Vegetable crop residues: Modelling N mineralization, optimalization and synchronization of the N (re)use using on- and off-farm organic materials and nitrification inhibitors

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1 Introduction

Intensive field vegetable production in Flanders (Belgium) is often characterized by an excessive use of N fertilization, resulting in large mineral N residues in the soil and large amounts of crop residues rich in nitrogen at the harvest. The nitrogen left in above ground residues can amount to over 200 kg N ha^{-1} for a number of Brassica crops. During mineralization of these crop residues, additional mineral N is released into the soil, resulting in large nitrate residues in the soil during the autumn and winter and serious problems with respect to nitrate leaching.

This specific situation of the intensive field vegetable production in relation to crop residues makes it very hard to comply with the current nitrate standards. The European Nitrate Directive states that the amount of nitrate in ground and surface waters has to be less than 50 mg NO_3^--N l^{-1} (11.3 mg N l^{-1}). However, the nitrate residue after a vegetable crop exceeds often the upper standard, resulting in a high potential risk of nitrate leaching.

This project looks at ways to manipulate and modify the N mineralization-immobilization turnover (NMIT) from vegetable crop residues by use of on- and off-farm organic materials in order to reduce nitrate leaching.

2 The N mineralization from vegetable crop residues

During this part of the research, the main goal was to create a good, quantitative knowledge about the N dynamic of vegetable crop residues. Up till now a lot of research has been done on aboveground crop residues, but less on underground residues (roots). Nevertheless, for example cabbages may leave large amounts of roots on the field after harvest, which may contain large amounts of N. This means that also roots may release important amounts of N upon mineralization. The first study was an inventory of vegetable root residues to get an idea of the root biomass left on the field after harvest and the N content of these root residues. In the second study the N mineralization from root residues was modelled using the biochemical composition.

2.1 Inventory of vegetable root residues

Roots from cabbages were collected from different fields in West-Flanders during the autumn of 2001. The results from the inventory are presented in Table 1.

Table 1 Root biomass, total N content and C:N ratio of roots from different cabbages (between brackets standard deviation)

Species and cultivars	Root biomass (ton DM ha^{-1})	Total N (% DM)	C:N ratio
Brussels sprouts (1)			
Adagia	2,64 (0,45)	1,03 (0,13)	38,3 (5,1)
Maximus (5)	3,80 (1,08)	2,12 (0,13)	20,2 (1,6)
Maximus (6)	2,74 (0,20)	1,63 (0,18)	26,3 (3,1)
Cyrus	1,96 (0,81)	1,83 (0,12)	22,7 (1,8)
average (1)	2,78 (0,96)	1,65 (0,43)	26,9 (7,7)
Savoy cabbage (2)			
Wirosa	1,15 (0,16)	2,17 (0,15)	20,1 (1,1)
Hamasa	1,67 (0,11)	1,34 (0,15)	33,2 (4,4)
average (2)	1,41 (0,30)	1,75 (0,45)	26,5 (7,2)
Red cabbage (3)			
Zelox	0,85 (0,09)	2,46 (0,22)	16,8 (2,0)
Reliant	1,19 (0,10)	2,15 (0,26)	20,3 (2,8)
Rodon	1,48 (0,36)	1,37 (0,08)	29,7 (2,4)
average (3)	1,17 (0,33)	1,76 (0,39)	24,3 (4,9)
White cabbage (4)			
Bingo	1,15 (0,10)	1,71 (0,24)	23,3 (3,4)
average (2)(3)(4)	1,25 (0,31)	1,87 (0,46)	23,8 (6,3)
Overall average	1,90 (1,02)	1,78 (0,46)	25,1 (7,0)

(5) and (6) were collected at two different fields

The inventory pointed out that cabbages leave large amounts of roots on the field after harvest: ca. 2.8 ton DM ha^{-1} for Brussels sprouts and ca. 1.3 ton ha^{-1} for the other cabbages. The N content of these roots was on average 1.8% on DM and the average C:N ratio was 25. The amount of N left on field in roots varies between 20 and 50 kg N ha^{-1}.

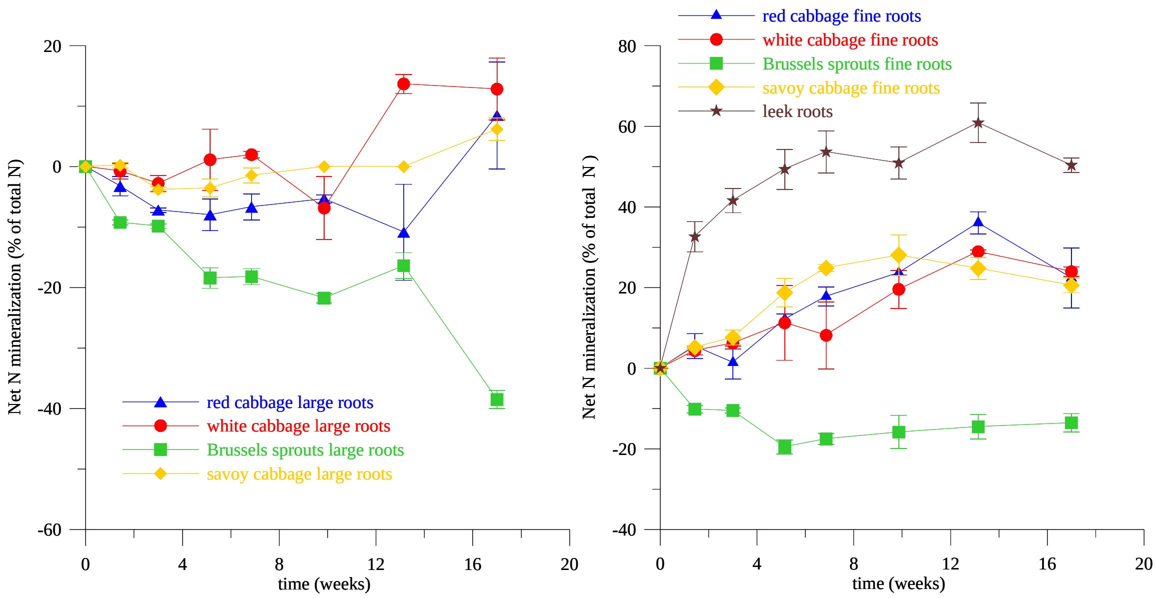
2.2 Modelling the N release from vegetable crop residues

A range of vegetable root residues (red cabbage, white cabbage, Brussels sprouts, savoy, leek) and green manures (ryegrass, white mustard) were analysed for total C and N content, water soluble content, hemicellulose, cellulose and lignin (Stevenson fractionation). The biochemical composition of the vegetable root residues and green manures is presented in Table 2.

Table 2 Chemical characteristics of the vegetable root residues and green manures (RC = red cabbage; WC = white cabbage; BS = Brussels sprouts; SC = Savoy cabbage; LR = leek roots; -La = large roots; -Fi = fine roots; RG = rye grass; WM = white mustard; -Le = leaves ; -St = stems; -Ro = roots)

Crop residue	D.M.	Total N	C:N ratio	Water soluble	Hemicellulose	Cellulose	Lignin
	%	g kg^{-1} DM		% OM	% OM	% OM	% OM
RCLa	23.3	14.3	30.9	15.6	35.2	7.5	41.7
RCFi	22.1	17.2	21.6	20.8	33.9	9.4	35.9
WCLa	26.5	13.3	34.5	16.0	39.1	26.1	18.8
WCFi	27.0	15.4	20.7	21.5	33.3	8.0	37.2
BSLa	32.3	9.3	46.5	21.4	32.3	30.5	15.8
BSFi	31.5	8.5	33.8	20.2	40.0	6.7	33.1
SCLa	29.8	14.8	30.3	16.3	37.6	7.9	38.2
SCFi	25.2	20.3	20.5	30.3	35.5	24.3	10.0
LR	11.2	35.7	11.2	28.4	36.6	15.9	19.1
RGLe	21.2	29.7	12.1	19.2	36.3	25.0	19.6
RGRo	15.9	16.9	22.7	17.6	32.4	27.4	22.6
WMLe	16.7	37.7	9.4	24.0	44.2	6.6	25.2
WMSt	17.0	20.8	19.2	10.0	32.2	29.3	28.5
WMRo	20.1	10.6	42.5	5.7	37.2	4.6	52.6

The N mineralization of each crop residue was determined from aerobic laboratory incubations (PVC tubes). Fresh chopped residues were incubated with soil at a constant temperature and moisture content. For the vegetable roots, the fine roots were separated from the large root and for the green manures, leaves, shoots and roots were separately incubated. The N mineralization (both NO_3^- and NH_4^+) was measured over a four month period at regular time intervals. The N mineralization patterns of the root residues and green manures are presented in Figures 1 and 2.



Figuur 1 Net N mineralization of the vegetable root residues: large roots (left) and small roots (right).

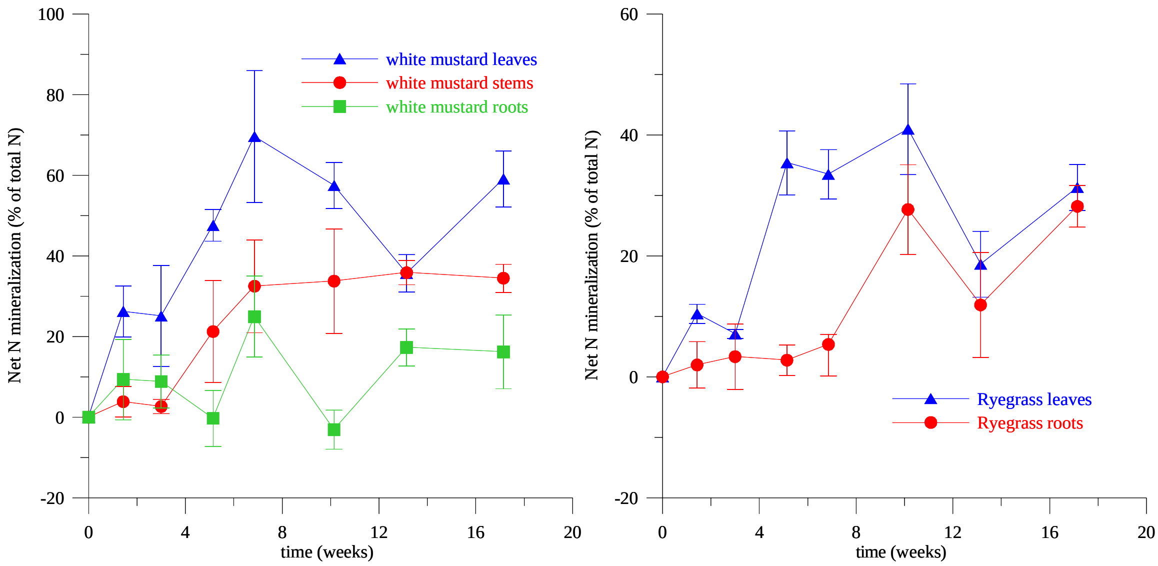


Figure 1 Net N mineralization of the green manures: white mustard (left) and ryegrass (right).

A single first order kinetics model was fitted to the N mineralization data: $N(t) = N_A(1 - e^{-kt})$ in which N(t) is the amount of N mineralized at time t (% of total added N); N_A is the amount mineralizable N (% of total added N) and *k* is the rate constant ($week^{-1}$). The results of the curve fitting are given in Table 3.

Table 3 Observed net N mineralization ($\%N_{min}$) of the crop residues four months after the incorporation (in % of total N) and the parameters of the first order model fitted to the N mineralization data (*k* = rate constant for mineralization of total N; N_A = potentially mineralizable N as percentage of total N). Standard error of parameter estimates between brackets. See Table 2 for abbreviations.

Crop residue	$\%N_{min}$	k ($week^{-1}$)	N_A (% of N_{tot})	R^2
RCLa[b]	8		8.0 (9.0)	
RCFi	22	0.09 (0.05)	38.4 (11.9)	0.759
WCLa[b]	13		13.0 (5.0)	
WCFi	24	0.05 (0.04)	50.1 (31.6)	0.763
BSLa	-38[a]	0.09 (0.04)	-39.7 (10.4)[a]	0.751
BSFi[b]	-14[a]		-13.5 (2.3)[a]	
SCLa[b]	6		6.0 (2.0)	
SCFi	21	0.23 (0.05)	26.0 (2.1)	0.835
LR	50	0.57 (0.07)	53.8 (1.4)	0.937
RGLe	31	0.31 (0.12)	32.4 (3.7)	0.620
RGRo[b]	28		28.2 (3.4)	
WMLe	59	0.38 (0.12)	54.9 (4.6)	0.679
WMSt	34	0.12 (0.05)	43.6 (9.3)	0.742
WMRo[b]	16		16.2 (9.2)	

[a] negative data indicates N immobilization
[b] first-order kinetics model was not a good fit; N_A is the percentage N mineralized at week 17 (between brackets: standard deviation); as a result k could not be estimated

The model parameters N_A and *k* were correlated with the biochemical composition through a Pearson correlation matrix and linear regression (Table 4). The parameter N_A was best correlated with the C:N ratio, which explained 74% of the variability. The net N mineralization rate constant *k* was best correlated with the lignin:N ratio, which explained 86% of the variability.

Table 4 Pearson correlation coefficients and the linear or curvilinear regression equations between net N mineralization parameters and the biochemical composition (N_{tot} = total N content (% DM); N_{org} = organic N content (% DM); L = lignin; W = water soluble fraction (% of organic matter); N_w = nitrogen content of the water soluble fraction (% of organic matter)). Only correlations significant at P< 0.01 are shown.

Parameter	Biochemical component	Correlation coefficient (R)		Regression equations
$\mathbf{N_A}$	C:N ratio	-0.86	linear	-2.03 C:N + 74.2
	$(C:N)_L$	-0.79	linear	$-0.45\ (C:N)_L + 69.1$
	N_{tot}	0.73	linear	$21.2\ N_{tot} – 17.4$
	N_{org}	0.73	linear	$22.2\ N_{org} – 18.2$
k	L:N	-0.94	curvilinear	$2.93\ (L:N)^{-1.21}$
	N_{org}	0.92	linear	$0.17\ N_{org} –0.16$
	N_{tot}	0.89	linear	$0.16\ N_{tot} – 0.15$
	$W \times N_W$	0.84	linear	$0.006\ (W \times N_W) – 0.04$

Substitution of the regression equations of the parameters N_A and *k* in the first-order model yielded following relationship for predicting the N mineralization of vegetable roots and green manures:

$$N(t) = [-2.03\ C:N + 74.2][1 – \exp(-(2.93\ (L:N)^{-1.21})t)]$$

where N(t) is the percentage of N mineralized at time t, C:N is the overall C:N ratio of the crop residue, and L:N is the ratio of lignin (in % of organic matter) over total N content (in % of dry matter).

Through the proposed model it is possible to predict the N mineralization of vegetable root residues from their C:N ratio and lignin:N ratio. This model has two strengths. First, the relationship between the (bio)chemical parameters and net N mineralization is independent of the length of the incubation period because they are linked to the parameters of a first-order kinetics model. This makes it possible to predict the N mineralization at any given time after residue incorporation. Secondly, the vegetable root residues and green manures differed largely in their biochemical composition and their N mineralization patterns. Hence, we expect that this model may be valid for other crop residues not included in this study. However, further validation is needed. The mineralization process is also influenced by other factors such as temperature, soil moisture content and soil bulk density. Therefore, the predicted N mineralization needs also to be adjusted for other environmental conditions before it can be used under field conditions.

3 Inventory and screening of organic waste products

The aim of this part is to examine the possibility of using organic waste products to manipulate the N mineralization of crop residues. These organic waste products are also called modifiers.

The organic waste products can be divided in two categories. The first category are those organic materials of which is known or suspected that they either slow down the N mineralization or immobilize the mineralized N. They will be used to limit the amount of soil mineral N when crop residues are incorporated. The use of these modifiers relies on the high C/N ratio of the materials (by which N is immobilized) and the high polyphenol content (polyphenols slow down the microbial activity and create N-protein complexes). Examples of organic materials of the first category are:

- straw
- green compost
- wood sawdust
- tannic acid
- paper sludge

The second category are those organic materials of which is suspected that they stimulate the N mineralization at the beginning of the next growth season. The use of these modifiers is based on the observation of a priming effect. A priming effect means that when organic material is incorporated in the soil, more N is released than the sum of the N content of the material and the N released from the unamended soil. Examples of these modifiers are:

- molasses
- vinasse
- dairy sludge
- malting sludge

This part of the projects contains following experiments:

- a screening of organic waste products on their potential to either immobilize N or stimulate the N mineralization;

- the influence of applying modifiers en crop residues on gaseous N losses (denitrification, nitrous oxide), since adding some waste products, like straw, increase the C content what, together with a high nitrate amount (from the crop residues), can lead to an increase in denitrification in wet conditions;

- the partitioning of N from crop residues into the different soil fractions after incorporation of organic waste products by use of labelled crop residues (^{15}N);

- field experiments for testing the reliability of the incubation results;

- the influence of nitrification inhibitors on the N dynamic of crop residues. Since nitrification inhibitors can delay the nitrification, the N will remain longer under ammonium form what will decrease the nitrate amount in the soil and also the risk of nitrate leaching.

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