Soil organic matter and structure in vertosols – using pastures to make a difference

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Abstract. Soil organic matter (SOM) drives vital soil chemical, physical and biological processes and is an important indicator of soil health and agricultural sustainability. Traditional cropping practices have caused a widespread decline in SOM concentrations in Australian soils. The adoption of no-till and stubble retention practices in cropping systems can help to reduce the decline but one of the most effective ways of improving SOM is the use of pasture phases or leys in a crop production system.

Introduction

Soil organic matter (SOM) has been widely accepted as an important indicator of soil health and sustainability in agricultural systems. Soil organic matter is a complex group of compounds and materials that play an important role in all aspects of soil fertility – chemical, physical and biological. SOM is an important source of nutrients for plants, has a very high cation exchange capacity, maintains soil aggregation, and is the food source for soil microbial populations. SOM is also seen as a potentially important global "sink" for atmospheric CO_2.

Most Australian soils are inherently low in SOM, between 0.5 and 4%. This is due to the dry environment which limits plant production and warm temperatures that promote rapid residue breakdown when moisture is available. Management practices have changed the cycling of plant residues by influencing the amount and quality of plant residues that are returned to the soil. The change from natural systems to cropping systems has also led to substantial losses of SOM-rich topsoils through erosion. These changes have caused a significant loss in SOM from many soils in a range of production systems. SOM fractions that are the most sensitive to changes in management are the most important in maintaining soil chemical and physical fertility.

Crop production on Australian soils has resulted in a rapid decline in organic fertility due to the need for mineralisation of SOM to provide essential crop nutrients, especially nitrogen (N), but also phosphorus (P) and sulfur (S). Declines in the total and active, or labile, fractions of SOM pool have been measured across a variety of soils and under a range of different crop management practices. This rapid loss in SOM has resulted in declines in physical, chemical and biological soil fertility (Dalal and Mayer 1986; Whitbread *et al.* 1998; Blair and Crocker 2000). Losses of the active fractions of SOM are easier to measure and have a greater influence on soil processes than losses of the total SOM (Fig. 1). The importance of SOM in determining soil fertility has meant that it has become a key indicator of sustainable agricultural systems.

The concentration of SOM that is found in soils is determined by the rate of inputs of organic materials,

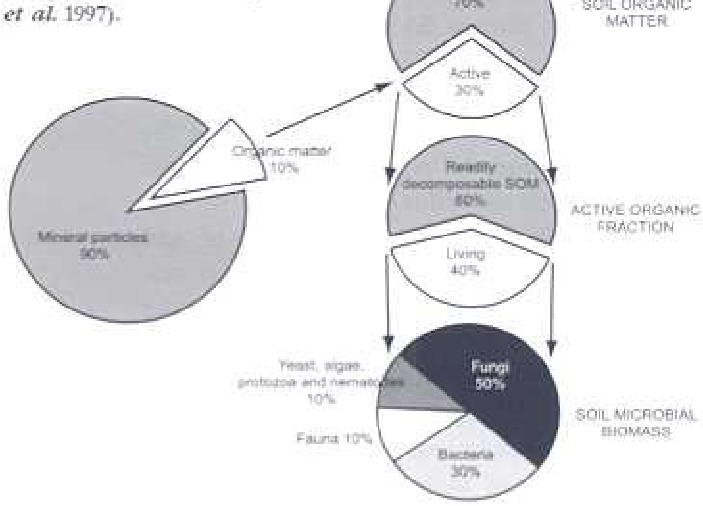

Figure 1. The composition of SOM (adapted from Gregorich *et al.* 1997).

primarily plant residues, and the rate at which these materials decompose. Decomposition rate is determined by several factors, most importantly temperature, and moisture, and also the quality of the residues themselves.

Loss of SOM results in a decline in the chemical fertility of soils as well as soil structure. This increases the risk of erosion, compaction, and consequently creates problems for plant establishment and growth. Management strategies to improve SOM include reduced or no-till cropping practices, residue retention, increased crop production through fertilisation, green manure crops or pasture leys/ phases, and the use of organic amendments, such as manures.

What are we doing to our soils under current management?

By converting native grasslands to agricultural production the cycling of SOM has been changed significantly. One of the most important changes is a reduction in the quantity and frequency of return of organic material to the soil. SOM levels are also determined by the rate of residue breakdown which is influenced by the quality of the material such as the carbon:nitrogen (C:N) ratio and the proportion of components that are resistant to breakdown, such as lignins and hemicellulose (Reicosky 1994). Another factor is the change in soil moisture regimes; under cropping systems, the soil often remains wet for long periods of time in the fallows between crops.

Cultivation effects SOM in several ways. Firstly, there is a dilution effect when organic matter (OM) rich topsoil is incorporated with deeper soil material that is lower in OM causing a dilution in the most fertile layers. This mixing of the SOM also exposes previously protected material to microbial breakdown causing a loss of SOM (Rasmussen and Collins 1991).

In 1981, NSW Agriculture commenced a long-term tillage study at the Liverpool Plains Field Station (LPFS) in northern NSW. This project investigated the use no-tillage (NT) farming in the northern grains area of NSW at various sites in the region. After 19 years of different tillage management strategies, changes in SOM were assessed in the various treatments and compared to an area of virgin grassland that was adjacent to the experimental site (Table 1). The active fraction of SOM was measured by oxidation of soil C with potassium permanganate (Blair *et al.* 1995). The changes in soil C fractions were compared with a nearby reference site that had not been cropped or heavily stocked to determine changes in SOM. This allowed the calculation of a carbon management index (CMI) in which the reference site had a CMI of 100, by definition. Water infiltration through various soil pore sizes and aggregate stability, or mean weight diameter, to wetting were determined to indicate the physical fertility. The ability of aggregates to maintain structure during wetting events means that rain is more likely to penetrate into the soil and contribute to plant growth. OM is one of the most important factors in maintaining aggregate structure.

A decline in all sustainability indicators with cropping was found in all of the tillage or crop rotation treatments. Both physical and chemical fertility parameters declined as a result of cropping with a small ameliorative effect of no tillage observed. Strong relationships were also found between SOM fractions and soil physical fertility measurements.

The results from a survey of commercial properties around the LPFS support those of the long term tillage study. Large declines in both labile and total C were observed between continuously-cropped soils and nearby native grass pastures. The declines in those sites with a predominant history of minimum or no-till management were not as great as those under conventional management and thus tended to have a higher CMI.

Table 1. Effect of cropping and fallowing on total soil C (mg C/g soil), and the labile C (mg C/g soil) fraction (0-5 cm), and the carbon management index (CMI) of a vertosol from LPFS

	Time of Sampling	Total C	Labile C	CMI
Apr- 98	Pre-sow	$11.64^{a\,A}$	2.13^{a}	77
	Reference	14.39	2.77	100
Dec- 98	Post-harvest	13.03^{b}	2.53^{b}	89
	Reference	15.73	3.06	100
Apr- 00	Post-fallow	10.92^{a}	2.12^{a}	64
	Reference	14.95	3.21	100

[A]Means followed by the same letter within columns are not significantly different according to DMRT $P<0.05$ (Reference sites were not included in the statistical analysis)

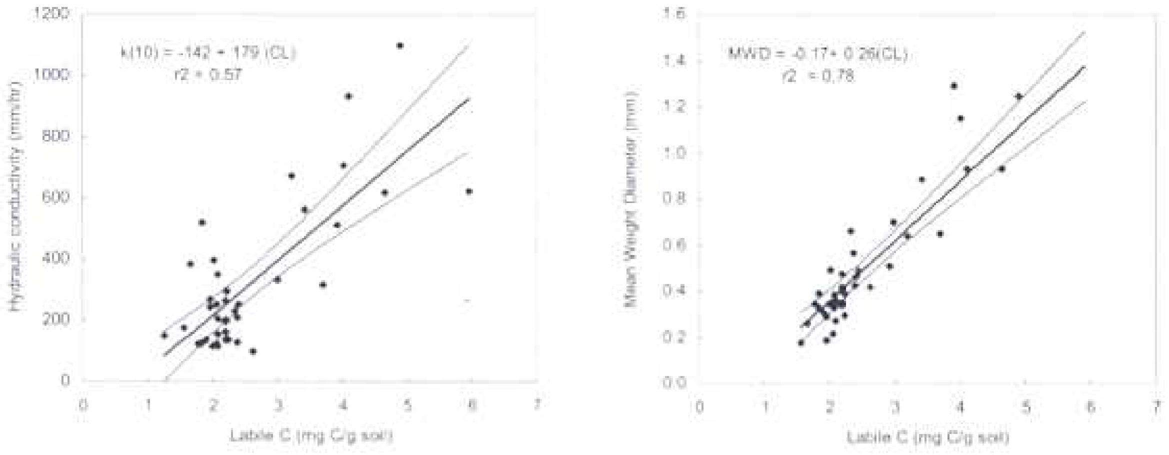

Figure 2. Relationship between water infiltration through macropores, soil structure and labile soil C fractions from a long term tillage trial and commercial paddocks from the Liverpool Plains.

Water infiltration through macropores, and aggregation were higher in the minimum and no till sites than those cultivated. This was especially evident on sites that had a large return of cereal crop residues due to flood damaged crops in the previous season. This large input in OM led to more macropores through increased water stable aggregation. The relationship between soil C fractions, especially labile C, and soil physical fertility measurements was significant (Fig. 2).

To maintain sustainable farming systems on the vertosol soils of the Liverpool Plains it is evident that no-till or minimum till farming systems combined with practices that maximise organic returns to the soil, such as pastures, are vital factors in maintaining soil fertility.

Using pastures to make a difference

The inclusion of pasture leys and the elimination of fallows have been shown in other studies to have a positive influence on SOM and sustainability. Grace *et al.* (1997) found that the inclusion of sown pastures is generally associated with an increase or at the minimum a slowing in the rate of decomposition of organic C. These increases were observed in many situations across Australia in which the cropping rotation included 2-4 years of pasture.

Pastures improve SOM by encouraging soil organisms through the constant supply of an energy source and reduced soil disturbance. The use of perennial grass-legume mixes increases the supply of OM through the improved supply of OM from the grass component and supply of N from the legumes. The use of legumes in the crop rotation is also preferred because of the benefits in grass weed control, lowering of disease levels and less potential for N immobilisation.

A survey of changes in soil properties in the Yallaroi area of northern NSW showed that well managed legume leys ameliorated the losses in soil C fractions and improved the CMI (Whitbread *et al.* 1998). Even in a soil that had only been brought into crop production 2 years previously there had been significant losses in soil C fractions, 43% labile C and 26% of total C.

Blair and Crocker (2000) showed that the use of no-till practices and the inclusion of pasture legumes improved physical fertility of a black earth (vertosol) and improved the CMI compared to long fallowing (Table 2). Chan *et al.* (1997) also showed that a vertosol with degraded levels of SOM could be ameliorated through the use of a pasture for 2 years. Soil organic C increased in this period and was also accompanied by increased available N, microbial biomass and soil structural stability. Hossain *et al.* (1996) found that the inclusion of a pasture which included a grass (purple pigeon grass and Rhodes grass) and a legume component (snail and barrel medic, and lucerne) was the only system that was able to increase the levels of organic C in a vertosol soil in southern Queensland. This system increased the total organic C by 2.7 t C/ha or 720 kg C/ha/yr during the pasture phase. This increase was attributed to additional contributions from the pasture phase root systems.

Table 2. Total and labile C (mg C/g soil) and the CMI determined by oxidation with 333 mM potassium permanganate for different crop rotations and a reference for a Black earth soil at Tamworth NSW (from Blair and Crocker 2000)

	Reference	Long Fallow	Continuous Wheat	Lucerne
Total C_T	35.50	14.53^{bA}	15.37^{ab}	16.00^{a}
Labile C_L	8.23	1.96^{c}	2.42^{bc}	2.60^{b}
CMI		21^{b}	27^{ab}	29^{a}

[A]Values in the same row followed by the same letter are not significantly different according to DMRT (P = 0.05).

Conclusions

Cropping practices have significantly reduced both active (labile) and total SOM in soils and this has lead to a decline in chemical and physical fertility. The use of no-till systems can slow the rate of losses in SOM, but continued declines are still likely. The use of pastures in the cropping system is one of the most effective means of increasing SOM and the sustainability of crop production. The increases in SOM associated with pastures are due to the larger returns of plant material, especially the below ground component, roots. The use of pastures in the cropping sequence also has other benefits in providing effective weed and disease breaks.

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