Nitrogen mineralization from an organically managed soil and nitrogen accumulation in lettuce

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Abstract

The potential of an organically managed Cambic Arenosol to supply nitrogen (N) from either an applied commercial organic fertilizer (granulated hen manure), a compost produced on-farm, or four different mixtures of both fertilizers was studied in a laboratory incubation and a pot experiment with lettuce. In the incubation experiment, a significant higher apparent N mineralization occurred after hen-manure application (53.4% of the organic N applied) compared to compost (4.5%) or mixed-fertilizer application (8.7% to 16.7%). The apparent N mineralization in a mixed treatment consisting of compost and half rate of hen manure (15.4% of the organic N applied) was significantly higher than that estimated based on the N mineralization for compost and hen-manure treatments (7.6%), proving that a combined application of both fertilizers enhanced organic-N mineralization when compared to separate fertilizer supply. In the pot experiment, a higher lettuce fresh-matter yield was obtained with hen manure (1.9 kg m^{-2}) than with compost (1.7 kg m^{-2}) or unfertilized control treatment (1.3 kg m^{-2}). Combined application of compost with only a half rate of hen manure led to yields (2.0 kg m^{-2}) equal to those obtained with only hen manure. A good correlation was observed between the N-mineralization incubation data and the N accumulated by lettuce plants in the pot experiment ($r = 0.983$). Hence, in the organic production of baby-leaf lettuce, a mixture of compost and hen manure appears to be a good fertilization alternative, since it allows a reduction by half of the typical amount of commercial fertilizer usually applied (granulated hen manure), cutting fertilization costs, and providing an amount of available N that allows maintaining lettuce yields.

Key words: apparent net N mineralization / compost / first-order kinetic model / hen manure / *Lactuca sativa* / soil mineral nitrogen

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1 Introduction

In the last decades, intensive applications of mineral fertilizers have substantially contributed to the pollution of ecosystems (atmosphere, soil, and water). The concern of farmers to reduce nutrient surpluses at farm level, as well as the new strategy of the European Union to develop more environmentally friendly farming practices, led to a considerable expansion in organic farming (*Le Guillou* and *Scharpé*, 2001; *van Diepeningen* et al., 2006). Indeed, organic farming may provide some options to reduce the environmental impact compared to conventional agriculture, but this farming system has to comply with the strict rules established by the EU (*European Council Regulation 834/2007*, 2007), namely by excluding the use of mineral nitrogen fertilizers. The application of compost is a recommended practice since recycling farm and agri-industrial residues provides several agricultural benefits (*e.g.*, preserve/restore soil organic C and control of plant diseases; *Hoitink* et al., 2001; *Flavel* and *Murphy*, 2006) and is a relatively cheap source of nutrients (*Raviv* et al., 2008). However, in mature composts most of the N exists in a recalcitrant form (*Sikora* and *Szmidt*, 2001; *Cabral* et al., 2006), *i.e.*, more resistant to mineralization than the organic N of "less stabilized" materials such as animal excreta (*Agehara* and *Warncke*, 2005; *Cordovil* et al., 2005) and N-rich crop residues (*Chaves* et al., 2006; *Rahn* et al., 2003). As most crops (particularly horticultural crops) have a high demand for N over a short time period, commercial organic fertilizers that are able to quickly supply available N (although rather expensive) are often used to ensure yields at competitive levels (*Raviv* et al., 2008).

The N present in organic fertilizers is mainly in organic form, which has to be mineralized before becoming plant-available (*Sikora* and *Szmidt*, 2001). Hence, it is essential to study N mineralization of such materials to estimate the amount and release rate of the applied organic N. This information is important for farmers to enable them to correctly define the amounts of compost and commercial organic fertilizers they need to apply according to the crop N requirements. Several

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studies (*Cordovil* et al., 2005; *Flavel* et al., 2005; *Nendel* et al., 2007) on N mineralization in soils amended with composted residues have been performed and *van Kessel* et al. (2000) reported that the rate and extent of N mineralization depends on the amendment composition. On the other hand, some studies showed that N release from N-rich crop residues can be manipulated by using organic materials of different quality (*Chaves* et al., 2006; *Rahn* et al., 2003). Thus, this study on the combined application of two organic fertilizers (on-farm-produced compost and hen manure), which differ considerably in terms of chemical characteristics, is of great interest in order to evaluate their effect on the dynamics of N mineralization and their contribution to plant nutrition.

Accurate information about N mineralization in soil–fertilizer mixtures can be obtained from incubation studies performed over short periods, where the temperature and soil moisture content can be held constant, unlike the situation in field studies (*Beraud* et al., 2005; *Cordovil* et al., 2005; *Flavel* and *Murphy*, 2006). Such information can also be complemented with plant experiments to assess the effect of these fertilizers on plant growth. In the present study, an on-farm compost, a fast-release organic N fertilizer (granulated hen manure), and several combinations of both fertilizers at different rates were applied to a sandy soil in order to compare the dynamics of N mineralization during an incubation experiment and also on the N accumulation by lettuce plants grown in pots.

2 Material and methods

2.1 Soil, compost, and hen manure

The upper layer (0–20 cm) of a soil under organic farming management for 2 years, collected from a farmer's field located in the SW of Portugal (Odemira, Boavista dos Pinheiros, 37°34′ N, 8°40′ W), was used in incubation and pot experiments. The soil was a Cambic Arenosol (*IUSS Working Group WRB*, 2006) with a pH (H_2O) of 7.4, containing 91.2% sand, 3.3% silt, and 5.5% clay, a total N content of 750 mg kg^{-1} (including 1.0 mg kg^{-1} NH_4^+-N and 7.4 mg kg^{-1} NO_3^--N), and an organic-C content of 9.3 g kg^{-1}.

The compost was produced on-farm in an aerated pile with mechanical turning during 120 d using (based on fresh weight) 3.8% rice husks, 15.4% orange peels, and 80.8% cow manure. During composting, the ratio of NH_4^+-N to total N decreased from 8.7% at starting time to 0.4% at the end. The compost stability was evaluated by the Dewar self-heating test (*FCQAO*, 1994) being classified as class V, the highest class of stabilization. Compost samples used in the present study were freeze-dried in order to reduce the water content and ground to pass a 2 mm sieve to obtain a more homogeneous sample. The fast-release organic N fertilizer, authorized for organic farming according to the *European Council Regulation 834/2007* (2007), consisted of fermented and granulated hen manure. The chemical characteristics of the compost and hen manure are shown in Tab. 1.

Table 1: Chemical characteristics of compost and hen manure.

Component (dry-matter basis)	Compost	Hen manure
Total N / g kg^{-1}	11.3	38.6
Soluble organic N / g kg^{-1}	1.04	12.4
NH_4^+-N / mg kg^{-1}	40.9	5118.6
NO_3^-- N / mg kg^{-1}	4.1	2.9
Organic C / g kg^{-1}	190.3	394.8
Soluble organic C / g kg^{-1}	9.2	77.5
C : N ratio	16.8	10.2
Organic matter (OM) / g kg^{-1}	315.8	720.9
Soluble cellular components / g (kg OM)$^{-1}$	842.7	688.4
Lignin content / g (kg OM)$^{-1}$	77.8	41.8
Cellulose content / g (kg OM)$^{-1}$	40.2	169.5
Hemicellulose content / g (kg OM)$^{-1}$	39.3	100.3
pH	9.3	6.6

2.2 Incubation experiment

Nitrogen mineralization was studied in a nonamended (unfertilized) soil and in six treatments established with different combinations of compost and hen manure applied to the soil (Tab. 2).

Before the experiment was set up, the soil moisture was adjusted to 60% of water-filled pore space (WFPS), in order to avoid denitrification, and pre-incubated at 25°C for 7 d. After this period, for each treatment, an amount of wet-soil equivalent to 600 g of air-dried soil was weighed, thoroughly mixed with the corresponding amounts of compost and hen manure, and placed in closed 2 L plastic containers (16 cm × 16 cm × 8 cm). Each treatment was replicated four times. An aerobic incubation was performed over 19 weeks at 25°C. The containers were periodically aerated to guarantee an aerobic environment. Water content was controlled by regularly weighing the containers for all treatments during the incubation period and adding distilled water whenever neces-

Table 2: Description of the treatments, fertilization rate (dry-matter basis), and equivalent amount of N applied (kg N ha^{-1}).

Treatment	Fertilization rate / mg (kg soil)$^{-1}$		Total N applied / kg ha^{-1}	
	hen manure	compost	hen manure	compost
S	0	0	0	0
SM300*	300	0	34.7	0
SC	0	6 650	0	225.4
SCM75	75	6 650	8.7	225.4
SCM150	150	6 650	17.4	225.4
SCM300	300	6 650	34.7	225.4
SCM600	600	6 650	69.5	225.4

* amount of commercial granulated hen manure usually applied in organic practice

sary. On days 0, 2, 7, 20, 42, 56, 77, 105, and 133 after fertilizers application, 10 g of soil were sampled from each container and soil mineral N (NH_4^+-N and NO_3^--N) was quantified as described in section 2.4. Based on the values of the mineral-N content obtained in each treatment, the net N mineralization (NNM) at time *t* was calculated as follows:

$$NNM_t \text{ (mg N kg}^{-1}) = \text{mineral } N_t - \text{mineral } N_{t=0}$$

The apparent net N mineralization (ANNM) also was determined as:

$$\text{ANNM (\%)} = (NNM_t - \text{soil mineral } N_t) / \text{organic N applied} \times 100$$

In the mixed treatments, the "estimated ANNM" (%) was calculated considering the amounts of hen manure and compost added in each treatment as well as their individual ANNM.

2.3 Pot experiment

A pot experiment with the same experimental design as the incubation experiment was performed in order to assess the effect of the different combinations of compost and hen manure on the yield and N uptake of lettuce plants (*Lactuca sativa L.*). Pots (height: 17.5 cm; volume: 3.75 L; surface area: 346.4 cm^2) were filled with an amount of wet-soil equivalent to 5 kg of dry soil homogeneously mixed with the respective amounts of compost and hen manure as described in Tab. 2. Fifty lettuce seeds were sown per pot and thinned to 20 plants after emergence. Each treatment was replicated four times. During the experiment, soil water content was controlled by weighing the pots each day and kept at 60% WFPS by adding distilled water. Lettuce plants were harvested 35 d later, and the fresh and dry biomass, total N, and nitrate content were determined.

The organic-N recovery (ONR), corresponding to the amount of organic N added *via* the fertilizers (compost and hen manure) that was accumulated by lettuce plants, was calculated for each treatment as follows:

$$\text{ONR (mg N [kg soil]}^{-1}) = (NR_i - NR_0 - \text{mineral } N_{\text{added via the fertilizers}}) / 5,$$

where NR_i and NR_0 refer to the amounts of N uptake by lettuce plants in treatment *i* and in the control treatment, respectively.

The apparent recovery rate of organic N by the plants (RR) was calculated for each treatment according to:

$$\text{RR (\%)} = \frac{\text{ONR}}{N_{org}} \times 100,$$

where N_{org} refers to the total organic N applied.

The "estimated value of ONR" was calculated considering the amount of hen manure and compost applied in each treatment and the values of RR determined for SM300 (hen manure only) and for SC (compost only).

2.4 Analytical methods

Soil and organic-fertilizer pH was determined after 1 h in a soil-to-water (1:2.5 w/v) suspension and in a fertilizer-to-water (1:5 w/v) suspension, respectively. Lignin, cellulose, and hemicellulose contents and the soluble cellular components in the organic fertilizers were determined according to the method of *van Soest* et al. (1991). Carbon in soil and fertilizers was determined by dry combustion at 1000°C and IR detection in a total-organic-carbon analyzer (Primacs TOC Analyser, Skalar Analytical B.V., Breda, The Netherlands). Total N in organic fertilizers and plants was evaluated by a Kjeldahl method (*Horneck* and *Miller*, 1998). Mineral N in organic fertilizers and soil was determined after extraction with 2 M KCl (1:5 w/v) by spectrophotometry using the Berthelot and sulphanilamide methods for ammonium (NH_4^+) and nitrate (NO_3^-), respectively (*Houba* et al., 1989). Soluble C and N in organic fertilizers were determined after extraction with 0.01 M $CaCl_2$ (1:10 w/v) in an elemental C and N analyzer (Formacs, Skalar Analytical B.V., Breda, The Netherlands) by combustion at 850°C followed by NIR detection for C and chemiluminescence detection for N. Soluble organic N was calculated by subtracting mineral N from soluble N both evaluated in the $CaCl_2$ extract. Nitrate in lettuce plants was determined directly with an ion-selective electrode after extraction following the method described by *Novozamsky* et al. (1983).

2.6 Data analysis

Results of the study were subjected to one-way analysis of variance to test significant differences in treatment effects, followed by the least-significant-difference (LSD) test at a 0.05-probability level for comparison of means (*Montgomery*, 1991).

For the qualitative analysis of the incubation results, the first-order kinetic model (*Stanford* and *Smith*, 1972) was used to describe the N mineralization in the different treatments:

$$N_{min} = N_0 \times (1 - e^{(-kt)}),$$

where N_0 is the amount of mineralizable N and k is the mineralization rate constant (d^{-1}).

3 Results and discussion

3.1 Cumulative N mineralization

The total amount of N mineralized in the incubation experiment ranged from 52.6 (control) to 68.4 mg N kg^{-1} (SCM600) after 133 d (Fig. 1). The amounts of N mineralized from the control soil were much greater than those previously reported for Portuguese agricultural soils (*Cordovil* et al., 2005; *Cabral* et al., 2006; *Fangueiro* et al., 2008), probably due to the organic-farming fertilization practice, that includes successive applications of organic matter. However, those values are within the range of those obtained by *Nendel* et al. (2004) in soils from Germany, incubated at 28°C.

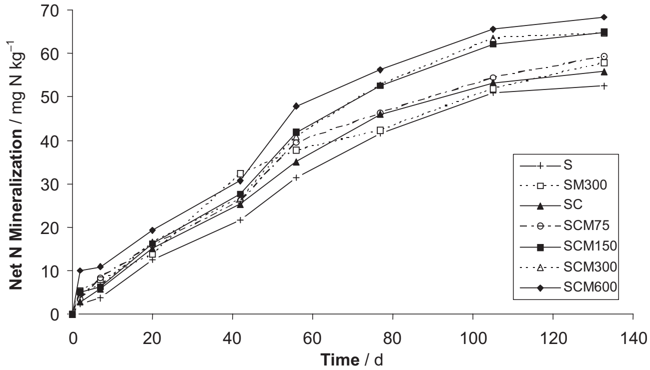

Figure 1: Net N mineralization (mg N [kg soil]$^{-1}$) observed during the 133 d incubation in the treatments studied. Mean values of three replicates. Standards errors were removed for clarity.

The N mineralization observed in SM300 (only hen manure) was significantly higher than in SC (only compost) during the first 7 weeks of incubation, even though much more organic N was applied in the SC treatment (Tab. 2). This result was probably due to the distinct characteristics of the two fertilizers (Tab. 1), *i.e.*, the high NH_4^+-N and soluble organic-N contents of hen manure compared to the compost and the higher soluble organic-C content of hen manure, which increases the amount and activity of the microbial biomass, resulting in the release of high amounts of N in a short time period (*Flavel* and *Murphy*, 2006; *Ribeiro* et al., 2010). Up to the end of the incubation, the amount of N mineralized in all treatments increased continuously, although at a lower rate after day 77 (Fig. 1). It is worth noting that at the end of the incubation period, no significant differences were detected between the N mineralized in the SM300 (amount of commercial fertilizer usually applied) and SCM150 treatment (mixture of compost with half the amount of hen manure).

The R^2 obtained fitting the first-order kinetic model to the NNM data varied from 0.974 to 0.989 indicating that this model is appropriate to examine the NNM data in our study (Tab. 3). The mineralization rate constants (k) determined with the first-order kinetic model for all the treatments including the control were all very close to each other and not statistically different with a mean value of 0.11 mg N kg^{-1} d^{-1} (Tab. 3). Similarly, no significant differences were obtained between the values of mineralizable organic N (N_0) for each treatment, which varied between 68.8 and 90.8 mg N kg^{-1}. *Wang* et al. (2003) showed that there is an inverse relationship between N_0 and k. As a solution to this problem, it is proposed to fit the data by varying only N_0 and using a constant value of k. This approach was used successfully in a previous study (*Cabrera* et al., 2005), where the rate constant k did not vary much between treatments as occurred in the present study. Hence, the data of net mineralizable N were fitted using the same model, but with the rate constant k fixed to the mean value previously obtained. As can be seen in Tab. 3, this procedure did not affect the quality of the data fitting, since the R^2 values obtained here are very close to those previously obtained. In terms of N_0, the following relationship can be established: SCM600 > SCM300 ≈ SCM150 > SCM75 ≈ SC ≈ SM300 > S, suggesting that the higher the amount of hen manure in the combined treatments, the higher the fraction of organic N that is mineralizable. It is worth noting that the N_0 values found in SM300 and SC were not statistically different although much more organic N was applied in the SC treatment (Tab. 2).

3.2 Apparent net N mineralization

At the end of the incubation period, the ANNM of the SM300 and the SC treatments corresponded to 53.4% and 4.5% of the total organic N applied, respectively (Tab. 4). Similar results were obtained previously by other authors using poultry manure (*Agehara* and *Warncke*, 2005; *Cordovil* et al., 2005) and mature composts (*Sikora* and *Szmidt*, 2001; *Cabral* et al., 2006). It is well known that N mineralization is mainly ruled by the C : N ratio of the organic materials added to soil (*Chadwick* et al., 2000; *Flavel* and *Murphy*, 2006; *Fangueiro* et al., 2008). Hence, the higher N mineralization of hen manure (SM300) relatively to that of compost (SC) may be explained, at least in part, by the lower C : N ratio (10.2) of hen manure compared with that of compost (16.8). However, the higher N mineralization observed in SM300 may be attributed not exclusively to the lower C : N ratio in hen manure, but may comprise a priming effect, which was induced by enhanced mineral-N input as a result of the applied hen manure on the native soil organic matter (*Kuzyakov* et al., 2000). In fact, hen manure shows a much higher mineral-N

Table 3: Model parameters and coefficients of determination (R^2) estimated using the first-order exponential model to the net N mineralization data of the different treatments studied.

Models	**Model parameters**	**Treatments**						
		S	SM300	SC	SCM75	SCM150	SCM300	SCM600
First-order kinetic model	N_0	78.30 ± 9.33[α]	68.78 ± 4.17	73.39 ± 5.31	75.40 ± 5.61	88.13 ± 6.95	90.76 ± 9.19	83.74 ± 6.91
	k	0.009 ± 0.002	0.013 ± 0.002	0.012 ± 0.001	0.012 ± 0.002	0.011 ± 0.001	0.010 ± 0.002	0.014 ± 0.002
	R^2	0.986	0.988	0.987	0.983	0.985	0.979	0.974
First-order kinetic model with constant k = 0.011d^{-1}	N_0	69.27 ± 1.18	76.60 ± 1.09	75.72 ± 1.08	79.19 ± 1.23	87.56 ± 1.30	87.61 ± 1.55	94.28 ± 1.82
	R^2	0.984	0.986	0.987	0.983	0.985	0.979	0.972

[α] Mean and standard error of three replicates

Table 4: Amounts of organic N applied and values of net N mineralized (NNM), apparent net N mineralized (ANNM), and estimated ANNM at the end of the incubation. Values of estimated ANNM were calculated considering the amount hen manure and compost in the mixed treatments and the respective final ANNM value determined in the treatment containing hen manure (SM300) and compost (SC) only. In each column, values marked by different lowercase letters are statistically different ($p = 0.05$) by LSD test

Treatment	Organic N applied / mg N kg^{-1}	NNM / mg N kg^{-1}	ANNM / %	Estimated ANNM / %
S	0	52.6^{c}		
SM300	10.0	57.9^{b}	53.4^{a}	
SC	74.9	55.9^{bc}	4.5^{d}	
SCM75	77.4	59.3^{b}	$^{\alpha A}$8.7^{cd}	^{A} 6.1^{c}
SCM150	79.9	64.9^{a}	^{A}15.4^{bc}	^{B} 7.6^{bc}
SCM300	84.9	64.7^{a}	^{A}14.3^{bc}	^{A} 10.2^{b}
SCM600	94.9	68.4^{a}	^{A}16.7^{b}	^{A} 14.8^{a}

$^{\alpha}$ In each row, capital letters are used for comparison between the determined and the estimated values of ANNM.

content (5121 mg kg^{-1}) relatively to compost (45 mg kg^{-1}). The former may induce a priming effect as previously found by *Bol* et al. (2003) and *Ribeiro* et al. (2010) dealing with soils treated with animal excreta. Furthermore, the carbon quality of the two organic fertilizers used here was significantly different (Tab. 1) and should also have influenced their N mineralization. In fact, *Ribeiro* et al. (2010) found that the carbon present in hen manure showed very low stability, being easily degraded by soil microorganisms and ensuring a faster release of nutrients to plants. On the contrary, mature composts having higher amounts of recalcitrant carbon fractions are much more resistant to microbial degradation (*Cabral* et al., 2006; *Ribeiro* et al., 2010).

In the combined treatments comparing the observed with the estimated ANNM values (calculated considering the amounts of hen manure and compost added in each treatment as well as their individual ANNM), the observed ANNM values in each treatment tended to be higher (Tab. 4). This effect was significantly higher in the SCM150 treatment, suggesting that organic-N mineralization was enhanced when the fertilizers were simultaneously incorporated in the soil. Therefore, it may be stated that the combined application of compost and hen manure induced an additional N mineralization. However, in our study it was not possible to identify the origin of this extra N mineralized (compost, hen manure, or soil organic matter). Enhanced N mineralization was observed in previous N-mineralization studies from soils amended with various organic compounds (*Flavel* and *Murphy*, 2006; *Nendel* and *Reuter*, 2007) but none of these studies clearly defined the origin of the surplus N mineralized.

It is important to note that, under field conditions, soil properties and environmental conditions can affect soil-organic-matter mineralization as well as the mineralization of the organic materials added to soil (*Nendel* et al., 2004; *Agehara* and *Warncke*, 2005; *Lamparter* et al., 2009). Soil texture is one of the main factors influencing N mineralization. In fact, several authors report that soils with higher clay content have longer time periods of initial immobilization and mineralize less N from the added materials (*Egelkraut* et al., 2000; *Thomsen* et al., 2003). Thus, it is expected to have a lower amount of mineralized N in undisturbed soils with higher clay contents than in the soil used in the present study. Nitrogen mineralization also depends on soil water content and increases till the optimum moisture content is achieved. However, high soil moisture contents that reduce soil aeration will reduce aerobic biological processes including N mineralization (*Sierra*, 1997; *De Neve* and *Hoffman* 2002). Nitrogen-mineralization process is also dependent on the soil-temperature regime. Most authors found that N mineralization increased continuously in the range from 5°C to 35°C, and this process is generally described by the Arrhenius or the quadratic functions (*Ellert* and *Bettany*, 1992; *Sierra*, 1997; *Nendel* et al., 2004). So, for an average soil temperature lower than 25°C (temperature used in this study) a lower amount of mineralized N is to be expected.

3.3 Pot experiment

Applications of hen manure, compost, or combinations of both fertilizers led to a significant increase in fresh yields relative to nonamended soil (Tab. 5). Furthermore, higher yields were obtained in treatments amended with hen manure (hen manure only and combined treatments) than with SC (only compost). It is notable that no significant differences occurred between yields obtained in the treatments SM300 (only hen manure) and SCM150 (mixture of compost with half of the usual amount of hen manure). Under conventional practice, lettuce yields are within the range of 1 to 2 kg m^{-2} (*Amanda* et al., 2009), while under organic practice *Vasconcelos* et al. (2007) found yields between 0.9 and 1.9 kg m^{-2}. Fertilizer treatments used in this experiment led to baby-leaf yields in an acceptable range (from 1.3 to 2.8 kg m^{-2}), when compared to both conventional and organic practices.

Higher values for N uptake by lettuce plants were observed in treatments amended with hen manure. A high N availability in hen manure can be the reason for the higher yields as well as

Table 5: Lettuce yield (kg fresh matter m^{-2}), lettuce nitrate content (mg NO_3^- [kg fresh matter]$^{-1}$), total N accumulation in lettuce (mg pot^{-1}), and soil mineral N at the end of the experiment (mg [kg soil]$^{-1}$). In each column, values marked by different letters are statistically different ($p = 0.05$) by LSD test.

	Lettuce yields / kg m^{-2}	Nitrate concentration / mg NO_3^- kg^{-1}	N accumulation / mg pot^{-1}	Soil mineral N / mg (kg soil)$^{-1}$
S	1.3^{e}	605.5^{b}	67.5^{e}	1.4
SM300	1.9^{c}	1411.9^{a}	100.0^{bc}	1.2
SC	1.7^{d}	1377.9^{a}	81.7^{d}	1.3
SCM75	1.8^{cd}	1184.0^{a}	92.3^{c}	1.7
SCM150	2.0^{bc}	1410.0^{a}	101.7^{bc}	1.3
SCM300	2.2^{b}	1519.0^{a}	106.9^{b}	2.2
SCM600	2.8^{a}	1334.6^{a}	142.7^{a}	1.8

the higher N accumulation by the plants in those treatments. Indeed, as already observed in the incubation experiment, a higher amount of applied organic N was mineralized in the treatments amended with hen manure. Moreover, hen manure, compost, and combinations of both organic fertilizers induced a significant increase in the NO_3^- concentration of lettuce plants as compared to the nonamended treatment. However, the values of NO_3^- concentration observed were all lower than the legal limit (2500 mg NO_3^- kg^{-1}) established by the EU (*European Commission Regulation 466/2001*, 2001).

At the end of the pot experiment, the values of organic-N recovery (ONR) observed indicate that, in each of the treatments, a significant amount of the organic N applied was mineralized and taken up by the lettuce plants (Tab. 6). The lowest ONR value was observed in the SC treatment, whereas the values of ONR increased with increasing amounts of hen manure applied.

Considering the values of apparent recovery rate of organic N (RR), a significantly higher value occurred for the SM300 treatment (47.98%) relative to other treatments amended with hen manure. This result was particularly evident for the SC treatment where only 1.14% of the organic N applied was taken up by the lettuce plants. In the combined treatments, an "estimated value of ONR" was calculated, considering the amount of hen manure and compost applied and the values of RR determined for SM300 (hen manure only) and for SC (compost only). The estimated ONR value was significantly lower than the observed only in the SCM75 treatment. Nevertheless, these results are consistent with those reported above, which suggest that a higher mineralization of the organic N applied occurs when both fertilizers are applied together, rather than when they are applied separately.

The results obtained in the pot experiment strengthen the conclusions from the incubation experiment. This result is shown by the good fit of the first-order-kinetic-model results and those obtained in the pot experiment. Values of predicted N mineralization (initial mineral N plus N-mineralized calculation based on the first-order kinetic model at day 35) were well correlated with N uptake by lettuce (r = 0.983; Fig. 2). This model was able to predict, with a high degree of confidence, the availability of N to lettuce plants.

Table 6: Observed and estimated values of organic-N recovery (ONR) and apparent recovery rate of organic N (RR) at the end of the pot experiment (35 d). In each column, values marked by different lowercase letters are statistically different (p = 0.05) by LSD test.

	ONR / mg N (kg soil)$^{-1}$		**RR** / %
	observed	estimated$^{\Psi}$	
SM300	4.81^{bc}		47.98^{a}
SC	0.85^{d}		1.14^{c}
SCM75	$^{\alpha A}$3.68^{c}	^{B}2.34^{c}	4.76^{bc}
SCM150	^{A}4.10^{bc}	^{A}3.54^{c}	5.14^{bc}
SCM300	^{A}5.88^{b}	^{A}5.95^{b}	6.93^{bc}
SCM600	^{A}13.05^{a}	^{A}10.75^{a}	13.76^{b}

$^{\Psi}$ values of "estimated ONR" were calculated considering the amount of hen manure and compost in the mixed treatments and the respective ONR value determined in treatment containing hen manure only (SM300) and compost only (SC).

$^{\alpha}$ In each row, capital letters are used for comparison between the determined and the estimated values of ONR in each treatment.

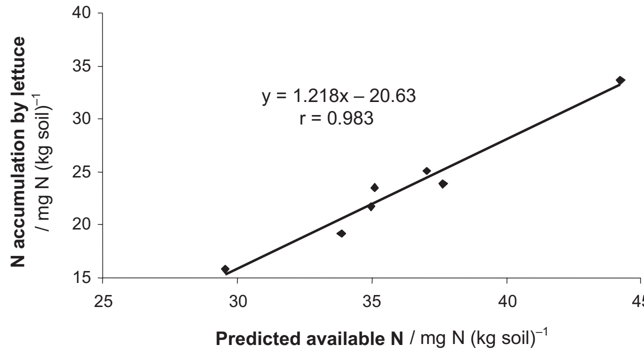

Figure 2: Correlation between the predicted available N in the incubation experiment (N_{min} initial + N mineralized, estimated by the first-order kinetic model at day 35) and the N accumulated by the lettuce plants in the pot experiment.

At the end of the pot experiment, the amount of mineral N in the soil for the different treatments was low (Tab. 5), showing that lettuce plants had taken up all mineralized N. Hence, the risk of nitrate leaching during the growing season should be low. However, as the dose of hen manure (fast-release N fertilizer) increases, a substantial amount of less stable organic N compounds might remain in the soil over time (residual effect), and a potential risk for nitrate leaching off-season can be expected. In fact, *Kirchmann* and *Bergström* (2001) reported that in farming systems where manures were used as N input, a clear tendency for increasing leaching losses was found requiring a reduction of organic-N input to levels below the expected optimum yield. In the present study, the highest yield (2.8 kg m^{-2}) was found for treatment SCM600 corresponding to the greatest amount of hen manure (Tab. 5) and consequently, a higher risk for off-season nitrate leaching has to be expected. However, the yield obtained in the treatment SCM150 (2.0 kg m^{-2}) was within the acceptable range for baby-leaf lettuce, although the amount of hen manure applied was four times lower than that applied in the SCM600 treatment and two times lower than in the SM300 treatment.

4 Conclusions

A mixture of compost and hen manure (SM150) appears as a good alternative to the usual fertilization practice (SM300—hen manure only), since it permitted a reduction by half of the typical amount of hen manure usually applied, cutting fertilization costs, and providing an amount of available N that allowed maintaining high yields. Furthermore, the presence of compost in the mixture may be considered closer to the organic-farming principles because it helps nutrient cycling within the farm system, reduces external nutrient inputs, and helps to preserve/restore soil C content.

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