Miljø- og Fødevareministeriet

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A Simple Model to Estimate Nitrogen Mineralization from Catch Crop Residues depending on their Chemical Composition

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Introduction

This report describes the development of a simple model that can be used to predict the amount and rate of mineral nitrogen (N) release of crop residues depending on their biochemical composition and the temperature. Mineralisation of the plant residue is assumed to follow an exponential decay function. The rate of decay was related to either the C:N ratio of the crop residue or the N concentration. To keep the model simple it was assumed that soil characteristics (soil texture, soil organic matter content) and management (historic use and fertilizer use) does not affect the rate of mineralisation and N release. Also soil moisture was assumed to be not limiting for the microbial activity driven mineralisation over the autumn/winter period.

Methods

Incubation study for parametrization of the model – Incubation Experiment 1

To obtain the decay rate constant the decay function was fitted to data from an incubation study, described in detail in (Thomsen et al., 2016). Briefly, the incubation study was performed with residues of fodder radish (*Raphanus sativus*, L.) of different age, white mustard (*Sinapsis alba*, L.), and perennial ryegrass (*Lolium perenne*, L.). These were incubated in a loamy sand soil at temperatures of either 2 or 10^{o}C for a total period of 7 months, and at a water content around field capacity. The amount of N released was measured after 1, 2, 4, and 7 months and was corrected by subtracting the amounts measured on controls without the addition of plant residues. Residue C/N ratios ranged from 10 to 25, and N concentrations from 17 to 40 mg N/ g dry matter (DM).

Incubation study for testing the model – Incubation Experiment 2

The model was then tested based on another incubation study described in (Li et al., 2018). In this incubation study plant tops and roots from two leguminous cover crops (red clover, *Trifolium pratense* L.), and winter vetch, *Vicia villosa*), and two non-leguminous cover crops (perennial ryegrass, *Lolium perenne* L., and fodder radish, *Raphanus sativus* L.) were incubated in a sandy loam at a temperature of 10^{o}C for a total period of 100 days. The C:N ratio of the plant tops ranged from 9 to 20, and for the roots from 13 to 20, and the N concentrations from 20,9 to 46,7 in the tops and from 17.7 to 30,9 mg N/ g dry matter.

Model description

With an exponential decay of the crop residue, the accumulation of N over with time is given by:

$$AN(DD) = AN\left(1 - exp^{-k\,t}\right) \quad (1)$$

where AN is the maximum amount of N that can be released over the relatively short time between the ploughing in of the cover crop and the sowing of the subsequent crop, in % of the added N, and k is an empirical rate constant (d^{-1}), and t is the time (d).

To account for the differences in temperatures within the incubation study (2 and 10oC), and also to make the model applicable for mineralization in field, the above time in the above equation was expressed as a function of Degree Days (DD) rather than days:

$$AN(DD) = AN\left(1 - exp^{-k\,DD}\right) \quad (2)$$

Where DD is the sum of the day (D) multiplied with the average temperature (T_{avg}):

$$DD = \sum D\, T_{avg} \quad (3)$$

Assuming that after an incubation at 10°C over a period of 7 months, all the 'short time mineralizable N' has been released, AN (%) was set to the net mineralization measured at the end of the incubation study.

Model Parameterisation

To obtain the required model values for equation 2, AN and k were related to various chemical characteristics of the residue, namely the N concentration (N_{conc}) and the C:N ratio:

$$AN_1\,(\%) = a_1 + b_1\,(N_{conc}) \quad (4)$$

$$AN_2\,(\%) = a_2 - b_2\,(C{:}N) \quad (5)$$

$$k_1 = c_1\,{N_{conc}}^{d_1} \quad (6)$$

$$k_2 = c_2\,(C{:}N)^{-d_2} \quad (7)$$

where a, b, c and d are empirical constants. The model parameterisation was based on data from Incubation experiemnet 1.

Results:

N amounts Mineralizable dependent on N concentration

To determine the relationship between the N amount mineralizable, AN (%), and the residue composition the net amount of N mineralized at 10°C after 7 months was fitted to either equation (4) or (5). Only the results for the relationship with the N concentration are given here, as this is likely the proxy that will be obtained from satellite data. It should, however, be noted that the use of the C:N ratio provided better prediction than the one based on the N_{conc}. The relationship found for the C:N ratio is provided in the Appendix.

The values found were when the fitting was done for the N_{conc} (Equation 4) were $a_1 = 1{,}35$ and $b_1 = 1{,}16$ with a coefficient of determination (R^2) of 0,64. The measured and predicted amount of N mineralized (as % of applied) after 7 months of incubation is shown in Figure 1a. Most of the values are close to the 1:1 line, indicating a good prediction of the mineralizable N. Figure 1 b shows the amount of mineralizable N as a function of the N concentration in the cover crop residue.

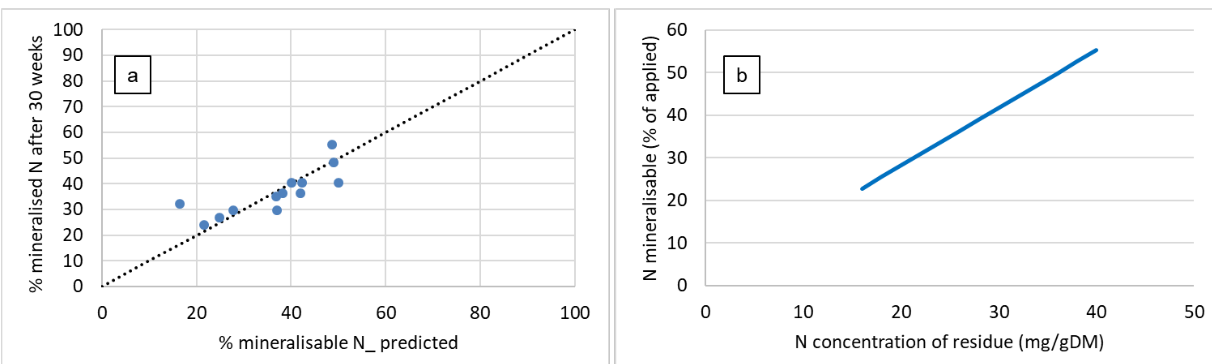

Figure 1. a) Measured and predicted mineralizable N (% of applied) after 7 months of incubation at a temperature of 10°C (symbols) and the 1:1 line (dotted line), and b) the relationship obtained between the N concentration of the crop residue and the mineralizable N (% of applied).

Mineralization rate as dependent on N concentration for N_{conc} > 24 mg N/ g DM

To obtain values for *k* all data measured over the duration of the incubation study, were used, regardless of the incubation temperature, as this was accounted for by the degree days. However, as immobilization was observed for crop residues with N_{conc} < 24 mg N/ g dry matter during the first part of the incubation study, the data were split into N_{conc} below and above this value, and only the group with N_{conc} > 24 mg N/ g DM was used to obtain the k value. For the group with N_{conc} < 24 mg N/ g DM a delay of the initial start of mineralization was assumed (for further details see below). Furthermore, as it was assumed that the rate of degradation, *k*, is independent on the value of AN, the measured N mineralization data with time were normalized prior to fitting to either equation (6) or (7). Again only the results for the relationship with the N concentration are given here, see other results are provided in the Appendix.

The values found were c_1 = 4,45 x 10-9; d_1 = 3,83 with a coefficient of determination (R^2) of 0,63. The normalized measured and predicted rates of mineralization for crop residues with N_{conc} > 24 mg N/ g DM are shown in Figure 2, and the back-transformed values of cumulative N mineralization (measured and predicted) for the various crop residues are shown in Figure 3 and 4 for incubation temperatures of 2 and 10°C. Considering the large variation in crop residue N_{conc} (ranging in this group from 26 to 40 mg N/ g DM for the fodder radish), and the difference in temperate the rate of mineralization is well predicted with our simple model, which estimates both the total amount of N mineralizable and the rate at which this occurs from the initial N concentration of the cover crop residue. An exception is the immobilization which was measured for ryegrass residues at a temperature of 10°C, which was not predicted by the model, and this also did not occur at a the lower incubation temperature of 2°C. The reasons for this are not known, suggesting that more incubation experiments with ryegrass are needed.

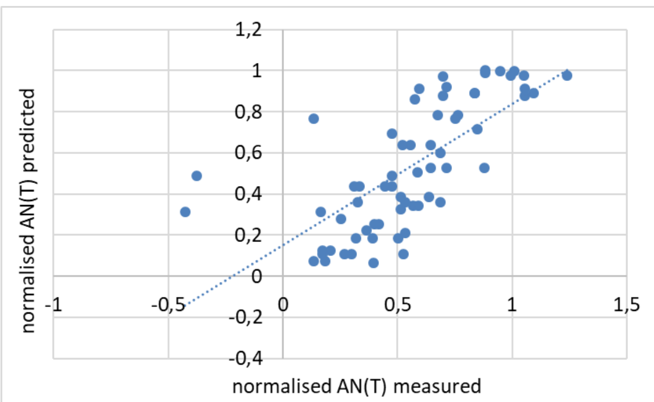

Figure 2. Measured and predicted normalized N mineralization at 1, 2, 4, and 7 months and incubation at temperature of 2 and 10°C and for residues with N concentrations N_{conc} > 24 mg N/ g DM.

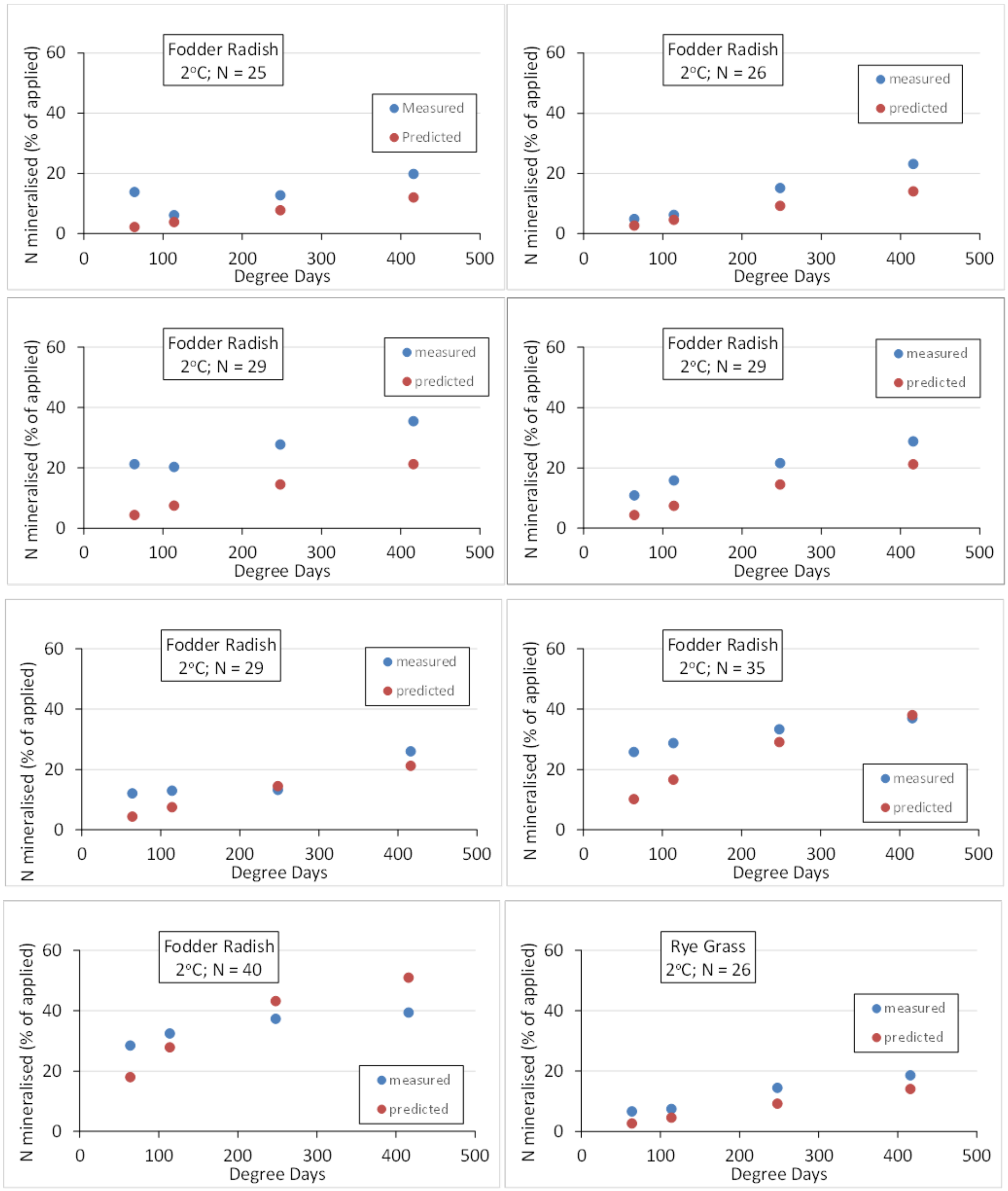

Figure 3. Measured and predicted cumulative N mineralization for various crop residues with N concentrations N_{conc} > 24 mg N/ g DM, and incubated at 2°C.

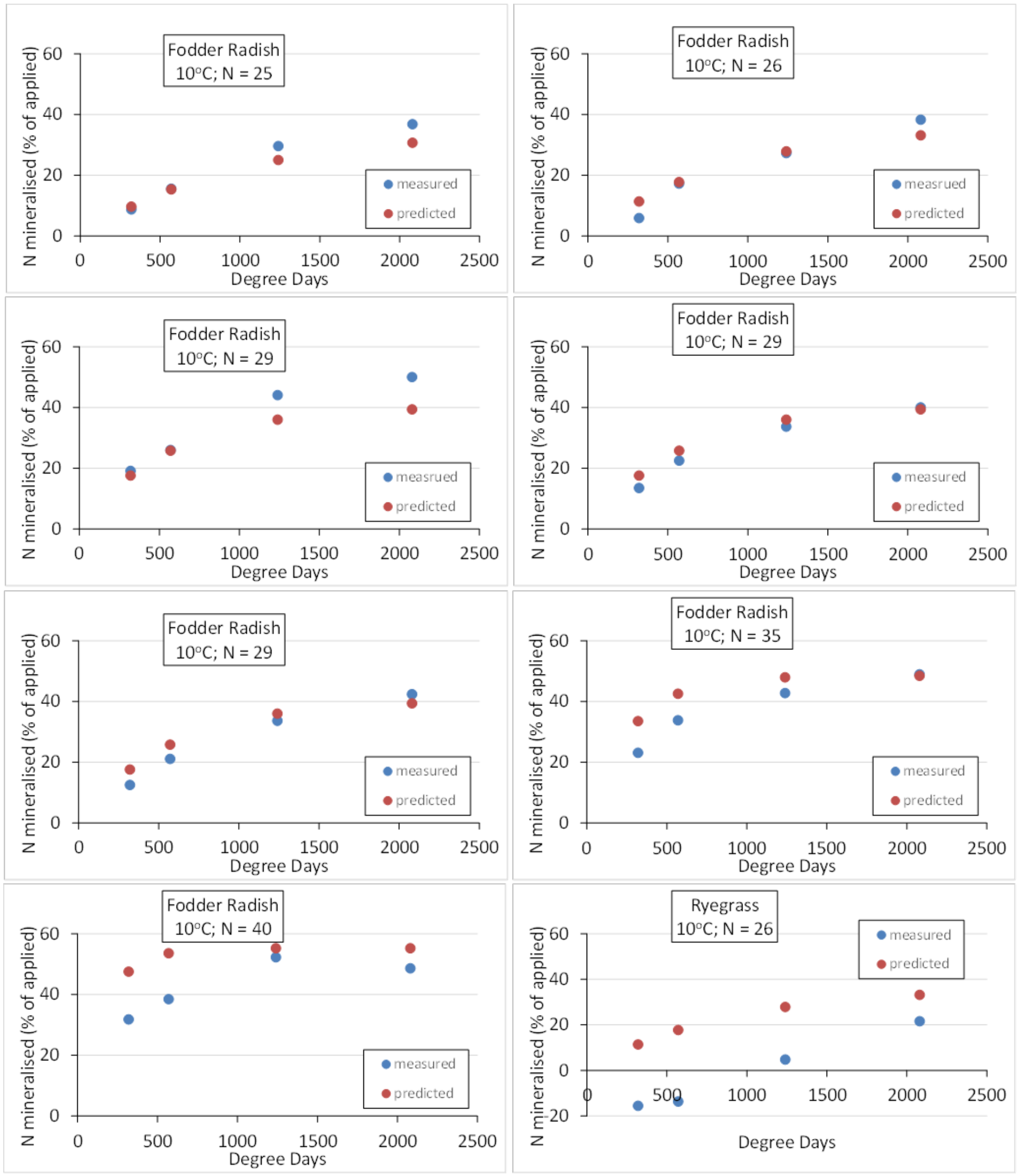

Figure 4. Measured and predicted cumulative N mineralization for various crop residues with N concentrations N_{conc} > 24 mg N/ g DM, and incubated at 10°C.

Mineralization rate as dependent on N concentration for N_{conc} > 24 mg N/ g DM

As mentioned before, due to the observed immobilization when plant residues had $N_{conc} < 24$ mg N/ g DM a delay of the initial start of mineralization was assumed. The delay of mineralization in DD was found by fitting the observed rates of mineralization to equation 2, assuming that the k values are the same as for residues with $N_{conc} > 24$ mg N/ g DM. The fitted delay was found to be 210 DD, which at a constant temperature of 10°C equates to a start of mineralization 21 days after incorporation of the residue ($R^2 = 0.64$). The normalized measured and predicted rates of mineralization for crop residues with $N_{conc} < 24$ mg N/ g DM are shown in Figure 5, and the back-transformed values of cumulative N mineralization (measured and predicted) for the various crop residues are shown in Figure 6 and 7 for incubation temperatures of 2 and 10°C. The immobilization in the early stage of incubation $N_{conc} < 24$ mg N/ g DM is well predicted with our model, with simply using a delay in the start of the immobilization and keeping the rate (*k* value) the same as for residues with higher N concentrations.

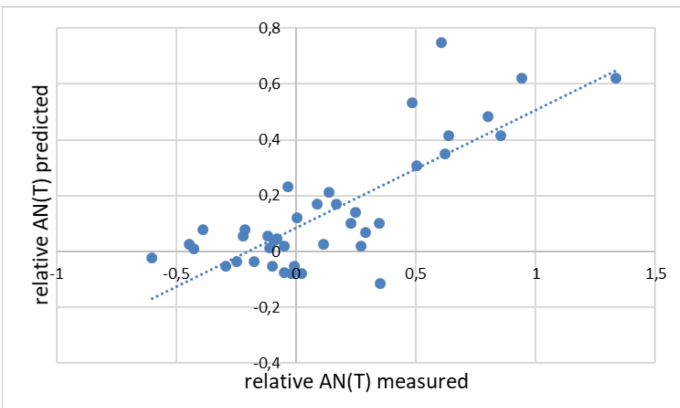

Figure 5. Measured and predicted normalized N mineralisation at 1, 2, 4, and 7 months and incubation at temperature of 2 and 10°C and for residues with N concentrations $N_{conc} < 24$ mg N/ g DM.

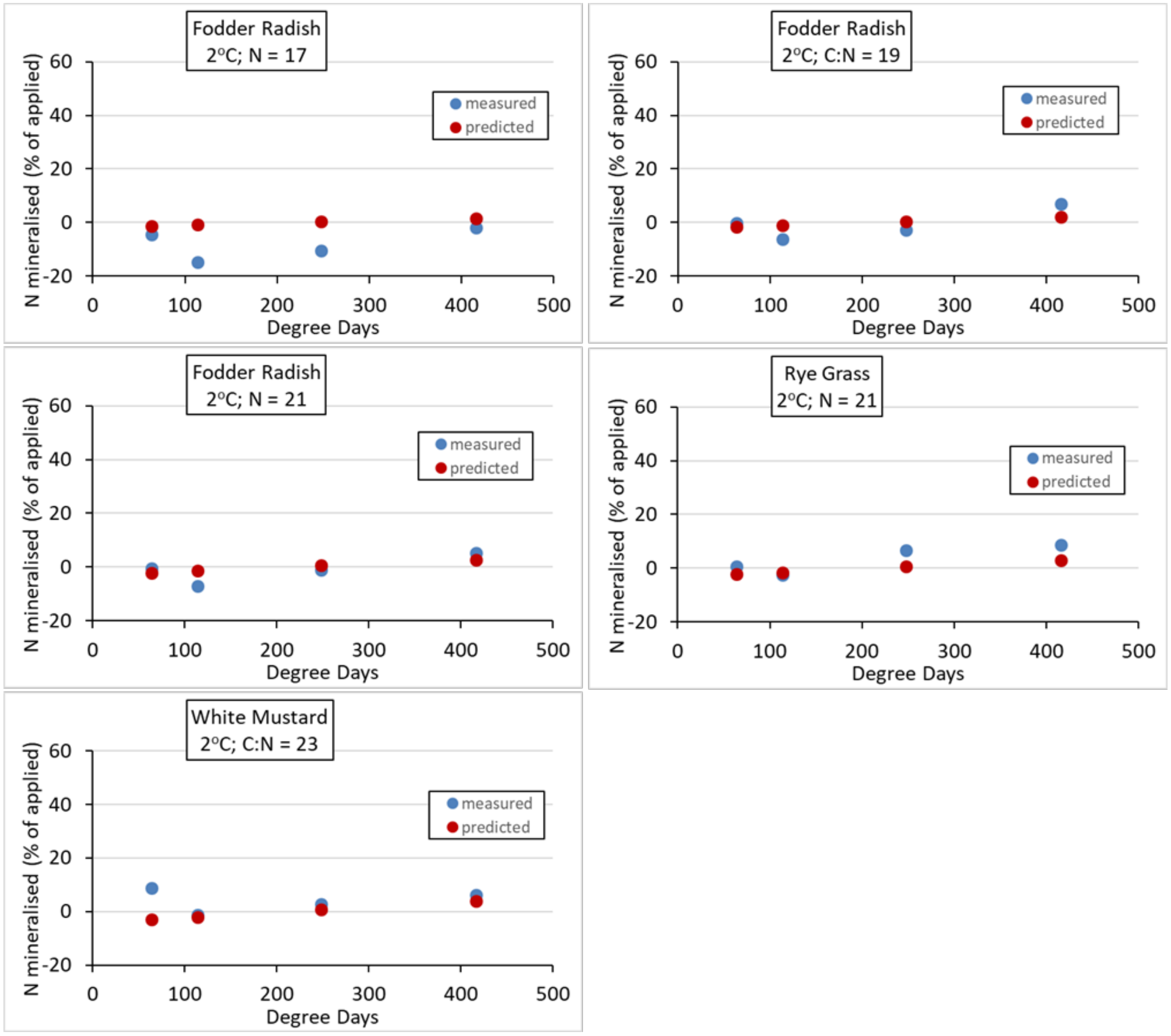

Figure 6. Measured and predicted cumulative N mineralization for various crop residues with N concentrations N_{conc} < 24 mg N/ g DM, and incubated at 2°C.

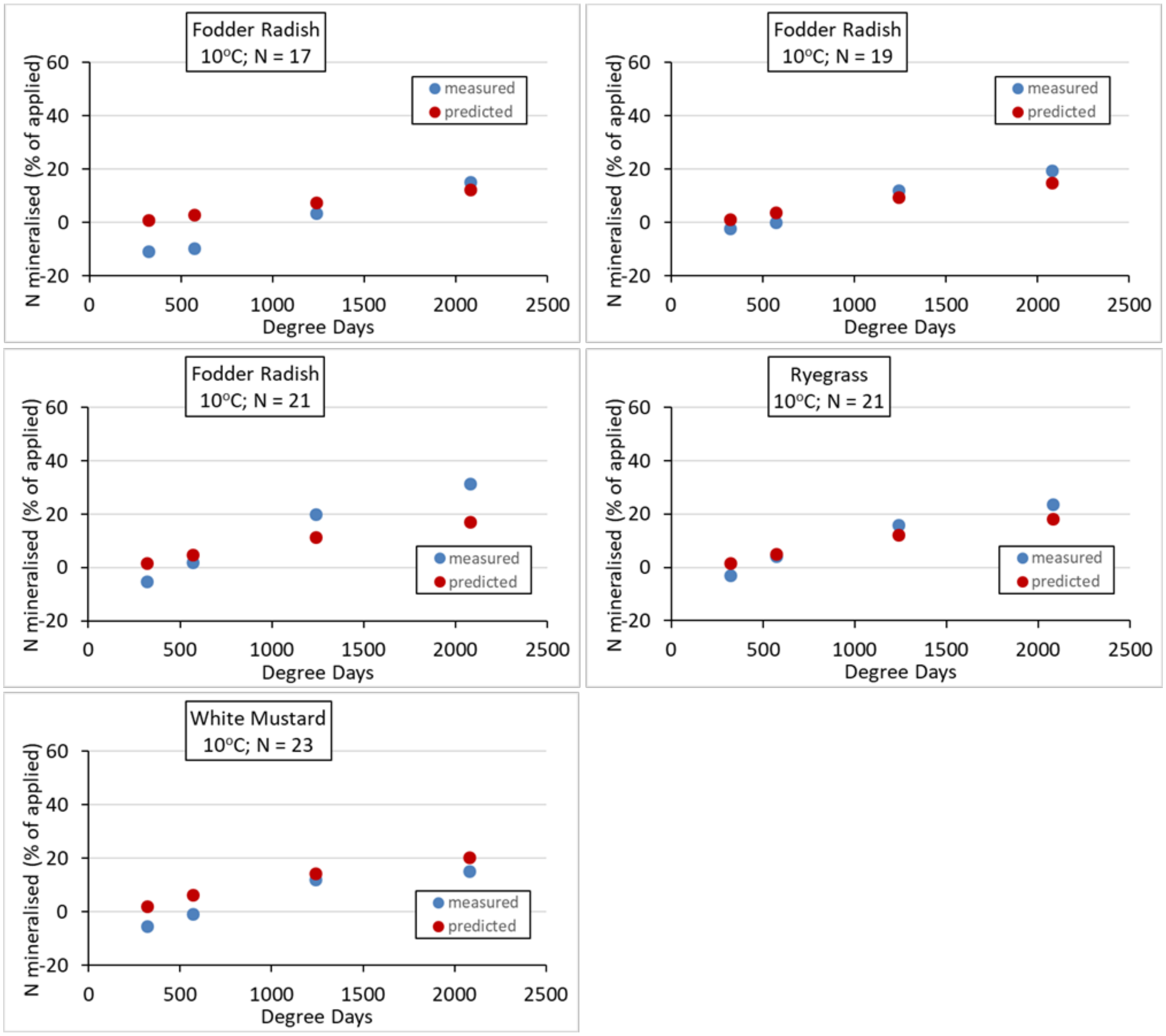

Figure 7. Measured and predicted cumulative N mineralization for various crop residues with N concentrations N_{conc} < 24 mg N/ g DM, and incubated at 10°C.

The predicted amount of N mineralized, and the rate at which the mineralization rate occurs, based on the relationships found between AN and *k* with the N_{conc}, is shown in Figure 8 for varius different crop residue N_{conc}. Here the prediction is shown as a function of DD. To obtain the prediction for a constant temperature the DD can simply be divided by that temperature. An example of the predicted N mineralization rate under field conditions with varying temperatures is shown in Figure 9, based on climate data from Askov. This simulation clearly shows the large effect of the N concentration on the amount that is mineralized over winter (and prone to leaching). Residues with lower N_{conc} have a much lower release rate, which results in a substantial amount of N that can be mineralized over the growing period.

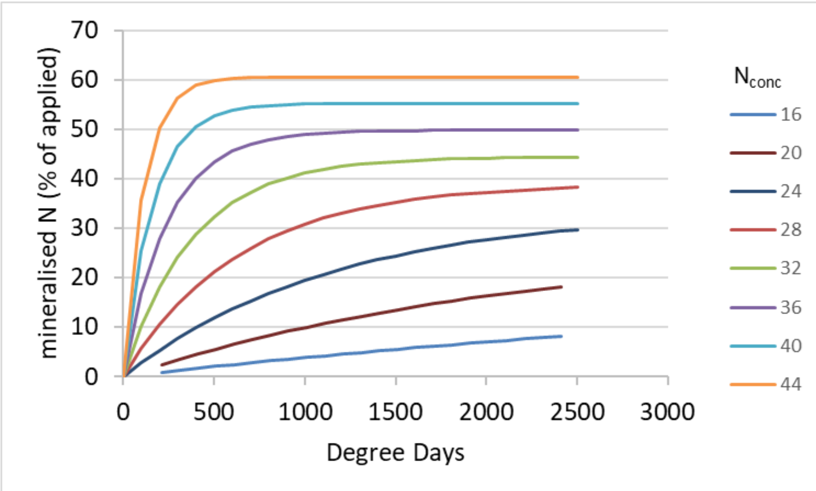

Figure 8. Cumulative N mineralization based on the N concentration (g/ kg DM) of the cover crop residue.

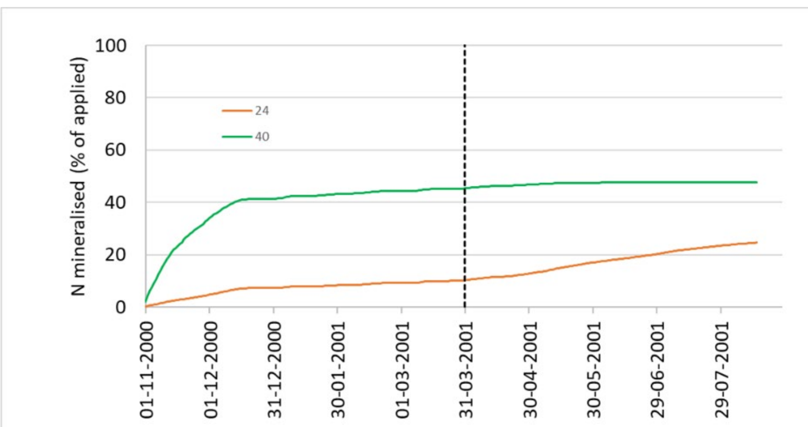

Figure 9. Cumulative N mineralization based on the N concentration (g/ kg DM) of the cover crop residue based on climate data from Askov. The broken line indicate the beginning of the growing season for the following crop.

Testing of the simple mineralization model

To evaluate the model and the appropriateness of the use of the N_{conc} for estimating the amount and rate of mineralization from cover crops model with the model parameters derived from a relatively small dataset, the model was tested on another dataset, referred to above as Incubation Experiment 2. The prediction of the simple model is quite good with a coefficient of determination of 0,87. This suggests that the model can also be used for estimating mineralization from residue roots, as shown in Figure 12. However the model generally overestimates the mineralization from legumes, Figure 11 and 12.

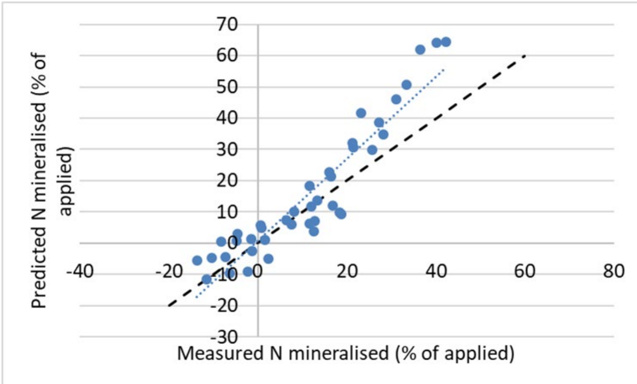

Figure 10. Measured and predicted N mineralization of at 7,14,30,60 and 100 days with an incubation temperature of 10°C and for aboveground and root residues with N concentrations ranging from 18 to 47 mg N/ g DM.

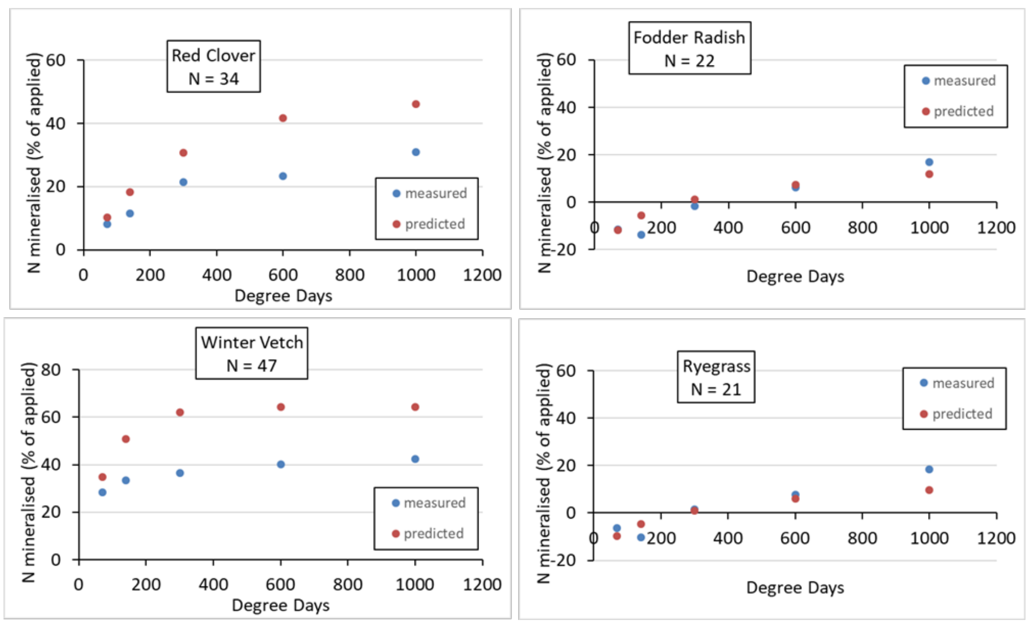

Figure 11. Measured and predicted cumulative N mineralization for various crop residues (aboveground material) with N concentrations incubated at 10°C, with legumes on the right side and non-legumes on the left.

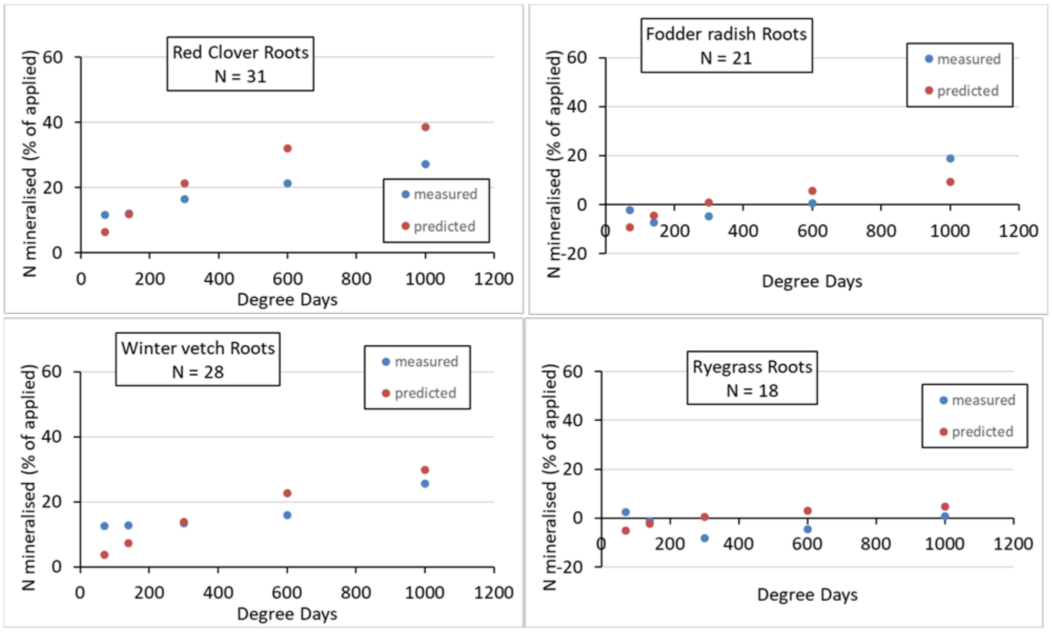

Figure 12. Measured and predicted cumulative N mineralization for various crop residues (root material) with N concentrations incubated at 10°C, with legumes on the right side and non-legumes on the left.

References

Li, F., Sørensen, P., Li, X., and Olesen, J. E. (2018). Carbon and nitrogen mineralization differ significantly between incorporated tops and roots of leguminous and non-leguminous catch crops.

Thomsen, I. K., Elsgaard, L., Olesen, J. E., and Christensen, B. T. (2016). Nitrogen release from differently aged Raphanus sativus L. nitrate catch crops during mineralization at autumn temperatures. *Soil Use and Management* 32, 183-191.

Appendix

Model parameterisation based on Incubation Experiment 1

This Appendix shows the results from the simple model based on the C:N ratio for estimating mineralization.

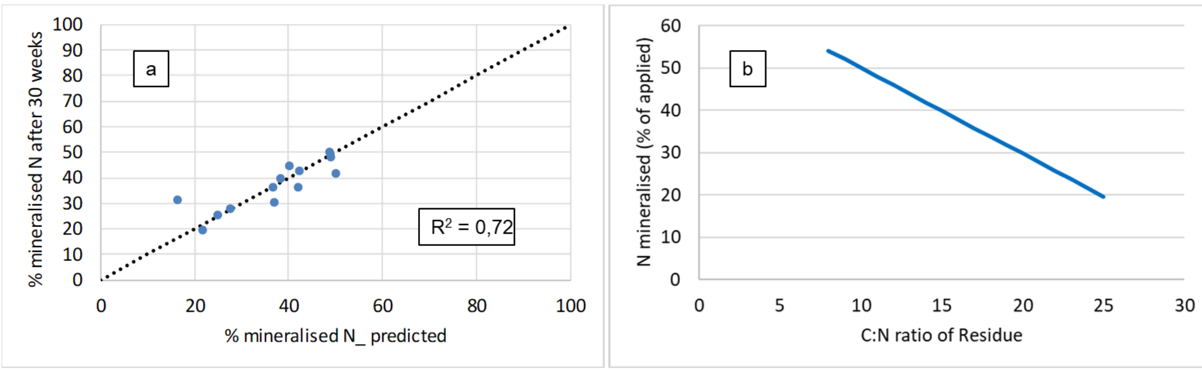

Figure A1. a) Measured and predicted mineralizable N (% of applied) after 7 months of incubation at a temperature of 10°C (symbols) and the 1:1 line (dotted line), and b) the relationship obtained between the N concentration of the crop residue and the mineralizable N (% of applied). Fitted values for Equation 7 were a_2 = 70,32 and b_2 =2,03

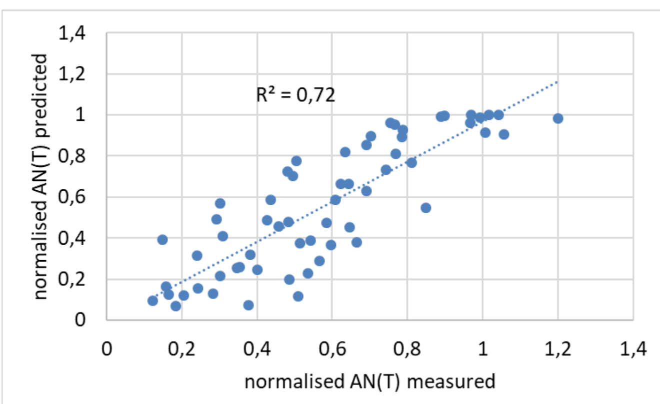

Figure A2. Measured and predicted normalized N mineralization at 1, 2, 4, and 7 months and incubation at temperature of 2 and 10°C and for residues with N concentrations C: N ≤19. Fitted values for Equation 7 were c_2 = 4,39 and d_2 =2,92.

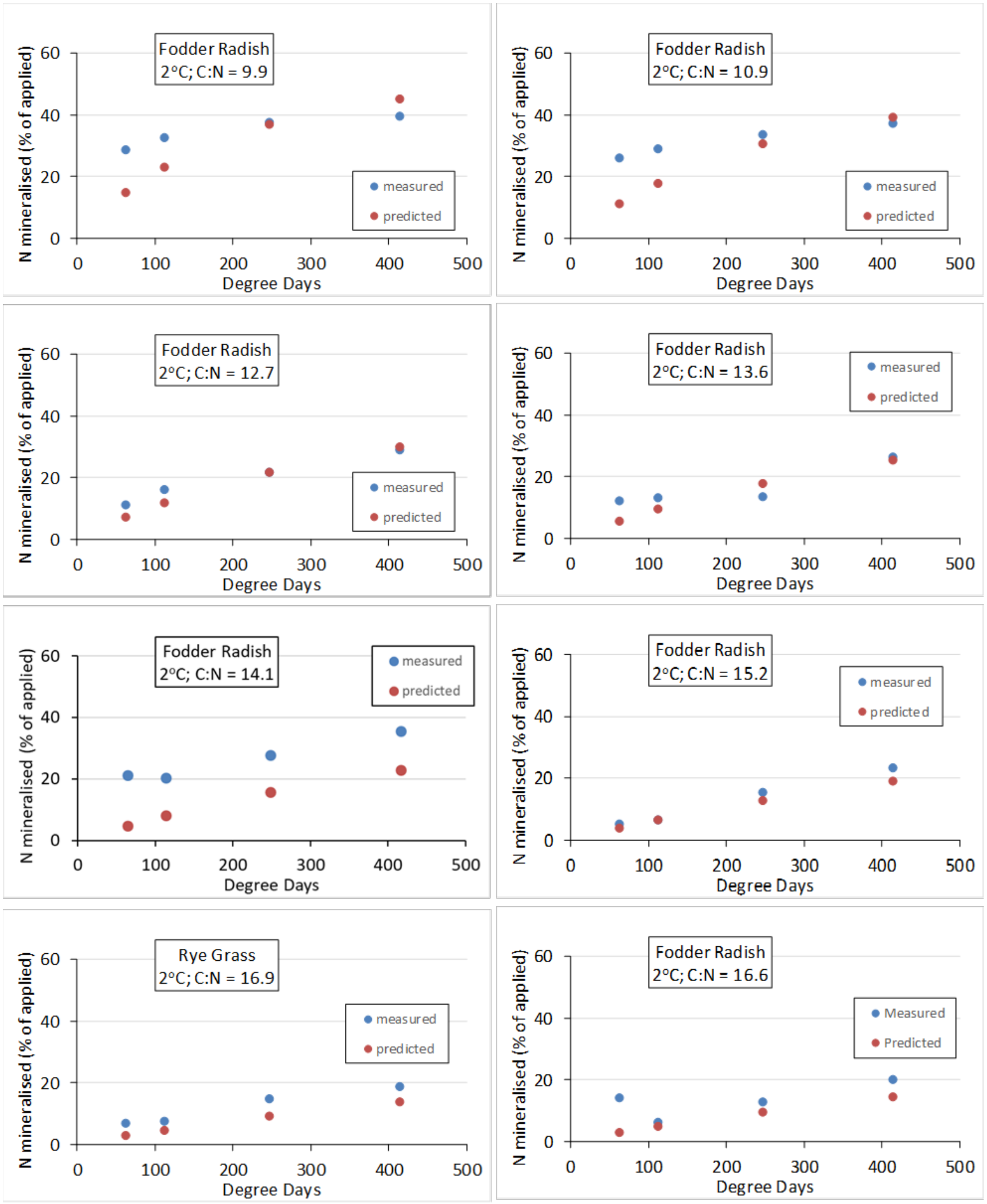

Figure A3. Measured and predicted cumulative N mineralization for various crop residues with N concentrations C:N ≤19, and incubated at 2°C.

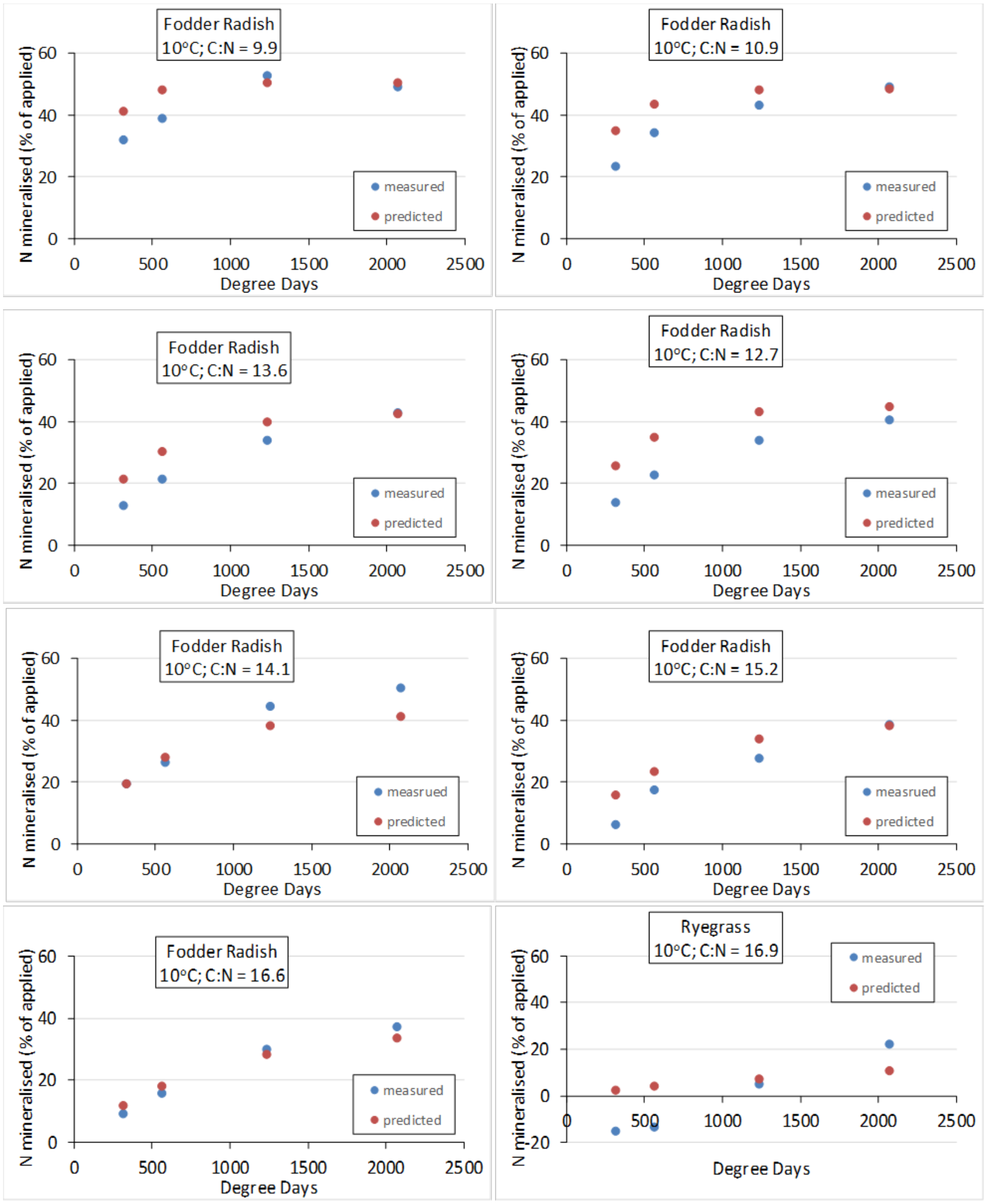

Figure A4. Measured and predicted cumulative N mineralization for various crop residues with N concentrations C:N ≤19, and incubated at 10°C.

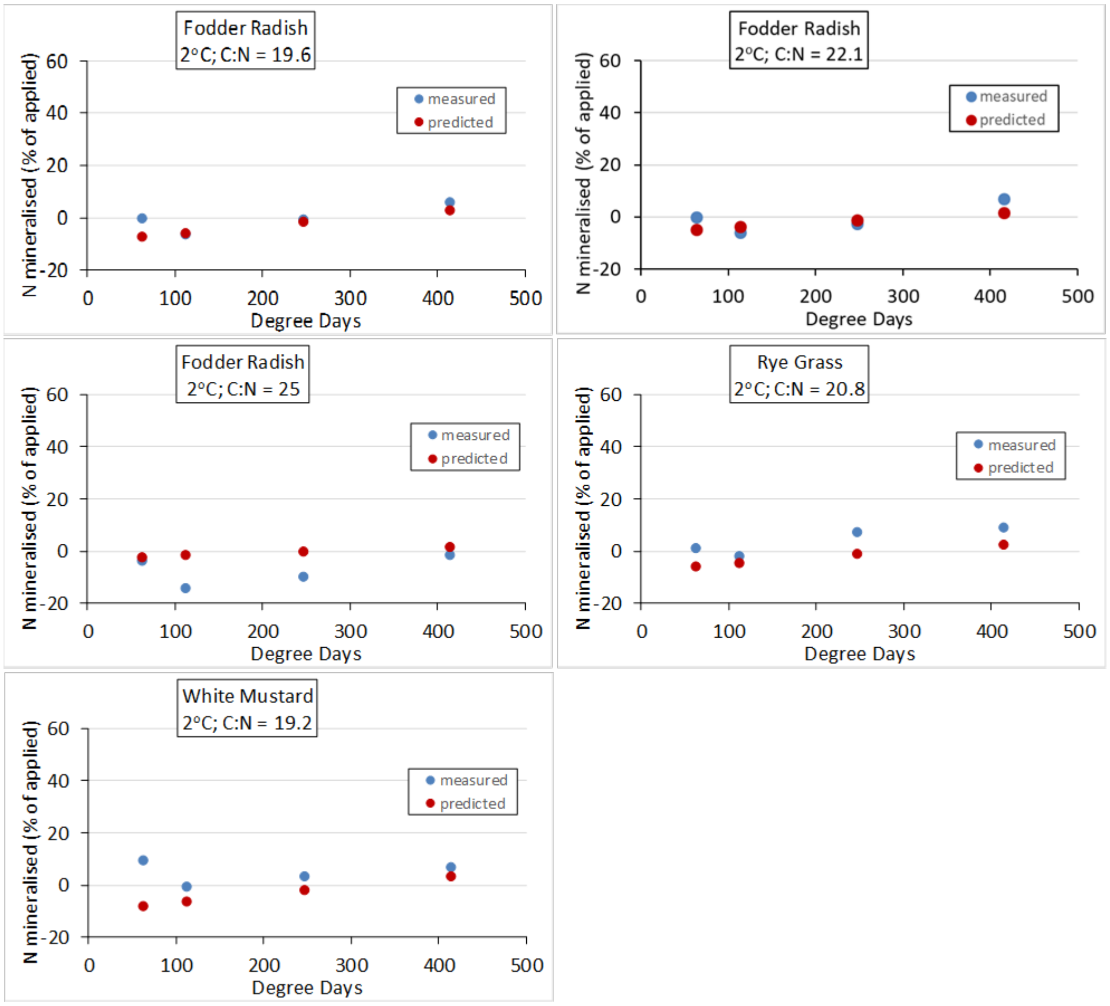

Figure A5. Measured and predicted cumulative N mineralization for various crop residues with N concentrations C:N >19, and incubated at 2°C.

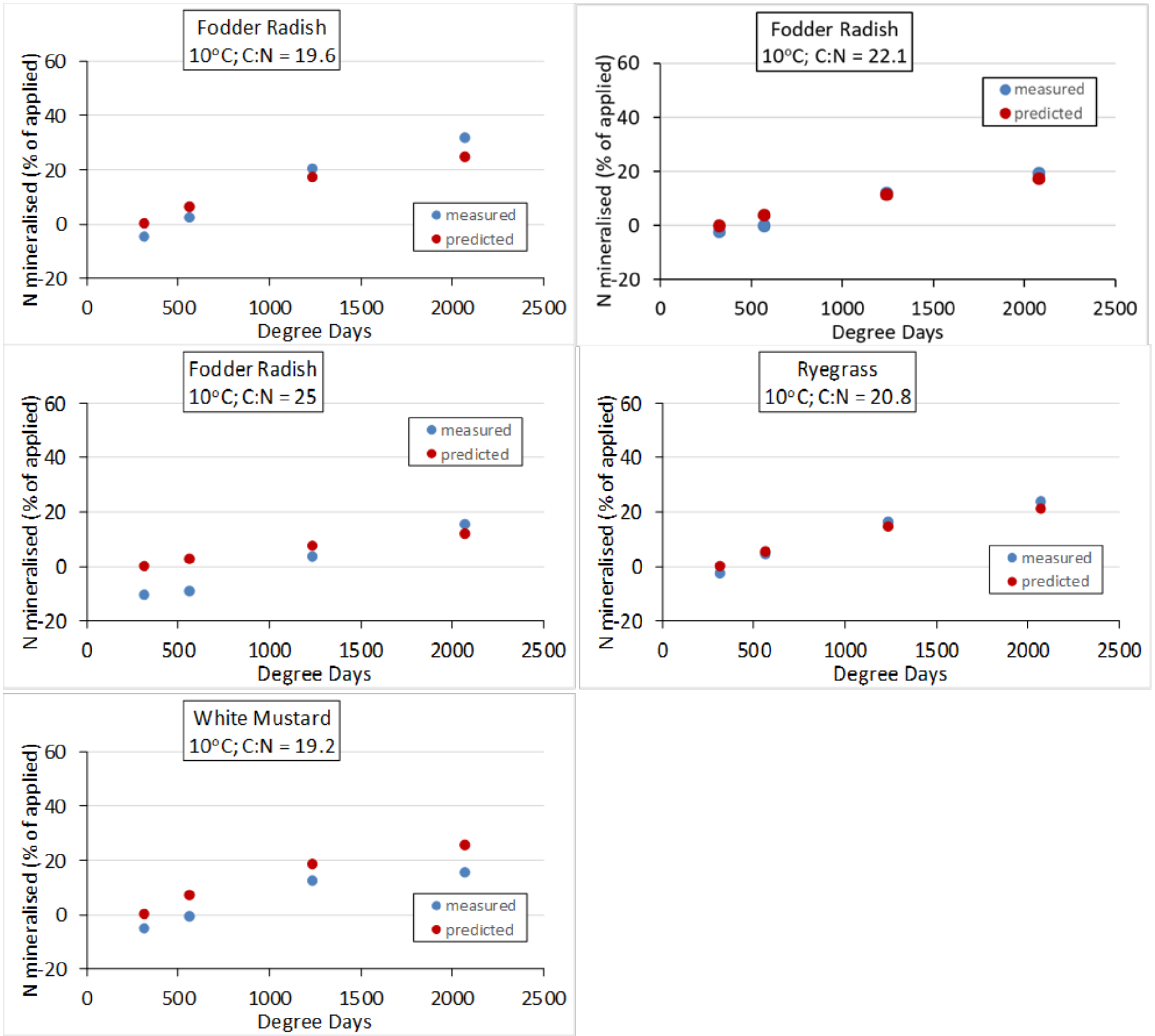

Figure A6. Measured and predicted cumulative N mineralization for various crop residues with N concentrations C:N >19, and incubated at 10°C.

Testing of the Model based on Incubation Experiment 2

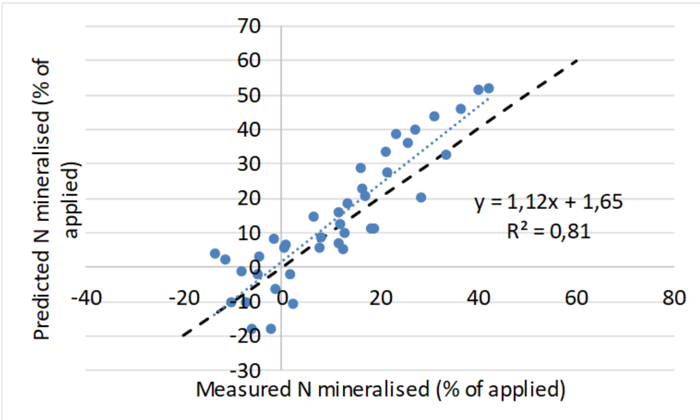

Figure A7. Measured and predicted N mineralization of at 7,14,30,60 and 100 days with an incubation temperature of 10°C and for aboveground and root residues with N concentrations ranging from 9 to 23.

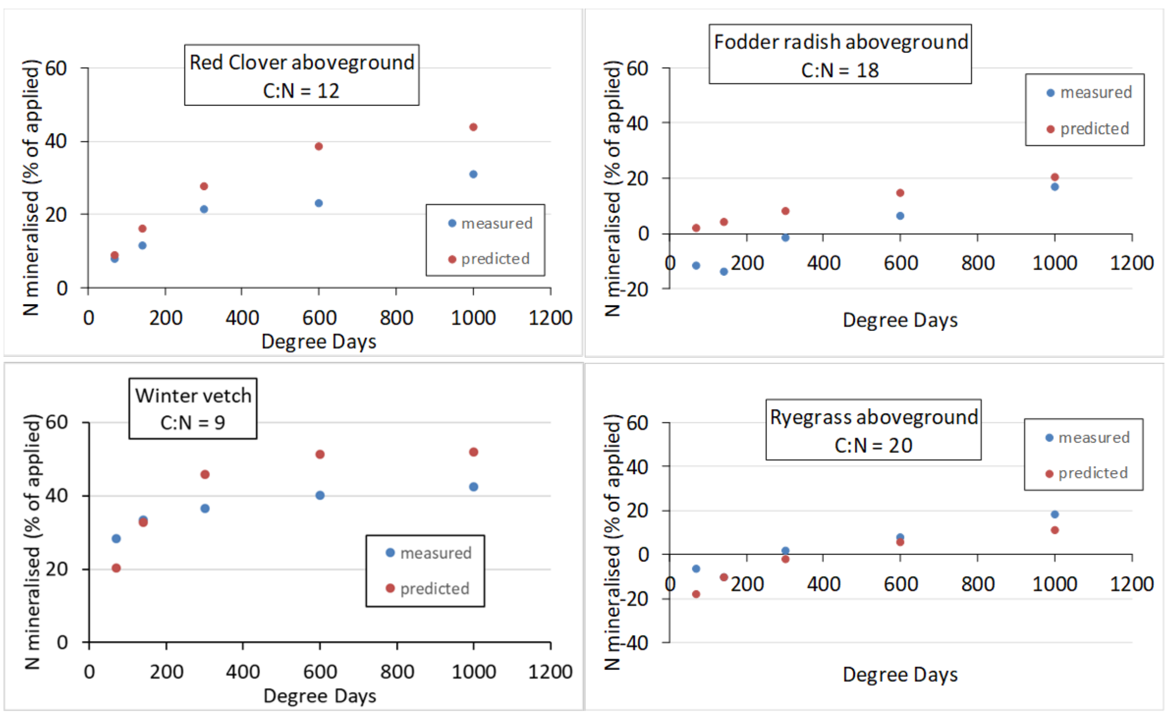

Figure A8. Measured and predicted cumulative N mineralization for various crop residues (aboveground material) based on C:N ratio incubated at 10°C, with legumes on the right side and non-legumes on the left.

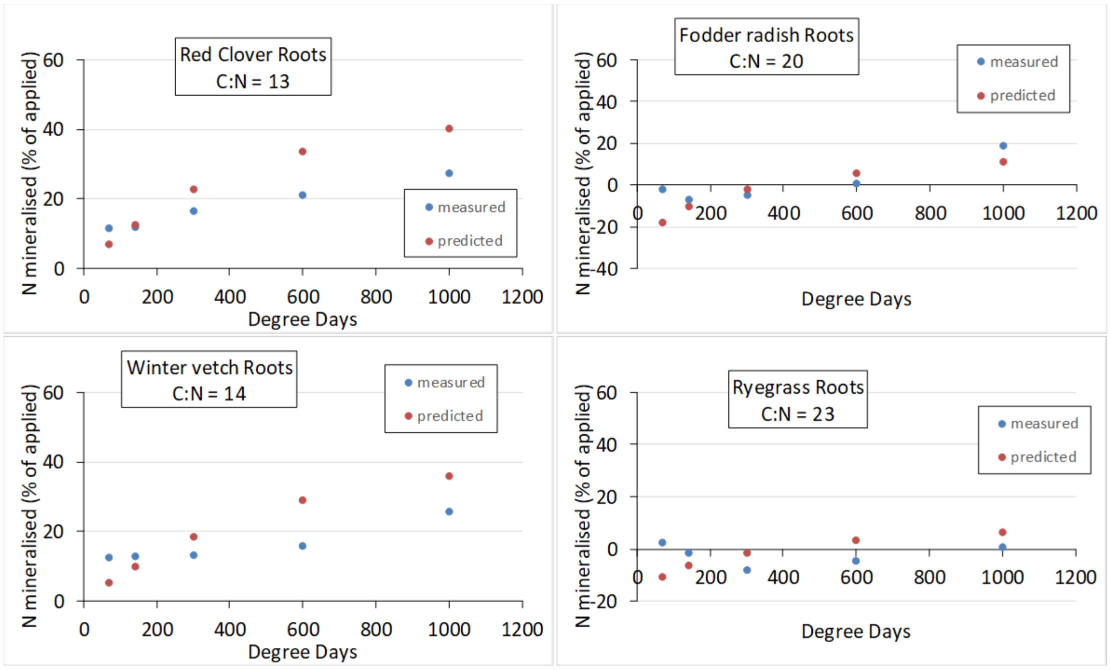

Figure A9. Measured and predicted cumulative N mineralization for various crop residues (root material) based on C:N ratio, incubated at 10°C, with legumes on the right side and non-legumes on the left.