Saving the life of farmland soils

A dust storm rolls across central NSW farmland. As our soils become more deficient in organic matter, they lose their structural stability and are more vulnerable to weather extremes. CSIRO Land & Water

Aware of a remorseless decline in the vital organic matter of Australian farmland soils because of land clearing and agricultural production, researchers, land managers and now, commercial players, are seeking ways to reverse the trend. It's an important quest: without organic matter, soil is essentially sterile, reducing the viability of both agricultural and surrounding natural systems.

The carbon hidden away in soil originates from plants and is the unglamorous and often forgotten part of the cycle of carbon between the land, oceans and atmosphere. Yet it is a fundamental component of soil's organic matter, integral to healthy soils and the productivity of agricultural and wider ecological systems, and an important sequester of the carbon in CO_2 that contributes to global warming.

Soil organic matter comprises all the living, dead and decomposing plants, animals and microbes in the soil along with the organic residues and humic substances they release.

'It includes carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur and it is a small but vital part of all soils,' says Mr Jan Skjemstad, formerly of CSIRO Land and Water. 'We now recognise four different types – crop residues, particulate organic matter, humus (usually the largest pool) and recalcitrant organic matter like charcoal – so it is a complex mixture of materials that vary in size, chemistry, degree of decomposition and interaction with soil minerals.'

Dr Ram Dalal, of the CRC for Greenhouse Accounting and the Queensland Department of Natural Resources, has also studied soil organic matter in croplands for many years and has reviewed its role.[1] He describes soil organic matter as containing both living and non-living organic components.

'Soil microbes, especially fungi and bacteria, and larger soil fauna are the living component while plant residues and various other organic materials represent the non-living portion,' says Dalal, 'and it is the microbes that are the main driving agent for organic matter turnover.'

The amount of organic matter in soil results from the balance of carbon inputs (vegetation and roots) and outputs (decomposition, leaching and erosion). This offers the prospect of fiddling with the rates of these inputs and outputs to

1 Dalal RC and Chan KY (2001). Soil organic matter in rainfed cropping systems of the Australian cereal belt. *Australian Journal of Soil Research* **39**, 435–464.

Land clearing, cropping and the export of agricultural produce from farmlands reduce soil organic matter. Composts made from reclaimed and recycled organic wastes from urban refuse could help restore essential nutrients to farmland soils. Suprijono Sujarjoto/ CSIRO Land & Water

manage or manipulate soil organic matter levels.

While this sounds promising, the biological, physical and chemical processes involved are complex, so boosting organic matter by, say, altering cropping systems isn't always that simple. For example, there are thresholds of soil organic matter content above which the various benefits for productivity or soil function level off, and clay soils respond differently to more sandy soils.

Soil organic matter is now universally regarded as important stuff. In a GRDC report,[2] Dr Evelyn Krull, of CSIRO Land and Water, and her colleagues, said that many farmers see increases in soil organic matter as desirable because this is usually directly related to better plant nutrition, ease of cultivation and seedbed preparation, greater aggregate stability, reduced bulk density, improved water holding capacity, enhanced porosity and earlier warming in spring. At a fundamental level, soil organic matter provides a reservoir of metabolic energy that enables a range of biological processes to occur in the soil.

A disappearing act

Many studies have documented the seemingly inevitable decline of soil organic matter following land clearing and use of conventional cropping systems.

To give an idea of this, researchers[3] found that percentage losses of organic carbon from Australian soils, already low in carbon compared to European soils for example, varied from 10–60 per cent over 10–80 years of cultivation, and other studies have recorded similar losses.[4]

Large losses of soil carbon can lead to land degradation while restoration of soil organic matter improves soil quality and enhances ecological sustainability. Indeed a study[5] by Dalal, and several colleagues, in the Brigalow region of the Murray–Darling Basin, found that soil organic matter is a useful indicator of both ecological and economic sustainability. They confirmed

One of the key reasons for the declining fertility in agricultural soils is the removal – some would say 'strip mining' – of nutrients in crops and other farm produce, and the degradation of organic matter following soil cultivation.

Why, then, are land clearing and cropping so detrimental to soil organic matter?

'The declining organic matter levels in croplands,' says Dalal, 'are mostly due to changes in temperature, moisture, soil aeration, exposure of new soil surfaces as aggregates are disrupted, reduced input of organic materials relative to grassland or forest returns, increased erosion, and the export of carbon and nutrients, such as nitrogen, phosphorus and potassium, from farms in produce.'

that organic matter declined exponentially as the cultivation period for cereal cropping increased. Consequently, nutrients such as soil nitrogen were in shorter supply and grain protein and grain yields fell, with clear economic implications.

One of the key reasons for the declining fertility in agricultural soils is the removal – some would say 'strip mining' – of nutrients in crops and other farm produce, and the degradation of organic matter following soil cultivation. Instead of being

2 Krull ES, Skjemstad JO and Baldock JA (2004). Functions of soil organic matter and the effect on soil properties. GRDC, www.grdc.com.au/growers/res_summ/cso00029/summary.htm

3 Russell JS and Williams CH (1982). Biogeochemical interactions of carbon, nitrogen, sulphur and phosphorus in Australian agro-ecosystems. In *The Cycling of Carbon, Nitrogen, Sulphur and Phosphorus in Terrestrial and Aquatic Systems.* (Eds LE Galbally and JR Freney) pp. 61–75 (Australian Academy of Science: Canberra).

4 To estimate organic matter, scientists usually multiply the (more easily determined) soil organic carbon value by a conversion factor of 1.72. If a 'Loss on Ignition' method is used, the relationship is the other way around.

5 Dalal RC, Eberhard R, Grantham T and Mayer DG (2003). Application of sustainability indicators, soil organic matter and electrical conductivity to resource management in the northern grains region. *Australian Journal of Experimental Agriculture* **43**(3), 253–259.

recycled into the soil, as they would in a natural system, plant and animal material (such as grains and meat) are sent to faraway markets and end up being consumed by people in towns and cities or manufactured into other foods or goods, or end up, eventually, as waste in garbage bins or as human waste in sewage. Urban centres, in fact, have become huge nutrient and carbon sinks. Over time, soils losing their carbon and nutrients to this process break down.

Declining soil fertility is the reason why, as Queensland EPA research indicates, average grain yields over the last 30 years have remained static, despite improved crop management practices (including the use of improved plant breeds), higher fertiliser application rates (e.g. nitrogen 300%) and better weed control.[6]

Sending organics home

Australia's organics recycling industry, represented by Compost Australia, is on a mission to reverse this trend. Dr John White, Managing Director of Global Renewables Limited (GRL), one of 60 organisations represented under the peak national body, is passionate about the need for sustainable agriculture in this country and believes that the industry can play an important part by collecting and processing organic residues, and returning them to farm soils as high quality mulch or compost products that will boost soil organic matter, improve water use efficiency and increase productivity.

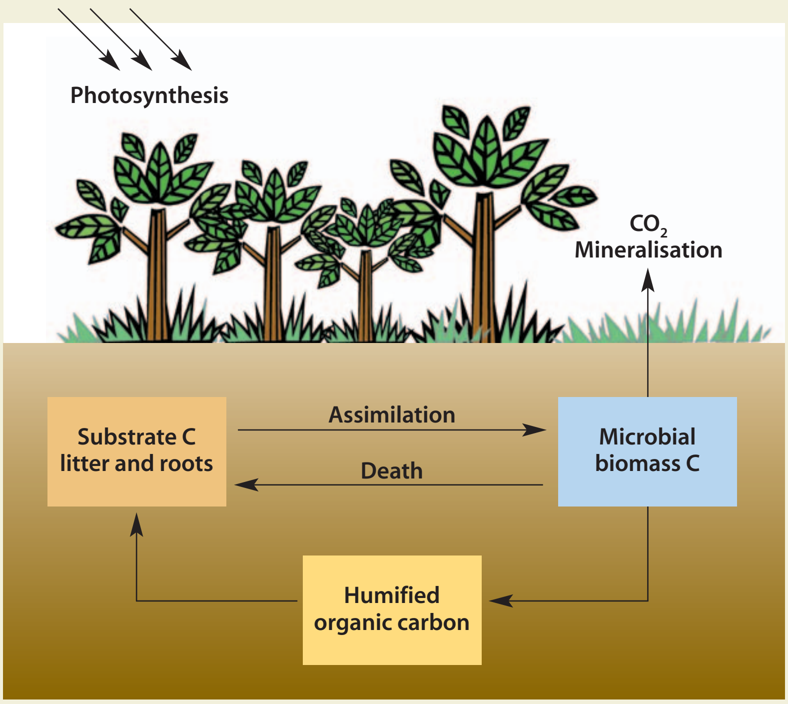
He has a vested interest too, as GRL collects urban waste, usually sent straight to landfill, and recycles the various components, including organic wastes, using a process known as UR-3R. The system stabilises the organic component, producing a compost that meets the stringent Australian standard for application to soils for farming.

'I believe Australian farmers are losing their soil organic matter and, encouraged by fertiliser companies, are increasingly addicted to synthetic fertilisers and pesticides,' Dr White told *Ecos*. 'And it is a vicious cycle because as soil organic matter declines, soils degrade, microbial activity declines and farmers must use more and more chemicals to maintain fertility, control weeds and pests and fight plant diseases.

'This is all detrimental to the environment, in particular as nutrients enter our rivers, lakes, groundwater and even marine waters, causing algal blooms, damage to coral reefs and so on. Also, loss of soil organic matter means soils retain less water, so farms are more vulnerable to the effects of drought,' White said.

Peter Wadewitz, Chair of Compost Australia, knows first-hand of the moisture boosting potential of organic composts and the promise they hold. 'We have seen dramatic water savings effects through the use of organic mulches in the wine industry and in tree crops,' he says.

'However,' he goes on, 'we cannot expect the farmers to fix Australia's problems on their own. We all have to help, and there is an easy way we can do that. In 2004/05, the organics recycling industry converted approximately 3.5 million tonnes of organic residues into valuable mulch and compost products. However, there are still millions of tonnes of useful organic materials wasted in Australian landfill sites each year. Much of this material could be separated, preferably at source, adequately processed and used to improve farm soils and productivity.'



The soil carbon cycle. Soil carbon originates from plants, while the amount of soil organic matter in the soil results from the balance between inputs (plant residues) and outputs (mostly microbial decomposition). JO Skjemstad

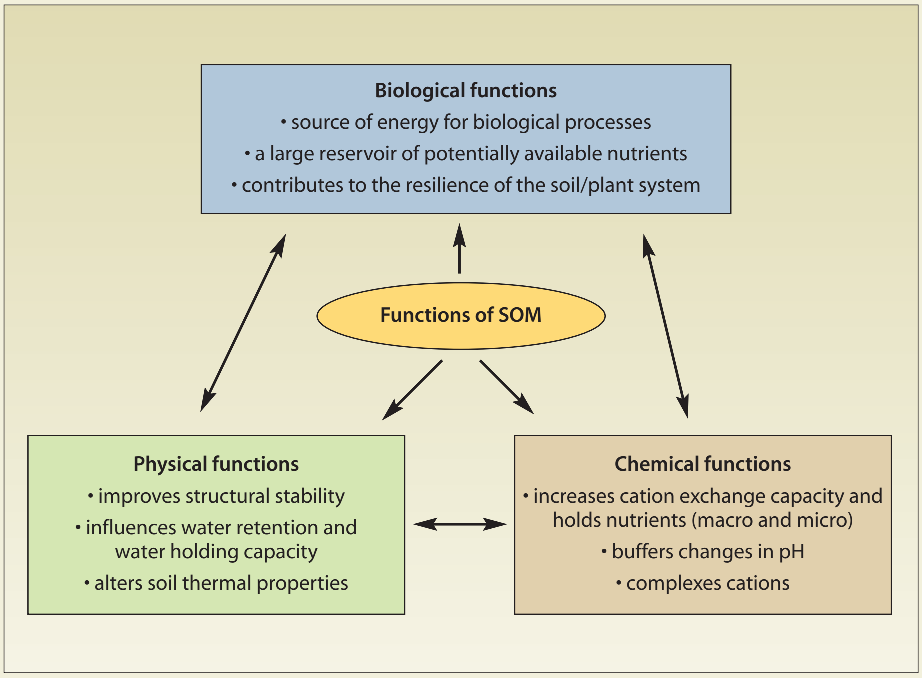
Dr John White at GRL concurs. 'Some 40 to 60 per cent of the waste in garbage bins is organic – food scraps, garden clippings, grass – and this amounts to about 11–12 million tonnes going to Australian landfill sites each year. At GRL, we separate this out, clean and deodorise it, and use microbes to process it into a compost that is suitable for agricultural soils. So we close the loop, sending organic matter back to farms, in much the same way that small-scale traditional village systems returned wastes to the soil.'

Dr White has been urging the Australian Government to follow the lead of the United Kingdom, which in following the European Union's 1999 Landfill Directive,[7] passed laws last year to progressively ban organics at landfills over the next decade, to minimise pollution of water tables through leaching and reduce greenhouse gas emissions. He argues that government incentives are needed to encourage farmers to manage their soils sustainably and suggests that 'organic' farming, already booming, is the best way to achieve this.

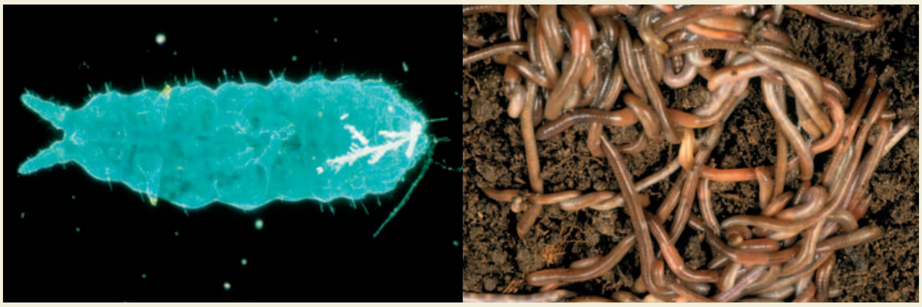
'Our government is beginning to get interested,' said White, 'perhaps motivated by greenhouse pollution problems, farmers going bankrupt and the likelihood that European countries, especially, will soon demand truly clean and green produce in international trading.'

Whilst, according to Compost Australia, strict organic farmers usually aim at minimising external inputs, and that includes carbon (in composts), the argument for recycling urban organics through agriculture is slowly gathering momentum across the wider farming community as the

6 Queensland EPA (2004). State of the Environment Queensland 2003, Brisbane.
7 The 1999 EU Landfill Directive demands from member countries that they progressively reduce the amount of organic matter (or unstabilised waste) that goes to landfill.



Soil organic matter (SOM) performs three functions – biological, physical and chemical – which are each interrelated. From Krull ES, Skjemstad JO and Baldock JA (2004)



Fungi, bacteria and larger soil fauna such as Collembola and earthworms (above) are the living component of soils. Microbes decompose organic materials to produce detritus while larger fauna produce castings and aerate the soil. CSIRO Land & Water

importance of maintaining soil organic matter levels is underscored, and the benefits of organic composts become more generally accepted. There are also mechanisms being worked on to reduce the significant cost commitments required for compost applications.

Some scientists, however, urge caution on soil amendments. Professor Keith Cameron and his colleagues at Lincoln University, New Zealand, argue[8] that while wastes may contain nutrients and, used properly, can serve as valuable fertilisers for agricultural production, they should not just be 'dumped' on soils.

'There needs to be good management of waste composition and application rate and appropriate guidelines to minimise damage and maximise benefits,' said Cameron. 'Recycling nutrients can improve sustainability, but excessive rates of application have been shown to cause nitrogen and phosphorus pollution of surface or groundwater and some wastes contain heavy metals, salts and pathogens or may have extremely low or high pH.

'Land application of wastes can have a variety of beneficial or detrimental effects on soil conditions, depending on the nature of the waste and the soil. Research and monitoring programs are therefore necessary to ensure that waste application systems are sustainable and do not damage soil quality.'

This sentiment is fully supported by Compost Australia. 'If we as an industry are not able to produce high quality, recycled organic products that are environmentally benign, that are fit for purpose and that deliver tangible benefits to the user, we will not last,' says Peter Wadewitz.

According to him, many farmers would like to use good quality compost on their land to improve soil properties, but are unsure whether this long-term investment in their soil 'infrastructure' pays off. Research around the country is currently focused on assessing the agronomic and economic as well as the environmental benefits of using recycled organic products in agricultural production systems, so farmers can make a well-informed decision about whether to use recycled organics or not.

In Queensland, the Brisbane City Council funded 'Returning the Favour' Project still has to run a year before yield and economic benefits are determined for vegetable growers in the Lockyer Valley. Meanwhile, Bob Paulin from the Western Australian Department of Agriculture and Food has identified some of the benefits of composted soil amendments to vegetable production in a four-year study.[9] His research found significant improvements, particularly on the sandy soils, in all soil characteristics measured, including increased soil organic matter, organic nitrogen, biological activity and diversity, cation (positively charged ions) exchange capacity, volumetric soil moisture along with improved soil pH and reduced bulk density. Economic analysis also indicated that the use of compost in vegetable production increases returns.

Bob Paulin's aim, like others, is not to replace the use of synthetic fertilisers, but rather to develop and establish truly sustainable agricultural production systems that are able to maintain and enhance soil fertility, supply healthy foodstuff and deliver an adequate income to farmers.

Long-term farming system trials, such as the famous Rothamstad trial at Broadbalk in England (since 1843),[10] have shown that use of mineral fertilisers on their own were not able to increase soil carbon levels. At best they maintained them. In many cases, combined use of organic and inorganic fertilisers provided the best yield responses.

8 Cameron KC, Di HJ and McLaren RG (1997). Is soil an appropriate dumping ground for our wastes? *Australian Journal of Soil Research* **35**, 995–1035.
9 Paulin B, Wilkinson K, O'Malley P and Flavel T (2005). Identifying the benefits of composted soil amendments to vegetable production. Horticulture Australia (HAL Report VG 990016).
10 See http://bretonplots.rr.ualberta.ca/quicktime/files/index.asp?page=Powerpoint. Look at slide 52 of the Powerpoint presentation.

Managing soil carbon

Another way to reverse declining soil organic matter is by managing the soil differently. We can't detail here the various land and crop management options and systems for boosting soil carbon levels, but suffice to say that the following aspects and practices feature prominently:

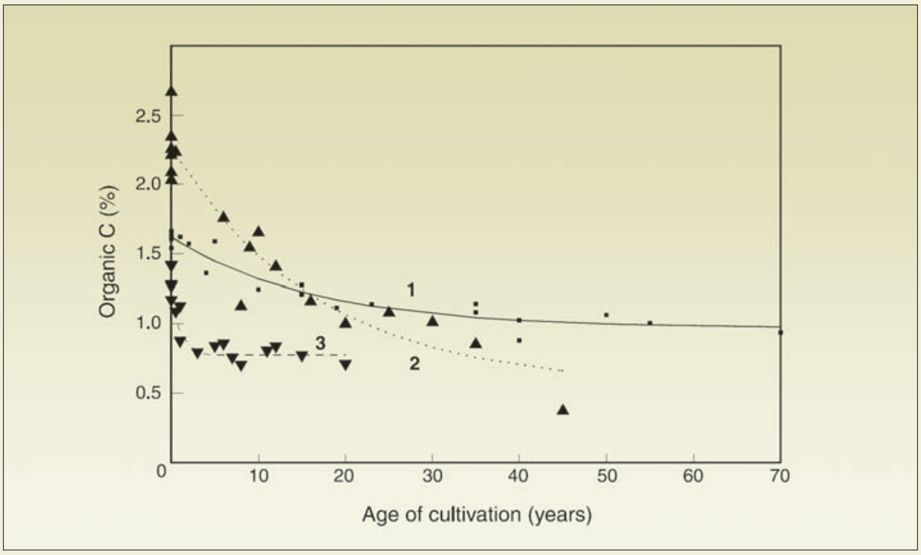
- use of pasture leys (where land is left in fallow to recharge);
- crop rotations, legumes and fertiliser applications;
- 'no till' or 'minimum till' systems and crop residue retention (conservation farming);
- no burning of stubble (as this destroys potential organic input and releases carbon);
- application of manures or recycled organics;
- lower stocking rates on grazing lands;
- retention of grasslands and trees or conversion of marginal lands to native vegetation;
- forestry plantations; and
- soil erosion control.

Pastures are an important tool because organic matter concentrations tend to be much higher under grass. Observations[11] of the world's ecosystems show that organic carbon concentrations in soils (to a depth of one metre) under various land uses were: 122.7 tonnes per hectare for tropical forests, 117.3 for tropical savannas, 96.2 for temperate forests, just 80 for crop-lands, but 236 for temperate grasslands.

Similarly, the importance of trees emerged in a recent study conducted by Dr Rick Young, of the NSW Department of Primary Industries, and several colleagues.[12]

'We found that continuous cultivation and cropping over 20 years or more significantly depleted carbon concentrations compared with grassy woodlands to a depth of 0.2 metres at all sites and to 0.6 metres at three sites in north-western NSW,' says Dr Young. 'The outstanding finding was that comparisons between land uses and the total amount of carbon stored at the seven sites we studied were dominated by the number of trees per hectare and the size of the trees.'

The researchers concluded that in most cases, maximum carbon – both soil carbon and total carbon on site (including biomass carbon) – will be maintained where some tree cover is retained.



On cultivated land, soil carbon gradually declines in the top 10 cm of various soils.
From Dalal RC and Chan KY (2001)

Organics from municipal waste are cleaned and processed into organic compost at Global Renewables Limited's recycling facilities. GRL

Dr Brian Tunstall of the Environmental Research and Information Consortium, and formerly with CSIRO, brings an ecological perspective to the question of restoring soil organic matter.

'Unfortunately, more than 75 per cent of Australian farming soils have organic carbon contents less than 1.75 per cent,' he says, 'indicating a widespread need to improve soil organic matter concentrations.'

He too is critical of the current broad-scale farming approach with its high inputs of mineral fertilisers, herbicides and insecticides, which he regards as symptomatic treatments that are unsustainable in the long term.

'We need to increase levels of soil nutrition to increase the amount of organic matter being recycled,' argues Dr Tunstall. 'But, to be sustainable, the nutrition should be increased by developing the natural processes, a functional soil, rather than treating soils as a hydroponic-like medium that simply acts as a reservoir for water and applied nutrients.

'The idea is to build up biological populations in the soil, not least the micro-organisms in organic matter which maintain a supply of essential elements to plants, rather than relying only on mineral fertiliser additions which negate the significance of microbes. A good practical example of this is sugar cane farmers in Queensland who have been using microbes to incorporate organic matter into the soil after harvesting.'

Overall, however, there are differing viewpoints on the benefits or otherwise of

11 Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ and Dokken DJ (2000). *Land Use, Land-use Change, and Forestry: A Special Report of the IPCC.* Cambridge University Press, Cambridge.
12 Young R, Wilson BR, McLeod M and Alston C (2005). Carbon storage in the soils and vegetation of contrasting land uses in northern New South Wales, Australia. *Australian Journal of Soil Research* **43**, 21–31.

Tomato yields in fields with poor soils (left) were improved (right) after the addition of 10 tonnes per hectare of carbon- and nutrient-rich compost (seen as the dark top covering) from recycled municipal waste. GRL/Katie Webster EcoResearch

mineral fertiliser additions. On the one hand, some scientists argue that reliance on mineral fertilisers contributes to the problem because these do not return carbon to the soil, while other scientists recommend use of mineral fertilisers to promote plant growth and hence increase the return of crop residues to the soil. What farmers choose to do probably depends on their preferred farming system and philosophy.

Soil carbon, sinks and global warming

Increasing concern about greenhouse emissions and climate change is renewing interest in soil's capacity to hold carbon. Perhaps surprisingly, there is more carbon sequestered in the world's soils (2500 billion tonnes, or 2500 Gigatonnes (Gt)) than in the atmosphere (807 Gt) or above-ground vegetation (560 Gt). Some 1550 Gt of this soil carbon, more than half, is in soil organic matter.

So the historical losses of soil organic matter represent a considerable contribution to greenhouse emissions. In Australia, more than half the CO_2-e (carbon dioxide equivalent) emissions from our agriculture sector are due to loss of organic carbon from the cereal belt. The good news is that this is a reversible process and there are bonus benefits.

'If we can reverse these cereal belt losses by restoring soil organic matter, there is the potential to lock up about 50 Megatonnes (Mt) of CO_2-e per year in the soil profile over a 20-year period,' said Dalal. 'That's almost 10 per cent mitigation of the current annual CO_2 emissions in Australia.'

Brian Tunstall calculates that an average organic matter increase of 2 per cent to a depth of 30 cm, achievable in many clay soils, represents a sequestration of 35 tonnes of carbon or 128 tonnes of CO_2 per hectare … and there are many hectares of farm land.

Jan Skjemstad is more cautious on soil sequestration. 'The problem is that the only way to increase soil carbon is to increase the amount of carbon going in through plant residues,' he said. 'This is limited by rainfall so even if stubble is burnt and all residues returned to the soil, there is a definite limit which is determined by climate, soil type and management.

'We estimate that if 16 million hectares of cropping land were completely put to full stubble retention and with more pasture included in rotations and with crop yields increased, 10 Mt of carbon sequestration per year (or 35 Mt CO_2-e) is about as much as you would get over a 30–40 year period. This assumes no droughts.'

Mr Skjemstad also points out that historically our lands have not been cropped for that long. 'As a result, not all of our soils are that "flogged" yet and so do not have the potential to recover that much. It really depends on when the soils were originally cleared,' he said.

He also highlights that there is great variation to take into account with the soil types and make-ups across Australia, and therefore their treatment and potential.

'Western Australia's soils are very sandy with relatively little organic matter, while across on the plains of Toowoomba in Queensland, farmers enjoy a very rich soil with high organic matter and nutrient levels – it can endure more intensive agriculture.'

Evelyn Krull, meanwhile, points out that adopting sensible land management practices to boost soil carbon has benefits that extend beyond the much-discussed greenhouse gas sequestration. She says direct benefits to the landowner include increased productivity, sustainability and, above all, better soil quality.

Besides the greenhouse benefits, there is a view that the next dramatic increase in crop production could come about by a deliberate increase in the biological activity of soil and by accessing nutrients through microbe-driven mechanisms.

One way of doing this is by addition of organic fertilisers on some farms, which could build soil carbon levels and, as a likely consequence, increase yields.

James Porteous and Steve Davidson

Declaration: Dr John White is an invited member of the Ecos *Editorial Advisory Committee, made up of representatives from areas of the national sustainability agenda.*

More information:
Soil organic matter overview:
www.dpiw.tas.gov.au/inter.nsf/WebPages/TPRY-5YW6YZ?open

Compost Australia:
www.compostaustralia.com