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JANUARY 2008 PRIMEFACT 735

Increasing soil organic carbon of agricultural land

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- Increasing soil organic carbon (SOC) can improve soil health and can help to mitigate climate change.
- Although there is a limit on the amount of organic carbon that can be stored in soils, the large losses in the past means that many Australian agricultural soils have the potential for large increases.
- SOC levels are influenced by management practices. Many management practices that are effective in increasing SOC are also effective in improving crop and pasture yields.
- The actual amount of soil carbon that can be stored is dependent on the farming system (management practices), soil type and climatic conditions, as well as the initial soil carbon level of the site.

What is soil organic carbon?

Soil organic carbon (SOC) is the carbon associated with soil organic matter. Soil organic matter is the organic fraction of the soil that is made up of decomposed plant and animal materials as well as microbial organisms, but does not include fresh and un-decomposed plant materials, such as straw and litter, lying on the soil surface. Soil carbon can also be present in inorganic forms, e.g. lime or carbonates in some soils in the drier areas.

Carbon cycle and soil carbon pools

SOC forms part of the natural carbon cycle (Figure 1). Organic material is manufactured by plants through the process of photosynthesis, using atmospheric carbon dioxide and water as raw materials. The plants (and the animals as part of the food chain) eventually die and return to the soil where they are decomposed and recycled. Minerals are released into the soil and carbon dioxide back to the atmosphere.

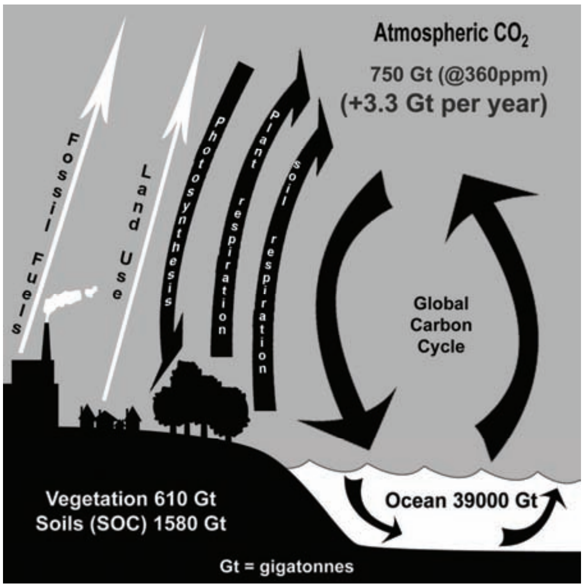

Figure 1. Soil organic carbon forms part of the natural carbon cycle (see Table 1).

(White arrows indicate additional human outputs)

There is a continuous turnover of organic carbon materials in soil, and SOC is not a uniform material but rather a complex mixture of organic compounds at different stages of decomposition.

It is convenient to divide total SOC into different pools dependent on their ease of decomposition, namely labile pool, slow pool and inert pool (Figure 2). The labile pool includes all the freshly added plant and animal residues as well as micro-organisms. As these are easily decomposed, they are labile. The slow pool includes well-decomposed organic materials, the humus. The inert pool refers to the fraction that is old, resistant to further breakdown and represents the products of the last stage of decomposition, e.g. charcoal.

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Table 1. Carbon pool size and changes due to human activities

Carbon pool size	
Vegetation	610Gt*
Atmosphere	750 Gt
Soil	1,580 Gt
Ocean	39,000 Gt
Carbon changes due to human activities	
Fossil fuel use	+ 5.5 Gt/year
Land Use	+ 1.6 Gt/year
Rate of carbon increase in the atmosphere	
	+ 3.3 Gt/year

Source: 'The carbon cycle, climate and the long–term effects of fossil fuel burning', J F Kastings, Consequences Vol 4, No 1, 1998.

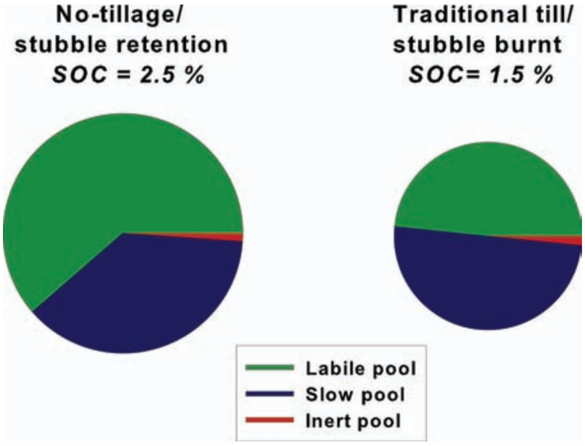
*Gt = Gigatonne, which is 1000 million metric tonnes

Therefore soils differ not only in total SOC but also in the composition of the different SOC pools.

Figure 2 shows the SOC level and its composition of a soil which has been under no-tillage and stubble retention (SOC = 2.5 %) and the same soil which has been under 3 pass tillage and stubble burning (SOC = 1.5 %) after 19 years.

Most of the SOC difference between the two soils is the loss of some of the labile fraction from the tilled soil. As a result the slow and inert pools make up a larger proportion of the total SOC of the 3–pass tillage and stubble burnt soil.

Figure 2. Soil organic carbon levels (sizes of the circles) and the three different carbon pools (individual slices) of the same soil under two different management practices in Wagga Wagga.



Importance of soil organic carbon in agriculture

Soil organic carbon as the basis of soil fertility

Soil organic carbon is important for all three aspects of soil fertility, namely chemical, physical and biological fertility.

Nutrient availability. Decomposition of soil organic matter releases nitrogen, phosphorus and a range of other nutrients for plant growth.

Soil structure and soil physical properties. SOC promotes soil structure by holding the soil particles together as stable aggregates improves soil physical properties such as water holding capacity, water infiltration, gaseous exchange, root growth and ease of cultivation.

Biological soil health. As a food source for soil fauna and flora, soil organic matter plays an important role in the soil food web by controlling the number and types of soil inhabitants which serve important functions such as nutrient cycling and availability, assisting root growth and plant nutrient uptake, creating burrows and even suppressing crop diseases.

As a buffer against toxic and harmful substances. Soil organic matter can lessen the effect of harmful substances e.g. toxins, and heavy metals, by acting as buffers, e.g. sorption of toxins and heavy metals, and increasing degradation of harmful pesticides.

> **'Soil organic carbon is the basis of sustainable agriculture'**

Soil organic carbon as a sink for atmospheric carbon

As a result of human activities releasing carbon dioxide into the atmosphere (particularly fossil fuel consumption and land use practices), the carbon pool in the atmosphere has increased and the elevated carbon dioxide is considered to be a contributory factor to the danger of global warming and climate change. However, SOC is a very important component of the global carbon cycle (see Figure 1 and Table 1). It is the largest component of the terrestrial carbon pools, approximately twice the amount of carbon in the atmosphere and in vegetation. If more carbon is stored in the soil as organic carbon, it will reduce the amount present in the atmosphere, and therefore help to alleviate the problem of global warming and climate change. This process of storing carbon in soil is called soil carbon sequestration.

How much carbon can be stored in soils?

There are a whole range of SOC levels in different soils. For instance, for the surface soils, SOC ranges from about 10% in the alpine soils to less than 0.5% in the desert soils. The amount of SOC stored in the soil profile can be considerable. For example, if there is 1% SOC over 30 cm soil depth, the amount of SOC stored over 1 hectare of land can weigh about 42 tonnes (see last section). Usually, the surface layer has the highest level of SOC which decreases with depth down the soil profile. The actual amount of SOC present in a soil is dependent on a number of factors.

Factors affecting soil carbon level

Soil carbon levels are determined by factors such as rainfall, temperature, vegetation and soil type and reach equilibrium values associated with individual systems and locations. However, these equilibria are disturbed when areas are cleared and used for agricultural production.

Globally, clearing natural vegetation for agriculture results in large reductions in SOC levels and further declines may occur due to management practices (Figure 3). In Australia, it has been estimated that, in many areas, soil carbon levels have dropped by up to 50% compared to pre-agricultural periods. Most of the reduction in SOC occurs in the surface soil layer, 0–10 cm. Therefore, soil carbon levels of agricultural soils are lower than corresponding soils under natural vegetation. This difference in SOC indicates the potential for soil carbon storage. As indicated in Figure 3, rapid decline in SOC occurs when land under natural vegetation is cleared and converted to agriculture but restoration of SOC level (e.g. under reduced tillage) occurs at a much slower rate.

In agricultural systems, soil carbon levels tend to be variable and dependent on management practices. The change in SOC is determined by the balance of carbon inputs over losses.

‘The challenge is to turn agricultural soils into effective carbon sinks’

Management practices that reduce soil organic carbon

Some management practices, such as fallowing, cultivation, stubble burning or removal, and overgrazing can reduce SOC by reducing inputs to the soil, increasing the decomposition of soil organic materials, or both.

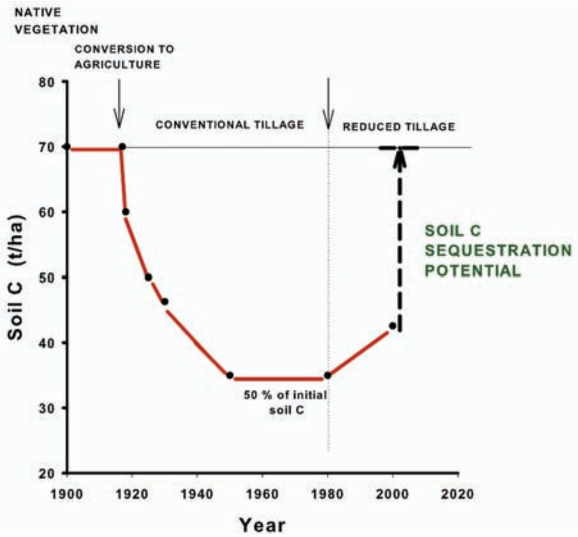


Figure 3. Historical change in SOC as a result of agricultural development, showing soil carbon sequestration potential

Cultivation. Cultivation operations can expose SOC and increase losses by decomposition and erosion. Historically, excessive cultivation using inappropriate implements resulted in soils being ‘over-worked’, and the consequent loss of SOC has caused many land degradation problems such as erosion and soil structural decline.

Fallowing. In the past, keeping the soil bare was a common cropping practice. Fallowing was maintained by repeated cultivation for weed control. SOC declines rapidly under fallowing because of the increased decomposition of organic matter due to the cultivation operations as well as the higher soil moisture conditions prevailing in the fallowed soils.

Management practices that increase soil organic carbon

There are a wide range of management options and farming practices that can increase SOC levels by either increasing inputs or decreasing losses, e.g. stubble retention (Table 2). Inputs can also be increased by direct additions of organic materials, composts, manure and other recycled organic materials.

Practices leading to increased productivity of crops and pastures – In theory, any management practice that can increase production from an area of land should lead to increased SOC storage because of the increase in carbon inputs. Farmers are familiar with practices such as fertiliser application, improved rotations, improved cultivars and irrigation which can lead to large yield increases. Productivity increases can also be achieved by crop intensification practices such as double cropping, opportunity cropping and multiple

Management category	Management practices to increase soil carbon
Crop management	Soil fertility enhancement Better rotation Erosion control Irrigation
Conservation tillage	Stubble retention Reduced tillage No-tillage
Pasture management	Fertiliser management Grazing management Earthworm introduction Irrigation Improved grass species Introduction of legumes Sown pasture Introduction of perennial pastures
Organic amendments	Animal manure Green manure Recycled organics

Table 2. Management practices that can increase soil organic levels of agricultural soils

cropping. However, it should be noted that some of the yield increasing practices involve the use of fertilisers and irrigation water which require large energy consumption and therefore increase carbon dioxide emission.

Conservation farming **–** This is rapidly gaining worldwide acceptance as a farming practice to improve soil and water conservation. In cropping, cultivation is either reduced (reduced tillage) or completely eliminated (no-tillage) and stubble (crop residue) is retained. Reduced tillage reduces carbon losses (from both reduced cultivation and reduced fossil fuel usage) and stubble retention increases carbon inputs to the soil; both of these lead to SOC increases.

Use of organic amendments **–** These are manure, plant debris, composts and biosolids from sewage which are applied to agricultural soils. They are all high in organic carbon and therefore represent additional carbon inputs to the system. Some of these recycled organics also contain a high plant nutrient content and can act as organic fertilisers, reducing the use of inorganic fertiliser. They are important for organic farming systems.

Some results from the Wagga Wagga long-term trial

In Wagga Wagga, a trial commenced in 1979 to examine crop yield and soil health (including soil carbon) under a range of cultivation and stubble management practices as well as rotations. After 20 years of monitoring, the results show that under continuous wheat cropping using the traditional practice of stubble burning and cultivation (3 scarifications), SOC was lost at the rate of nearly 400 kg/ha/yr. From the long-term trial results, the impact of different management practices can be estimated. For instance, no-tillage helped to save 169 kg C/ha/yr compared to traditional tillage, whereas stubble retention helped to save 108 kg C/ha/yr compared to stubble burnt. A crop/pasture rotation sequestered more carbon than continuous cropping. The most C conserving system was wheat/subclover pasture (1:1) with the wheat under no-till and stubble retention, where SOC was increasing at a rate of 185 kg C/ha/yr. These long-term trial results highlight the importance of management practices in determining the SOC level and show that by using the right management practices we can turn a farm from C source to C sink.

> **‘The long term trial results highlight the fact that by using the right management practices, we can turn a farm from C source to C sink’**

Farming systems to increase soil organic carbon

The improved management options (Table 2) are all proven practices that may be readily incorporated into existing farming systems to improve agronomic performance, conserve water and reduce erosion. They can also result in higher crop yields. Increased SOC results from a greater return of organic matter into the soil in the form of stubble and root matter (stubble retention), and reduced losses from cultivation and runoff. Therefore, the adoption of farming systems that can increase SOC is a win-win situation. In addition to mitigating climate change, systems that increase SOC are also more productive, more profitable and more sustainable.

However, the effectiveness of a particular management practice in increasing soil carbon is site specific and dependent on local factors such as climate, soil types and management skill. In soil carbon sequestration, as we are interested only in the net carbon change, simple low-energy options such as conservation farming, grazing management and better rotation are particularly attractive.

Role of pasture in farming systems – current research project

In southern NSW, pasture is an integral component of farming systems. In the pasture/crop rotation system, the pasture helps to restore nitrogen fertility and soil structure. However, there is little information on the ability of the different pastures and the effect of management of the pasture on soil carbon levels. A new project has been started to fill in this knowledge gap. Soil carbon levels of different pasture treatments from two long-term trials in Wagga Wagga and additional paired sites across the region will be used to compare soil carbon levels for a range of pasture types and pasture management. The comparisons will include different pastures (annual vs perennial; native vs sown) and different pasture management practices (grazing and nutrient management). From the results, soil carbon models will be developed to predict soil carbon sequestration under different pastures in different parts of the region over time.

Measuring soil carbon

- SOC is usually measured in the laboratory on soil samples collected from the field. There are two kinds of test for SOC determination, namely one which is based on acid digestion and the other based on combustion principle. The latter measures all the carbon presents in a sample of soil whereas the former measures only part of the organic carbon.
- SOC results are usually expressed as % C by weight (i.e. g C per 100 g of soil). SOC results can be converted to soil organic matter (SOM) level by multiplying SOC value by a conversion factor of 1.72. This assumes that SOM present in soil, on average, is made up of 58 % carbon.
- Very often it is more practical to express SOC on per ha basis, namely as tonnes C per ha. To perform such calculation, knowledge of the bulk density of the soil to the sampling depth and the sampling depth is needed. As an example, if SOC = 1.0 % and bulk density of the soil = 1.4 Mg/m^3 to 30 cm depth (1 Mg = 1000 kg = 1 tonne), the amount of SOC present in the soil to 30 cm depth of 1 hectare of land can be worked out as follows.

Tonnes carbon per ha	**=**	**SOC (%)**	**x**	**Soil bulk density (Mg/m^3)**	**x**	**Sampling depth (cm)**
	=	**1.0**	**x**	**1.4**	**x**	**30**
	=	**42 tonnes/ha**				

To obtain reliable SOC results, it is important firstly to collect a representative soil sample and secondly to have the soil samples analysed by an accredited laboratory using standard methodology.

ISSN 1832-6668

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