Can we build-up carbon and can we sell it?

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Soil organic carbon: What is it?

Soil organic carbon is a complex and heterogeneous mixture of materials. These materials vary in their physical size, chemical composition, degree of interaction with soil minerals and extent of decomposition.

Although determining the impact of management practices on soil organic carbon contents is important, it does not tell us anything about the type of organic carbon present. For example, is the organic carbon dominated by pieces of plant residue or more recalcitrant charcoal? It is therefore important to determine the composition of soil organic carbon to gain an appreciation for the implications of management practices and changes in organic carbon content on soil productivity.

Consultants' Corner

Consultants' Corner is a new initiative by *Australian Grain*. This series of articles will highlight current GRDC-funded research with a particular focus on the commercial implications of adopting cutting-edge research.

We now recognise four different types of soil organic carbon:

- Crop residues – shoot and root residues less than two mm residing on and in the soil;
- Particulate organic carbon – individual pieces of plant debris that are smaller than two mm but larger than 0.053 mm;
- Humus – decomposed materials less than 0.053 mm that are dominated by molecules stuck to soil minerals; and,
- Recalcitrant organic carbon – dominated by pieces of charcoal.

Functions of organic carbon/ organic matter in soil

Organic carbon/organic matter contributes to a variety of functions in soils. These functions can be broadly classified into three types: Biological, chemical and physical (Figure 1). Strong interactions (represented by the grey arrows) often exist between these different functions. For example, the biological function of providing energy that drives microbial activity also results in improved structural stability and creates organic materials that can contribute to cation exchange and pH buffering.

What determines soil organic carbon content?

The amount of carbon in a soil results from the balance between inputs (plant residues) and losses (microbial decomposition and associated mineralisation).

In Figure 2 the bucket represents the amount of carbon a soil could potentially hold. This amount will vary with factors such as soil clay content, soil depth, and bulk density and is not influenced by management. The bucket will be smaller for a sand than a clay soil.

Inputs are controlled by the type and amount of plant residue added to the soil. Any practice that enhances productivity

FIGURE 1: Functions performed by organic matter present in cropping soils

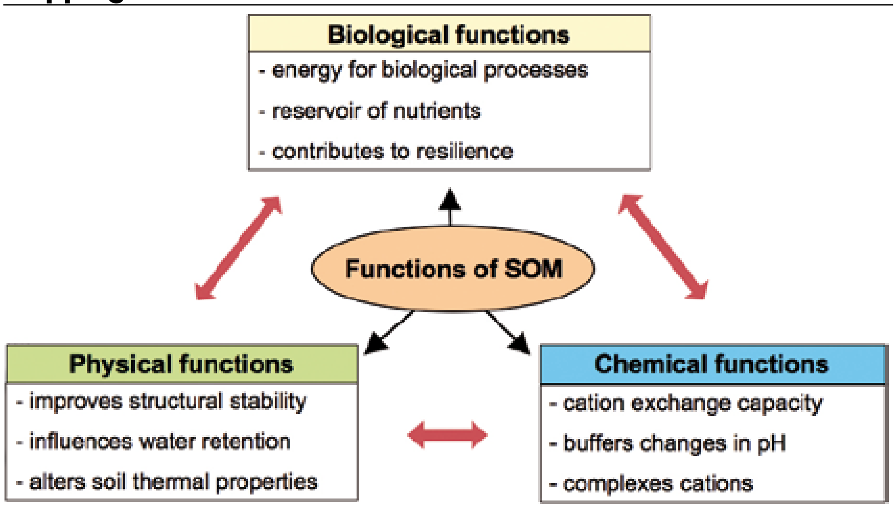
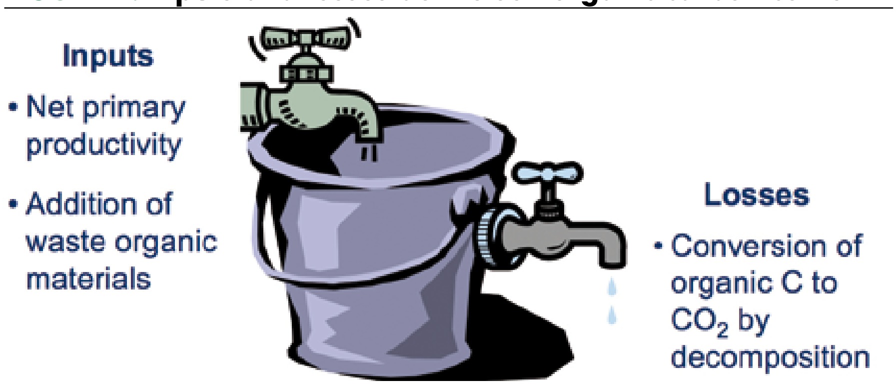


FIGURE 2: Inputs and losses define soil organic carbon content



Jeff Baldock.

and the return of plant residues (shoots and roots) to the soil opens the input tap.

For example, appropriate use of fertilisers to maximise productivity also maximise returns of organic residues to the soil. But an upper limit of input exists in Australian dryland agriculture because of the limitation that the availability of water places on potential plant productivity.

Losses of carbon from soil result from decomposition and conversion of carbon in plant residues and soil organic materials into carbon dioxide. Processes that accelerate decomposition open the losses tap further.

The content of organic carbon in a soil therefore results from the balance between carbon inputs and losses over many years.

How much organic matter can be retained in soil?

In Figure 3 the size of the bucket in Figure 2 is represented by the bar labelled 'Potential sequestration'. This gives the maximum organic carbon content that could be attained for a soil where no limitation on inputs exist – ($SOC_{potential}$). The potential amount of plant material that can be produced at any given location is limited by environmental conditions (limiting factors) that may be beyond the control of a farmer.

In Australian dryland agriculture, the availability of water provides such a limitation. Because this places an upper limit on plant production and thus inputs, it also restricts soil organic carbon to a level indicated by the bar labelled 'Attainable sequestration' – ($SOC_{attainable}$). The value of $SOC_{attainable}$ is the realistically best case scenario for any production system. To achieve $SOC_{attainable}$ no constraints to productivity can exist. But reductions in productivity due to a series of reducing factors (for example, low nutrient availability, weed growth, disease, subsoil constraints, and so on) can reduce the amount of plant residue returned to the soil to values lower than optimum.

This further reduces soil organic carbon content to the level indicated by the bar labelled 'Existing sequestration' – (SOC_{actual}).

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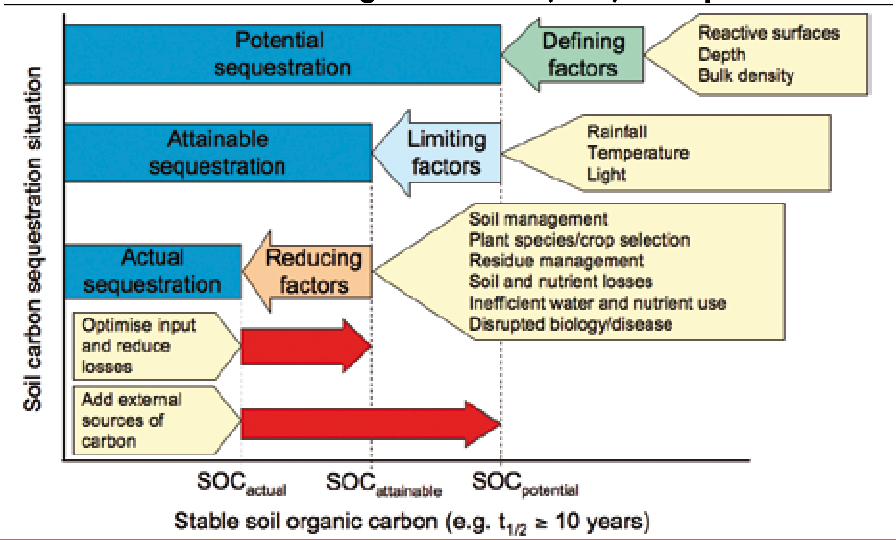
FIGURE 3: Levels of soil organic carbon (SOC) for a particular soil



◁5…BUILDING SOIL CARBON

Optimising agricultural management will allow $SOC_{contents}$ to move from SOC_{actual} values towards $SOC_{attainable}$ but it is not possible to move beyond this point due to the restrictions on plant inputs induced by water availability or what ever other factor may be placing an upper limit on plant productivity.

The only way to further increase soil organic carbon is to add an external source of carbon (compost, waste residues, and so on) on a regular basis.

Calculating changes in soil organic carbon content

An equation can calculate the amount of organic carbon found in a soil by using values for the depth (cm) of the soil layer of interest, the soil bulk density (g/cm^3) and the soil carbon content (%). The equation [below], indicates that a 20 cm layer of soil having a bulk density of 1.2 g/cm^3 and a carbon content of 1.2 per cent contains approximately 29 tonnes of carbon per hectare.

Organic C (T C/ha) =
Depth (cm) x Bulk density (g/cm^3) x
Carbon content (%)

TABLE 1: Equilibrium soil organic carbon content (SOC_{actual}) predicted using the RothC soil carbon cycling model for three regions in SA with a different climate type

	Clare	Roseworthy	Waikerie
Growing season rain (mm)	491	338	170
French-Shultz slope (kg grain/mm)	20	20	20
French-Shultz intercept (mm)	180	110	80
Water limited potential grain yield (tonnes/ha)	6.2	4.6	1.8
Average productivity (85%)			
Grain yield (tonnes/ha)	5.3	3.9	1.5
Total shoot dry matter (tonnes/ha)	11.7	8.6	3.4
Equilibrium soil carbon content			
Modelled amount of C in 0–30 cm soil layer (T C/ha)	98	78	41
Estimated % C in the 0–10 cm soil layer	3.5	2.8	1.5

All soils were assumed to have equal clay content (15%) and bulk density (1.4 g/cm^3)

TAKE HOME MESSAGES

Composition of soil organic carbon

- Soil organic carbon is composed of a wide range of different materials with different chemical and physical properties and different extents of decomposition.

Roles of organic carbon/organic matter in soil

- Soil organic matter contributes to a variety of biological, chemical and physical properties of soils.
- Chemical – cation exchange, pH buffering, reduces effects of sodicity.
- Physical – water retention, soil structural stability, soil temperature.
- Biological – energy for microbes, provision of nutrients and resiliency.
- Each fraction of soil organic carbon contributes differently to various soil properties.

Calculating changes in soil organic carbon content

- Soil carbon content represents the balance between inputs and outputs.
- Values are required for the depth, bulk density and carbon content of the soil layer you are interested in to determine how much carbon is present.
- If management changes induce changes in bulk density – these must be accounted for in the sampling/calculations.
- Corrections for inorganic C are required.
- Changes in soil carbon content are slow and typically require at least five years to be detectable.
- Simulation models can be used to predict the likely outcomes of management practices on soil carbon content.

$$ from sequestration – fact or fiction?

- Optimising crop productivity will maximise carbon inputs and soil organic carbon content.
- At current prices, it is hard to justify modifying management practices for the sole purpose of selling carbon credits.

Suggestions have been put forward that altering management practices can increase soil organic carbon content from two per cent to four per cent in five years. Is this really possible?

If we use the same bulk density as above (1.2 g/cm^3) and restrict our calculations to the top 10 cm of soil where organic carbon is most easily increased, at two per cent carbon the soil would contain 24 tonnes of carbon per hectare. At four per cent carbon the same soil layer would contain 48 tonnes of carbon per hectare.

This indicates that 24 tonnes of carbon per hectare would have to be added to the soil. Since plant residues contain approximately 45 per cent C this would equate roughly to 50 tonnes per hectare of dry matter (DM). If this increase was to occur over five years, then an additional 10 tonnes DM per hectare above that currently being added would be required if no decomposition occurs.

Since we know that at least 50 per cent of the added plant residues will decompose, annual additions of approximately 20 tonnes DM per hectare above that currently being added would be required to achieve an increase in soil organic carbon content from two to four per cent in five years.

Under dryland conditions typical of the Australian cereal belt, increases in returns of dry matter of this magnitude are unlikely and so it is hard to substantiate such changes in C content. But in specific locations where rainfall may not be used efficiently to produce agricultural crops/pastures (particularly regions with significant amounts of summer rainfall and where annual crops are being produced) significant increases in crop production and residue returns are possible by modifying existing management practices.

Conversion of annual to perennial pastures and altering grazing practices from set stocking to rotational grazing may enhance plant dry matter production and increase soil carbon content.

Predicting the amount of organic carbon that can be present in soil

Soil organic carbon content changes very slowly. When this fact is considered along with the annual variability in rainfall measurements of soil organic carbon over several decades may be required to accurately define the effects of particular management treatments on soil organic carbon contents.

We have used a soil carbon model (RothC) to predict the likely SOC_{actual} values that would be obtained under wheat

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production using average climatic conditions and retaining all crop stubble. At each location the water limited grain yield was calculated using the French-Schultz approach.

To define the potential long term soil carbon content (equilibrium soil carbon content), 85 per cent of this water limited grain yield was used along with a harvest index of 0.45 and a root:shoot ratio of 0.5 to calculate the crop residue addition rate including roots.

The equilibrium soil C contents (T C/ha) predicted for the 0–30 cm layer at each location are presented in Table 1. Estimates of the associated carbon content in the 0–10 cm soil layer are also presented in Table 1. It should be noted that in these modelling analyses a constant clay content of 15 per cent was used at all sites.

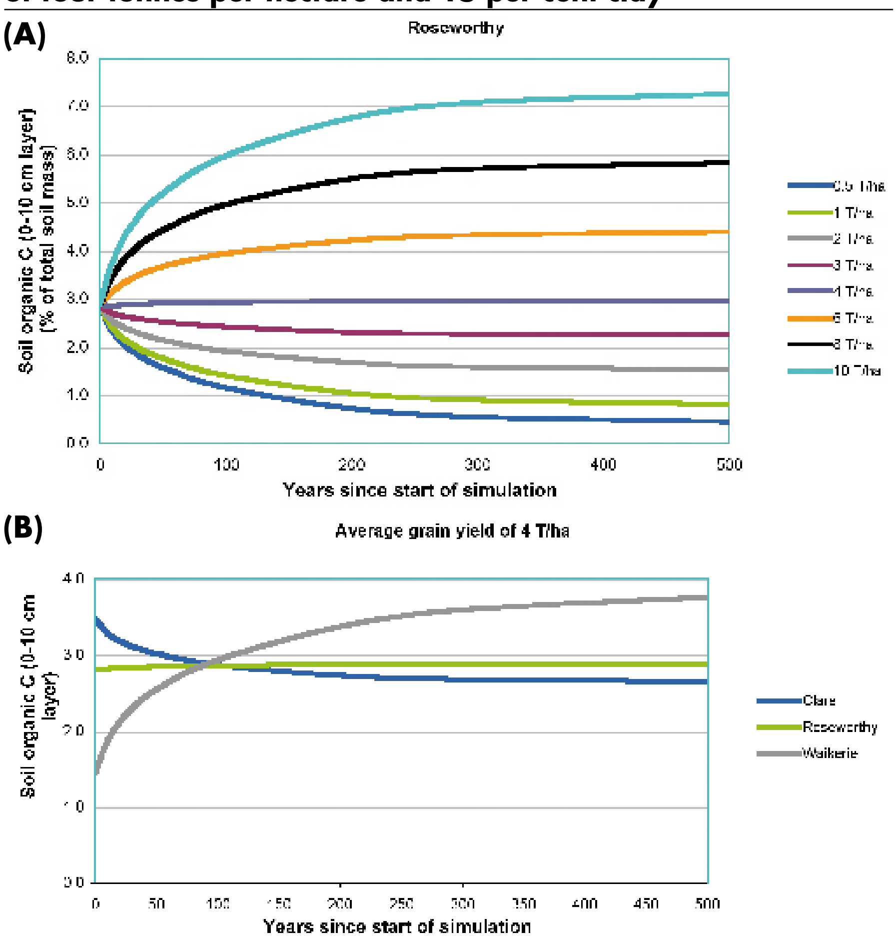
If actual clay contents are lower, the equilibrium C content will decrease and if actual clay contents are higher, the equilibrium C content will increase (Table 2) because clay can protect organic carbon from decomposition.

In Figure 4 the estimated changes in soil organic carbon content (%) of the 0–10 cm layer that occur with different levels of wheat production (grain yield) are presented. Results indicate that a sustained productivity of about four tonnes per hectare per year of wheat grain yield is required to maintain the equilibrium soil carbon content at Roseworthy (Figure 4a).

TABLE 2: Equilibrium 0–30 cm soil organic carbon content (T C/ha) predicted using the RothC soil carbon cycling model for different soil clay contents under continuous wheat production at Waikerie, Roseworthy and Clare, SA

Soil clay content (%)	Clare	Roseworthy	Waikerie
5	81	65	35
15	98	78	41
30	108	93	46

FIGURE 4: Changes in soil organic carbon content predicted using the RothC soil carbon cycling model for different levels of average wheat grain yield in Roseworthy (A) – Part (B) shows the different behaviour of soils (Waikerie, Roseworthy and Clare) with a different climate at a constant wheat grain yield of four tonnes per hectare and 15 per cent clay



200 years of eight tonne yields

To double soil carbon content from three per cent to six per cent would require a sustained production of wheat grain of eight tonnes per hectare per year for approximately 200 years.

For soils with a constant clay content (15 per cent) but different climates (for example, Clare, Roseworthy or Waikerie), the model predicts large differences in the equilibrium soil carbon content under a sustained production of four tonnes per hectare per year of the wheat grain (Figure 4b).

Whereas this yield will maintain the current soil carbon content in Roseworthy, the same yield will decrease soil carbon in Clare by almost one per cent in the top 10 cm and increase soil carbon in Waikerie by about two per cent in the top 10 cm over a 500 year period.

The large difference in the behaviour of Waikerie and Clare soils results from the influence that climate exerts on the rate of decomposition of the added crop residues. The drier climatic conditions at Waikerie result in slower decomposition rates and allow carbon to accumulate – while at Clare, the wetter conditions result in higher decomposition rates and a gradual loss of carbon.

It is very unlikely to produce four tonnes per hectare per year of wheat grain at Waikerie. So the model results shown in Figure 4b are not realistic and are presented only to show the influence that climate can have on the rates of decomposition.

$$ from sequestration – fact or fiction?

There is no doubt that soils could potentially hold more carbon. The challenge is to be able to do this while still maintaining an economically viable farm enterprise. Some potential options include:

- Enhancing the proportion of perennial vegetation in pastures or conversion of paddocks that continually give negative returns to perennial vegetation;
- Increased retention of crop residues, reduced stocking rates and increased use of green manure crops to return more plant material to the soil; and,
- Optimise farm management inputs to maximise water use efficiency and so maximise the return of crop residues to soil.

With current prices of more than $20 per tonne of sequestered carbon and the slow potential rates of soil carbon change, it will be hard to economically justify modifying management practices for the purpose of selling carbon credits alone. At this stage, carbon credits should be considered as a secondary benefit that may be realised whilst attempting to enhance soil productivity by building soil carbon content.

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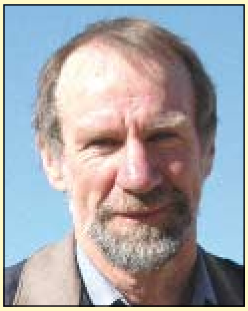
THE COMMERCIAL VIEW

With Allan Mayfield, Consultant, Clare SA



Allan Mayfield.

"Maintaining or increasing soil organic carbon falls in line with good farming practice. There is no doubt about the benefits of having higher organic carbon for nutrient turnover and improved soil structure. But there is an upper limit for different situations and this will be less in sand than in clay, and less in lower rainfall areas. It all relates to the amount of biomass we can grow.

"Growers aiming for high water use efficiency through good seedling establishment, adequate nutrition and good pest and disease management will generally increase crop biomass. Also, maintaining crop residues will reduce wind and soil erosion and help retain soil moisture for crop production. But excessive residues can cause problems such as poorer weed control from soil incorporated herbicides and increases in diseases and soil dwelling pests such as slugs.

"Increasing water use efficiency and greater profitability should be the main aim, while any build up in soil organic carbon is a secondary benefit. It's not a bad thing to run down soil organic carbon in some situations. Going from pasture to a cropping system, for example, will run the levels down, but that doesn't necessarily equate to less productivity on farm. With the use of fertilisers in cropping we can maintain high productivity, applying more nitrogen in the form of the fertiliser, adding to what's being released from the soil. The balance here will depend on the cost of fertilisers compared with the costs of achieving higher soil carbon levels.

"Growers should be cautious with suggestions about quickly building soil organic carbon. Claims of big increases in soil organic carbon are not substantiated by science. We don't see rapid and large increases in soil organic carbon in the field unless a large amount of amendment (such as animal manure) has been added.

"Currently there is no commercial test available to separate the active carbon from the inactive carbon. Until such a test becomes available growers cannot reliably assess the active carbon and, hence, the potential availability of other nutrients such as nitrogen. Fertiliser test strips and monitoring for available nutrients are better ways of determining the nutrient status of crops and pastures.

"We shouldn't be anticipating the financial benefits from selling carbon credits as they are still a long way off. Current prices per tonne of sequestered carbon are not high enough to warrant the changes in farming practices needed to achieve big lifts in organic carbon. There are also issues with accurately measuring changes in organic carbon. As a general rule, good farming practices which increase productivity will produce the financial rewards and will likely result in maximum soil carbon levels for the farming practice implemented."