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EXPLAINER

TECHNOLOGY
TOWARDS NET ZERO

Australia's Soil Carbon Opportunities and Risks

More carbon is stored in soil than in the atmosphere and all plant life combined. Soil carbon sequestration is the process in which carbon dioxide (CO_2) is removed from the atmosphere by plants and stored in soils. Sequestering carbon in soils not only removes carbon dioxide from the atmosphere but can also improve soil health, potentially increasing agricultural yields and delivering ecosystem benefits — but what are the barriers to this technology becoming a widespread emissions reduction strategy?

As a signatory to the Paris Agreement, Australia has made commitments to reduce greenhouse gas emissions by 26-28 per cent, compared to 2005 levels, by 2030.* If we are to meet, or go beyond, these commitments to a net zero emissions economy, soil carbon sequestration may be an important enabler for net emissions reduction.

KEY POINTS

- Soil carbon has potential to contribute to an Australian negative emissions strategy by offsetting emissions from high emitting industries.
- Soil carbon sequestration was one of the initial 5 priorities in the Australian government's emission reduction technology roadmap, with over $200 million set aside in the 2021-22 Federal Budget to improve and protect Australia's soils.
- Unfortunately, the costs of measuring soil carbon change in some cases may exceed the returns generated by carbon credits for farmers, who may also face costs associated with a required change in land management. There is a clear need for low-cost, accurate technologies and methods to measure soil carbon.
- Improvements in the technology and methodology of soil carbon measurement, better understanding of the most effective sequestration practices for each region, and an improved market for Australian Carbon Credit Units (ACCUs), could see soil carbon abatement become a viable source of income for farmers as we move towards net zero emissions in Australia.

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* The Paris Agreement is a legally binding international treaty on climate change that commits to limit global warming to well below 2 degrees, preferably at 1.5 degrees Celsius. It was adopted by 196 Parties at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

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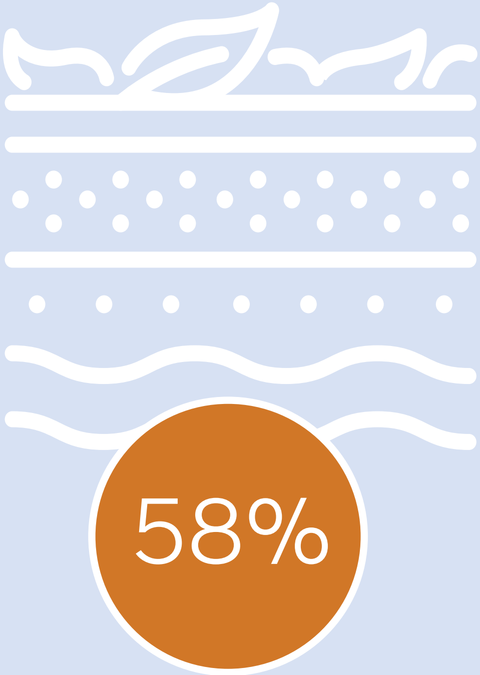
Soil carbon sequestration was one of the initial 5 priorities in the Australian government's emission reduction technology roadmap[1], with over $200 million set aside in the 2021-22 Federal Budget to improve and protect Australia's soils. This investment has been geared towards encouraging farmers to test and improve soil, and to assist in the development of technologies that facilitate participation in the Emissions Reduction Fund.[2] Successful development and implementation of these technologies will involve careful consideration of the risks and benefits for Australia's farmers, and further development of enabling technologies that measure soil carbon.

This explainer sets out the barriers and opportunities to the use of soil carbon as an enabling technology in Australia's transition to net zero emissions.

WHAT IS SOIL CARBON?

Soil carbon refers to both the carbon in organic matter which has a critical role in the chemical, physical and biological health of soils, and to inorganic carbon that occurs as carbonate minerals (such as limestone) or charcoal in soils. This explainer deals specifically with carbon in soil organic matter which can be influenced by land management practices.



The carbon content of soil organic matter is approximately 58 per cent by weight.[3]

The amount of organic carbon in the soil is in a dynamic balance between inputs of organic materials from plant residues, roots and exudates, and outputs via decomposition by microorganisms and soil animals, and erosion. An overview of this dynamic system is shown in Figure 1.

Under stable management, soil organic matter reaches a steady state equilibrium: that is, the amount of carbon coming into and out of the soil remains in balance. When land management is changed, loss or gain in soil carbon content can occur rapidly at first, before a new steady state equilibrium is slowly attained. This can take 20 to 100 years.

Soil carbon is of interest to a range of Australian stakeholders, from farmers and researchers, to industry and governments. It is a potential as a source of carbon abatement which stores carbon that would otherwise enter the atmosphere in gases such as CO_2 and methane and contribute to climate change. Soil carbon has potential to contribute to an Australian negative emissions strategy by offsetting emissions from high emitting industries such as transport and industrial processing.

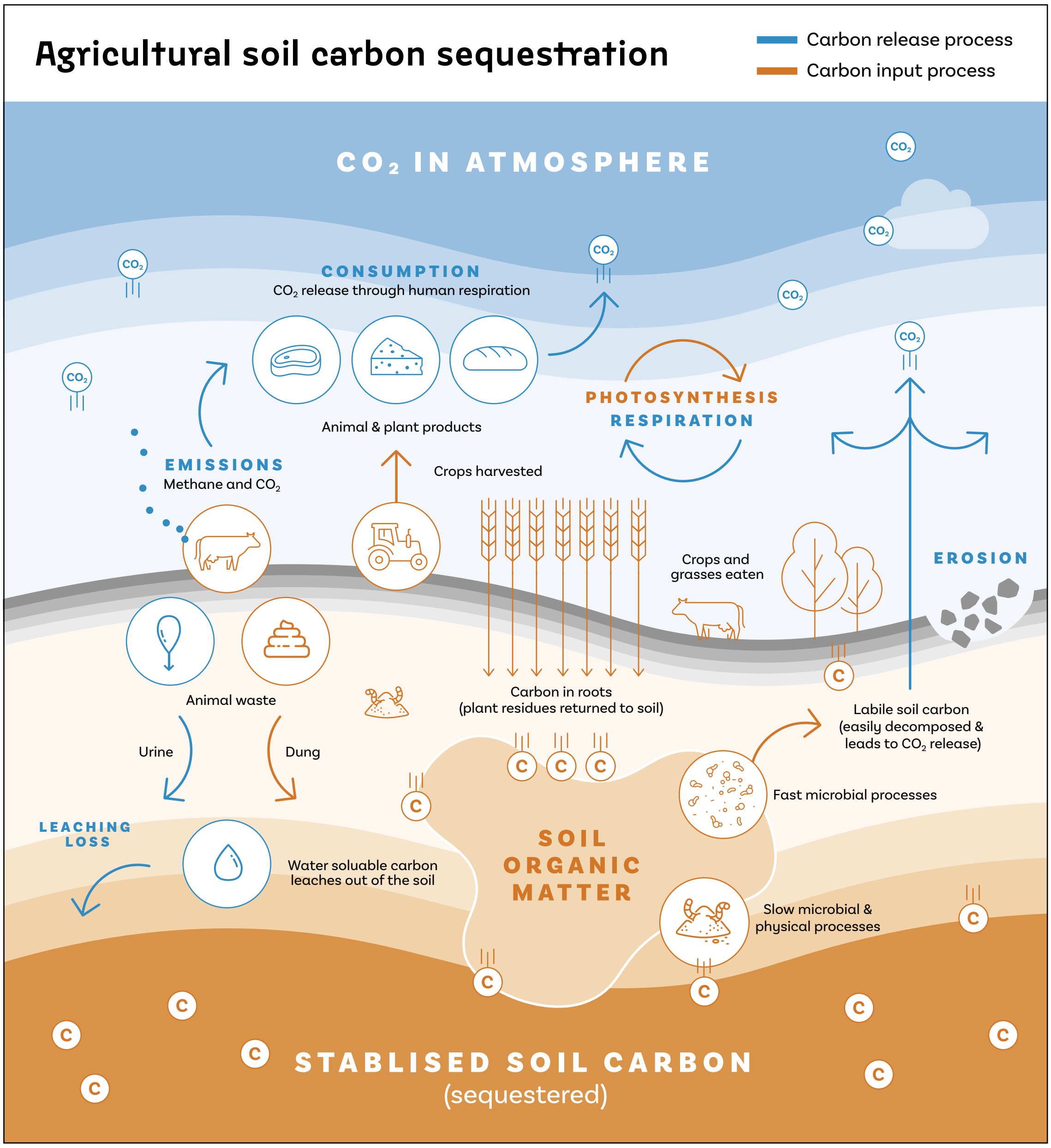


FIGURE 1. Agricultural soil carbon sequestration Carbon naturally enters and leaves the soil through a range of complex processes occurring simultaneously. By changing land management practices, the amount of carbon stored in soils can be increased or decreased.[4]

WHAT CONDITIONS AFFECT SOIL CARBON CONTENT?

The organic carbon content of soil can be influenced by rainfall, temperature, soil type, land use, and farming systems, and is highly variable within the landscape.

Higher rainfall can increase soil carbon content through increased plant growth and the return of more plant residues to the soil. This increase may be balanced to some extent by a faster decomposition rate of the soil organic matter.

The storage of organic carbon is also greater with **increasing clay content**. This is because organic compounds form very stable complexes with clay particles which physically protects incorporated organic matter from decomposition. In sandy soils, organic matter is more accessible for decomposition and subsequent loss.

Soil carbon content may be increased **when plant growth is accelerated by irrigation and fertilizer application**. However, some of these benefits may be lost if other greenhouse gas emissions are increased. For example, higher emissions of nitrous oxide through the use of nitrogen-based fertilisers — which is essential for maximum crop productivity — mean more carbon must be sequestered to offset these associated emissions. This is a challenge for farmers because nitrous oxide has approximately 300 times the global warming potential of carbon dioxide (on a 100-year time scale), so it is a potent greenhouse gas.[5]

Changing agricultural land use from cropping to pasture generally increases soil carbon content. For example, on five farms in New South Wales that moved from cropping to pasture, soil carbon storage increased over five years from 0.6 to 1.3 tonne (t) C/hectare(ha)/year.[6] However, carbon storage rates generally slow over time and the emission of other greenhouse gases (such as nitrous oxide and methane) could increase if the new pasture is then grazed by ruminants.

Replacing annual plants with perennials may improve organic carbon content as longer growing seasons increase plant production. The largest gains in soil organic carbon occur when cultivated agricultural land is converted to permanent grasslands (at the expense of cultivated food crops), or when degraded land is revegetated.

Applying organic materials (such as plant waste) adds carbon to the soil at the site of application, but whether this translates to a net increase in carbon storage depends on what else the organic material would be used for. If the materials would otherwise have been burnt or decomposed in landfill (potentially producing methane), applying them to soil will create a net environmental gain as more carbon is stored in the soil. However, if the application is simply transferring organic material — such as crop residues or compost — from one site to another, there is no net increase in soil carbon storage overall and therefore no abatement.

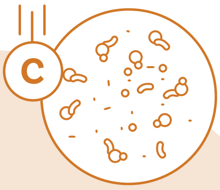
These factors show there are many variables that affect the success of soil carbon enrichment projects. These uncertainties can influence participation in soil carbon activities and should guide research into the variable effects of environmental and soil factors on the accumulation of soil carbon. Emerging technologies for measuring soil carbon need to focus on overcoming the problem of spatial variability in soil carbon, and so reducing uncertainty and lowering costs.

MEASURING SOIL CARBON AND ABATEMENT

When organic carbon is stored in soils for long periods rather than released to the atmosphere as carbon dioxide, it provides a climate change mitigation benefit called an abatement. To achieve net abatement, any change in soil carbon storage must be balanced against net changes in emissions of other greenhouse gases, such as nitrous oxide and methane, produced within that agricultural system.

To measure abatement, the emissions of all greenhouse gases, and increases in soil carbon storage, are measured per ha and expressed in terms of carbon dioxide equivalents (CO_2-e). For example, one tonne of methane — a significant greenhouse gas produced by ruminants (cattle and sheep) — is equivalent in warming potential over 100 years to approximately 30 tonnes of carbon dioxide. Having a net abatement of one tonne CO_2-e is used to provide one carbon credit, this credit then offsets the equivalent emission of greenhouse gas produced elsewhere.

Schemes such as the Australian Emissions Reduction Fund (ERF) reward activities that increase soil carbon storage to achieve net abatement. The accurate and cost-effective measurement and verification of soil carbon changes are essential to produce valid carbon credits. Soil sampling designs and analysis methods which aim to reduce uncertainty in these measurements have been developed. However, it is currently very expensive (estimates of $30 to $100/ha) to measure soil carbon at a paddock scale.[7] **The costs alone may exceed the returns generated by carbon credits for farmers who are already facing other costs of soil carbon enrichment. There is a clear need for low-cost, accurate technologies and methods to measure soil carbon.**



Technologies for Measuring Soil Carbon

The current standard method of measuring soil carbon in the field is to collect soil cores according to a stratified, random design and analyse the soil cores for total organic carbon by a dry combustion method.

The bulk density and gravel content are measured at the same time. This method is time-consuming and expensive.

However, new techniques are being developed using multisensory probes that can measure these properties on intact cores, provided that the sensors are calibrated in the first instance against actual soil measurements for a particular site.[8] This approach is potentially much more cost-effective than the standard method.

Simulation models which can predict soil carbon change in response to management change are available. However, these models require initial soil measurements to baseline the soil carbon status and they also need to be rigorously validated against direct measurements. The increased availability of remotely sensed satellite and aerial imaging has resulted in some over-simplified non-peer reviewed relationships for indicative estimates of soil carbon across landscapes.

ECONOMIC OPPORTUNITIES AND INCENTIVES FOR FARMERS

A landholder may earn income from soil carbon farming by registering a project with the Clean Energy Regulator to provide carbon abatement. The offsets generated are in the form of Australian Carbon Credit Units (ACCUs), with one ACCU representing one tonne of CO_2-e abatement. These ACCUs can be bought by the government or sold as credits in the more flexible voluntary market to businesses.

The Clean Energy Regulator asks farmers to consider a range of factors prior to participation in soil carbon projects in the ERF, including their ability to undertake new land management activities, to measure increases in soil carbon, and whether stored carbon will be maintained for at least 25 years.

Any income from carbon credits must be balanced against project compliance costs, including the costs of measuring soil carbon, and the potentially significant costs associated with changing land management. These latter costs, or opportunity costs, are measured as the change in gross margin of the farming business and can often exceed the income earned from ACCUs. For example, detailed analysis of farms in the Western Australian wheatbelt indicated that farmers would forgo more than $80 in profit per ha for any additional tonne of CO_2-e stored in soil.[9] Australian researchers recently concluded that sustained increases in stored soil carbon (>1t C/ha/year) are difficult to achieve even under the most favourable land management.[10]

These findings highlight the significant economic challenges associated with the use of soil carbon sequestration. For this technology to be useful as a cost-effective means of emissions reduction and abatement, further R&D is required to develop cost-effective means of estimating soil carbon across landscapes and time.

SOIL CARBON SEQUESTRATION IN ACHIEVING NET ZERO EMISSIONS

Since the inception of the ERF in 2015, only one soil carbon project has been awarded ACCUs.[11] There are several barriers for farmers to undertake soil carbon projects, including the complex regulations, the cost of participation (including the opportunity costs), the long contract period (at least 25 years) and the uncertainty of achieving verifiable increases in soil carbon. Farmers face uncertainty that they may not achieve increases in soil carbon for several reasons, including the spatial variability of soil carbon in the field, and the variable influences of major determining factors such as rainfall.

To participate in the ERF purchasing scheme for carbon credits, farmers must bid in a reverse auction whereby the lowest bid sets the price (averaging about AUD$12 per ACCU since 2015). This means that the value farmers can derive from soil carbon projects varies depending on the market. **These uncertainties highlight the need for more cost-effective technologies to improve methods for measuring soil carbon accurately in the landscape. Further research is needed into the effect of biophysical constraints imposed by different environments and soil types so more effective management activities can be developed for soil across different landscapes.**

As pressure mounts for Australia to reach net zero emissions, polluting industries must act to reduce their own emissions. Businesses purchasing carbon offsets as a negative emission strategy coupled with modifying their own operations to reduce emissions will help Australia move towards net zero. With more businesses competing to buy ACCUs, their price will likely rise, resulting in a greater financial incentive for farmers to participate in the ERF. For example, under the EU's revamped Emissions Trading Scheme and in the USA — where private companies offer farmers the opportunity to earn tradable credits — the price of carbon credits is considerably higher than in Australia. Importing countries are already discussing tariffs on Australian exports that are not produced under conditions of reduced carbon emissions. **This will create a powerful incentive for businesses to buy ACCUs in the future and increase the value and viability of soil carbon activities under the ERF.**

CONCLUSION

As Australia sets targets for net zero emissions and industries look to accordingly decarbonise their assets, investments and operations, technologies to offset emissions will play an important role. Soil carbon sequestration is a technology which has potential to contribute to offsetting emissions from other sectors that are hard to decarbonise. However, if agricultural export markets increasingly demand carbon neutral products, there will be a strong incentive for farmers to prioritize the use of any carbon abatement credits they develop to offset farm emissions to achieve net carbon neutrality on the farm.

While the potential of soil carbon has been demonstrated on a small scale, there are several challenges to the widespread adoption of this approach to undertake significant carbon abatement. These include technological barriers to measuring soil carbon sequestration and economic barriers for farmers to participate.

These barriers have so far prevented soil carbon from gaining momentum as a widespread abatement strategy in Australia, the potential for co-benefits associated with soil carbon sequestration should be considered by farmers when choosing to participate in carbon farming. Increasing soil carbon could increase productivity and improve ecosystem services (the benefit derived by landholders from an ecosystem) in several ways. Farmers can directly benefit from improved productivity of their land, and improved ecosystem services may occur with better soil structure, increased water-holding capacity, and soil biological activity. Ecosystem services may also be improved through reduced erosion (associated with more stable soil structure) and increased biodiversity resulting from revegetating degraded land.

These private and public benefits may currently outweigh financial returns to be gained from carbon credits under the ERF. However, improvements in the technology and methodology of soil carbon measurement, and an improved market for Australian ACCUs, could see soil carbon abatement become a viable source of income for farmers as we move towards net zero emissions in Australia.

SOIL CARBON DEFINED

Soil carbon content is measured as the weight of carbon per unit weight of soil, while soil carbon storage is measured as the weight of carbon per unit volume to a standard depth, usually 30 cm.

Measurement of change in soil carbon storage must take account of any changes in bulk density and gravel content.

Carbon in stable forms that is stored for a long time such as 100+ years is referred to as 'sequestered'. Bulk density is measured as the weight divided by the volume of an intact soil core, and gravel comprises rock fragments greater than 2 mm diameter.

Soil carbon content

Measured as the weight of carbon per unit weight of soil

Soil carbon storage

Measured as the weight of carbon per unit volume to a standard depth (30 cm)

Sequestered carbon

Carbon in stable forms that is stored for a long time such as 100+ years

CONTRIBUTORS

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