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The APSIM Manure Module: Improvements in Predictability and Application to Laboratory Studies

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Abstract

Existing models are able to capture the pattern of N release from plant materials based on their C/N ratios. However, these models are unable to simulate the more complex pattern of N release reported for some animal manures, especially for manures that exhibit initial immobilisation of N even when the C/N ratio of the material suggests it should mineralise N.

This paper reports on progress towards developing a capability within the APSIM SoilN module to simulate nitrogen release from these manures. The SoilN module was modified so that the three pools that constitute added organic matter can be specified in terms of both the fraction of carbon in each pool and also their C/N ratios. The previous 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. 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 mineralisation from a range of livestock feeds and manure samples.

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). Considerable literature exists reporting decomposition and nutrient-release patterns for a variety of organic materials and this information has been drawn together and used for improvement of soil fertility through better management of organic inputs (e.g. Giller and Cadisch 1997; Palm et al. 2001).

If simulation 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 be able to reliably describe the release of nutrients from these 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.

The manner in which the dynamics of soil carbon and nitrogen are modelled in APSIM's SoilN module (Probert et al. 1998; Probert and Dimes 2004) is similar to what is found in many other models — see reviews by Ma and Shaffer (2001) and McGechen and Wu (2001). Briefly, crop residues and roots

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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, while 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. 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 a gross immobilisation 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.

However, changing the pool sizes alone cannot alter whether a source exhibits initial net N mineralisation or immobilisation (since this is determined by the C:N ratio of the substrate). In studies of the mineralisation of N from various manures, Kimani and co-workers (unpublished) and Delve et al. (2001) encountered situations where there was an initial immobilisation 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 mineralisation. This behaviour cannot be modelled without assuming that the three FPOOLs also differ in their C:N ratios.

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 ratios of each FPOOL. In the modified model, each FPOOL is assumed to decompose without changing its C:N ratio. The rates of decomposition of the three FPOOLs were not changed from the released version of APSIM (viz. 0.2, 0.05 and 0.0095 day^{-1}, respectively, under non-limiting temperature and moisture conditions).

Using the modified model, we explored three different approaches to simulate how an organic input decomposes:

1. using the released version of ASPIM SoilN (v 2.0)
2. 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
3. with the fractional composition and C:N ratios differing between all three FPOOLs.

Materials and Methods

Simulation of mineralisation 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^{-1}. The effect of different organic inputs was investigated by incorporating materials that contained a constant amount of N (100 mg N kg^{-1} soil) but with varying C:N ratio. A control system was also simulated without any added organic input.

Simulation of laboratory incubation studies

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

Using a leaching-tube incubation procedure (Stanford and Smith 1972), they measured net N mineralisation for feeds and manure 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^{-1}, C/N ratio of 10 and pH (in water) of 5.9. The incubations were conducted at 27°C.

Kimani and co-workers (unpublished data) carried out a mineralisation study, using the same methodology as Delve et al. (2001), for a selection of manure samples collected on-station and from farms in central Kenya. Analytical data for these materials included total and water soluble C and N, but not fibre analyses.

Results

Experimental data (S.K. Kimani et al., unpublished data) that indicated the need to reconsider how N mineralisation from organic inputs is modelled are illustrated in Figure 1. For a wide range of manures, their results consistently show an initial immobilisation or delay in mineralisation 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 mineralisation from plant materials (e.g. Constantinides and Fownes 1994), where plant materials with low C:N typically exhibit positive net mineralisation from the start of the incubation period.

The manure samples studied by Delve et al. (2001), with C:N ratios in the range 20–27, had even more complex patterns of mineralisation; some materials showed initial net mineralisation before an extended period of immobilisation lasting for at least 16 weeks of incubation (see below).

Modelling N mineralisation from hypothetical sources

Simulation of mineralisation for sources with different C:N ratios using the released version of APSIM SoilN is shown in Figure 2. The results are in general agreement with experimental studies for plant materials where net N mineralisation 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 mineralisation occurs from the outset. However, with C:N > 20, there is initially immobilisation of mineral-N and it is only as newly formed soil organic matter is re-mineralised that mineral-N in the system begins to increase.

Effects of changing the composition of the input by modifying the C:N ratios of the different FPOOLs are shown in Figures 3 and 4. In Figure 3, 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 immobilisation demand, and the higher the C:N ratio of FPOOL1 the greater the initial immobilisation. If, however, the C:N of FPOOL1 is higher, there must be compensating falls 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

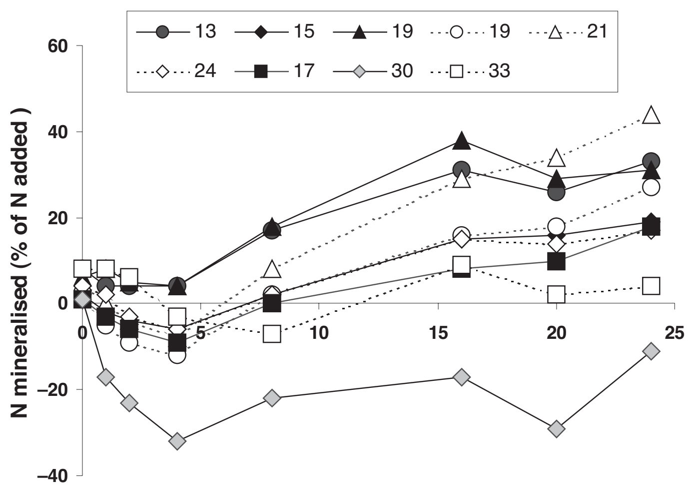

Figure 1. Net nitrogen mineralised from different manures in an incubation study lasting 24 weeks. C:N ratios of the manures are shown in the legend. Source: S.K. Kimani et al., unpublished data.

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

In Figure 4 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, with the C:N of FPOOL1 fixed at 10. With the low C:N in the rapidly decomposing pool, there can be an initial net mineralisation, especially when the C:N of FPOOL2 is also relatively low. However, as FPOOL1 is depleted, there can be a switch from net mineralisation to net immobilisation. Increasing the C:N of FPOOL2 results in increasing immobilisation and immobilisation persists for longer.

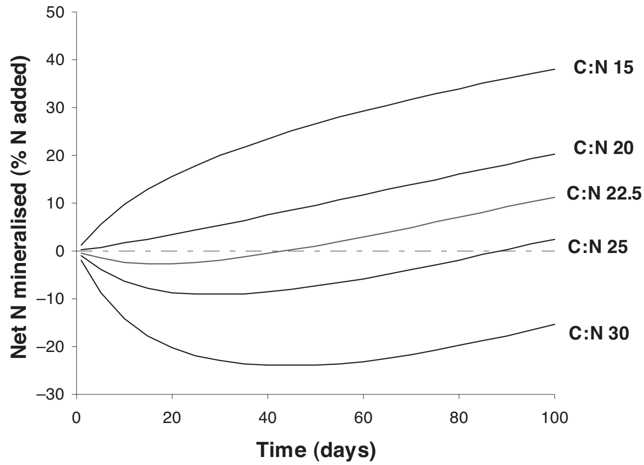

Figure 2. Simulation of nitrogen mineralisation from organic inputs with different C:N ratios using the released version of APSIM SoilN. The model assumes that all inputs have the same fractional composition in terms of the three FPOOLs (0.2:0.7:0.1), and that, for a given source, all FPOOLs have the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

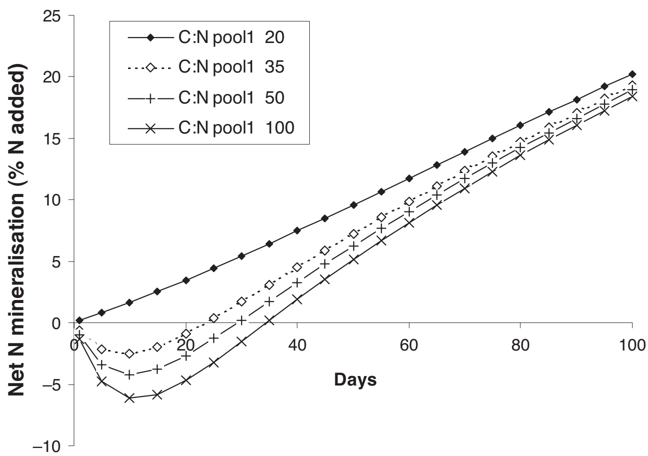

Figure 3. Effect of changing the composition of organic inputs by modifying the C:N ratios of the FPOOLs. In this example, the inputs have fractional composition of 0.2:0.7:0.1, overall C:N ratio of 20, and C:N ratio of FPOOL1 as shown in the legend (with C:N ratios of FPOOLs 2 and 3 being equal).

Modelling the mineralisation study of Delve et al. (2001)

The modelled net mineralisation from hypothetical sources display patterns of N release that are similar to experimental data. Notably, the several weeks delay before mineralisation became positive, as exhibited by several of the manures studied by Kimani and co-workers (Figure 1), is consistent with variation in the C:N ratio of FPOOL1 (Figure 3). On the other hand, the longer delay reported by Delve et al. (2001) is more like the pattern shown in Figure 4 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 assume that acid detergent lignin (ADL; Van Soest et al. 1987), 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 was carried out for each source with different combinations of C:N in the two pools (constrained by the C:N of the total DM). This enabled selection of the C:N giving an acceptable fit to the observed data (see Figure 5).

The net N mineralisation for the feeds and a selection of the manure samples studied by Delve et al. (2001) is shown in Figure 6. 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 1.

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

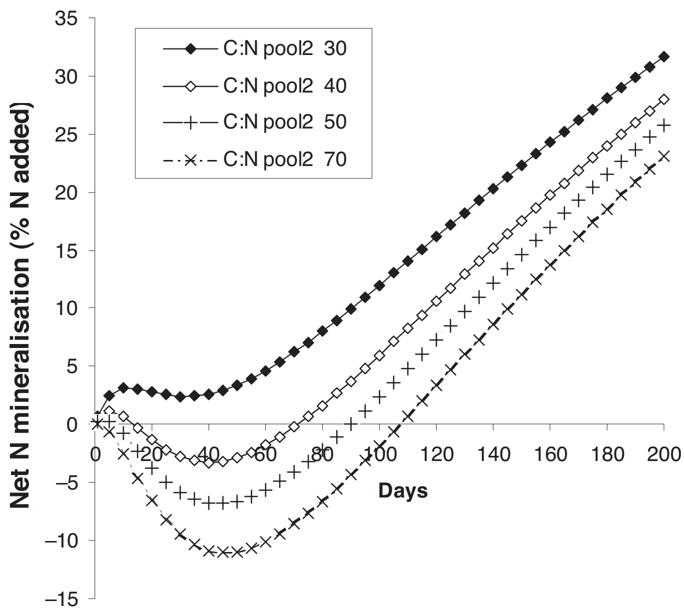

Figure 4. Effect of changing the quality of organic inputs by varying the C:N ratios of the FPOOLs. In this example, the inputs have fractional composition of 0.1:0.7:0.2, overall C:N ratio of 20 and C:N ratio of FPOOL1 of 10, with C:N of FPOOL2 as shown in the legend.

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 manure samples than for the feeds, with the poorest fit for the poultry waste. The pattern of net mineralisation 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 immobilisation to mineralisation that occurred after about 50 days was not maintained, and further net immobilisation occurred later in the incubation. Delve et al. (2001) could not explain the behaviour of this material.

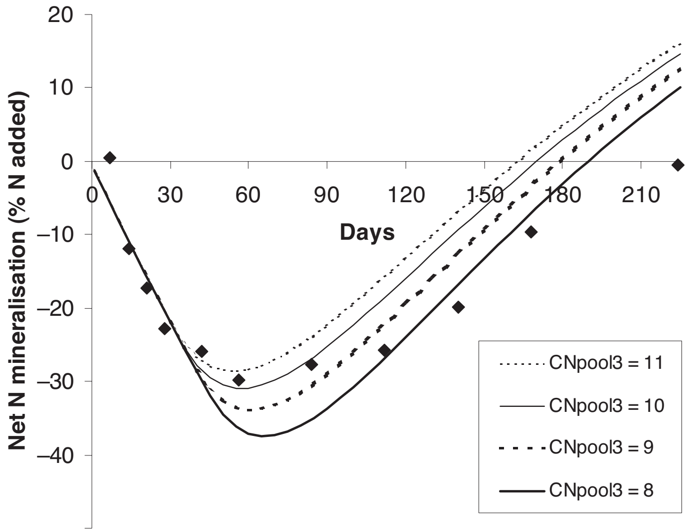

Figure 5. Illustration of how appropriate values for the C:N ratios of FPOOL2 and 3 were selected. In this example, the observed data for manure derived from the straw diet are compared with model output with different C:N ratios. Choice of a "best" value is a compromise between the maximum immobilisation and the longer-term mineralisation.

Table 1. Composition of organic materials (feeds and faecal samples) used for simulating the mineralisation study of Delve et al. (2001). 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 mineralisation and measured data.

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[a]	86	6	84.5	9.5	24	103	103
Calliandra – manure (30%)[b]	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

[a] Simulated N mineralisation was not sensitive to partitioning of N between pools 2 and 3.
[b] Value in parentheses denotes proportion of supplement in diet.

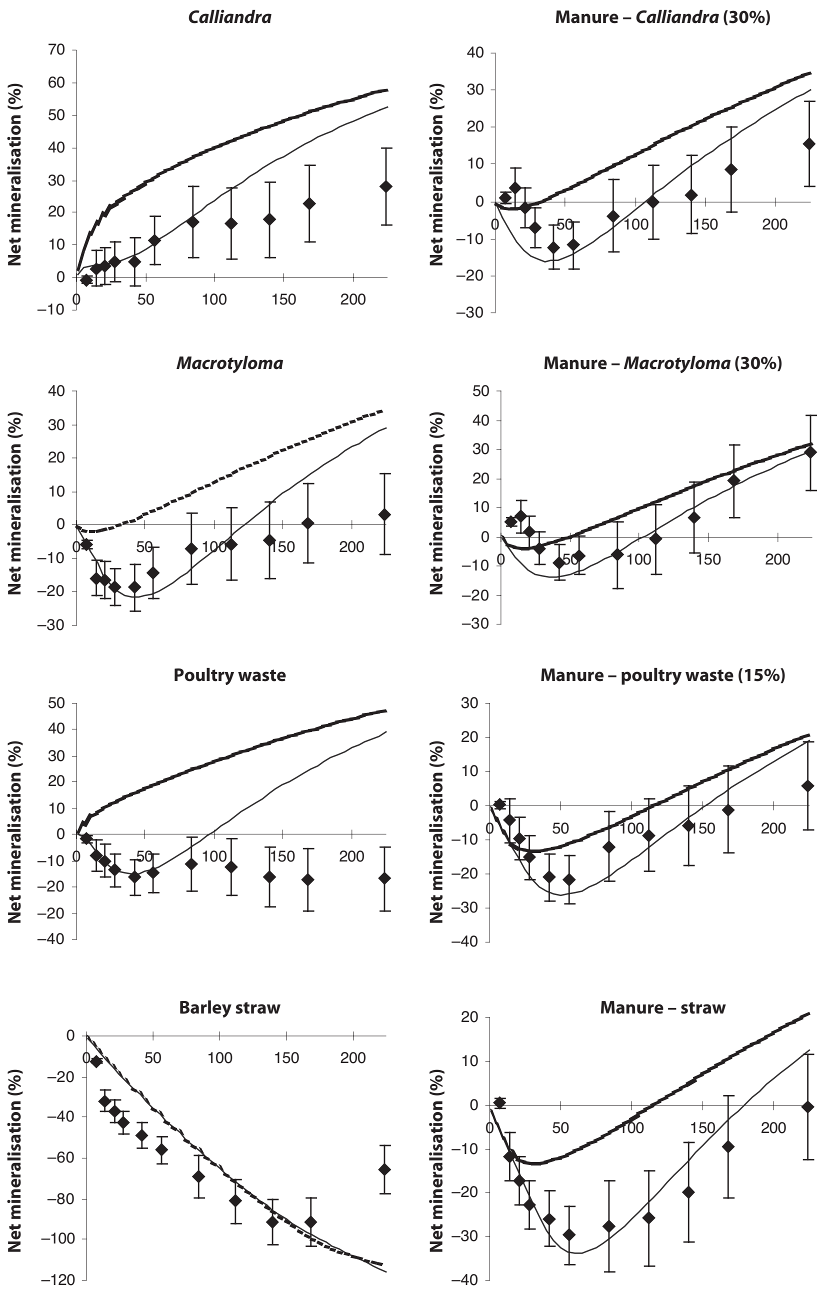

Figure 6. Net nitrogen mineralisation from feeds and faecal materials (data of Delve et al. 2001). Experimental data shown as symbols with bars representing ± standard errors. The heavy broken line is for the model where all organic material is assumed to decompose with the same C:N ratio; the continuous 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 1.

The simulation for the barley straw (C:N 86) predicts that immobilisation continues for at least 200 days. Because all mineral N initially present in the soil becomes immobilised in this treatment, the simulated immobilisation is determined by the rate of mineralisation of the control treatment and is not sensitive to how N is partitioned between FPOOLs 2 and 3 in the decomposing substrate.

Discussion

Models are capable of capturing the gross effect of C:N ratio on mineralisation/ immobilisation from plant residues (as illustrated in Figure 2). However, they are not able to represent the more complex pattern of mineralisation/immobilisation that has been reported from laboratory incubation studies of N release from manures with low C:N (e.g. Figure 1). 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 mineralisation data of Delve et al. (2001) (shown in Figure 6) and chemical composition of their materials (Table 1) indicate that the measured water-soluble component had a smaller C:N than the bulk materials. To simulate the observed mineralisation data it was necessary to assume that the materials had higher C:N in FPOOL2 than in FPOOL3.

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 characterise the quality factors that determine N mineralisation from plant residues might also be applicable to manures, or that models which simulate N mineralisation 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 mineralisation that is observed for various organic sources. 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 Figure 6 for the manures required C:N in FPOOL2 in the range 36–66, with corresponding C:N in FPOOL3 of 9–11 (Table 1).

For the feed materials (*Calliandra*, *Macrotyloma*, poultry waste), the predictions were not as good as those for the manure samples. To obtain a reasonable fit in the early stages of the mineralisation, 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.

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