A model of animal manure nitrogen mineralisation in soil

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Abstract
A general model was developed for net mineralisation of pig and cattle slurry N in arable soil under cool moist climate conditions. The model is based on a 3-year field experiment and literature data and describes the cumulative net mineralisation of manure N during the initial 5 years after spring application. The model estimates a faster mineralisation rate for organic N in pig slurry compared to cattle slurry, and the model includes an initial N immobilisation phase for both manure types. The model estimates a cumulated mineralisation of 71% of the organic N in pig slurry and 51% of the organic N in cattle slurry after 5 years. These estimates are in accordance with other mineralisation studies and studies of manure residual N effects.

Key Words
Organic N, slurry, mineralisation, immobilisation, modelling

Introduction
Animal manures contain organic N that is released slowly and cause residual N effects in the years following application (Schröder et al. 2007). To account for this mineralisation knowledge on the temporal release of organic manure N is important for securing appropriate management measures. Due to significant mineralisation from soil organic N and risk of inorganic N losses from soil, it is difficult to measure the mineralisation of manure N directly over longer periods. To better distinguish the contributions of manures from the total mineralisation a model of the mineralisation of manure N is needed for a proper estimation of leaching from mineralised manure N.
Currently a new model for estimation of nitrate leaching is being developed in Denmark including a sub-model of leaching from animal manure inputs in the years after application. The present work presents a general and easy-to-use manure N mineralisation model describing the first five years net mineralisation course. The model is based on a 3-year field study of residual effects of cattle and pig slurry application and the model outputs are compared with data from other studies of mineralisation and residual N effects of manures.

Methods
The model was based on data from field experiments previously reported by Sørensen and Amato (2002) and Sørensen (2004). Plots were supplied with slurry (pig or cattle) or mineral fertiliser with all plots receiving the same amount of inorganic N, except in control plots without N application. The slurries included excreta and unutilized feed plus bedding. In the following years all plots received mineral fertiliser at the same rate (120 kg N ha^{-1}), and spring barley and ryegrass catch crops were established in all 3 years. The N uptake in barley and catch crops was measured and the additional N uptake in manured plots determined. Net N mineralisation due to manure was estimated using the assumption that the apparent N recovery (ANR) in barley from mineralised N was similar to the 60% ANR that was measured for mineral N fertiliser. For calculating net mineralisation in autumn/winter after the spring barley harvest, we assumed that 70% of the mineralised N was available to the catch crop and that 70% of the available N was recovered giving ANR of 70% x 70% = 49%. This was supported by results by Li et al (2015) who recovered 49% of applied labelled nitrate in tops of a ryegrass cover crop at the same location.
The mineralisation of manure N in year 4 and 5 was based on the estimated mineralisation of residual manure N in year 3. This was done by extrapolation using data from Hart et al. (1993). They measured wheat uptake of residual labelled N in soil in each year during five years after labelling wheat plant residues by applying ^{15}N-labelled fertiliser in the first year (Hart et al. 1993). We assumed that the relative release of residual N between years was similar to their findings, with residual N defined as organic N remaining in soil at the start of a season/year. Their crop uptake of residual ^{15}N in soil was 6.6%, 3.5%, 2.2% and 2.2% in years 2-5 after the application. The mineralisation of residual manure N in the year 4 and 5 was estimated by multiplying the mineralisation of residual N in year 3 with the factor 2.2/3.5= 0.63.

Results and discussion

Manure mineralisation model

The studies by Sørensen and Amato (2002) and Sørensen (2004) showed an initial immobilisation phase and that the net mineralisation of slurry N was close to zero or slightly negative during the first 3-4 months, as crop N uptake was similar or lower after slurry application compared to a mineral fertiliser reference receiving the same amount of inorganic N. This is in accordance with a number of other studies. In the model we therefore assume that net mineralisation from slurry is zero until 4 months after application (Fig. 1). In the following catch crop and in the 2nd and 3rd year N uptake was higher after manure application than in the mineral fertiliser reference (Table 1), indicating that there was an extra N mineralisation due to organic N in the manures and due to remineralisation of immobilised N.

Table 1. Additional N uptake (expressed as a percentage of the organic N input in the slurry) measured in barley crops and ryegrass catch crops (CC) after application of cattle or pig slurry in the first year and compared to a mineral N fertiliser treatment. All plots received the same amount of inorganic N for a barley crop in the first year (data from Sørensen and Amato, 2002; Sørensen, 2004).

Manure	1st year	2nd year		3rd year	
	Ryegrass CC	Spring barley	Ryegrass CC	Spring barley	Ryegrass CC
Cattle slurry avg. 3 application methods (81 kg org N/ha), loamy sand (n =12)	8.5	4.3	4.7	1.9	2.5
Pig slurry avg. 3 application methods (51 kg org N/ha), loamy sand and sandy loam soils (n =24)	12.6	9.5	5.3	2.6	2.6

Based on the additional N uptake (Table 1), net N mineralisation of manure N was estimated using the assumption that ANR in barley from mineralised N was similar to ANR that was measured in the same crop after adding mineral N fertiliser (Table 2).

Table 2. Estimated net mineralisation of organic N in pig and cattle slurry during 3 years after application based on the observed apparent N recovery (ANR) in crops in Table 1 and assuming ANR in spring barley similar to ANR measured for mineral N and 70% ANR of the available N in grass and that 70% of mineralised N in autumn/winter was available for the ryegrass catch crop (CC).

	1st year	2nd year		3rd year	
	Ryegrass CC	Spring barley	Ryegrass CC	Spring barley	Ryegrass CC
Estimated ANR of mineralised N (%)	49	60	49	60	49
Cattle slurry net mineralisation (% of organic N input)	17	7.2	10	3.1	5.0
Pig slurry net mineralisation (% of organic N input)	26	16	11	4.4	5.4

In Table 3 mineralisation in the first 3 years is taken from Table 2 and mineralisation in the following 2 years was estimated by extrapolation based on data from Hart et al. (1993). This approach was supported by the fact that the modelled mineralisation in year 3 could be well predicted from mineralisation year 2 using Hart et al. (1993). For instance for cattle slurry the mineralisation of residual organic N could be estimated as 20% x 3.5/6.6= 11%, while our model based on experimental data predicted 12% mineralisation of residual N in the third year (Table 3).

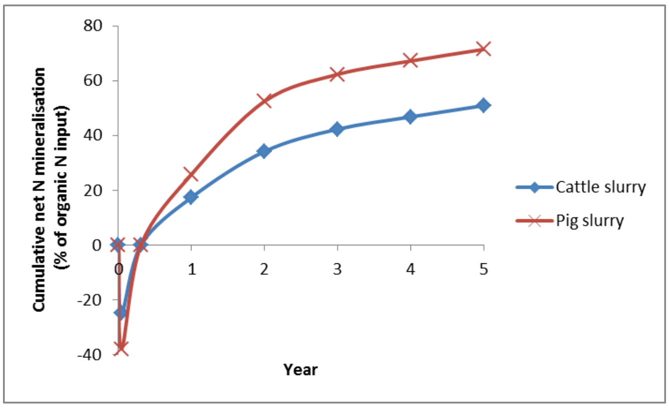

Figure 1. Cumulative net mineralisation of cattle and pig slurry N in soil during five years estimated by a new model.

Table 3. Model estimations of the yearly mineralisation of cattle and pig slurry N. The first 3 years N release is based on data in Table 2. The last 2 years were based on extrapolations using data from Hart et al. (1993).

Manure	1st year	2nd year	3rd year	4th year	5th year
Cattle slurry (% of residual organic N)	17	20	12	7.8	7.8
Pig slurry (% of residual organic N)	26	36	21	13.0	13.0
Cattle slurry (% of organic N input)	17	17	8.1	4.5	4.1
Pig slurry (% of organic N input)	26	27	9.8	4.9	4.3

After five years the cumulated net N mineralisation is estimated to be 71% of the organic N input in pig slurry and 51% of the organic N in cattle slurry (Fig. 1).

Comparison with other experimental data

Van Faassen and van Dijk (1987) studied N mineralisation from different manure types over 18 months after application to two contrasting soil types containing ca 3 % clay (sandy soil) and ca 18 % clay (sandy loam). They applied different faeces samples from cattle, pig and poultry. The mineralisation was studied in the Netherlands in pots placed in the field and the soil was unplanted. The manures were applied in spring (April) and experiments were repeated in two years. They observed very low or even negative mineralisation in the winter period, so the observed mineralisation during the first 0-6 months was nearly equal to the first year mineralisation and mineralisation in the second period (6-18 months) was nearly equal to the second year. In the first year the measured N mineralisation in the sandy loam soil was nearly similar to our model calculation (18% and 31% for cattle and pig vs. 17% and 27% in our model), while it was higher in the sandy soil (Table 4). In the second year their measured manure N mineralisation was significantly lower than in our model calculation (8-14% and 11-17% for cattle and pig vs. 17% and 27% in our model). Our model was based on soils with 9-18% clay. Thomsen and Olesen (2000) found no clear relationship between soil clay content (ranging from 11-45%) and manure N mineralisation in soil. In the experiment reported by Sørensen (2004) we did not measure higher residual effects of cattle slurry on a more sandy soil with only 4% clay than in the loamy sand with 9% clay (unpublished results).

Table 4. Net N mineralisation estimated as percentage of added organic N from animal manures measured during field incubation in pots. The manures were applied as fresh faeces or as anaerobically stored faeces in spring (data from van Faassen and van Dijk 1987).

Manure type	0-6 months		6-18 months	
	Sandy soil (3% clay)	Sandy loam soil (18% clay)	Sandy soil (3% clay)	Sandy loam soil (18% clay)
Cattle	37	18	14	8
Pig	41	31	17	11
Broiler manure	83	81	8	7

Chadwick et al. (2000) determined net N mineralisation from different manure types from N uptake in grass grown in pots under controlled temperature conditions (Table 5). They found that the mineralisation became low and nearly constant from all manure types after 4 months. The manures were stripped for ammonium-N before application which may have reduced the initial immobilisation and thereby increased the net mineralisation slightly.

Table 5. Cumulated N mineralisation from different manure samples after 199 days (3184 accumulated degree days above 0°C) estimated from apparent N recovery in grass and expressed as % of applied organic N taken up in grass in pots. All ammonium-N was stripped before manure application (data from Chadwick et al. 2000).

Manure type	% org. N mineralised (range)	% org. N mineralised (average)	% org. N mineralised (year 1 in our model)
Cattle slurry	2-19	12	17
Cattle FYM	11-24	14	-
Pig slurry	21-37	27	26
Pig FYM	18-30	21	-
Poultry manure	16-56	29	-

The study by Chadwick et al. (2000) indicated that there was no clear difference in N mineralisation between slurries and solid manures from the same species (Table 5), and a similar model therefore can be used for both organic N in slurry and solid manure. The average first year mineralisation rate was nearly twice as high from pig manures compared with cattle manures after 3184 degree days of decomposition which is equal to about one year under Danish conditions. The average first year mineralisation was close to the mineralisation estimated in our model, when also considering the high variation between different manure samples (Table 5).

Schröder et al. (2007) estimated the accumulated nitrogen fertiliser replacement value (NFRV) of up to four years repeated injection of cattle slurries to grassland. By relating the fertiliser value to the organic N applied with the manure and assuming that about 90% of the mineralised N was available for grass uptake, an approximate yearly mineralisation rate of organic N in cattle slurry was calculated to be 21% both in the first and the second year (Table 6). This showed a higher mineralisation in year 2 than in our model (21% vs 17% in year 1 and 2) but a good agreement between the measurements and the model estimates in year 3 and 4 (8% and 6% vs. 8% and 5% in our model). The experiment was carried out on a sandy soil and this could possibly explain the higher N mineralisation rate in the first years compared to our model. We can also not exclude an effect of slightly higher average temperatures in the Netherlands causing faster mineralisation rates.

Table 6. Nitrogen fertiliser replacement values (NFRV) measured after 1-4 years repeated applications of cattle slurry by injection to grassland in the Netherlands (S1UNi and S2UNi data from Schröder et al. 2007) and estimated yearly mineralisation rate of organic manure N.

Year	NFRV slurry 1 % of tot-N	NFRV slurry 2 % of tot-N	NFRV slurry avg % of tot-N	NFRV Yearly effect % of tot-N	NFRV Yearly effect % of Org N input	Estimated N mineralisation % of org N input*
1	54	66	60	9.5**	19	21
2	66	73	69.5	9.5	19	21
3	70	76	73	3.5	7	8
4	74	77	75.5	2.5	5	6

*Assuming that 90% of the yearly mineralisation was available for crop uptake in grass

** NFRV in the first year minus mineral N in the slurry (NH4-N/total N was 0.505)

Conclusion

A new empirical model can be used to estimate the yearly mineralisation from organic N applied in pig and cattle slurries in arable soils under cool moist climate conditions. The estimated net N mineralisation is in accordance with results in a number of field studies with manure applied under wet temperate climate conditions in different countries. The model can be used for estimating residual effects of manure both in terms of fertiliser value and as input in model calculations of long-term nitrate leaching loss from manure N.

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