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Effects of low temperature, soil water content and soil type on mineralisation of catch crop shoot material

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Abstract

Success of catch crops in increasing the efficiency of nitrogen utilisation depends on both their total nitrogen uptake and the timely mineralisation of nitrogen from catch crop material incorporated into soil. The timely mineralisation depends on the mineralisation rate and the incorporation time. With information on mineralisation rates at low temperatures, the timing of incorporation of catch crops could be optimised. This study was done to supply such information.

A sandy and a loamy soil mixed with either shoots of winter rye or oil radish, or without crop material were incubated in open, rolled plastic bags at 0, 4, 10 and 20 °C (loamy soil only at 10 °C) at several gravimetric water contents (10 - 15 % for sandy, 18 - 38 % for loamy soil). NH_4^+-N and NO_3^--N concentrations were measured after 0, 8, 15 and 20 weeks and mineral nitrogen concentrations (N_{min}) were calculated as their sum.

N_{min} increased until 15 weeks after the start of incubation and then decreased, probably due to denitrification induced by oxygen exhaustion in the plastic bags. N_{min} generally increased with temperature, but even at 0 °C 45-60 % of crop nitrogen was present as N_{min} after 8 weeks, compared to 62-72 % at 20 °C. There was no clear effect of water content on N_{min}. Initially, N_{min} was higher in loamy than in sandy soil, but later this was reversed. NH_4^+-N concentrations first increased and then decreased with time, and were inversely related to temperature and water content. This indicates that nitrification is more hampered by low temperatures and low water contents than mineralisation. NO_3^--N concentrations increased until the measurement at 15 weeks at all temperatures, and then decreased, except at 0 °C, where they levelled off. NO_3^--N concentrations increased with temperature, and with water content at 0, 4 and 10 °C, but no clear water content effect was observed at 20 °C.

It is concluded that mineralisation rates increased with temperature. At 0 °C there was still considerable mineralisation.Variation in water content in the used ranges did not have a strong effect on mineralisation rates.

Introduction

Success of catch crops in increasing the efficiency of nitrogen utilisation depends on both their total nitrogen uptake and the timely mineralisation of nitrogen from catch crop material after incorporation into soil. After spring incorporation of catch crop material, mineralisation can be too slow for supplying nitrogen to the following crop, presumably due to slow decomposition at low soil temperatures (Meisinger et al., 1991). However, a part of the nitrogen in catch crop material incorporated in autumn can be mineralised, and leached, before the end of the winter leaching period (Landman, 1990; Jensen, 1992). The timing of catch crop incorporation could be optimised if information were available on the mineralisation rates of catch crop nitrogen under winter and spring conditions.

The optimisation could be done with the help of a simulation model. This has the advantage that the mineralisation can be calculated for various combinations of crop materials, soils and weather conditions. In simulation models, the decomposition rates of organic materials are described by Arrhenius or linear functions of temperature in the range from 0 to 25 °C. In their models, Keulen and Seligman (1987), Kersebaum and Richter (1991) and Habets and Oomen (1993) estimated decomposition rates to be about zero at 0 °C, although decomposition of wheat material after 30 days of incubation at 0 °C was found to be half of that at 15 °C (Stott et al., 1986). In the models, nitrogen dynamics are calculated from decomposition rates and C/N ratios. In this way, both mineralisation and immobilisation can be calculated.

This study aims to quantify the rates of mineralisation and nitrification of nitrogen in catch crop shoot material incubated at low temperatures, for different water contents and soil types. The data will be used to derive a temperature relationship for decomposition and mineralisation of catch crop material.

Materials and methods

A sandy and a loamy soil mixed with shoots of winter rye (*Secale cereale* L. cv. Halo) or oil radish (*Raphanus sativus* L. cv. Pegletta) or without crop material were incubated in plastic bags at 0, 4, 10 and 20 °C (loamy soil only at 10 °C) and several water contents. NH_4^+-N and NO_3^--N concentrations were measured after 4 days (only for samples of soil with winter rye and soil only at 4 °C) and 8,15 and 20 weeks. There were 3 replicate bags for each treatment at each measurement.

A few days before the start of the incubation, the sandy soil (a glacial sand) was collected at Wageningen, the Netherlands. The soil was air dried and passed through a 1 cm sieve to remove stones. The loamy soil had been collected at Marknesse, the Netherlands, and stored air dry for several years. It was classified as a heavy loamy Zuiderzee soil (Stichting voor Bodemkartering, 1965). Some soil characteristics are given in Table 1.

Catch crop material of winter rye and oil radish was obtained by growing these crops on a fertilised potting soil in a greenhouse at Wageningen, from April 15 to May 20, 1993. Then the shoots were cut off at ground level and cut into pieces of ca. 1 cm. Shoot characteristics are given in Table 1.

The shoots were mixed by hand with the soil in a dry weight ratio of 1:100 (shoot : soil). Compared to field conditions, this ratio is very high, but it was chosen to ensure significant differences between nitrogen concentrations in the different treatments. Gravimetric water contents of 10, 12 and 15 % for the sandy soil and 18, 30 and 38 % for the loamy soil were installed by adding demineralised water. The water contents of the fresh crop materials were included in these water contents. Samples of 101 ± 15 g soil mixture were put in polypropyleen bags. The bags were weighed, rolled up around the samples and stored

Table 1. Characteristics of the used soils and crop materials.

material	total N ($g\ kg^{-1}$)	organic N (%)	NO_3^--N (%)	NH_4^+-N (%)	C/N	pH
sandy soil	1.40	99.3	0.6	0.1	n.d.	5.7
loamy soil	1.57	98.5	1.1	0.5	n.d.	7.6
rye shoot	61.6	86.2	13.2	0.6	6.6*	
radish shoot	51.9	88.6	11.0	0.4	7.9*	

*: for calculation of C/N a C-content of 408 g kg^{-1} was assumed (Vigil and Kissel, 1991).
n.d. = not determined

in cardboard boxes at 0, 4, 10 and 20 °C. As soon as possible, after 4 days, a part of the bags containing soil with winter rye shoots or soil only and stored at 4 °C, was analysed. The data from these bags were used as the initial values for all temperature treatments. After 8, 15 and 20 weeks samples were analysed from all treatments. Physical disturbance of the samples was prevented as much as possible. Unfortunately, the samples incubated for 15 weeks at 10 and 20 °C had to be transferred to other climate rooms for 3 weeks.

At each sampling, the bags were weighed to determine water loss during incubation. A subsample of about 30 g fresh soil mixture was extracted with 0.01 M $CaCl_2$ (Houba et al., 1989). NH_4^+-N was determined colorimetrically by the indophenol blue method and NO_3^--N colorimetrically after reduction to NO_2^- as α-naphtylamine-paradiazobenzene-parasulphonic acid (Houba et al., 1986). Remaining soil material from each bag was used for determination of the gravimetric water content by weighing about 50 g of soil before and after drying overnight at 105 °C. Mineral nitrogen concentrations (N_{min}) were calculated as the sum of the NH_4^+-N and NO_3^--N concentrations.

Results

Water loss during incubation was negligible. The results for sandy and for loamy soils, and for rye and radish showed the same trend. The shown figures, of rye mixed with sand, (see below) were chosen as examples of this trend.

N_{min} increased until 15 weeks and then decreased (Figure 1), probably due to denitrification induced by oxygen exhaustion in the plastic bags. There were no systematic effects on mineralisation resulting from variation in water content, and therefore, Table 2 represents N_{min} averaged over the water contents. N_{min} generally increased with temperature, but for sand mixed with rye at 10 and 12 % water, it was higher at 0 or 4 °C than at 10 °C. Even at 0 °C N_{min} was considerable: 45-60 % of crop nitrogen was present as N_{min} after 8 weeks, compared to 62-72 % at 20 °C. Initially, N_{min} was higher in loamy than in sandy soil, but at the later measurements this was reversed, implying that the mineralisation rate was ultimately lower in the sandy soil than in the loamy soil or that the denitrification rate was higher than in the sandy soil. This result confirms the findings of other studies (Verberne et al., 1990). The mineralisation flush during the first 4 days of incubation was higher in the loamy soil, so that on average 34 % of the nitrogen added with the rye shoots was already in N_{min} at the first measurement (Table 2). N_{min} was higher with rye than with oil radish, but when N_{min} in the soil-crop mixtures, minus that in the blank, was expressed as a percentage of the added nitrogen, this difference was clear only at 15 weeks after the start of the incubation (Table 2).

Table 2. The percentage of crop nitrogen recovered as N_{min} in the course of the incubation, for the different soil types and temperatures. N_{min}-values of the crop-soil samples minus those of the samples with only soil were divided by the amounts of added crop nitrogen. Averages over the different water content treatments ± standard deviations are presented. * : same measurement for all temperatures (see materials and methods).

soil	crop	temp (°C)	N_{min} (%) 4 days	N_{min} (%) 8 weeks	N_{min} (%) 15 weeks	N_{min} (%) 20 weeks
sand	rye	0	18 ± 1*	52 ± 3	74 ± 5	56 ± 4
		4	18 ± 1*	51 ± 3	81 ± 6	56 ± 3
		10	18 ± 1*	58 ± 4	74 ± 2	60 ± 2
		20	18 ± 1*	68 ± 3	99 ± 2	54 ± 2
	radish	0	-	51 ± 6	54 ± 7	52 ± 2
		4	-	52 ± 3	64 ± 6	59 ± 3
		10	-	64 ± 2	60 ± 5	47 ± 3
		20	-	64 ± 4	83 ± 3	48 ± 4
loam	rye	10	34 ± 1	33 ± 9	57 ± 6	54 ± 4
	radish	10	-	44 ± 7	51 ± 11	48 ± 4

NH_4^+-N concentrations (Figure 2 and 3) first increased and then decreased with time, and decreased with temperature and water content. This indicates that nitrification is hampered more than mineralisation by low temperatures and low water contents. Richter (pers. comm.)

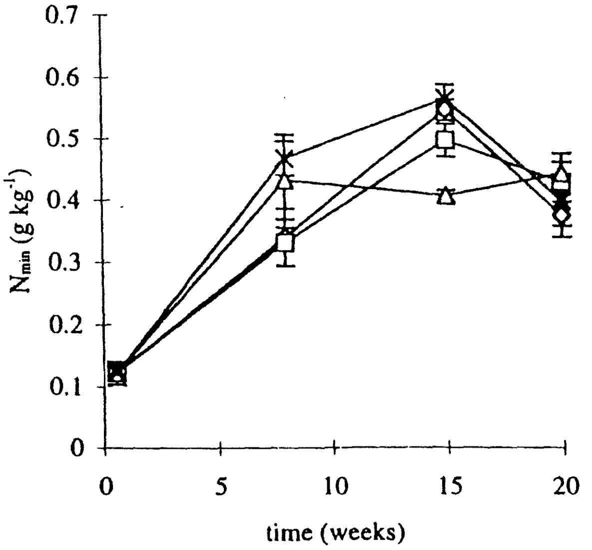

Figure 1. The time course of N_{min} (g kg^{-1} oven dry soil) in the samples of sandy soil mixed with rye shoot residues, during incubation at 0, 4, 10 and 20 °C, at the gravimetric water content of 12 %.
◇ = 0 °C, □ = 4 °C, Δ = 10 °C, ✕ = 20 °C.

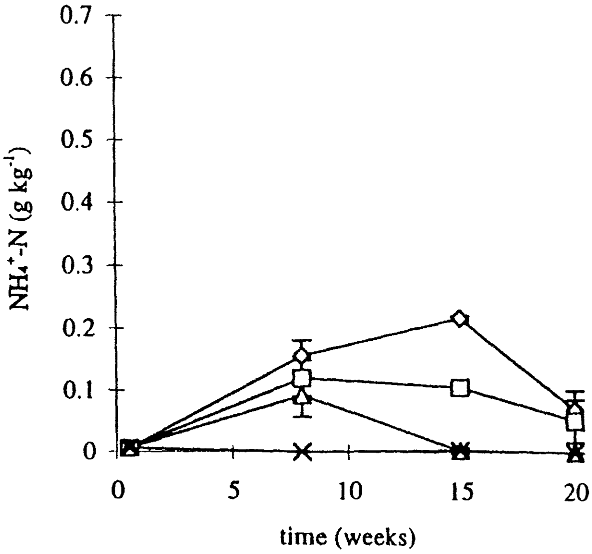

Figure 2. The time course of NH_4^+-N concentrations (g kg^{-1} oven dry soil) in the samples of sandy soil mixed with rye shoot residues, during incubation at 0, 4, 10 and 20 °C, at the gravimetric water content of 12 %.
◇ = 0 °C, □ = 4 °C, Δ = 10 °C, ✕ = 20 °C.

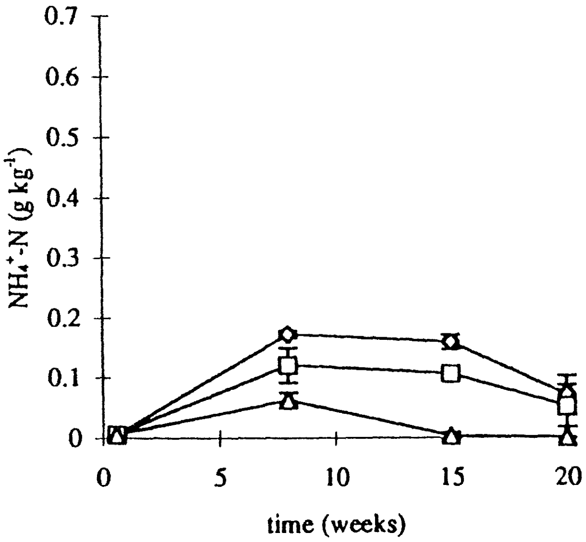

Figure 3. The time course of NH_4^+-N concentrations (g kg^{-1} oven dry soil) in the samples of sandy soil mixed with rye shoot residues, during incubation at the gravimetric water contents of 10, 12 and 15 %, at 4 °C.
◇ = 10 % water, □ = 12 % water, Δ = 15 % water.

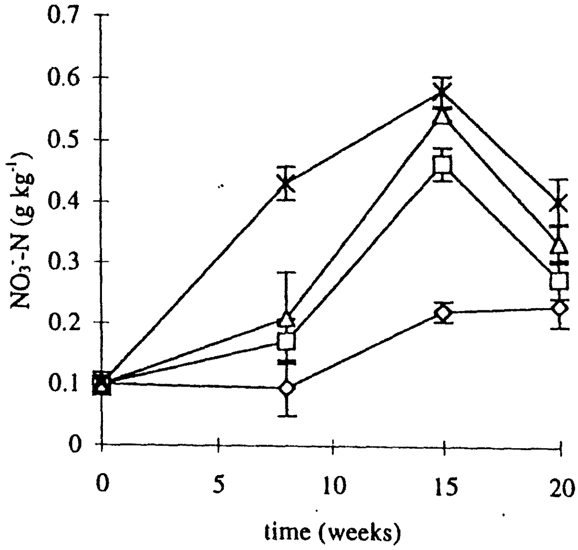

Figure 4. The time course of NO_3^--N concentrations (g kg^{-1} oven dry soil) in the samples of sandy soil mixed with rye shoot residues, during incubation at 0, 4, 10 and 20 °C, at the gravimetric water content of 10 %.
◇ = 0 °C, □ = 4 °C, Δ = 10 °C, ✕ = 20 °C.

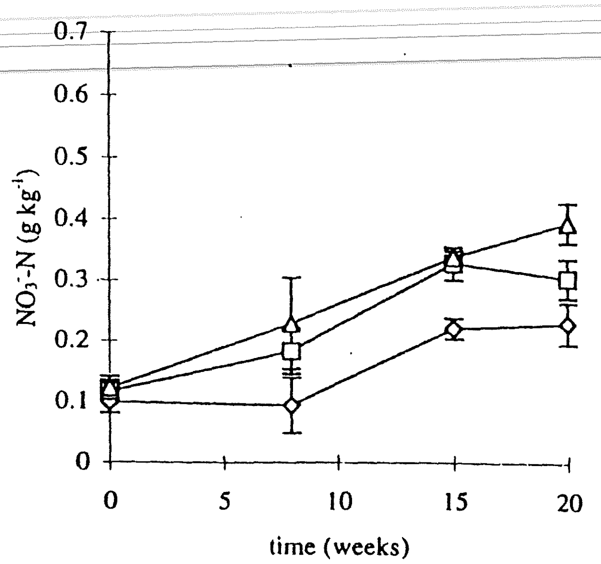

Figure 5. The time course of NO_3^--N concentrations (g kg^{-1} oven dry soil) in the samples of sandy soil mixed with rye shoot residues, during incubation at the gravimetric water contents of 10, 12 and 15 %, at 0 °C. ◇ = 10 % water, □ = 12 % water, Δ = 15 % water.

found a comparable decrease in ammonium content when temperature increased from 10 to 35 °C. Addiscott (1983) did not find a difference in reaction to temperature between both processes. NH_4^+-N concentrations were higher in loamy than in sandy soil (data not shown).

NO_3^--N concentrations (Figure 4 and 5) increased with time until 15 weeks at all temperatures, and then decreased, except at 0 °C, where they levelled off. They rose with temperature. They increased with water content at 0, 4 and 10 °C, but no clear effect was observed at 20 °C. The rise in NO_3^--N concentrations with water content supports the hypothesis that nitrification is hampered at low water contents; the denitrification rate is expected to increase at higher water contents, likely to induce more anaerobic spots in the soil (Weier et al., 1993). Nitrification was fast enough to compensate for the consequent decrease in NO_3^--N concentrations.

Without addition of crop material all concentrations were about one tenth of those in the samples with crop material (data not shown).

Discussion

Method

The data suggest that in all treatments denitrification occurred (Figures 1, 4 and 5, Table 2), despite the low water contents of some of the treatments. The supply of oxygen to the bags has probably been insufficient. The plastic is permeable to gases, and the bags were not sealed, so that supply of air was possible. However, the bags were rolled up around the samples and then piled in cardboard boxes, so that diffusion of oxygen to the samples could have been insufficient. This could be avoided by spreading the bags on trays instead of piling them on top of each other, and rolling up the empty end of each bag beside the sample instead of around the sample. Moreover, the bags could be pearced. However, all these measures might promote loss of water during incubation, so that storage in an environment with a high relative humidity would be necessary.

The air drying, and, for the loamy soil, storing of the soil prior to the experiment affects the microbial population in the soil. After rewettting a mineralisation flush of the soil organic matter is expected (Birch, 1958). Because the N_{min} levels in the blanks were much lower than those in the crop-soil mixtures, this flush is not expected to have affected the results on the mineralisation of the catch crop material strongly.

The water content of the soil samples and the soil-crop samples could not be unambiguously adjusted to the same level, because it is not clear to what extent the water in the crop material was available to microorganisms, and how this changed during incubation. Especially for the lowest water content this is problematic, because here about 90 % of the water was in the crop material at the start of the incubation. A difference in water availability might cause different decomposition rates of the soil organic matter in the soil samples and the soil-crop samples. In this experiment the N_{min} levels and the increase with time in the blank were about one tenth of those in the soil-crop mixture, and the effect of water content on N_{min} was small. Therefore, it can be postulated that differences in soil organic matter mineralisation rate between soil samples and soil-crop samples due to variation in water content were negligible.

The mineralisation rate at 0 °C might be affected by freezing and thawing of the samples, depending on the constancy of the temperature in the climate room. It should be compared with measurements at just above zero temperatures to separate the temperature effect from the freeze-thaw effect.

Mineralisation

The crop material used had high nitrogen contents (Table 1), 61.6 g kg^{-1} in the rye shoots, and 51.9 g kg^{-1} in the radish shoots. In field situations the nitrogen content of catch crops at the moment of incorporation will mostly be lower (14 - 36 g kg^{-1}) (Jensen, 1992; Thorup-Kristensen, 1993), and therefore, mineralisation will be slower. Temperature relationships for decomposition are, however, mostly described independently of the composition of the organic material, although different relations can be applied for resistant organic matter and decomposable organic matter (Nordmeyer and Richter, 1985). In further research, the mineralisation of nitrogen from older, field-grown catch crop material is currently examined at low temperatures.

From these data a temperature relationship for the relative rates of decomposition and mineralisation of catch crop material could be deduced, for the range of used moisture contents. It must be assumed then that no priming effect of the addition of the crop material on decomposition of native organic matter occurs. Moreover, a distinction must be made between the nitrogen in organic form and in nitrate present in the catch crops. Whitmore and Groot (1994) postulate that crop nitrate could be directly included in the soil nitrate pool. The high values of nitrate in the soil at 4 days after the start of the incubation support this (Table 2).

Nitrification

The results indicate that under low temperature conditions a considerable part of N_{min} can be present as ammonium (Figures 2 and 3). This implies that a correct description of soil nitrogen dynamics should include both mineralisation and nitrification. However, in some of the models describing soil nitrogen dynamics, mineralisation and nitrification are clustered as one process (e.g. Groot and Willigen, 1991), because nitrification is not expected to be rate limiting for the production of nitrate from organic nitrogen. Consequently, ammonium concentrations are assumed to be negligible and nitrate concentrations could be overestimated, leading to overestimation of leaching of mineralised nitrogen.This could occur especially at low temperatures, for instance after autumn incorporation of catch crop material. However, if mineralisation is slower, for instance when crop materials with lower nitrogen contents are incorporated, the nitrification rate may not be limiting indeed, so that ammonium concentrations will be low.

Conclusions

It is concluded that mineralisation rates increased with temperature, but were considerable even at 0 °C, and that variation in water content in the used ranges had only a marginal effect on mineralisation rates. Mineralisation was faster in the sandy than the loamy soil. Nitrification was more than mineralisation hampered by low temperatures and low water contents.

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