Carbon storage in vegetable soils

Take home message

- **Growers can reduce the greenhouse impact of vegetable production by maintaining and preventing further loss of stored soil carbon (mitigation) which will also have soil health and productivity benefits.**
- **Increasing organic matter inputs (crop residues, cover crops and composts) and reducing losses (cultivation and fallow) are key to maintaining soil carbon stores and improving soil health and productivity.**
- **Increasing long-term stored carbon in vegetable soil (sequestration) is difficult due to the intensity of production.**

Carbon in soils

Soils store carbon. Lots of it!

In the top 30cm of soil 1 hectare will have more than 50 tC/ha in the topsoil, when your soil contains 1.5% soil carbon.

But our agricultural soils have lost up to half of their carbon, returning to the atmosphere as the greenhouse gas carbon dioxide[1]. This has contributed to the rise in atmospheric carbon dioxide levels and associated climate change.

The good news is that there are soil management practices which can be used to reduce greenhouse gases through either:

- ***Mitigation***: stopping or reducing further losses of soil carbon to the atmosphere (avoided emissions).
- ***Sequestration***: increasing soil carbon stored in the soil.

[1] Chan, K. Y., Cowie, A., Kelly, G., Singh, B., Slavich, P. (2008). Scoping paper: Soil organic carbon sequestration potential for agriculture in NSW.NSW Department of Primary Industries.

Maintaining or increasing soil carbon makes good sense – for the environment and for soil productivity. While climate scientists talk about soil carbon, you will know it better as soil organic matter. And the productivity benefits of soil organic matter are legendary:

- Providing a slow release supply of nutrients
- Improving cation exchange capacity and nutrient-holding ability
- Buffering against soil acidity
- Improving soil structure and aggregate stability
- Improving soil water holding capacity
- Reducing erosion risk

This Factsheet summaries the opportunities and management options for mitigating or sequestering soil carbon in vegetable soils.

Box 1: Soil carbon – soil organic matter

Most soil tests will show organic matter as a percentage.

When you send your soil to the lab, what is actually measured is soil carbon. This is then used to estimate soil organic matter. In practice, soil carbon is multiplied by 1.72 to given soil organic matter.

An example

In the example above we had 50 tC/ha when the soil contained 1.5% soil carbon.

Converting this to soil organic matter, by multiplying by 1.72, gives more than 80 tC/ha and 2.6% organic matter. That's at least two semi-trailers of organic matter in one hectare of soil!

The field work was supported by an Australian Government Action on the Ground Project. Soil Wealth is funded by Horticultural Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

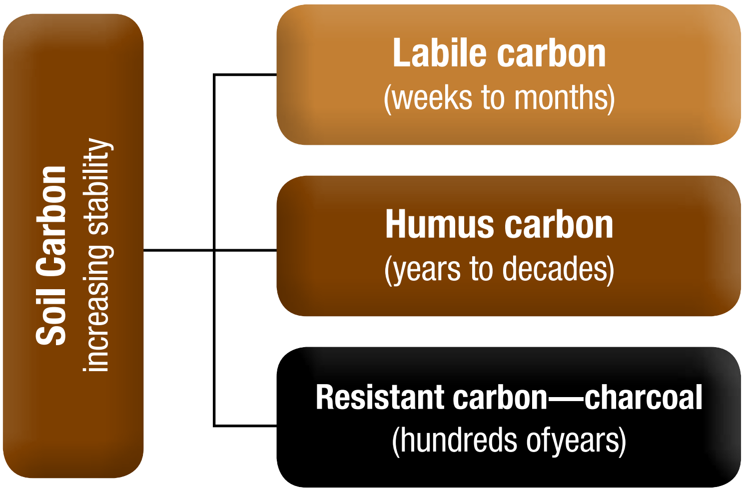

Diagram 1 The commonly recognised forms of soil carbon and their stability in soil.

Types of soil carbon

There are different types of soil carbon which vary in their properties, decomposition rates and influence on soil health, fertility and function[2].

The three types of soil carbon commonly recognised are shown in Figure 1. Understanding the types of soil carbon and how they respond to management will help you understand the potential for mitigation or sequestration of carbon in your soil.

Labile carbon is made up of partially decomposed organic matter and soil microbes. It is sensitive to the amount of fresh organic matter inputs, such as cash-crop residues, cover crops and compost, and is typically short-lived. Labile carbon lasts only weeks to months before being broken down to more complex stable forms of soil carbon (humus) by soil microbes.

Decomposition can be rapid under warm, moist nutrient-rich condition, as typically found in vegetable soils.

Labile carbon is the major food source for soil microbes and as a result influences many soil functions. Labile carbon is important in maintaining and developing soil structure, particularly in sandy and loam soils. The rapid decomposition makes labile carbon an active source of nutrition for soil microbes and plants.

As the most dynamic of the soil carbon types, labile carbon is a good early indicator of how management practices may be changing soil carbon.

In the field, labile carbon is most visible as the "glue" binding the aggregates around plant roots.

Humus carbon is relatively stable, lasting for years to decades due to the organic compounds in humus being more complicated or physically protected by clays. Both of these slow microbial decomposition.

Humus carbon plays a role in all key soil functions, such as soil structure and moisture retention, storing and releasing nutrients, and general soil health.

In the field this gives soil the dark colour of the topsoil and the "sweet" smell of a healthy soil.

Resistant carbon is dominated by charcoal. The type of carbon is very stable and may last for hundreds of years. Resistant charcoal changes little over time and while being a carbon store it contributes little to the key soil functions.

In vegetable soils it is most likely in alluvial soil along rivers, where charcoal has been deposited after fires. As charcoal can persist for hundreds of years these soils can be located a long way from the current river channel.

In the field, charcoal may be seen as dark flecks through the soil profile.

[2] This Factsheet doesn't cover inorganic soil carbon such as carbonate. If your soil contains significant amounts of inorganic carbon, e.g. soils containing limestone, specialist information should be sought.

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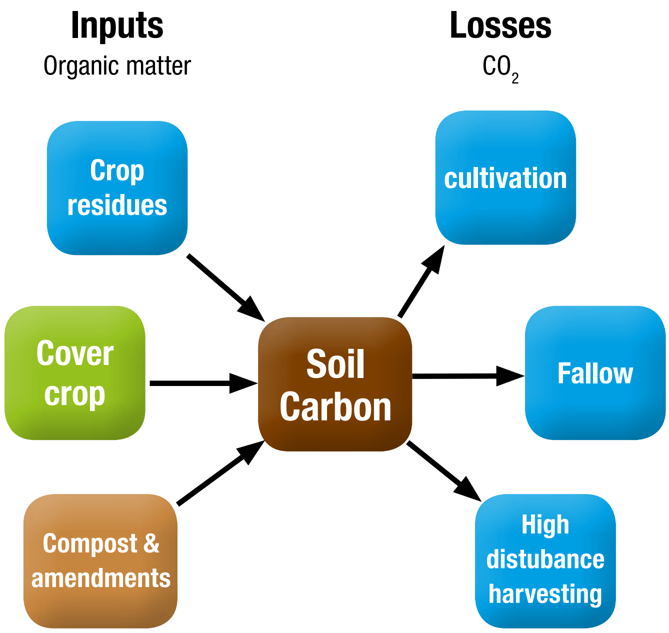

Diagram 2. Changes in soil carbon is mainly determined by how management affects the inputs of organic matter and their losses

Soil tests and the types of soil carbon

Commercial soil test will give total soil carbon (or soil organic matter – box 1), which measured all three types of soil carbon outlined in diagram 1.

Most commercial labs can also measure labile carbon separately (sometimes called active carbon). The ratio of labile-to-total-soil-carbon can be a good way to track how your soil is responding to changes in soil management.

High levels of resistant carbon in your soil can make soil test results difficult to interpret as they mask any change in soil carbon due to management. Specialist soil advice is required if high levels of resistant carbon are suspected in your soil.

Soil carbon and vegetable soils

The intensity of vegetable production systems makes it difficult to sequester carbon in the soil in the long-term. However, it is possible to mitigate further loss of soil carbon, as shown in the case study.

The main motivation for growers to maintain or build soil carbon will be to improve soil health and productivity. Any climate change mitigation benefits will be a bonus on top of these productivity benefits.

What determines how much soil carbon is in the soil?

The soil carbon you have today is a balance of the inputs of organic matter and the losses[3] through microbial decomposition, as summarised in diagram 2. While the principles are nice and simple, the management of these inputs and losses in intensive vegetable productions systems is anything but simple.

Intensive vegetable production is characterised by low inputs of organic matter and practices which promote high losses. Specific practices are required to address this imbalance to maintain or build soil carbon.

The intensity of vegetable production limits inputs of organic matter into the soil from crop residues. Multiple, short growing season crops, (e.g. baby leaf) result in the soil being fallow or with young, low biomass crops for most of the time, limiting the input of organic matter into the soil from the shoots, roots and root exudates. When crops are grown for longer the harvesting of much of the crop for sale (e.g. lettuce and cabbage) restricts organic

[3] Erosional losses of soil and associated soil carbon can be large but are not considered here. For ways of protecting your soil refer to the *Erosion—How to Protect Your Soil* Factsheet. However, these losses are not considered in this Factsheet.

matter input into the soil to largely the root systems. Disease pressure can sometimes mean crop residues are removed to reduce disease carry-over.

Intensive vegetable production systems are also characterised by high levels of soil disturbance, which promote soil carbon loss through exposing soil carbon to the soil microbes and ensure soils are well aerated. At the end of some crops there is a high level of disturbance during harvest (e.g. carrots and leeks), further promoting the loss of soil carbon.

Vegetable production also creates ideal conditions for soil microbial activity through irrigation and fertiliser application during the summer, creating warm, moist and usually well-aerated soil.

Practices with the greatest potential to mitigate soil carbon loses involve both increasing organic matter input and reducing losses.

Increasing organic matter input

Composts and amendments – importing organic matter

In intensity vegetable cropping, importing organic matter in the form of composts and amendments is a viable option. Depending on the maturity of the products composts will be a mix of fresh organic matter and labile and humus carbon. Regular additions of compost or amendments can help maintain or build soil carbon.

There are restrictions on the use of composts and other amendments due to food safety requirements. This can restrict the use of composts in some vegetable production systems. Also, composts and amendments can be expensive to buy and spread, while the increase in soil carbon can be short-lived[4]. Biochar is another option being considered to increase soil carbon. As biochar is similar to charcoal, it tends to be more resistant to decomposition. To date, trials have produced varying results with respect to increasing soil carbon and improving soil productivity[5].

Cover crops – growing your own organic matter.

Cover crops can be used strategically to boast organic matter input to the soil. Cover crops can produce bulk organic matter where it is need and through the action of the roots and root exudates can have a bigger impact on the soil than just the amount of organic matter produced. When a cover crop replaces a fallow period the benefits can be considerable. Improvements in the levels of labile carbon can be seen quite quickly.

In managing cover crops in vegetable production systems, the following need to be considered: identifying cropping windows, matching cover crops to the window, having sufficient water to grow the cover crop, managing the transition from cover to cash crop, any specialised benefits, and pest and disease considerations.

Changing rotation – adding higher biomass cash crops.

Organic matter input can also be increased by changing the crop rotation to either include a higher biomass cash crop where less is harvested, e.g. beans or corn, or rotating through a pasture phase for grazing or hay. This option requires more land area and is ideally suited to more extensive mixed farming enterprises.

Reducing losses

Reducing losses through less aggressive tillage.

Reduced till and permanent beds can reduce the amount of soil disturbance and help maintain soil carbon levels. The use of reduced till systems typically involves a system change to permanent beds[6]. It is usually necessary to rebuild the soil carbon, and associated soil structure before using “softer” tillage practices.

Fallow.

Minimising fallow period will help reduce losses of soil carbon. When a soil is fallow decomposition of soil carbon continues but there are no ongoing inputs from cash or cover crops.

[4] Favoino, E., Hogg, D. (2008). The potential role of compost in reducing greenhouse gases. Waste Management & Research, 26(1), 61–69

[5] Kuppusamy, S., Thavamani, P., Megharaj, M., Venkateswarlu, K., and Naidu, R. (2016). Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions. Environment international, 87, 1–12.

[6] Reduced till in vegetable production – Cultivate less and improve your profits. Soil Wealth Factsheet http://www.soilwealth.com.au/imagesDB/news/RedtillSW12150203.pdf

Case study: Managing to stop soil carbon loses and improve soil productivity

Ed and James Fagan are third-generation growers on the family farm which has been producing vegetables since 1943, and broad acre crops since 1886.

The intensity of traditional vegetable production was taking its toll, with the soil requiring more cultivation and fertiliser, while yields continued to struggle.

The soil was in decline. Soil carbon had declined from 2.7% in uncropped soil to 0.7% after more than 50 years of intensive vegetable cropping. That's a loss of 75 tC/ha!

Ed and James needed to try something different to improve their soil. They introduced reduced-till, permanent beds to reduce further losses of soil carbon. But after 50 years of vegetable cropping they need to put more organic matter back into the soil and build their soil carbon. Especially now that they were growing babyleaf spinach, with the associated low organic matter input and frequent cultivation.

In conjunction with AHR, Ed and James tried ryegrass cover crops or compost to add some more organic matter and build soil carbon in their permanent beds system. A ryegrass cover crop was grown in the beds for eight months adding more than 4t/ha of organic matter*, but, importantly, additional organic matter would have been added through the roots and root exudates. Over the same period 10t/ha of compost* was applied in two applications.

The good news is that the ryegrass cover crop and compost has stopped the decline in soil carbon, showing that cover crops and compost can mitigate carbon loss. Because much of this increase was in labile carbon, soil management will need to continue adding organic matter to sustain those improvements in soil carbon. While it will not be possible to get the soil back to the levels of 50 years ago, before cropping began, it is important both for greenhouse impacts and soil productivity to stem further losses of soil carbon.

Growing the ryegrass cover crop has not only mitigated soil carbon loss, but, importantly, it has helped to transform troubled paddocks into more productive soils. Soil structure has improved, input costs are down and crop yields are on the improve.

Adding compost also helped to mitigate soil carbon loss. But the cost of composts, together with handling and food safety make it a second-best option for Ed and James. In other vegetable farms, where land is at a premium, reducing the time to grow cover crops, compost may be the most suitable option.

Ed and James see cover crops, combined with reduced tillage and permanent beds, as the way forward to improve the productivity of their soil and make sure the family is still growing vegetable in another 50 years.

Ryegrass cover crop at the Fagan family farm.

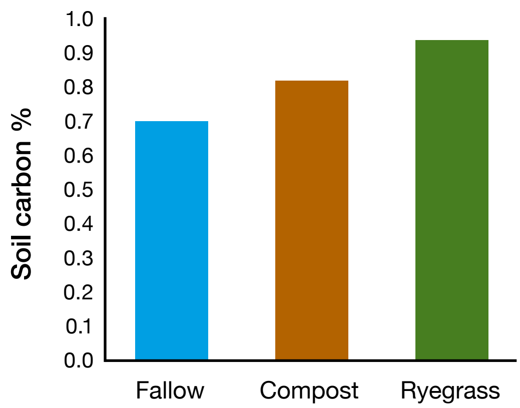

Figure 1. The ryegrass cover crop and compost were able to stop further soil carbon loses.

*Ryegrass and compost rates are in dry weights.