NSW GOVERNMENT | Local Land Services

TEN WAYS
to build soil carbon

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(Photo: NSW DPI)

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Acknowledgement of Country

Greater Sydney Local Land Services (GS LLS) operates in and delivers services throughout Country of First Nations people in the Greater Sydney region. GS LLS recognises First Nations people hold a continuous and deep connection to Country and this in turn holds significance to the broader community.

GS LLS recognises and respects Elders and cultural knowledge holders, both past and present, while acknowledging and respecting the unique and diverse enduring cultures and histories of all First Nations people.

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Contents

This booklet is designed as an introduction to 10 strategies farmers can use to build soil organic carbon within their farming systems. The information in this booklet is just a start and strategies will need to be assessed against economic, environmental and personal goals and then tailored for each property. When implementing these strategies, soil testing is recommended to benchmark and track changes in soil organic carbon over time. Resources with more detailed information are provided with each of the strategies and at the end of this booklet.

Introduction

Soil organic carbon (SOC) is the main component of soil organic matter (SOM) (approximately 58 percent) and is what actually gets measured in the laboratory. Soil organic matter is made up of organic materials in varying states of decay, including small pieces of roots, stems and leaves (less than 2 mm), partially decomposed organic matter, microbes and charcoal. Australian soils also contain char (fine charcoal) in varying quantities.

SOC is often divided into 'active' (typically 20-40 percent of soil carbon) and 'stable' (typically 60-80 percent of soil carbon) components. SOC is in a constant state of flux and can be decomposed quickly (days, months) or slowly (years). Stable SOC is often referred to as 'humus' and is more resistant to decomposition. Active SOC is often referred to as 'labile', turns over relatively quickly and relates to the biological fertility and nutrient availability of a soil.

Why is soil organic carbon important?

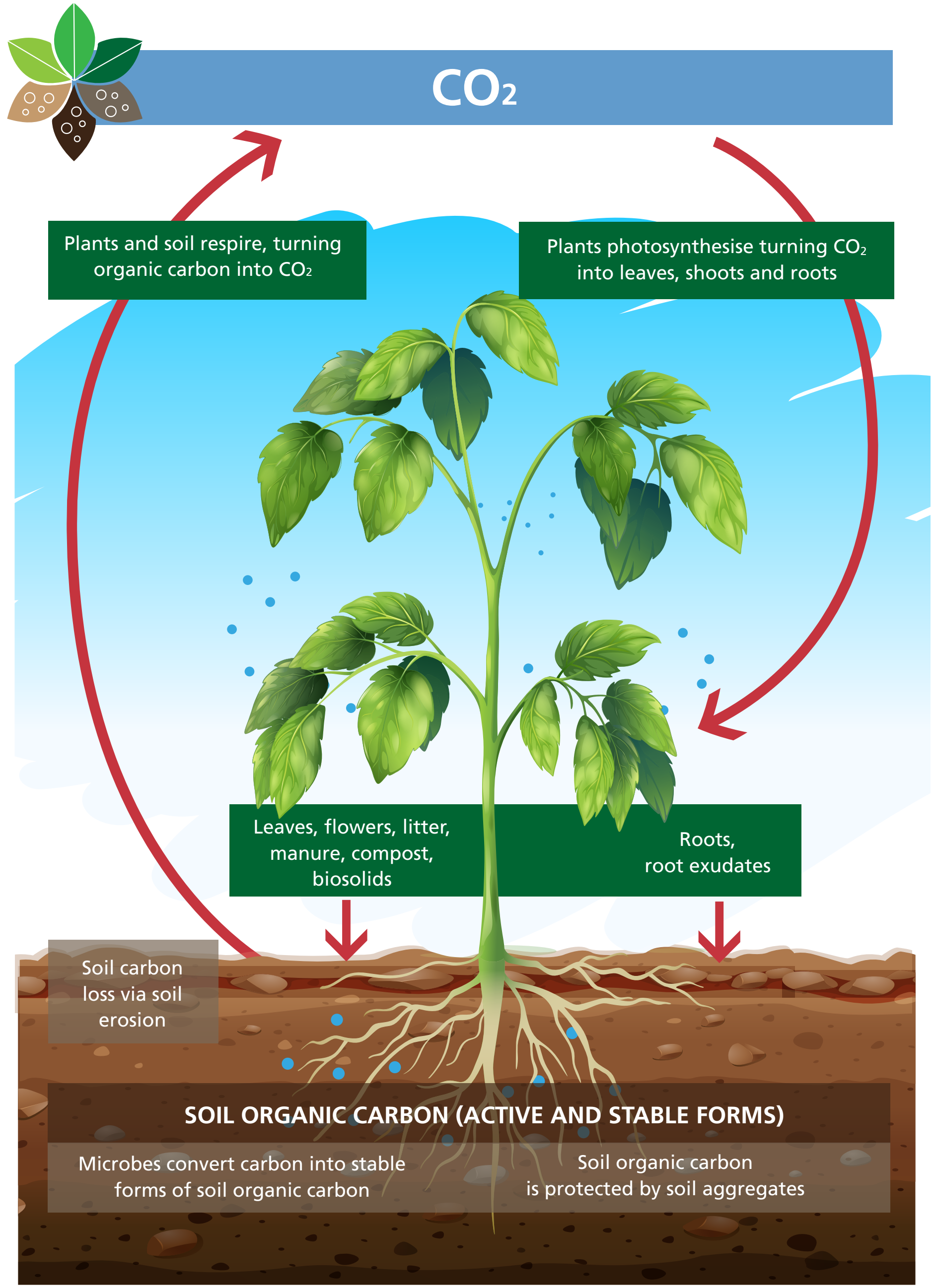
SOC plays an important role in stabilising soil structure, holding and releasing plant nutrients and contributing to soil water holding capacity. SOC is also a large sink of carbon with potential to mitigate climate change by storing carbon in the soil that would otherwise be warming the atmosphere. Increasing SOC has production benefits, as well as opportunities to diversify income through carbon markets and sustainability credentials.

How is soil organic carbon increased?

Adding carbon, reducing losses of carbon and protecting existing carbon in the soil are the three main pathways for increasing SOC. Management strategies to increase SOC act on these pathways by enhancing the inputs and minimising the losses.

Plant-based carbon is the main input of SOC in agricultural systems. This includes roots, shoots, leaves, flowers, crop residues and root exudates. Soil microbes convert fresh organic matter into more stable (protected) forms of SOC, such as humus. Decomposition of SOM by microbes and erosion are the main losses of SOC from the system.

Increasing SOC can be slow and the rate will vary depending on soil type, climate, vegetation, level of SOC and management. Generally, soils with a low SOC content will increase SOC faster than soils high in SOC. Soil type will also determine the amount of carbon a soil can potentially hold onto. In turn, best management strategies will depend on the soil type, climate, enterprise type, land use history, farm plans and the condition of the soil and environment.



(Illustration Kerry Hardy)

Overview of 10 ways to build soil carbon

	Adding carbon to the system	Reducing carbon losses from the system	Protecting carbon in the system
1. Pasture management Optimise pasture growth through species selection and input management	More biomass production	Good ground cover / less soil erosion	Good ground cover / less soil erosion Deep roots adding carbon at depth Improved soil structure Nitrogen available for microbial population (from legumes)
2. Grazing management Optimise the intensity and timing of grazing (and rest)	More biomass production	Good ground cover / less soil erosion	Deep roots adding carbon at depth Improved soil structure Diverse microbial population
3. Cover crops (incl. green manure and inter-row crops) Grow crops to keep the soil covered in between main crops	More biomass production	Good ground cover / less soil erosion	Nitrogen available for microbial population (from legumes)
4. Pasture cropping Sowing winter cereals into perennial pastures	More biomass production	Less soil disturbance	Improved soil structure
5. Changing crop-pasture sequence Increase the frequency or duration of pastures in a cropping rotation	More biomass production, especially in roots	Less soil disturbance	Improved soil structure Nitrogen available for microbial population (from legumes)
6. Adding lime, gypsum, nutrients Optimise plant growth by managing chemical and physical soil constraints	More biomass production		Nutrients available for microbial population
7. Adding carbon-rich materials Compost, manure, biosolids	Addition of organic matter More biomass production		Addition of microbes
8. Minimising or strategic tillage Eliminate or reduce mechanical cultivation of the soil		Less soil disturbance	Improved soil structure
9. Stubble retention Retain crop residues on the soil surface	Remove less biomass from system	Surface protected by residues from erosion	
10. Restoring degraded sites	More biomass production	Good ground cover / less soil erosion Less soil disturbance	Improved soil structure

(Photo: Adam Little)

Multi-species pasture blend for the Sydney region - a diversity of pasture helps to increase soil carbon because different plants support accumulation of soil organic carbon in different ways.

(Photo: Adam Little)

(Photo: NSW DPI)

(Photo: NSW DPI)

Legume species add nitrogen to the soil, supporting soil microbes converting fresh organic matter into stable forms such as humus.

Maintaining good ground cover protects soil from erosion and associated loss of soil carbon.

Pasture management

1

Optimising pasture growth through selection of grass, legume, brassica and herb species, fertiliser management (including manures), irrigation and grazing management are all strategies to improve SOC under pasture. Grazing management is covered in **Section 2**. The mix of grasses, legumes, brassicas and herbs, both annuals and perennials, will be determined by soil type, soil pH and climate, as well as feed requirements for livestock. The requirements for additional nutrients or other amendments to support plant growth will depend on chemical and physical soil constraints, including pH (see **Section 6** and **7**).

HOW IT WORKS

Greater pasture density and diversity equates to greater additions of carbon (in the form of plant roots and shoots) to the soil. Multi-species pastures support increased SOC in different ways. For example, legume species add nitrogen to the soil, supporting soil microbes converting fresh organic matter into stable forms. Carbon from deep-rooted perennial species such as prairie grass, chicory or lucerne is stored deeper in the soil and decomposes more slowly than SOC closer to the soil surface. The maintenance of good ground cover reduces erosion and associated loss of SOC.

ADDITIONAL BENEFITS

Productive pastures also benefit animal health and nutrition by creating a feed source with increased micro and macro nutrients. Healthy pastures and soils increase economic value, related to the resilience and profitability within a livestock production system. Good groundcover reduces weed pressure and enables better water infiltration into the soil.

FURTHER READING

- A farmer's guide to increasing soil organic carbon under pastures (Industry and Investment NSW)

The relatively short period of grazing of plants in their vegetative state and the rest period between grazing encourages persistence and growth of diverse pasture species.

Rotational grazing on multi-species pastures in Dooralong, NSW. Frequent rotation of cattle encourages a diversity of pasture species and supports soil carbon accumulation.

Grazing management

2

The timing and intensity of grazing on pastures and livestock types (e.g. sheep, cattle or poultry), in conjunction with other pasture management (**Section 1**), will determine the amount of biomass and root growth left behind after the removal of livestock. Rotational grazing, time-control and cell grazing systems are approaches to grazing that focus on plant growth cycles and recovery. These systems rotate livestock through a series of paddocks, allowing pastures to rest before animals return. This involves monitoring pastures for available feed (dry matter). The number of paddocks, the intensity and duration of grazing and the rate of rotation is determined by the rate of plant growth and pasture composition. Fencing infrastructure and labour required for implementation are also considered.

HOW IT WORKS

Under rotational, time-control and cell grazing, the relatively short period of grazing of plants in their vegetative state and the rest period between grazing encourages persistence and growth of diverse pasture species. Animals have less opportunity to be selective and manure is spread more evenly across the paddocks. It also allows perennials to replenish their root reserves (rest is timed for plant reproduction or persistence) and time for microbes to work. More plant growth, both above and below ground, provides additional carbon inputs to the soil. Enhanced root growth also improves soil structure which protects soil carbon from decomposition.

ADDITIONAL BENEFITS

The benefits outlined in **Section 1** relate to successful grazing management as well. Moreover, grazing management supports diverse pasture species and supports diverse soil microbes which play a role in building and protecting SOC. A well grazed paddock will produce healthy livestock with less pest and disease pressures.

FURTHER READING

- Grazing Strategies (MLA)

Brassica cover crop to be ploughed in as a green manure at the Greater Sydney Local Land Services Demonstration farm. The forage value and good ground cover is also visible.

(Photo: Adam Little)

Multi-species, inter-row cover crop adding plant diversity to the system.

Macerating cover crops before green manuring in a trial at the Greater Sydney Local Land Services Demonstration Farm.

Introducing cover crops

3

Cover crops can take many forms and are grown in between main crops to keep the soil covered. Cover crops are also called 'break crops' when crops are chosen to reduce disease and pest pressure in the main crop. Known as green manuring, cover crops can also be incorporated into the soil. Cover crops can be applied to intensive viticulture and horticulture production, cereal production and pastures. In perennial systems such as orchards, inter-row cover crops are referred to as inter-row insectaries or sod culture. Considerations when choosing cover crops include the main crop types (including leguminous) and cover crop features such as bulkiness, strength of root system and time to establishment. In some cases, terminating cover crops before they go to seed by mowing or incorporating them into the soil are strategies that reduce the risk of the crop becoming weedy or dominant.

HOW IT WORKS

The roots and above ground growth from cover crops are a source of fresh organic inputs (carbon) to the soil. Cover crops add plant diversity to the system which supports accumulation of soil carbon as well. By keeping the soil covered, runoff and erosion are reduced when it rains thereby retaining organic matter and nutrients in topsoil. If legumes are included in the mix of cover crops, nitrogen that supports soil microbes to convert fresh organic matter into stable forms is added to the system

ADDITIONAL BENEFITS

Cover crops can improve soil structure at the surface by reducing potential surface crusting and at depth through root activity. For example, tillage radishes can be used to breaks up surface crusting. Enhancing soil organic matter has the additional benefit of improving soil fertility. Cover crops can also be used to reduce weeds and break disease cycles impacting main crops (e.g. biofumigant or break crops). Inter-row cover crops that provide a refuge for beneficial insects provide pest control.

FURTHER READING

- Protect your land – use cover crops (NSW Department of Primary Industries)
- Cover crops for Australian vegetable growers (Hort Innovation)
- Optimising cover cropping for the Australian vegetable industry (Hort Innovation)

Sowing plant species into standing pasture with minimum disturbance to retain groundcover and soil structure.

(Photo: Claudia Whythes)

Multi-species pasture on Colin Seis' property, Winona, in the Central Tablelands.

Pasture cropping

4

Pasture cropping involves producing cereal crops while retaining perennial or improved pastures. Variations in pasture cropping systems include the use of herbicides to minimise competition for emerging crops and whether crops are used for grain or forage. In a coastal system such as Greater Sydney, ryegrass and other species including cereals can be over-sown or sod seeded over Kikuyu to create a winter/early spring feed source.

HOW IT WORKS

Pasture cropping minimises soil disturbance (see minimising tillage in **Section 8**). Minimising soil disturbance helps to maintain soil structure which physically protects SOC and slows down the rate of decomposition by soil microbes. Additionally, pasture cropping retains and regenerates perennial grasses which increases biomass production and therefore adds more carbon to the soil. Pasture cropping retains groundcover and reduces loss of SOC by erosion.

ADDITIONAL BENEFITS

Regeneration of degraded pastures by incorporating pasture cropping techniques results in a more resilient long-term pasture system. Moreover, the synergies between crops and pastures in pasture cropping enables the integration of cropping and livestock production with fewer chemical and machinery inputs.

FURTHER READING

- Pasture cropping (NSW DPI)
- Pasture cropping (Winona - The home of pasture cropping)
- Pasture Cropping: Is it an option on your place (Central West Local Land Services)

(Photo: Michael Mather)

Multi-species pasture including legumes.

Legume pasture species fix nitrogen from the atmosphere into a form that can be used by plants and microbes.

Changing crop-pasture sequence

5

Increasing the frequency or duration of well-managed pastures (particularly by including legumes – **Section 1**) in a cropping rotation can increase SOC, improve soil nutrition and water infiltration. Management considerations for this strategy include matching pasture species with soil type, pH and climate. Farm planning and economic evaluation of new rotations will be important to determine if this strategy fits the farm and enterprise type.

HOW IT WORKS

Legume pasture species such as vetch or cowpeas fix nitrogen from the atmosphere into a form that can be used by plants and microbes. This additional source of nitrogen promotes microbial activity that supports accumulation of SOC. And, pastures compared to crops, have more roots relative to above ground biomass so this phase of a rotation increases the amount of fresh organic inputs to the soil below ground. Pasture species with deeper roots such as prairie grass and lucerne also increase the volume of organic inputs at depth.

ADDITIONAL BENEFITS

Increased nutrients in the soil can lead to increased yields in the cropping phases. The deeper roots in pasture species may improve soil structure and increase nutrient cycling at depth and the increased ground cover during a pasture phase enhance water infiltration into the soil. Diversifying rotations also includes benefits such as disease breaks and diversification of income.

FURTHER READING

- Pastures in Cropping Rotations – North West NSW (NSW Agriculture)

(Photo: Adam Little)

Nutrient availability, particularly nitrogen, phosphorous and sulphur, also influence the efficiency and rate that microbes break down fresh organic matter into stable forms (i.e. humus).

Soil testing and interpretation supports decisions relating to nutrient and ameliorant applications.

Farmers in Greater Sydney at a soil carbon field day learning about the value of simple soil tests.

Adding lime, gypsum, nutrients (addressing chemical and physical soil constraints)

6

Nutrient application and soil amelioration depend on the soil type, pH, plant species and condition. Soil testing and leaf analysis provide information to support decisions relating to nutrients required and in what forms they are present. Soil tests will also indicate the level of acidity and whether applying lime or dolomite will have beneficial outcomes. Soil compaction, surface crusting or sodicity may be overcome with the application of gypsum. However longer-term strategies include increasing and maintaining higher levels of SOM.

HOW IT WORKS

Optimising plant growth through addition of nutrients or managing acidity or physical soil constraints increases the supply of fresh organic matter to the soil through more plant roots and above ground residues. Nutrient availability, particularly nitrogen, phosphorous and sulphur, also influence the efficiency and rate that microbes break down fresh organic matter into stable forms (i.e. humus).

ADDITIONAL BENEFITS

Managing for optimised soil health, soil nutrients, plant growth and quality results in optimal crop and pasture yields which can translate into increased profits and a long-term sustainable enterprise.

FURTHER READING

- Five easy steps to ensure you are making money from superphosphate (CSIRO and NSW DPI)
- Rapid Assessment of Soil Health Manual (David Hardwick)
- Soil Sampling Fact Sheet 2 (Local Land Services)

Spreading compost. Compost and composted manure generally contain more stable carbon compared to less "mature" organic amendments.

Carbon-rich amendments boost soil microbial populations that support accumulation of soil carbon.

Vegetable growers in Greater Sydney learning about the benefits of compost at crop trials on the Greater Sydney Local Land Services Demonstration Farm.

Adding carbon-rich materials

7

Carbon-rich or organic soil amendments such as manure, biosolids and compost, provide nutrient, carbon and microbial inputs to the soil. Decisions to apply these types of amendments will depend on the nutrient requirements for the crop and soil and whether it is economically viable to provide nutrition in this form.

HOW IT WORKS

Carbon-rich amendments directly add organic matter to the soil. The amount of carbon that is incorporated into SOC, depends on the amount and type of amendment applied (including carbon content), temperature, moisture and tillage. Like in soil, the active carbon in the amendment degrades quickly while the stable carbon degrades more slowly and therefore contributes more to long-term increases in SOC. Compost and composted manure generally contain more stable carbon compared to less "mature" organic amendments.

ADDITIONAL BENEFITS

Carbon-rich amendments potentially improve plant production by boosting soil microbial populations, improving soil structure, buffering soil acidity, slowly releasing nutrients and reducing the incidence of soil borne plant pathogens and pests.

FURTHER READING

- The benefits of using compost for mitigating climate change (NSW Environment Climate Change and Water)
- The breakdown on composts (National Vegetable Extension Network)
- Soil Biology Fact Sheet 7

(Photo: NSW DPI)

When soil structure is preserved, soil organic carbon is physically protected from decomposition.

(Photo: Terry Cooke)

Optimising the frequency and type of tillage is a balancing act based on benefits such as enhanced soil structure and water infiltration versus challenges such as increased reliance on herbicides for weed control.

Minimising or strategic tillage

8

No-till, minimum-till or strategic-tillage systems eliminate or reduce mechanical cultivation of the soil profile when preparing for or after planting. Minimising tillage usually involves a system change which can be challenging at first. Minimising tillage is a popular component of 'conservation agriculture' along with stubble retention (see **Section 9**). Decisions about tillage relate to soil constraints (structural and chemical), length of cropping cycle, crop disease and weed control. Optimising the frequency and type of tillage is a balancing act based on potential outcomes such as enhanced soil structure and water infiltration versus an increased reliance on herbicides for weed control.

HOW IT WORKS

Minimising or strategic tillage maintains soil structure which preserves and maintains SOC. SOC is physically protected from decomposition in soil aggregates (the basis of soil structure). Tillage breaks up soil aggregates, making the SOC readily available for microbes to quickly consume it and transform it into carbon dioxide. When tillage is repeated, SOC is depleted over time and in turn the food source of the soil microbial population (carbon) needed to cycle organic matter and form micro-aggregates to protect SOC is depleted.

ADDITIONAL BENEFITS

Through maintenance of soil structure, minimising or strategic tillage allows better infiltration of water and water retention in the soil profile and reduces the risk of erosion. Moreover, minimising tillage removes some mechanical operations from the system and may result in reduced labour, machinery and input costs.

FURTHER READING

- Strategic Tillage Fact Sheet (GRDC)

(Photo: NSW DPI)

Leaving crop residues on the soil surface increases the input of carbon to the soil and retains soil moisture.

(Photo: NSW DPI)

Over time, stubble breaks down and contributes to soil organic carbon. The rate of break down depends on the ratio of carbon to nitrogen in the residues and the availability of nitrogen in the soil.

Stubble retention

9

Often practised with minimum till, retaining stubble (crop residue) on the paddock is a popular method of not only retaining soil moisture, but increasing SOC. Management approaches to stubble retention are often varied depending on your environment. These approaches address ease of sowing, nitrogen immobilisation (leading to N deficiency for subsequent crops) and pests and disease control issues. Changes in management over time include machinery developments, inter-row sowing, grazing, addition of nutrients, crop rotations and use of pesticides and herbicides.

HOW IT WORKS

Leaving crop stubble on the surface increases the input of carbon to the soil. The rate of decomposition contributing to the accumulation of SOC will depend on the ratio of carbon to nitrogen in the residues and the availability of nutrients (particularly nitrogen) in the soil. In some cases, the addition of nitrogen is needed to retain more of the carbon in the stubble as SOC and not to deplete nitrogen for subsequent crops.

ADDITIONAL BENEFITS

Adoption of stubble retention has been predominantly motivated by moisture conservation benefits. Stubble retention increases water infiltration and slows moisture loss through evaporation allowing for more plant-available moisture for subsequent crops. Retaining stubble also protects soil from erosion. Additionally, long-term conservation of nutrients is also seen as a benefit of retaining stubble as the nutrients in the crop residues are returned to the system.

FURTHER READING

- Developments in stubble retention in cropping systems in southern Australia (GRDC)
- Benefits of retaining stubble (Soil Quality)

(Photo: NSW DPI)

Revegetating steep slopes slows erosion and reduces the amount of soil carbon lost with eroding soil.

(Photo: NSW DPI)

Revegetating river banks and excluding stock supports soil carbon accumulation and has additional benefits such as improved stream water quality.

Restoring degraded sites

10

Changing land use to repair land degradation is site specific and depends on the type and cause of degradation. Repairing damage and addressing the cause of degradation are both required. Erosion for example, is a major source of SOC loss and can be caused by a lack of vegetative groundcover. Management strategies for maintaining groundcover to protect the soil surface and reduce the amount of erosion include fencing off steep, riparian and eroded areas from livestock, managing grazing timing and intensity, planting grasses, shrubs and trees, soil amendments, minimising mechanical soil disturbance as well as managing drainage and overland flow.

HOW IT WORKS

Eliminating the cause and slowing down erosion reduces the rate of SOC lost from eroding soil. Improving plant growth on degraded areas produces more biomass and therefore provides more carbon into the system which, overtime, will restore soil health.

ADDITIONAL BENEFITS

Restoring and protecting land from soil erosion halts the loss of a valuable resource needed for our environment and food production.

FURTHER READING

- Saving soil – A landholders guide to preventing and repairing soil erosion (NSW Department of Primary Industries)

Further information

NSW Department of Primary Industries has a variety of fact sheets and webinars on soil carbon including:

- Soil organic matter in cropping systems
- A farmer's guide to increasing soil organic carbon under pastures
- Increasing soil organic carbon of agricultural land

- Management practices for increasing soil carbon (CSIRO)
- Soil Carbon and Organic Matter Fact Sheet 6 (Local Land Services)
- Soil carbon (Department of Agriculture, Fisheries and Forestry)
- Carbon soils in vegetable soils (SoilWealth)
- Soil biology and the landscape (United States Department of Agriculture)
- LOOC-C - A landscape options and opportunities for carbon abatement calculator (CSIRO)

Watch or listen:

- Soil carbon conversation starter webinar
  https://www.youtube.com/watch?app=desktop&v=IgGFagxccCI
- The Secrets of soil carbon webinar series
  https://www.youtube.com/playlist?list=PLbeXAybNsB_G2xRYc6_ECnvtm8GLNZfn8
- Big Shift for Small Farms podcast episode on "Soil carbon opportunities"
  https://anchor.fm/the-big-shift