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Inquiry into soil carbon sequestration in Victoria
Submission no. 25

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Executive Officer
Environment and Natural Resources Committee
Parliament House
Spring Street
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To the Executive Officer,

Re: Inquiry into Soil Sequestration in Victoria

We thank you for the opportunity to make a submission to the inquiry into soil carbon sequestration in Victoria. We believe that this inquiry is much needed and well-timed to highlight the role that soil carbon sequestration can play in mitigating greenhouse gas emissions and improving agricultural productivity in Victoria.

This submission, prepared with the joint input of a group of Monash University researchers with expertise in soil carbon, presents an overview of the issues around returning carbon to soils, retaining carbon in soils and the measurement and modelling of soil carbon and dynamic processes. Monash University has strong research links with the Victorian Department of Primary Industries and the Department of Sustainability and Environment, relating to soil carbon sequestration.

We identify the need for an integrated strategy for sequestering carbon in soils, including the need for further research, which takes advantage of the significant natural resources that the state of Victoria has to offer.

Please feel free to contact Dr. Philip Wallis on (03) 9905 8709 or Phil.Wallis@msi.monash.edu.au for any further information or clarification regarding our submission.

Yours sincerely,

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Parliamentary Inquiry into Soil Carbon Sequestration in Victoria

Monash University Submission

Soil Carbon Opportunities for Victoria

Table of Contents

Introduction

Soils are capable of storing large quantities of carbon in a stable form, providing an opportunity for the sequestration of atmospheric carbon dioxide. A recent report from the Wentworth Group of Concerned Scientists highlighted the economic benefits of terrestrial carbon markets in offsetting greenhouse gas emissions and repairing degraded landscapes (Wentworth Group of Concerned Scientists 2009).

This review of soil carbon opportunities in Victoria considers some of the issues and ideas for sequestering carbon in soils, using local sources of carbon, in order to improve agricultural productivity and reduce levels of atmospheric carbon dioxide.

Soil organic carbon

Soil organic carbon (SOC) contains both living components (plant tissues, fungi, bacteria and fauna) and non-living components (detritus, black carbon and humus). Detritus consists of dead, but still recognisable, organic matter, while humus is essentially a complex mixture of partially decomposed organic residues. Humus can be further classified into three major components (or humic substances), based on their extractability: 1) fulvic acid, which is lowest in molecular weight and soluble in acid and alkali; 2) humic acid, which is higher in molecular weight and not soluble in acid; and 3) humin, which insoluble in both acid and alkali.

SOC plays an important role in soil fertility and structure by regulating nutrient availability and by binding together the inorganic components of the soil. The humic component of soils, in particular, contributes to water retention, cation exchange capacity, aggregation and nutrient provision in soils (Sparks 2003; Stevenson 1994).

Humic substances are a relatively stable form of carbon in soils, often associated with inorganic components such as clay minerals, which offer protection from decomposition. Black carbon, a natural product of burnt biomass or introduced in the form of ‘biochar’ or ‘agrichar’, is a more stable form of carbon, but is relatively inert and does not appreciably contribute to soil fertility and structure (Lehmann 2007; Lehmann and Joseph 2009).

Biochar has been receiving considerable publicity in the media of late (e.g. Saturday Age, November 21st) but there is a need for considerably more scientific research into such materials (Fyfe 2009).

Soils can store carbon in large quantities and in a relatively stable form, which provides a significant opportunity for mitigation of atmospheric carbon dioxide, with added benefits to soil health and agricultural productivity.

Depletion of soil carbon has been significant in Australian soils through land clearing, soil tillage, cropping and associated European farming methods that were introduced into Australia. Losses of 1-2% soil carbon represent significant inputs into CO_2 levels in the atmosphere. Replenishing soil carbon to the equilibrium levels prior to the introduction of European land management practices has enormous potential to mitigate atmospheric carbon dioxide.

Sequestration of atmospheric carbon dioxide in soils

The sequestration of carbon in soils is achieved indirectly through various mechanisms that convert atmospheric carbon dioxide into stable forms of soil carbon.

1. *Uptake of carbon dioxide through photosynthesis*

Photosynthesis is the primary mechanism for converting atmospheric carbon dioxide into plant biomass. All soil carbon sequestration (including biochar) is ultimately derived from this process. Plant growth requires sunlight, water, carbon dioxide, nitrogen, phosphorus and trace nutrients.

2. *Growth and retention of live biomass in the soil*

The growth of plant biomass, for example as plantation forests, is one way of introducing organic carbon to soils. In order for this to be considered carbon sequestration, the live biomass needs to be maintained and not burnt or harvested.

3. *Addition of non-living biomass to the soil*

Non-living biomass can be introduced to soils ‘in situ’ when living biomass is allowed to die and decay or from external biomass sources, such as plant litter, green waste or biochar added to the soil.

4. *Decomposition of non-living biomass*

Once non-living organic matter is introduced to soils, it undergoes a sequence of decomposition steps. These begin with the rapid mineralisation of ‘labile’, or easily decomposed, plant matter into carbon dioxide, water and ammonia. These labile organic components are typically found in the cytoplasm of plant cells and are made up of saccharides (sugars), organic acids, amino acids and enzymes and play a key role in soil ecology by providing energy and nutrients to the bacteria and fungi that feed on and break down these molecules (Bollag et al. 1998).

The organic molecules that make up the cell walls and other structural components of plant matter are less easily decomposed and often break down into what is known as the particulate organic carbon fraction. These molecules primarily include cellulose and lignin, but also hemicelluloses, waxes and proteins, which are all relatively resistant to microbial decomposition, but still provide an energy source to specialised fungi and bacteria and can be chemically decomposed through weathering.

It is worth noting that decomposition processes usually result in the vast majority of organic matter returning to the atmosphere as carbon dioxide, although the extent to which this occurs can be controlled by the method of introduction to the soil. For instance, in most circumstances, plant matter left on the surface of a soil is decomposed more rapidly and to a greater extent than that which is buried in the soil.

An exception to this process is ‘biochar’, which is considered to be relatively inert to decomposition and is effectively unaltered when introduced into a soil, making it stable for extremely long time periods (Lehmann et al. 2006). However, this is not the major form of stable soil carbon in soil. It can be formed naturally (through fires) or introduced from pyrolysis of biomass, as is being currently advocated (with limited data).

5. Stabilisation and polymerisation of organic residues

All that remains after the decomposition of plant matter and particulate organic carbon are chemically-resistant, cross-linked macro-molecules; otherwise known as humic substances. This fraction of soil organic matter comprises the major component of natural stable soil organic matter and hence the most significant repository of stable soil carbon. There is some debate as to the processes by which humic substances are formed and their molecular structure, but there it is a broad consensus that they play an important role in soil health. Appropriate land and soil management practices can assist the build-up and retention of humic substances in soil.

The overall balance of organic carbon in soils results from the difference between the rates of build-up and of loss. In this context, carbon sequestration occurs when the conditions in the soil are modified to favour carbon build-up relative to loss. Factors that influence both carbon build-up and loss include soil temperature, nutrient availability, sunlight and moisture levels, which subsequently influence levels of microbial activity and rates of plant growth. Other environmental factors, such as disturbances (e.g. wind, harvesting, fire and flood), can alter the balance, usually to the loss side of the equation.

Carbon in soils is ultimately derived from plant photosynthesis. ***A functional definition of soil carbon sequestration is that it occurs when the balance between carbon build-up and loss in the soil favours build-up relative to loss.***

Promoting Build-up of Soil Carbon

Clearing for agriculture has contributed to a major portion of the total global emissions of greenhouse gases over the last century. Clearing trees from the land exposes soils to more intense weathering from rainfall, wind and the sun, which causes carbon dioxide to be released, as well as more potent greenhouse gases such as methane and nitrous oxide. The legacy of this widespread clearing is a large quantity of atmospheric carbon dioxide and the depletion of soil carbon on cleared land.

Current agricultural practices also continue to contribute to carbon emissions. Practices such as burning crop stubble, soil tillage, over-application of fertilisers, as well as livestock emissions and methane generation from rice cultivation, generate a large proportion of Australia’s greenhouse gas emissions from agriculture.

Agricultural soils in Victoria are now severely depleted of soil carbon. This presents an opportunity to increase the level of SOC towards the capacity that the soil can hold. The aim should be to re-establish soil carbon to the previous equilibrium levels or higher, than those that existed prior to European disturbance. This can be achieved through the input of different organic sources of carbon.

Living sources of carbon

Carbon can be directly returned to soils by planting trees and crops to take-up atmospheric carbon dioxide. The strategy of enhancing biomass production introduces carbon to soils, which increases the rate of humification and transfer of carbon into recalcitrant and stable humic substances. Furthermore, the transfer of stable organic carbon forms into deep sub-soil layers, where it is more likely to be stabilised, can be facilitated by enhancing soil biodiversity and structure (Lal 2004).

However, large-scale reafforestation projects can cause unintended consequences for water resources, as growing trees consume large volumes of water. As Victoria's water resources are already critically stressed and projected to be even more so under climate change, this could be a significant limitation to carbon sequestration through large-scale reafforestation projects; a topic for further research.

Question # 1 What are the systemic consequences of large-scale reafforestation for carbon sequestration, particularly with respect to water resources?

Greenwaste streams

Greenwaste provides a valuable source of high-quality carbon from garden and supermarket waste streams. Other industrial waste products, such as fly-ash or slag, can be combined with green wastes to produce organic-rich topsoil. It is important to avoid green waste ending up in landfills, as the anaerobic (low oxygen) environment of the landfill means that biomass breaks down into methane, which is a potent greenhouse gas.

As a carbon source, however, green waste sources are highly dispersed, requiring extensive transport, and are valued for other uses, such as potting mix, mulch and compost. This waste stream has also been proposed as a feedstock for biochar production.

Humic soil amendments

Humic substances, as described above, are a stable carbon store in soils that play a key role in soil fertility and structure. Soil amendments containing humic substances can indirectly or directly facilitate carbon sequestration by improving soil conditions so as to assist plant growth. This is potentially the most useful application of humic substances and there is considerable scientific literature to support the growth stimulant effect of humic substance applications (Eyheraguibel et al. 2008; Puglisi et al. 2009). Humics may also facilitate carbon sequestration by protecting more labile (easily decomposable) plant matter from mineralisation (Spaccini et al. 2002). Such humic-rich soil amendments can be prepared from coal and other carbon-rich sources including peat. The oxidation of brown coal yields a product rich in humic and fulvic materials, which is significant as Victoria has extensive reserves of brown coal in the LaTrobe Valley. However, converting one stable form of carbon to another, and using energy to do so, needs to be considered carefully.

Soil acidity is a significant constraint on crop productivity in Australia. Calcium-saturated humate- and fulvate-rich soil amendments, derived from Victorian Loy Yang brown coal, have been demonstrated to be effective in treating acidified soils by reducing exchangeable aluminium and increasing pH (Peiris et al. 2002). Soil aggregate stability was improved in acidic soils using potassium humate derived from Victorian brown coal (Imbufe et al. 2005). Humic amendments can be added to soils with existing farm machinery, either sprayed as a liquid, applied as pellets with a seeder or with a fertiliser spreader. Application rates range from 0.5 kg/ha to 1000 kg/ha, depending on the form of product (e.g. liquid, solid, slow-release) and the application method used (e.g. fertigation, foliar spray, top-dressing). Humic amendments can also be co-applied with other fertilisers, for example, as humic-coated granules of phosphate fertiliser. Humic substances applied with fertilisers and/or fertilisers formulated with humic substances may also result in more efficient use of plant nutrients as well as the enhanced soil carbon sequestration.

Black carbon (biochar & charcoal)

Black carbon is a component of global soil carbon pool that is relatively inert and cycles slowly through the carbon cycle (Major et al. 2009). Black carbon naturally occurs in the form of charcoal produced by wildfire, or synthetically as biochar. Black carbon is not easily classified as a single entity; rather, black carbon presents as a continuum ranging from charred biomass, to combustion residues to highly condensed structures (Hammes et al. 2007). Biochar (or agrichar) is a product formed by pyrolysis of plant matter; that is, the 'burning' of plant biomass in a low- or no-oxygen environment (because there is no O_2 present, there is little CO_2 produced). The carbon-rich biochar produced in this way is, to a high degree, chemically and biologically inert, and can be added to soils to directly sequester carbon (Sohi et al. 2009).

However, it is also claimed that biochar can improve soil conditions and assist plant growth, thus facilitating carbon sequestration indirectly. While it is not entirely clear how this occurs, some propose that the char acts as a protective substrate for nitrogen-fixing bacteria, which stimulate plant growth (Carbolea 2009). Biochar has also been shown to assist plant growth when used in conjunction with a nitrogenous fertiliser (Chan et al. 2007). Biochar is proposed to adsorb significant amounts of plant nutrients which can be accessed by plants. It is also claimed to provide a "substrate" for beneficial microbes that assist plant growth by making plant nutrients more readily available. The chemical-biological interactions claimed by char proponents require further research.

Question # 2 Does biochar provide additional benefits to soil fertility and structure and what are the mechanisms by which this occurs?

Biochar exhibits one advantage in its use as a carbon offset: it is relatively easy to measure what is added to the soil, while remaining confident that it won't break down. While this is useful for carbon accounting, it might not translate into improved soil fertility. Additionally, if biochar were to become a popular carbon offset in Australia, it could result in unintended consequences, such as the conversion of useful agricultural products to black carbon or the use of agricultural land to produce biomass expressly for biochar production.

The potential to return organic matter to soil that is severely depleted in carbon, as a result of land clearing and unsustainable agricultural practices, provides an opportunity to store large quantities of carbon while also improving soil health. There is debate as to whether biologically-active forms of soil carbon sequestration are more desirable than sequestration with relatively inert forms of carbon. Furthermore, this also raises questions around the advantages and disadvantages of either in-situ sequestration (i.e. enhanced plant growth) or ex-situ sequestration (i.e. burial of black carbon).

The life cycle assessment on biochar clearly needs to be done with energy and carbon footprint factors needing to be assessed. All energy inputs and outputs should be quantified with consideration given to the biomass sources used (waste from crops, green waste), transport to a pyrolysis plant, transport to the paddock (clearly distance is a primary consideration here) and the quantities needed to benefit soil. Proponents claim the energy of producing the material comes from the biomass that is pyrolysed; this also requires thorough assessment.

Question # 3 What does life cycle assessment reveal about the advantages and disadvantages of in-situ versus ex-situ soil carbon sequestration?

Preventing Soil Carbon Loss

In addition to restoring levels of soil carbon, changes to clearing policies and farming practices need to be implemented to ensure that further depletion does not occur and any carbon captured is not lost again. We need to think in the context of a new higher equilibrium of carbon in soils. A build-up phase must occur, then a new steady state; logically, it cannot be a continuous build-up!

Carbon-sensitive farming practices

Farming practices that result in less disturbance to the soil, or that minimise the application of fertiliser, are generally able to reduce carbon losses from the soil. These practices can be classified as follows:

1. ***No-tillage or conservation tillage.***

   Tillage of soil (the preparation of soil by ploughing or turning) is done to loosen soil to encourage the deeper growth of plant roots, and to mix crop residues back into the soil. Tillage causes compaction of the soil below the tilled layer, and exposes soil carbon to mineralisation. Farming practices that minimise or eliminate tillage can increase the levels of soil carbon (Chatterjee and Lal 2009).

   In the duplex (texture-contrast) soils of south-eastern Australia, no-till practices on cropping, pasture and horticultural soils have the ability to significantly reduce the rate of SOC loss (Slattery and Surapaneni 2002).

2. ***Ground cover and mulching***

   Cover crops are planted alongside a main crop, either just before or after harvest, in order to reduce soil erosion and increase SOC (Hartwig and Ammon 2002). Continuous cropping, utilising cover crops between harvests, provides perpetual carbon inputs to soil and leads to higher carbon accumulation compared with standard tillage/fallow methods (Minoshima et al. 2007).

   Mulch consists of either a natural or synthetic cover placed over the soil to moderate heat exchange and conserve soil moisture as well as to limit soil erosion. Residue mulch consists of plant components that remain after crop harvesting.

3. ***Nutrient management***

   Over-application of fertiliser contributes significantly to agricultural greenhouse gas emissions from microbial breakdown of nitrogen in soils. Nitrous oxide (N_2O) is produced from the excessive use of nitrogen fertilisers and disturbance of soils and has a global warming potential 296 times that of carbon dioxide (Dalal et al. 2003). Managing levels of nutrient application to suit soil conditions can reduce the emission of greenhouse gases.

   Organic matter from biomass, by its very nature, also contains N, P, S and other minor nutrients. There are concerns in some quarters that increasing soil biomass, and hence SOC, locks up higher levels of these nutrients, costing farmers who apply these nutrients through fertilisers. The turnover of the nutrients (e.g. movement of N or P between organic and inorganic pools) needs to be better understood.

   One could also argue that with a higher level of soil biomass (and hence soil C) soil fertility is enhanced indirectly through physical and biochemical improvements. Furthermore, the fraction of material that is “turning over” in a higher soil biomass equilibrium situation, means that more plant nutrients are also turning over, hence less external fertiliser applications are required, bearing in mind mass balance issues regarding returning what is being removed from the land.

   An emerging problem for food production in the future will be addressing the dwindling P reserves for producing traditional P fertilisers. We will need to come up with better efficiencies in the use of P fertilisers. Higher carbon levels in soils, provided it is the right form of C, may have a significant effect on more efficient use of applied P as well as accessing P reserves in the soil (Schefe et al. 2008).

Question # 4 What is the effect of humic substances on the efficiency of nitrogen fertilisers and how can these contribute to improved nutrient management?

Land use change

Some land uses are incompatible with certain soil types, leading to long-term decline in soil health. Repeated application of fertilisers causes soil acidification, as does the use of some leguminous crops.

Harvest of forests can also release significant levels of carbon to the atmosphere through soil disturbance and decomposition or burning of residues (McAlister and Horne 2009).

> Permanent changes need to be made to the way our soils are managed, in order to ensure that more sustainable use is made of the land so that carbon is retained in the soil for longer.

Measurement and Modelling of Soil Carbon Sequestration

One of the reasons why agricultural emissions have not been included in Australia's proposed Carbon Pollution Reduction Scheme is the sector includes thousands of small emitters and that the measurement and calculation of these would be too complex (DCC 2008). This is despite the fact that agriculture contributes 15.6 per cent of Australia's net greenhouse gas emissions, in carbon dioxide equivalents (CO_2-e). Land use, land use change and forestry contribute an additional 6.9 per cent, meaning that nearly a quarter of Australia's total greenhouse gas emissions come from the land.

The potential to sequester carbon in soils, and thus turning a carbon source into a carbon sink, should give impetus to developing methods to account for the carbon balance of soils.

Direct measurement of soil carbon

Soil organic carbon content is usually measured directly by taking soils cores and using a chemical oxidant and measuring how much oxidant was consumed, or by combusting the sample and measuring CO_2 evolution, or calculating mass balance. Soil colour measurements can also be used as a proxy for soil carbon, but are not accurate in soils with low carbon content (Viscarra Rossel et al. 2008).

The above methods only determine total organic carbon (TOC) and do not distinguish between different fractions. A rapid method for determining soil organic carbon using mid-infrared (MIR) spectroscopy can be used to differentiate the particulate organic carbon fraction and charcoal carbon from TOC (Janik et al. 2007).

Remote sensing of soil carbon

Levels of organic carbon in soils can be estimated using remote sensing combined with dynamic modelling, but with only moderate accuracy (Zhou et al. 2008). Soil colour, as derived from visible band satellite imagery, can be used to estimate levels of soil carbon, but as mentioned above are not accurate in soils with low levels of organic carbon.

Dynamic modelling of soil carbon

Modelling carbon sequestration across a landscape is a complex process that requires detailed geographic information on climate, land use, soil type and topography. The Environmental Systems Modelling Platform (EnSym) developed by the Victorian Department of Sustainability and Environment (DSE) is one such example (DSE 2009a). This approach utilises a range of biophysical models to evaluate the level of carbon sequestration for a range of management activities.

An Integrated Strategy for Sequestering Carbon in Soils

Soil carbon sequestration occurs when the build-up of carbon in the soil exceeds the losses. This means that a strategy for increasing the level of carbon in soils needs to include both the means to add carbon and the means to prevent its loss.

Carbon sequestration needs to be thought of as restoring levels of soil carbon to a higher equilibrium. Replenishing soil carbon to the equilibrium levels prior to the introduction of European land management practices has enormous potential to mitigate atmospheric carbon dioxide.

Scope for carbon biosequestration in Victoria

The State of Victoria has a number of key advantages that would support an integrated strategy for sequestering carbon in soils, including the following:

Extensive agricultural production

Victoria produces approximately one quarter of export in food and fibre Australia-wide, on only three per cent of the total agricultural land (DPI 2008). Farmers manage more than 60 per cent of Victoria's land, which means that active management for carbon sequestration could be widespread if the incentives to do so exist. In the agricultural sector, Victoria has thousands of "land managers" (i.e. our farmers) dealing with soil every day (either directly or indirectly). This resource could be harnessed in a massively useful way to sequester soil C in the future. Of course, there must be economic incentives, such as increased farm production yields, lowering costs, payment for carbon storage, as well as an education program to bring about the change.

Additional benefits will come from raising soil organic matter levels, hence soil C, in terms of overall agricultural productivity and environmental benefits.

A rich source of carbon for producing humic soil amendments

Extensive brown coal and peat reserves provide an opportunity for producing humic rich organic soil amendments that would improve soil condition and assist plant growth (Jackson et al. 1996). Life cycle analyses would need to be carried out.

Incentives for private land owners to sequester carbon in soils

The management of private land to restore native vegetation and protect existing remnant vegetation could be the most cost-effective and equitable way of sequestering carbon in Victoria. However, private land owners require an incentive to manage their land to sequester carbon.

Carbon tender

The approach championed by the DSE's ecoMarkets program is a tendering process (e.g. EcoTender) where land owners bid for funding to improve their land. Funding is provided from a pre-defined pool and tenders are evaluated based on an environmental benefits index and the amount of carbon sequestered. This aim of this program is to deliver multiple environmental outcomes at the scale of whole river catchments in the most cost-effective way. The ecoMarkets approach could be expanded to include more of a focus on soil carbon sequestration (DSE 2009b). The amount of carbon sequestered would be limited by the funding available in the tender; however, this approach has the advantage that is favours bids that offer the greatest cost-effectiveness and also provides measurable multiple environmental benefits.

Carbon offset market

Carbon offsets are activities that sequester carbon that are commissioned to balance out the carbon emissions generated by another businesses' or individual's activities. A regulated carbon offset market that includes soil carbon sequestration could be used to match carbon offset projects with carbon emitters in a cost-effective way. With the decision to exclude agricultural emission from the Government's proposed Carbon Pollution Reduction Scheme, the amended scheme includes an alternative ‘offset credits’ program. Permits can be traded for abatement of agricultural emissions attributed to livestock, manure management, fertiliser use, burning of savannas, burning of agricultural residues, rice cultivation, avoided deforestation, regrowth forests on deforested land and soil carbon on deforested land (from 2013) (DCC 2010).

Promotion of inherent benefits

Land owners who manage their land for productive agriculture could potentially benefit from carbon sequestration activities through increased agricultural productivity and long-term improvements to soil fertility. The Victorian Government could promote conservation agriculture to producers through an extension or start-up scheme.

A discussion of carbon sequestration strategies for Victoria

Assuming that the right incentives exist for private land owners to manage their land for carbon sequestration, the different strategies potentially available for sequestering carbon will produce different outcomes.

Large-scale revegetation, restoration and protection of remnant vegetation

A strategy of broad-scale revegetation of cleared land, restoration of degraded vegetated areas and protection of remnant vegetation would provide multiple benefits for carbon sequestration, terrestrial biodiversity and river and wetland health. The carbon sequestration benefits of this strategy would accrue over the time it takes for vegetation to mature and would require a management strategy to prevent loss or deterioration of revegetated areas (Vesk and Mac Nally 2006).

A disadvantage of this strategy is that it would prevent land being used for other productive purposes; however, the value of the environmental goods and services provided by the restored land could exceed the land’s productive value if the incentives were right (Harper et al. 2007). Wide-scale revegetation could also result in unintended consequences in the form of increased fire risk and potentially increased abstraction of water from rivers.

Conservation agriculture

Adopting conservation agricultural practices on productive land would decrease agricultural greenhouse gas emissions, sequester carbon in the soil and would help to restore and maintain soil health. As the land would still be under agricultural production, the carbon sequestration potential is less per area of land compared to revegetation; however, the large area of cropping land in Victoria means that widespread adoption of conservation agriculture would add up to a significant amount of carbon sequestration.

Humic amendments from brown coal

Humic amendments, used in concert with conservation agricultural practices, can promote the gradual build-up of soil organic carbon to a higher equilibrium level by stimulating plant growth. The role of humic amendments as a plant growth stimulant means that relatively low application rates are required.

Biochar production, distribution and use on soils

Two models of biochar production are available: i) centralised production in one or more large industrial pyrolysis plants; and ii) distributed production using on-farm machinery (Laird et al. 2009). Centralised production has the benefit of being more cost-effective per unit of biochar produced, would produce a more consistent and higher-quality product, the plant could be setup (at least in part) to run off the hydrocarbon product resulting from biochar production and the biochar could be pelletised for easier distribution. The main disadvantage of this method is the cost and emissions of greenhouse gases associated with transport of biomass to the plant and of biochar to farms. Additionally, this method would see a redistribution of carbon from one location to another; for example, biomass from native forests could end up on farms.

Were biochar to be produced on-farm using a small biomass pyrolysis unit, then many of the transport costs and emissions are reduced. Carbon produced on the farm would end up back on the same land. However, unless the technology for producing biochar on this scale is suitably developed, the biochar product may not be of the quality needed to have any benefit to the soil. For example, when biochar is produced below 400 °C, the resulting product has a low pH, CEC and surface area, which are not desirable for soil fertility (Lehmann 2007).

A thorough life-cycle assessment would need to be done on both of these alternatives to determine the total cost (including externalities) and the net value of carbon sequestration (taking into account emissions generated in every stage of the biochar production and distribution process).

Potential for Carbon Biosequestration in Soils

The amount of carbon that can be potentially sequestered in Australia’s soils is subject to widely varying claims. This section includes a discussion of how different groups have calculated carbon sequestration potential and comments on the feasibility of various strategies.

Garnaut Report, 2008

Chapter 22 of the Garnaut Review Final Report deals with the role that “transforming rural land use” can play in abatement of greenhouse gases (Garnaut 2008). The report estimates that approximately 1060 Mt CO_2-e/yr can be reduced or removed from agricultural, land use and forestry sectors.

This analysis includes biofuel production to offset fossil fuel use, as well as widespread rehabilitation of degraded grazing lands and arid landscapes, carbon farming, reduction of livestock methane emissions and ceasing all deforestation. Conservation agriculture was estimated to be able to remove 68Mt CO_2-e/year from the atmosphere.

CSIRO Analysis, 2009

This report, commissioned by the Queensland Premiers Climate Council, provided an in-depth analysis of both the “technical potential” for greenhouse gas abatement through land-use change and the amount considered “attainable” (CSIRO 2009). This report came up with figures for the State of Queensland of 293 Mt CO_2-e/yr for the full technical potential and 140 Mt CO_2-e/yr as an attainable amount. This analysis also produced an estimate for Australia’s total abatement potential through land-use change of 1017 Mt CO_2-e/yr (this figure was also quoted in the Wentworth Group’s report).

This analysis (as with the Garnaut Review) includes an assessment of emission prevention (e.g. cutting livestock enteric emissions or reduced land clearing) as well as activities that increase the store of carbon in soils (e.g. rehabilitating degraded rangelands or carbon forestry). The report used an assumption of $20/tonne for carbon to identify areas that would have suitable incentive to convert to carbon forestry.

Major Points

The following are points to consider in devising a policy or strategy for carbon biosequestration in Victoria

1. Strategies for carbon biosequestration should also take into account the abatement of emissions from agriculture and land clearing. This would not only increase the potential of land management practices to offset greenhouse gas emissions, but would also avoid unintended consequences; for example, the release of N_2O (a potent GHG) from fertilisation of carbon crops would most likely result in a net increase in emissions.
2. Furthermore, any strategy to sequester carbon in soils should include an integrated suite of measures to both prevent loss of carbon from the soils (e.g. conservation agriculture) and increase build up (e.g. plant growth stimulants).
3. Incentives are required for private land owners to modify their land use or agricultural practices to be geared towards carbon sequestration. To achieve wide-scale adoption of any carbon biosequestration strategy, a suitable incentive framework needs to be developed, such as a tender or regulated carbon offset market.

References

Bollag, J.M., Dec, J., and Huang, P.M. (1998), 'Formation mechanisms of complex organic structures in soil habitats', *Adv. Agron.,* 63, 237-66.

Carbolea (2009), 'Research Areas - Biochars', <http://www.carbolea.ul.ie/biochar.html>, accessed 12 November.

Chan, K. Y., et al. (2007), 'Agronomic values of greenwaste biochar as a soil amendment', *Australian Journal of Soil Research,* 45 (8), 629-34.

Chatterjee, A. and Lal, R. (2009), 'On farm assessment of tillage impact on soil carbon and associated soil quality parameters', *Soil & Tillage Research,* 104 (2), 270-77.

CSIRO (2009), *An Analysis of Greenhouse Gas Mitigation and Carbon Biosequestration Opportunities from Rural Land Use*, eds Sandra Eady, et al. (St Lucia, QLD: Commonwealth Scientific and Industrial Research Organisation).

Dalal, Ram C., et al. (2003), 'Nitrous oxide emission from Australian agricultural lands and mitigation options: a review', *Australian Journal of Soil Research,* 41 (2), 165-95.

DCC (2008), 'Carbon Pollution Reduction Scheme: Australia's Low Pollution Future. White Paper, Volumes 1&2', (Canberra: Department of Climate Change, Commonwealth of Australia).

--- (2010), 'Department of Climate Change - Agriculture - Think Change', <http://www.climatechange.gov.au/government/initiatives/cprs/who-affected/agriculture.aspx>, accessed 5 February.

DPI (2008), 'Future Farming. Productive, Competitive and Sustainable', (Department of Primary Industries, Victoria).

DSE (2010), 'The science behind ecoMarkets', <http://www.dse.vic.gov.au/ecomarkets>, accessed 28 January.

--- (2009b), 'Securing Our Natural Future. A white paper for land and biodiversity at a time of climate change', (East Melbourne: Victorian Government Department of Sustainability and Environment).

Eyheraguibel, B., Silvestre, J., and Morard, P. (2008), 'Effects of humic substances derived from organic waste enhancement on the growth and mineral nutrition of maize', *Bioresource Technology,* 99 (10), 4206-12.

Fyfe, Melissa (2009), 'Green hype, or is biochar the key to carbon control?', *The Age,* November 21.

Garnaut, Ross (2008), *The Garnaut Climate Change Review: Final Report* (Port Melbourne, Victoria: Cambridge University Press).
Hammes, Karen, et al. (2007), 'Comparison of quantification methods to measure fire-derived (black/elemental) carbon in soils and sediments using reference materials from soil, water, sediment and the atmosphere', *Global Biogeochem. Cycles,* 21.
Harper, R. J., et al. (2007), 'The potential of greenhouse sinks to underwrite improved land management', *Ecological Engineering,* 29 (4), 329-41.
Hartwig, Nathan L. and Ammon, Hans Ulrich (2002), 'Cover Crops and Living Mulches', *Weed Science,* 50 (6), 688-99.
Imbufe, Albert U., et al. (2005), 'Effects of potassium humate on aggregate stability of two soils from Victoria, Australia', *Geoderma,* 125 (3-4), 321-30.
Jackson, W. R., et al. (1996), 'Characterisation of brown coal humic acids and modified humic acids using pyrolysis gcms and other techniques', *International Journal of Coal Geology,* 32 (1-4), 229-40.
Janik, L. J., et al. (2007), 'The prediction of soil carbon fractions using mid-infrared-partial least square analysis', *Australian Journal of Soil Research,* 45 (2), 73-81.
Laird, David A., et al. (2009), 'Review of the pyrolysis platform for coproducing bio-oil and biochar', *Biofuels, Bioproducts and Biorefining,* 3 (5), 547-62.
Lal, R. (2004), 'Agricultural activities and the global carbon cycle', *Nutrient Cycling in Agroecosystems,* 70 (2), 103-16.
Lehmann, Johannes (2007), 'Bio-energy in the black', *Front. Ecol. Environ.,* 5 (7), 381-87.
Lehmann, Johannes, Gaunt, John, and Rondon, Marco (2006), 'Bio-char Sequestration in Terrestrial Ecosystems – A Review', *Mitigation and Adaptation Strategies for Global Change,* 11 (2), 395-419.
Lehmann, Johannes and Joseph, Stephen (eds.) (2009), *Biochar for environmental management: science and technology* (UK: Earthscan) 416.
Major, Julie, et al. (2009), 'Fate of soil-applied black carbon: downward migration, leaching and soil respiration', *Global Change Biology,* 9999 (9999).
McAlister, Scott and Horne, Ralph E. (2009), 'Climate change responses: carbon offsets, biofuels and the life cycle assessment contribution', in Ralph Horne, Tim Grant, and Karli Verghese (eds.), *Life Cycle Assessment: Principles, Practice and Prospects* (Melbourne, Australia: CSIRO Publishing).
Minoshima, H., et al. (2007), 'Soil Food Webs and Carbon Dynamics in Response to Conservation Tillage in California', *Soil Science Society of America Journal,* 71 (3), 952-63.
Peiris, Damayanthi, et al. (2002), 'The use of Ca-modified, brown-coal-derived humates and fulvates for treatment of soil acidity', *Australian Journal of Soil Research,* 40 (7), 1171-86.
Puglisi, Edoardo, et al. (2009), 'Effects of a humic acid and its size-fractions on the bacterial community of soil rhizosphere under maize (Zea mays L.)', *Chemosphere,* 77 (6), 829-37.
Schefe, Cassandra R., et al. (2008), 'Interactions Between Organic Amendments and Phosphate Fertilizers Modify Phosphate Sorption Processes in An Acid Soil', *Soil Science,* 173 (7).
Slattery, W. J. and Surapaneni, A. (2002), 'Effect of soil management practices on the sequestration of carbon in duplex soils of southeastern Australia', *Agricultural Practices and Policies for Carbon Sequestration in Soil*, 107-17.
Sohi, S., et al. (2009), 'Biochar's roles in soil and climate change: A review of research needs', (CSIRO Land and Water Science Report 05/09), 64.
Spaccini, R., et al. (2002), 'Increased Soil Organic Carbon Sequestration through Hydrophobic Protection by Humic Substances', *Soil Biol. Biochem.,* 34, 1839-51.
Sparks, D.L. (2003), *Environmental Soil Chemistry* (2nd edn.; San Diego: Academic Press).
Stevenson, F.J. (1994), *Humus Chemistry: Genesis, Composition, Reactions* (New York: John Wiley & Sons).
Vesk, Peter A. and Mac Nally, Ralph (2006), 'The clock is ticking--Revegetation and habitat for birds and arboreal mammals in rural landscapes of southern Australia', *Agriculture, Ecosystems & Environment,* 112 (4), 356-66.

Viscarra Rossel, R. A., Fouad, Y., and Walter, C. (2008), 'Using a digital camera to measure soil organic carbon and iron contents', *Biosystems Engineering,* 100 (2), 149-59.
Wentworth Group of Concerned Scientists (2009), 'Optimising Carbon in the Australian Landscape. How to guide the terrestrial carbon market to deliver multiple economic and environmental benefits.'.
Zhou, Tao, et al. (2008), 'Estimation of soil organic carbon based on remote sensing and process model', *Frontiers of Forestry in China,* 3 (2), 139-47.