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Nitrogen release and nitrogen use efficiency of plant derived nitrogen fertilisers in organic horticultural soils under glasshouse conditions

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Abbreviations

ψ_m	water matric potential
^{15}N	labelled nitrogen
ANI	added nitrogen interaction
ANOVA	analysis of variance
C	carbon
C/N	carbon/nitrogen ratio
$CaCl_2$	calcium chloride
CAL	calcium acetate lactate
CEC	cation exchange capacity
C_{org}	organic carbon
DF	degree of freedom
DM	dry matter
H_2O	water
hPa	hecto Pascal
HPLC	high performance liquid chromatography
ICP	inductively coupled plasma emission spectrometer
K	potassium
K_2O	potassium oxide
K_2SO_4	potassium sulfate
KCl	potassium chloride
LSD	least significant difference
M	mole
Mg	magnesium
MPa	mega Pascal
MS	mass spectrometer
N	nitrogen
N_2	molecular nitrogen
N_{min}	mineralised nitrogen
NO_3^--N	nitrate-nitrogen
N_t	total nitrogen
OM	organic matter
P	phosphor
$p \leq 0.05$	5% probability level
pH	potential of hydrogen
r^2	coefficient of determination
RCB	randomised complete block

more abbreviations are explained in the text

1 General Introduction

Nitrogen (N) fertiliser application in organic farming is regulated by the European Union Standards (EEC no. 2092/91) on organic production of agricultural products and additionally by standards of organic producers organisations. N sources in organic farming are organic fertilisers such as crop residues, legumes, animal manure and commercial organic fertilisers (*Power* and *Doran*, 1984). In the past, organic vegetable crops were fertilised mainly with animal residues like horn, blood- or meat-meal. However, due to the risk of contaminations with BSE (*Bovine Spongiform Encephalopathy*) infected material alternative fertilisers are required (*Schmitz* and *Fischer*, 2003). Therefore, there is a need to use plant-derived (milled seeds of grain legumes) and industrially-processed organic (plant and microbial residues) N fertilisers as a sole N addition to organic horticultural crops.

So far little is known about the N release from plant-derived and industrially-processed organic N fertilisers, whereas N release from crop residues is frequently described. Crop residues were screened for correlations between simple biochemical characteristics and N release to reveal their suitability as N fertilisers. Indeed, the N release of crop residues has been known to often depend on their N content (*Iritani* and *Arnold*, 1960; *Frankenberger* and *Abdelmagid*, 1985; *Trinsoutrot* et al., 2000; *Mendham* et al., 2004) or C/N ratio (*Vigil* and *Kissel*, 1991). However, in some studies these factors did not work and other characteristics such as (lignin + polyphenol)/N ratio and polyphenol content have been identified to be more important (e.g. *Fox* et al., 1990; *Constantinides* and *Fownes*, 1994; *Handayanto* et al., 1994). For an appropriate N supply to crops a rapid and reliable information about N release is also required for plant-derived and industrially-processed organic N fertilisers. Therefore, characteristics of these fertilisers have to be investigated for the prediction of their N release. This is especially important, because many types of grain legumes are available and frequently new industrially-processed organic N fertilisers are placed on the market. Due to the slower N mineralisation of organic compared to mineral fertilisers a selection of suitable fertilisers is of particular importance. It has to be tested, whether a prediction of the N release can be deducted from relatively low input (incubation) experiments without plants or whether more comprehensive studies

with plants are needed. The comparability of incubation, pot and glasshouse experiments has to be investigated for the transferability of the results.

Soils used in horticulture vary in soil texture and even at a similar soil texture in a wide range of N_t and C_{org} content (*Legg* and *Stanford*, 1967). Attention has to be directed to potential interactions between fertilisers and soils, because N release may be influenced by abiotic parameters such as texture and C_{org} content of the soil and by biotic parameters (antibiosis, neutralism, probiosis). Most studies addressing the effect of soil characteristics on N release of incorporated crop residues and manure frequently indicate, that fine textured soils increase (*Egelkraut* et al., 2000) and elongate N immobilisation (*Whitmore* and *Groot*, 1997; *Egelkraut* et al., 2000) and subsequently decrease N mineralisation compared to sandy soils (*Bosatta* and *Ågren*, 1997; *Egelkraut* et al., 2000; *Griffin* et al., 2002; *Thomsen* et al., 2003b). The net mineralisation in fine textured soils is assumed to be lower, because the organic matter (OM) is physically protected against decomposition (*Hassink*, 1992). However, contrasting studies are also reported (e.g. *Paré* and *Gregorich*, 1999). Furthermore, N turnover of OM added to soil in crop residues and manure affects the availability of N mineralised from both added and native soil OM (*Thomsen* et al., 2003a). A larger positive “added nitrogen interaction” (ANI) was measured in a soil with higher C_{org} and N content compared to a soil with lower C_{org} and N content (*Hart* et al., 1986). Due to these findings, recommendations for the application of plant-derived and industrially-processed organic N fertilisers may have to be adapted to different soils. Therefore, it should be known, whether soil characteristics affect the prediction of N release from these fertilisers.

Results obtained under laboratory conditions and the N application strategies concluded from these findings have to be verified under glasshouse conditions. In glasshouses temperature and water content are adjustable to ideal conditions for net N mineralisation and plant growth and in these terms are comparable to laboratory conditions, which can be optimised. Therefore, a transfer of results from laboratory to glasshouse conditions is probably possible. Under warm climatic conditions (tropics) a rapid initial N mineralisation of incorporated crop residues within two to eight weeks was observed (*Thönnissen* et al., 2000b). The N release should be synchronised with the demands of vegetable crops to result in a high N efficiency (*Iritani* and *Arnold*, 1960). The time of incorporation of crop residues into soil will modify the time of N release in soil. *Båth* (2001) reported, that a late incorporation (four weeks after

transplanting) caused a significantly lower N uptake of leek than an early incorporation (two weeks after transplanting). It can be assumed, that N application strategies may vary with different plant-derived and industrially-processed organic N fertilisers and soils.

The objective of this study was to test, if (i) a prediction of the N release from grain legumes and industrially-processed organic N fertilisers of plant and microbial origin is possible, (ii) different soils affect the N utilisation of these fertilisers, (iii) results from laboratory studies are transferable to glasshouse conditions and (iv) yield of horticultural crops and N utilisation of plant-derived and industrially-processed organic N fertilisers can be improved by N application strategies. To reach these aims, several milled seeds of grain legumes and industrially-processed organic N fertilisers were investigated for their net N mineralisation in an incubation experiment. N utilisation of fertilisers (unlabelled and ^{15}N labelled) in different soils was measured in pot experiments using perennial ryegrass as a model plant. In the glasshouse experiments with tomatoes grown under the regulations of organic production, fertilisers were applied at different times and yield, N uptake and N mineralisation in soil were investigated. For comparative reason fertilisers which in the past have been investigated by other authors, were used as references (Rizi-Korn, Horn).

2 Nitrogen release from plant-derived and industrially-processed organic nitrogen fertilisers used in organic horticulture

2.1 Abstract

As a consequence of the BSE-crisis, alternatives for fertilisers derived from animal residues are being sought for use in organic horticulture. Grain legumes (milled seeds of pea, yellow lupin, and fababean) and organic fertilisers of industrially-processed plant and microbial residues (Maltaflor®-spezial, Phytoperls®, Agrobiosol®, Rizi-Korn) were investigated as to their suitability as a replacement fertiliser. An incubation study was conducted to determine their net N mineralisation with one soil, whereas a pot experiment with four soils was used to determine the apparent N utilisation by perennial ryegrass. The objectives of this study were (1) to determine simple fertiliser characteristics that describe the N release and (2) to assess the influence of different soils on fertiliser N release.

Seventy percent of the total net mineralisation occurred within the first two weeks of the incubation experiment. The total net N mineralisation of the applied N was dependent on the fertiliser and ranged between 42-61% at the end of the experiment. Net N mineralisation was more closely related to the N content (r^2=0.97***) of the fertilisers than to their C/N ratio (r^2=0.79***), although both relationships were highly significant. Similar results, but with weaker relationships (r^2=0.60***), were obtained from the pot experiment determining apparent N utilisation. In both experiments, two industrially-processed residues of the seven tested fertilisers (Phytoperls®, Agrobiosol®) were not included in the analysis. Results from the pot experiment indicated that the apparent N utilisation of ryegrass was influenced by the soil, particularly the soil texture and soil organic matter, if the N content of fertilisers was low. In conclusion, the N content of the fertilisers was found to be a good indicator for their N release in most cases, although soils can modify this process.

2.2 Introduction

Vegetable crops have specific requirements for nitrogen (N) supply. Therefore, the N fertilisers that are used to produce organic vegetables should ensure high N turnover, fast N availability and continuous N supply.

Most vegetable growers provide their N supply through organic fertilisers, which predominantly contained animal residues such as horn or blood- or meat-meal in the past. However, fertilisers without animal residues are now required because of the BSE (*Bovine Spongiform Encephalopathy*) crisis (*Schmitz* and *Fischer*, 2003), with milled seeds of grain legumes and organic fertilisers of industrially-processed plant and microbial residues being used the most commonly. Many types of these fertilisers are available because of the varying composition of grain legumes in response to genotype and growing environment (e.g. *Bhardwaj* et al., 1998). Moreover, newly formulated industrial fertilisers are frequently placed on the market. For all these plant-derived and industrially-processed organic fertilisers, the potential for N release has to be specified before use and should be described by simple measures. Although these fertilisers differ markedly in N mineralisation (*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 glasshouse conditions. With crop residues, a rapid initial N mineralisation was observed after which the rate of mineralisation decreased (*Müller* and *Sundman,* 1988; *De Neve* and *Hofman*, 1996; *Thönnissen* et al., 2000b; *Khalil* et al., 2005). Numerous studies have attempted to find a relation between N mineralisation and the biochemical characteristics of crop residues. Frequently, either N content (*Iritani* and *Arnold*, 1960; *Frankenberger* and *Abdelmagid*, 1985; *Trinsoutrot* et al., 2000; *Mendham* et al., 2004) or C/N ratio (*Vigil* and *Kissel*, 1991) were strongly correlated to the N release of crop residues. However, other factors such as polyphenol content (*Constantinides* and *Fownes*, 1994) or a combination of factors (e.g. (lignin + polyphenol)/N ratio; *Fox* et al., 1990; *Handayanto* et al., 1994) 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 mineralisation. The question arises whether the N release of plant-de-

rived and industrially-processed organic fertilisers can be explained by similar characteristics as for crop residues.

N mineralisation of crop residues was strongly influenced by soil characteristics (*Smith* and *Sharpley*, 1990; *Drury* et al., 2003), particularly by clay content and CEC (*Khalil* et al., 2005). As such, the soils used in organic horticulture, which differ greatly in texture and OM, could affect fertiliser N release.

The objectives of this study were to test (1) whether N release of milled grain legumes and organic fertilisers of industrially-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 a pot experiment with perennial ryegrass. In both experiments, milled seeds of three grain legumes and three organic fertilisers of industrially-processed residues were compared with the commonly used fertiliser Rizi-Korn.

2.3 Materials and methods

2.3.1 Fertilisers

Milled seeds of three grain legumes (pea, *Pisum sativum* L.; yellow lupin, *Lupinus luteus* L.; and fababean, *Vicia faba* L.), organic fertilisers of industrially-processed residues from plants (Maltaflor®-spezial and Phytoperls®) and microorganisms (Agrobiosol®), and one reference fertiliser (Rizi-Korn) were investigated in both incubation and pot studies. Fertilisers were selected to obtain a wide range in N content and C/N ratio (Tab. 2-1). The N content of grain legumes ranged between 3.0-4.0%, whereas that for organic fertilisers of industrially-processed residues was much higher. The C content of the investigated fertilisers 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 fertiliser of industrially-processed residues.

Residues with a small particle size showed a stronger and longer N immobilisation and subsequently lower N mineralisation than did those with a large size (*Jensen*, 1994; *Corbeels* et al., 2003). Therefore, to minimise particle size effects so as to better compare the investigated fertilisers, grain legumes were coarsely milled to pass through a 1.5 mm screen (shear-mill, BRABENDER, Duisburg, Germany) and the

organic fertilisers of industrially-processed residues were sieved to pass through a 2.0 mm screen. Previous experiments have shown no differences in N release between these both particle sizes.

Table 2-1: N and C content and C/N ratio of plant-derived and industrially-processed organic fertilisers.

Fertiliser	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 fababean	4.0	40	9.9
Organic fertilisers of industrially-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 fertiliser)	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

2.3.2 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 (Tab. 2-2). The four glasshouse soils (0-20 cm, ≤ 5 mm) were obtained from organic vegetable growers.

Table 2-2: Characteristics of the glasshouse soils used.

Soil name	Soil horizon	Clay	Silt	Sand	C_{org}	N_t	C/N	pH $CaCl_2$	P CAL	K CAL	organic horticulture
		(——— % ———)							(mg / 100 g dry soil)		(years in cultivation)
S_{lOM} [(a)]	mollic [(b)]	9	26	65	1.4	0.11	12.8	7.1	11	n.d. [(c)]	2
S_{hOM} [(a)]	hortic [(b)]	12	18	70	3.1	0.28	11.1	7.5	17	43	32
L_{lOM} [(a)]	hortic [(b)]	23	56	21	1.9	0.23	8.4	7.1	17	22	13
L_{hOM} [(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

2.3.3 Incubation experiment

Seven plant-derived and industrially-processed organic fertilisers containing 40 mg N were mixed with 150 g dry, sandy soil low in OM (S_{lOM}) in 500 ml polyethylene flasks. The amount of fertiliser corresponded to 200 kg N/ha. Soil samples without added fertiliser 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 ψ_m = -0.016 MPa (9.4% gravimetric soil water content).

After incubation, the soil was analysed for nitrate (0.01 M $CaCl_2$, 1:2 soil:extractant; *Vilsmeier*, 1984) and ammonium (2 M 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).

2.3.4 Pot experiment

Four soils (Tab. 2-2) were tested in a pot experiment using five-liter Mitscherlich pots. Eight hundred milligrams of fertiliser 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 fertiliser was also included as a control. Perennial ryegrass seeds (*Lolium perenne*, L. cv. Li-floria; 1.5 g) were sown after the addition of the fertiliser. The pots were covered with a lid until the germination of the ryegrass and were regularly watered with distilled water to achieve 60% maximum water holding capacity. This value is equivalent to 16% (S_{lOM}), 19% (S_{hOM}), 18% (L_{lOM}), 34% (L_{hOM}) gravimetric soil water content.

In one soil (S_{hOM}), the germination of ryegrass was inhibited in the treatments with grain legumes. Therefore, 0.75 g of ryegrass were 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 13 weeks of cultivation, ryegrass was cut three times to 1.5 cm stubble height. Ryegrass was oven-dried for 24 h at 105°C to determine the dry matter content. Samples were milled 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 utilisation was calculated as the additional N uptake of ryegrass compared to the control divided by the added fertiliser N.

2.3.5 Statistical analyses

Statistical analyses used a paired t-test with a nominal alpha of 0.05 (SAS, Version 8.2). Furthermore, the SAS procedure “proc reg” was used to test relationships between selected datasets.

2.4 Results

2.4.1 Net nitrogen mineralisation

During the incubation period, net N mineralisation differed among the fertilisers. The reference fertiliser Rizi-Korn reached the highest net N mineralisation (70%) of all the fertilisers at the end of the incubation period and was one of the most rapidly mineralising fertilisers as well (Fig. 2-1). At the beginning of the incubation, high mineralisation rates were also observed for the industrial fertilisers Maltaflor®-spezial, Agrobiosol® and Phytoperls®, and milled seeds of fababean. But after 43 days, these fertilisers mineralised significantly less N as compared to Rizi-Korn. For two fertilisers, milled seeds of lupin and pea, net N mineralisation was negligible until day four and remained low throughout the whole incubation period. Consequently, only 40% of the added N was mineralised from these fertilisers by the end of the experiment. N mineralisation of all fertilisers, except pea, occurred primarily within 15 days (about 70%). Maximum net N mineralisation seemed to be largely attained after four weeks of incubation.

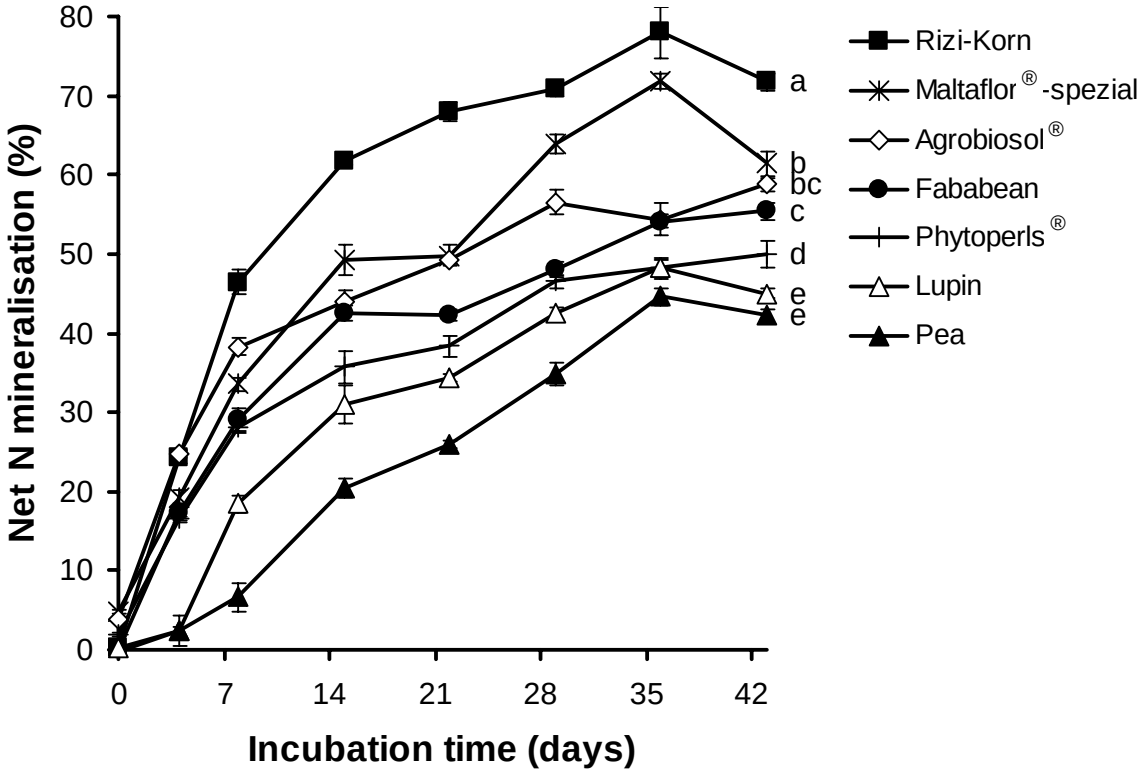

Figure 2-1: Time course of net N mineralisation of plant-derived and industrially-processed organic N fertilisers applied to a sandy soil low in OM during 43 days of incubation at 20°C and ψ_m = -0.016 MPa.

Letters indicate significant differences at the end of the incubation period (LSD, $p \leq 0.05$).
Error bars indicate standard deviations and are contained within the symbol if not indicated.

A very strong relationship ($r^2=0.97^{***}$) between the N content of the fertilisers and their net N mineralisation was found except for Agrobiosol® and Phytoperls® (Fig. 2-2a). These latter two fertilisers were characterised by high N contents and very narrow C/N ratios that are atypical for plant-derived materials. As such, they did not show the same relationship as the other fertilisers because their net N mineralisation was much lower in relation to their N content.

Because the C/N ratio was mainly determined by the variation in N content (Tab. 2-1), similar results were found for the relationship between net N mineralisation and C/N ratio (Fig. 2-2b). The coefficient of determination of the correlation was also high ($r^2=0.79^{***}$), but less significant compared to the N content.

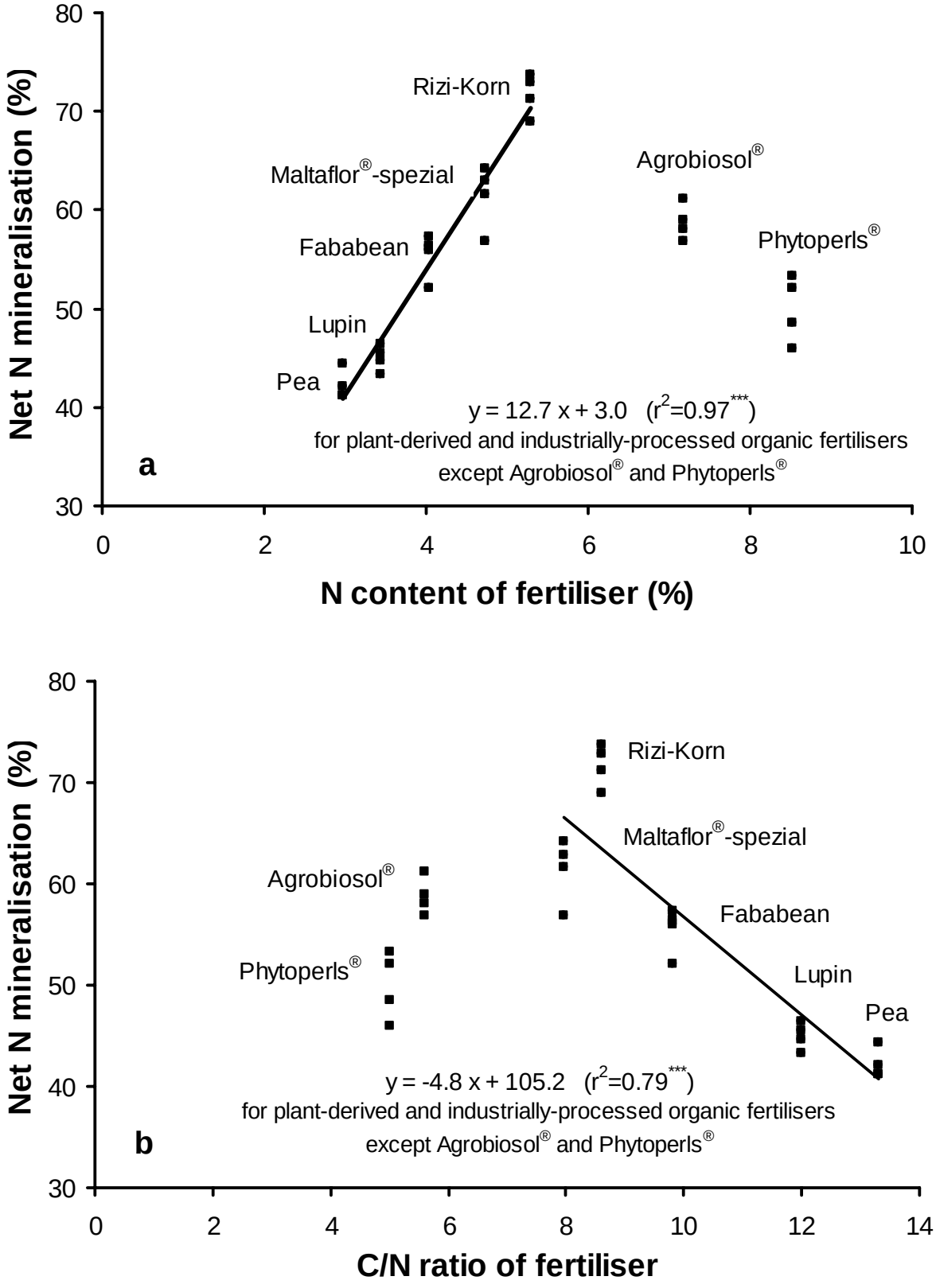

Figure 2-2: Relationship between net N mineralisation and N content (a) or C/N ratio (b) of plant-derived and industrially-processed organic N fertilisers applied to a sandy soil low in OM after 43 days of incubation at 20°C and ψ_m = -0.016 MPa.

2.4.2 Apparent nitrogen utilisation

As compared to the incubation experiment, largely similar results were obtained from the pot experiment with ryegrass and four different soils. The time course of the apparent N utilisation of all fertilisers with one soil (S_{lOM}) is shown in Figure 2-3 as a typical example.

The N mineralisation of the fertilisers differed strongly throughout the experiment. Most of the N released was already detected at the first cut (about 60% of the total mineralisation) except for pea and lupin.

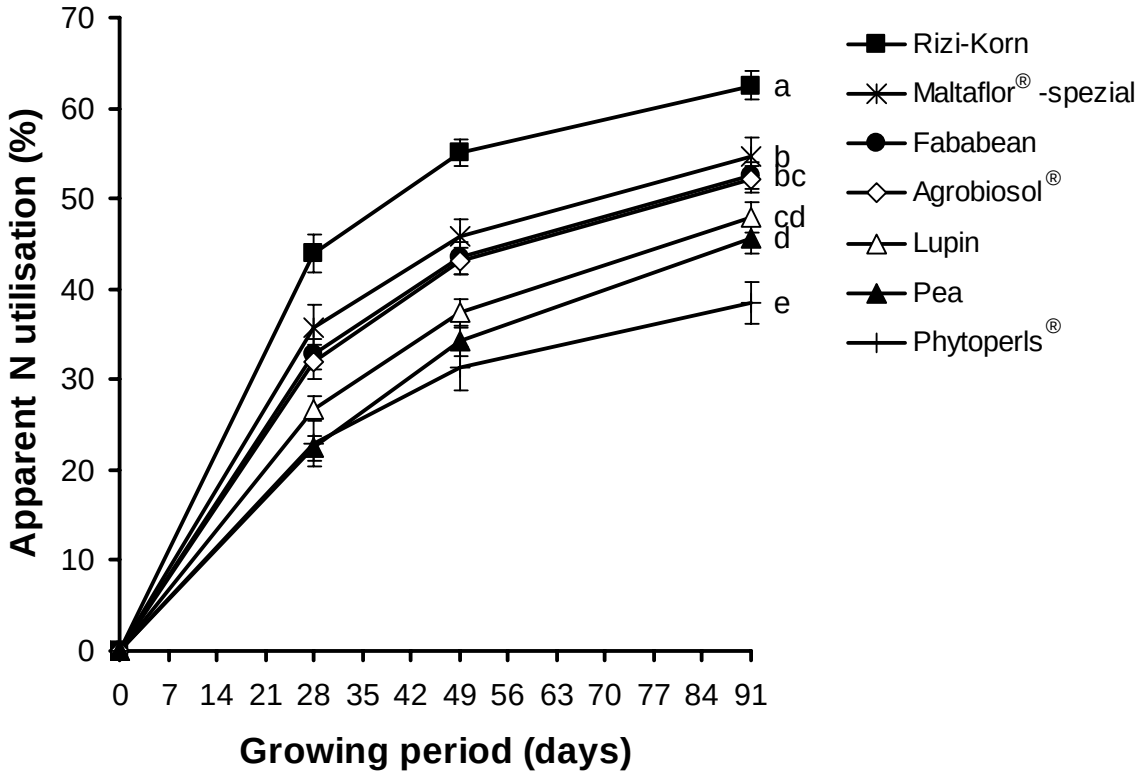

Figure 2-3: Apparent N utilisation of plant-derived and industrially-processed organic N fertilisers by perennial ryegrass during the pot experiment with sandy soil low in OM. Ryegrass was grown 91 days at 60% maximum water holding capacity and shoots were harvested three times.

Letters indicate significant differences at the end of the experiment (LSD, $p \leq 0.05$).
Error bars indicate standard deviations and are contained within the symbol if not indicated.

The apparent N utilisation in the pot experiment resulted almost in the same ranking of fertilisers as was found for the net N mineralisation in the incubation experiment. Only Phytoperls® performed comparatively poorer. However, compared to the net N mineralisation in the incubation experiment, the apparent N utilisation was about

10% lower for most fertilisers, but higher for lupin and pea. In spite of the longer experimental time as compared to the incubation experiment, the apparent N utilisation did not reach saturation at the end of the pot experiment.

For all tested soils and fertilisers, the apparent N utilisation was significantly related to each of N content and C/N ratio of the fertilisers (r^2=0.60*** and r^2=0.47***, respectively), again with the exclusion of Agrobiosol® and Phytoperls® (Fig. 2-4). However, a much higher variation in the apparent N utilisation in comparison to the incubation experiment was observed. Rizi-Korn showed a slightly higher apparent N utilisation than expected from its C/N ratio.

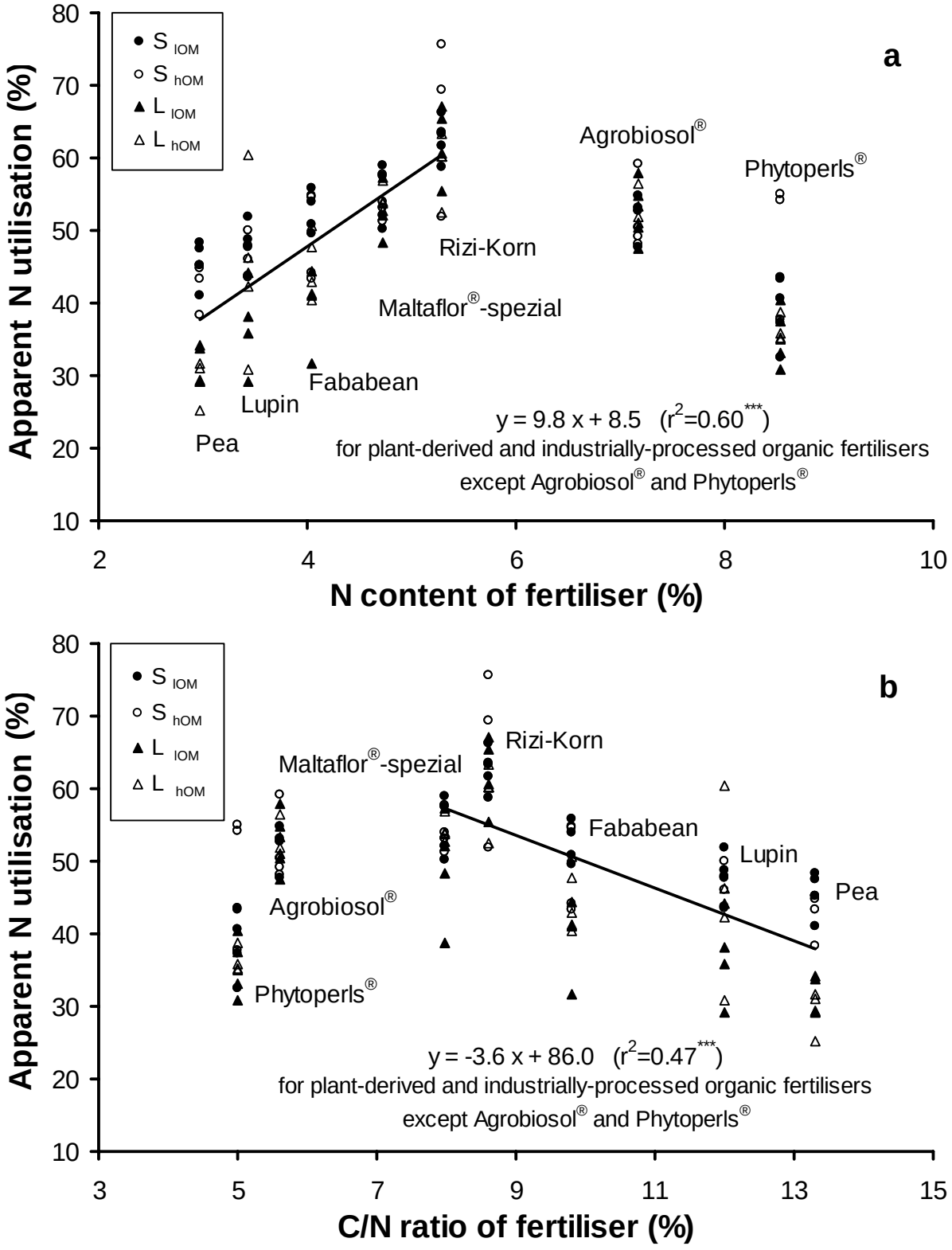

Figure 2-4: Relationship between apparent N utilisation of perennial ryegrass and N content (a) or C/N ratio (b) of plant-derived and industrially-processed organic N fertilisers as found with four different soils. Apparent N utilisation was calculated based on the cumulative N uptake (three cuts) during 91 days of growth.

Coefficient of determination was significant at the 0.1% probability level (n=80).

S: Sand, L: Loam, $_{lOM}$: low content of OM, $_{hOM}$: high content of OM

2.4.3 Effect of soils on the apparent nitrogen utilisation

For all soils, the apparent N utilisation of ryegrass increased with increasing N content of fertilisers except with Phytoperls® and Agrobiosol® (Tab. 2-3). The highest apparent N utilisation was achieved with Rizi-Korn. Intermediate values were generally obtained with Maltaflor®-spezial and Agrobiosol®, whereas the apparent N utilisation of milled seeds of pea was consistently low. An ANOVA indicated a highly significant effect of the fertilisers on the apparent N utilisation (Tab. 2-3). However, the soil type significantly influenced apparent N utilisation as well, with the difference in the apparent N utilisation between the best and the least efficient fertilisers being smaller for sandy soils than for the loamy soils. Moreover, the ANOVA revealed a weak, but significant interaction between the soils and the fertilisers. Ryegrass growing in L_{lOM} and fertilised with milled seeds took up relatively small amounts of N as compared to the other soils, whereas the apparent N utilisation with Phytoperls® in S_{hOM} was very high. By contrast, Agrobiosol®, Maltaflor®-spezial and Rizi-Korn seemed to supply ryegrass with similar amounts of N regardless of the soil (Tab. 2-3).

Table 2-3: Apparent N utilisation of perennial ryegrass from plant-derived and industrially-processed organic N fertilisers in four different soils after 91 days. ANOVA results present the effect of fertilisers, soils and their interaction on the apparent N utilisation.

Soil	Pea (3.0% N)	Lupin (3.4% N)	Faba-bean (4.0% N)	Maltaflor®-spezial (4.7% N)	Rizi-Korn (5.3% N)	Agrobio-sol® (7.2% N)	Phyto-perls® (8.5% N)
	Apparent N utilisation (%)						
S_{lOM}	46 d	48 cd	53 bc	55 b	63 a	52 bc	39 e
S_{hOM}	43 c	47 bc	49 bc	54 b	65 a	52 bc	48 bc
L_{lOM}	32 d	37 cd	40 c	49 b	62 a	53 b	36 cd
L_{hOM}	29 c	45 b	45 b	54 a	59 a	53 ab	36 c

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

Letters indicate significant differences among fertilisers for each soil (LSD, $p \leq 0.05$).
S: Sand, L: Loam, $_{lOM}$: low content of OM, $_{hOM}$: high content of OM

2.4.4 Comparison of the incubation and pot experiments

The data of the pot experiment supported the main findings of the incubation experiment, with a comparison of net N mineralisation to apparent N utilisation reflecting the similarity of the results (Fig. 2-5). Ideally, a 1:1 linear relationship might be expected if N release from the fertilisers was the same in both experiments. A strong linear relationship was indeed found, albeit only if Phytoperls® was excluded. Both experiments indicated the same ranking of the fertilisers when tested with the same soil.

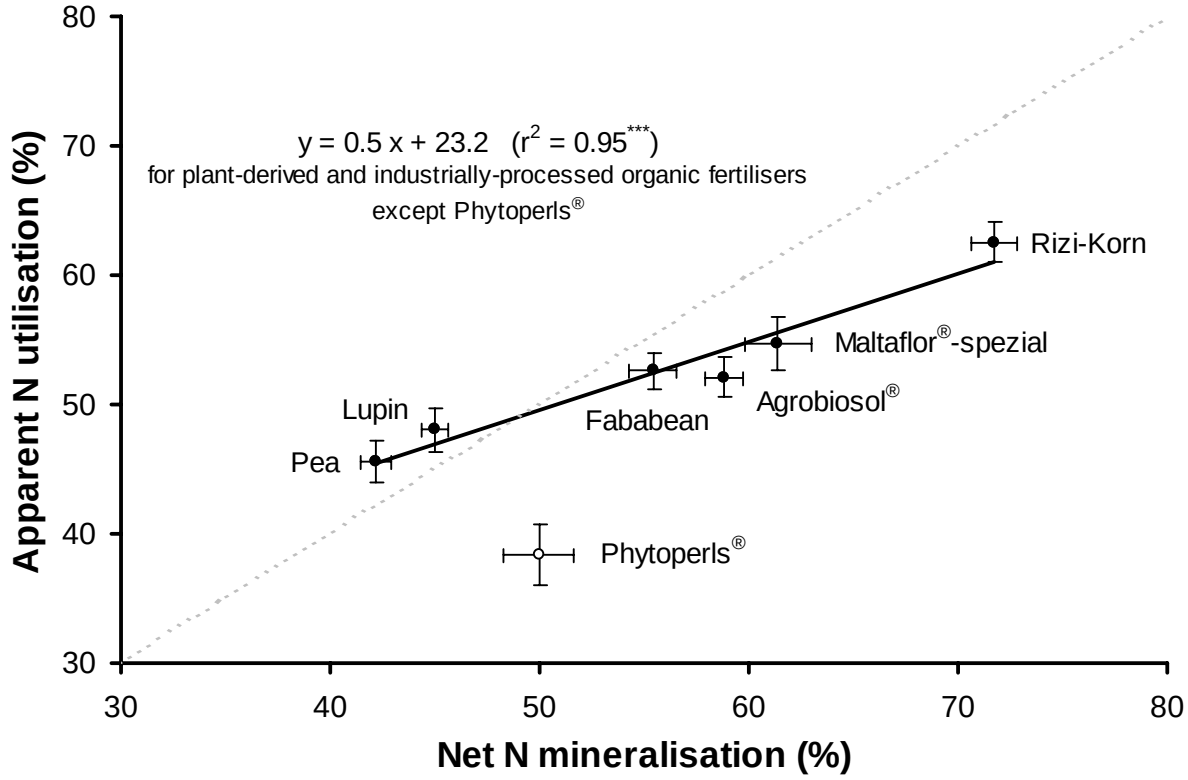

Figure 2-5: Relationship between apparent N utilisation measured at the end of the pot experiment (91 days) and net N mineralisation measured at the end of the incubation experiment (43 days) as obtained for a sandy soil low in OM.

Coefficient of determination was significant at the 0.1% probability level (n=6).

2.5 Discussion

In both experiments, the plant-derived and industrially-processed organic fertilisers differed strongly with regard to net N mineralisation and apparent N utilisation. This confirms earlier experiments with milled seeds of grain legumes and organic fertilisers of industrially-processed residues (*Braun* et al., 2000; *Schmitz* and *Fischer*, 2003) and is in agreement with results reported for crop residues (e.g. *Frankenberger* and *Abdelmagid*, 1985; *Smith* and *Sharpley*, 1990; *Khalil* et al., 2001; *Corbeels* et al., 2003; *Khalil* et al., 2005). N release was determined primarily by the N content of the fertilisers. Similarly, the C/N ratio predicted the N release in both experiments comparatively well. Two fertilisers, Agrobiosol® and Phytoperls® did not fit the observed relationship such that their N release has to be predicted differently. Moreover, Phytoperls® represented the only fertiliser that did not obey the highly significant relationship observed between N mineralisation and apparent N utilisation by ryegrass. A close relationship between N mineralisation and N utilisation of crop residues was also found by *Iritani* and *Arnold* (1960) and *Kuo* and *Sainju* (1998). The unusual N release characteristics of Phytoperls® is supported by other reports in the literature. Data from *Schmitz* and *Fischer* (2003) show a relatively poor N mineralisation of Phytoperls® as well. By contrast, *Heuberger et al.* (2005) reported a high N uptake of basil from this fertiliser 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 fertilisers could be ascribed to the relatively high C/N ratio of Rizi-Korn. For crop residues varying in N content, N mineralisation is often more closely correlated to the N content than to the C/N ratio (*Iritani* and *Arnold*, 1960, 0.9-4.0% N: r=0.93, C/N=10-48: r=-0.80; *Frankenberger* and *Abdelmagid*, 1985, 1.3-5.9% N: $r=0.93^{***}$, C/N=7-34: $r=0.88^{***}$; *De Neve* et al., 1994, 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 mineralisation for each sampling date throughout the 16 weeks of incubation (*Constantinides* and *Fownes*, 1994). Consequently, fertiliser N content is a suitable indicator for predicting the N release of plant-derived material as well as of some of the industrially-processed fertilisers, provided the N content of the fertilisers

are sufficiently different. If the difference in N content is too small, no correlation between N content and net N mineralisation will be found (*De Neve* and *Hofman*, 1996). Our data indicate that most of the applied N mineralised within 5-6 weeks. Seventy percent of this final N release occurred within 15 days. It can therefore be concluded that all the fertilisers examined allow for a fast N availability.

Different soils did not modify the relationship between apparent N utilisation 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-derived and industrially-processed organic fertilisers, with the effect of different soils being dependent on the fertiliser applied. For instance, the N uptake of ryegrass from fertilisers with a relatively high N content (Maltaflor®-spezial, Rizi-Korn, Agrobiosol®) was not influenced by the soil type. By contrast, N uptake from pea, the fertiliser with the lowest N content, seemed to be affected by soil texture because N utilisation by ryegrass was higher on sandy soils than on loamy soils. *Becker* et al. (1994) found that the N release from crop residues in an incubation study was much higher in a clay than in a sandy soil. A similar result was obtained by *Schmitz* and *Fischer* (1994) in a pot experiment with ryegrass fertilised with horn. The apparent N utilisation 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. An effect of soil texture on N mineralisation was also described by *Strong* et al. (1999) and *Khalil* et al. (2005).

In addition to soil texture, OM might also modify N transformation processes in soil. Here, the loamy soil low in OM resulted in the lowest N utilisation of ryegrass if grain legumes or Phytoperls® were applied. This negative effect was not observed with Agrobiosol® and Rizi-Korn. But, 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 utilisation of grain legumes on the loamy soil low in OM confirmed that ground residues incorporated into soil resulted in larger and longer N immobilisation and subsequently in a lower re-mineralisation in the finer textured soil than in the coarse textured soil (*Corbeels* et al., 2003). *Smith* and *Sharpley* (1990) concluded that no particular effect of soil type on N mineralisation was evident. The conflicting results highlight the need for further re-

search to clarify the role of soil characteristics in N release of plant-derived and industrially-processed organic fertilisers.

2.6 Conclusion

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

3 Influence of soil on the nitrogen utilisation of ryegrass from plant-derived and industrially-processed organic nitrogen fertilisers

3.1 Abstract

Organic vegetable growers that seek an alternative to animal residue based organic nitrogen (N) fertilisers can select among a number of different plant-derived and industrially-processed organic fertilisers. However, the effect of soil properties on the N release of these fertilisers has not yet been studied. Therefore, three pot experiments were conducted to investigate the influence of different soils on the N utilisation of these fertilisers. Grain legumes (unlabelled and ^{15}N labelled) and industrially-processed plant residues were applied as fertilisers to ryegrass as a model plant, with the effects being evaluated by the calculation of the apparent N utilisation and, in one case, by the N use efficiency.

The N release was influenced by the N content of the fertilisers, with the apparent N utilisation and the N use efficiency increasing with increasing N content. In addition, soils modified N utilisation by the plants, but this effect was dependent upon the N content of the fertilisers. If the N content was low (pea), the apparent N utilisation by ryegrass was significantly higher in the coarse textured soils as compared to the fine textured soils. However, if the N content of the fertiliser was high, plant N uptake was unaffected by the soils. In an experiment conducted with a wider range of soils, the apparent N utilisation of two fertilisers with a medium N content differed between the soils, although the differences were not obviously related to any of the soil texture, soil C_{org} content, or N mineralisation of the unfertilised soil. However, a higher N mineralisation from the unfertilised soils was associated with a higher N use efficiency of ryegrass from all tested fertilisers, indicating a positive soil-fertiliser interaction in these soils. It is concluded that none of the soil parameters examined could account in isolation for variations in the N utilisation of the fertilisers in different soils. However, the use of fertilisers with a high N content are generally recommended to achieve a high N utilisation, especially for fine textured soils and soils with a high N release.

3.2 Introduction

Sources of nitrogen (N) for crop production in organic farming include N_2 fixation by legumes and organic fertilisers such as crop residues, animal manure or commercial organic fertilisers (*Power* and *Doran*, 1984). As a result of the recent BSE-crisis, the use of grain legumes and organic fertilisers of industrially-processed plant residues has become increasingly common. In general, the N release of these fertilisers was found to be closely related to their N content (*Stadler* et al., 2006). More specifically, in the year of application, N availability from organic fertilisers determined as mineral-fertiliser equivalents ranges widely from 10 (biocompost) to 90% (urine). For fertilisers used in organic horticulture, these values typically vary between 30-70% (*Gutser* et al., 2005). Consequently, soils tend to increase in total organic matter (OM) and mineralisable N (*Power* and *Doran*, 1984) when these fertilisers are regularly applied. Soil N supply – both initial levels, which can now be quantified quickly and cost-effectively (*Schmidhalter*, 2005), and mineralisable soil N are important components in optimising N fertiliser application (*Olfs* et al., 2005).

Soils used for horticulture can differ greatly in their N_t and C_{org} content as well as in their textures (*Legg* and *Stanford*, 1967). Hence, a key question is whether or not the different soil properties affect the N release of plant-derived and industrially-processed organic fertilisers. For instance, it is documented that soil affects the N mineralisation of incorporated material like crop residues or manure. Soils that were high in silt and clay immobilised more N from crop residues (1.3-2.8% N) than did sandy soils (*Egelkraut* et al., 2000). Moreover, remineralisation of immobilised N shows a greater delay in soils with a higher clay content (*Whitmore* and *Groot*, 1997; *Egelkraut* et al., 2000). It has also been suggested that fine textured soils tend to mineralise less N from crop residues and manure than do coarse textured soils (*Bosatta* and *Ågren*, 1997; *Egelkraut* et al., 2000; *Griffin* et al., 2002; *Thomsen* et al., 2003b). This is supported by a significant negative relationship between clay + silt content and the N mineralisation rate of grassland soils (*Hassink*, 1994), which is explained by a physical protection of OM against decomposition (*Hassink*, 1992).

Thomsen et al. (2001) showed that an increase in soil clay content from 10 to 40% decreased the net N mineralisation of ^{15}N labelled ryegrass by about 10%, whereas the addition of silt sized organomineral complexes did not affect net N mineralisation. They hypothesized that soil texture has only a small effect on net N mineralisation in

soils with similar mineralogical compositions and cropping histories, and identical soil water matrix potentials. *Paré* and *Gregorich* (1999) reported that the effect of soil texture is dependent on the kind of crop residue used: N mineralisation from maize (2.5% N) and soybean (1.7% N) was highest in fine textured soils, but was highest from alfalfa (3.4% N) in a sandy soil. Furthermore, alfalfa showed a positive “added nitrogen interaction” (ANI) in sandy soil and a negative ANI in more fine textured soils, whereas the ANIs of maize and soybean were negative for all soils.

Only a few reports deal with the interaction of incorporated organic fertilisers and soil OM. For mineral fertilisers, *Hart* et al. (1986) found a larger positive ANI for $(^{15}NH_4)_2SO_4$ in a soil with higher C_{org} content compared to a soil that was lower in C_{org}. When ryegrass was grown in 21 different grassland soils fertilised with ^{15}N labelled ammonium nitrate, yield without and with fertiliser was related to the total OM of the soils ($r=0.68^{***}$, $r=0.69^{***}$), but was not significantly related to their clay or sand content or their soil pH (*Whitehead*, 1984). Moreover, the correlation coefficients between N use efficiency and different soil properties (sand, silt and clay content; OM; C/N ratio of the OM) were not significant ($r<0.3$). The amount of available N from either fertilised or unfertilised soils was not significantly related to either total soil OM or soil N_t ($r<0.4$) (*Whitehead*, 1984).

In their recent review, *Cabrera* et al. (2005) recommended that additional research on the effect of soil characteristics on net N mineralisation should be conducted. Furthermore, given that the body of evidence indicates that the N release of plant-derived and industrially-processed organic N fertilisers may depend on soil properties, we examined the influence of different soils on the N utilisation of ryegrass fertilised with plant-derived (unlabelled and ^{15}N labelled) and industrially-processed organic fertilisers in pot experiments.

3.3 Materials and methods

3.3.1 Pot experiments

Three sets of pot experiments with ryegrass (in five-liter Mitscherlich pots) were conducted using different plant-derived and industrially-processed organic N fertilisers varying in N content (Tab. 3-1). We examined a number of different soils (Tab. 3-2a, Tab. 3-2b), all of which were already managed according to the European Union Standards (EEC no. 2092/91) on organic production of agricultural products over a period of anywhere from 2 to 33 years. Glasshouse and field soils (0-20 cm layer) were sieved (≤ 5 mm) and homogenised. The soils varied greatly in texture and in their C_{org} content, the latter of which is presented as a subscript behind the soil name throughout the remainder of the chapter.

Table 3-1: N and C content and C/N ratio of the tested fertilisers.

Fertiliser	N content (%)	C content (%)	C/N ratio
Coarse meal of straw from pea and fababean [(c)]	1.5	44	30.1
Coarse meal of pea [(a)]	3.0	40	13.3
Coarse meal of lupin [(a)]	3.4	41	12.0
Coarse meal of pea [(c)]	3.7	44	11.7
Coarse meal of fababean [(a, b)]	4.0	40	9.9
Coarse meal of lupin [(c)]	4.6	46	9.9
Maltaflor®-spezial [(a, b)]	4.7	38	8.0
Rizi-Korn [(a)]	5.3	46	8.6

[(a)] fertilisers used in the first pot experiment with unlabelled fertilisers
[(b)] fertilisers used in the second pot experiment with unlabelled fertilisers
[(c)] fertilisers used in the third pot experiment with ^{15}N labelled fertilisers

In the first pot experiment, coarse meal of each of pea (*Pisum sativum* L., 3.0% N), lupin (*Lupinus luteus* L., 3.4% N) and fababean (*Vicia faba* L., 4.0% N); Maltaflor®-spezial (4.7% N); and Rizi-Korn (5.3% N) were each tested in four soils (Tab. 3-2a). In the second pot experiment, coarse meal of fababean (4.0% N) and Maltaflor®-spezial (4.7% N) were each investigated in seven soils (Tab. 3-2b). In the third pot experiment, the fate of N from ^{15}N labelled fertilisers derived from coarse meal of a straw mixture from pea and fababean (1.5% N), and a coarse meal of either pea (3.7% N) or lupin (4.6% N), was studied in each of four soils (Tab. 3-2b).

Table 3-2a: Characteristics of the soils used in the first pot experiment.

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

[a] subscript denotes C_{org} content

[b] soil names and horizons follow *FAO* (1998)

[c] n.d. – not determined

Table 3-2b: Characteristics of the soils used in the second pot experiment (unlabelled fertilisers) and in the third pot experiment (^{15}N labelled fertilisers).

Soil name	Soil horizon	Clay	Silt	Sand	C_{org}	N_t	C/N	pH $CaCl_2$	P CAL	K CAL	organic farming
		(———— % ————)							(mg / 100 g dry soil)		(years in cultivation)
sandy loam $_{1.2}$ [a, b, c]	ochric [b]	10	30	60	1.2	0.12	9.8	6.2	10	11	9
silt loam $_{1.3}$ [a, b, c]	ochric [b]	16	67	16	1.3	0.13	10.2	6.4	4	23	9
sandy loam $_{1.7}$ [a, b, c, d]	mollic [b]	9	26	65	1.7	0.14	12.4	7.6	10	9	3
silt loam $_{3.0}$ [a, b, d]	hortic [b]	23	56	21	3.0	0.27	11.1	7.0	27	41	14
sandy loam $_{3.4}$ [a, b, c, d]	hortic [b]	12	18	70	3.4	0.31	10.8	7.6	23	61	33
silt loam $_{4.8}$ [a, b, c, d]	hortic [b]	24	53	23	4.8	0.39	12.4	7.3	39	21	17
silty clay loam $_{6.6}$ [a, b, c]	hortic [b]	28	53	19	6.6	0.64	10.3	7.7	46	11	17
loam $_{8.4}$ [a, b, c]	hortic [b]	20	43	37	8.4	0.63	13.3	7.3	36	12	19

[a] subscript denotes C_{org} content

[b] soil names and horizons follow *FAO* (1998)

[c] soils used in the second pot experiment without labelled fertilisers

[d] soils used in the third pot experiment with ^{15}N labelled fertilisers

Fertiliser in the amount of 800 mg N/pot (255 kg N/ha) was mixed into the upper layer of the soil in either four (first experiment) or three replicates (second and third experiments) and compared with a control treatment without fertiliser. Perennial ryegrass (*Lolium perenne*, L. cv. Lifloria; 1.5 g/pot) was sown either one day (first experiment) or two weeks (second and third experiments) after fertiliser addition. Pots were irrigated regularly with distilled water to achieve 60% maximum water holding capacity. This was equivalent to 12% gravimetric soil water content for sandy loam $_{1.2}$, 21% for silt loam $_{1.3}$, 16% for sandy loam $_{1.4}$, 15% for sandy loam $_{1.7}$, 18% for silt loam $_{1.9}$ and silt loam $_{3.0}$, 19% for sandy loam $_{3.1}$, 20% for sandy loam $_{3.4}$, 26% for silt loam $_{4.8}$, 28% for silty clay loam $_{6.6}$, 34% for silt loam $_{8.0}$ and 31% for loam $_{8.4}$.

All pots of the first experiment were uniformly treated with 0.3 g potassium as K_2SO_4 one week after the first harvest. In the other two experiments, 0.2 g potassium was applied one week before the first harvest and one week after the second harvest. Pots in the third experiment and those containing sandy loam $_{3.4}$ in the second experiment were also fertilised with 0.1 g potassium one week after the third harvest.

During the 13 (first experiment) or 12 weeks of cultivation (second experiment), ryegrass was harvested three times (and four times for the sandy loam $_{3.4}$ soil in the second experiment). After drying (105°C for 24 h), the N content of each harvest was analysed separately using an FP-328 Nitrogen/Protein Determinator (LECO CORPORATION, St. Joseph, Michigan, USA). The apparent N utilisation was calculated from the total N uptake of all three cuttings.

In the third experiment, ryegrass yields from four cuttings over 13 weeks were summed. After drying (60°C for 3 days), N and ^{15}N content for each harvest were analysed separately using an ANCA-MS (EUROPA SCIENTIFIC SL 20-20, Crewe, GB).

3.3.2 Calculation of apparent nitrogen utilisation and nitrogen use efficiency

Apparent N utilisation of ryegrass was calculated as:

Apparent N utilisation (%) = apparent N uptake (g/pot) / total N applied (g/pot) x 100

Apparent N uptake (g/pot) = (DM_{fert} x N_{fert}) - ($DM_{control}$ x $N_{control}$),

where DM_{fert} is the dry matter yield of the fertilised pots (g/pot), N_{fert} is the N content of the ryegrass in the fertilised pots (%), $DM_{control}$ is the dry matter yield of the control pots (g/pot), $N_{control}$ is the N content of the ryegrass in the control pots (%).

N use efficiency was calculated as:

N use efficiency = 100 x N_{dfF} (g/pot) / total N applied (g/pot),

where N_{dfF} is N derived from fertiliser, which was calculated as:

N_{dfF} (g/pot) = N_{dfF} (%) x N uptake (g/pot)

N_{dfF} (%) = atom % ^{15}N excess of plant N / atom % ^{15}N excess of fertiliser N,

where atom % ^{15}N excess was obtained by subtracting the abundance of the control sample (plant and soil respectively) from the measured value.

3.3.3 Statistical analyses

Statistical analyses employed a t-test (LSD-test) using a nominal alpha value of 0.05 (SAS, Version 8.2).

3.4 Results

3.4.1 Apparent nitrogen utilisation

The apparent N utilisation of ryegrass from the five plant-derived and industrially-processed organic residues was influenced predominantly by the fertiliser used (F = 45.69), but also to a lesser degree by the soil (F = 10.93). An increase in fertiliser N content increased the apparent N utilisation in each soil (Fig. 3-1), whereas the influence of the soil on the apparent N utilisation was dependent on the fertiliser. No effect of the soil was observed when the N content of the fertilisers was high. By contrast, the apparent N utilisation of ryegrass grown in the sandy loam soils was significantly higher compared to the silt loam soils under the application of a fertiliser

with a low N content (pea). Consequently, the decline in apparent N utilisation from fertilisers of decreasing N contents was less significant in the coarse textured soils.

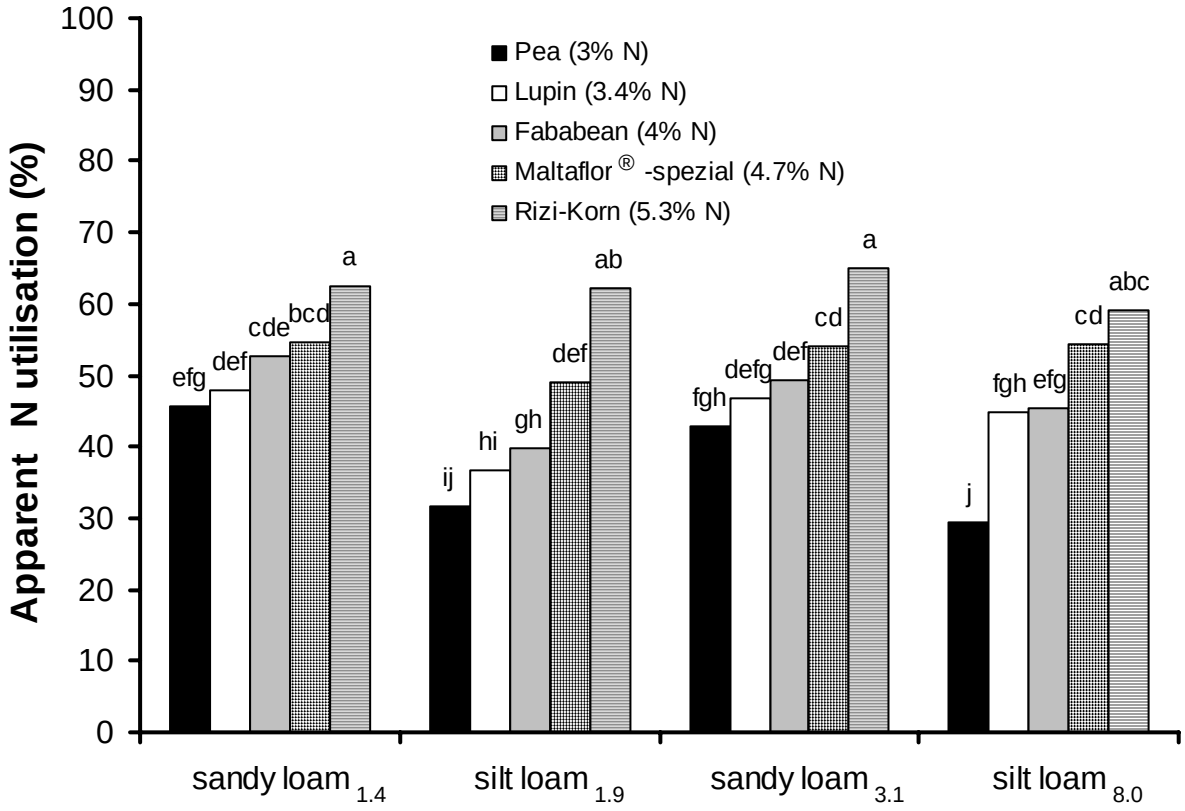

Figure 3-1: Apparent N utilisation of perennial ryegrass from plant-derived and industrially-processed organic N fertilisers in four different soils after 91 days. ANOVA results present the effect of fertilisers, soils and their interaction on the apparent N utilisation.

Different letters indicate statistically significant differences (LSD, $p \leq 0.05$).
subscript denotes C_{org} content

ANOVA	main effects + interactions	DF	F Value	Pr > F
	fertiliser	4	45.69	< 0.0001
	soil	3	10.93	< 0.0001
	soil x fertiliser	12	1.56	0.1276

To confirm the influence of soil texture on N utilisation, a second experiment using a higher number of soils was conducted, but only two fertilisers (fababean, Maltaflor®-spezial) with similar, intermediate values of N content were used. Their effect on the apparent N utilisation was statistically still significant, although the probability value was higher compared to the previous experiment. Both the influence of the soils on the N uptake of the plants (F = 9.75) and the interaction between soils and fertilisers

(F = 3.14) were significant. Milled seeds of fababean and Maltaflor®-spezial both showed a relatively high level of N utilisation in all soils (Fig. 3-2), although specific values did vary from 60% (Maltaflor®-spezial for silty clay loam $_{6.6}$) to about 40% (fababean for either silt loam $_{4.8}$ or loam $_{8.4}$). The N utilisation of fababean was equal to that of Maltaflor®-spezial, except for two soils (silt loam $_{4.8}$ and loam $_{8.4}$) where the N utilisation of fababean was significantly lower. In contrast to the first experiment, differences in the apparent N utilisation between the fertilisers were not obviously related to the soil texture. For example, in the fine textured, silt soils, the apparent N utilisation of Maltaflor®-spezial was both superior (silt loam $_{4.8}$, loam $_{8.4}$) or equal (silt loam $_{1.3}$, silty clay loam $_{6.6}$) to that of fababean.

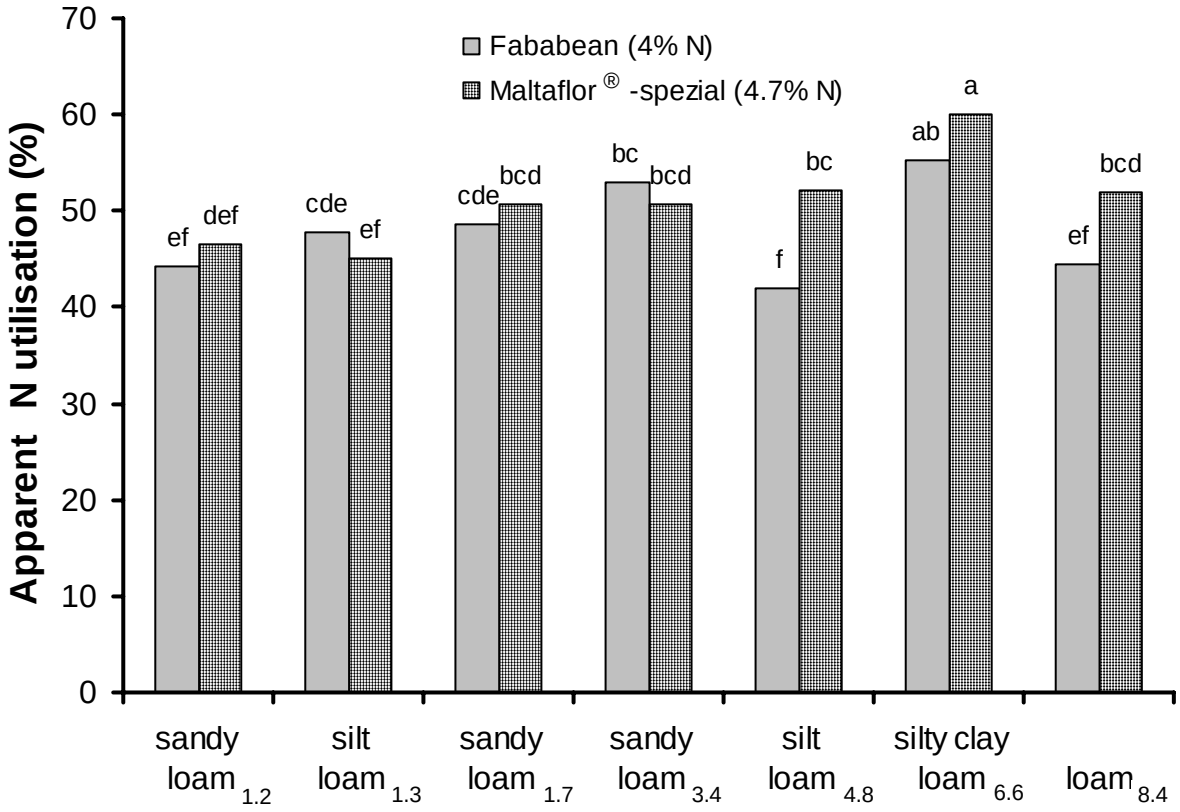

Figure 3-2: Apparent N utilisation of perennial ryegrass from fababean and Maltaflor®-spezial in seven different soils after 84 days. ANOVA results present the effect of fertilisers, soils and their interaction on the apparent N utilisation.

Different letters indicate statistically significant differences (LSD, $p \leq 0.05$).
subscript denotes C_{org} content

ANOVA	main effects + interactions	DF	F Value	Pr > F
	fertiliser	1	9.26	0.0051
	soil	6	9.75	< 0.0001
	soil x fertiliser	6	3.14	0.0176

For both fertilisers, the apparent N utilisation tended to increase slightly in those soils with higher C_{org} contents. However, it was equally apparent, particularly for fababean, that soils high in C_{org} (e.g., silt loam $_{4.8}$, loam $_{8.4}$) could not accommodate a high N utilisation. Because these soils combine high C_{org} content with a silty, finer soil texture, we assumed that the turnover of organic substance might explain the observed differences in the N utilisation between the soils.

3.4.2 Nitrogen uptake from unfertilised soils

The turnover of the organic substance can be described by the amount of N uptake of plants from native, unfertilised soils. The N uptake by ryegrass from unfertilised soils differed greatly between the different soils (Fig. 3-3). Two soils in particular (sandy loam $_{3.4}$, silt loam $_{4.8}$) released high amounts of plant available N, whereas the N uptake from the remaining soils was much lower. The N release from a given soil was not obviously related to its C_{org} content. Moreover, no clear relationship existed between the N availability (Fig. 3-3) from a given, unfertilised soil and the apparent N utilisation (Fig. 3-2). Soils with a high N release (sandy loam $_{3.4}$, silt loam $_{4.8}$) did lead to neither extremely high nor low fertiliser N utilisation, but one of these soils (silt loam $_{4.8}$) showed distinct differences in the N utilisation between fababean and Maltaflor®-spezial. Moreover, soils with low or very low N release lead to any of high (silty clay loam $_{6.6}$), low (sandy loam $_{1.2}$, silt loam $_{1.3}$) or even fertiliser dependent (loam $_{8.4}$) apparent N utilisation. Consequently, the turnover of soil OM – determined as plant N uptake from native soils – also could not account for differences in the apparent N utilisation.

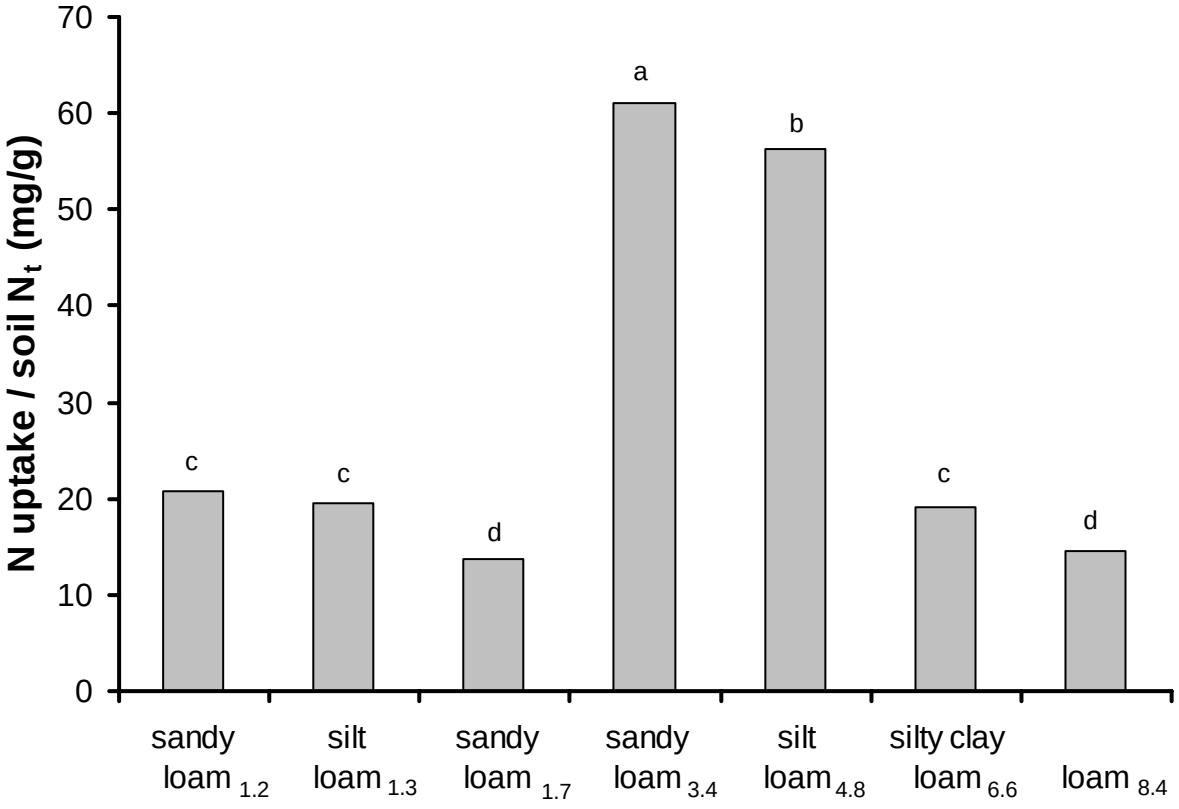

Figure 3-3: N uptake of perennial ryegrass related to total soil N in seven unfertilised soils after 84 days.

Different letters indicate statistically significant differences (LSD, $p \leq 0.05$).
subscript denotes C_{org} content

3.4.3 Nitrogen use efficiency

A further way to follow the fertiliser N turnover processes in more detail is the application of ^{15}N labelled material, which can help specify the interaction between soil and fertiliser through the proportion of fertiliser N in plant N uptake (= N use efficiency). In this experiment, the results were similar to those in the previous experiment: soil N release determined as plant N uptake from the unfertilised soils differed greatly, with both high (sandy loam $_{3.4}$, silt loam $_{4.8}$) and low (sandy loam $_{1.7}$, silt loam $_{3.0}$) values being observed (Tab. 3-3). The apparent N utilisation increased when the N content of the plant-derived fertilisers was higher, and the overall influence of the fertilisers ($F = 3800$) was much stronger than that of either the soils themselves ($F = 112$) or of the interaction between fertilisers and soils ($F = 38$), although each effect was very highly significant. The application of straw immobilised N, which was more evident in the soils with a higher N release. For these latter soils, the increase in the apparent N utilisation with increasing fertiliser N content was more

pronounced than for those soils demonstrating a low N release. These differences were not as obviously associated with the soil texture as was the case in the first experiment, although the role of soil N release became increasingly evident when the two groups of soil textures (sandy and silty soils) were considered separately. Then a relationship of soil N release with soil C_{org} content was observed. And in this case, straw immobilised more N and pea mineralised less N from soils with a high N turnover, whereas the apparent N utilisation of lupin was higher in such cases. Generally, the soil dependent differences in the apparent N utilisation were more obvious for the low N fertilisers than for those fertilisers with high N content.

Table 3-3: N uptake of perennial ryegrass from unfertilised soils and apparent N utilisation of perennial ryegrass from plant-derived N fertilisers in four different soils after 91 days. ANOVA results present the effect of fertilisers, soils and their interaction on the apparent N utilisation.

Soil	N uptake / soil N_t	Straw (1.5% N)	Pea (3.7% N)	Lupin (4.6% N)
		Apparent N utilisation		
	mg/g	(——————— % ———————)		
sandy loam $_{1.7}$	17 c	-1 a	45 a	49 ab
sandy loam $_{3.4}$	64 a	-15 c	33 b	53 a
silt loam $_{3.0}$	14 d	-7 b	34 b	41 c
silt loam $_{4.8}$	60 b	-22 d	24 c	47 b

ANOVA	main effects + interactions	DF	F Value	Pr > F
	fertiliser	2	3800	< 0.0001
	soil	3	112	< 0.0001
	soil x fertiliser	6	38	< 0.0001

Different letters indicate statistically significant differences among soils for each fertiliser (LSD, $p \leq 0.05$).

subscript denotes C_{org} content

Similar to the apparent N utilisation, N use efficiency increased when fertiliser N content was higher (Tab. 3-4), although the differences were less pronounced. Nitrogen was even taken up from straw and this was significantly higher in those soils higher in N release. The difference in the N use efficiency of higher N content fertilisers (pea, lupin) was less clearly related to this soil parameter. The N uptake from lupin was higher in soils with higher N releases, but N use efficiency for pea could not be attributed to either soil N release or to soil texture alone. However, subdividing the

soils into two groups of similar soil texture again suggested that, within each of the groups of the sandy and the silty soils, N use efficiency of all tested fertilisers was superior in soils with a high N release.

Table 3-4: N use efficiency of perennial ryegrass from plant-derived fertilisers in four different soils after 91 days. ANOVA results present the effect of fertilisers, soils and their interaction on the N use efficiency.

Soil	Straw (1.5% N)	Pea (3.7% N)	Lupin (4.6% N)
	N use efficiency		
	(——————— % ———————)		
sandy loam $_{1.7}$	4 c	38 b	39 c
sandy loam $_{3.4}$	14 a	42 a	47 a
silt loam $_{3.0}$	3 c	30 c	34 d
silt loam $_{4.8}$	10 b	37 b	41 b

ANOVA	main effects + interactions	DF	F Value	Pr > F
	fertiliser	2	9131	< 0.0001
	soil	3	561	< 0.0001
	soil x fertiliser	6	20	< 0.0001

Different letters indicate statistically significant differences among soils for each fertiliser (LSD, $p \leq 0.05$).

subscript denotes C_{org} content

3.5 Discussion

In this study, N utilisation of plant-derived and industrially-processed organic N fertilisers was significantly correlated with the N content of fertilisers, confirming earlier results (*Stadler* et al., 2006). Across the whole range of fertilisers with their differing N contents (ranging from low in straw at 1.5% N to high in Rizi-Korn at 5.3% N), soil dependent differences in the apparent N utilisation were less pronounced at higher fertiliser N contents. However, the apparent N utilisation for fertilisers with a medium N content (fababean, Maltaflor®-spezial) might also be significantly affected by soil properties.

Fertilisers with a lower N content (straw, pea) generally released less N or even immobilised more N in the silty soils as compared to the sandy soils, although in one experiment (straw and pea 3.7% N) this was only true within the two groups of soils that were similar in the N turnover of organic substance. A lower N utilisation of organic fertilisers on silty soils is supported by the majority of related studies in the literature. Crop residues and manure, both of which had a low N content, tended to result in a lower or slower N mineralisation in finer textured soils as compared to coarser ones (e.g. *Egelkraut* et al., 2000; *Thomsen* et al., 2003b). However, our results indicate that the apparent N utilisation of fertilisers is less determined by soil texture if the N content of the former is medium or higher.

Soil texture was therefore not the only factor affecting the apparent N utilisation. When soils are subdivided into two groups of similar texture (i.e., sandy versus silty soils) it was indicated that soil C_{org} content within each group might play a certain role for the apparent N utilisation. This finding was the most obvious for straw (1.5% N) and pea (3.7% N), where the N immobilisation of straw and the lower apparent N utilisation of pea were more pronounced in the higher C_{org} content soils. However, this trend may also be restricted to fertilisers with lower N contents and, in some cases, it was not possible to relate observed differences in apparent N utilisation to soil C_{org} contents. The latter finding agrees with results obtained by *Whitehead* (1984) who observed that the apparent N utilisation of ^{15}N labelled ammonium nitrate by ryegrass in 21 soils ranged between 45-67%, but was not related to soil C_{org} content. Similarly, *Legg* and *Stanford* (1967) showed that the fertiliser N uptake ($^{15}NO_3^-$) by oat on 12 surface greenhouse soils ranging from 0.5-3.9% C was also not related to soil C_{org} content.

Apart from soil C_{org} content, the turnover of the organic substance might affect the N utilisation of fertilisers on different soils. Soils with a high OM turnover are thought to have a large pool of labile, decomposable C and a smaller pool of stable, texture dependent C (*Rühlmann*, 1999). In two of the soils investigated here (sandy loam $_{3.4}$, silt loam $_{4.8}$), the OM turnover as determined by the N uptake of plants from native, unfertilised soils significantly exceeded those of the remaining soils. This N release by the two soils was also not obviously related to their soil C_{org} contents, which is in agreement with other studies (*Tabatabai* and *Al-Khafaji*, 1980; *Whitehead*, 1984; *Warren* and *Whitehead*, 1988) that reported that the cumulative N uptake of plants from unfertilised soils with a wide range of organic substance was at best only weakly correlated to this parameter. In contrast to these studies, however, *Vellinga* and *André* (1999) reported that soil N mineralisation from unfertilised soils was significantly affected by soil OM. *Magdoff* (1991) obtained the highest amounts of available N from soils with medium N_t and C_{org} content. He explained this result by the fact that at low OM contents, the mineralisation rate was high, but less N was available due to low contents of organic N. And soils high in N_t and C_{org} had low mineralisation rates which consequently resulted in low amounts of mineralised N as well. This might explain the high N mineralisation observed here in both the sandy loam $_{3.4}$ and silt loam $_{4.8}$. The mineralisation in these soils was markedly superior to those of all other soils, regardless of whether their C_{org} contents were higher or lower.

Magdoff (1978) concluded that soils with a high mineralisation rate of soil OM may also rapidly mineralise N from manure and in a soil with a low soil N mineralisation rate manure N release will be lower. Our studies indicate that soils with a high N release will not necessarily result in a high apparent N utilisation of the fertilisers. However, the N release from unfertilised soils was still a suitable indicator for the gross N turnover of fertilisers, particularly within the same soil texture. The fertiliser N use efficiency was significantly higher on soils with high soil N release (sandy loam $_{3.4}$, silt loam $_{4.8}$). In these soils, ryegrass took up markedly more fertiliser derived N and this was true for all three tested fertilisers. This observation is supported by results of *Whitehead* (1984). However, when soils were grouped according to a similar level of N release, the role of soil texture for the N turnover becomes more visible. In this case, apparent N utilisation and N use efficiency were always higher in the coarse textured soils regardless of the fertiliser applied. This may indicate that OM is less stable in the coarser textured soils and consequently less of the fertiliser N is incor-

porated into the soil OM. Nevertheless, the uniformity of the relationship between the N release and N use efficiency cannot explain the observed soil dependent differences in the apparent N utilisation.

Although we found that the soils affected the apparent N utilisation, we can conclude from our results that the influence of the fertilisers with different N contents was greater than that of the soils, which is in agreement with *Smith* and *Shapley* (1990). However, there was no single clear indicator that explained the role of soil properties. Soil texture, C_{org} or soil N turnover could all affect the apparent N utilisation, although there were also soils that deviated from a more general principle.

3.6 Conclusion

The N utilisation of plant-derived and industrially-processed organic N fertilisers was affected greatly by the N content of fertilisers and also by the soils, albeit to a lesser degree. The soil-dependent variations could not be clearly explained by any of the investigated soil parameters (texture, C_{org} or soil N release). Differences in apparent N utilisation between the soils were lower when fertiliser N contents were high. At low fertiliser N contents, however, N utilisation on fine textured soils could be low and this effect was even more pronounced when the N release of these soils was high. Consequently, fertilisers with a higher N content are to be recommended for fine textured soils. In such cases, where the soils release a high amount of N, only fertiliser with a high content of readily degradable N will maintain a high N supply to the plants.

4 Nitrogen release from plant-derived and industrially-processed organic nitrogen fertilisers applied to organically grown tomatoes (*Lycopersicum esculentum* MILL.)

4.1 Abstract

In organic horticulture animal-derived fertilisers such as meat- or blood-meal are to be replaced by plant-derived or industrially-processed organic nitrogen (N) fertilisers due to BSE crisis. The objectives of this study were to investigate (1) the N release from plant-derived and industrially-processed organic N fertilisers under glasshouse conditions, (2) their effect on N uptake and yield of tomatoes and (3) the role of fertiliser timing. In two subsequent years grafted tomatoes were grown in glasshouse and fertilised with 20 g N/m^2 as Maltaflor®-spezial, coarse meal of fababean and horn at different times within a 30 cm wide fertiliser-band. The fertiliser was applied before or six weeks after planting in one dosage or split into two dressings.

In both years, plant-derived and industrially-processed organic N fertilisers mineralised rapidly. Yields of tomatoes, plant N uptake and apparent N utilisation obtained with Maltaflor®-spezial or fababean were comparable to those of horn in both years. When the N release of the unfertilised soil was high, the split application of fababean did not affect yield of tomatoes nor total shoot N uptake. A sole late N application of Maltaflor®-spezial decreased the N uptake when the N release of the unfertilised soil was low. The apparent N utilisation did not exceed 19-33% in the first year due to a high N uptake in the control, but increased in the following year to 26-57%, because of the poorer growth in the unfertilised control. There were marked differences in the amount of NO_3^--N remaining in soil during and after cultivation, so that the N supply by Maltaflor®-spezial was higher compared to fababean and horn. Split application of a readily available organic fertiliser could be promising and an additional N mineralisation could be expected by a regular hoeing of formerly fertilised plots.

4.2 Introduction

For many years, vegetable growers used animal residues like horn-, blood- or meat-meal to meet nitrogen (N) demand of the plants (*Haworth*, 1961); in contrast, farm-yard manure is seldom used. However, due to the BSE (*Bovine Spongiform Encephalopathy*) crisis alternative fertilisers are required (*Schmitz* and *Fischer*, 2003). Therefore, plant-derived and industrially-processed organic N fertilisers that can be divided into milled seeds of grain legumes and processed crop residues from the food and feed industry, are becoming more common. Previous studies either determined the N release from plant-derived and industrially-processed fertilisers (*Laber*, 2003) or investigated the effect of these fertilisers on the yield of vegetable crops (e.g. *Koller et al.*, 2004). Studies on the N release from plant-derived and industrially-processed fertilisers combined with the N uptake by vegetable crops are still missing. However, such research was done with green manure. N mineralisation in soil increased within two (*Båth*, 2001) to eight weeks (*Thönnissen* et al., 2000b) after application of green manure and declined thereafter. Therefore, the efficiency of the fertiliser on yield depends largely on the synchrony between N release of crop residues and N demand by the growing crop (*Iritani* and *Arnold*, 1960). An adaptation of the N release to plant demand will depend on the time of application: incorporation of red clover two weeks after planting, resulted in marginally higher N uptake of leek compared to an incorporation at planting, but incorporation four weeks after planting caused a significantly reduced N uptake (*Båth*, 2001). The time course of N uptake markedly differs between vegetable crops (*Matsumoto* et al., 1999) and for tomatoes N uptake, measured by the difference of NO_3 in the soil in the planted vs. unplanted plots, starts 1-3 weeks after planting (*Thönnissen* et al., 2000b). *Yaffa* et al. (2000) concluded from their application strategy that all fertiliser should be applied within 8 weeks after transplanting to synchronise N availability with early tomato growth.

The N release from plant-derived and industrially-processed organic fertilisers was mostly related to their N content (*Stadler* et al., 2006) and the principles therefore resemble those of crop residues. The N mineralisation of these fertilisers was rapid and largely completed within four weeks of incubation. Therefore, the time course of the N release of these fertilisers may favourably match the early N demand of tomatoes. On the other hand, if the whole N amount of fertiliser is applied at planting there will be a high N surplus during the early tomato growth. But, mineral N in soil may be prone to losses by leaching or immobilisation (*Blankenau* and *Kuhlmann*, 2000).

Hence, it might be expected that a split application of plant-derived and industrially-processed organic fertilisers could be favourable for long-growing crops.

Two plant-derived fertilisers (coarse meal of fababean and Maltaflor®-spezial) were applied to organically grown tomatoes in glasshouse to investigate (1) their N release in soil, (2) their effect on N uptake and yield of tomatoes and (3) the role of the timing of fertiliser application.

4.3 Materials and Methods

4.3.1 Glasshouse experiments

Tomatoes (*Lycopersicum esculentum* MILL.) were grown in glasshouses for two years in 2003 and 2004 at the research station for organically grown vegetables of the Bavarian State Institute for Viticulture and Horticulture, Bamberg, Germany. The soil was a sandy loam, low in organic matter (OM) (Tab. 4-1). Soil texture was analysed by pipette analysis (*Gee* and *Bauder*, 1986), C_{org} and N_t by dry combustion (*Hoffmann*, 1997), and pH was determined in 0.01 M $CaCl_2$ extract. The experimental soil was well supplied with nutrients as indicated in Table 4-1. P, K, and Mg were analysed by ICP (ICP Emission Spectrometer, Liberty 200, VARIAN, Basel, Switzerland) by using calcium acetate lactate (CAL) for P and K, and $CaCl_2$ for Mg as extractants. Previous to the tomato crop oil radish (*Raphanus sativus* L. var. oleiformis) was used as intercrop in 2003 or winter rye (*Secale cereale* L.) in 2004. Shoots and roots of the intercrop were removed two (2003) or six (2004) weeks before tomatoes were planted. Soil was tilled to a depth of 20 cm with a rotary hoe. Grafted tomatoes variety “Voyager” (rootstock “Brigeor”) were transplanted in double rows per plot (55 cm plant to plant, 60 cm interrow distance and 120 cm distance between the double rows, 2 plants/m^2) on April 17, 2003 and on April 7, 2004. Shoots were harvested on August 26, 2003 and on August 23, 2004. The experimental layout was a RCB design with four replicates. However, due to a heavy, but locally restricted abundance of nematodes (*Meloidogyne* spp.), only three replications were evaluated.

Table 4-1: Characteristics of the soil (sandy loam (*FAO*, 1998)) in the glasshouses at the research station of the Bavarian State Institute for Viticulture and Horticulture, Bamberg, Germany.

Clay	Silt	Sand	C_{org}	N_t	C/N	pH $CaCl_2$	P CAL	K CAL	Mg $CaCl_2$
(——————— % ———————)						(mg / 100 g dry soil)			
9	26	65	1.6	0.13	12.1	7.4	9	9	20

Plant protection was managed by using beneficial organisms. Weed was regularly removed by hand. Air temperature in the glasshouse ranged between 20°-35°C in 2003 and 20°-30°C in 2004. Average soil temperature, as measured in 2003, was around 20°C in 20 cm depth. Drip irrigation (two tubes for each row, 33 cm dripping distance) was regulated by tensiometers, which were monitored four times each day. Irrigation started when the soil matric potential decreased below -80 hPa. Approximately 750 mm H_2O/m^2 was applied during the extremely hot and sunny summer of 2003, while this amounted to 360-430 mm H_2O/m^2 in 2004.

4.3.2 Fertiliser application

Prior to the planting of tomatoes 10 g K_2O/m^2 was broadcasted as Patentkali® and 20 g N/m^2 was either applied as coarse meal of fababean, Maltaflor®-spezial (Maltaflor), sieved to 2 mm, or horn (Tab. 4-2) within a fertiliser-band of 30 cm. These early fertilised treatments were called: Fababean 20/0 g N/m^2, Maltaflor 20/0 g N/m^2, and Horn 20/0 g N/m^2. In both years an unfertilised treatment ("Control") was included to monitor N mineralisation from soil. In 2003 two further treatments were tested, where half of the N rate was applied as fababean before planting and half of it as fababean (Fababean 10/10 g N/m^2) or Maltaflor®-spezial (Fababean/Maltaflor 10/10 g N/m^2) six weeks after planting at the stage of fruit initiation. In 2004 two other treatments were fertilised six weeks after planting: Maltaflor 0/20 g N/m^2 or Maltaflor 0/10 g N/m^2. At each N application all treatments including the control were hand hoed 5-10 cm deep and irrigated.

Table 4-2: N and C content and C/N ratio of the tested organic fertilisers.

Fertiliser	N content (—— % ——)		C content (—— % ——)		C/N ratio	
	2003	2004	2003	2004	2003	2004
Fababean (coarse meal of fababean)	4.2	4.2	40	40	9.4	9.4
Maltaflor (Maltaflor®-spezial)	4.7	3.6	38	39	8.4	10.8
Horn (per 1/3 hornmeal, -grit, -chipping)	13.2	14.1	42	45	3.2	3.2

4.3.3 Sampling and analyses

During the growth period red tomatoes were regularly collected in subplots from six plants twice each week and additional samplings included side shoots in 2003 1-2 times each week and stripped leaves 3 times during the growth period. The aboveground biomass of these plants was harvested at the end of the growth period and divided into remaining red and green tomatoes and shoots. For all plant parts fresh biomass weight was determined and subsamples were dried at 105°C for 24 hours to determine total dry matter yield. Dry samples of the shoots were milled to pass through a 1.5 mm sieve (shear-mill, BRABENDER, Germany), the red and green tomatoes were finely milled with a coffee mill. N content was analysed according to the DUMAS method (FP-328 Nitrogen/Protein Determinator, LECO CORPORATION, St. Joseph, Michigan, USA).

Composite soil samples for analysis of nitrate-N were taken from 6 cores at each depth (0-15 cm, 15-30 cm, 30-60 cm) within the fertiliser-band before planting of tomatoes and at regular intervals during the growth period. After sampling, soil samples were kept frozen. Gravimetric soil water content was determined and the soil was extracted with 0.01 M $CaCl_2$ (1:2 soil:extractant). After filtration (589/2 ½ SCHLEICHER & SCHÜLL, Dassel, Germany) soil extracts were subsequently frozen. Nitrate was measured photometrically after separation by HPLC (KONTRON INSTRUMENTS, Au i.d. Hallertau, Germany) according to *Vilsmeier* (1984).

4.3.4 Statistical analyses

Statistical analyses were performed at the 0.05 probability level using t-test (LSD-test) for pairwise comparison (SAS, Version 8.2).

4.4 Results

4.4.1 Yield

The yield of tomatoes included all harvested red tomatoes and the green tomatoes at the end of the growth period. Only 1-2% of all red tomatoes were not marketable independent of the treatment or year. In both years the yield level of tomatoes obtained with plant-derived and industrially-processed organic fertilisers was comparable to horn (Tab. 4-3a). But in 2004 the differences in yield within the fertilised treatments were higher than in 2003. Yield produced in the unfertilised control was high in 2003 and reached 83-91% of the fertilised treatments. In 2004 the differences between the unfertilised and the fertilised plots were higher with 64-76%, indicating lower soil N supply in 2004. The splitting of the N rate (Fababean 10/10 g N/m^2, Fababean/Maltaflor 10/10 g N/m^2) did not affect the yield in 2003 (Tab. 4-3b). The sole N application of 20 g N/m^2 (Maltaflor 0/20 g N/m^2) or even 10 g N/m^2 (Maltaflor 0/10 g N/m^2) six weeks after planting in 2004 resulted in a somewhat lower yield compared to the application of 20 g N/m^2 as Maltaflor®-spezial before planting (Maltaflor 20/0 g N/m^2), but the differences were statistically not significant.

Table 4-3a: Cumulative tomato yield (red + green) of grafted tomatoes ("Voyager", rootstock "Brigeor") grown in glasshouse (2 plants/m^2) fertilised with 20 g N/m^2 as fababean, Maltaflor (Maltaflor®-spezial) or horn before or six weeks after planting in 2003 and 2004.

Fertiliser treatment	**Tomato yield** (——— kg/m^2 ———)	
	2003	2004
Control	11.9 b	8.9 b
Fababean 20/0 g N/m^2	13.1 a	11.7 a
Maltaflor 20/0 g N/m^2	14.1 a	13.9 a
Horn 20/0 g N/m^2	14.3 a	12.0 a

Letters indicate significant differences (LSD, $p \leq 0.05$) within one year.

Table 4-3b: Cumulative tomato yield (red + green) of grafted tomatoes ("Voyager", rootstock "Brigeor") grown in glasshouse (2 plants/m^2) fertilised with fababean, Maltaflor (Maltaflor®-spezial) and horn at different N rates (10 or 20 g N/m^2) and times of application (before or six weeks after planting) in 2003 and 2004.

Fertiliser treatment	**Tomato yield** (——— kg/m^2 ———)	
	2003	2004
Fababean 20/0 g N/m^2	13.1 a	
Fababean 10/10 g N/m^2	13.6 a	
Fababean/Maltaflor 10/10 g N/m^2	13.5 a	
Maltaflor 20/0 g N/m^2		13.9 a
Maltaflor 0/20 g N/m^2		11.7 a
Maltaflor 0/10 g N/m^2		10.9 a

Letters indicate significant differences (LSD, $p \leq 0.05$) within one year.

4.4.2 Nitrogen uptake

For the early application of 20 g N/m^2 the N uptake of plant-derived and industrially-processed organic fertilisers was comparable to horn in both years (Tab. 4-4a). N uptake in the control treatment without fertiliser application that describes the N release from soil was much higher in 2003 than in 2004 (68 as compared to 40 g N uptake / kg soil N_t). Consequently, the N uptake from the unfertilised control reached 76-84% of the fertilised treatments in 2003 and 53-68% in 2004. In 2004 also the trend of a lower N uptake from fababean compared to Maltaflor®-spezial was more pronounced than in 2003. The splitting of the N rate into two applications did not affect the N uptake (Tab. 4-4b) in 2003. However, the N application six weeks after planting in 2004 (Maltaflor 0/20 g N/m^2) resulted in a significantly lower N uptake compared to the N application before planting (Maltaflor 20/0 g N/m^2). This reduction occurred irrespective of whether 20 or 10 g N/m^2 were applied. The apparent N utilisation was generally higher in 2004 (26-57%) than in 2003 (19-33%). In both years the apparent N utilisation of fababean tended to be lower than that of Maltaflor®-spezial and horn but this was statistically not significant. Fertiliser splitting in 2003 or late application in 2004 had no effect on the apparent N utilisation, despite the somewhat higher apparent N utilisation of the early Maltaflor®-spezial application (Maltaflor 20/0 g N/m^2).

Figure 4-4a: Cumulative N uptake of grafted tomatoes ("Voyager", rootstock "Brigeor") grown in glasshouse (2 plants/m^2) and apparent N utilisation of tomatoes fertilised with 20 g N/m^2 as fababean, Maltaflor (Maltaflor®-spezial) and horn before or six weeks after planting in 2003 and 2004.

Fertiliser treatment	N uptake (——— g/m^2 ———)		Apparent N utilisation (——— % ———)	
	2003	2004	2003	2004
Control	20.0 b	12.5 b		
Fababean 20/0 g N/m^2	23.7 a	18.5 a	19 a	30 a
Maltaflor 20/0 g N/m^2	26.5 a	23.8 a	33 a	57 a
Horn 20/0 g N/m^2	26.4 a	20.1 a	32 a	38 a

Letters indicate significant differences (LSD, $p \leq 0.05$) within one year.

Table 4-4b: Cumulative N uptake of grafted tomatoes ("Voyager", rootstock "Brigeor") grown in glasshouse (2 plants/m^2) and apparent N utilisation of tomatoes fertilised with fababean, Maltaflor (Maltaflor®-spezial) and horn at different N rates (10 or 20 g N/m^2) and times of application (before or six weeks after planting) in 2003 and 2004.

Fertiliser treatment	N uptake (——— g/m^2 ———)		Apparent N utilisation (——— % ———)	
	2003	2004	2003	2004
Fababean 20/0 g N/m^2	23.7 a		19 a	
Fababean 10/10 g N/m^2	23.7 a		19 a	
Fababean/Maltaflor 10/10 g N/m^2	23.7 a		19 a	
Maltaflor 20/0 g N/m^2		23.8 a		57 a
Maltaflor 0/20 g N/m^2		17.7 b		26 a
Maltaflor 0/10 g N/m^2		15.7 b		32 a

Letters indicate significant differences (LSD, $p \leq 0.05$) within one year.

4.4.3 Soil nitrate content

In both years fertiliser application markedly affected the nitrate content only in the uppermost layer in 0-15 cm (Fig. 4-1), whereas deeper layers in 15-30 cm and 30-60 cm contained much less nitrate (data not presented). In the control treatment nitrate content was low in the uppermost soil layer. Type of fertiliser, time of application and hand hoeing strongly influenced the nitrate content in the soil. Hand hoeing generally increased the soil nitrate content except in the control.

In 2003 the increase in soil nitrate content after the application of Maltaflor®-spezial was higher compared to the other fertilisers. After a peak value of 35 g NO_3^--N / m^2

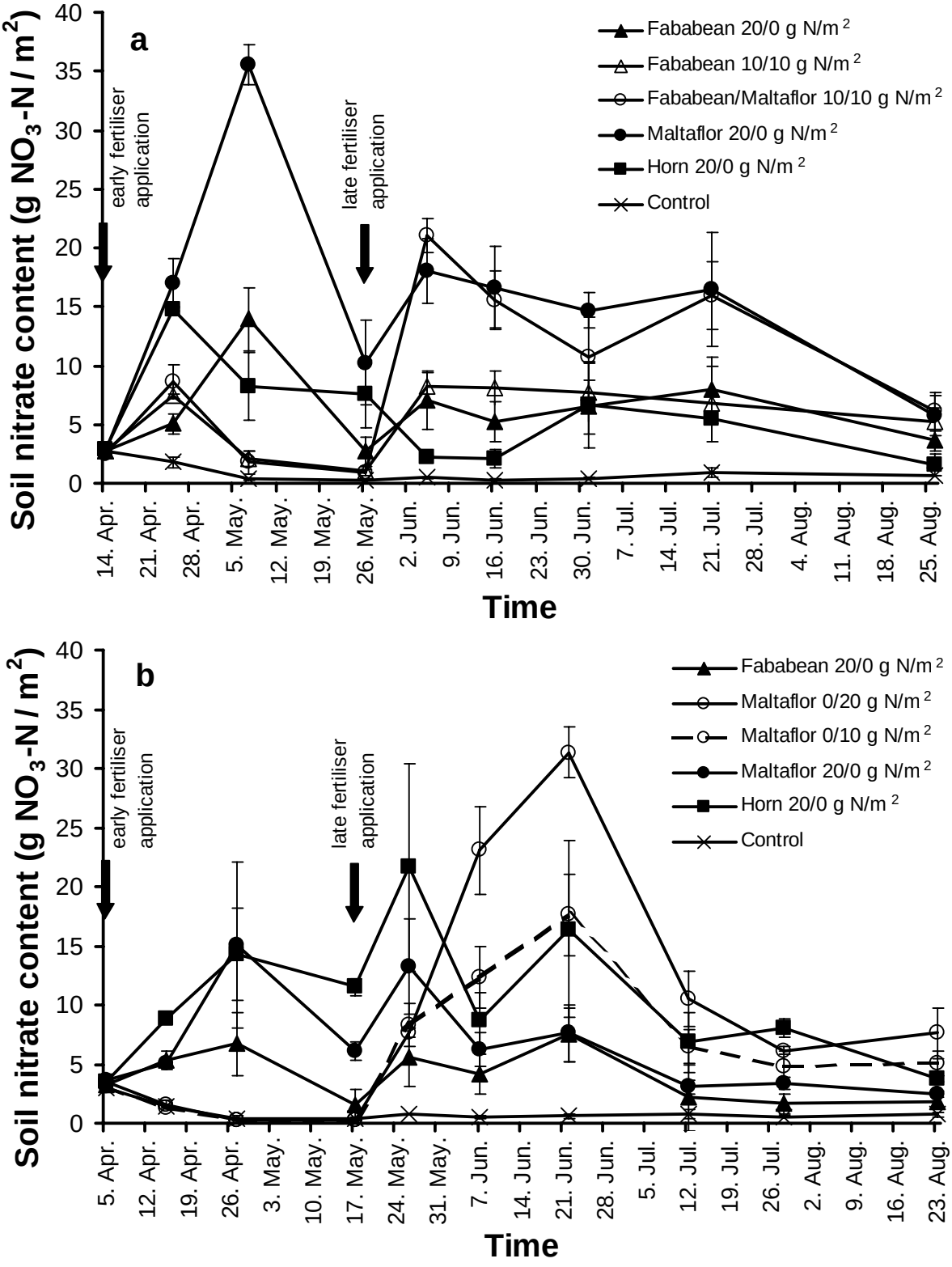

Figure 4-1: Nitrate content in soil (0-15 cm) fertilised with fababean, Maltaflor (Maltaflor®-spezial) and horn at different N rates (10 or 20 g N/m^2) and times of application (before or six weeks after planting) in the glasshouse in 2003 (a) and 2004 (b). Fertiliser was applied within a 30 cm wide fertiliserband and thereafter all treatments were hand hoed 5-10 cm deep. Water was supplied by drip irrigation of 2 tubes/row at 33 cm dripping distance and started when the soil matric potential decreased below -80 hPa.

the nitrate content remained at 10-20 g NO_3^--N / m^2 until one month before the end of the experiment. With horn and fababean nitrate content in the soil reached only 2.5-10 g NO_3^--N / m^2. In 2004 results were somewhat different: the application of horn caused the nitrate content of soil to remain at a quite high level, while "Maltaflor 20/0 g N/m^2" did not increase the nitrate content that much. But, late applications of Maltaflor®-spezial (Maltaflor 0/20 g N/m^2, Maltaflor 0/10 g N/m^2) again strongly increased the soil nitrate content to levels similar to those of 2003. Finally, at the end of the experiments soil nitrate content of all fertiliser treatments was comparable in both years in the uppermost soil layer.

4.4.4 Apparent nitrogen recovery

Apparent N recovery was calculated to include nitrate remaining in soil for fertiliser evaluation. Apparent N recovery is the additional N uptake by plants (N uptake of fertiliser treatments minus N uptake of the control) plus the additional nitrate-N in the soil (nitrate-N of fertiliser treatments minus nitrate-N of the control) at the end of the growth period compared to the amount of fertilised N. Apparent N recovery of fertilisers was higher in 2004 than in 2003 (Tab. 4-5). Horn released 37-57%, fababean 34-43% and Maltaflor®-spezial 59-68% of the applied N.

Table 4-5: Apparent fertiliser N recovery of fababean, Maltaflor (Maltaflor®-spezial) and horn applied at different N rates (10 or 20 g N/m^2) and times of application (before or six weeks after planting) in 2003 and 2004. Apparent fertiliser N recovery consisted of additional N uptake of tomatoes (N uptake of fertiliser treatments minus N uptake of control) and additional NO_3-N in the 0-60 cm soil layer (additional nitrate-N of fertiliser treatments minus nitrate-N of control) compared to the amount of N applied by fertilisers to tomatoes at the end of the growth period.

Fertiliser treatment	**Apparent N recovery** (——— % ———)	
	2003	2004
Fababean 20/0 g N/m^2	34 a	37 a
Fababean 10/10 g N/m^2	43 a	
Maltaflor 0/10 g N/m^2		81 a
Fababean/Maltaflor 10/10 g N/m^2	46 a	
Maltaflor 0/20 g N/m^2		68 a
Maltaflor 20/0 g N/m^2	59 a	68 a
Horn 20/0 g N/m^2	37 a	57 a

Letters indicate significant differences between fertiliser treatments (LSD, $p \leq 0.05$) within one year.

4.5 Discussion

Yield and N uptake of tomatoes fertilised with plant-derived and industrially-processed organic N fertilisers were similar to those fertilised with horn, indicating that they can substitute for animal residue based organic fertilisers. In both years the application of fertilisers significantly increased yield of tomatoes irrespective of the type of fertiliser or the application strategy. Comparably, *Abdul-Baki* (1996) measured higher marketable yield and fruit weight of tomatoes grown in cover-crop mulches compared to bare plots without mulch. However, *Tourte* et al. (2000) found no significant differences in the yield of marketable tomatoes between the control and an application of woolypod vetch, although their N rate (approx. 175 kg N/ha) was similar to ours. These somewhat contrary results may be caused by the often marginal effect of green manure on yield of tomatoes on fertile soils, but its high effects on poor soils (*Thönnissen* et al., 2000a). The N supply of the soil may be also the reason for the higher differentiation of tomato yield between fertilised and unfertilised plots in 2004 compared to 2003. This differentiation was more pronounced for the N uptake than for the tomato yield. The very high N uptake of the control in 2003, was partly related to the high nitrate input with the irrigation water (up to 5.3 g N/m^2) and partly the result of the high net N mineralisation. Therefore, the effect of fertiliser application on yield and N uptake was low, resulting in an apparent N utilisation of 19-33%. In 2004 apparent N utilisation of the same treatments was much higher (30-57%) due to a markedly lower yield of the control. This was probably caused by a reduced nitrate input with the irrigation water (less than 1.8 g N/m^2) and a lower N release from soil.

Previous incubation and pot experiments (*Stadler* et al., 2006) have shown that from both fababean and Maltaflor®-spezial a high and rapid N release could be expected that may temporarily exceed the N requirement of the tomato plants. However, on the one hand any surplus of mineral N in soil may be prone to losses by leaching or immobilisation (*Blankenau* and *Kuhlmann*, 2000). On the other hand a minimum content of mineral N in soil is needed to support a proper plant growth (*Feller* and *Fink*, 2002). Therefore, a fertiliser application strategy like splitting that reduces intermittently occurring N excess in soil may be favourable. However, in 2003 the splitting of the N rate resulted neither in higher yield nor in higher N uptake or apparent N utilisation of tomatoes. This was most probably due to the fact that the N availability was not different between the two treatments: the early application of 20 g N/m^2 of fababean caused no persistently high NO_3^--N surplus after fertiliser application that might

have been prone to N losses. Moreover, after six weeks when the second dose of the split application was applied and both treatments were hand hoed a similar increase of mineral N content in soil was measured for both treatments. This level of N supply was maintained almost until harvest. In view of the missing yield differences, the N supply of the tomatoes in both treatments was obviously not significantly different during crucial stages of development.

In contrast to the incubation and pot experiments (*Stadler* et al., 2006) net N release from Maltaflor®-spezial differed from fababean in the glasshouse experiment. During the whole growth period soil mineral N content with Maltaflor®-spezial markedly exceeded that of fababean, which resulted in a higher apparent N recovery, although this was statistically not significant. Especially after each Maltaflor®-spezial application mineral N content was boosted by a high short-term N release. Therefore, from a split application of a readily available organic fertiliser like Maltaflor®-spezial a higher N efficiency might be expected. However, particularly if soil N release is low a single late fertiliser application even with a readily available organic fertiliser like Maltaflor®-spezial runs the risk of yield deprivation. Similar results are presented by *Båth* (2001): a late application of green manure (clover) caused a delay in growth and N uptake of leek and high values of nitrate in soil at harvest. However, further experiments must substantiate the positive yield effect of a split fertiliser application of Maltaflor®-spezial in contrast to those of fababean.

4.6 Conclusions

The tested fertilisers Maltaflor®-spezial and fababean will act as rapid N sources, ensuring a sufficient N supply for vegetable crops in organic horticulture comparable to those of established animal-derived organic fertilisers like horn. Vegetable crops with a long-lasting growth period should be fertilised before planting. During the vegetation period a regular hoeing of the formerly fertilised plots will generally increase N mineralisation and should therefore be part of an optimised fertiliser management strategy. Data suggest that a split application is more promising with a readily available organic fertiliser like Maltaflor®-spezial compared to fababean.

5 General Discussion

5.1 Biochemical characteristics and nitrogen release of the fertilisers

The N content of plant-derived and industrially-processed organic N fertilisers was a good predictor for the N mineralisation of the fertilisers in the incubation study ($y = 12.7 x + 3.0$; $r^2=0.97^{***}$) and in the pot experiments ($y = 13.2 x - 5.3$; $r^2=0.76^{***}$), if two fertilisers were excluded (Phytoperls®, Agrobiosol®). However, the range of the net N mineralisation for a given fertiliser N content differed by about ±5-10%. Due to this high range, no relation between N content and N release was found for the two fertilisers used in the glasshouse experiments, because their N content was similar.

A high correlation was also found between the N release of crop residues and their N content under controlled conditions (*Iritani* and *Arnold*, 1960; *Frankenberger* and *Abdelmagid*, 1985; *Trinsoutrot* et al., 2000) as well as under field conditions (*De Neve* et al., 1994). Therefore, the N content of plant-derived and industrially-processed organic N fertilisers is presumably a good predictor for their N release also under field conditions. Phytoperls® and Agrobiosol® mineralised less N than it would have be expected from the N content. It can be assumed that the manufacturing process is responsible for the transformation of N into more stable compounds that are less available to microbial decomposition. The influence of the manufacturing process on the N release of these industrially-processed organic N fertilisers should be further clarified.

The relation between N content and N release of most plant-derived and industrially-processed organic N fertilisers was also valid when all tested soils were pooled ($y = 9.6 x + 7.6$; $r^2=0.46^{***}$). However, this increased the range in N mineralisation from a fertiliser with a given N content from 1-9% to 14-31%. This higher range is caused by the effect of soil and the interaction between soils and fertilisers. Consequently, an exact prediction of the N release from a given fertiliser in an unknown soil is not possible. Other factors than the tested soil parameters (texture, C_{org} content, N release of soil) seem to influence the N release of plant-derived and industrially-

processed organic N fertilisers as well. Further research with a higher number of different soils and fertilisers should clarify the impact of soils on fertiliser N release.

In all tested soils fertilisers with medium or high N content (fababean, Maltaflor®-spezial, Rizi-Korn) released relatively high amounts of N within the first 2-5 weeks after application in the model and glasshouse experiments. Moreover, yields with these fertilisers were mostly comparable to those obtained with horn. Therefore, they can certainly substitute animal-derived residues for vegetable crops with long as well as with short growing periods. A rapid release of nitrate during the first few days of incubation and an initially very rapid growth of ryegrass was also found with crop residues (*Stockdale* and *Rees*, 1995). However, pea (3.0% N) and lupin (3.4% N) mineralised N slowly within the initial period. This observation is in accordance with *Jensen* (1995), who reported that pea residues (straw) even with a high N content (up to 2.4% N) may cause net N immobilisation, since soil-N may be immobilised simultaneously with the mineralisation of residue-N during early stages of decomposition.

5.2 Apparent nitrogen recovery in different experiments

The net N mineralisation of fertilisers in the incubation study was approx. 8% higher than the apparent N utilisation of the aboveground harvested ryegrass in the pot experiments. *Browaldh* (1997) explained this discrepancy with the absence of roots during incubation and a possible suppression of net N mineralisation of the added material in the rhizosphere of plants. The roots of ryegrass were not measured in our pot experiments, but may contain a high amount of N. Indeed, *Nicolardot* et al. (1995) analysed 6.9% of the ^{15}N (labelled rye) in the roots of ryegrass.

In the glasshouse experiments residual NO_3^--N remained in the soil at the end of the growing period of the tomatoes and therefore, apparent N recovery of fertilisers was higher than their apparent N utilisation. In contrast, N_{min} in soil was marginal in the pot experiments with ryegrass and so the apparent N recovery of fertilisers and their apparent N utilisation was similar. The apparent N recovery of fertilisers was comparable in pot and glasshouse experiments, whereas the apparent N utilisation was much lower in the glasshouse than in the pot experiments. This indicates that ryegrass and tomatoes differed in their N uptake efficiency, which was confirmed by

Rühlmann and *Geyer* (2001) and attributed to differences in the length of the growing period and rooting depth.

The apparent N recovery of plant-derived and industrially-processed organic N fertilisers that ranged between 25-70% of applied N, may increase with higher fertiliser N amounts. For grassland soils, *Vellinga* and *André* (1999) calculated that the apparent N utilisation is low at low N application rates, but increases up to 65-70% with N amounts of more than 250 kg/ha. N recovery by vegetable crops did not decrease even at a N supply of 300 kg/ha (*Rühlmann* and *Geyer*, 2001).

5.3 Fertiliser application strategies

As indicated from the present experiments, plant-derived and industrially-processed organic N fertilisers with a high N content are recommended to obtain a high fertiliser N release. This is even more important if fertilisers are applied to fine textured soils because fertilisers with a low N content showed lower N utilisation in fine textured compared to coarse textured soils.

As the apparent N utilisation of plant-derived and industrially-processed organic N fertilisers was not affected by the soil N status, even soils with a high N release should be fertilised and fertilisers with a high content of readily available N should be selected. An additional N mineralisation can be achieved by regular tilling of formerly fertilised plots that should be done after each fertiliser application and within the growing period of tomatoes.

At least part of the fertiliser amount should be applied before transplanting, because a sole late N application decreased tomato yield and the apparent N utilisation from plant-derived and industrially-processed organic N fertilisers. The early N application is of particular importance on fine textured soils due to their lower N release compared to coarse textured soils. This may be concluded from *Strong* et al. (1999), where more clayey soils led to a negative impact on N mineralisation, whereas more sandy soils were positively correlated to N mineralisation.

It might be expected that a split fertiliser N application before and six weeks after transplanting may increase yield and apparent N utilisation, if a fertiliser with a rapid and high N release (e.g. Maltaflor®-spezial) is used instead of a moderately mineralising fertiliser (e.g. fababean). However, a split application of organic fertilisers may

not be beneficial at lower temperatures that are suboptimal for N mineralisation because of a reduced N release from the fertiliser. At low temperatures (3°C) the processes of the turnover of N and energy rich components are not running simultaneously and N mineralisation and N immobilisation may occur more separate in time (*Magid* et al., 2004). Therefore, N immobilisation of plant-derived and industrially-processed organic N fertilisers may occur later at lower temperatures compared to higher temperatures. Consequently, it is pertinent to consider the timing of application for these fertilisers at low temperatures.

5.4 Transfer of the results to field conditions

Rate and level of N release obtained under controlled conditions (*Das* et al., 1993; *Gonçalves* and *Carlyle*, 1994; *Quemada* and *Cabrera*, 1997; *Magid* et al., 2004) may not directly be transferred to field conditions, because temperature and soil moisture fluctuations are different from those under glasshouse conditions and are above all subject to seasonal fluctuations. The effect of temperature (10°C, 20°C, 25°C) on N release was found to be higher than that of soil moisture (ψ_m = -0.03 MPa, ψ_m = -0.2 MPa, ψ_m = -1.7 MPa) (*Sierra*, 1997). In a preliminary incubation experiment conducted under controlled glasshouse conditions, net N mineralisation of plant-derived and industrially-processed organic N fertilisers in a sandy soil was little affected by both temperature (15°C, 20°C, 25°C) and soil moisture levels (ψ_m = -0.0063 MPa, ψ_m = -0.016 MPa, ψ_m = -0.1 MPa). However, if a fertiliser with a low N content (pea 3.0% N) was used the N release was lower at 15°C and this effect was even more pronounced at ψ_m = -0.016 MPa and ψ_m = -0.1 MPa (data not shown). *Müller* and *von Fragstein* (2005) observed in an incubation experiment at 5°C a slightly faster N release from lupin compared to castor bean, whereas at higher temperatures (15°C) N release from castor bean was higher. Consequently, the effect of temperature on N release is dependent on the fertiliser. Nitrogen release was higher under oscillating conditions of drying and rewetting of the soil compared to a moisture regime uniformly near field capacity (*Herlihy*, 1979). Therefore, the N release in the field may be higher than in the glasshouse if temperatures are comparable. In contrast to continuously moist soils, *Strong* et al. (1999) observed under varying moisture conditions a positive influence of more clayey soils on N release and a negative influence of more sandy soils. It may therefore be concluded that an

early N supply to field grown vegetables is extremely important for coarse textured soils. However, particularly in spring and early summer soil temperatures in field are below those in glasshouse. The influence of soil moisture differs on clayey and loamy soils compared to sandy soils, because *Thomsen* et al. (2003a) reported an optimum (ψ_m = -0.006 MPa) for net NO_3^--N production from manure in coarse textured soil, whereas in fine textured soils net nitrification increased approximately linearly in the range of ψ_m = -0.15 MPa up to ψ_m = -0.0015 MPa. Consequently, moisture conditions, soil texture and their interaction influence N mineralisation of fertilisers.

Losses of N by leaching into deeper soil layers were negligible in the glasshouse experiments. However, vegetable production in the field may cause higher N leaching. Especially in the wet season N may be leached to soil layers below 60 cm (*Riley* et al., 2003) particularly within the first month of the growing period (*Thönnissen* et al., 2000b). Furthermore, gaseous N losses may occur under glasshouse as well as under field conditions. Nitrous oxide emissions increased especially after incorporation of material with low C/N ratio of 7.5 (*Baggs* et al., 2000). Therefore, in the field it may be advantageous to split the application of Maltaflor®-spezial to avoid the risk of N leaching due to high peaks of N mineralisation. Furthermore, industrially-processed organic N fertilisers like Maltaflor®-spezial may cause higher nitrous oxide emissions than grain legumes, because of the lower C/N ratio of the former.

Further experiments on different sites and growing seasons should investigate the N release from plant-derived and industrially-processed organic N fertilisers under field conditions.

6 Outlook

The N mineralisation of most plant-derived and industrially-processed organic N fertilisers can be predicted, if their N content is known. An explanation for the lower N release of Phytoperls® and Agrobiosol® concerning the N content is still missing. Therefore, additional parameters are needed to explain the N mineralisation of these fertilisers.

Variations in the N utilisation of the fertilisers in different soils could not be attributed to texture, C_{org} or soil N release in isolation. Maybe other soil parameters or a combination of soil factors enable to explain the observed soil-related differences in the N utilisation of the fertilisers for all soils.

Results from the incubation experiments could be transferred to pot and glasshouse experiments because N mineralisation of plant-derived and industrially-processed organic N fertilisers was comparable in all experiments with almost the same ranking of fertilisers. Therefore, plant experiments are not obviously essential to evaluate the ranking of N release between the fertilisers, but for more precise prediction of the absolute N release a model plant like ryegrass is more suitable. However, the lower apparent N utilisation of Phytoperls® by ryegrass as compared to the net N mineralisation during the incubation could not be explained.

With respect to a plant growth adapted N supply it is supposed that fertilisers with a high and rapid N release (i.e. Maltaflor®-spezial) should be applied in split doses. However, advantages of this strategy as compared to a single application should be verified in additional experiments.

Plant-derived and industrially-processed organic N fertilisers with a high N release are suitable to supply vegetables in organic horticulture. However, in the year of application they mineralise only up to 60% of the total N applied. Consequently, it can be assumed that the regular application of these fertilisers over several years will tend to increase total soil OM and N that can potentially be mineralised. It should therefore be kept in mind whether long-term application of these fertilisers may require a modified application strategy.

7 Summary

As a consequence of the BSE-crisis, alternatives for fertilisers derived from animal residues are being sought for use in organic horticulture. Therefore, the N release of grain legumes (milled seeds of pea, yellow lupin, and fababean) and organic fertilisers of industrially-processed plant and microbial residues (Maltaflor®-spezial, Phytoperls®, Agrobiosol®, Rizi-Korn) was investigated. In an incubation study with one sandy soil (C_{org}: 1.4%) net N mineralisation of the fertilisers (N content: 3.0-8.5%, C/N: 5.0-13.3) was measured. In pot experiments the apparent N utilisation by perennial ryegrass was determined. In order to investigate the effect of soils on fertiliser N release the pot experiments were conducted with a number of soils with different soil textures (sandy loam - silty clay loam) and C_{org} contents (C_{org}: 1.2-8.4) that were sampled from organic horticultural farms. In these experiments the N utilisation was calculated from unlabelled or ^{15}N labelled fertilisers. Two fertilisers with a relatively high N release (fababean, Maltaflor®-spezial) were selected to be examined in glasshouse experiments with grafted tomatoes (variety “Voyager”). The effect of the fertilisers on the yield and the apparent N utilisation of shoots (vegetative biomass plus fruits) was examined. In these experiments also the influence of the termination of fertiliser application was investigated by splitting the whole N amount of 20 g N/m^2 into two dressings of 10 g N/m^2.

During the 7 weeks of incubation net N mineralisation of the applied N (40 mg N / 150 g dry soil) ranged from 42-50% (pea, lupin, Phytoperls®) up to 55-61% (fababean, Agrobiosol®, Maltaflor®-spezial) and was highest with Rizi-Korn (72%). For all fertilisers 70% of the total net mineralisation occurred within the first two weeks. With the exception of Phytoperls® and Agrobiosol® net N mineralisation was closely related to the N content (r^2=0.97***) of the fertilisers, and to a lesser degree, to their C/N ratio (r^2=0.79***). The relation between fertiliser N content and N release was confirmed by pot experiments with ryegrass. For example, the apparent N utilisation after a 13 weeks growth period was correlated to the fertiliser N content with r^2=0.60*** and to the C/N ratio with r^2=0.47***, excluding Phytoperls® and Agrobiosol®. It was concluded that the N content of the fertilisers is a good indicator for the N release of most of the tested fertilisers.

Besides the N content, soil affected the N utilisation of the fertilisers, but the soil effect was less pronounced compared to the fertiliser N content. Three pot experiments with ryegrass revealed different soil parameters that may affect fertiliser N utilisation. In the first pot experiment with four soils the apparent N utilisation of fertilisers with a low N content (pea) was significantly lower in the fine textured soils compared to the coarse textured soils, whereas fertilisers with higher N contents showed no differences between soils. A second pot experiment conducted with a wider range of seven different soils demonstrated that the apparent N utilisation of two fertilisers with a medium N content (fababean, Maltaflor®-spezial) may differ between soils as well. This effect was neither related to soil texture nor to C_{org} content. Moreover, the soil dependent differences in the apparent N utilisation were not related to the soil N release potential, determined as N mineralised from the unfertilised soil, although the soils showed a wide range in this characteristic. In the third pot experiment conducted with four soils and ^{15}N labelled fertilisers (1.5-4.6% N) the apparent N utilisation was not related to the N use efficiency (N derived from the fertilisers related to the total N apply). However, a higher N use efficiency from all tested fertilisers was observed on soils with a higher mineralisation of soil-N. From the results obtained it is concluded, that more than one soil parameter may account for variations in the N utilisation of the fertilisers in different soils. However, to provide a sufficient N supply for the plants, it is recommended to use fertilisers with a high N content especially for fine textured soils and for soils with a high N release and to fertilise all soils independently of their N release potential.

Fababean and Maltaflor®-spezial were tested for tomato production under glasshouse conditions in two vegetation periods in comparison to horn. In both years and for both fertilisers tomato yield and total shoot N uptake was comparable to horn. The apparent N utilisation was lower in 2003 (fababean: 19%, Maltaflor®-spezial: 33%, horn: 32%) than in 2004 (fababean: 30%, Maltaflor®-spezial: 57%, horn: 38%). The lower level of the apparent N utilisation in 2003 was due to the higher soil N release and higher nitrate input with the irrigation water. Residual NO_3^--N in both years increased the level of apparent N recovery (plant N uptake plus NO_3^--N remaining in soil; 2003 / 2004: 34% / 37% for fababean, 59% / 68% for Maltaflor®-spezial, 37% / 57% for horn) as compared to the apparent N utilisation. When the N release of the soil was high (2003), the splitting of the total fertiliser N amount into two applications had no affect on tomato yield and total shoot N uptake. But when the

N release of the soil was low (2004), N application only six weeks after planting decreased the N uptake. A split application of a readily available organic fertiliser like Maltaflor®-spezial could be promising and an additional N mineralisation could be achieved by regular tilling of formerly fertilised plots.

Results with plant-derived and industrially-processed organic N fertilisers obtained from the incubation experiment were transferable to those from pot experiments. A transfer of these results, which were determined under climatic conditions that are usual in glasshouses, to vegetable production in glasshouse was also possible. However, the present results will not offhand be transferable to field conditions due to the impact of temperature and water supply on N mineralisation and due to losses of N mainly by leaching. Hence, the effectiveness of plant-derived and industrially-processed organic N fertilisers to supply field-grown vegetables has to be investigated under field conditions at different sites and growing seasons.

From the results obtained here it can be resumed that grain legumes and organic, industrially-processed fertilisers from plant and microbial residues provide a sufficient N supply for organically grown horticultural crops with long growing periods under glasshouse conditions and they are therefore suited to substitute animal residue-derived fertilisers.

8 Zusammenfassung

Im ökologischen Gemüsebau wird aufgrund der BSE-Krise Ersatz für die tierischen Reststoffdünger gesucht. Deshalb wurde die N-Wirkung von Körnerleguminosenschroten (Erbsen-, Lupinen-, Ackerbohnenschrot) und industriell verarbeiteten organischen Düngern aus pflanzlichen und mikrobiellen Rückständen (Maltaflor®-spezial, Phytoperls®, Agrobiosol®, Rizi-Korn) untersucht. In einem Inkubationsversuch mit einem sandigen Boden (C_{org}: 1.4%) wurde die Netto-N-Mineralisation der N-Dünger (N-Gehalt: 3.0-8.5%, C/N: 5.0-13.3) gemessen. In Gefäßversuchen wurde die scheinbare N-Ausnutzung durch einjähriges Weidelgras bestimmt. Um den Einfluss des Bodens bei der N-Umsetzung der Dünger zu testen, wurden die Gefäßversuche mit Böden von ökologischen Gemüsebaubetrieben, die unterschiedliche Texturen (sandy loam - silty clay loam) und C_{org}-Gehalte (C_{org}: 1.2-8.4) aufwiesen, durchgeführt. In diesen Experimenten wurde die N-Ausnutzung von unmarkierten und ^{15}N-markierten Düngern bestimmt. Zwei Dünger mit einer relativ hohen N-Freisetzung (Ackerbohnenschrot, Maltaflor®-spezial) wurden für Gewächshausversuche mit veredelten Tomaten (Sorte „Voyager“) ausgewählt. Der Einfluss der Dünger auf den Ertrag und die scheinbare N-Ausnutzung des gesamten Sprosses (vegetative Biomasse und Früchte) sowie die Terminierung und Verteilung der N-Menge (20 g N/m^2 oder zwei Gaben von je 10 g N/m^2) wurde untersucht.

Während des 7-wöchigen Inkubationsversuches bewegte sich die Netto-N-Mineralisation der Düngermenge (40 mg N / 150 g trockener Boden) von 42-50% (Erbse, Lupine, Phytoperls®) bis zu 55-61% (Ackerbohne, Agrobiosol®, Maltaflor®-spezial) und war am höchsten bei Rizi-Korn (72%). Bei allen Düngern wurden 70% der insgesamt mineralisierten N-Menge bereits in den ersten zwei Wochen freigesetzt. Mit Ausnahme von Phytoperls® und Agrobiosol® war die Netto-N-Mineralisation mit dem N-Gehalt (r^2=0.97***) und etwas weniger mit dem C/N-Verhältnis (r^2=0.79***) der Dünger korreliert. Die Beziehung zwischen dem N-Gehalt der Dünger und ihrer N-Freisetzung bestätigte sich in Topfversuchen mit Weidelgras. Nach einer 13-wöchigen Wachstumsdauer korrelierte die scheinbare N-Ausnutzung mit dem N-Gehalt der Dünger (r^2=0.60***), jedoch weniger eng mit dem C/N-Verhältnis (r^2=0.47***) mit Ausnahme der beiden Dünger Phytoperls® und Agrobiosol®. Es wird gefolgert, dass sich

der N-Gehalt gut zur Vorhersage der N-Freisetzung der meisten getesteten Dünger eignet.

Neben dem N-Gehalt beeinflusste der Boden die Ausnutzung des Dünger-N, allerdings zu einem geringeren Anteil als der N-Gehalt der Dünger. Drei Gefäßversuche mit Weidelgras wurden durchgeführt um zu prüfen, ob verschiedene Bodenparameter die Ausnutzung des Dünger-N beeinflussen. Während im ersten Gefäßversuch mit vier Böden die scheinbare Ausnutzung von Dünger-N bei geringem N-Gehalt im Dünger (Erbse) auf fein texturierten Böden signifikant geringer als auf grob texturierten Böden war, ergaben sich bei Düngern mit einem hohen N-Gehalt keine Unterschiede zwischen den Böden. In einem zweiten Gefäßversuch mit einer größeren Spannweite von sieben verschiedenen Böden wurden auch Unterschiede in der scheinbaren N-Ausnutzung zweier Dünger mit mittlerem N-Gehalt (Ackerbohne, Maltaflor®-spezial) festgestellt. Dieser Effekt stand aber weder in Beziehung zur Bodentextur noch zum C_{org}-Gehalt. Ebenso wenig waren die bodenbezogenen Unterschiede in der scheinbaren N-Ausnutzung vom N-Nachlieferungspotential des Bodens, gemessen über die N-Aufnahme aus ungedüngtem Boden, abhängig, obwohl sich die Böden hierin deutlich unterschieden. Auch im dritten Gefäßversuch mit vier Böden und ^{15}N-markierten Düngern (1.5-4.6% N) stand die scheinbare N-Ausnutzung nicht in Beziehung zur tatsächlichen N-Ausnutzung (N aus dem Dünger in Bezug zur Düngermenge). Eine höhere tatsächliche N-Ausnutzung aller getesteten Dünger wurde aber auf Böden mit einer höheren N-Mineralisation des ungedüngten Bodens erzielt. Aus den oben erwähnten Ergebnissen wurde geschlossen, dass mehr als ein Bodenparameter für die Variation in der N-Ausnutzung der Dünger in den verschiedenen Böden verantwortlich ist. Um eine ausreichende N-Versorgung für die Pflanzen sicherzustellen wird empfohlen, besonders auf fein texturierten Böden und auf Böden mit einer hohen N-Mineralisation Dünger mit einem höheren N-Gehalt einzusetzen und alle Böden unabhängig von ihrem N-Nachlieferungspotential zu düngen.

Ackerbohnenschrot und Maltaflor®-spezial wurden unter Gewächshausbedingungen über zwei Vegetationsperioden als Dünger zur Tomatenproduktion im Vergleich mit Horn getestet. In beiden Jahren und für beide Dünger war der Tomatenertrag und die Gesamt-Sprossaufnahme mit Horn vergleichbar. Die scheinbare N-Ausnutzung war im Jahr 2003 geringer (Ackerbohne: 19%, Maltaflor®-spezial: 33%, Horn: 32%) als im Jahr 2004 (Ackerbohne: 30%, Maltaflor®-spezial: 57%, Horn: 38%). Die geringere

scheinbare N-Ausnutzung in 2003 wurde auf das höhere N-Nachlieferungspotential des Bodens und auf den höheren Nitrat-Input über das Bewässerungswasser zurückgeführt. Aufgrund eines Nitratrestes im Boden in beiden Jahren stieg die scheinbare N-Wiederfindung (N-Aufnahme durch die Pflanzen plus Boden NO_3^--N; 2003 / 2004: 34% / 37% für Ackerbohne, 59% / 68% für Maltaflor®-spezial, 37% / 57% für Horn) im Vergleich zur scheinbaren N-Ausnutzung. Auf dem hohen N-Nachlieferungspotential des Bodens (2003) wirkte sich eine Teilung der gesamten N-Menge in zwei Gaben nicht auf die N-Aufnahme durch den gesamten Spross aus. Dagegen wurde bei niedrigerem N-Nachlieferungspotential des Bodens in 2004 der Ertrag und die N-Aufnahme durch eine alleinige Düngung sechs Wochen nach der Pflanzung negativ beeinflusst. Eine Teilung der N-Gabe von schnell verfügbaren organischen Düngern erscheint vielversprechend und eine zusätzliche N-Mineralisation kann durch das regelmäßige Hacken bereits gedüngter Flächen erreicht werden.

Die Ergebnisse mit pflanzlichen und industriell verarbeiteten organischen N-Düngern, die im Inkubationsexperiment erzielt wurden, waren auf Gefäßversuche übertragbar. Eine Übertragbarkeit dieser auf Gewächshausklimabedingungen basierenden Ergebnisse auf die Gemüseproduktion im Gewächshaus war ebenfalls möglich. Aber die vorgestellten Ergebnisse sind nicht ohne weiteres auf Feldbedingungen übertragbar, da dort der Einfluss von Temperatur und Wasser stärker variiert und höhere N-Verluste durch Auswaschung zu erwarten sind. Daher muss die Effektivität von pflanzlichen und industriell verarbeiteten organischen N-Düngern zur Düngung von Freilandgemüse unter Feldbedingungen auf mehreren Standorten und zu verschiedenen Jahreszeiten untersucht werden.

Zusammenfassend wurde aus den hier vorgestellten Ergebnissen geschlossen, dass Körnerleguminosen und industriell verarbeitete organische Dünger aus pflanzlichen und mikrobiellen Rückständen eine ausreichende N-Versorgung für ökologisch produzierte Gemüsekulturen mit langer Kulturdauer unter Gewächshausbedingungen sicherstellen und dass diese daher geeignet sind, tierische Reststoffdünger zu ersetzen.

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