

# Modelling nitrogen mineralization from manures: representing quality aspects by varying C:N ratio of sub-pools

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## Abstract

The mineralization/immobilization of nitrogen when organic sources are added to soil is represented in many simulation models as the outcome of decomposition of the added material and synthesis of soil organic matter. These models are able to capture the pattern of N release that is attributable to the N concentration of plant materials, or more generally the C:N ratio of the organic input. However, the models are unable to simulate the more complex pattern of N release that has been observed for some animal manures, notably materials that exhibit initial immobilization of N even when the C:N of the material suggests it should mineralize N. The APSIM SoilN module was modified so that the three pools that constitute added organic matter could be specified in terms of both the fraction of carbon in each pool and also their C:N ratios (previously it has been assumed that all pools have the same C:N ratio). It is shown that the revised model is better able to simulate the general patterns on N mineralized that has been reported for various organic sources. By associating the model parameters with measured properties (the pool that decomposes most rapidly equates with water-soluble C and N; the pool that decomposes slowest equates with lignin-C) the model performed better than the unmodified model in simulating the N mineralization from a range of feeds and faecal materials measured in an incubation experiment.

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## 1. Introduction

The cycling of nutrients through the decomposition of plant residues is important in all ecosystems. However, in the soil fertility management of many tropical farming systems, organic sources play a dominant role because of their short-term effects on nutrient supply to crops (Palm et al., 2001). There is now a considerable literature reporting decomposition and nutrient release patterns for a variety of organic materials from tropical agro-ecosystems. This information has been drawn together so that it can be used for improvement of soil fertility through better management of organic inputs (e.g. Giller and Cadisch, 1997; Palm et al., 2001), and understanding has

emerged of how resource quality factors influence the release patterns.

In nutrient and capital poor tropical farming systems, effective use of whatever nutrient sources are available will be required to raise and maintain productivity (Giller et al., 1997). If models are to be useful in helping to design farming systems that use various nutrient sources more effectively, it is a requirement that the models must be able to reliably describe the release of nutrients from the different organic sources. Palm et al. (1997) pointed out that there is little predictive ability for making recommendations on combined use of organic and inorganic nutrient sources. One reason for this is the inability of models to adequately capture the short-term dynamics of the release of nutrients from organic materials.

In this paper we report on how one particular model, Agricultural Production Systems Simulation Model

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(APSIM, McCown et al., 1996; Keating et al., 2003, web site [www.apsim.info](http://www.apsim.info)), represents the decomposition of organic inputs, and how the quality of the inputs influences nitrogen release. The manner in which the dynamics of soil carbon and nitrogen are modelled in APSIM's SoilN module (Probert et al., 1998) is similar to what is found in many other models—see reviews by Ma and Shaffer (2001) and McGechan and Wu (2001). Models do differ in the pool structure used to describe the decomposition of organic inputs, with the pools differing in their rates of decomposition. However, we are unaware of any model where the pools differ in chemical composition, with the effect that inputs decompose with constant composition. We show that the assumption that all pools have the same C:N ratio fails to adequately represent the observed behaviour for release of N from some organic inputs. We present a modification of APSIM SoilN which allows for different C:N ratios in each pool. The modified model was able to better match the mineralization/immobilization of N observed in laboratory incubation studies.

## 2. Modelling the decomposition of organic sources

The development of the APSIM SoilN module (Probert et al., 1998) can be traced back via CERES models (e.g. Jones and Kiniry, 1986; Godwin and Jones, 1991) to PAPRAN (Seligman and van Keulen, 1981). Briefly, crop residues and roots added to the soil, are designated fresh organic matter (FOM) and are considered to comprise three pools (FPOOLS), sometimes referred to as the carbohydrate-like, cellulose-like and lignin-like fractions of the residue. Each FPOOL has its own rate of decomposition, which is modified by factors to allow for effects of soil temperature and soil moisture. For inputs of crop residues and roots it has usually been assumed that the added C in the three FPOOLS is always in the proportions 0.2:0.7:0.1. In this manner the decomposition of added residues ceases to be a simple exponential decay process as would arise if all residues were considered to comprise a single pool.

Although the three fractions have different rates of decomposition, they do not have different compositions in terms of C and N content. Thus whilst an input might be specified in terms of the proportion in each of the FPOOLS, thereby affecting its rate of decomposition, the whole of the input will decompose without change to its C:N ratio. If the analogy can be made with the dissolution of a substance, we might say that the whole of the residues decompose congruently. Alternatively the system can be described as having three soil organic C pools but only one organic N pool (Gijsman et al., 2002).

The release of C and N from the decomposing FOM pools is determined by the mineralization and immobilization processes that are occurring. The C that is decomposed is either evolved as CO<sub>2</sub> or is synthesized into soil organic matter. APSIM SoilN assumes that the pathway for synthesis of stable

soil organic matter is predominantly through initial formation of soil microbial biomass (BIOM), though some C is transferred directly to the more stable pool (HUM). The model further assumes that the soil organic matter pools (BIOM and HUM) have C:N ratios that are unchanging through time. The formation of BIOM and HUM thus creates an immobilization demand that has to be met from the N released from the decomposition of the FOM and/or by drawing on the mineral N (ammonium- and nitrate-N) in the system. Any release of N during the decomposition process in excess of the immobilization demand results in an increase in the ammonium-N. The model operates on a daily time step, so that decomposition of the FOM pools is happening simultaneously with decomposition of the soil organic matter pools (BIOM and HUM).

If we ignore the dynamic nature of the system, the N mineralization from a substrate can be expressed succinctly as (Whitmore and Handayanto, 1997)

$$N_{\text{mineralized}} = C_{\text{decomposed}} \{1/Z - E/Y\} \quad (1)$$

where  $Z$  is the C:N ratio of the decomposing substrate,  $E$  is a microbiological efficiency factor which can be taken to be 0.4 (the value in APSIM SoilN for the proportion of the decomposing carbon that is transformed into soil organic matter), and  $Y$  is the C:N ratio of the soil organic matter being formed. Eq. (1) implies that there is a C:N ratio of substrate that determines whether decomposition results in net N mineralization or immobilization. Assuming the initial product of decomposition is soil microbial biomass with  $Y=8$  (the value used in APSIM SoilN), the critical value can be calculated as 20. As shown by Whitmore and Handayanto (1997), this expression accounts for much of the variation found in the data that have examined N mineralized (or immobilized) in relation to the C:N ratio of the added organic matter.

The rate of net N mineralization is dependent on the rate of decomposition. Thus allowing the distribution of carbon between the three FPOOLS to be a model input that characterizes the organic substrate will alter the rate of net N mineralization (as shown by Quemada and Cabrera, 1995; Quemada et al., 1997). However, changing the pool sizes alone cannot alter whether a source exhibits initial net N mineralization or immobilization (since this is determined by the C:N ratio of the substrate).

In studies of the mineralization of N from various manures, Delve et al. (2001) encountered situations, where there was an initial immobilization of N, despite the fact that the overall C:N ratio of the material was such that it would be expected to result in net mineralization. This behaviour cannot be modelled satisfactorily by existing models.

### 2.1. Modifications to the model

Modifications were made to the APSIM SoilN module so that any input of organic material could be specified in terms

of both its fractionation into the three FPOOLS, and the C:N ratio of each FPOOL. In the modified model, each FPOOL is assumed to decompose congruently. The rates of decomposition of the three FPOOLS were not changed from the released version of APSIM (0.2, 0.05 and 0.0095 day<sup>-1</sup>, respectively under non-limiting temperature and moisture conditions).

Using the modified model, we have explored the effects on simulated N mineralization from hypothetical sources that differ in respect of firstly, their fractional composition (the proportion of C in the 3 FPOOLS), and secondly, the C:N ratios of the FPOOLS.

The effects are illustrated by contrasting four assumptions as to how an organic input decomposes:

1. Using the released version of ASPIM SoilN (v 2.0);
2. Changing the fractional composition of the FPOOLS but with the C:N ratio being the same in all pools;
3. Changing the FPOOLS to have different fractional compositions and different C:N ratios, in the first instance with FPOOL1 differing from a common value for FPOOLS 2 and 3;
4. With the fractional composition and C:N ratios differing between all 3 FPOOLS.

## 2.2. Specification of model inputs

The modifications made to the model result in extra information being needed to specify the inputs. Ideally it should be possible to derive the necessary information from known (measured) properties of the organic sources.

The experimental data reported by Delve et al. (2001) have been used to investigate whether the analytical data for a range of feeds and faecal samples can be used to specify the model to simulate the N mineralization measured in a laboratory incubation experiment.

## 3. Materials and methods

### 3.1. Laboratory incubation studies

Delve et al. (2001) used a leaching tube incubation procedure (Stanford and Smith, 1972) to measure net N mineralization for feeds and faecal samples resulting from cattle fed a basal diet of barley straw alone, or supplemented with 15 or 30% of the dry matter as *Calliandra calothyrsus*, *Macrotyloma axillare* or poultry manure. The soil used was a humic nitisol with organic C content of 31 g kg<sup>-1</sup>, C:N ratio of 10 and pH (in water) of 5.9. The incubations were conducted at 27 °C. Data were reported on the chemical composition of the feeds and faecal samples including: total C and N; water-soluble C and N; acid detergent fibre (ADF), neutral detergent fibre (NDF) and acid detergent lignin (ADL) (Van Soest et al., 1987).

The same methodology was used to measure net N mineralization for nine cattle manure samples. These were selected to provide a wide range of C:N ratios from a collection of 45 manures obtained from farms in Central Kenya and on-station at National Agricultural Research Centre, Muguga. Analytical data for these materials included total and water-soluble C and N, ash and lignin, but not the full range of fibre analyses carried out by Delve et al. (2001).

### 3.2. Simulation of mineralization from hypothetical sources

The model was configured to simulate a simple incubation study, involving a single layer of soil under conditions of constant temperature (25 °C) and at a soil water content that ensured there was no moisture restriction on decomposition. Initial nitrate-N concentration in the soil was 20 mg N kg<sup>-1</sup>. The effect of different organic inputs was investigated by incorporating materials that contained a constant amount of N (100 mg N kg<sup>-1</sup> soil) but with varying C:N ratio. A control system was also simulated without any added organic input.

The output from the simulations are presented as net mineralization/immobilization expressed as a percentage of the N added:

$$\text{N mineralization(\%)} = 100 \times (\text{Mineral-N}_{\text{input}} - \text{Mineral-N}_{\text{control}}) / \text{N added} \quad (2)$$

where Mineral-N<sub>input</sub> is the simulated ammonium- + nitrate-N in systems with the added source, and Mineral-N<sub>control</sub> in the absence of any input.

### 3.3. Simulation of laboratory incubation studies

The model was specified to simulate the incubation study of Delve et al. (2001). In this case the organic sources were added on an equal mass basis (rather than equal N) and the incubations were carried out at 27 °C.

## 4. Results

The mineralization data for the cattle manures from Central Kenya are shown in Fig. 1 and the analytical data for the manures studied are set out in Table 1. The results consistently show an initial immobilization or delay in mineralization lasting several weeks, even for materials that have overall C:N ratios of less than 20. This pattern of response is noticeably different to studies of N mineralization from plant materials (e.g. Constantinides and Fownes, 1994). Plant materials with low C:N typically exhibit positive net mineralization from the commencement of the incubation period.

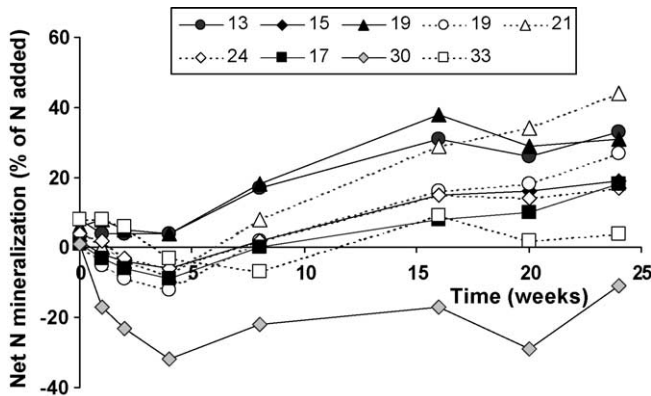


Fig. 1. Net nitrogen mineralized from different manures in an incubation study lasting 24 weeks. C:N ratios of the manures are shown in the legend.

Other authors also report initial N immobilization followed by net mineralization in experiments with animal manures having low C:N ratios (Trehan and Wild, 1993; Olesen et al., 1997). The faecal samples studied by Delve et al. (2001), with C:N ratios in the range 20–27, had even more complex patterns of mineralization; some materials showed initial net mineralization before an extended period of immobilization lasting for at least 16 weeks of incubation (see Fig. 7).

#### 4.1. Modelling N mineralization from hypothetical sources

Simulation of mineralization for sources with different C:N ratios using the released version of APSIM SoilN is shown in Fig. 2. The results are in general agreement with experimental studies for plant materials, where net N mineralization is closely related to the N content and hence C:N ratio (e.g. Constantinides and Fownes, 1994; Tian et al., 1992). For sources with C:N < 20, net mineralization occurs from the outset (as predicted by Eq. (1)). However, with C:N > 20, there is initially immobilization of mineral-N and it is only as newly formed soil organic matter is re-mineralized that mineral-N in the system begins to increase.

The lower pane of Fig. 2 shows the same data plotted against the C:N ratio for different periods of incubation. Again the pattern of response is familiar from experimental

data that have been used to infer the C:N ratio of a substrate, around 20–25, that determines whether net mineralization or immobilization occurs. The simulations show that the C:N ratio of the substrate that results in zero net mineralization changes with the period of incubation, increasing from approximately 21 at day 10 to 26 at day 100. Such an effect has not generally been recognized when discussing critical C:N ratios with respect to mineralization/immobilization, though its importance was noted by De Neve and Hofman (1996). Thus incubation period is a factor that will complicate efforts to compare results from different incubation studies. Furthermore other aspects of the incubation conditions can also be expected to have similar effects as the incubation period; in particular higher incubation temperature, which increases decomposition rates, will have much the same effect as increasing the incubation period.

The effect of changing the input by modifying the proportion of the C in each of the FPOOLS is illustrated in Fig. 3. For inputs with low C:N (< 20), a greater proportion of material in the FPOOLS with lower rates of decomposition simply slows the release of mineral-N. Where C:N is > 20 so that net immobilization occurs, inputs with a greater proportion of material with lower rates of decomposition result in less immobilization during the early stages of decomposition, but it also takes longer before the system exhibits positive net mineralization. Simply changing the proportions of the input between the three pools with unaltered C:N ratio cannot cause a switch from causing net mineralization to immobilization, or vice versa.

Effects of changing the composition of the input by modifying the C:N ratios of the different FPOOLS are shown in Figs. 4 and 5. In Fig. 4, all materials have the same overall C:N ratio, but the C:N ratio of FPOOL1 is now greater than for the material in pools 2 and 3. The result is that the material in FPOOL1 which decomposes most rapidly creates an immobilization demand, and the higher the C:N ratio the greater the initial immobilization. However, if C:N of FPOOL1 is higher, there must be compensating decreases in the C:N ratios of the other pools. As incubation time increases, the differences between different materials decrease so that there is little longer-term effect of

Table 1  
Analytical data for manures from Central Kenya that were studied in the incubation experiment

Sample no.	Total DM basis			Water soluble components			Lignin (%)	Ash (%)
	C (%)	N (%)	C:N	C (%)	N (%)	C:N		
1	32.7	1.1	30	2.0	0.01	197	11	13
2	28.5	1.3	21	2.1	0.02	103	11	10
3	29.1	1.5	19	3.1	0.02	153	15	10
4	24.9	1.9	13	4.0	0.14	29	17	19
5	17.7	1.2	15	1.6	0.06	27	12	26
6	30.3	1.6	19	2.6	0.06	43	15	12
7	28.5	0.9	33	1.8	0.06	30	17	18
8	30.6	1.8	17	1.9	0.12	16	15	16
9	39.6	1.6	24	4.4	0.14	31	18	11



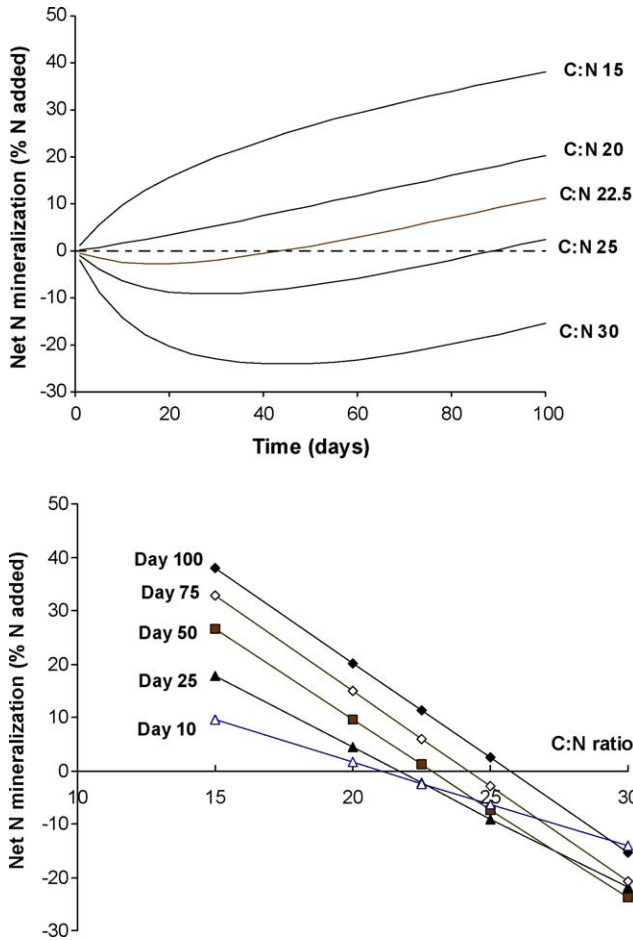


Fig. 2. Simulation of nitrogen mineralization from organic inputs with different C:N ratios using the released version of APSIM SoilN. The model assumes that all inputs have the same fractional composition in terms of the three FPOOLs (0.2:0.7:0.1), and that, for a given source, all FPOOLs have the same C:N ratio.

the C:N ratios of the FPOOLs on net mineralization which is determined largely by the overall C:N ratio.

In Fig. 5 the effect of varying the C:N ratios of FPOOLs 2 and 3 is shown. Again all materials have the same overall C:N ratio and here the C:N of FPOOL1 is also fixed at 10. With the low C:N in the rapidly decomposing pool, there can be an initial net mineralization, especially when the C:N of FPOOL2 is also relatively low. However, as FPOOL1 is depleted, there can be a switch from net mineralization to net immobilization. Increasing the C:N of FPOOL2 results in increasing immobilization and the immobilization persists to longer times.

4.2. Modelling the mineralization study of Delve et al. (2001)

The modelled net mineralization from hypothetical sources display patterns of N release that are similar to experimental data. Notably the delay of several weeks before net mineralization becomes positive exhibited by several of the manures in Fig. 1 is consistent with variation

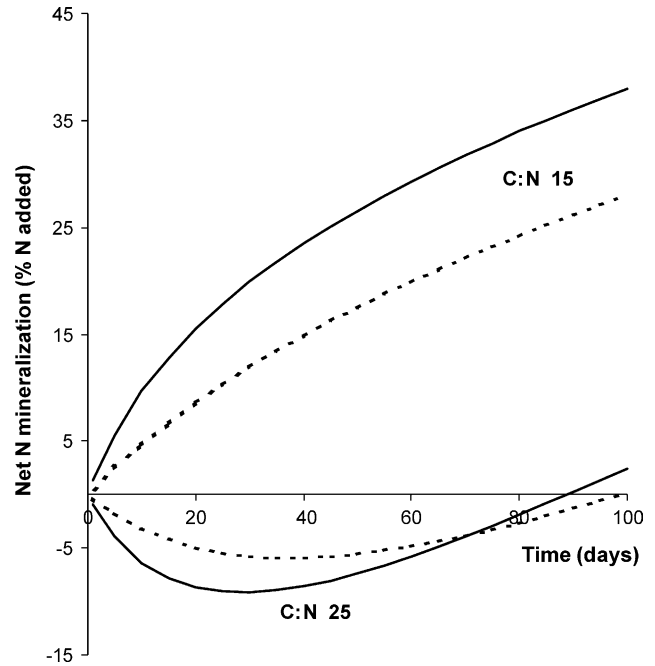


Fig. 3. Effect of changing the composition of organic inputs by varying the proportions in the three FPOOLs. The continuous lines refer to substrates, where FPOOLs comprise 0.2:0.7:0.1 of the total carbon; the dashed lines 0.01:0.49:0.5. The C:N ratios of all FPOOLs (for a given source) are the same.

in the C:N ratio of FPOOL1 (Fig. 4). On the other hand, the longer delay reported by Delve et al. (2001) is more like the pattern shown in Fig. 5 associated with variation in FPOOL2 and 3.

We have attempted to use the analytical data reported by Delve et al. (2001) to specify the ‘quality’ aspects of organic inputs represented in the model. We assume the soluble components of C and N equate to FPOOL1; thus the analytical results are sufficient information to determine the proportion of total C in this pool and its C:N ratio. Also we

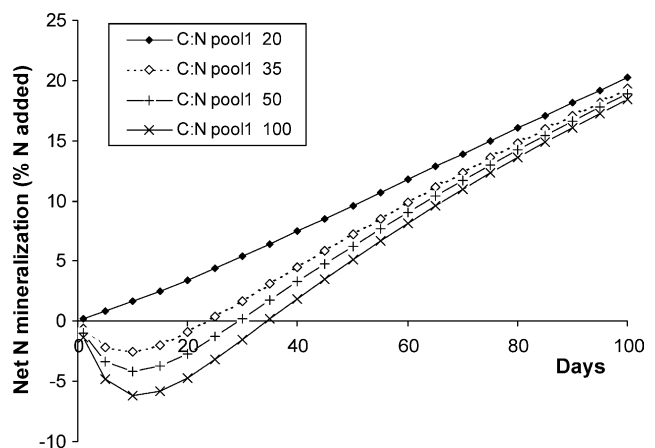


Fig. 4. Effect of changing the composition of organic inputs by modifying the C:N ratios of the FPOOLs. In this example, the inputs have fractional composition of 0.2:0.7:0.1, overall C:N ratio of 20, and C:N ratio of FPOOL1 as shown in the legend (with C:N ratios of FPOOLs 2 and 3 being equal).

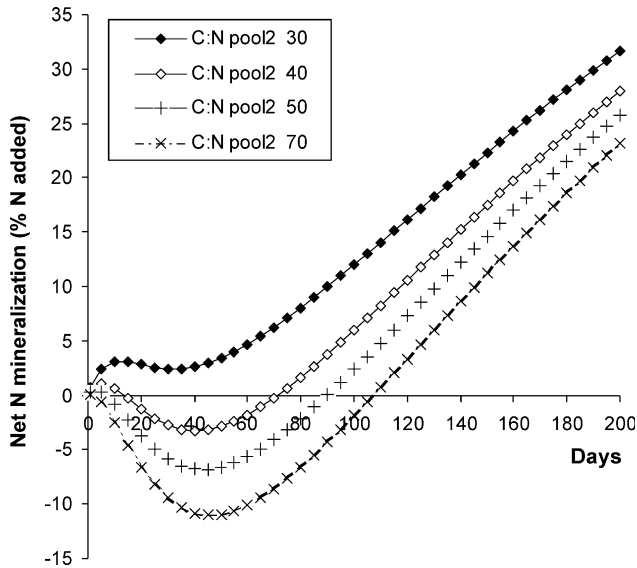


Fig. 5. Effect of changing the quality of organic inputs by varying the C:N ratios of the FPOOLS. In this example, the inputs have fractional composition of 0.1:0.7:0.2, overall C:N ratio of 20 and C:N ratio of FPOOL1 of 10, with C:N of FPOOL2 as shown in the legend.

assume that ADL, which is a proximate measure of lignin, equates to FPOOL3 permitting the fraction of C in this pool to be estimated; the fraction of C in FPOOL2 is found by difference. Since the overall C:N ratio (on a total dry matter basis) is also known, the only missing information is the distribution of non-water soluble N between pools 2 and 3. A series of simulations were carried out for each source with different combinations of C:N in the two pools (constrained by the C:N of the total DM) which enabled selection of the C:N ratios giving an acceptable fit to the observed data.

It is to be noted that the simulated net N mineralization from an organic source is only influenced by the mineralization exhibited by the control treatment when there is inadequate mineral N in the system to meet an immobilization demand. The simulation of N mineralization for the control is shown in Fig. 6. Although there is a slight under-prediction, the general pattern agrees well with the measured data and was considered acceptable for comparing the net mineralization from the different materials.

The net N mineralization for the feeds and a selection of the faecal samples studied by Delve et al. (2001) is shown in Fig. 7. The outputs from two simulations are compared, these being the outputs from the modified and unmodified versions of the model. The input data used for the modified model are set out in Table 2.

For most of the materials the goodness of fit is substantially better for the modified than for the unmodified model. Using the analytical data to specify the fraction of C in each of the FPOOLS and the C:N ratio of FPOOL1, it was possible to choose values for the C:N ratios of FPOOL2 and FPOOL3 to obtain satisfactory fits with the measured data.

In general the fit is better for the faecal samples than for the feeds, with the poorest fit for the poultry waste.

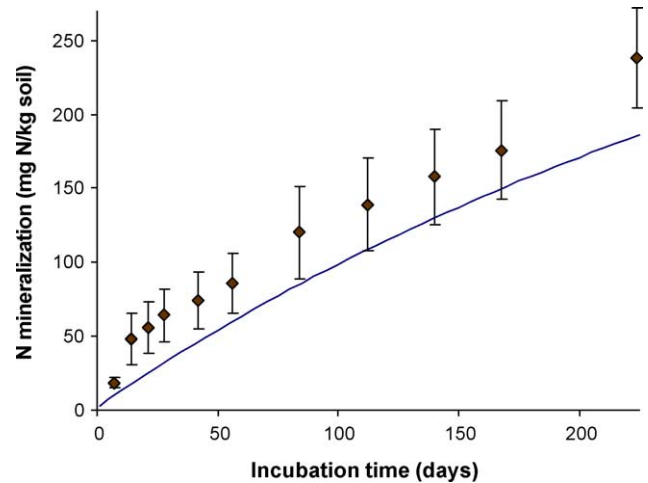


Fig. 6. Simulation of the control treatment of Delve et al. (2001). The symbols denote measured data with error bars representing  $\pm$  standard error of the mean of three replicates. The continuous line is the output from the model.

The pattern of net mineralization measured for the poultry waste, which had an overall C:N ratio of 17, is different from the other materials in that the change from immobilization to mineralization that occurred after  $\sim$ 50 days was not maintained, and further net immobilization occurred later in the incubation. Delve et al. (2001) had no satisfactory explanation for the behaviour of this material.

The simulation for the barley straw (C:N 86) predicts that immobilization continues for at least 200 days. Early in the incubation all mineral N in the system is immobilized for this treatment. Thus the immobilization, calculated as net mineralization using Eq. (2), is determined solely by the rate of mineralization of the control treatment and is not sensitive to how N is partitioned between FPOOLS 2 and 3. The under-prediction of net immobilization by the barley straw (Fig. 7) is the same lack of fit as the under-prediction of N mineralization in the control treatment (Fig. 6).

## 5. Discussion

The essence of Eq. (1) is built into many dynamic simulation models that describe the decomposition of organic residues and the associated mineralization of N. Such models are capable of capturing the gross effect of C:N ratio (as illustrated in Fig. 2) on mineralization/immobilization from plant residues. However, they are not able to represent the more complex pattern of mineralization/immobilization that has been reported from laboratory incubation studies of N release from manures with low C:N (e.g. Figs. 1 and 7). To capture these patterns of N release it is necessary to conceptualise the organic input as comprising discrete fractions that differ not only in their rates of decomposition but also in their chemical (i.e. C and N) composition.

The observed behaviour shown in Fig. 1 suggests that the fraction of the substrate that decomposes fastest has a higher

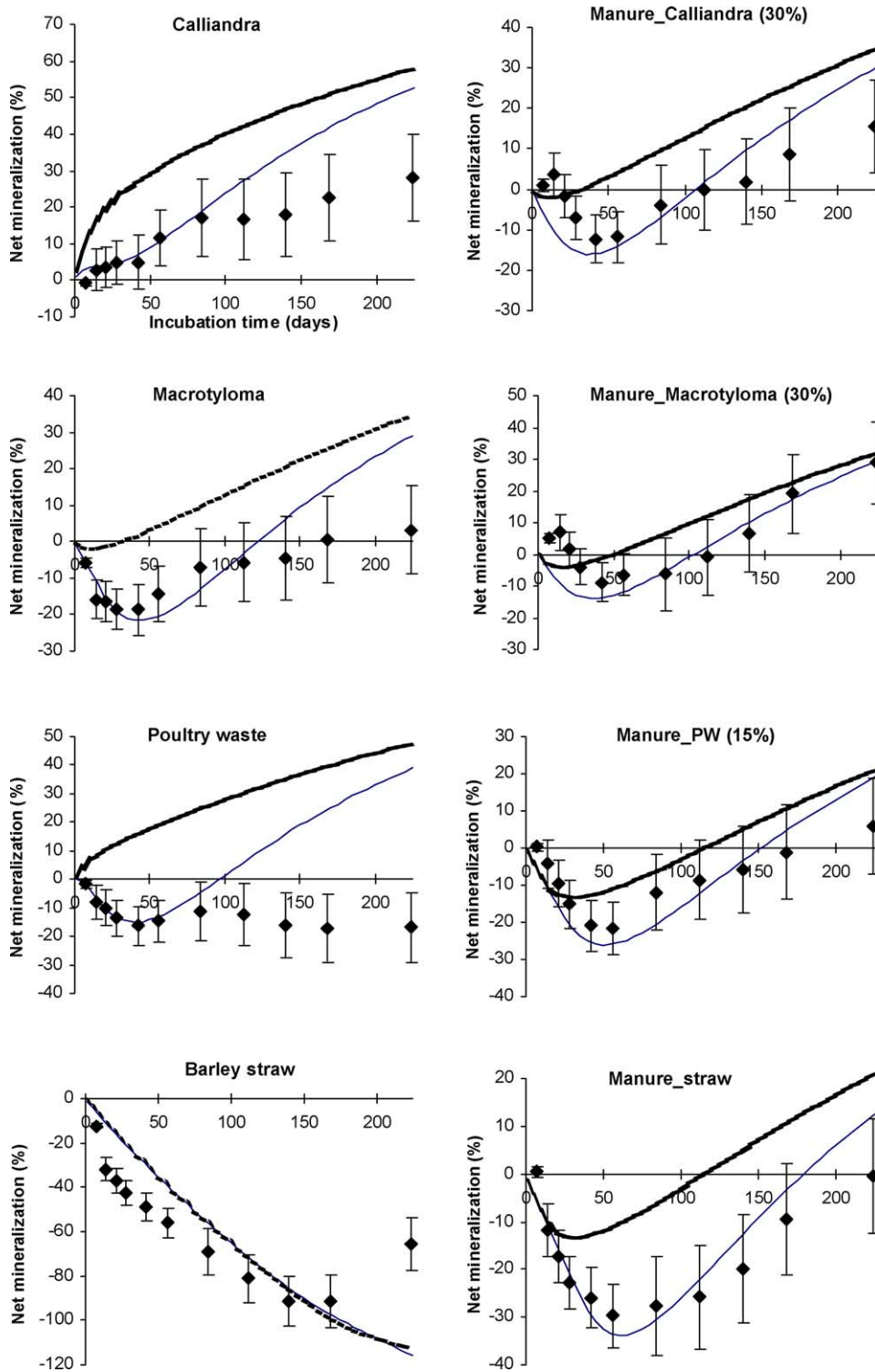


Fig. 7. Net nitrogen mineralization from feeds and faecal materials (data of Delve et al., 2001). Experimental data shown as symbols with bars representing  $\pm$  standard errors. The heavy broken line is for the model, where all organic material is assumed to decompose with the same C:N ratio; the continuous line is for the model with different C:N ratio in each FPOOL. Parameters used to specify the different sources (proportion of C and C:N in the three FPOOLS) are set out in Table 2.

C:N ratio than the bulk of the material. The C and N composition of the manures (Table 1) shows that the C:N ratio of the water-soluble component is generally higher than for the whole manure—in the case of samples 1–3

much higher, whilst for samples 7 and 8 there was little difference between the water-soluble fraction and the rest of the material. This pattern was consistent for the collection of 45 manures; the C:N ratio averaged 21 (SD=5) on a whole

Table 2  
Composition of organic materials (feeds and faecal samples) used for simulating the mineralization study of Delve et al. (2001)

Sample	Overall C:N	Proportion of carbon in FPOOLS (%)			C:N of FPOOLS		
		Pool 1	Pool 2	Pool 3	Pool 1	Pool 2	Pool 3
Calliandra	13	12	74	14	9	44	3
Macrotyloma	22	16	74	10	17	67	4
Poultry waste	17	5	88.5	6.5	4.5	202	1.5
Barley straw <sup>a</sup>	86	6	84.5	9.5	24	103	103
Calliandra_Manure (30%) <sup>b</sup>	22	4	74	22	16	40	9
Macrotyloma_Manure (30%)	23	5.5	73.5	21	14	36	11
Poultry waste_Manure (15%)	27	4.5	82	13.5	12	41	10
Barley straw_Manure	27	9	71.5	19.5	20	66	9

Overall C:N ratio was measured; FPOOL1 based on measured C and N as water soluble components; proportion of C in FPOOL3 based on measured ADL. C:N of FPOOL2 and 3 selected, subject to constraint that must be consistent with overall C:N, to give reasonable fit between simulated N mineralization and measured data.

<sup>a</sup> Simulated N mineralization was not sensitive to partitioning of N between pools 2 and 3.

<sup>b</sup> Value in parentheses denotes proportion of supplement in diet.

dry matter basis and 68 (SD=60) in the water-soluble fraction (data not presented).

In contrast, the mineralization data of Delve et al. (2001) (Fig. 7) and chemical composition of their materials (Table 2) indicate that the measured water-soluble component had a smaller C:N than the bulk materials. To simulate the observed mineralization data it was necessary to assume that the materials had higher C:N in FPOOL2 than in FPOOL3.

To some extent, this difference between in the C:N of the water-soluble components in the two studies might be explained by the nature of the manures. Those in the study of Delve et al. (2001) were fresh faecal material, whereas the manures collected in Central Kenya came from farm situations, where they would have been exposed to varying degrees of weathering that would be expected to have removed some water-soluble components. However, if this is the explanation, we are unable to satisfactorily account for why the analytical data for the manures should still indicate considerable amounts of water-soluble C, nor why the resultant manures should have increased C:N for the water-soluble components.

What is rather simplistically called ‘manure’ is usually a complex mixture of faeces, urine, bedding material, feed refusals and soil! To add to the complexity it may have undergone further composting and weathering with loss of some components. Thus it is perhaps naïve to expect that the methods used to characterize the quality factors which determine N mineralization from plant residues might also be applicable to manures. Similarly that models which are able to simulate N mineralization from plant residues might also simulate N release from manures.

By simulation of hypothetical materials, we have shown that such a model can be parameterised to simulate the general pattern of N mineralization that is observed for various organic manures and feeds. Nonetheless, it remains a challenge to know how appropriate parameters should be selected for a given source and/or how to derive the parameter values from other information that may be available as analytical data for

supposed ‘quality factors’. Here we have used data for C and N in the water-soluble components to specify FPOOL1, and the measured ADL to specify the C in FPOOL3. To obtain the goodness of fit shown in Fig. 7 for the manures required C:N in FPOOL2 in the range 36–66, with corresponding C:N in FPOOL3 of 9–10 (Table 2). Attempts to estimate the C:N of FPOOL2 from measured data for N associated with ADF and NDF (Delve et al., 2001) produced values that were considerably higher (range 63–174 for the manure samples) with the corresponding values for FPOOL3 becoming very narrow (<0.8); the goodness of fit for simulations of N mineralization using these values were substantially worse than those shown in Fig. 7.

For the feed materials (Calliandra, Macrotyloma, poultry waste), the predictions were not as good as for the faecal samples. To obtain a reasonable fit in the early stages of the mineralization a high C:N in FPOOL2 is required, but this results in very low values of C:N for FPOOL3 and over-prediction as the incubation period progresses beyond 100 days.

The resource quality factors that have been shown to influence N release from organic sources are the C:N ratio (or N concentration in plant materials for which C concentration varies little), lignin and polyphenol concentrations (Palm et al., 2001). Our studies suggest that the effect of lignin is consistent with the concepts in the model in as much as higher lignin content can be represented by a greater proportion of the C in the slow decomposing pool. But it is also necessary to hypothesize that the FPOOLS differ in their C:N ratio.

Whitmore and Handayanto (1997) have suggested a mechanism to represent the effect of polyphenols (or strictly the protein binding capacity) on decomposition. They propose that a proportion of the substrate associated with the polyphenols be diverted to the more stable soil organic matter pool. The polyphenol concentrations in the materials studied by Delve et al. (2001) were low (<1.6%) except for the Calliandra feed. Manures have been reported generally to have low polyphenol concentration (Palm et al., 2001;



Herbert Murwira, personal communication). Thus the present data are unsuited for testing how the model might accommodate the effects of polyphenols as a quality factor influencing decomposition and N release.

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## References

- Constantinides, M., Fownes, J.H., 1994. Nitrogen mineralization from leaves and litter of tropical plants; relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biology & Biochemistry* 26, 49–55.
- Delve, R.J., Cadisch, G., Tanner, J.C., Thorpe, W., Thorne, P.J., Giller, K.E., 2001. Implications of livestock feeding management on soil fertility in the smallholder farming systems of sub-Saharan Africa. *Agriculture, Ecosystems and Environment* 84, 227–243.
- De Neve, S., Hofman, G., 1996. Modelling N mineralization of vegetable crop residues during laboratory incubations. *Soil Biology & Biochemistry* 28, 1451–1457.
- Gijsman, A.J., Hoogenboom, G., Parton, W.J., Kerridge, P.C., 2002. Modifying DSSAT crop models for low-input agricultural systems using a soil organic-matter module from CENTURY. *Agronomy Journal* 94, 462–474.
- Giller, K.E., Cadisch, G., 1997. Driven by nature: a sense of arrival or departure. In: Cadisch, G., Giller, K.E. (Eds.), *Driven by Nature: Plant Litter Quality and Decomposition*. CAB International, Wallingford, UK, pp. 393–399.
- Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W.D., Mafongoya, P.L., 1997. Building soil nitrogen capital in Africa. In: Buresh, R.J., Sanchez, P.A., Calhoun, F. (Eds.), *Replenishing Soil Fertility in Africa*, pp. 151–192. SSSA Special Publication No. 51.
- Godwin, D.C., Jones, C.A., 1991. Nitrogen dynamics in soil-plant systems. In: Hanks, J., Ritchie, J.T. (Eds.), *Modeling Plant and Soil Systems* Agronomy Monograph 31. ASA, CSSA, and SSSA, Madison, WI, pp. 287–321.
- Jones, C.A., Kiniry, J.R., 1986. *CERES-Maize: A Simulation Model of Maize Growth and Development*. Texas A & M University Press, College Station, Texas.
- Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* 18, 267–288.
- Ma, L., Shaffer, M.J., 2001. A review of carbon and nitrogen processes in nine U.S. soil nitrogen dynamic models. In: Shaffer, M.J., Ma, L., Hansen, S. (Eds.), *Modeling Carbon and Nitrogen Dynamics for Soil Management*. Lewis Publishers, Boca Raton, FL, pp. 55–102.
- McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., Freebairn, D.M., 1996. APSIM: a novel software system for model development, model testing, and simulation in agricultural research. *Agricultural Systems* 50, 255–271.
- McGechan, M.B., Wu, L., 2001. A review of carbon and nitrogen processes in European soil nitrogen models. In: Shaffer, M.J., Ma, L., Hansen, S. (Eds.), *Modeling Carbon and Nitrogen Dynamics for Soil Management*. Lewis Publishers, Boca Raton, FL, pp. 103–171.
- Olesen, T., Griffiths, B.S., Henriksen, K., Moldrup, P., Wheatley, R., 1997. Modeling diffusion and reaction in soils: V. Nitrogen transformations in organic manure-amended soil. *Soil Science* 162, 157–168.
- Palm, C.A., Myers, R.J.K., Nandwa, S.M., 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, R.J., Sanchez, P.A., Calhoun, F. (Eds.), *Replenishing Soil Fertility in Africa*, pp. 193–217. SSSA Special Publication No. 51.
- Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G., Giller, K.E., 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment* 83, 27–42.
- Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C., Strong, W.M., 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems* 56, 1–28.
- Quemada, M., Cabrera, M.L., 1995. Using the CERES-N model to predict N mineralized from cover crop residues. *Soil Science Society of America Journal* 59, 1059–1065.
- Quemada, M., Cabrera, M.L., McCracken, D.V., 1997. Nitrogen release from surface-applied cover crop residues: evaluating the CERES-N submodel. *Agronomy Journal* 89, 723–729.
- Seligman, N.G., van Keulen, H., 1981. PAPRAN: a simulation model of annual pasture production limited by rainfall and nitrogen. In: Frissel, M.J., van Veen, J.A. (Eds.), *Simulation of Nitrogen Behavior of Soil-Plant Systems*. PUDOC, Wageningen, The Netherlands, pp. 192–221.
- Stanford, G., Smith, S.K., 1972. Nitrogen mineralization potentials of soils. *Soil Science Society of America Proceedings* 36, 472–495.
- Tian, G., Kang, B.T., Brussaard, L., 1992. Effects of chemical composition on N, Ca and Mg release during incubation of leaves from selected agroforestry and fallow plant species. *Biogeochemistry* 16, 103–119.
- Trehan, S.P., Wild, A., 1993. Effects of an organic manure on the transformations of ammonium nitrogen in planted and unplanted soil. *Plant and Soil* 151, 287–294.
- Van Soest, P.J., Conklin, N.L., Horvath, P.J., 1987. Tannins in foods and feeds. In: *Cornell Nutrition Conference for Feed Manufacturers*. Department of Animal Science and Avian Science, Cornell University, New York, pp. 115–122.
- Whitmore, A.P., Handayanto, E., 1997. Simulating the mineralization of N from crop residues in relation to residue quality. In: Cadisch, G., Giller, K.E. (Eds.), *Driven by Nature: Plant Litter Quality and Decomposition*. CAB International, Wallingford, UK, pp. 337–348.