CSIRO

CSIRO Submission 10/377

Inquiry into soil sequestration in Victoria

Parliament of Victoria Environment and Natural Resources Committee

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Summary

The Parliament of Victoria Environment and Natural Resource Committee is holding an enquiry into soil sequestration in Victoria.

The terms of reference for this inquiry are to:

(a) explore possible benefits to the agricultural industry;
(b) explore possible environmental benefits;
(c) consider methodologies for measurement of the effects of carbon sequestration, including any potential issues associated with the measurement of benefits;
(d) identify the costs;
(e) identify any possible harms or detriments;
(f) identify linkages with the proposed carbon pollution reduction scheme and other relevant Federal Government policies;
(g) identify linkages with existing Victorian Government policies; and
(h) explore options for the Victorian Government to support the benefits (if any) of soil sequestration.

CSIRO's submission addresses terms a, b and e. Background material is provided after the section addressing the terms of reference.

CSIRO expertise

CSIRO has significant expertise to bring to bear on the integrative considerations raised by the inquiry.

1. CSIRO has undertaken a review of the soil carbon sequestration potential by Australian agriculture on behalf of the Department of Climate Change (December 2009).
2. CSIRO has completed a review of the technical and practical aspects of biochar (http://www.csiro.au/resources/Biochar-climate-change-and-soil.html).
3. In May 2009 CSIRO undertook for the Queensland Premiers Office of Climate Change an Analysis of GHG Mitigation and Carbon Biosequestration Opportunities from Rural Land Use (http://www.csiro.au/resources/carbon-and-rural-land-use-report.html).
4. CSIRO leads and manages a National Soil Assessment Program aimed at identifying the baseline soil carbon content of regional soils under differing management regimes, and aims to develop rapid assessment techniques to assess soil carbon content and fractions.
5. In addition, CSIRO launched a National Research Flagship, Sustainable Agriculture, to provide scientific solutions to increasing agricultural productivity while reducing carbon emissions and environmental impact per unit of agricultural production.

From this background, the following points are submitted in response to the specific questions raised by the Committee.

Inquiry term (a) and (b) Possible benefits to the agricultural industry and environmental benefits

Benefits from soil carbon sequestration could come from either the direct effects of increased soil organic matter or from changes in practices that lead to increased soil organic matter and in addition result in co-benefits.

<u>Benefits of increasing soil organic matter content include:</u>

1. Increased plant productivity associated with improved soil structure, water holding capacity and fertility. Major soil reserves of nitrogen sulphur and to some extent phosphorus are present in organic matter and, generally, insufficient organic matter or slow decompostion rates of organic matter is a cause of deficiencies of these nutrients. The National Land and Water Resources Audit (2001) shows that under current agricultural practices carbon, nitrogen and phosphorus balances and stores in Victorian soils are among the highest in the nation. For example over half of Victorian agricultural soils have a soil carbon % greater than 2% compared with the national average that finds 25% of land to have organic carbon values less than 1% and with only 25% have a value exceeding 2%. Nevertheless fertiliser rates per unit area are among the nations highest in Victoria, and this application must be balanced against increased risks of soil acidification and potential loss of soil cations leached with nitrate. Currenly over 4.5 Ma of Victorian soils are acidic (pH 4.8 or less) with another 5.4 Mha at risk over the next 20 years. Potential controls of acidification include better management of soil carbon to reduce reliance on nitrogen fertilisers.
2. Improved nutrient retention increasing production, decreasing fertiliser requirements and decreasing leaching to groundwater and transport to waterways.
3. Improved soil drainage decreasing waterlogging effects on production.
4. Reduced erosion associated with the protective effects of increased surface residue, increases in soil water infiltration rate and improvement of soil structure and soil aggregation.
5. Reduced surface evaporation associated with mulching effect of surface residues.
6. Increase soil microbial mass and biodiversity and soil macrofauna abundance.
7. Sorption of pesticides and reduced off-site transport of agro-chemicals.

<u>Benefits of Biochar addition include</u>

1) Biochar from urban, agricultural and forestry biomass waste has the potential to help combat greenhouse gas emissions by (a) displacing fossil fuel use through co-generated bioenergy, (b) sequestering C through the conversion of a labile organic material into biologically stable material, (c) potentially decreasing N_2O and CH_4 emissions from soils, (d) avoiding emissions of CH_4 produced from landfill, (e) reducing energy requirements for soil tillage, (f) increasing C sequestration by plants through increased crop vigour and (g) reducing emissions associated with the manufacture of fertiliser. However, before wide scale adoption of residue removal in both agricultural and forestry settings is promoted, it is important to define the impact of such a practice on soil carbon levels.

2) Biochar used as a soil amendment can have beneficial effects for plant production as it may (a) reduce soil acidity, (b) increase or retain plant productivity with a lower amount of fertiliser use and (c) more efficiently retain nutrients and avoid leaching from the soil profile. Given the increasing acidification of soil across Victoria subjected to heavy and continuous fertiliser action, the ameliorative effect of biochar may be beneficial.

3) Biochar may enable soil and vegetation to adapt to climate change by (a) increasing water holding capacity of soils, (b) increase soil pliability and (c) increasing water infiltration.

4) Development of a biochar industry has the potential to diversify business in agriculture to include carbon sequestration and bioenergy production through:

- Additional jobs at regionally distributed slow-pyrolysis units.
- New business opportunities for biochar sale and distribution.

Importantly, it must be acknowledged that the level of potential amelioration offered by biochar application will vary with the nature of the feedstock material and biochar production conditions. For any organic residue or biochar additions full life-cycle analysis is necessary to assess the abatement potential. This analysis is part of CSIRO's existing work.

Inquiry term (e), possible deterimental effects of soil sequestration

<u>Soil carbon</u>

A number of problems can be associated with high levels of organic matter is soils. These include:

1. Water repellence in sand-surface soils in southern Australia can arise from coating of sand grains.
2. The increased acidity resulting from organic matter accumulation in soils can increase the availability of some trace metals and toxicities may develop over long time periods.
3. Use of soil as a sequestration option will place an onus on future managers of that land to maintain practices to keep carbon stocks. This will reduce future land management options. It is important to remember that soil carbon sequestration is the net effect of input rates and loss rates. Changes in input rate or loss rates through changes in productivity, changes in farm management and inputs such as fertiliser or irrigation, changes in climate or changes in the quality of organic matter inputs may lead to soil carbon stocks reaching a new equilibrium.
4. Building soil carbon through high manure inputs can lead to nitrogen and phosphorus losses to streams and groundwater with eutrophication risk.

<u>Biochar</u>

While biochar may lead directly or indirectly to increased production in some soils the effects are not universal. In fact, some biochars may have adverse effects on plant growth, and not all soils respond to biochar additions in the same way.

Studies have reported positive effects with regard to crop production from biochar addition but these are often associated with highly degraded or nutrient poor soils. Application of biochar to fertile and healthy soils does not always yield a positive change.

In addition biochar addition may increase pH which will affect nutrient dynamics in soil. Further there is the potential for biochar to immoblise previously available plant N.

Interaction of biochar with existing soil carbon pools is ambiguous. Some studies indicate that it may provide added benefit of stabilising existing organic matter. However there are studies that suggest it can accelerate decomposition of the existing organic matter.

The net greenhouse gas benefit of biochar is dependent on appropriate production techniques. Greenhouse gases produced during inappropriate pyrolysis can negate sequestration benefits in biochar.

Generation of biochar under uncontrolled conditions or uncontrolled production methods can result in toxic substances being produced during the combustion process and may result in negative effects on plant growth. In terms of potential risk to human health posed by biochar, attention has focused on two classes of toxic compounds, PAH and dioxin, associated with the combustion process. With appropriate combustion technologies, PAH and dioxin production (per unit of char created) are comparable to those produced by prescribed burning and do no not exceed the normal levels found in soil. Consideration must also be given for the risk from toxic sustances within feedstocks (e.g. heavy metals in biochars made from biowaste materials).

Most biochars have a high degree of stability and therefore can reside in soil for long periods of time (>1000 years). Information on the extent to which physical breakdown of biochar changes the balance in its properties, paticularly with respect to soil water dynamics and nutrient retention, sorption and availability is limited.

Current CSIRO research relevant to the enquiry

Active research in CSIRO relevant to the inquiry:

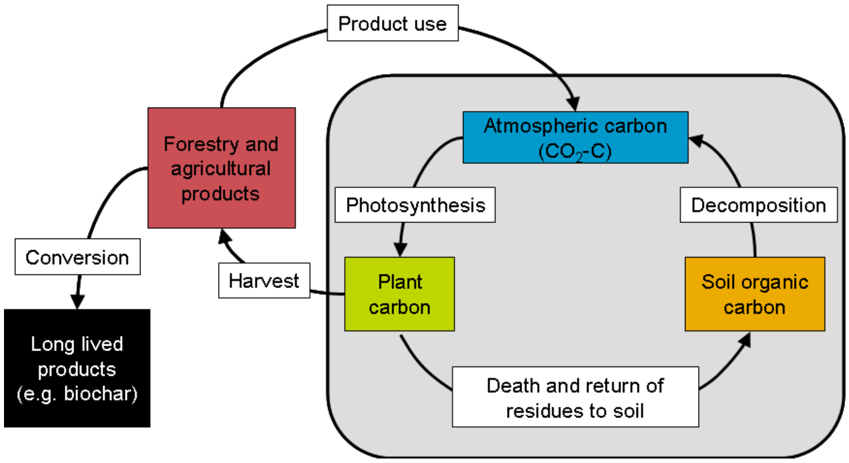
1. The National Soil Carbon Program designed to quantify inputs, amounts and forms of organic carbon in Australian soils and to design rapid assessment techniques.

2. Biochar: a number of projects are underway with the objective of analysing how feedstock and production methods affect biochar properties and the effect these properties have on plant production. This involves both field and pot trials.

3. Land use change and trade-offs under climate policy: CSIRO is investigating how actions in pursuit of carbon pollution may affect land-use patterns. One such option to be considered will be the extent to which a price for soil carbon sequestration might act as a driver for land use change.

Background
Atmospheric carbon continuously cycles through the plants and soils (**Figure 1**). In natural ecosystems the carbon cycle is limited to the components and fluxes identified within the grey box in **Figure 1**. Carbon is removed from the atmosphere by plants which convert CO_2-C into the various forms of organic carbon required for them to grow and reproduce. When plants die or components senesce, carbon is added to the soil. Decomposition of both the added carbon and that previously present in the soil returns carbon back to the atmosphere as CO_2-C. Under native unmanaged conditions, the amount of carbon present in each component becomes constant and the rates of carbon capture (via photosynthesis) and loss (via decomposition) become equivalent. In managed systems (e.g. lands used for agriculture or forestry), additional components and fluxes need to be considered, principally the removal of carbon associated with the harvesting of products. However, other factors such as the addition of fertilisers or water can significantly alter the rates of photosynthesis and/or decomposition and lead to significant changes in the size of the carbon cycle components.

Figure 1. The terrestrial carbon cycle. Components (coloured boxes) and fluxes (white boxes) inside the grey area correspond to the carbon cycle under native unmanaged conditions. Items located outside the grey box identify the additional components and fluxes that need to be considered in managed systems.



Sequestration of carbon refers to the permanent removal of carbon from the atmosphere. This can be achieved by increasing the size of the plant carbon or soil organic carbon components identified in **Figure 1** and then maintaining that increase through time. Additionally, a sequestration of atmospheric carbon can occur if a component of the carbon cycle is converted into a long-lived product such as biochar. Biochar refers to thermally altered forms of organic carbon created through a high temperature, low oxygen combustion process known as pyrolysis. The carbon present in biochar is typically stabilised against biological decomposition. Thus biochar can persist in soil environments for a greater time than the uncharred material from which it was created which leads to a sequestration of carbon.

Since carbon entering the soil was initially captured by photosynthesis, plant productivity sets an absolute upper limit to potential carbon inputs to the soil system (unless carbon is imported, as for example biochar or composts, or eroded material is deposition). In fact, over large regional areas, net primary productivity appears to control the carbon balance of soils.

In addition to organic carbon, some soils contain inorganic carbon. From the point of view of carbon sequestration within soil, only the organic components are considered. Soil organic carbon (SOC) can exist in a variety of different forms, collectively called soil organic matter (SOM). SOC includes the carbon associated with all living and non-living organic material in the soil. The living component includes plant roots, soil fauna and microorganisms. The non-living component, representing the bulk of SOC, includes a spectrum of material from fresh residues and simple monomeric compounds to highly condensed, irregular polymeric structures with residence times varying from days to millennia. The various forms of SOC can be divided into a series of fractions based on size and chemical composition (**Table 1**) (Baldock, 2007). Methodology exists to selectively define the allocation of SOC to the fractions identified in **Table 1** and to use these fractions in association with a soil carbon simulation model to estimate the potential outcome of changes in management practice on SOC content (Skjemstad et al., 2004).

Table 1. Definition of the various forms of non-living organic carbon that can exist in a soil.

Type of SOC	Composition of the indicated form of SOC
Surface plant residue organic carbon (SPR)	Plant residues residing on the soil surface (forest litter layers, crop/pasture residues)
Buried plant residues organic carbon (BPR)	Pieces of organic debris >2mm in size residing within the soil matrix
Particulate organic carbon (POC)	Organic carbon associated with soil particles ranging in size from 2 mm to 50 µm typically existing as pieces of semi decomposed plant residues
Humus carbon (Humus)	Organic carbon associated with soil particles <50 µm existing as small well decomposed pieces and molecules adsorbed onto soil particles <50 µm.
Resistant organic carbon (ROC)	Carbon associated with charcoal or biochar that is resistant to biological decomposition.

While some forms of SOC (such as particles of charcoal) are very stable, in many cases ‘sequestration’ in soil does not mean that any particular atom of carbon is trapped in the soil for a long period of time. Rather, sequestration requires that the net stocks in the soil are increased within a background of carbon cycling between the soil and the atmosphere. However, the nature of the carbon accumulated will define the vulnerability of that carbon to future change. For example, if the more biologically decomposable POC fraction is increased by a given management intervention, this carbon would be more vulnerable to future loss when compared against a management practices that resulted in an increase in humus carbon.

Increases in the stocks of SOC can occur either by increasing organic matter input rates or reducing loss rates (either through changes to the form of carbon input into soil or changed conditions that reduce decomposition rates). Following a change in management, practice or climate the subsequent change in inputs and outputs will lead soil to shift to a new equilibrium so long as the conditions and practices remain constant. These changes in soil carbon can take long periods of time to equilibrate with in excess of 50 years of constant management required to reach new equilibrium values (Petersen et al., 2005)

An additional issue requiring consideration is how long has the traditional management been imposed and what effect has this had on soil carbon content at the point of changed management. If traditional cropping systems have been in place for an extended period of time and soil carbon has been run down, it will be easier to build carbon up again than in a situation where carbon has not been run down. Where carbon has not been run down, it is possible that what ever management regime is imposed, soil carbon may continue to decline even under improved management, just not as fast as it would under traditional (exploitive) management.

While quantities of carbon in any hectare are modest (perhaps 50 t/ha in the top 30 cm), when summed over large areas the total amount and the effect of carbon loss over the 40-50 Mha or more of managed agricultural lands within Australia is significant.

Past clearing of agricultural lands has generally resulted in losses of SOC; however, exceptions to this have been noted, particularly agricultural production and fertiliser application have been initiated on sandy low fertility/low carbon content soils (Skjemstad and Spouncer, 2003). Globally, Lal (2004) estimated that 78 Pg of SOC have been lost due to agricultural practices with 26 Pg attributed to erosion and 52 Pg attributed to mineralisation. Through the use of best management practices it is estimated that 50-66% of the historic losses could be sequestered in soil over the next 50 years (Lal, 2004). For the Australian cropping soils (26 Mha), Dalal and Chan (2001) estimated that 290 Mt C may have been released into the atmosphere in the first 20 years of cereal cropping. If it is assumed that 60% of the emitted C can be recovered by improved management practice, an average potential carbon sequestration rate for Australian cropping soils of 0.14 t C/ha/y is obtained.

Soils are not able to accrue carbon indefinitely – it is postulated that under any given system of management, soil C will eventually achieve an equilibrium point (be ‘saturated’) beyond which no additional sequestration will occur.

To estimate the influence of pasture management on soil carbon several studies have been examined (Conant et al., 2001; Skjemstad and Spouncer, 2003; Young et al., 2009). Extracting the Australian data from Conant *et al.* (2001)indicated that 1) fertilization of pastures increased soil carbon by 0.24 tC/ha/yr (stdev = 0.12, n=11) and 2) other improvements (e.g. irrigation, presence of legumes) increased soil carbon by 0.11 tC/ha/yr (n = 4). However, the number of data points was small and values may not be representative.

Young et al. (2009) examined the conversion from 22 yrs of continuous cultivation and cropping to 6 yrs of perennial pastures on the Liverpool Plains, QLD. This region receives 680 mm of rain per year with a summer dominance but averaged 770mm during the study. Three types of pasture systems were examined (Lucerne, Lucerne + Phalaris, and a C3 + C4 mix composed of Panic, wallaby and bluegrass). The mean accumulation rate of soil carbon derived from time series data was 0.35 tC/ha/yr.

Data from FullCAM calibrations where the conversion from continuous wheat to pasture in WA trials was examined (Skjemstad and Spouncer, 2003), showed 0.59 tC/ha/yr (s.d. = 0.44, n = 6) relative gain and absolute increase of 0.30 tC/ha/yr (s.d. = 0.25, n = 6).

When reporting rates of sequestration of carbon in soil, it is important to distinguish between temporal measurements that define the actual rate of soil carbon change, and soil carbon differences between applied treatments which define the relative change. Where two different management practices are compared, without the measurement of temporal changes, the SOC difference between the two treatments can only be considered as relative.

The following average values for sequestration of carbon in Australian soils are provided from a CSIRO report currently under review:

1) Conversion to pasture (annual or perennial) from cultivation -
  Relative change: 0.5 – 0.6 tC/ha/yr
  Rate of change: 0.3 tC/ha/yr

2) Pasture improvement (fertilizer, grazing and irrigation changes)
  Relative change: 0.1 – 0.3 tC/ha/yr
  Rate of change: uncertain

The biggest changes in soil carbon induced by management change are noted early after the change in management occurs. It is not correct to assume that a given management strategy will result in a constant rate of soil carbon change through time. This may appear to occur in the first years after management change, but the size of any annual change will decrease through time. Commonly recommended practices such as low or no tillage which afford easily applied management changes to sequester soil carbon are already practiced over significant areas.

The major soil carbon opportunity identified in a recent CSIRO report (Eady et al., 2009) was to restore carbon in degraded grazing lands and this clearly involved reductions or a cessation of grazing. The report makes it clear that achieving carbon sequestration on grazing lands would potentially come at a significant cost to the producer / landowner. The biophysical potential soil carbon sink in the Australian rangelands in the CSIRO report (Eady et al., 2009) was estimated at 100M t CO2-e/ha/yr for 40 years. The potentially attainable sink for Qld, while requiring concerted policy action and practice change to be achieved, was estimated at 18 Mtonnes CO2-e/ha/yr for 40 years. These sinks were deemed to have the highest complexity and uncertainty of any of the sinks examined in the report (Eady et al., 2009). Similarly practically realisable abatement potential from cropping land was estimated to be negligible, if the land is to stay under cropping. Converting cropping land to permanent pasture is generally expected to build soil carbon, but this issue was not explicitly address in the CSIRO report (Eady et al., 2009). The implication of these studies is that while great potential exists for storing carbon in soils through management changes, realising these changes may be very difficult, may involve significant costs to landowners and may take a long time to accrue.

Unlike natural lands, lands under active management offer the possibility to import carbon from other sources and areas. Thermally stabilized (charred) biomass (biochar) from existing residues or purpose grown resources is one such option. Biochars are stable forms of charcoal produced usually around 450-500^{o}C and under low oxygen combustion in a process known as pyrolysis. Biochars have the potential to store carbon for very long periods. The nature and properties of biochar depend heavily on the material from which they are produced and the pyrolysis conditions. The properties of biochar appear to affect the benefits that can be obtained from their application to agricultural land.

For example, biochar made from manure will have a higher nutrient content than biochar made from wood cuttings. However, the biochar from the wood cuttings tends to be more stable over a longer period of time. Similarly biochar that is produced at 700^{o}C is likely to have a much greater adsorptive capacity and a higher degree of micro-porosity compared with biochar produced at 400^{o}C. The biochar produced at the higher temperature will consequently have a greater potential for adsorption of toxic substances and for rehabilitation of contaminated environments.

The challenge for sustainable agriculture is to balance the needs for food and fibre production with the need to maintain or increase the soil carbon stocks for both its role in sustaining production and sequestering carbon.

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