Pools, building blocks and cost - three parts of the soil carbon story

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Key messages

- Stable soil organic matter (humus) contains C, N, P and S in predictable and constant proportions.
- The supply of N, P or S (and not just C input) can limit the formation of humus.
- Carbon sequestration and greenhouse gas emission from soil can be affected by limited nutrients.
- Zero or minimum tillage primarily leads to a build-up of undecomposed plant material (not humus) near the soil surface which can easily be decomposed (with an accompanying loss of carbon from the system) if the soil is cultivated.

Background

A project involving field trials and laboratory experiments is currently underway to investigate the effect nitrogen, phosphorus and sulphur availability may have on the formation of the stable portion of soil organic matter, commonly referred to as humus. The field trials are being conducted at 'Oxton Park' Harden and on a property just outside Dunkeld, near Hamilton, Victoria. The laboratory experiments are using soils from the field sites as well as from an irrigated rice/wheat property near Leeton, NSW and from a rain-fed cereal cropping area near Buntine, W.A. The project has essentially two major parts (1) incorporation of fresh stubble with and without extra nutrients both in the field and using laboratory incubations and evaluation of the amount of humus formed and (2) evaluation of a range of soils to test the hypothesis that humus has constant proportions carbon, nitrogen, phosphorus and sulphur (C:N:P:S). Meaningful results on the first part of the project are not expected until 2010 and this paper deals primarily with the second objective and discusses some possible implications.

To get a wider variety of soils for evaluating the carbon:nitrogen:phosphorus:sulphur ratio (C:N:P:S ratio) farmers in the region from where the laboratory soils were collected were invited to submit soils for evaluation with no restriction on the type of soil to be submitted. A wide selection of soils was submitted including cropped, pasture and virgin soils. The cropped soils were generally regularly fertilised while the pastures soils ranged from irregularly to rarely fertilised. Fifty five soils were submitted making fifty nine soils in total.

Definitions

Unfortunately there are no universally accepted definitions for two terms that it are vital to understand when considering how the organic component of the soil reacts to different management regimes. I am going to use the definitions generally recognised by the Soil Society of America as given below.

Soil organic matter (SOM): The organic fraction of the soil exclusive of undecayed plant and animal residues, equivalent to **humus,** and considered to be very stable, even following cultivation.

Light fraction (LF): Undecomposed or partially decomposed plant decomposition that contains greater than 1/6 recognisable fibres (after rubbing) of undecomposed plant remains. Bulk density is usually very low. It is not considered part of the SOM but is obviously a component of the soil.

The Pools

To investigate the hypothesis that SOM may have constant proportions of C:N:P:S it is important to recognise that soils can contain significant amounts of LF material which can either be included with the largely mineral soil when it is analysed or analysed separately. The plant residues are referred to as the light fraction, because they float if a soil sample is shaken in a container of water, while humus is often referred to as the heavy fraction, because it is largely associated with the mineral components of the soil and sinks.

Three soils with different management histories from the Harden area provide a good example of how much of this LF material can be in some soils and how including or removing it can affect analysis results.

	C	N	P	S	C:N	C:P	C:S
'complete' soils with light fraction included							
Virgin soil, never farmed, never fertilised (> 100t light fraction ha^{-1})	3.503	0.232	0.024	0.022	15.1	148	160
Long term pasture (> 100t light fraction ha^{-1})	3.959	0.351	0.037	0.031	11.3	106	128
Long term cropping (< 10t light fraction ha^{-1})	2.123	0.180	0.034	0.017	11.8	62	121
''cleaned' soils with light fraction removed							
Virgin soil, never farmed, never fertilised (> 100t light fraction ha^{-1})	2.061	0.165	0.021	0.015	12.5	99	139
Long term pasture (> 100t light fraction ha^{-1})	2.765	0.256	0.035	0.022	10.8	80	123
Long term cropping (< 10t light fraction ha^{-1})	1.978	0.169	0.033	0.015	11.7	61	130

Table 1. Analysis of three Harden soils with light fraction included or light fraction removed

The virgin and pasture soils contained more than 100 t/ha of LF material in the top 10 cm while the long term cropped soil contained less than 10 t/ha. This LF material is normally left in soil when it is analysed for soil C but removing it can significantly alter one's view of how healthy a soil might be. The soil C levels of the virgin and pasture soils dropped significantly by removing the LF material before analysis while the long term cropped soil hardly changed, with the virgin and cropped soils now having similar soil C values. Some researchers believe it is the loss of this LF material that is largely responsible for the reduction in soil C levels that are often encountered when virgin soils are put into cropping perhaps challenging the view that cropping always leads to a loss of what some may see as "true" soil C or humus. Additionally, evidence suggests that the increase in soil C levels usually seen in soils after a pasture phase or subjected to minimum till is essentially due to a build-up of this LF material (which can be easily lost if cultivation commences) and not due to a build-up of humus.

The Building Blocks

It has been suggested that humus has constant proportions of C:N:P:S with a ratio of 10,000:833:200:143 being found in the literature. The 59 Australian soils were cleaned, light fraction removed, and analysed for total C, N, organic P and S. There was a strong relationship between C, N, S and organic P in the soils (Figure 1). The data suggests that 10,000 units of humus C requires 844 units N and 141 units S, which is very similar to the amounts indicated by the C:N:P:S ratio found in the literature, however the data also suggests that 10,000 units of humus C only requires 53 units P while the ratio suggest 200

units P. It is known there are issues relating to the analysis of soil P and allocating which pool it belongs to but it is clear more research is needed on these issues to accurately determine the amount of P required to form humus.

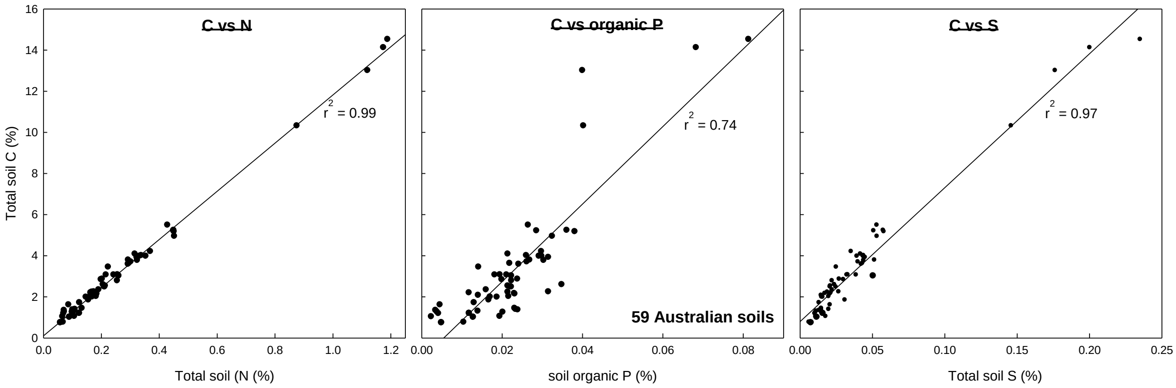

Figure 1. C:N, C:organic P, C:S for 59 Australian soils

The cost

One tonne (1000kg) of C (as humus) is associated with 80kg N, 20kg P and 14kg S. These nutrients must remain if the C is to be retained. So the question arises as to what “potential” costs are involved. The simplest approach is to assume that their value is similar to the cost of replacing them with fertiliser, as illustrated in Table 2.

Carbon trading is normally based on a tonne of CO_2 equivalent. The trading prices for CO_2 in existing markets around the world range from $5-10 per tonne (Chicago Climate Exchange) to $40 (EU/Kyoto compliance protocols). Based on these trading prices for CO_2 a tonne of C in humus (equivalent to 3.7 t CO_2) would currently be worth $20-$150. This is considerably less than the estimated value of nutrients locked up, as shown in Table 2 below.

Nutrient	Amount (kg)	Approx price/kg nutrient ($)	Approximate cost ($)
N	80	1.50	120
P	20	5.00	100
S	14	2.00	28
			$248

Calculated at 2009 fertiliser costs

Table 2 Estimates of the value of N, P, & S locked up with each tonne of C in humus

I must make it clear however that I am not saying that all these nutrients must come from a fertiliser bag. Other associated research has shown that there can be a significant increase in nitrogen fixing soil bacteria when crop residues are retained and so the system “can bring in some of this extra nitrogen itself”. Also, in some parts of the world, significant quantities of S come down in rainfall. This S is normally very labile and easily leaches through the soil. It has been suggested that if the soils contain significant quantities of decomposing crop residues the microbes will use some of this “free” S to aid in the decomposition process leading to enhanced humus formation. The amount of N fixed or S captured from rainfall will no doubt vary in different areas and more research is needed to accurately estimate a true cost associated with building soil C. However whether these nutrients are applied by man or are “brought in by the system” the evidence strongly suggests they must be there if the C is to build-up and be retained.

Some Possible Implications

Soils should be fractionated into light and heavy fractions before analysis to determine which pool contains what amounts of C and to determine if management practices affect both pools equally.

If soil carbon trading becomes a reality then knowing which pool one's carbon is in and how it might react to different soil management regimes may be an issue of prime importance.

Humus, generally considered to be a very stable form of soil C, always contains C, N, P and S and in precise proportions. A limited supply of N, P or S (and not just limited C inputs) could limit the formation of humus.

A limited supply of N, P or S could reduce the decomposition of plant residues leading to a build-up of light fraction material, and could increase the proportion of greenhouse gases emitted when residues eventually decompose.

Pasture phases and zero or minimum tillage primarily lead to a build-up of undecomposed plant material (not humus) which can easily be decomposed (with an accompanying loss of carbon from the system) if the soil is cultivated.

More research is needed to establish a "true cost" of building soil C in order to establish if "trading soil C" might be a profitable venture.

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