Plant and Soil **181:** 25–30, 1996.

Temperature effects on C- and N-mineralization from vegetable crop residues

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Key words: C-mineralization, crop residues, incubation, N-mineralization, temperature

Abstract

Net N-mineralization and nitrification from soil organic matter and from vegetable crop residues (leaf-blades of cauliflower and stems of red cabbage) were measured at 4 temperatures during aerobic incubation in the laboratory. C-mineralization from leaf-blades of cauliflower was monitored at 3 different temperatures. N-mineralization from soil organic matter was best described by zero order kinetics N(t)=kt whereas N- and C-mineralization from the crop residues were described by single first order kinetics. Stems of red cabbage mineralized much more slowly than leaf-blades of cauliflower. S-shaped functions were fitted to the relationship between the rate constants of both C and N-mineralization and temperature. The rate parameter κ of the S-shaped function reflects the temperature dependence of the mineralization rate k. The parameter κ for N-mineralization of the stem material (κ=5.36) was significantly higher than for the leaf-blades (κ=3.38), indicating that there is a strong interaction between temperature and resistance to degradation in the soil. N-mineralization from soil organic matter was least sensitive to temperature (κ=2.63). Temperature dependence of nitrification was not significantly different from mineralization over the temperature range considered. Rate constants for C-mineralization of cauliflower leaf-blades were higher than for N-mineralization, but the temperature dependence of the rate constants was not significantly different for both processes.

Introduction

Efficient use of N fertilizers is only possible if mineralization of organic N from different sources is fully understood. Most research on the dependence of N-mineralization on temperature has focused on mineralization from soil organic matter (Addiscott, 1983; Beck, 1983; Cassman and Munns, 1980; Kowalenko and Cameron, 1976; Lochmann et al., 1989; Stanford et al., 1973) or mineralization from residues of agricultural crops and green manures (Honeycutt et al., 1993; Pal et al., 1975). Mineralization from residues of vegetable crops and its relation to temperature, especially the quantitative aspects, has been studied in less detail. However, in regions with intensive vegetable production these residues contribute considerably to the mineral N content of the soil, which can be either beneficial (supply of N to subsequent crops) or harmful (N leaching to ground water in winter). To predict the release of N from these vegetable residues it is most important to quantify the relationship with the most influential environmental factor, i.e. temperature. With respect to the prediction of leaching it is necessary to differentiate between mineralization and nitrification of these crop residues.

In this paper quantitative relationships are established between N- and C-mineralization parameters of vegetable crop residues and temperature.

Materials and methods

Pretreatment of soil and plant material

The soil used in the incubation trials is a loamy sand soil from Pittem (West-Flanders) which has been used several years for the growing of chicory. The soil was sampled at a moisture content well above FC and was allowed to dry to a moisture content of 80% of FC.

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The soil was not air dried in order to minimize disturbance of microbial activity. Visible plant material and stones were removed by hand and large soil aggregates were crumbled. Two kinds of crop residues were added: leaf-blades of cauliflower (considered to mineralize very fast) and the upper part of stems of red cabbage (considered more resistant to mineralization). The fresh crop residues were chopped into small pieces of ± 0.5 cm^2. The dry matter content was 14.1% and 19.3% and the total N content 3.46% and 1.90% for leaf-blades of cauliflower and stems of red cabbage respectively.

N-mineralization

For the N-mineralization trials plastic tubes with an inner diameter of 46.3 mm were used. Each tube was filled with 317 g moist soil mixed thoroughly with 6 g of fresh chopped crop residues. When calculated for a surface of 1 ha (ratio of 1 ha to surface of the tube) this corresponds to approximately 36 tons of fresh crop residues. For leaf-blades of cauliflower this is a realistic amount. For stems of red cabbage this is a high amount, but when incorporating lower amounts the mineralization process can not be followed accurately (especially at the lower temperatures when mineralization is very limited). The soil-crop residue mixture was slightly compacted to obtain a bulk density of 1.4 g cm^{-3}. The tubes were covered with a single layer of parafilm in order to keep moisture content at 80% of FC throughout the trial. Tubes were stored at 4 temperatures: 5.5, 10, 16 and 25 °C. For each temperature a series of blanks (no crop residues) was included. Sampling took place by removing intact tubes. Samples were removed in 3 replicates after 9, 23, 35, 54, 76, 93 and 112 days, extracted with KCl and analyzed for NO_3^--N and NH_4^+-N with a continuous flow autoanalyzer. The sum of NH_4^+-N and NO_3^--N measured at a certain time is further referred to as N-mineralization.

C-mineralization

C-mineralization was determined using glass jars with an inner diameter of 105 mm. Each jar was filled with a mixture of 300 g moist soil (80% of FC) + 10 g of fresh chopped crop residues (leaf-blades of cauliflower). For the C-mineralization trials more crop residue had to be incorporated per 100 g of soil than for the N-mineralization trials to allow accurate measurements towards the end of the incubation (when only very small amounts of C are being respired). Small vials filled with 15 mL of 1 *N* NaOH were placed into the jars to trap evolved CO_2. The jars were closed airtight and incubated at 3 different temperatures: 5.5, 10 and 16 °C. For each temperature a series of blanks was included. Analysis (in duplicate) of evolved CO_2 took place by removing the vials and titration with HCl after addition of $BaCl_2$.

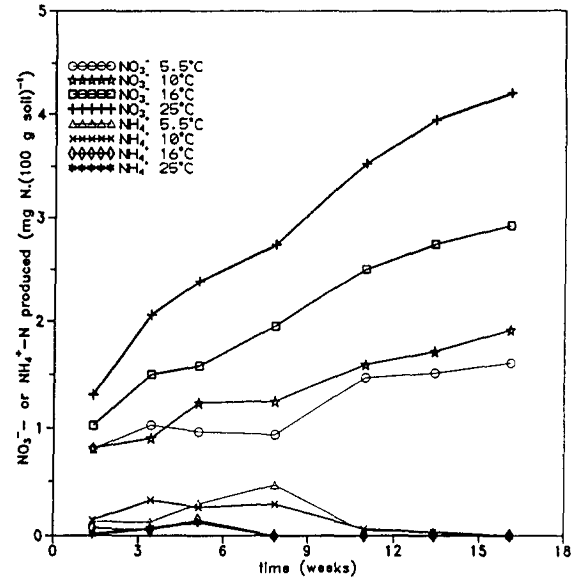

Figure 1. NO_3^- - and NH_4^+-N produced in the blank soil.

Results

N-mineralization and nitrification

The N-mineralization from the blank soil (no crop residues) is given in Figure 1. Because the disturbance of the microbial biomass was kept minimal, there is hardly any flush of mineral nitrogen (Richter et al., 1982) at the start of the incubation. There is a relatively important rise in NH_4^+-N amounts at 5.5 and 10 °C between 2 and 8 weeks after the start of the incubation, but after 10 weeks the amounts of NH_4^+-N are negligible. The zero order kinetics model N(t) = k.t (with N(t) the amount of N mineralized after time t) was used to describe N-mineralization and nitrification from the blanks. The values of the rate constants k are given in Table 1. When calculated on field scale for a soil layer of 30 cm, N-mineralization for this soil ranges from 1.8 (at 5.5°C) to 7.9 kg N ha^{-1} week^{-1} (at 25 °C).

The N-mineralization from the crop residues is given in Figures 2 and 3. For leaves of cauliflower

Table 1. Values of the rate constants k and R^2 (R_a^2) values (zero or first order model) for the different temperatures (CaLb = leaf-blades of cauliflower, RcSu = upper part of stems of red cabbage).

	Temperature (°C)							
	5.5		10		16		25	
	k	R^{2a}	k	R^{2a}	k	R^{2a}	k	R^{2a}
N-mineralization								
Blank soil	0.043	0.917	0.057	0.902	0.123	0.980	0.188	0.970
CaLb	0.123	0.958	0.141	0.963	0.290	0.922	0.635	0.993
RcSu	0.031	0.837	0.040	0.834	0.102	0.887	0.353	0.954
Nitrification								
Blank soil	0.057	0.871	0.075	0.972	0.130	0.981	0.193	0.987
CaLb	0.080	0.823	0.079	0.798	0.204	0.873	0.383	0.941
RcSu	0.031	0.845	0.033	0.725	0.098	0.886	0.304	0.910
C-mineralization								
CaLb	0.282	0.972	0.354	0.983	0.565	0.982	–	–

[a] For non-linear curve fitting R_a^2 values (adjusted R^2 values) are used rather than R^2 values as a measure of goodness of fit.

N-mineralization is fast at all temperatures and temperature changes above 16 °C do not further increase mineralization. At 5.5 and 10 °C important amounts of NH_4^+-N are present up to 2 months after the start of the incubation (more than 40 % of total N at 10 °C after 5 weeks, Fig. 4). The upper part of stems of red cabbage are mineralized much more slowly, especially at 5.5 and 10 °C. The lower rate of N-mineralization is also reflected in the smaller amounts of NH_4^+-N that are formed (less than 10% of total N). N-mineralization and nitrification from the crop residues was described using the single first order kinetics model:

$$N(t) = N_A.(1 - e^{-kt}) \qquad (1)$$

with N_A the amount of mineralizable N expressed in % of total residue N (Table 1). Because immobilization (net negative values of NH_4^+-N or NO_3^--N) occurred only in very few cases for the stem material and was not significant, negative values of net NH_4^+-N or NO_3^--N were set equal to zero in the curve fitting procedure. First N_A was calculated for 25 °C and this value of N_A was then used for the other temperatures, i.e. it is supposed that only the rate constant k, and not N_A, is affected by temperature. The values of N_A are 82.2% and 66.7% of N_{tot} for the leaf-blades and the stems respectively.

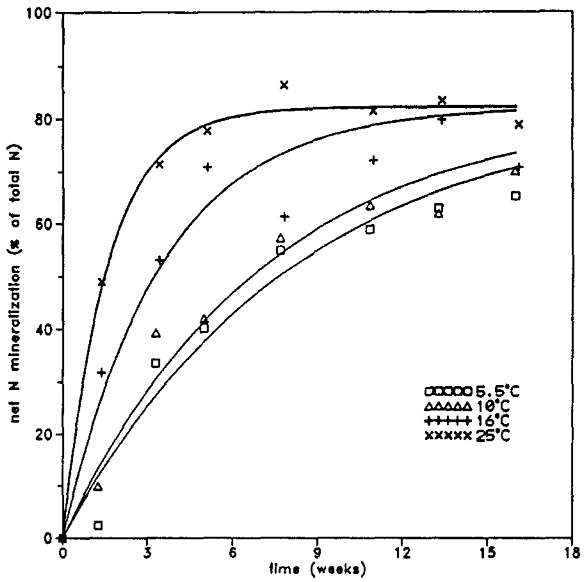

Figure 2. Net N-mineralization (NO_3^--N + NH_4^+-N) from leaf-blades of cauliflower with a first order model fitted to the data.

C-mineralization

C-mineralization of leaf-blades of cauliflower (Fig. 5) was also described by single first order kinetics, giving a very close fit (Table 1). Now the image is quite different. The rate constants for C-mineralization are much higher than for N-mineralization, but C_A (the amount

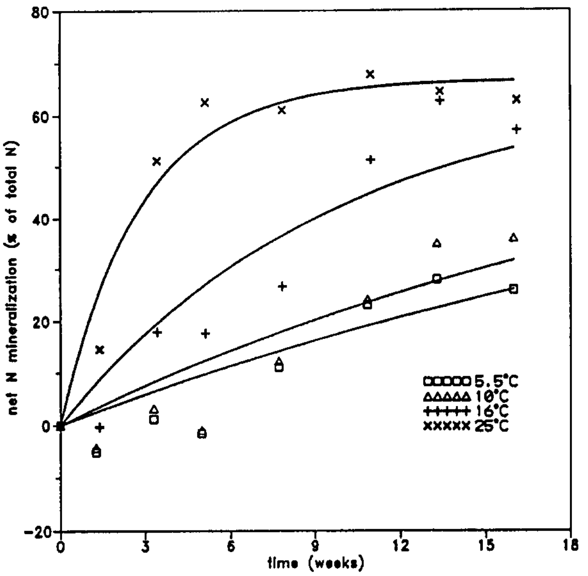

Figure 3. Net N-mineralization (NO_3^--N + NH_4^+-N) from the upper part of stems of red cabbage with a first order model fitted to the data.

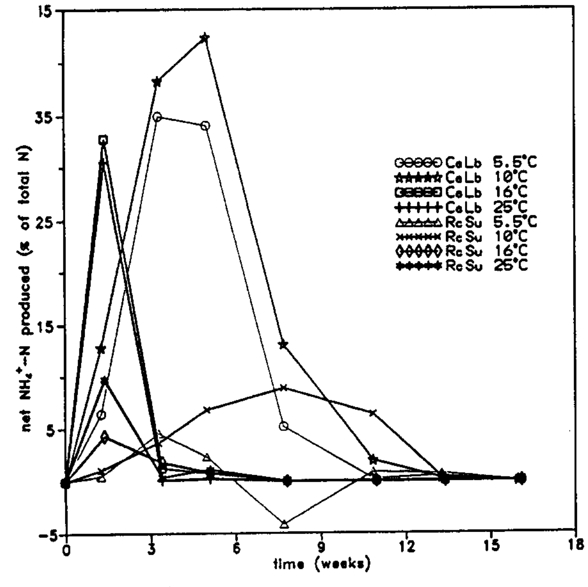

Figure 4. Net NH_4^+-N produced during the incubation of the crop residues (abbreviations: see Table 1).

of mineralizable C expressed in% of total residue C) amounts to 63% of total C, which is considerably smaller than N_A. It is remarkable that the final level of C mineralized is slightly higher at 5.5 °C as compared to the higher temperatures. This is comparable to results given by Pal et al. (1975), who found that more C was

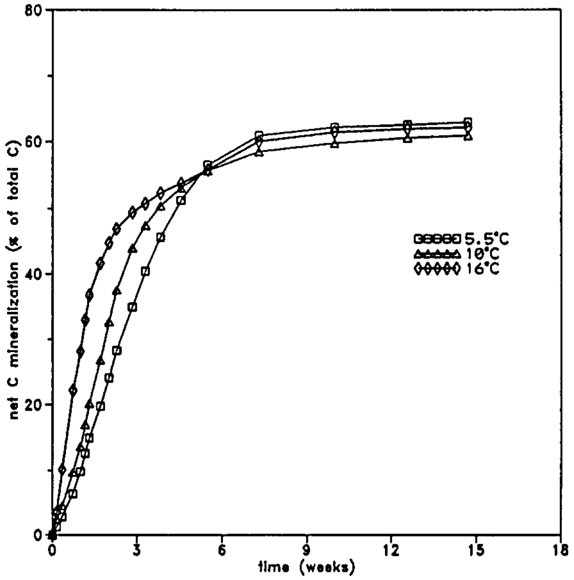

Figure 5. Net C-mineralization (expressed in% of total added C) from leaf-blades of cauliflower.

lost from straw incubated with soil at 22 °C than at 37 °C.

Quantification of the influence of temperature

For modelling the influence of temperature on both C- and N-mineralization an S-shaped function is used. We did not use an Arrhenius type relationship $k = A.e^{-B/T}$ because of several reasons. It has no biological significance as related to soil biomass (the optimum temperature for the Arrhenius equation is ∞), the fitting is poor if points close to 0 °C are included (Addiscott, 1983; Stanford et al., 1973) because the equation uses the absolute temperature, and its parameters, especially A, are not easy to interpret (Addiscott, 1983). The equation used here is:

$$k(T) = k_{opt}.e^{\left(-\kappa\left(1-\frac{T}{T_{opt}}\right)^2\right)} \qquad (2)$$

k(T) is the rate constant as a function of temperature, k_{opt} the maximum rate constant, T_{opt} the optimum temperature (in °C) and κ a rate parameter reflecting the temperature sensitivity of k. The number of data points here was too small to determine the optimum temperature in the equation from the curve fitting. According to Beck (1983) the optimum temperature for ammonification of organic N is ± 50 °C. T_{opt} in the equation here is set at 37 °C because above that temperature nitrification is severely restricted and eventually ceases at 45 °C (Beck, 1983; Stanford et al., 1973). For

Table 2. Parameters of the curve fitting of the rate constants k as a function of temperature and temperature quotients (Q_{10} values) (k_{opt} = value of the rate constant at optimum temperature; CaLb, RcSu: see Table 1). Bracketed values represent standard deviations

	k_{opt}	κ	R_a^2	Q_{10}	
				5.5–16 °C	16–25 °C
N-mineralization					
Blank soil	0.256 (0.017)	2.63 (0.14)	0.971	2.72	1.60
CaLb	0.900 (0.179)	3.38 (0.57)	0.986	2.26	2.39
RcSu	0.619 (0.193)	5.36 (0.93)	0.995	3.10	4.00
Nitrification					
CaLb	0.538 (0.116)	3.17 (0.46)	0.981	2.43	2.01
RcSu	0.512 (0.142)	5.00 (0.89)	0.995	3.01	3.52
C-mineralization					
CaLb	1.323 (0.008)	2.55 (0.01)	0.899	1.94	–

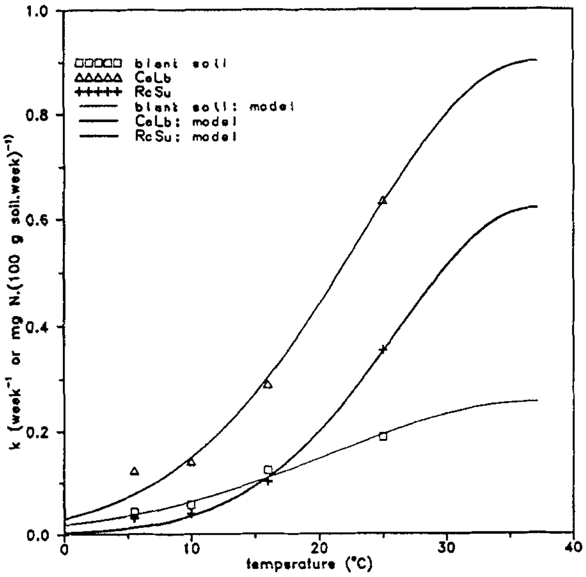

Figure 6. The S-shaped temperature model fitted to the N-mineralization rate constants of the blank soil and the crop residues (abbreviations: see Table 1).

C-mineralization the optimum temperature is also set at 37 °C (according to Roper (1985) C-mineralization is maximal between 25 and 45 °C). Although several authors found N-mineralization to occur at 0°C (Lochmann et al., 1989; Stadelmann et al., 1983), we considered it here to be negligible and the point k(0)=0 was included in the curve fitting procedure. The fitted curves for N-mineralization are given in Figure 6. Table 2 summarizes the results for N-mineralization, nitrification and C-mineralization.

Discussion

There is an obvious difference between the two kinds of crop residues. Indeed, the value of κ for the stems is significantly (p=0.019) higher than for the leaf-blades, which is equivalent to a significant interactive effect in a crop x temperature ANOVA of the rate constants k. This indicates that there is a strong interaction between temperature and kind of crop residue: N-mineralization from resistant crop residues will be more enhanced by a rise in temperature than N-mineralization from more easily degradable residues. This is comparable to results from Nuske and Richter (1981), in which temperature favoured N-mineralization from old (resistant) soil organic matter more than from fresh soil organic matter.

As pointed out by Addiscott (1983) for soil organic matter, there is no difference here in temperature sensitivity between N-mineralization and nitrification of crop residues. There is a lag of several weeks between N-mineralization and nitrification at temperatures of 10°C and below (Fig. 4), which means that leaching of NO_3^--N from these crop residues will also be delayed. For nitrification from the blank soil no values are given in Table 2 because the (small) differences in k values between nitrification and mineralization are merely a consequence of the pretreatment of the soil (some excess NH_4^+ is formed in the beginning of the trial). C- and N-mineralization from leaf-blades of cauliflower were not significantly different in their response to temperature. In the first weeks of the mineralization process the C/N ratio of the added cauliflower residues drops at the lower temperatures (5.5 and 10 °C). But eventually, because N-mineralization is more complete than C-mineralization, the material remaining after 15 weeks has a higher C/N ratio (the C/N ratio for leaf-blades of cauliflower at 16 °C rises from 10.1 at the start of the incubation to 19.5 after 15 weeks).

The Q_{10} values were also calculated. As can be seen in Table 2 these values heavily depend on the kind of organic matter (soil organic matter, crop residues). Especially the Q_{10} values for the stem material deviate much from the value $Q_{10} = 2$ accepted by Stanford et al. (1973) for soil organic matter.

In conclusion we can say that for modelling purposes not one but several relationships describing the influence of temperature on N-mineralization will have to be used, depending on the kind of crop residue or the kind of organic matter considered. Further research including more crop residues will have to clarify whether these crop residues can be classified into groups with a similar temperature dependence for N-mineralization.

Acknowledgements

Financial support by the EC (EC project No. 8001-CT91-0115) and the IWONL (Institute for Encouraging Scientific Research in Industry and Agriculture) is gratefully acknowledged.

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Section editor: R Merckx