BIOECONOMY SCIENCE INSTITUTE | Manaaki Whenua Landcare Research

Soil Carbon Sequestration 101

The big picture

There is a global need for strategies that actively reduce emissions from fossil fuels, prevent loss of carbon from soils and vegetation, and remove atmospheric carbon dioxide (CO_2) via sequestration. These strategies need to be feasible to implement, effective, and affordable.

Increasing soil carbon is a win-win solution for land owners and land managers, mitigating greenhouse gas emissions while improving soil health. In New Zealand, the agricultural sector produces about 50% of net anthropogenic greenhouse gas emissions. The greenhouse gases of most concern are methane, nitrous oxide, and CO_2. With approximately 55% of New Zealand's land area covered by agriculture, farmers play a critical role in maintaining (and potentially increasing) soil carbon to combat climate change.

Carbon sequestration

Carbon sequestration is the process by which CO_2 from the atmosphere is transferred and accumulates in reservoirs such as soil and plants. Think of carbon as a bank balance, with deposits (e.g. from photosynthesis) and withdrawals (e.g via respiration) (Figure 1).

- A **carbon sink** absorbs more carbon from the atmosphere than it emits, like a savings account.
- A **carbon source** emits more carbon than it absorbs, like an overdraft.
- If we decrease carbon emissions and increase carbon sequestration, eventually we can become 'debt-free' (reach net zero).

One area on a farm (for example, a forest) may be a carbon sink, while another (such as a cropping block) may be a source. It is the net balance that matters, and this applies from farm to global scales. From the perspective of climate change, we shouldn't be concerned about the total stock of carbon in soils or vegetation. It is the **change** in these stocks (and whether it is positive or negative) due to land-use activities that matters most.

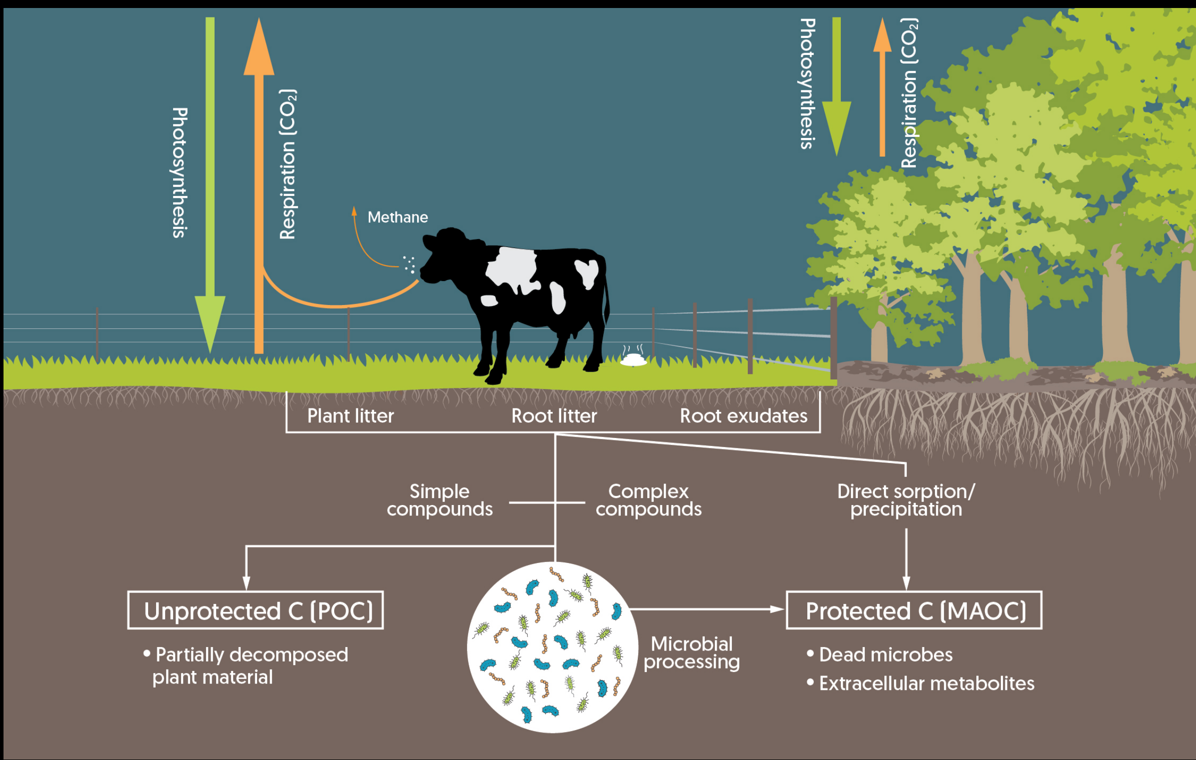

Figure 1. Conceptual diagram of the carbon cycle in a farm ecosystem. Carbon dioxide (CO_2) is fixed from the atmosphere by plants via photosynthesis. Most of the CO_2 fixed is lost from the system via respiration of plants, soil microbes and grazing animals. Some carbon is retained in tree biomass, and some enters the soil as plant litter, root litter, root exudates, and via dung and urine deposited by grazing animals. Carbon entering the soil is processed through microbial activity and mineral interaction. A small proportion can be retained in either unprotected particulate organic carbon (POC) or protected mineral-associated organic carbon (MAOC) pools. The thickness of the green and orange arrows are proportional to the carbon flow. To sequester carbon in the system, inputs (green) need to be increased, losses (orange) decreased, or both.

Carbon sequestration in soils

Globally, soil contains more carbon than plants and the atmosphere combined. Therefore even modest carbon gains or losses from soil can influence atmospheric CO_2 concentrations. Carbon is also important for soil health, improving soil structure, nutrient cycling, water retention, drought resistance, and plant productivity.

Plants absorb CO_2 from the atmosphere for photosynthesis. Much of the absorbed CO_2 is released back into the atmosphere via respiration from plants, soil microbes and grazing animals (Figure 1). A small proportion of total carbon inputs can be retained in the soil, and over time (decades) under a given land use and management regime (e.g. dairy pasture), soil carbon stocks will reach a 'steady state', whereby carbon inputs and losses are balanced. Figure 2 shows estimates of steady state soil and vegetation carbon stocks for different land use classes.

- **Types of soil carbon:** Soil carbon can be found in two broad forms: particulate organic carbon (POC) and mineral-associated organic carbon (MAOC). MAOC is tightly bound to soil mineral particles, making it 'protected' and less accessible to microbes, while POC remains 'unprotected' and is more readily decomposed (Figure 1). Both forms are beneficial, but MAOC is generally more stable and therefore critical for long-term carbon sequestration.
- **The role of soil microbes:** Microorganisms are crucial in multiple direct and indirect ways for soil carbon sequestration. Microbes directly contribute to carbon accumulation by breaking down plant inputs into organic matter (a combination of carbon and other elements), releasing some CO_2 back into the atmosphere in the process. Microbial activity shapes soil aggregate structure and facilitates the transfer of carbon between unprotected and protected forms. Microbial biomass itself is a key precursor to stabilised soil carbon.
- **Importance of Organic Soils**: Organic Soils (also known as peat soils) are slowly formed over thousands of years from the accumulation of partially decomposed plant material in areas where high water tables slow the decomposition process. When land is drained for agriculture, lowered water tables facilitate oxygen diffusion into the soil, increasing decomposition rates and leading to permanent loss of soil carbon as CO_2. Approximately 90% of New Zealand's Organic Soils have been drained, and they contribute 6–7% of national net GHG emissions despite occupying only about 1% of the land area.

Changes in land use and management practices could potentially have a big impact on carbon stocks at the farm and national scale (Figure 2). For more details on our current research in this space, follow the QR code link below.

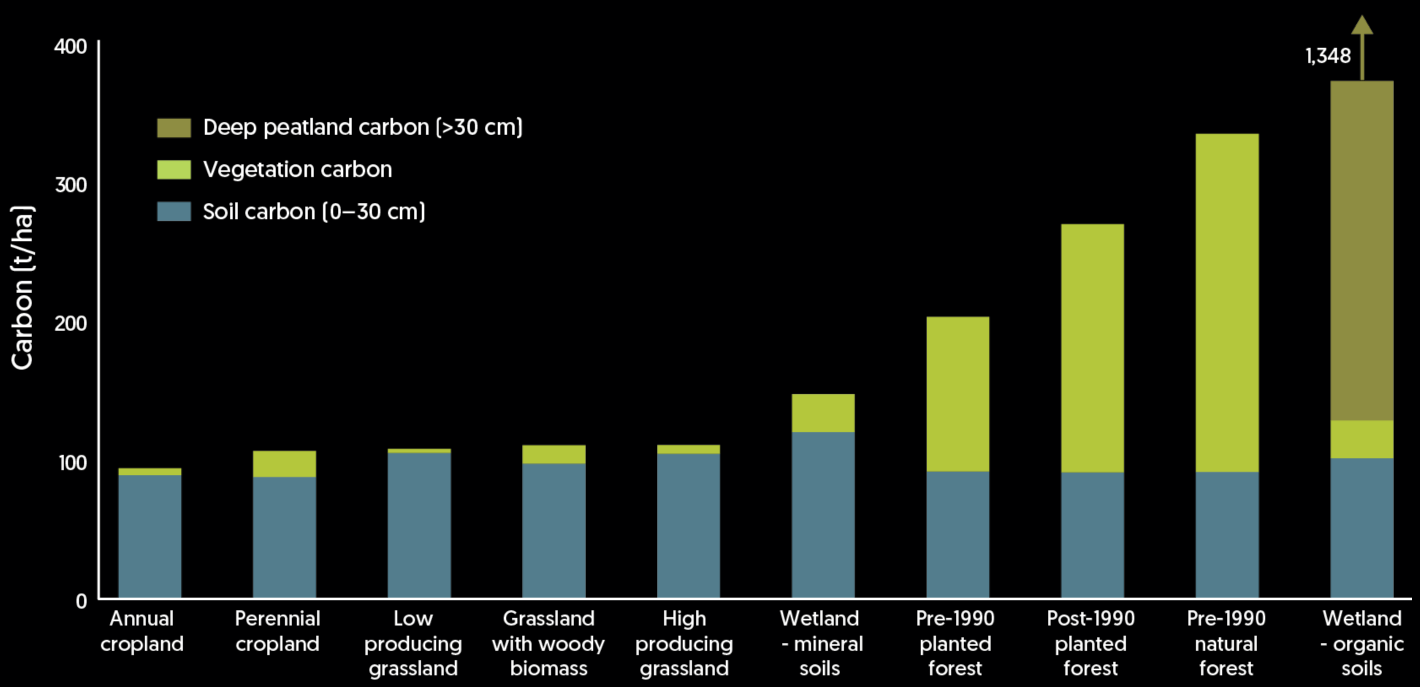

Figure 2. Soil and vegetation carbon stocks across various land use types, measured in tonnes per hectare (adapted from The Parliamentary Commissioner for the Environment, 2019). Soil carbon stocks are measured to 30 cm depth, except for wetlands on Organic Soils (peatlands) which include an estimate based on average peatland depth (3.9 m). Mineral soils also contain carbon deeper than 30 cm, however there are fewer measurements recorded than for 0–30 cm depth, so estimates are less certain. *Note: estimates of soil carbon stocks for different land uses will be refined and updated periodically as new data is collected and analysed.*