (g kg^{-1} initial N)
Field incubation			
FYMC	$Nm = 510\ [1\text{-}exp(-0.005t\text{-}0.000199t^2)]$ $F_{(3,11)} = 5181^{***}$ $R^2 = 0.99^{***}$	237	508
COF	$Nm = 705\ [1\text{-}exp(-0.094t\text{-}0.000336t^2)]$ $F_{(3,11)} = 461^{***}$ $R^2 = 0.92^{***}$	171	705
Green manure	$Nm = 210\ [1\text{-}exp(0.007t\text{-}0.000187t^2)]$ $F_{(3,11)} = 88^{***}$ $R^2 = 0.91^{***}$	91	203
Laboratory incubation			
FYMC	$Nm = 167\ [1\text{-}exp(-0.034t\text{-}0.000555t^2)]$ $F_{(3,9)} = 51^{***}$ $R^2 = 0.81^{**}$	237	167
COF	$Nm = 764\ [1\text{-}exp(-0.049t\text{-}0.000264t^2)]$ $F_{(3,9)} = 89^{***}$ $R^2 = 0.88^{***}$	171	764
Green manure	$Nm = 243\ [1\text{-}exp(-0.001t\text{-}0.000657t^2)]$ $F_{(3,9)} = 43^{***}$ $R^2 = 0.86^{***}$	91	243

aerobic microbial activity occurs between 50 and 70% WHC (Stres et al. 2008). However, Agehara and Warncke (2005) reported that N mineralization during 12 weeks of incubation was not statistically different between 70% and 90% WHC. These authors also found that N mineralization was similar between 15–20°C and 20–25°C. In fact, soil microbial community can adapt to low temperatures (Borowik and Wyszkowska 2016a). Soil microbial community is likely controlled through feedback of enzyme activity, favoring the microbes that produce enzymes with increased activity in field conditions (Wallenstein et al. 2011). Moreover, several authors found that soil wetting and drying cycles may increase N mineralization (Rey et al. 2005; Xiang et al. 2008). Probably for the reason that drying provides new substrates from dead microbial biomass (Mengel et al. 1996). Also, the mechanical disruption of soil aggregates caused by drying and rewetting may increase N mineralization (Smith et al. 2003).

The mineralized N from green manure at the end of the experimental period (168 days) was comparable under field or laboratory incubations. However, the pattern of N release was different between field incubation and controlled laboratory conditions since N mineralization from green

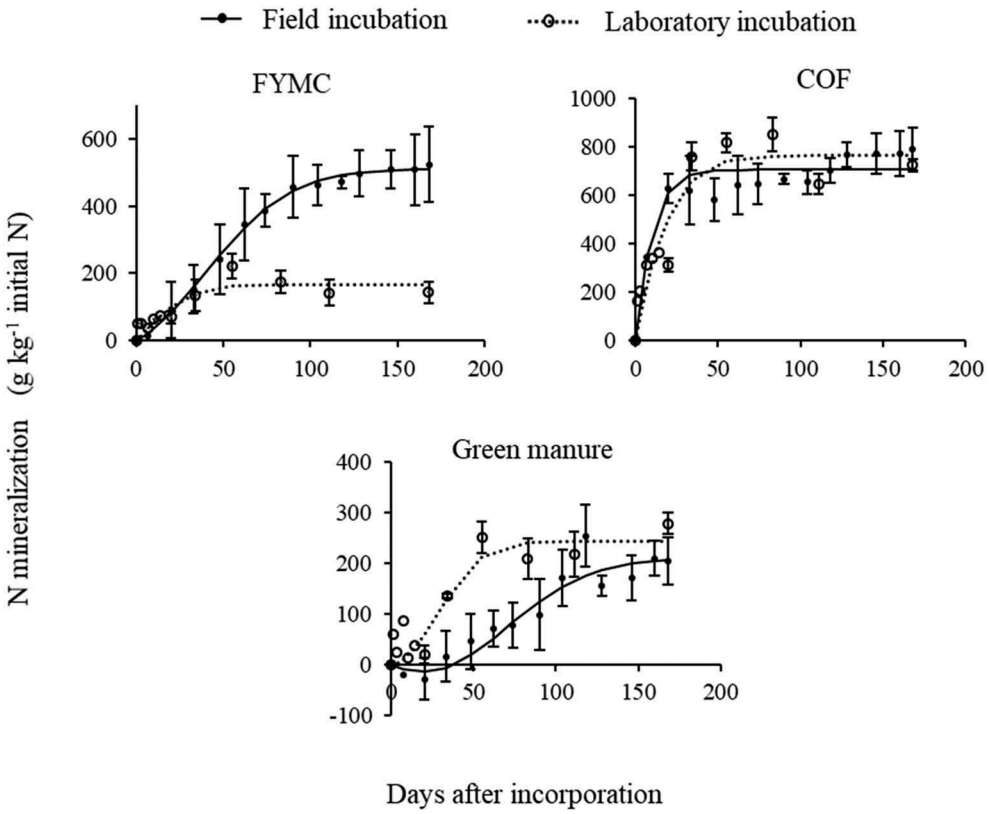

Figure 2. N mineralization (g kg^{-1} initial N) for farmyard manure compost (FYMC), commercial organic fertilizer (COF) or green manure during field and laboratory incubations. N mineralization equations are described in Table 2.

manure decreased during the first days of field incubation compared to laboratory incubation (Figure 2). This decrease can be explained by the increase in soil water content to full WHC from 7 to 20 days after the beginning of field incubation (Figure 1) that may have induced a negative effect on N mineralization (Hassan 2013; Murwira, Kirchmann, and Swift 1990). The highest C/N ratio in green manure (20) compared to FYMC (12) and COF (4) promoted a slight N immobilization (38 days) as the turning point between N mineralization and immobilization ranges between 15 and 40 (Cabrera, Kissel, and Vigil 2005; Salmeron, Isla, and Cavero 2011).

The N mineralized from FYMC was slightly lower in field incubation than in laboratory incubation between 7 to 20 days probably due to the increase of soil water content similar to what happened after green manure incorporation. However, after 168 days of incubation, N mineralization from the FYMC clearly increased from 167 g kg^{-1} initial N in laboratory conditions to 508 g kg^{-1} of initial N in the field incubation (Table 2). Although smaller for laboratory conditions compared to field incubation, the FYMC N mineralization in laboratory incubation (167 g kg^{-1} initial N) was within the range of values commonly found in laboratory incubations (Antil et al. 2011; Hadas and Portnoy 1997; Morvan and Nicolardot 2009).

In laboratory incubation, CO_2-C evolved from green manure (955 mg kg^{-1}) was much greater than the amount of CO_2-C evolved from FYMC (78 mg kg^{-1}) indicating an increase in soil microbial activity with green manure (Table 3). The CO_2-C evolved from FYMC was 1.5 times the soluble C and approximately 4% of total C. Probably, the addition of available C from the fresh cover crops into the soil contributed to enhance available C and the activity of soil microorganisms

Table 3. Applied C (mg kg soil^{-1}) and evolved CO_2-C (mg kg soil^{-1}) from farmyard manure compost (FYMC), commercial organic fertilizer (COF), green manure (GM), FYMC with GM and COF with GM, in the laboratory incubation.

	C applied, mg kg^{-1}		
Organic amendments	Total C	Soluble C	CO_2-C evolved, mg kg^{-1}
FYMC	1982	49	78
COF	491	61	236
Green manure	1136	200	955
FYMC + green manure	3118	249	1066
COF + green manure	1627	261	1113

(Elfstrand, Bath, and Martensson 2007; Kautz, Wirth, and Ellmer 2004) and probably increased N mineralization from FYMC in the field incubation.

The decreasing of N mineralization from FYMC in laboratory incubation may be related to a significant change and decrease of microbial biomass due to freezing of the samples before laboratory incubation. For example, Wallenius et al. (2010) found a decrease between 20% and 30% of enzyme activity in compost after freezing. Moreover, frozen storage reduced accumulated CO_2 evolution in composts by 110 to 277% depending on the maturation degree of the compost, indicating a deep decrease of microbial activity (Wu and Ma 2001). On the other hand, this increase of growth and activity of soil microorganisms can promote the degradation of recalcitrant soil organic matter (priming effect), increasing N mineralization in the field (Blagodatskaya and Kuzyakov 2008; Fu et al. 2000; Pascault et al. 2013). In addition, materials derived from root exudates that may increase N mineralization are excluded in laboratory incubation (Yamasaky, Taterno, and Shibata 2011).

The pattern of mineralized N from COF was similar for field and controlled laboratory conditions (Figure 2). The COF was rapidly mineralized in both types of incubation and the mineralized N (N_m), predicted by the mineralization model was 705 and 764 g kg^{-1} of initial N for field and laboratory incubations, respectively (Table 2). The mineralized N from COF increased fast even under less favorable climatic conditions (high soil moisture content). Eldridge et al. (2008) also concluded that the accumulated mineralized N from immature biosolid fertizer (C/N = 6) was very similar in field and laboratory incubations (611 and 595 kg ha^{-1}, respectively).

In contrast to FYMC, the amount of CO_2-C evolved from COF during the laboratory incubation period was approximately 4 times the amount of COF soluble C, and approximately half the amount of its total C (Table 3). Hence, the chemical characteristics of COF, independently of the presence of green manure led to rapid N mineralization after quick colonization by the soil microorganisms. Indeed, high total N (99.6 g kg^{-1}) and mineral N contents (5.4 g kg^{-1}), low C/N ratio (4.3), and high amount of available C and N (52.2 and 21.2 g kg^{-1}, respectively) were also reported by other authors to increase microbial activity with the release of high amounts of mineral N in a short period of time (Antil et al. 2011; Martin-Olmedo and Rees 1990; Stadler et al. 2006).

Crop nitrogen uptake

Crop N accumulation (kg ha^{-1}) was calculated multiplying crop total N content (g kg^{-1}) by crop dry weight (t ha^{-1}). Crop N uptake is usually less than 50% of soil available mineral N (Fageria and Baligar 2005). Here, N accumulation for both crops ranged from 42% to 58% of mineralized N in the 0–15 cm top layer of soil, during field incubation. These values are comparable to those reported by Carsky et al. (1990) who found that N accumulation in the above ground of maize was 69% of N mineralization in the 0–15 cm top layer determined by buried bag incubation technique.

The FYMC released 120.4 kg N ha^{-1} of available N (237 kg ha^{-1} × 0,508 g kg^{-1} initial N) for the growth period of cabbage and carrot (Table 2). As the increase in N accumulation for both crops was

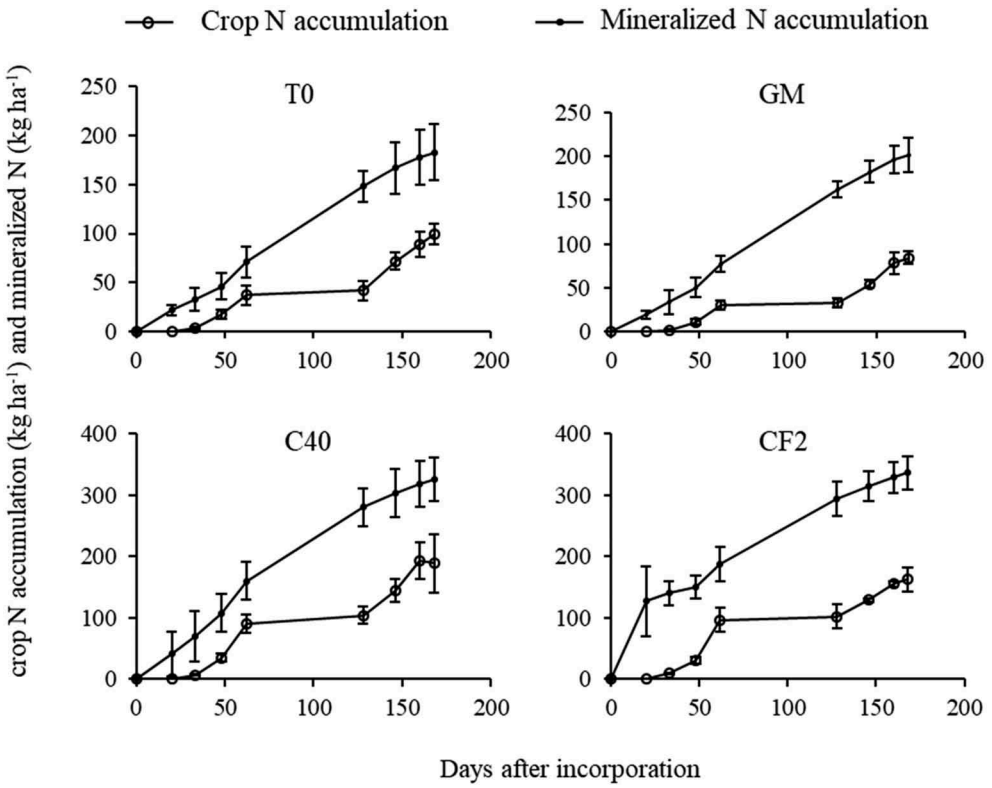

Figure 3. Crop N accumulation in cabbage and carrot and accumulated mineralized N in the field incubation for green manure (GM), GM with FYMC (C40), GM with COF (CF2) and for the control treatment without fertilization (T0).

103.8 kg ha^{-1} with FYMC (difference between crop N accumulation in C40 and GM treatments) it may be suggested that these crops recovered 86% of the mineralized N from FYMC (Figure 3). Although the available N released from COF (120.2 kg ha^{-1}) was similar to FYMC, crop N accumulation increased only 78.0 kg ha^{-1}. Therefore, N recovery by the crops for this organic fertilizer decreased to 65%, which means that one-third of available N would probably be leached after COF application, whereas only 14% of FYMC mineralized N was prone to leaching.

In the laboratory incubation, the N release from FYMC during 168 days (39.6 kg ha^{-1}) was much below the increase on crop N accumulation (103.8 kg ha^{-1}) with FYMC application. Therefore, laboratory incubation was not effective to predict N mineralization from FYMC. On the contrary, N recovery by the crops from COF was similar under laboratory and field conditions (60 and 65% respectively), confirming that both incubations may have accurately predict N mineralization from COF. In addition, a strong positive correlation ($p < .001$) between mineralized N and crop N accumulation during the growth period of both crops was found in the field incubation for T0, GM, C40 and CF2 ($R^2 = 0.89$; $R^2 = 0.88$; $R^2 = 0.91$ and $R^2 = 0.83$ respectively). Therefore, the field incubation may be a useful indicator to predict N availability from different organic amendments, with more or less rapid mineralization, as suggested by Yan et al. (2006) and Monaco et al. (2010).

Conclusions

Nitrogen mineralization from COF with high total N content, low C/N ratio and high amounts of available C and N was accurately predicted by both, laboratory and field incubations. On the

contrary, N mineralization from FYMC and green manure were significantly different in field incubation compared to laboratory conditions. Therefore, more reliable laboratorial methods will be needed to improve the similarity between N mineralization under laboratory and field conditions.

The strong correlation found between mineralized N in field incubation and crop N accumulation indicates that field incubation can be a reliable method to estimate N availability for crop uptake.

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