SOM Pools: Fact or fiction, functional or fanciful

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Abstract

There are many models of the dynamics of soil organic matter (SOM) and almost as many ways of conceptualising its composition. But concepts need to be parameterised and model behaviour needs to reproduce reality. Modern methods attempting to measure SOM composition are showing great promise for parameterising these models but one simple approach is often overlooked, using what we already know. For example, the behaviour of SOM under different agricultural systems, for different soil types, or in different regions is often well understood and for a model to be credible, it must reproduce this behaviour. Whilst this is generally accepted, modellers are not always aware of the value of this data for building their model, rather than just for testing their model. It is possible to deduce, *a priori*, the apparent SOM composition from observed changes in measured total C and C:N ratio. Form follows function, or in this case, SOM composition can be deduced from soil behaviour. This is demonstrated using simple deductions applied to a long term dataset to predict changes in SOM and crop productivity.

Key Words

APSIM, simulation, soil organic matter

Introduction

Interest in modelling of soil organic matter (SOM) has been increasing with awareness of its importance for soil health, plant nutrition and the global carbon balance. Many models of SOM processes have been developed and show great promise for describing observed dynamics in natural, forestry and agricultural systems. To describe the nature of the SOM, model developers usually describe the bulk SOM as consisting of a collection of pools, each of which reflects a collection of organic components which behave in a certain manner. Each of these pools often varies from the other pools in terms of its rate of turnover, size and N content. One of the most important decisions of any modeller is how to distribute C and N across these various pools. There is increasing interest in methods to provide direct measures of modelled pools (e.g. Skjemstad *et al.* 2004) and these are showing promise in easing the task of modellers. There is however other information available to model users that should be taken into account. This information revolves around soil function. The behaviour of SOM under different agricultural systems, for different soil types, or in different regions is often well understood. For any model to be credible, it must reproduce this observed behaviour. This is generally accepted. However, modellers are not always aware of the additional value of this data for building their model. This short paper will demonstrate a simple case where the known behaviour of a soil was used to deduce the required parameterisation of a model, *a priori*.

Methods

The model used in this example was the Agricultural Production Systems Simulator (APSIM) (Keating *et al.* 2003). APSIM's component-based design allows individual models to interact via a common communications protocol on a daily time step. Models are available for many major crop, pasture and tree species as well as the main soil processes affecting agricultural systems (e.g. water, C, N and P dynamics, and erosion) (Probert *et al.* 1998). APSIM also provides a flexible agricultural management capability enabling the user to specify complex crop rotations and land management regimes. APSIM Version 7 was used.

Testing of the APSIM modelling capability was undertaken using the detailed data from the cropped catchment within the Brigalow Catchment Study (BCS) (Cowie *et al.* 2007) near Theodore, Queensland, Australia (24.81° S, 149.80° E). This study had been established to investigate the change in catchment water balance and decline in soil fertility after clearing of native Brigalow (*Acacia harpophylla*) forest. Brigalow is a leguminous tree, and soils within these forests contain large amounts of C and N. The data set includes crop production and organic matter decline, runoff and deep drainage and chloride leaching (Radford *et al.* 2007, Thornton *et al.* 2007). The BCS includes data for three soil types occurring within three catchments with contrasting land use (uncleared, pasture, cropping). To simplify this analysis, only the most common soil type (upper clay)(see Cowie *et al*. (2007)) within the cropping catchment has been used. The cropping catchment was cleared in 1982 with the first crop being planted during the summer of 1984. Crops during the period to March 2005 were wheat (*Triticum aestivum*) and sorghum (*Sorghum bicolor*) and no fertiliser was applied.

Configuration of the model was undertaken using a wide range of available information. Agronomic records of sowing dates, cultivar selection, plant populations, tillage and weed spraying were used to reproduce the historical management. Long term soil moisture measurements were used to infer soil hydrological parameters. Long term air temperature and solar radiation data for the Brigalow Research Station (Australian Meteorological Bureau Station Number 035149) was combined with rainfall from the catchment monitoring station.

The APSIM-SoilN model includes pools to account for fresh organic matter, microbial biomass, humic and inert C within the soil (Probert *et al*. 1998). All default parameters (Probert *et al*. 1998) describing the rates and efficiencies of C flows between pools were retained as these had been previously tested on relevant datasets within the study region. Parameterisation of these soil organic matter pools followed a multi-step process making use of data from a variety of sources. Long term soil C data are available for the BCS (Radford *et al*. 2007) to a depth of 0.3 m (0-0.1, 0.1-0.2, 0.2-0.3 m). This is the depth to which most roots are found in Brigalow forests and to where the majority of C is lost after clearing. Total soil C was partitioned into pools so as to reproduce the two main emergent behaviours of the soil C and N during the BCS: (1) a rapid (~9 years) early phase of C decomposition after clearing of the forest followed by a longer slower decline, and (2) a steady increase in soil C:N ratio over time. The soil C lost during the rapid phase of decomposition would, by definition, need to be assigned to the faster soil pools. It is assumed that this C would be mostly in the form of fresh organic matter in natural systems. The increase in soil C:N ratio is likely to be the result of changes in soil C composition from a system dominated by low C:N ratio labile soil pools, to a state consisting mostly of more resistant or inert pools with higher C:N ratios. The process therefore was as follows:

We assumed that the majority of soil C during the period of slow C decline resides within the inert and humic pools. Crop residues decompose rapidly in these systems and microbial biomass constitutes a small fraction of the total C. If we further assume, that the inert C can be represented by measurements of charcoal C (Skjemstad *et al*. 2004) and that the N content of this pool is low, we can estimate the size and C:N ratio of the humic pool during this later period of decline as the bulk of the N would be contained in the humic pool. Charcoal C was partitioned between the surface layers such that the resultant C:N of the humic pool in each layer was similar. This resulted in an average C:N for the humic pool of 12.8 and this was subsequently applied across the entire soil profile.

The C:N of the humic pool remains constant within the APSIM model as does the amount of inert C. This being the case, the partitioning of the initial soil C can be performed on the basis of the relative value of the bulk soil C:N and the C:N for the humic and fresh organic matter pools. Or put another way, the partitioning of C into various pools of differing N content must reproduce the measured C:N of the soil as a whole. Prior to clearing, large amounts of fresh organic matter would have been present in surface soil within the native plant community. We set the C:N of fresh organic matter to a value of 8 based on the ratio of losses of C and N from the profile and have assumed that much of this material will be lignin from partially decomposed organic matter in a native plant community at a climax state. The C:N of the humic pool is taken from step i above. The parameterisation derived from this logic is shown in Table 1. This configuration should provide a linked decline in soil C and N, and thus the observed change in bulk soil C:N over time as the faster, low C:N pools decline. The final data required for model initialisation concerns the input of C and N to the soil surface after clearing of the native vegetation. Bulldozers were used to fell trees and these were left on the ground for many months before burning, raking of unburnt coarse woody debris, and cultivation (Cowie *et al*. 2007). Surface litter and felled foliage, bark and twigs from standing trees would have been susceptible to decomposition in the period before burning. Coarse woody debris would not have decomposed significantly in the period before it was burned and removed. Measurements of total C and N content of surface litter and standing vegetation have been made for brigalow forests (Moore *et al*. 1967; Dowling *et al*. 1986). From this data we estimate that approximately 40 t ha-1 of biomass with a C:N ratio of approximately 30 would have been on the soil surface subsequent to clearing.

Results

APSIM was able to adequately describe the major processes and resultant changes in soil C and N content within the surface (0-0.3 m) soil layers. The observed and predicted time courses of crop productivity and soil fertility are demonstrated in Figure 1. Clearing of native vegetation resulted in a rapid decline in soil C and N in the surface 10 cm and these trends are captured by the model (Figure 1a,b). The model was also able to predict the levels of C and N within the soil once the rapid losses of labile material had been completed and the input and decomposition of soil organic matter approached a new equilibrium. Predictions of general productivity are similar to observation though the yields in some seasons showed large discrepancies (Figure 1c). Some of these can be attributed to the impacts of weeds, pests and diseases which are not represented within the model. It is therefore not unexpected that the model would significantly over-predict measurement in some seasons. The impact of declining fertility upon productivity has previously been illustrated using the observed time trends in protein content of wheat grain (Radford *et al.* 2007). A very similar trend can be observed in the measured and predicted wheat grain protein contents (Figure 1d). This gives confidence that impact of declining fertility upon crop growth is being captured by the dynamic model. In general, the emergent behaviour of the soil in terms of C rundown, N mineralisation and subsequent crop productivity has been reproduced by the model.

Conclusion

This paper highlights the issue of parameterisation of SOM models. Whereas others have explored the use of targeted laboratory techniques to parameterise individual soil C pools (Skjemstad *et al.* 2004; Roxburgh *et al.* 2006), we have demonstrated that simple logic applied to emergent soil behaviour can be used in a similar way. Form follows function, or in this case, SOM composition can be deduced from soil behaviour. The choice between these two approaches to parameterising soil C pools is similar to that available in soil hydrology, where soil hydraulic properties can be obtained from laboratory or functional measures. Both approaches are valid (Williams *et al.* 1991). The differing rates of decay of C and N, the resultant changes in soil C:N ratio, and the decline in crop productivity are all well understood for these systems and so model parameterisation should take all these factors into account in a simple yet meaningful way. For example, failure to account for the changes in N mineralisation with changing soil C composition will impact upon predictions of crop production, which is the source of C input into the soil. Modelling of soil C and N should combine attempts to measure soil C composition with considerations of soil function and the method employed above provides a framework for such considerations.

Table 1. Initial C and N pools (kg ha^{-1}) for layers in the surface 0.3 m.

	Depth			
	0-0.1 m	0.1-0.2 m	0.2-0.3 m	Total
<u>Carbon (kg ha^{-1})</u>				
Inert	7590	2460	2600	12650
Humic	17348	10933	9556	37837
Microbial	867	546	477	1890
FOM	11600	94	92	11786
Total	37405	14033	12725	64163
<u>Nitrogen (kg ha^{-1})</u>				
Humic	1355	854	746	2955
Microbial	108	68	59	235
FOM	1450	2	2	1454
Total	2913	924	807	4644

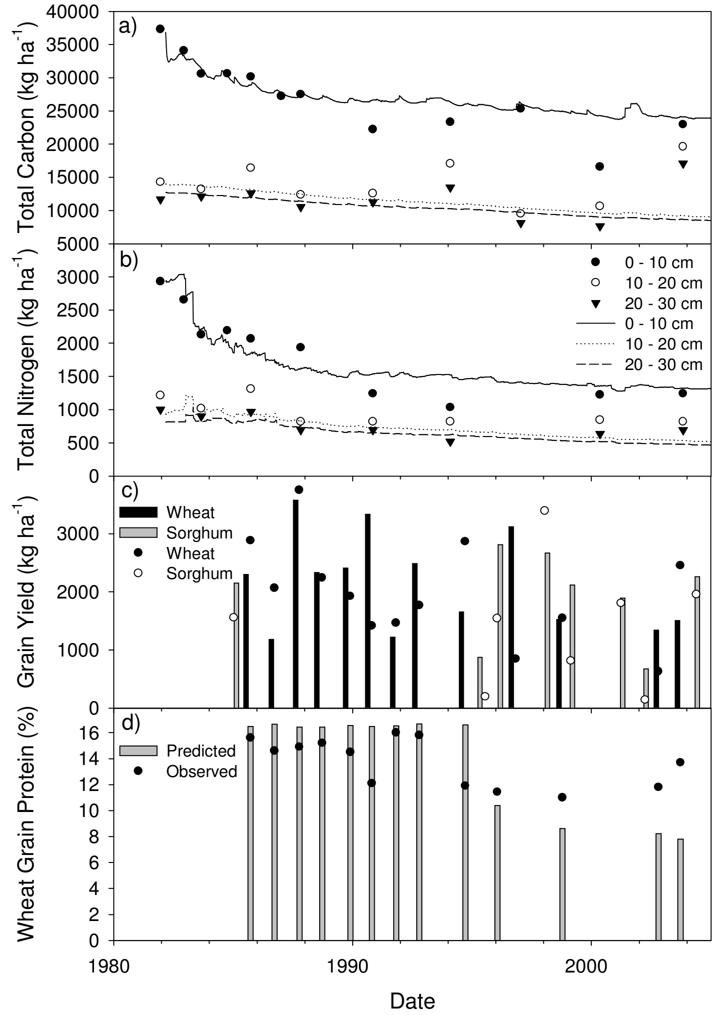

Figure 1. Observed and predicted time courses of a) soil carbon and b) total soil nitrogen (observed as symbols and predicted as lines, see legend) as well as c) grain yield and d) wheat grain protein content (observed as symbols, predicted as bars).

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