Storing carbon in soil

Can we slow a revolving door?

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There are several important reasons for maintaining or increasing the carbon content of soils.

Organic matter is critical for supporting many important soil functions that contribute to production and protect the environment. These include improving soil structure, nutrient and water retention, and providing a food source for soil microorganisms.

Carbon makes up about 50% of soil organic matter and in New Zealand soils there is on average about 100 t of soil carbon in the top metre of each hectare of grazing land[1].

The transfer of carbon dioxide to soil organic matter through photosynthesis is an important buffer for managing the total production of greenhouse gases that contribute to global climate change. There is more carbon held in soil than in plants and the carbon dioxide in the atmosphere above.

Most of the carbon dioxide released to the atmosphere from human activity has come from the burning of fossil fuels with about 10 to 15% coming from land use change in recent years[2].

Where does soil carbon come from?

Plants convert carbon dioxide from the atmosphere into sugars through photosynthesis. These sugars are converted into leaves and roots and are converted back to carbon dioxide when needed to produce energy for the plant.

Carbon enters the soil when leaves and roots die, or are eaten and excreted, or when carbon leaks from roots into the surrounding soil. It is thought that roots contribute the majority of carbon to soil, whereas much of the vegetation and excreta on the soil surface are converted to carbon dioxide[3].

The plant carbon that enters the soil is used by microorganisms as a food source, with the majority being respired back to the atmosphere as carbon dioxide. The remainder is converted into microbial biomass and microbial by-products that are transferred into the surrounding soil. Some of this transferred carbon can be bound by clay particles to form soil aggregates and is protected from further decomposition.

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As a result of this cycling, there are several carbon pools in soil, including plant litter (fragments that are recognisable or partially decomposed), microbial biomass and various stabilised carbon pools in aggregates that have been processed by microbes.

While litter and the microbial biomass turn over relatively quickly (months to years), the stabilised pools can last for a very long time – 10 to >1000 years. To increase carbon content of soil in the long-term, it is important that newly sequestered carbon is stored in these stabilised pools and not just as plant litter that could decompose very rapidly to carbon dioxide.

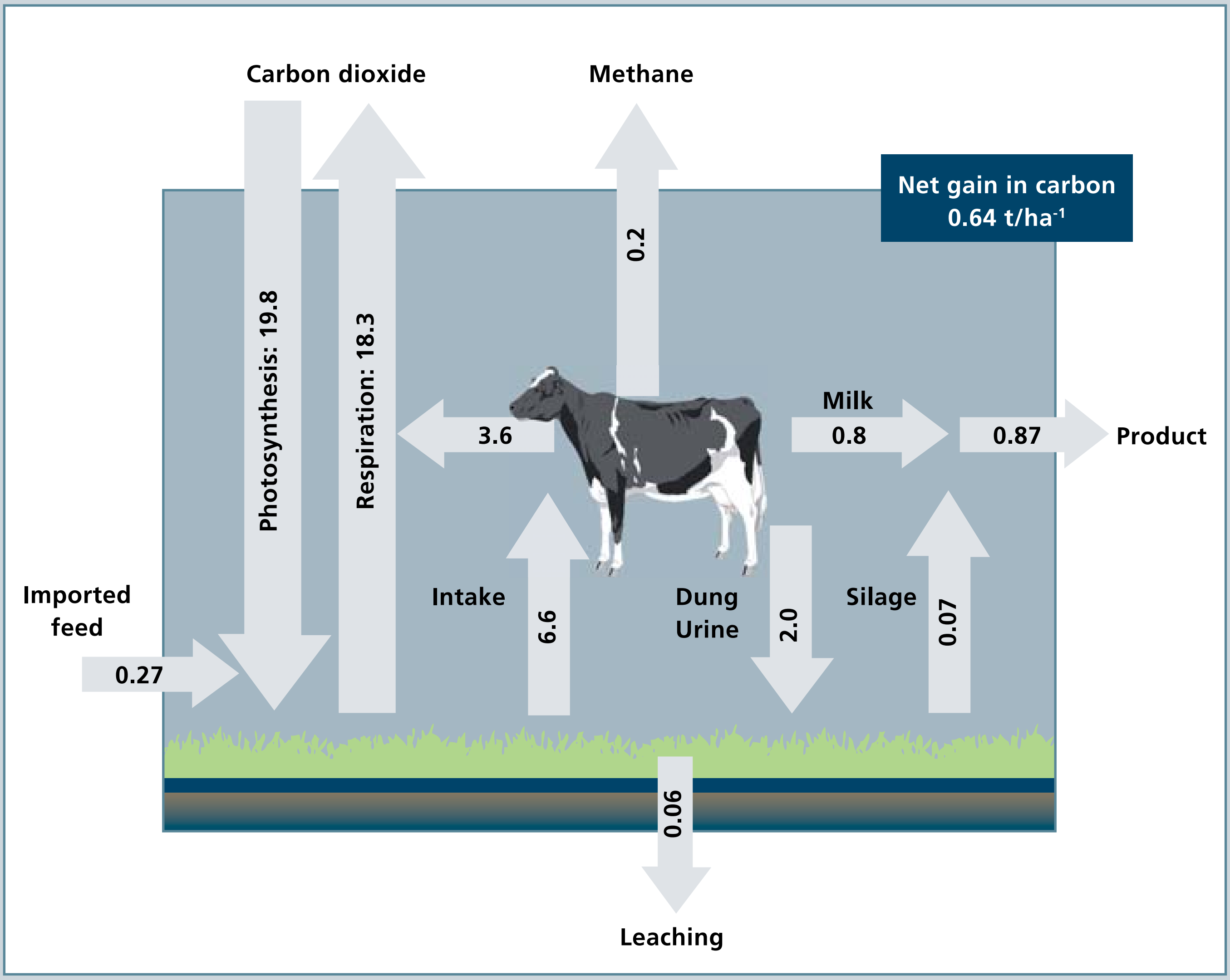
So while there can be very large inputs of carbon to soil every year, this is usually matched by exports of carbon in the same year. This is a major reason why increasing carbon storage in soil is a slow process. As an example, all the flows of carbon into and out of an example dairy farm in the Waikato have been measured (Figure 1)[4].

In this study, nearly 20 t of carbon were fixed per hectare, by pasture during the year. Other inputs of carbon included imported feed (0.27 t). Of this incoming carbon, the majority was cycled back to the atmosphere through plant respiration but also respiration by cows after feeding on grass.

A small fraction was released as methane (0.2 t) and 0.87 t was exported in product (milk and silage). Leaching losses were estimated at 0.06 t per hectare but this number is a very rough estimate. When accounting for all the inputs and outputs, this dairy farm gained about 0.64 t of carbon per hectare.

These carbon balances are site specific and vary from year to year but serve as an example of the size of the fluxes that contribute to changes in soil carbon.

Figure 1. The flows of carbon into and out of Scott Farm (DairyNZ, Newstead) grazed by dairy cows in 2008[4], with all values in tonnes of carbon ha^{-1} yr^{-1}. Internal cycling (pasture uptake, dung/urine and cow respiration) were estimated using published data[5]. Uncertainties are not shown to maintain clarity but estimated uncertainty for net carbon gain was 0.55 t carbon ha^{-1}. Uncertainties for other fluxes were estimated at 0.08 (imported feed), 0.1 (product), 0.05 (methane), and 0.2 (leaching).



Soil carbon differs between land uses

The amount of carbon held in soil depends on the balance of carbon inputs from photosynthesis and losses from respiration. But imports and exports of carbon from the ecosystem also need to be taken into account.

The amount of soil carbon differs between common New Zealand land uses (Table 1)[1].

Using pasture soils grazed by drystock (100 t c/ha) as a point of comparison Table 1 shows differences due to other land use. For example, if pasture was converted to exotic forest, on average the soil would contain about 16 t carbon ha^{-1} less.

Table 1. Land use effects on the stock of carbon in the top 30 cm of soil comparing pasture to listed land use[1] .

New land use	Difference in soil carbon stock compared to pasture (t carbon per hectare)
Exotic forest	-16 (7)
Natural shrub	-12 (5)
Natural forest	-1 (5)
Cropland	-11 (8)
Horticulture	-9 (7)

Recent changes in soil carbon in pastures?

While conversion from one land use to another can result in large changes in soil carbon stocks[1], less is known about the influence of different pasture management practices, such as different grazing intensities.

Soil profiles were sampled from pastures around New Zealand, and compared to previous samplings[6]. This study found that the amount of carbon in dairy pastures had declined by about 0.73 t ha^{-1} y^{-1} in the previous 27 years, while there was no change in the carbon content of drystock grazing flat land.

The carbon content of hill country grazed by drystock had increased by about 0.52 t ha^{-1} y^{-1}. Lastly, the carbon content of tussock grasslands had not changed. It is not known whether these changes are ongoing or these soils have now reached a new steady state.

The reasons for losses under dairying are not entirely understood and are being investigated by a number of research groups. One thought is that dairy cow urine patches can extract organic matter from soil, making it more vulnerable to decomposition by microorganisms[7] or that there are lower inputs of carbon into soil under dairying pastures.

The reasons for gains in hill country are also not entirely clear but may be due to the slow re-accumulation of carbon following sheet erosion that occurred when land was first cleared from forest to be converted to pasture (Parfitt et al., submitted). For example, New Zealand's rivers currently export about 14 t km^{-2} y^{-1} in dissolved and particulate carbon from erosion processes[8].

Efforts to increase soil carbon in New Zealand?

There is a maximum amount of carbon that a particular soil can protect, for a given level of plant inputs. For example, clay-rich soils can protect more carbon than sandy soils.

Because carbon in soils under dairy grazed pastures has declined, they are below their maximum storage capacity, so provide an opportunity to increase carbon again. There are many approaches for increasing carbon content in agricultural soils, including altering cropland management and restoring organic and degraded soils[9].

In New Zealand, studies are examining if increasing the mix of pasture species with deeper/more roots, e.g. chicory and plantain, can increase carbon content. An advantage of increasing the carbon content of soils through root inputs, is that the carbon is deposited next to clay particles, encouraging formation of aggregates which stabilise this new carbon.

Studies are also examining if earthworms can incorporate leaf litter from the surface into the soil and if the addition of biochar can be stabilised in soil. This is not a simple challenge because, in general, soils lose carbon fast and recover it only slowly.

Conclusion

There is no doubt that soils are a vast store of carbon and partially control the carbon dioxide content of the atmosphere. Maintaining soil organic matter is also crucial for production and environmental protection.

Land-use change and management practices are central to maintaining soil carbon, because these can both increase and decrease soil carbon. Pasture systems can store large amounts of soil carbon and there may be an opportunity to store more in New Zealand dairy systems with multiple benefits.

Active research is investigating approaches to achieve this goal through the New Zealand Agricultural Greenhouse Gas Research Centre.

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