Building soil carbon for your business

Peter Grace[1], Richard Eckard[2] and Warwick Badgery[3]

[1]School of Biology & Environmental Science, Queensland University of Technology
[2]Department of Agriculture and Food, The University of Melbourne
[3]NSW Department of Primary Industries

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Take home messages

- Many growers are already employing soil sequestration practices as the norm, but only additional activities are valid for claiming a carbon offset
- Soil carbon sequestration in grains systems is low unless a pasture phase is included
- When estimating carbon credits all greenhouse gases must be included i.e. soil carbon sequestration is potentially negated by nitrous oxide and other emissions
- The long term benefits of increasing soil organic matter for soil health are more profitable and low risk compared to the soil carbon market.

Introduction

Soil organic matter is the backbone of any sustainable farming system. In recent times, there has been significant interest in the role that soils can play in helping Australia meet its greenhouse gas reduction targets. Under the federal government's Australian Emissions Reduction Fund (ERF) which financially rewards carbon offsets, there are two legislated methods which involve soil organic matter or more specifically increases in soil organic carbon. These procedures are very specific and require detailed certified measurements of soil organic carbon and bulk density over nominated time periods. A number of international voluntary soil carbon methods also exist, but their validity as offsets in Australia may be questionable.

To engage in these soil carbon offset markets, farmers must first be able to demonstrate they are undertaking management activities which are in addition to their normal practice. For example, a farmer who changes to zero till practices will be rewarded if they have registered the field (i.e. defined a Carbon Estimation Area) and can show a measurable change in soil organic carbon in the top 30 cm or deeper. A farmer who has employed zero till for many years is unlikely to be rewarded unless there is some additional modification to this practice.

Unfortunately, placing a price on soil carbon has skewed the discussion away from what really matters to farmers, which is soil health and productivity. Soil organic matter, of which only half (~58%) is soil organic carbon has multiple benefits, most notably, maintaining nutrient supply and soil structure. Soil organic carbon is usually only about 1 to 5% of the total soil mass, with the higher concentrations normally under long-term grasslands or crop rotations with significant pasture phases.

What is soil organic carbon?

There is some confusion about what constitutes soil organic carbon. Plant residues on the soil surface, roots and buried plant residues (>2 mm) are not accounted for as soil organic carbon. These first need to be broken down into smaller fractions and decomposed to be considered soil organic carbon, which is why the soils are first sieved to two millimetres before an analysis, to remove all larger fractions. Gravel content and inorganic carbon (or carbonates in alkaline soils) must also be taken into account when accurately quantifying soil organic carbon.

Fractions considered to be part of the soil organic carbon (as per a soil analysis) would be Particulate Organic Carbon (POC; 2.0 – 0.05 mm) or labile C, Humus (<0.05 mm) or stable C, with Resistant Organic Carbon (ROC) being historic charcoal from fires or burning of stubbles. In other words, we must not confuse roots with soil organic carbon.

For sustained productivity, increasing the relative amount of POC is beneficial as this is readily decomposable and a supply of nutrients. To have confidence to sell soil carbon, you want a significant amount of carbon in a more recalcitrant (slowly decomposing) form i.e. stable, so that you have confidence that it will still be there in 25 to 100 years. These permanence time frames are required to engage in carbon markets.

Building soil organic matter

The inherent benefits and the role of soil organic matter for productive and profitable agriculture are well documented (Table 1).

Table 1: Biological, physical and chemical co-benefits that high soil organic matter may confer to an agricultural production system.

Biological roles	Physical roles	Chemical roles
- Reservoir of nutrients - Biochemical energy - Increased resilience - Biodiversity	- Water retention - Structural stability - Thermal properties - Erosion	- Cation exchange - pH buffering - Complex cations

(Source: Jeff Baldock)

Building soil organic carbon is basically an input-output equation; the inputs are crop and pasture residues and roots. The outputs are CO_2 from microbes which are actively decomposing and transforming the carbon fractions, using them as energy but in the process releasing nutrients back to the soil to support plant growth. As much as 90% of the carbon input is lost as CO_2. Soils with a higher clay content have a greater capacity to store carbon per unit of inputs. In a good rainfall year, the inputs increase in response to plant growth with a subsequent increase in outputs and an accumulation of carbon. Carbon inputs exceed outputs. In a drought, carbon inputs drop dramatically in response to reduced plant growth, but the outputs remain because the microbes respond to episodic wetting events and soil carbon decreases. Carbon outputs exceed inputs. Fallow years are good example of significant losses in soil carbon.

In Australia, rainfall determines the majority of soil carbon change in a stable management system (see Meyer *et al.,* 2015). Unless there is a significant change in management, e.g. moving out of conventional cultivation into permanent pasture in a high rainfall zone, the majority of the annual change in soil carbon is a function of rainfall, biomass production and its decomposition. Change in soil carbon in mixed cropping system can often be large and unpredictable, particularly from labile, relatively decomposable carbon (Badgery *et al.,* 2020).

Australia has over 20% more rainfall variability than most countries in the world (Love 2005). Banking on selling soil carbon and its permanence is therefore high risk given the frequency of drought. For example, Badgery *et al.,* (2020) reported that after 12 years of increases in soil carbon, this was reversed in the following 3 years in less than favourable climatic conditions.

In contrast, recent research has demonstrated that just two of the co-benefits of high soil organic matter (i.e. nitrogen mineralisation and water retention) confers as much as $150 per hectare per year productivity value in a pasture system in western Victoria, when the carbon trading value under the same scenario is less than $20 per tonne per hectare year (Meyer *et al.,* 2015). This raises the question, should farmers focus on trading soil carbon, or just bank the inherent productivity benefit of having higher soil organic matter, as there is no paperwork no contracts no liabilities, but all the productivity benefits can be banked? In addition, when the farm needs to demonstrate carbon neutral production in the next decade, this soil carbon will be essential to offset the balance of the farmers greenhouse gas emissions.

How much soil carbon can be accumulated?

The current level of organic carbon in soils across the northern grains zone is well below what can be achieved if we consider the impact of 100 years of conventional agriculture (Figure 1).

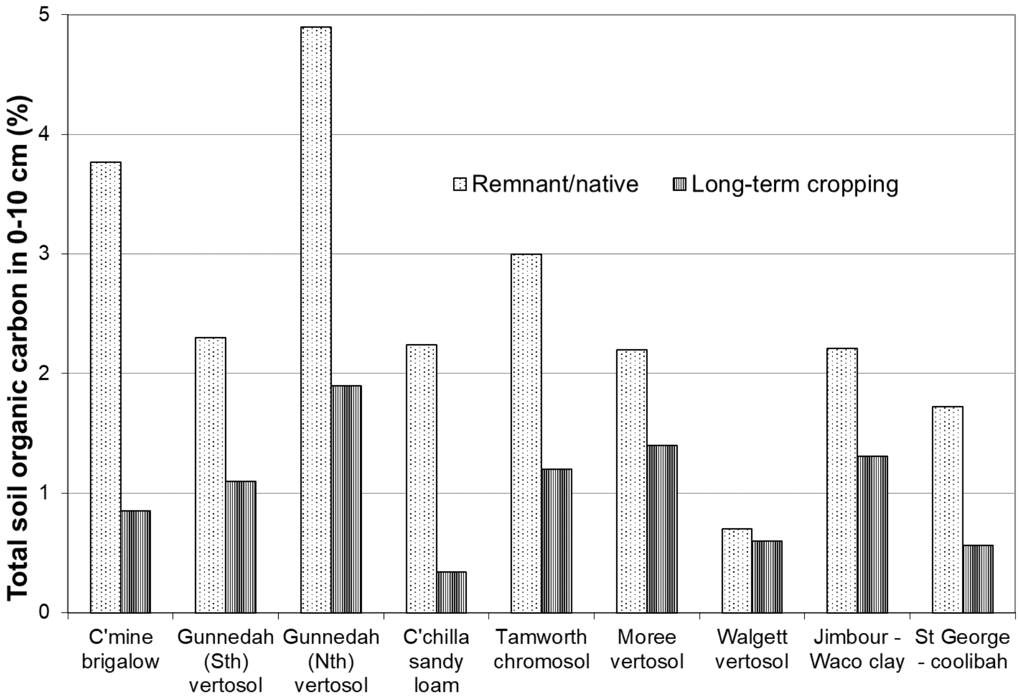

Figure 1. Impact of long-term cropping on soils of the northern grains zone (Lawrence *et al.,* 2017).

The SATWAGL long-term trial at Wagga (Chan *et al.,* 2011) has demonstrated the clear benefits of stubble retention, zero tillage and pasture phases for increasing soil carbon (Table 2). Over a 25-year period, stubble retention compared to burning was 2.2 t C/ha higher, zero tillage compared to conventional cultivation was 3.6 t C/ha higher, and a pasture rotation every second year was between 4.2 and 11.5 t C/ha higher than continuous cropping.

Many of these management practices, as well as reduced fallows, are now commonplace in grains systems of Australia. Soils have potentially reached a new (but low) steady state i.e. little change over time, provided the management does not change. A shift to a pasture-based farming system offers high potential for soil carbon gains (Figure 2) and its benefits, but a major consideration is obviously whether there is enough flexibility on-farm and profitability within the livestock sector to make this transition and to consider the potential for additional emissions from livestock.

Table 2. Change in soil organic carbon (SOC, kg C/ha over 0–0.30m soil depth) and final stock (t C/ha) under different rotation, tillage, and stubble and pasture management in the SATWAGL long-term field experiment (1979–2004) (adapted from Chan *et al.,* 2011)

Treatment	Tillage	Stubble	Rotation	SOC change (kg C/ha/year)	sig	Final stock (t C/ha)
T1	NT	SR	W/L	-52	n.s.	40.5
T2	CC	SR	W/L	-174	*	38.3
T3	NT	SB	W/L	-98	n.s.	39
T4	CC	SB	W/L	-176	*	35.4
T5	CC	SB	W/W	-278	**	33.6
T6	CC	SB	W/W-N	-193	*	34.6
T7	CC	SR	W/C-G	-2	n.s.	41.7
T8	NT	SR	W/C-M	257	*	48
T9	CC	SR	W/C-M	104	n.s.	43.1

NT, No tillage; CC, 3-pass tillage; SR, stubble retained; SB, stubble burnt; W/L, wheat/lupin rotation; W/C, wheat/clover rotation; W/W, wheat/ wheat; N, N fertiliser; G, grazed; M, mown. *$P < 0.05$; ** $P < 0.01$; n.s., not significant

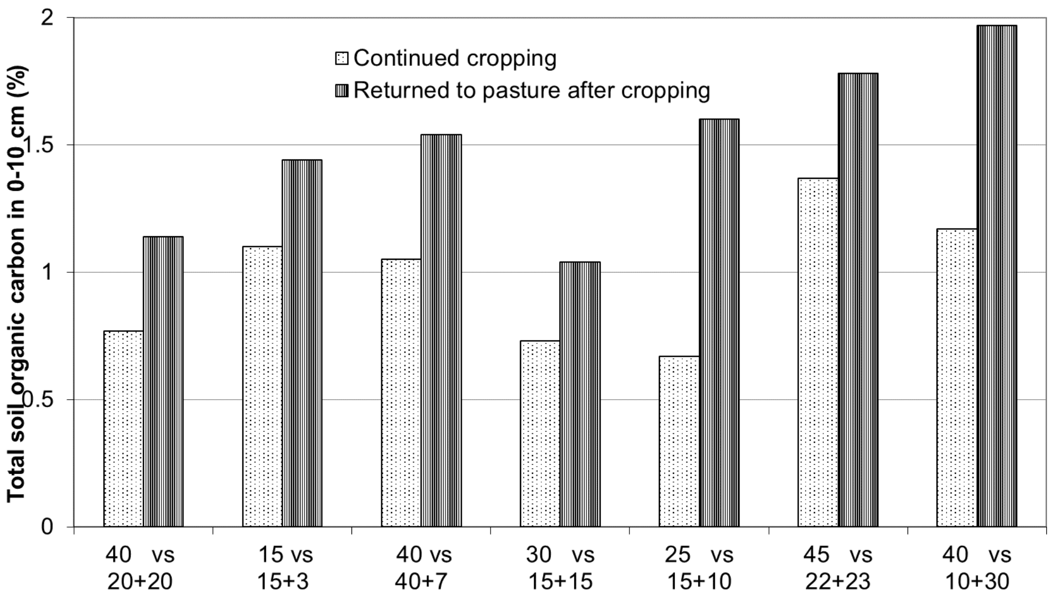

Figure 2. Changes in soil organic carbon levels after shifting from crop to pasture in the northern grains region (Lawrence *et al*., 2017). First value is the total duration of the cropping phase, second value is the duration of the cropping and pasture phases.

Over the past few years there has been an increase in the number of farmers and carbon aggregators making claims of increases in soil carbon that do not align with the published peer-reviewed science. Although conservative, the values presented in Table 3 are those estimated by the Australian government official carbon model (FullCAM), showing likely increases in soil carbon in response to management. What is also seemingly ignored in claims of soil carbon increase, is the assumption this can continue in perpetuity, which defies the law of diminishing returns. The more carbon you sequester, the more carbon inputs you then require to maintain this level every year.

Table 3: Modelled soil carbon sequestration potential as stipulated and the Australian government ERF Offset method: Estimating Sequestration of Carbon in Soil Using Default Values, Methodology Determination 2015[1]

	Categories of sequestration potential (t C/ha/year)		
Project management activity	Marginal benefit	Some benefit	More Benefit
Sustainable intensification	0.03	0.16	0.45
Stubble retention	0.02	0.08	0.20
Conversion to pasture	0.06	0.12	0.23

[1]https://www.legislation.gov.au/Details/F2018C00126

Where soil has a low organic matter content, but high clay content and good rainfall (i.e. a high potential to increase soil organic matter), it is possible to achieve rates of soil carbon sequestration that exceed those presented in Table 3. The initial high carbon sequestration rates (i.e. the first 5 to 10 years with rates from 0.7 to 1 t C/ha/year in the top 30 cm when converting cropland to pasture; Meyer *et al.,* 2015; Robertson & Nash, 2013) will result in a new steady state after 10 years that matches the rainfall and management imposed. In contrast, the same conditions but with a high soil organic matter starting point, would only vary in direct relation to annual rainfall and distribution.

Another factor that limits the ability to determine changes in soil C is the large spatial variability that is found within a paddock. A high level of soil sampling is needed to detect differences in soil C between two time points. For example, Singh *et al.* (2013) found that a spatially optimised design, including stratification according to landform and yield mapping, needed at least 48 cores to reduce the standard error of measurement to less than 2 t C/ha at 0-30 cm in a 68 ha paddock. This is major limitation to cost-effectively verifying changes in soil C.

A new approach to managing soil organic matter in Australia

Perhaps there is a need to consider soil organic matter differently in the Australian context, by managing it more specifically for soil types by farming systems and also managing differently in high versus low rainfall periods. Sandy or granitic soils have very limited capacity to build soil organic matter as carbon is less protected to decomposition by microorganisms in these soil types, whereas clay soils generally have far higher potential to sequester carbon when rainfall is sufficient to maintain carbon inputs from stubble, roots or residual pasture biomass.

The key to building soil carbon, is to understand the capacity for the soil to store carbon in your specific environment (climate x soil type) and management system. This capacity varies considerably even within the same district. Therefore, we should not treat the landscape with a single sequestration potential, but target the areas that are low in carbon but high in sequestration potential e.g. the rehabilitation of degraded lands.

We should also be thinking of El Niño versus La Nina years quite differently, in that we have probably built more soil organic matter in eastern Australia during the recent La Nina, than in the previous three dry years put together. Higher rainfall year should focus on strategies that maximise the sequestration of carbon in our soils, and in low rainfall or drought periods, we focus on minimising the losses. Rather than focus on building soil carbon year by year, a longer-term approach would aim for a net increase in carbon over a 10 year period.

Short-term gain may mean long-term pain

Finally, whilst carbon neutrality is being strongly supported by the agricultural supply chain companies, there is an inevitable point where farmers will need to demonstrate progress towards lower emissions farming systems. Any increase in soil organic carbon you bank as a credit, will be negated by in-field emissions e.g. CO_2 from fuel, N_2O from N fertilisers or CH_4 from grazing livestock. Selling soil or tree carbon means that when the asset **value** leaves your property, you are left with the liability of maintaining what is now someone else's asset for the next 25 to 100 years (short term gain, long term pain). If the soil carbon is sold internationally, it also leaves the industry and the country, making any industry or national carbon sequestration targets increasingly difficult to achieve . Once the soil carbon is sold, the new buyer will be using it against their carbon footprint, which means that the farm will never again be able to use that soil carbon against their future liability, making their carbon neutral target increasingly impossible to achieve. The low risk option is to bank the inherent productivity benefit of improved soil health and don't sell your soil carbon, as you will need this asset for the day when you might need to table it against the balance of your own greenhouse gas emissions to meet supply chain demands.

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Contact details

Peter Grace
Professor of Global Change
Queensland University of Technology
Email: pr.grace@qut.edu.au