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Soil organic matter in cropping systems

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Dr Susan Orgill, Leader, Soil R&D South, Soil and Water R&D Unit, Wagga Wagga Agricultural Institute

Key points

- Farm productivity is linked to the soil functions that rely on decomposition of organic matter. There is agronomic value in building soil organic matter.
- Soil organic matter is typically ~58% carbon by weight; the other ~42% includes essential nutrients (N, P, S, K etc) in varying quantities.
- Carbon is what is usually measured in soil analysis. It is important to be aware of what is being reported, soil organic carbon (SOC) versus soil organic matter (SOM). SOM is typically estimated as SOC x 1.72.
- Carbon is cycling on your farm already. To build organic carbon in your soil, the supply of organic matter (through stubble, pasture phases, cover crops, composts etc) needs to be greater than the loss of organic matter through decomposition and erosion.
- Both plants and soil microbes need nutrients. Bacteria and fungi use nutrients to decompose organic matter, and it is the accumulation of microbial detritus in soil that builds humus. Without adequate nutrients (e.g. N, P, K and S) it is not possible to maintain or build humus.

What is soil organic matter (SOM)? How is this different to soil organic carbon (SOC)?

Soil organic matter (SOM) is the organic fraction of soil that is closely associated with the mineral component of the soil. It is made up of materials in varying states of decay. Soil organic matter includes:

- small pieces of plant material (< 2 mm in size!)* including roots, stems and leaves,
- partially decomposed organic matter,
- microbes, and
- charcoal or char (often called resistant SOC).

** By convention, SOC content is determined on the soil after passing it through a 2 mm sieve. This removes larger pieces of plant material such as large roots and pieces of stubble, leaves and stems. Including such large pieces of plant material in the determination of SOC results in highly variable and inconsistent results and is not a good indication of the SOC that can actively influence soil properties.*

> *Carbon is the measurable component of SOM, with SOM being approximately 58% carbon by weight. The remainder includes nutrients (N, P, K, S etc) and the mass of oxygen and hydrogen within the soil organic matter.*

There are different types of SOC and these can be described based on their form and vulnerability to decomposition. It is the 'active' or 'labile' pool, typically about 20-40% of SOC, that can be most easily influenced by management, time of year and climatic conditions. This pool is dynamic and turns over in days to months and years. The labile pool of SOC is made up of:

- soluble carbon (~2 to 5% of total SOC) that is largely in soil solution and easily extracted in water,
- microbial carbon (~5 to 10% of total SOC) that is the component in the living microbial biomass, and
- particulate organic carbon (POC; ~25% of SOC) which is largely derived from plant material and animal residues recently returned to soil.

The more stable fraction of SOC is often referred to as 'humus' and accounts for approximately 60 to 80 % of total SOC in most soils. Humus is largely composed of microbial detritus and is more resistant to degradation than labile carbon. Humus accumulates in soil and turns over in the order of years to decades and millennia. Another stable fraction of SOC is char (fine fragments of charcoal-like material) and in some Australian soils this fraction can account for up to 35% of the total SOC (but it is often much less).

Why is SOC important?

Soil organic carbon plays an important role in a wide range of soil physical, chemical and biological functions. Soil organic carbon is also an important store of carbon that can help reduce atmospheric CO_2 concentrations. Soil organic carbon contributes to:

- improving cation exchange capacity (CEC), especially in sandy soils and soils with low activity clays such as kaolins and kandites (Kandosols),
- buffering soil nutrient supply (N, P and S),
- improving buffering capacity against acidification,
- maintaining stable soil structure, especially in sandy and loamy soils leading to increased water infiltration/rainfall capture and increased aeration of soil,
- improving plant available water in many soils, and
- providing energy for the activity of soil organisms that drive other soil processes.

SOC in Australian cropping soils

Declining SOC reduces overall soil health and agricultural productivity as it affects numerous soil functions and processes. The decline in SOC from agricultural soil has been considerable in Australia, largely due to cultivation and continuous cropping in a dry climate on typically old and weathered soils. It is estimated that SOC has decreased by 51% in the surface 10 cm of Australian cropping soils (Luo et al. 2010). There are several reasons for this decline, including: i) reduced OM supply to soil, ii) increased rate of OM decomposition associated with tillage and altered soil aeration, moisture and temperature, iii) movement of SOC down the profile due to tillage and OM incorporation, iv) reduced capacity to protect OM in soil due to structural degradation and v) increased soil erosion by wind and water. Realistically, it is likely to be due to a combination of these factors, as well as the influence of soil type and climate on plant production and OM decomposition.

While our soils have incurred a decline in SOC, there is plenty of evidence that management practices such as crop rotations, nutrient application, pasture rotations (including legumes) and conservation cropping can slow or reverse this decline and can even increase SOC content. By increasing biomass production, replacing soil nutrients and reducing the loss (erosion) or degradation (soil respiration associated with cultivation) of SOM, SOC levels can be partially or fully restored.

There is considerable opportunity for land management practices that maximise plant production and minimise physical soil disturbance to increase SOC to pre-agriculture levels, or beyond!

How do I measure SOC?

For most soils in order to measure the total SOC it is recommended to use the dry combustion method (LECO®). If your soil contains carbonates, then it is more reliable to use the dry combustion method with sulphurous acid (H_2SO_3) pre-treatment or the Heanes method. If you don't know if your soil has carbonates (they are forms of inorganic carbon), and your soil pH_{Ca} is >8.0, then it is advised to assume it does, and use the aforementioned methods. The Walkley and Black method was traditionally used to measure SOC but has been demonstrated to measure only approximately 80% of the total SOC in many soils. Remember the number from the lab is only as good as your sampling (see Fertcare's 'A guide for fit for purpose soil sampling').

Strategies to build SOC in NSW cropping systems

The potential to increase SOC depends on soil type, climate, vegetation and land management. Increasing plant growth and production is a major factor; however, this is largely driven by the influence of agro-climatic zone on overall net primary productivity, as well as the expected decomposition rates.

Most carbon that contributes to SOM in both natural and agricultural systems is plant-derived carbon through photosynthesis. Plants contribute to SOM through:

- Above ground components: plant litter including leaves, flowers, stems, crop residues and stubble. An important mechanism is the transfer of this material into the soil through tillage, worm and other soil macrofauna activity and the movement of soluble SOC.
- Below ground components: exuding carbon rich substances ("exudates") through their roots into the rhizosphere and root growth.

Based on the annual carbon balance of a typical Australian wheat crop, approximately 40% of total annual carbon is allocated below ground in roots and root exudates. In grazing systems, carbon is also returned to the soil through animal excreta.

Soil microorganisms (bacteria, fungi and archaea) degrade fresh OM and this process enriches the nutrient content of SOM. That is, decomposition of fresh OM by microbes narrows the C:N:P:S ratios in SOM. This is particularly important where fresh

OM inputs have wide nutrient ratios (such as C-rich wheat stubble), as it means that the efficiency of conversion of wheat stubble to SOM by soil microbes is strongly mediated by the availability of nutrients such as N, P and S. Nitrogen drawdown occurs when there is insufficient N in the fresh OM and the soil microbes use soil N in the decomposition process. In some circumstances this can result in a deficiency of N for the following crop. This scenario is exacerbated where stubble loads are high (e.g. over 4 t/ha), and in these cases the addition of extra nutrients (through mineral or organic sources) may facilitate a greater quantity of stubble-derived carbon moving into the more stable forms of SOM.

In cropping systems, there are multiple strategies to reduce the loss of SOC or build SOC during the crop and pasture phases through plant and soil management. However, it is important to remember that increases in SOC may be subtle and slow, practices need to suit your business goals and be economically and environmentally sound. Strategies include:

- Changing the crop and pasture sequence (frequency and duration of pasture phase); including a pasture and/or legume phase or a green manure crop. (Often in rotations there can be a small decline on SOC during the cropping phase followed by a restoration of the SOC during the pasture phase);
- Introducing cover crops;
- Managing nutrient inputs to optimise plant growth and/or the decomposition of crop residues into more stable forms of SOC (humus);
- Applying lime to overcome acidic soil constraints;
- Applying gypsum to overcome sodicity, compaction or surface sealing;
- Minimising tillage, and in some cases considering strategic tillage (to overcome a soil constraint or plant disease);
- Retaining stubble;
- Identifying degraded soils (e.g. scalded or eroded areas) and changing practice or landuse; and
- Adding carbon-rich materials (e.g. composts, biosolids and manures) to the soil as amendments.

In particular, the strategies listed on the left:

- *Increase the amount of above- and below-ground fresh OM inputs to soil,*
- *Influence the location of fresh OM inputs in the soil profile, and*
- *Influence the rate of fresh OM conversion to more stable forms of SOM (such as humus)*

For more information:

Dr Susan Orgill E: Susan.Orgill@dpi.nsw.gov.au

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