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Crops use-efficiency of nitrogen from manures permitted in organic farming

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Abstract

The current increase in the organic agriculture segment has created a new market for fertilisers permitted for use in organic farming. Off-farm N sources for organic farming are scarce, considering the restriction on the use of chemical fertilisers. Thus, when some products are permitted in organic agriculture, commercial opportunities become available. In this study we compare the performances of Vegethumus (Veg) and Phenix (Phe), two manures that are permitted in organic farming, with several other manures, ammonium nitrate (AN) and control treatments. A 3-year field trial and a pot experiment were carried out in order to estimate dry matter yield, N uptake, and N nutritional status of the crops, as well as soil N availability, the latter was assessed by using anion exchange membranes inserted into the soil. Apparent N recovery (ANR) values in the field trial were 6.3% and 58.2% in Veg and AN plots, respectively, after the application of 380 kg N/ha in the previous five growing seasons. In the pot experiment, the ANR of Veg and Phe, the organic amendments permitted in organic farming, were 5.0% and 13.6%, while Beiraadubo (Bei) and Nutrisoil (Nut) had ANR of 27.2% and 42.0%. The poor results of the amendments permitted in organic farming, in light of their high prices suggest that their use must be carefully considered by farmer in their fertilization strategies.

Keywords: N management; Commercial organic amendment; Anion exchange membrane

1. Introduction

Over the last few decades, the world has witnessed a rapid development of the organic agriculture segment. Organic farming systems aim to produce safe food with the least harmful environmental impact by imposing severe restrictions on the use of synthetic agrochemicals. From the viewpoint of conventional agriculture, organic farming could mean extensive modifications in crop rotation and cropping systems. Regarding the restrictions on the use of chemical fertilisers, the principal challenge to convert a conventional farm to organic is to provide N at rates and times to ensure acceptable crop yields.

Nitrogen management in agro-systems has been extensively studied due to the particular importance of this nutrient for crop yield and quality, and due to its potential negative impact on ecosystems. Diverse methodologies based on *in situ* and laboratory incubations, chemical extractions and electro-ultrafiltrations have been developed to improve the accuracy of N recommendation programs (Stanford and Smith, 1972; Németh, 1985; Gianello and Bremner, 1986; Bhogal et al., 1999). The greatest difficulty in N advisory systems is to quantify the rate and time at which the native soil organic matter releases its N to the crops. The magnitude of the problem increases when organic amendments are added to the soil. The balance of their N mineralization/immobilization processes depends on the nature of these substrates and on the ecological conditions of each agro-system. In this respect, some attempts to improve N recommendations have been made, such as the development of decay series for organic substrates (Pratt et al., 1976), empirically crediting the N contributions of amendments and green manures to the next crop (Shepherd et al., 1996; Andreski and Bundy, 2002) or using N mineralization indices performed by similar laboratory incubations and chemical extractions as referred for soils. However, the recommendation of precise N rates regarding crops needs remains a very difficult task (Walley et al., 2002; Rodrigues, 2004b).

Splitting the application of N fertilisers over the growing season improves the synchronization between soil-available N and

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crop demand (Westermann et al., 1988). Sidedress N applications should be based on pre-sidedress soil or on plant tests used as indicators of soil available N. The pre-sidedress soil nitrate test became well known after the work of Magdoff et al. (1984). Thereafter, many researchers included this soil N availability index in their studies. Crop N nutritional indices determined at pre-sidedress, such as petiole nitrate content, stem nitrate content and leaf greenness, were also widely used (Blackmer and Schepers, 1994; Singh et al., 2002; Rodrigues, 2004a). These N indicators are used in N recommendation programs after the definition of threshold levels below which the crop needs to be supplemented with more N. However, the quantification of optimal sidedress N rates, based upon crop N nutritional indices or pre-sidedress soil nitrate tests (Baethgen and Alley, 1989; Scharf, 2001; Rodrigues et al., 2005), is the final step in improving N use-efficiency.

There are two main ways to supply crop N requirements in organic farming systems: through introducing or reinforcing legumes in crop rotations and/or through using organic amendments permitted in organic agriculture. Legumes must not only be able to fulfil their own N needs, by fixing atmospheric N_2, but they must also supply enough N for the succeeding crops. In many farming systems, however, legumes produce poor commercial returns unless they play a role as green manure. The organic amendments increase soil organic matter and also provide nutrients, including N; however, many farms do not have supplies of manure, due to the absence of livestock.

Nitrogen management in organic farming systems is complex (Pang and Letey, 2000; Delden, 2001). The use of organic amendments permitted in organic farming as a N source do not necessarily ensure an adequate synchronization of available N and crop demand. The balance of the mineralization–immobilization process of organic residues is highly unpredictable, even when N indicators of manure composition, such as N content and C/N ratio are used (Geypens and Vandendriessche, 1996). Thus, in organic farming the N supplies to crops may be too small, perhaps the most common situations, but also to large. Since organic-N cannot be easily split, it is questionable if organic farming can prevent the N losses incurred through nitrate leaching, denitrification and ammonia volatilization. The introduction of catch crops could mitigate N losses from soils (Martinez and Guiraud, 1990; Vos and Van der Putten, 2001); however, during the year, there are always fallow periods or low crop growth phases where N is not taken up by plants (Rodrigues et al., 2002). On the other hand, the progressive accumulation of soil organic matter could increase the risk of soil N losses (Aronsson and Torstensson, 1998).

The development of organic agriculture has led to the emergence of new markets for commercial amendments approved for organic farming. Considering the relatively high prices of some of these products, it is essential to carefully examine their fertilising value. In this study, the agronomic performance of organic amendments was compared to that of synthetic N fertilisers and control treatments in field trials and pot experiments.

2. Materials and methods

2.1. Field experiment

The field trial took place on Sta Apolónia experimental farm located in Bragança, NE Portugal (41°48′N, 6°44′W), with silage-maize (*Zea mays* L.) and silage-triticale (*Triticosecale* Wittm.). The region benefits from a Mediterranean climate. Mean annual records of precipitation and temperature are 743 mm and 12.2 °C, respectively. The soil is a loamy Eutric Cambisol comprised of 66% sand, 18% silt and 16% clay. In October 2002, soil organic matter was 11.5 mg kg^{-1}, pH(H_2O) 6.0 and extractable soil P and K (ammonium lactate and acetic acid) were very high 119 and 186 mg kg^{-1}, respectively. Thus, P and K fertilisers were not applied during the study.

Maize and triticale were inserted into a quadrennial rotation with two crops per year, where maize and potatoes were grown as summer main crops (June–September) and triticale as winter crop (October–May). The data recorded in this study were taken from the italicized part of the entire crop rotation: potato/triticale-maize/*triticale-maize/triticale-maize/triticale*. The field trial started in October 2002 and finished in May 2005. Triticale was sown on 29 October 2002, 22 October 2003, and 27 October 2004 and cut on 27 May 2003, 18 May 2004 and 18 May 2005, respectively, in the three consecutive seasons. Maize was sown on 12 June 2003 and 9 June 2004 and cut on 18 September 2003 and 23 September 2004. Maize was sprinkle-irrigated during the growing season. The depth and timing of irrigations were determined in accordance with FAO guidelines (Allen et al., 1998).

Five treatments were arranged in a completely randomized design with four replications. The experimental setup included two rates of N as Vegethumus, similar rates of N as ammonium nitrate and the control treatment (Table 1). In order to evaluate the residual effect of the continuous N applications, in the last triticale growing season (2004/2005) no AN or Veg were applied (Table 1). Vegethumus was incorporated into the soil before the seed was sown; whereas most of the AN was applied at sidedress. Ammonium nitrate and Veg were applied in variable weights depending on their dry matter % and N content, in order to apply the N rates shown in Table 1.

Dry matter yield, N uptake, leaf greenness (SPAD-502 chlorophyll meter) and stem nitrate concentration were used to compare the different treatments. Dry matter (DM) yields were

Table 1
Nitrogen applied as ammonium nitrate (AN) and Vegethumus (Veg); 1 and 2 represents simple and double N rates

Growing season	N applied (kg/ha) (basal + sidedress)				
	Control	Veg1	Veg2	AN1	AN2
Triticale (2002/2003)	0 + 0	40 + 0	80 + 0	0 + 40	30 + 50
Maize (2003)	0 + 0	60 + 0	120 + 0	0 + 60	40 + 80
Triticale (2003/2004)	0 + 0	30 + 0	60 + 0	0 + 30	0 + 60
Maize (2004)	0 + 0	60 + 0	120 + 0	0 + 60	40 + 80
Triticale (2004/2005)	0 + 0	0 + 0	0 + 0	0 + 0	0 + 0
Total N (kg/ha)	0	190	380	190	380

recorded from 1 and 2 m^2 field samples for triticale and maize, respectively. Sub-samples with approx. 1000 g were dried to obtain dry matter %. Thereafter, the sub-samples were ground and N content measured by steam distillation and acid titration in a Kjeltec Autoanalyser 1030. In maize, chlorophyll-SPAD values were obtained from 30 readings made on the newest fully expanded leaf when the leaf collar was exposed. Within the leaf, the readings were taken from a point one-half the distance from the leaf tip to the collar and halfway between the leaf margin and the leaf midrib (Peterson et al., 1993). For triticale, despite the differences in leaf morphology, a similar procedure was followed. Stem nitrate concentrations were obtained from 30 tillers of triticale and 6 plants of maize, randomly chosen from each plot and cut at 5 cm above ground level. The lower 15 cm of the stems were separated from nodes and the fresh tissues macerated and boiled for 15 min with ≈100 ml of distilled water. After cooling, sample volumes were brought up to 200 ml from which nitrate concentrations in extracts were determined using a RQflex reflectometer (Rodrigues, 2004a).

2.2. Pot experiment

The pot experiment was conducted between 18 May 2004 and 20 April 2005. The soil was loamy textured with 65% sand, 19% silt and 16% clay. Soil organic matter was 6.9 g kg^{-1}, pH(H_2O) 6.0 and extractable soil P and K were 18 and 60 mg kg^{-1}, respectively. The soil was screened (6 mm mesh) and air-dried. The pot experiment included eight fertilization treatments: four commercial organic amendments, Veg, Phe, Nut and Bei, the former two of which are permitted in organic farming; composted cattle (*Bos taurus*) manure (CM); chestnut bark (CB), a by-product of removing the skins of chestnut fruit; AN and the control. Some characteristics of the organic amendments are shown in Table 2. Each pot received a mixture of 10 kg of soil and 1.5 g of N, varying the weights of amendments and fertiliser with their dry matter % and N content. Six pots per treatment (six replications) were used in the experiment.

Three maize seeds were sown per pot on 5 June 2004, followed by the first irrigation with 1800 ml of distilled water per pot. After emergence, the plants were thinned to one plant per pot. During the growing season, the soil was maintained at a moisture status that allowed for adequate crop development. The volumes of each irrigation varied among pots, taking into account the different transpiration rates of the plants grown under different fertilization treatments. Dishes under the pots prevented water losses and nitrate leaching. Shortly after crop emergence, a nutrient solution with P, K, Ca, Mg, Fe, Zn, Mn, Cu, B, and Mo was added to all pots in the respective rates of 150, 150, 120, 40, 10, 10, 5.5, 2, 1, and 0.1 mg kg^{-1} of soil.

Nitrogen released from fertilisers and manures during the growing period was monitored by recovering the NO_3^- adsorbed in 1 cm × 2 cm strips of an anion exchange membrane (AEM) inserted directly into the soil with the help of a thin spatula. SPAD readings were recorded on 8 July and 2 August 2004, 33 and 58 days after the maize had been sown, following a similar methodology used in the field trial. The AEM were buried in the soil on 16 June and 29 July and removed on 23 June and 5 August, respectively. The AEM strips were tied with a fishing line allowing for easy removal from the soil. The AEM strips removed from the soil were washed with distilled water to remove soil particles and NO_3^- was then eluted in flasks containing 20 ml of 0.5 M HCl (Qian and Schoenau, 1995). Nitrate concentrations in the extracts were determined by UV–vis spectrophotometry. The strips were regenerated in $NaHCO_3$ before being reused.

We decided to end the maize cycle in the vegetative phase (6–8 leaves), on 20 August, since, in some treatments (mainly CB and control) the plants showed severe N-deficiency symptoms and had started to senesce. The decision for an early cut of plants was made in order to avoid N losses by NH_3 volatilisation from the canopy (Wetselaar and Farquhar, 1980). After the maize was harvested, the soil was kept moist to stimulate microbial activity. The AEM were inserted again on 9 September and removed on 14 September.

The trial continued during the winter with turnip (*Brassica campestris*) and rye (*Secale cereale*). The six pots used for maize were randomly divided for turnip and rye, following the experiment with three replications per crop. Sowing of rye and turnip took place on 23 September. Shortly after the crops' emergence, on 13 October, a nutrient solution without N was added again. An excess of seed was sown in each pot, but after emergence, only 20 turnip and 20 rye plants were kept. The growth of the winter crops was very poor due to soil N exhaustion by the maize. The turnip was cut on 10 March 2005, when a lot of plants began to show senescent leaves; the rye was cut on 12 April 2005. The samples of maize, turnip and rye were dried and ground for determination of dry matter and N content.

Data analysis was carried out using JMP 5.1 software. After ANOVA examination, the means with significant differences ($\alpha < 0.05$) were separated by the Tuker–Kramer HSD test. The

Table 2
Selected characteristics of the organic amendments used in field and pot experiments

	Dry matter (%)	TOOC[b] (g kg^{-1})	Nitrogen (g kg^{-1})	C:N	NH_4^+ (g kg^{-1})	NO_3^- (g kg^{-1})
Nutrisoil	85.9	458.1	144.2	3.2	45.20	13.07
Phenix	95.3	484.5	64.3	7.5	4.30	2.60
Vegethumus[a]	77.1	590.7	22.8	25.9	0.19	4.84
Beiraadubo	61.1	542.1	29.5	18.4	1.14	6.01
Cattle manure	24.7	533.7	22.3	23.9	0.11	4.69
Chestnut bark	61.0	571.5	5.9	96.9	0.09	5.33

[a] Mean values of samples from two different Veg lots (2002 and 2004).
[b] Total oxidizable organic C (2 h hot digest with sulphuric acid and K-dichromate).

Table 3
Triticale N uptake, dry matter yield and N nutritional indices as a function of the rate and the source of N

N applied (kg/ha) (basal + sidedress[a])	SPAD[a]	SPAD[b]	Stem-NO_3[c] ($mg\,kg^{-1}$)	N uptake[d] (kg/ha)	DM yield[d] (Mg/ha)
Control (0 + 0)	41.8 a[e]	36.6 b	Not detected	53.0 b	7.2 b
Veg40 (40 + 0)	41.5 a	36.3 b	Not detected	51.3 b	6.3 bc
Veg80 (80 + 0)	41.3 a	37.2 b	Not detected	49.4 b	5.8 c
AN40 (0 + 40)	42.3 a	49.9 a	11.1	74.7 a	10.4 a
AN80 (30 + 50)	42.5 a	50.3 a	121.2	87.2 a	11.4 a
ANOVA (*P*)	0.918	0.000	–	0.000	0.000

[a] 17 March, Zadoks 31.
[b] 10 April, Zadoks 32.
[c] 5 May, Zadoks 55.
[d] 27 May, Zadoks 75.
[e] Means with the same letter in columns are not different by Tukey–Kramer HSD test ($\alpha < 0.05$).

apparent N recovery (ANR) was estimated according to the following equation:

$$\text{ANR} = \frac{\text{N uptake on fertilized plots} - \text{N uptake on control}}{\text{N applied as fertiliser}} \times 100$$

3. Results

3.1. Field experiments

In the first growing season, AN led to significant ($\alpha < 0.05$) increases of triticale dry matter yield and N uptake in comparison with control and Veg (Table 3). Vegethumus applied at an amount equivalent to 80 kg N/ha (Veg80) led to significantly lower dry matter yield than control. Mean triticale N uptake in Veg80 was also slightly lower than in Veg40 and control plots. On 17 March, before the sidedress AN applications, SPAD values were similar among all treatments. After the sidedress N application, AN40 and AN80 showed SPAD values significantly higher than that of Veg and control treatments. Forty-nine days after the sidedress, high stem nitrate contents persisted in only the AN80 plots. The results of the first growing season of triticale (October 2002–May 2003) showed that Veg did not release N to the crop. On the other hand, AN did increase dry matter, N uptake and N nutritional indices.

Table 4 shows the results for maize, the second crop of the study. We can observe a similar pattern of the previous year among the different treatments. The N applied as inorganic source improved dry matter yield, N uptake and N nutritional indices above the control whereas Veg did not. Stem nitrate content before sidedress N applications was higher in AN120 plots (with 40 kg of N applied on sowing) than that of the other treatments. After sidedress, SPAD values and stem nitrate content were higher in AN120 and AN60 than in Veg and control. After 80 (triticale) + 120 (maize) kg N/ha had been applied in the same plot as Veg, no positive effect on crop growth resulting from organic manuring was observed.

In the second growing season of triticale (October 2003–May 2004), Veg maintained mean SPAD values, N uptake and dry matter yields similar or even slightly lower than control (data not shown). Three growing seasons after the trial start, Veg had still not released any N to the crop. When using AN, just 30 kg N/ha were required to significantly improve N uptake and SPAD values over the control. The higher AN rate (60 kg N/ha) significantly increased N uptake and SPAD values in comparison to all the other treatments.

The performance of Veg seemed to be slightly different in the second maize growing season in comparison with the three previous crops. Mean dry matter yield and mean N uptake were significantly higher in Veg than in control plots (Table 5). SPAD readings followed the same pattern. Thus, after four seasons of continuous Veg applications in the same plots, using a total amount of 380 kg N/ha, some N seemed to be available to the crop. Ammonium nitrate applied in this season (AN120) resulted in higher dry matter yield, N uptake and SPAD readings than when Veg was applied. The SPAD readings taken after the sidedress N application also highlighted the difference between AN and Veg. The SPAD readings were taken 12 days after the

Table 4
Maize N uptake, dry matter yield and N nutritional indices as a function of the rate and the source of N

N applied (kg/ha) (basal + sidedress[a])	SPAD[a]	Stem-NO_3[a] ($g\,kg^{-1}$)	SPAD[b]	Stem-NO_3[b] ($g\,kg^{-1}$)	N uptake[c] (kg/ha)	DM yield[c] (Mg/ha)
Control (0 + 0)	47.0 a	6.3 c	44.5 b	0.6 b	106.5 b	18.8 bc
Veg60 (60 + 0)	47.7 a	13.8 b	42.2 b	0.3 b	105.0 b	17.6 c
Veg120 (120 + 0)	47.6 a	14.2 b	42.7 b	0.2 b	102.4 b	18.2 bc
AN60 (0 + 60)	48.2 a	6.3 c	49.0 a	7.3 a	177.8 a	21.4 ab
AN120 (40 + 80)	49.1 a	26.3 a	50.2 a	5.8 a	186.9 a	22.7 a
ANOVA (*P*)	0.167	0.000	0.001	0.001	0.000	0.040

[a] 17 July, 6–8 leaf stage.
[b] 26 July, 8–10 leaf stage.
[c] 18 September, full dent stage.

Table 5
Maize N uptake, dry matter yield and SPAD values as a function of rate and type of N fertilization source

N applied (kg/ha) (basal + sidedress[a])	SPAD[a]	SPAD[b]	N uptake[c] (kg/ha)	DM yield[c] (Mg/ha)
Control (0 + 0)	34.3 b	31.5 c	76.2 c	10.1 d
Veg60 (60 + 0)	39.9 a	34.2 bc	105.8 b	14.3 bc
Veg120 (120 + 0)	42.9 b	35.6 bc	99.3 b	14.9 b
AN60 (0 + 60)	33.9 b	37.7 b	96.8 b	12.9 c
AN120 (40 + 80)	39.9 a	43.8 a	138.0 a	18.3 a
ANOVA (*P*)	0.003	0.012	0.000	0.000

[a] 23 July, 6–8 leaf stage.
[b] 4 August, 8–10 leaf stage.
[c] 18 September, full dent stage.

Table 6
Total dry matter yield, total N uptake, ANR and AUE after the five growing seasons of triticale and maize

Total N applied (kg/ha)	Total DM yield (Mg/ha)	Total N uptake (kg/ha)	ANR (%)
Control (0)	46.8	326.6	–
Veg 1/2 rate (190)	49.2	354.6	14.7
Veg full rate (380)	50.5	350.4	6.3
AN 1/2 rate (190)	57.8	454.1	67.1
AN full rate (380)	68.6	547.7	58.2

sidedress application of 80 kg N/ha of AN, which promoted the greenness of the leaves.

In the fifth growing season, no N was applied in the experiment. Triticale dry matter yield and N uptake were recorded to evaluate the residual effect of previous N applications. None of the treatments produced significantly higher mean dry yields and N uptake than the control. Dry matter yields and N uptake ranged between 4.3 and 6.0 Mg DM/ha and 43.0 and 57.2 kg N/ha.

To compare the final performance of Veg, AN and control treatments in the field trial, we used total dry matter yields and N uptake during the five growing seasons as well as the ANR (Table 6). The analysis of these parameters highlights the inefficacy of Veg to supply N to the crops. Vegethumus applied at rates of 380 kg N/ha led to total DM yields of 3.7 Mg/ha above the control and 18.1 Mg/ha below AN applied at similar N rates. In Veg plots, the ANR were only 6.3 and 14.7% of applied N when 380 and 190 kg N/ha were used, respectively. If AN was the N source, applied at the same rates as Veg, the ANR were 58.2% and 67.1%, respectively.

3.2. Pot experiment

A pot experiment with maize followed by two winter crops, rye and turnip, was conducted in the Summer season of 2004 and winter season of 2004/2005. The winter crops were grown without N application to allow for the complete exhaustion of the nutrient. Early in the season, 33 days after the maize had been sown, the plants grown in CB pots exhibited chlorosis, a symptom of a marked N-deficiency. The mean SPAD value was 20.0, which is a significantly lower value than that registered in control pots (Table 7). Vegethumus presented mean SPAD values slightly lower than the control. Ammonium nitrate and the organic amendments with high N contents, such as Nut (14.4% N) and Phe (6.4%), gave the highest mean SPAD values. On the second SPAD readings, 58 days after sowing, the behaviour of the different treatments was not much different. However, Bei exchanged its position with Phe. The former seemed to release more N later in the growing season. At 58 days after sowing Veg presented slightly higher SPAD values than control, but the means were not statistically different.

N uptake was highest in Nut pots (Table 7). A slightly lower value was recorded with AN fertiliser. Beiraadubo seemed to release more nitrogen as the growing season progressed. The nitrogen uptake by maize was significantly higher in Bei than in Phe, CM and Veg pots. Mean N uptake in Veg pots was even lower than that in the control, although the differences were not significant. Chestnut bark yielded very low values when compared with all the other treatments. As expected, there was a clear relationship between N uptake and above ground dry matter yield. The plants in treatments that took up most N generally produced higher dry matter yields (Table 7).

Table 7
SPAD-values, N uptake and dry matter yield of maize in pot experiment

	SPAD[a]	SPAD[b]	N uptake[c] (mg/pot)	DM yield[c] (g/pot)
Control	32.5 cd	22.8 c	292.6 d	50.7 cd
Chestnut bark	20.0 e	21.5 c	86.5 e	13.2 e
Vegethumus	29.3 d	25.9 bc	235.7 d	39.5 d
Cattle manure	37.4 abc	30.5 b	359.8 cd	51.9 bcd
Beiraadubo	36.5 bcd	37.3 a	651.9 b	66.9 ab
Phenix	42.6 ab	28.4 b	478.6 c	64.9 abc
Nutrisoil	44.1 a	41.1 a	856.0 a	73.6 a
Ammonium nitrate	44.0 a	37.9 a	812.6 a	79.5 a
ANOVA (*P*)	0.000	0.000	0.000	0.000

[a] 8 July, 2 leaf stage.
[b] 2 August, 6 leaf stage.
[c] 20 August, 8 leaf stage.

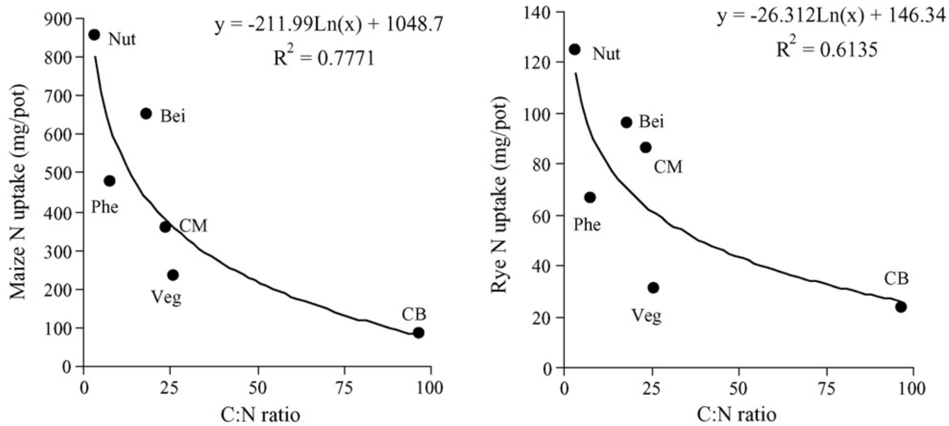

Fig. 1. Relationship between C:N ratios of organic amendments and N uptake by maize and rye.

Table 8
Nitrates recovered by the anion exchange membranes used in pot experiment

	Nitrate concentrations in extracts (mg/l)		
	16–23 June	29 July–5 August	9–14 September
Control	78.9 cd	17.9 bc	14.5 bc
Chestnut bark	18.3 d	12.9 c	9.7 c
Vegethumus	56.2 cd	17.8 bc	13.6 bc
Cattle manure	116.9 bc	21.7 bc	51.0 a
Beiraadubo	52.0 cd	52.3 a	44.4 ab
Phenix	221.2 a	21.7 bc	32.4 abc
Nutrisoil	225.2 a	35.6 ab	58.6 a
Ammonium nitrate	239.3 a	28.9 bc	37.9 abc
ANOVA (*P*)	0.000	0.000	0.000

Soil N availability measured by nitrate adsorbed in AEM allows the clarification of some aspects of maize N uptake, dry matter yield and SPAD values (Table 8). The application of CB reduced the available inorganic-N in soil by microbial immobilization, thus restricting maize growth. The AEM results confirmed that Bei was released N in lower amounts than CM and Phe in the first weeks after sowing, but as the growing season progressed, the net N mineralization rates in Bei pots significantly increased. Twenty-five days after the end of the maize growing cycle (at 14 September), soil nitrate availability levels were not very dissimilar to those of the previous AEM extraction. The amendments applied to the maize crop did not provide enough N to allow for a successful growth of winter crops. However, the pots that presented high residual soil nitrates in September allowed for better winter crop growth. Chestnut bark and Veg, for instance, gave lower mean N uptake and dry matter yield of cover crops than the control did (Table 9). Nutrisoil showed the highest ANR, indicating that almost all of its N was available for crops in a period shorter than 1 year.

Fig. 1 shows the relationship between the C:N ratio of organic amendments and N uptake by maize and rye. It seems clear that Veg and Phe, the organic amendments permitted in organic agriculture, were the substrates that released less N, taking into account their C:N ratios. Better performances were shown by Bei and CM in both maize (short-term) and rye (long-term) experiments.

4. Discussion

In the field experiments, AN caused a significant increase in dry matter yields and N nutritional indices compared to Veg and control treatments. In the first four growing seasons, triticale/maize/triticale/maize, the application of 380 (80 + 120 + 60 + 120) kg N/ha as Veg gave similar dry matter yields and N uptake than the control did. Veg had a C:N ratio of 25.9 (Table 2). Douglas and Magdoff (1991), working with 19 different organic residues, concluded that organic substrates with C:N ratios between 11 and 25 usually result in net N mineralization. Other studies have shown that ANR from manures

Table 9
Dry matter yield and N uptake of turnip and rye and total ANR

	Turnip DM (g/pot)	Turnip N uptake (mg/pot)	Rye DM (g/pot)	Rye N uptake (mg/pot)	ANR[a] (%)
Control	0.9 b	17.7 b	4.2 bcd	47.9 bc	–
Chestnut bark	0.7 b	12.5 b	2.0 d	23.7 c	−15.4
Vegethumus	0.9 b	14.6 b	2.7 cd	30.8 c	−5.0
Cattle manure	3.5 ab	62.9 ab	7.8 abc	86.1 abc	7.0
Beiraadubo	5.1 a	97.0 a	8.4 ab	96.3 ab	27.2
Phenix	2.3 ab	38.1 ab	6.1 abcd	66.4 abc	13.6
Nutrisoil	4.6 a	84.5 a	10.8 a	125.0 a	42.7
Ammonium nitrate	4.4 a	74.0 ab	7.9 abc	85.0 abc	37.1
ANOVA (*P*)	0.000	0.001	0.000	0.001	

[a] Total ANR was determined by adding N uptake of both maize and rye crops (rye was the cover crop that recovered more N).

is usually low (Beauchamp, 1986; Paul and Beauchamp, 1993; Fauci and Dick, 1994; Rodrigues et al., 2001). However, despite its relatively high C:N ratio, Veg displayed an unusually long period of apparent net N immobilization.

In the fifth growing season, AN and Veg did not lead to significant residual effects on triticale dry matter yield and N uptake. Similar results were reported by Paul and Beauchamp (1993) using urea as a N source. Nitrogen not recovered in the season of application seems to be lost from soil, thus not providing any benefits to the succeeding crop.

The field methodologies used in this study were not able to explain the fate of N applied as Veg and not recovered by the crop. Organic manuring could promote N losses by denitrification (Smith and Chambers, 1993) and ammonia volatilization (Holding, 1982) compared to plots receiving inorganic-N. Part of the N applied could also remain immobilized in the soil organic matter or fixed in clay minerals. However, it is unquestionable that there was a huge difference in dry matter yield of Veg380 (50.5 Mg DM/ha) and AN380 (68.6 Mg DM/ha) if all five growing seasons were taken into account.

In the pot experiment, Veg gave rise to slightly lower maize dry matter yields and N uptake than control. The nitrate adsorbed by AEM and SPAD readings in Veg and control pots were similar during the summer season. Results of Veg were not better in the winter season with turnip and rye, thus confirming how poor Veg was as a N source. The results of Veg were lower when compared with several conventional manures used in other studies (Pratt et al., 1976; Beauchamp, 1986; Bitzer and Sims, 1988; Paul and Beauchamp, 1993).

The N uptake by maize was significantly lower on Phe than that on AN pots. SPAD values and soil nitrate content were high on the first determination date, but as the growing season progressed, SPAD readings and nitrate recovery in AEM showed a clear decrease. Total (maize + rye) ANR of Phe was only 13.6%, a very low value if its C:N ratio and total- and inorganic-N content are taken into account. Castellanos and Pratt (1981) propose that composting produces materials of high stability of both C and N, reducing odours and creating better physical properties of manures. On the other hand, they showed that composting dramatically reduces the value of manures as an N source. Phe and Veg are both composted and pelleted amendments, and their performance seems to be in accordance with the results reported by Castellanos and Pratt (1981). The use of AEM showed that a portion of Phe-N become available early in the season, whereas the remainder seemed to persist hidden for a long period of time.

Nutrisoil led to maize dry matter yields and crop N recoveries in the pot experiment that were similar to AN. The SPAD values, the nitrate extracted by AEM and the residual N effect on winter cover crops were also similar. The N content of Nut is 144.2 mg kg^{-1} and the C:N ratio 3.2, which confer to this amendment a similar pattern in the soil to that of inorganic N fertilisers.

The apparent N recovery of Bei was higher than that of Phe. SPAD readings and nitrate concentrations in AEM extracts showed that this amendment releases its N later in the season but at a time appropriate to produce acceptable maize yields and with high N recovery. The net N mineralization persists over the winter period, and dry matter yield and N uptake of cover crops were the highest among all tested N sources. Beiraadubo is a composted material but has a high moisture content. Fresh manures seem to release more N than older manures, which are highly composted, pelleted and dried.

Cattle manure showed a positive effect on winter crop growth, seeming to act as a very slow release N source. However, the CM showed a complete incapacity to provide enough N for maize, the first crop after manure application in the pot experiment. The low ANR of farmyard manures are results that agree with previous studies (Rodrigues et al., 2001; Paul and Beauchamp, 1993; Beauchamp, 1986; Fauci and Dick, 1994).

Chestnut bark produced an expected result. The C:N ratio of this product is very high (96.9). During all the pot experiment CB showed a complete incapacity to promote crop growth. Soil available N indicators presented low levels during all the growing seasons. However, there are no reasons to suspect phytotoxic effects, but only for a high demand for soil inorganic N reserves during the mineralization process. Microorganisms are very competitive for inorganic N when an energetic source is available (Zaccheo et al., 1993). Thus, net N immobilization would have persisted over the entire trial period.

The results of field and pot experiments show the difficulty in managing organic N sources. Crop N recovery from organic amendments is usually low and the timing and amount of N that is released to the crop is very difficult to predict. Organic amendments that are permitted in organic farming did not exhibit particularly good performances. Thus, we conclude that organic farming, with specific regard to N management, is not necessarily more environmentally friendly than conventional farming, as was previously reported by Sileica and Guzys (2003). On the other hand, commercial organic amendments permitted in organic farming are often expensive. In addition, if the crops have high demands for N, dry matter yield could be severely reduced. These facts must be carefully considered by farmers and technical advisers because they could jeopardize both the profitability and sustainability of the farming system.

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