The potential of soil to securely sequestrate carbon: expanding the horizon

Leigh Sullivan and Jeff Parr
Southern Cross University
Australia
Conversion factors

1 tonneC $\sim$ 3.7 tonnes CO$_2$

1 tonneC $\sim$ 1.6 tonnes organic matter (variable)

$10$ per tonne CO$_2$e $\sim$ $37$ per tonne C
This presentation will focus on:
1) the soil organic carbon sequestration processes that operate over the long term (i.e. up to 1,000s yrs), and
2) the potential that exists in agriculture, forestry etc. to manage these processes to maximise the secure storage of carbon in soil.
Organic matter decomposition in soil.

Organic material added to soil

Source: Brady and Weil (1999)
Organic material undergoes many decomposition cycles.

Source: Brady and Weil (1999)
Main long term C products of decomposition usually considered to be:
1. CO₂
and

soil humus
(highly decomposed soil organic matter)
The main long term storage mechanism of humus in soil is within organo-mineral complexes such as between clay particles and within micro-aggregates.

Source: Brady and Weil (1990)
However, there are other forms of organic carbon derived from plants that can sequester significant amounts of carbon in the long term by ‘bypassing’ the decomposition process.

Source: Brady and Weil (1990)
Charcoal
Results from the incomplete combustion of plant materials.
Chemically inert re: decomposition.
PhytoOC - Phytolith Occluded Carbon

Silica accumulations (phytoliths or plantstones) form naturally in the leaves of many plant types.

Organic carbon within the silica encasement of phytoliths can be physically protected from decomposition in soil for many millennia.
What is the ‘natural’ long term potential of soil to sequestrate carbon?

Fig. 1 Organic carbon accumulation in New Zealand sand dunes

slope = long term average soil organic carbon accumulation rate

slope = 2.1 g m$^{-2}$ yr$^{-1}$
Over this period average soil organic carbon accumulation rates in upland soils varied from:

- 0.2 gC m\(^{-2}\) yr\(^{-1}\) for polar deserts, up to 10 gC m\(^{-2}\) yr\(^{-1}\) in some forests,
- the global mean was 2.4 gC m\(^{-2}\) yr\(^{-1}\).

The long term sequestration of soil organic carbon in the last ~10,000 years was relatively low: only ~0.7% of net primary production.
The current annual rate of carbon (as CO₂) increase in the atmosphere is 10 times greater than the global mean soil carbon accumulation rate.

Accordingly, it is thought that the low organic carbon storage potential of soil means that soil organic carbon sequestration will have only a relatively minor long term role to play in decreasing CO₂ in the atmosphere.
Of course, much of the land around the globe is under active vegetation management and not under ‘natural’ vegetation.
What is the potential for long term carbon sequestration in soil under active vegetation management?

Three main processes:

1) Storage of decomposable organic carbon by physical protection within micro-aggregates or other organo-mineral complexes,

2) Charcoal, and

3) PhytOC.
Physically protected carbon within organo-mineral complexes

It has long been known that the organic carbon content is a soil property that is sensitive to land management practices.
- excessive cultivation can deplete soil organic carbon,
- reduced tillage, reversion of cropland to grassland, and reforestation can increase soil organic carbon.

Soil carbon sequestration rates from reduced tillage, reversion of cropland to grassland, and reforestation have been shown to vary markedly from site to site.
The capacity of soil to store decomposable organic carbon by physical protection within micro-aggregates or other organo-mineral complexes seems to be finite.

Once these complexes are saturated any added decomposable organic carbon cannot be protected from decomposition.

Even if this capacity has been severely depleted it can be re-saturated rapidly (e.g. within 30 years by growing pasture).
None-the-less, comprehensive reviews of global trials have shown soil organic carbon accumulation as a result of changing land management practices:

- The global average for the establishment of forest or grassland on cultivated land was an organic carbon sequestration rate of 33 gC m\(^{-2}\) yr\(^{-1}\).

- The global average for the conversion of tillage practices from conventional to zero tillage in cropping areas was an organic carbon sequestration rate of 57 gC m\(^{-2}\) yr\(^{-1}\).

Importantly, carbon sequestration arising from these practices was not able to be sustained indefinitely: for the tillage changes, the soil organic carbon content generally reached a new equilibrium after 15 to 20 years.
Can the other forms of soil organic carbon that are sequestered for the long term expand the organic carbon storage potential of soil?
Charcoal

Any soil carbon sequestration enhancement approach based on increasing charcoal contents of soil would have to involve great care to limit detrimental outcomes of burning including the initial CO$_2$ flux to the atmosphere, a lowered return of organic matter to the soil, and consequently a lower soil biotic activity.
PhytOC

The opal encasement provides very effective physical protection for the occluded carbon against decomposition processes in the soil compared to the other organic carbon fractions. PhytOC can resist decomposition for millenia.
From a soil science point of view it is important to recognise that:

1) The carbon occluded in phytoliths is in the original cellular constituents.

2) This carbon can be considered as ‘passive’ or ‘inert’ and not subject to soil chemical processes such as mineralisation or cation exchange.

3) Phytoliths pass through digestive systems and natural fire regimes without substantial change or loss of carbon.

4) Soil phytolith contents are generally < 3% but can be much greater.

5) Soil phytoliths being a. fine-sized and b. located preferentially on the soil surface layers, are easily removed by both wind and water erosion processes.
The final section of this presentation will present two scenarios for expanding our soil carbon sequestration horizons with reference to management of PhytOC in crops.
The global PhytOC accumulation rate under natural conditions has been estimated to be from 0.4 to 0.9 gC m\(^{-2}\) yr\(^{-1}\) for native vegetation communities.

However, the PhytOC yield of crops can be much higher than those for native vegetation. The PhytOC yield of sugar cane and sorghum can be from 4 to 20 times higher than those for native vegetation.

This presents the possibility of expanding the potential of soil to store organic carbon by growing high PhytOC yielding plant types.
Modelled organic carbon sequestration in soil: scenario I

Assumptions:
1) PhytOC decomposition of 25% per millenia.
2) vegetation is grown continuously.
3) natural carbon sequestration as for global average (Schlesinger, 1990).
Modelled organic carbon sequestration in soil: scenario II

Additional assumptions:
1) the effect of change of tillage from conventional to zero tillage causes an organic carbon sequestration rate of 57 gC m⁻² yr⁻¹ over 25 years.
2) the soil is nearing its mature (and hence low) natural rate of carbon accumulation.
What is the potential of such enhanced soil organic carbon sequestration rates relative to the current CO$_2$ increase?

If the long term PhytOC yield of crops and trees grown on arable or forested land was enhanced equivalent to that for sugar cane, this would result in the secure additional sequestration of 0.8 billion tonnesC yr$^{-1}$, ~26% of the current annual rate of atmospheric carbon (as CO$_2$) increase.
The data presented here indicates that:
1) Although some soil organic carbon sequestration mechanisms become saturated relatively rapidly, other long term soil carbon sequestration mechanisms are not as constrained and could be utilised to expand the organic carbon storage potential of soil considerably.
2) If suitable incentives were available to land managers for the environmental service of enhanced carbon sequestration that accrues from growing high PhytOC yielding vegetation, then the expanded soil organic carbon storage capacity afforded by this process could start to be realized within the short term.