

Catch crops in organic farming systems without livestock husbandry-model simulations

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Abstract

This paper presents simulations of the soil-plant-atmosphere model DAISY based on an organic crop rotation with incorporation of different catch crops following pea as a leguminous cash crop. Special emphasis was put on the simulation of N-mineralisation/-immobilisation and of soil microbial biomass N. The DAISY model was able to simulate soil mineral N and soil microbial biomass N after soil incorporation of catch crop plant residues to some extent. Several processes need further attention and may be integrated into the DAISY model: (1) soil tillage induced mobilisation of organic material including considerable amounts of organic N, (2) winter killing of sensitive plant species and varieties, (3) decomposition of plant residues at the soil surface as occurring after winter killing, (4) decomposition of easily decomposable plant residues at low temperatures, (5) soil microbial residues as an organic pool temporarily protected against turnover. Furthermore, reliable criteria for the subdivision of green plant residues into an easily decomposable pool and a more recalcitrant pool have to be developed.

Keywords: organic farming, catch crop, DAISY, modelling, mineral N, soil microbial biomass

Introduction

Modelling of the C and N turnover in agro-ecosystems is one of the tools used for the development of new organic crop rotations. Point of departure for our investigation was the following hypothesis: The soil-plant-atmosphere model DAISY is able to simulate organic crop rotations including an extended use of catch crops and green manure.

This paper presents model simulations based on a field experiment with incorporation of different catch crops following pea as a leguminous cash crop.

An important factor for the development of new crop rotations for stockless organic farming systems is the expected N mineralisation and immobilisation after soil

incorporation of the plant materials. Therefore, special emphasis was put on the simulation of N-mineralisation/-immobilisation and of soil microbial biomass N.

Materials and Methods

Field Experiment

The field experiment with 3 replicates was placed at the Agricultural Research Centre Aarslev (10°27' E, 55°18' N) located at the isle of Funen (Denmark) in wet temperate climate (Throrup-Kristensen, 2001). Mean yearly temperature and precipitation were 8.1°C and 719 mm respectively during the period 1986 to 1998.

Data from the first year of the experiment reported by Throrup-Kristensen (2001) were chosen for this investigation. The soil in the first year was a Typic Luvisol. The topsoil was a sandy loam with 14.6% clay, $\text{pH}_{(\text{CaCl}_2)}$ 7, 2.0% C and 0.15% N.

Pea was sown 22 April 1996. In stead of harvesting pea, the above ground plant material was ploughed into the soil completely 25 July 1996. 2 August 1996 different catch crops were sown. For the model simulations we chose four catch crops differing in chemical properties (Table 1) and growth patterns. Oil radish (*Raphanus sativus* cv. *oleiformis*) and winter rape (*Brassica napus* cv. *napus*) died completely during winter. Italian ryegrass (*Lolium multiflorum*) and rye (*Secale cereale*) were partly killed during winter time. The remaining plant material was incorporated into the soil by rotavation 2 April 1997. Thereafter, the soil remained as bare fallow. After rotavation, soil microbial biomass N (N_{mic}) and mineral N (N_{min}) were measured 5 times until 1 July 1997 to a depth of 25 cm. Soil microbial biomass was estimated by chloroform fumigation extraction (Brookes *et al.*, 1985). Total N in the extracts was measured after persulphate-oxidation at 120°C for 30 minutes, according to Cabrera and Beare (1993). N_{mic} was calculated as the difference between fumigated and non-fumigated samples multiplied by an f_{EN} -factor of 1.85 (Brookes *et al.*, 1985; Joergensen and Mueller, 1996). Soil mineral N (NH_4^+ and NO_3^-) was measured in the non-fumigated 0.5 K_2SO_4 -extracts by colorimetric methods using flow-injection analysis (Keeney and Nelson, 1982).

Table 1 Properties of the above ground catch crop plant materials before soil incorporation. afdm = ash free dry matter.

plant	total						water insoluble			water soluble		
	C_t	N_t	C/N	cellulose	lignin	lignin/N	C	N	C/N	C	N	C/N
	[% afdm]			[% afdm]			[% C_t]	[% N_t]		[% C_t]	[% N_t]	
rye	49.0	4.3	11.3	19.8	2.9	0.7	60.9	49.3	14.9	39.1	50.7	9.0
Italian ryegrass	48.9	4.2	11.7	22.8	3.9	0.9	74.3	61.0	14.3	25.7	39.0	7.7
winter rape	47.9	3.9	12.5	30.7	7.0	1.8	72.6	56.3	16.1	27.4	43.7	9.9
oil radish	48.5	3.4	14.3	33.5	8.1	2.39	77.7	67.7	16.4	22.3	32.3	7.7

The DAISY model

DAISY is a deterministic model which simulates water-, energy-, C- and N-fluxes in a one-dimensional soil-plant-atmosphere system (Hansen *et al.*, 1990; Hansen *et al.*, 1991). In this study, an open DAISY version (Abrahamsen and Hansen, 2000) was used.

Three discrete soil organic pools (added organic matter (AOM), soil microbial biomass (SMB) and native nonliving soil organic matter (SOM)), soil mineral N (N_{min}) and soil respiration (CO_2) are simulated by the soil-organic-matter submodel (Figure 1).

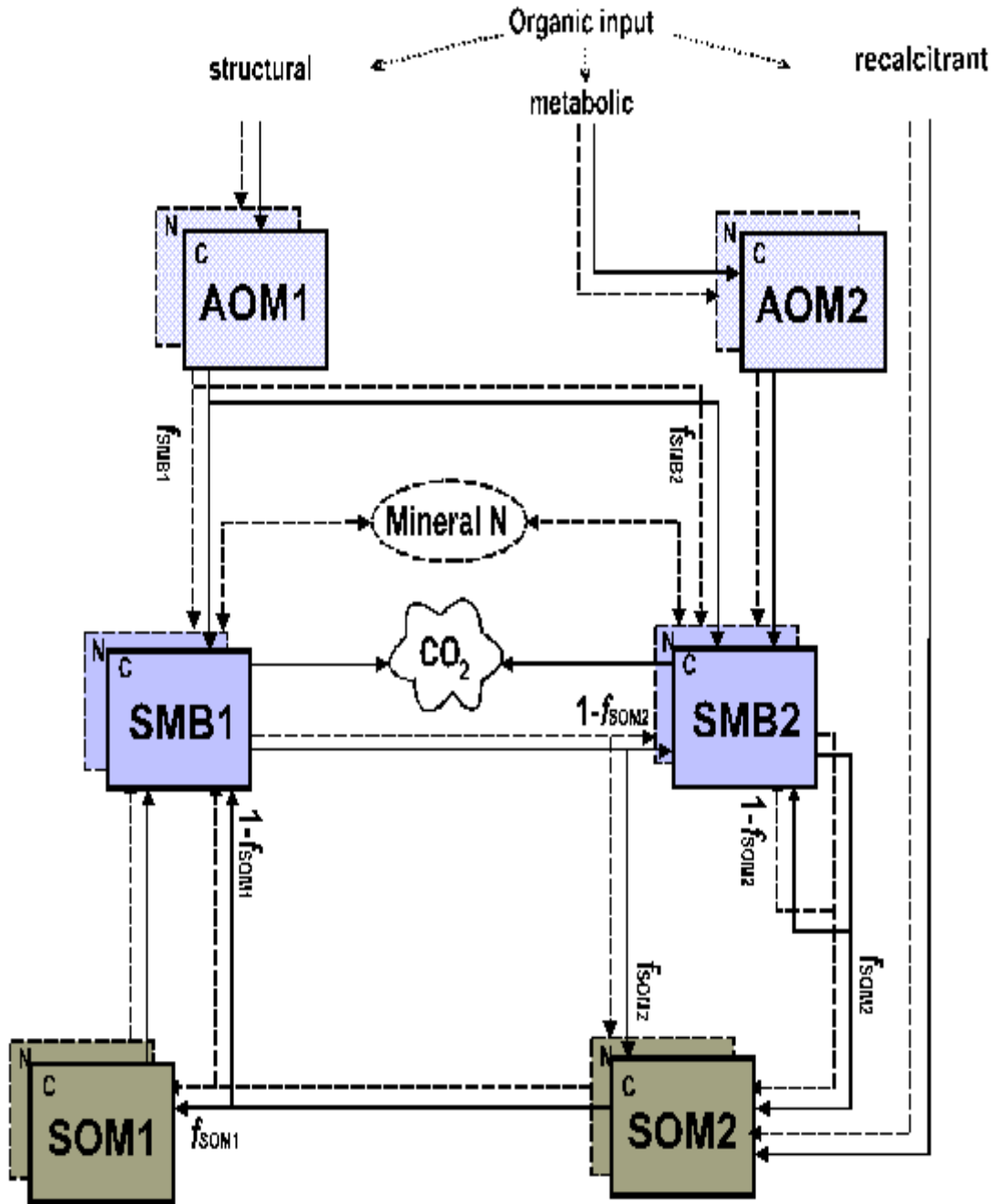


Figure 1 C and N fluxes between the various pools and subpools of organic matter, mineral N and evolved CO_2 in the DAISY submodel for Soil Organic Matter (Hansen *et al.*, 1990, 1991). AOM = Added Organic Matter, SMB = Soil Microbial Biomass, SOM = native dead Soil Organic Matter. f_x = partition coefficient.

Plant residues are simulated as AOM. The organic pools (AOM, SMB, SOM) are each considered being a continuum having a certain range of turnover rates. In the original development of the model, it was found that these continuums could be simulated satisfactorily if each pool is subdivided into two subpools, one with a slower turnover (i.e. SOM1) and one with a faster turnover (i.e. SOM2). Furthermore, it was assumed that the turnover of the pools follows first order kinetics.

Turnover rate coefficients under standard conditions (10°C, -10 kPa, 0% clay) are defined for each carbon pool. For SMB1 and SMB2, death rate coefficient and maintenance respiration rate coefficient have to be defined separately. In order to determine actual rate coefficients, the rate coefficients under standard conditions are multiplied by modifiers that are functions of the actual soil temperature and of the actual soil water potential. Additionally, modifiers depending on the soil clay content are added for the pools SOM1, SOM2 and SMB1.

Carbon fluxes into microbial biomass are multiplied by substrate utilisation efficiencies which define the fraction of substrate C, that can be used for microbial growth. The remaining substrate C is respired as CO₂.

After each time step, the N pools are calculated from the actual amount of the C-pool by multiplication with the reciprocal value of a fixed C/N ratio for each pool. Net N-mineralisation or N-immobilisation is then derived from the N-balance.

If immobilisation occurs during growth of SMB1 and SMB2, this growth may be limited by the lack of mineral N in the soil. The basic time step of the *soil-organic-matter* submodel is 1 hour. A more detailed description of the soil-organic-matter submodel is given by Mueller *et al.* (1997).

For the comparisons with the measured values, total simulated soil microbial biomass N (N_{mic}) was calculated as the sum of SMB1-N and SMB2-N.

Detailed descriptions of the whole DAISY model are given by Hansen *et al.* (1990 and 1991) and by Abrahamsen and Hansen (2000).

Soil physical and chemical properties were parameterised using measured data. The soil organic matter module was parameterised using a setup calibrated on a field experiment with incorporation of rape straw (Mueller *et al.*, 1997).

For the simulation of pea, a plant module including symbiotic N₂-fixation was used. For the simulation of Italian ryegrass and rye, default plant modules were used. Oil radish was simulated using a plant module calibrated in an earlier investigation (Thorup-Kristensen *et al.*, 1997). Winter rape was simulated using a modification of the same plant module. Plant residues (AOM) were subdivided by simply allocating the water-insoluble C and N to AOM1 and the water-soluble C and N to AOM2 according to Table 1 (Muller *et al.*, 1997).

The modelling scenarios

In a first step, dry matter production of the modelled pea was fitted to the amounts of plant dry matter and plant N measured in the field before soil incorporation by rotavation. Simultaneously, the initial amount of N_{mic} was adjusted with respect to the correct simulation of N_{mic} during spring 1997 in the fallow treatment (Figure 3).

In a second step, the plant modules for grass, rye, oil radish and winter rape were fitted to the amounts of plant dry matter and plant N before and after winter (Figure 2). Due to missing algorithms for winter killing, this process had to be simulated by manually increasing leaf and root death rates during periods of very low temperature.

Oil radish and winter rape died completely during winter. This was simulated by a shallow soil incorporation at the end of December 1996.

No further adjustments have been done on the parameterisation of the soil organic matter turnover.

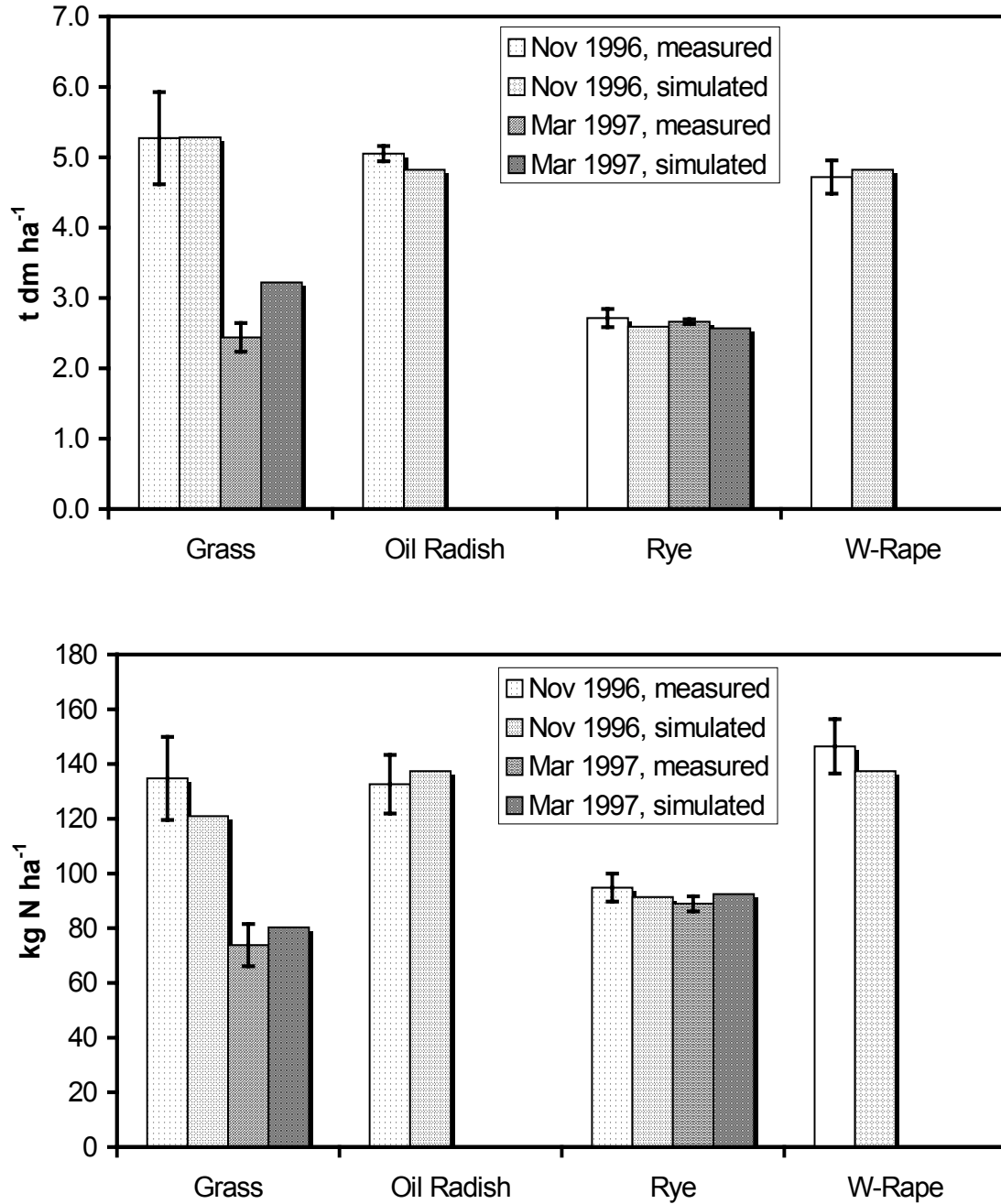


Figure 2 Amount of dry matter and N in the different catch crops before (shoot and root) and after winter (shoot only). Measured and model simulated values. Bars show standard errors.

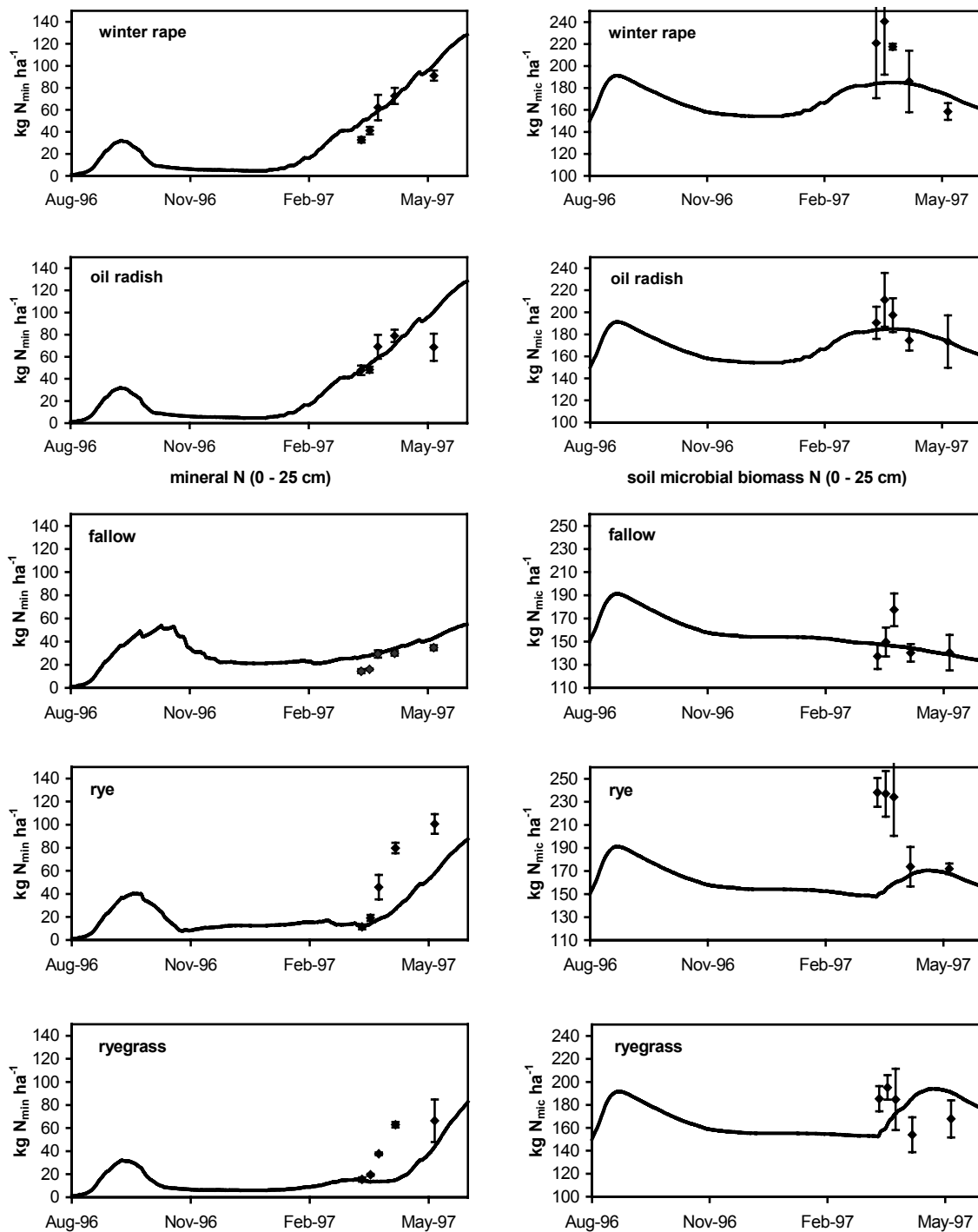


Figure 3 Mineral N (N_{min}) and soil microbial biomass N (N_{mic}). Measured (diamonds) and model simulated values (lines). Bars show standard errors.

Results and Discussion

Fallow treatment

It was possible to simulate dry matter and N in the above ground plant material of pea (data not shown). This was an important prerequisite for the model simulation of the following period in the different modelling scenarios.

In the fallow treatment, simulated soil microbial biomass N was in the correct order of magnitude during spring 1997 (Figure 3). However, it was not possible to simulate the doubling of N_{mic} and N_{min} within the first three sampling dates after rotavation (Figure 3). This may be due to the fact, that DAISY does not include algorithms for the simulation of organic matter mobilisation by soil tillage.

Catch crop treatments

As shown in Figure 2, simulated dry matter and N in the catch crops was in the correct order of magnitude both before and after winter. It was decided to accept slight over or underestimations without further modifications of the plant modules.

The DAISY model underestimated N_{min} in April and May 1997 in the rye and ryegrass treatments. In addition, the model was not able to simulate the early increase of N_{mic} correctly. Simulated N_{mic} -peaks appeared too late (rye and ryegrass) and were too low (all treatments except ryegrass). The observations indicate, that the turnover of winter killed plant material began earlier and happened faster in the field than predicted by the model.

Winter killed plant material remained at the soil surface. It was visible in the field, that decomposition of these plant residues began during late winter and early spring. In the DAISY model however, plant material is decomposing only after incorporation into the soil, which means after rotavation 2 April 1997. As a result, the turnover of rye and ryegrass residues was initiated too late. Bio-incorporation of plant residues as simulated by the DAISY model could not compensate for this shortcoming.

In the winter rape and oil radish treatments, the early increase of N_{min} was simulated satisfactorily. Here, the complete dying of the plants during winter was simulated by shallow soil incorporation at the end of December 1996. This enabled the DAISY model to initiate the turnover of the plant residues earlier.

Another aspect may explain late simulated decomposition: The current DAISY temperature modifier reduces the turnover rates of the organic matter pools at 5°C to only 25% of the rates at 20°C. Below 0°C, turnover rates are zero. This is in contrast to Magid *et al.* (2001) who showed that disproportionately high N-mineralisation rates from green manures can occur at low temperatures which may have implications for modeling in cool temperate agro-ecosystems.

A further explanation may be the simple subdivision of the plant residues (AOM) in water-insoluble C and N (AOM1) and water-soluble C and N (AOM2). Mueller *et al.* (1998) suggested that a considerable part of the water-insoluble C and N deriving from green plant materials may be easily decomposable and should be allocated to AOM2.

Except for the ryegrass treatment, the measured N_{mic} -peaks in early spring were more pronounced than the simulated peaks. This indicates a preliminary microbial incorporation of AOM-N followed by a fast release of N from the N_{mic} -pool. If assuming, that this release leads to net N mineralisation, model predictions of N_{min} should have failed in the same order of magnitude as release of N from N_{mic} occurred.

However, the difference between measured and model simulated values was bigger for N_{mic} than for N_{min} . Hence, a part of the N released from microbial biomass must have remained as microbial residues protected against mineralisation (Mueller *et al.*, 1998). Denitrification as a possible sink for N was not measured in the field and it is therefore an uncertainty in our considerations. This point needs further attention in later investigations.

At the last sampling date in the oil radish treatment, the decay of simulated N_{mic} led to an ongoing simulated N-mineralisation in the model simulations. During this period measured N_{min} and N_{mic} remained fairly constant. Simulated N_{min} clearly exceeds measured N_{min} . To some extent, this is also visible in the other treatments. Obviously, soil microbial biomass returns to a steady state earlier in the field than simulated by the model.

The differences between the four catch crop treatments can not be explained by the properties of the plant materials measured before soil incorporation (Table 1). As mentioned above, considerable parts of the plant residues decomposed before sampling in April 1997. Hence, the data shown in Table 1 may not reflect the properties of the original plant residues. This may also have led to a partly wrong subdivision of AOM.

Conclusion

The DAISY model was able to simulate mineral N after incorporation of catch crop plant residues to some extent only. The following processes need further attention and may be integrated into the DAISY model:

- Soil tillage induced mobilisation of organic matter which can mobilise considerable amounts of organic N
- Winter killing of sensitive plant species and varieties
- Decomposition of plant residues at the soil surface as occurring after winter killing
- Decomposition of easily decomposable plant residues at low temperatures
- Soil microbial residues as an organic pool temporarily protected against turnover
- Furthermore, reliable criteria for the subdivision of green plant residues (AOM) into AOM1 and AOM2 have to be developed.

Acknowledgements

This study has been financed by the Danish Agricultural Research Centre for Organic Farming under the NICLEOS project and by the Danish University Consortium on Sustainable Land Use and Natural Resource Management (DUCED-SLUSE).

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