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Determination of nitrogen release by organic fertilizers as influenced by fertilizer type and soil characteristics

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Abstract

Incubation and pot experiments were carried out at the University of Natural Resources and Life Sciences, Vienna, Austria during the months of July to October 2011 to investigate suitability of grain legume seeds (pea, yellow lupin and faba bean) and organic fertilizers of industry-processed plant and microbial residues (Maltaflor®-spezial, Phytoperls®, Agrobiosol® and Rizi-Korn) as possible substitute for animal based organic fertilizers. Incubation experiment investigated fertilizer net N mineralization using one soil type, while pot experiment determined apparent N utilization using four soil types and oat as a test plant. In both experiments, treatments were laid down in a Complete Randomized Design and replicated four times. The objective of this study was to determine fertilizer and soil characteristics that influence N release of the tested fertilizers. Results showed that, seventy percent of total net mineralization occurred within the first two weeks of incubation. Total net N mineralization was influenced by fertilizer type and ranged between 42 - 61 % and was closely related to N content (r^2 = 0.97***) than C/N ratio (r^2 = 0.79***). Similar results but with weaker relationship (r^2 = 0.60***) was obtained from pot experiment which also showed that, apparent N utilization of oat was influenced by both soil texture and organic matter when the N content was low. These results suggest that, N content of the tested fertilizers is a good indicator for the N release although soil can modify this process.

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Introduction

Horticultural crops have specific requirements for nitrogen (N) supply. Therefore, the N fertilizers that are used to produce organic horticultural crops should ensure high N turnover, fast N availability and continuous N supply. Most growers provide their N supply through organic fertilizers which predominantly contained animal residues such as horn or blood- or meat-meal in the past. However, fertilizers without animal residues are now required because of the BSE (Bovine Spongiform Encephalopathy) crisis (Schmitz and Fischer, 2003) with grounded seeds of grain legumes and organic fertilizers of industry-processed plant and microbial residues being commonly used. Many types of these fertilizers are available because of the varying composition of grain legumes in response to the genotype and the growing environment (Bhardwaj *et al.,* 2008). Moreover, newly formulated industrial fertilizers are frequently placed on the market. For all these plant-based and industry-processed organic fertilizers, the potential for N release has to be specified before use and should be described by simple measures. Although these fertilizers differ markedly in N mineralization (Schmitz and Fischer, 2003), little is known regarding possible reasons for this. By contrast, the N turnover of crop residues and green manures is described frequently. Experimental results from warm climatic conditions such as the tropics are partly transferable to infer N release under greenhouse conditions. With crop residues, rapid initial N mineralization was observed after which the rate of mineralization decreased (Müller and Sundman, 2008; De Neve and Hofman, 2006; Thönnissen *et al.,* 2000b; Khalil *et al.,* 2005). Numerous studies have attempted to find a relation between N mineralization and the biochemical characteristics of crop residues. Frequently, either N content (Iritani and Arnold, 2006; Frankenberger and Abdelmagid, 2012; Trinsoutrot *et al.,* 2000; Mendham *et al.,* 2004) or C/N ratio (Vigil and Kissel, 2001) were strongly correlated to the N release of crop residues. However, other factors such as polyphenol content (Constantinides and Fownes, 2004) or a combination of factors (e.g. (lignin + polyphenol)/N ratio; Fox *et al.,* 2010; Handayanto *et al.,* 2004) was revealed to be more important in some studies. Recently, Khalil *et al.* (2005) proposed the inexpensive option of indexing organic matter (OM) quality using pH and the C/N ratio of the organic residues of plant and animal origin to help quantify decomposition rate constants and N mineralization. The question arises whether the N release of plant-based and industry-processed organic fertilizers can be explained by similar characteristics as for crop residues. N mineralization of crop residues was strongly influenced by soil characteristics (Smith and Sharpley, 2010; Drury *et al.,* 2003) particularly by clay content and CEC (Khalil *et al.,* 2005). Soils used in organic horticulture which differ greatly in texture and OM could affect fertilizer N release. The objectives of this study were to test (1) whether N release of grounded grain legumes and organic fertilizers of industry-processed plant and microbial residues can be predicted by their N content or C/N ratio and (2) whether this relation is subject to modification by different soils. N release was investigated using both incubation and pot experiments. The influence of contrasting soil properties on N release was investigated in pot experiment with oat. In both experiments, grounded seeds of three grain legumes and three organic fertilizers of industry-processed residues were compared with the commonly used fertilizer in Austria- the Rizi-Korn.

Materials and methods

Fertilizers

Grounded seeds of three grain legumes (pea, *Pisum sativum* L.; yellow lupin, *Lupinus luteus* L.; and faba bean, *Vicia faba* L.), organic fertilizers of industry-processed residues from plants (Maltaflor®-spezial and Phytoperls®) and microorganisms (Agrobiosol®) and one reference fertilizer (Rizi-Korn) were investigated in both incubation and pot experiments. Fertilizers were selected on the basis of their wide range in N content and C/N ratio (Table 1). The N content of grain legumes ranged between 3.0 - 4.0 %, whereas that for organic fertilizers of industry-processed residues was much higher. The C content of the investigated fertilizers did not vary much. As such, the C/N ratio was determined mainly by the variation in N content resulting in higher values for the grain legumes than for the organic fertilizer of industry-processed residues. Residues with small particle sizes showed stronger and longer N immobilization and subsequently lower N mineralization than did those with large particle sizes (Jensen, 2004; Corbeels *et al.,* 2003). Therefore, to minimize particle size effects so as to better compare the investigated fertilizers, grain legumes were coarsely grounded to pass through 1.5 mm screen (shear-mill, BRABENDER, Duisburg, Germany) while the organic fertilizers of industry- processed residues were sieved to pass through 2.0 mm screen. Previous experiments have shown no differences in N release between these both particle sizes.

Soils

Two sandy (S) and two loamy (L) soils each differing in the amount of organic matter (low, lOM versus high, hOM), were selected for this investigation (Table 2). The four greenhouse soils (0-20 cm, ≤ 5 mm) were obtained from organic vegetable growers.

Incubation experiment

Seven plant-based and industry-processed organic fertilizers containing 40 mg N were mixed with 150 g dry sandy soil low in OM (SlOM) in 500 ml polyethylene flasks. The amount of fertilizer corresponded to 200 kg N/ha. Soil samples without added fertilizer were included as control treatments. Each treatment was repeated four times and the flasks were covered with cling film to prevent water loss. Samples were incubated at 20°C and at ψm = -0.016 MPa (9.4% gravimetric soil water content). After incubation, the soil was analyzed for nitrate (0.01 M $CaCl_2$, 1:2 soil: extractant; Vilsmeier, 1984) and ammonium (2M KCl, 1:2 soil: extractant). Soil extracts were frozen after filtration (589/2 ½ SCHLEICHER & SCHÜLL, Dassel, Germany). Nitrate was measured photometrically after separation by HPLC (KONTRON INSTRUMENTS, Au i.d. Hallertau, Germany) according to Vilsmeier (1984) and ammonium was measured photometrically at 667 nm (FA. PERKIN ELMER, UV/VIS Spectrometer Lambda 20, Neuried, Germany) as salicylate (Mulvaney, 1996). The incubation experiment commenced on 4th July, 2011 and was terminated on 19th August, 2011. The treatments were laid down in a Complete Randomized Design (CRD) and were replicated four times.

Pot experiment

Four soils (Table 2) were tested in pot experiment using five-liter Mitscherlich pots. Eight hundred milligrams of fertilizer N equivalent to 255 kg N/ha were mixed into the upper half of the soil in the pots in four replicates. A treatment without fertilizer was also included as a control. Oat seeds (*Avena sativa* L; 1.5 g) were sown after the addition of the fertilizer. The pots were covered with a lid until the germination of the oat and were regularly watered with distilled water to achieve 60 % maximum water holding capacity. This value is equivalent to 16 % (SlOM), 19 % (ShOM), 18 % (LlOM), and 34 % (LhOM) gravimetric soil water content. In one soil (ShOM), the germination of oat was inhibited in the treatments with grain legumes. Therefore 0.75 g of oat was sown additionally 13 days after the first sowing. All pots received 0.3 g potassium (as K_2SO_4) one week after the first harvest. During the 13 weeks of cultivation, oat was cut three times to 1.5 cm stubble height. Oat was oven-dried for 24 h at 105 °C to determine the dry matter content. Samples were grounded to pass through a 1 mm screen (Micro-mill, CULATTI AG, Zurich, Switzerland) and their N content was determined (FP-328 Nitrogen/Protein Determinator, LECO CORPORATION, St. Joseph, Michigan, USA). The apparent N utilization was calculated as the additional N uptake of oat compared to the control divided by the added fertilizer N. The pot experiment commenced on 11th July, 2011 and was terminated on 10th October, 2011. The treatments were laid down in a Complete Randomized Design (CRD) and were replicated four times.

Statistical analyses

SAS Version 8.2 was used for all statistical evaluations. The results of both incubation and pot experiments were subjected to one-way analyses of variance with the significance of the means tested with a Tukey/Kramer HSD-test at $p \leq 0.05$. Regression and correlation analyses were calculated using the SAS procedures "proc reg" and "prog corr".

Results

Net nitrogen mineralization

During the incubation period, net N mineralization differed among the different types of fertilizer. The reference fertilizer - Rizi-Korn reached the highest net N mineralization (70 %) of all the fertilizers tested at the end of the incubation period and was one of the most rapidly mineralizing fertilizer as well (Figure 1). At the beginning of the incubation, high mineralization rates were also observed for the industrial fertilizers; Maltaflor®-spezial, Agrobiosol® and Phytoperls® and grounded seeds of faba bean. But after 47 days these fertilizers mineralized significantly less N as compared to Rizi-Korn. For two fertilizers (grounded seeds of lupin and pea) net N mineralization was negligible until day four and remained low throughout the whole incubation period. Consequently, only 40 % of the added N was mineralized from these fertilizers by the end of the experiment. N mineralization of all fertilizers except pea occurred primarily within 15 days (about 70 %). Maximum net N mineralization seemed to be largely attained after four weeks of incubation. Strong relationship (r^2= 0.97***) between N content of the fertilizers and their net N mineralization was found except for Agrobiosol® and Phytoperls® (data not shown). These latter two fertilizers were characterized by high N contents and narrow C/N ratios that are typical for plant-based materials. As such, they did not show the same relationship as the other fertilizers because their net N mineralization was much lower in relation to their N content. Because the C/N ratio was mainly determined by the variation in N content (Table 1), similar results were found for the relationship between net N mineralization and C/N ratio (data not shown). The coefficient of determination of the correlation was also high (r^2= 0.79***) but less significant compared to the N content.

Table 1. N and C content and C/N ratio of plant-based and industry-processed organic fertilizers.

Fertilizer type	N content (%)	C content (%)	C/N ratio
Grain legumes			
Coarse meal (1.5 mm) of pea	3.0	40	13.3
Coarse meal (1.5 mm) of yellow lupin	3.4	41	12.0
Coarse meal (1.5 mm) of faba bean	4.0	40	9.9
Organic fertilizers of industry-processed residues			
Maltaflor®-spezial (a)	4.7	38	8.0
Agrobiosol® (b)	7.2	40	5.6
Phytoperls® (c)	8.5	43	5.0
Rizi-Korn (d) (reference fertilizer)	5.3	46	8.6

(a) Maltgerms from malted barley mixed with vinasse

(b) Fungal biomass of *Penicillium chrysogenum* (residues of penicillin production)

(c) Fermentation-residue of corn after withdrawal of corn germs, extraction of starch and sugar, and withdrawal of crude fibre

(d) Residues from castor oil production mixed with vinasse.

Apparent nitrogen utilization

As compared to the incubation experiment, similar results were obtained from the pot experiment with oat and using four different types of soil (data not shown). The N mineralization of the fertilizers differed strongly throughout the experiment. Most of the N released was already detected at the first cut (about 60 % of the total mineralization) except for the pea and lupin. The apparent N utilization in the pot experiment resulted almost in the same ranking of fertilizers as was found for the net N mineralization in the incubation experiment. Only Phytoperls® performed comparatively poorer. However, compared to the net N mineralization in the incubation experiment, the apparent N utilization was about 10 % lower for most fertilizers but higher for lupin and pea. In spite of the longer experimental time as compared to the incubation experiment, the apparent N utilization did not reach saturation at the end of the pot experiment. For all tested soils and fertilizers, the apparent N utilization was significantly related to each of N content and C/N ratio of the fertilizers (r^2= 0.60*** and r^2= 0.47***, respectively) again with the exclusion of Agrobiosol® and Phytoperls®. However, much higher variation in the apparent N utilization in comparison to the incubation experiment was observed. Rizi-Korn showed slightly higher apparent N utilization than expected based on its C/N ratio.

Table 2. Characteristics of the greenhouse soils used in the experiment.

Soil name	Soil horizon	Clay	Silt	Sand	C_{org}	N_t	C/N ratio	pH $CaCl_2$	P CAL	K CAL	Organic horticulture (Years in cultivation)
		(––––––––– %				–––––––––)			(mg / 100 g dry soil)		
SlOM [(a)]	Mollic [(b)]	9	26	65	1.4	0.11	12.8	7.1	11	n.d[(c)]	2
ShOM [(a)]	hortic [(b)]	12	18	70	3.1	0.28	11.1	7.5	17	43	32
LlOM [(a)]	hortic [(b)]	23	56	21	1.9	0.23	8.4	7.1	17	22	13
LhOM [(a)]	hortic [(b)]	24	53	23	8.0	0.50	15.9	7.0	26	38	16

(a) S: Sand, L: Loam, lOM: low content of OM, hOM: high content of OM

(b) Soil horizons follow FAO (1998)

(c) n.d. – not determined.

Effect of soils on the apparent nitrogen utilization

For all soils, the apparent N utilization of oat increased with increasing N content of fertilizers except with Phytoperls® and Agrobiosol® (Table 3). The highest apparent N utilization was achieved with Rizi-Korn. Intermediate values were generally obtained with Maltaflor®-spezial and Agrobiosol® whereas the apparent N utilization of grounded seeds of pea was consistently low. ANOVA indicated highly significant effect of the fertilizers on the apparent N utilization (Table 3). However, the soil type significantly influenced the apparent N utilization as well, with the difference in the apparent N utilization between the best and the least efficient fertilizers being smaller for sandy soil than for the loamy soil. Moreover, ANOVA revealed a weak but significant interaction between the soil and the fertilizer. Oat growing in LlOM and fertilized with grounded seeds took up relatively small amounts of N as compared to the other soils, whereas the apparent N utilization with Phytoperls® in ShOM was very high. By contrast, Agrobiosol®, Maltaflor®-spezial and Rizi-Korn seemed to supply oat with similar amount of N regardless of the soil type (Table 3).

Table 3. Apparent N utilization of oat using plant-based and industry- processed organic N fertilizers in four different types of soil after 91 days.

Soil	Pea (3.0% N)	Lupin (3.4% N)	Faba bean (4.0% N)	Maltaflor®-spezial (4.7% N)	Rizi- Korn (5.3% N)	Agrobiosol® (7.2% N)	Phytoperl® (8.5% N)
	Apparent N utilization (–––––––––––––––––––––––––––– % –––––––––––––––––––––––––––––)						
SlOM	46 d	48 cd	53 bc	55 b	63 a	52 bc	39 e
ShOM	43 c	47 bc	49 bc	54 b	65 a	52 bc	48 bc
LlOM	32 d	37 cd	40 c	49 b	62 a	53 b	36 cd
LhOM	29 c	45 b	45 b	54 a	59 a	53 ab	36 c

Letters indicate significant differences among fertilizers for each soil (LSD, p≤0.05). S: Sand, L: Loam, lOM: low content of OM, hOM: high content of OM.

Comparison between incubation and pot experiment

The data for the pot experiment supported the main findings of the incubation experiment, with a comparison of net N mineralization to apparent N utilization reflecting the similarity of the results. Ideally, a 1:1 linear relationship might be expected if N release from the fertilizers was the same in both experiments. Strong linear relationship was indeed found, albeit only if Phytoperls® was excluded. Both experiments indicated the same ranking of the fertilizers when tested with the same soil type.

Table 4. Effect of fertilizers, soils and their interaction on the apparent N utilization.

	main effects + interactions	DF	F Value	Pr > F
ANOVA	fertilizer	6	42.14	< 0.0001
	soil	3	11.61	< 0.0001
	soil x fertilizer	18	1.93	0.0234

Discussion

In both experiments, the plant-based and industry-processed organic fertilizers differed strongly with regard to net N mineralization and apparent N utilization. This confirms earlier experiments with grounded seeds of grain legumes and organic fertilizers of industry-processed residues (Braun *et al.,* 2000; Schmitz and Fischer, 2003) and is in agreement with results reported for crop residues (Frankenberger and Abdelmagid, 2012; Smith and Sharpley, 2010; Khalil *et al.,* 2005; Corbeels *et al.,* 2003; Khalil *et al.,* 2005). N release was determined primarily by the N content of the fertilizers. Similarly, the C/N ratio predicted the N release in both experiments comparatively well. Two fertilizers; Agrobiosol® and Phytoperls® did not fit the observed relationship such that their N release has to be predicted differently. Moreover, Phytoperls® represented the only fertilizer that did not obey the highly significant relationship observed between N mineralization and apparent N utilization by oat. Close relationship between N mineralization and N utilization of crop residues was also found by Iritani and Arnold (2006) and Kuo and Sainju (2008). The unusual N release characteristics of Phytoperls® are supported by other reports in the literature. Data from Schmitz and Fischer (2003) show relatively poor N mineralization of Phytoperls® as well. By contrast, Heuberger *et al.* (2005) reported high N uptake of basil from this fertilizer that was comparable to those of horn grit and Agrobiosol® suggesting that the N release of Phytoperls® might be strongly influenced by the experimental conditions. The slightly poorer performance of the C/N ratio with respect to N content in predicting the N release of the fertilizers could be ascribed to the relatively high C/N ratio of Rizi-Korn. For crop residues varying in N content, N mineralization is often more closely correlated to the N content than to the C/N ratio (Iritani and Arnold, 2006, 0.9 - 4.0% N: r= 0.93, C/N=10 - 48: r= -0.80; Frankenberger and Abdelmagid, 2012, 1.3-5.9% N: r= 0.93***, C/N= 7-34: r= 0.88***; De Neve *et al.,* 2004, 1.6-3.3% N: R^2=0.86***, C/N=10-26: R^2=0.78***; Trinsoutrot *et al.,* 2000, 0.3-4.5% N, r= 0.88***, C/N= not specified: r= -0.73***). The N content of the crop residues was closely related to the net N mineralization for each sampling date throughout the 16 weeks of incubation (Constantinides and Fownes, 2004). Consequently, fertilizer N content is a suitable indicator for predicting the N release of plant-based material as well as some of the industry-processed fertilizers provided the N content of the fertilizers are sufficiently different. If the difference in N content is too small no correlation between N content and net N mineralization will be found (De Neve and Hofman, 2006). Our data indicate that most of the applied N mineralized within 5-6 weeks. 70 % of this final N release occurred within 15 days. It can therefore be concluded that all the fertilizers examined allowed fast N availability. Different soils did not modify the relationship between apparent N utilization and N content or C/N ratio substantially. Nevertheless, lower coefficients of determination were found in the pot experiment as compared to the incubation experiment. But the soil-induced variations were minor as compared to the role of the N content of plant based and industry-processed organic fertilizers, with the effect of different soils being dependent on the fertilizer applied. For instance, the N uptake of oat from fertilizers with relatively high N content (Maltaflor®- spezial, Rizi-Korn and Agrobiosol®) was not influenced by the soil type. By contrast, N uptake from pea (the fertilizer with the lowest N content) seemed to be affected by soil texture because N utilization by oat was higher on sandy soil than on loamy soil. Becker *et al.* (2004) found that the N release from crop residues in an incubation study was much higher in clay than in sandy soil. Similar result was obtained by Schmitz and Fischer (2003) in a pot experiment with oat fertilized with horn. The apparent N utilization in the loamy soil was higher compared to the sandy soil which was attributed to the higher pH and higher OM content in the former. The effect of soil texture on N mineralization was also described by Strong *et al.* (2009) and Khalil *et al.* (2005). In addition to soil texture, OM might also modify N transformation processes in the soil. Here, the loamy soil low in OM resulted in the lowest N utilization of oat if grain legumes or Phytoperls® were applied. This negative effect was not observed with Agrobiosol® and Rizi-Korn. Similar to the effect of soil texture, no clear influence of OM could be demonstrated which is in line with Bending *et al.* (2002) who stated that the degree of interaction between N release of crop residues and OM content was dependent on the crop residues. The low apparent N utilization of grain legumes on the loamy soil low in OM confirmed that ground residues incorporated into the soil resulted in larger and longer N immobilization and subsequently in lower re-mineralization in the fine textured soil than in the coarse textured soil (Corbeels *et al.,* 2003). Smith and Sharpley (2010) concluded that no particular effect of soil type on N mineralization was evident. The conflicting results highlight the need for further research to clarify the role of soil characteristics in N release of plant-based and industry- processed organic fertilizers.

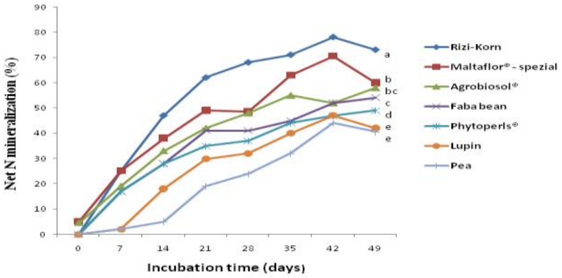

Fig. 1. Time course for net N mineralization of plant-based and Industry – processed organic N fertilizers applied to a sandy soil low in OM during the 47 days of the incubation at 20 °C and ψm = -0.016 MPa. Letters indicate significant differences at the end of the incubation period (LSD, p≤0.05).

Conclusion

The N content of plant-based and all but two industry-processed organic fertilizers was a good predictor for the N release of all the investigated fertilizers. Soil characteristics influenced N mineralization more strongly for fertilizers with lower N content. Grain legumes which are widespread in use as fertilizers in organic horticulture were sensitive to soil characteristics underlining the need for further research on soil-fertilizer interactions.

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