REDUCING NEW ZEALAND'S
AGRICULTURAL GREENHOUSE GASES:

SOIL CARBON

NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

PGgRc
PASTORAL GREENHOUSE GAS
RESEARCH CONSORTIUM

WORKING TOGETHER

THE UNIVERSITY OF
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Te Whare Wānanga o Waikato

KO TE TANGATA

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WHY SOIL MATTERS FOR CLIMATE CHANGE

Globally, there is more carbon in soil than in terrestrial plants and the atmosphere combined.

Because soil is such an important reservoir of carbon, relatively small changes in the amount of carbon stored in soil could have significant effects on net greenhouse gas emissions. Management approaches that increase the amount of carbon stored in soils could offset some of the emissions of other greenhouse gases from agriculture, methane and nitrous oxide[1]. On the other hand, practices that deplete soil carbon and release it back into the atmosphere can add to the emissions of other greenhouse gases.

From a climate change perspective, what matters is not the total quantity of carbon in soils, but whether this quantity changes over time.

Given the potentially significant contribution that changes in soil carbon could make to New Zealand's total agricultural emissions, it is essential to understand trends and identify management practices that can increase soil carbon – but equally, to avoid practices that would result in carbon losses.

This fact sheet summarises current scientific knowledge about soil carbon in New Zealand, the management options that are known or suspected to influence soil carbon, and research underway to expand our knowledge and to inform on-farm practices.

[1]NZAGRC-PGgRc fact sheet: What we are doing

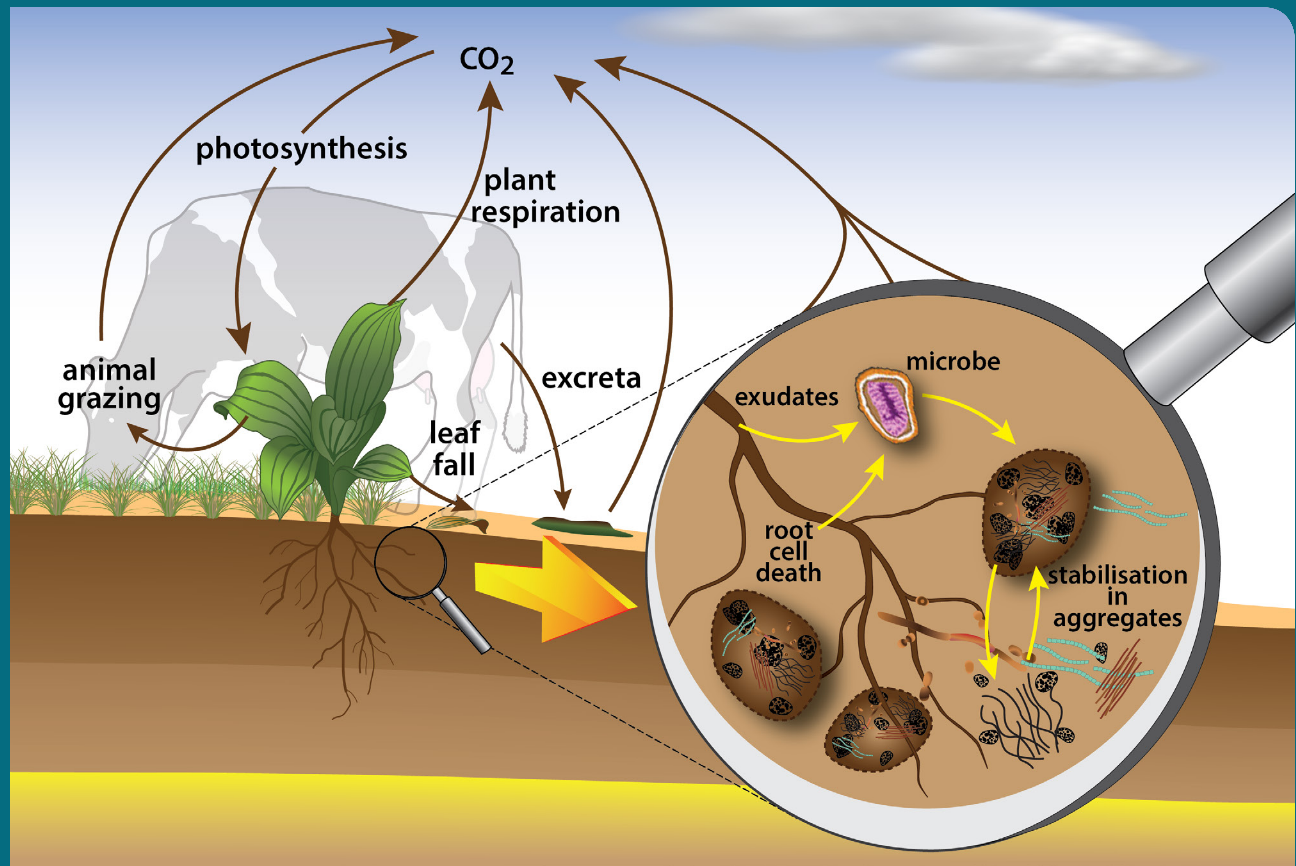
HOW IS CARBON STORED IN THE SOIL?

Carbon is constantly being moved between the atmosphere, plants and soil.

During the process of photosynthesis, plants, algae and some micro-organisms use sunlight to convert carbon dioxide and water into sugars that are incorporated into their cells – some of which are consumed by animals.

Decomposing animal material (including dung), plant matter (such as leaf litter and roots), fungi, worms, bacteria and a diverse array of other micro-organisms contribute carbon to the soil. Most of this organic material degrades quickly; the microbes feeding on it release carbon dioxide back into the atmosphere as they respire.

However, a small proportion of this organic material becomes tightly bound to the mineral surfaces of soil particles or encapsulated in soil aggregates (clumps of soil particles). In this state, the carbon in soil organic matter is physically protected and less accessible to microbes – it is said to be "stabilised" and can remain locked away for tens to hundreds of years.



Carbon enters the soil as animal excreta and decaying plant matter. Under the surface, plant roots also actively exude carbon while worms, beetles and other creatures living in the soil excrete carbon in their dung and breath. The animals and the plant roots eventually die, providing more carbon. Microbes feed on all these carbon sources. When the microbes respire, most of the carbon is released into the atmosphere as carbon dioxide but some of it bonds to the surfaces of silt and clay minerals and may be held in soil aggregates, where it becomes protected from decomposition for decades to hundreds of years.

The rate of build-up of soil carbon is limited by the amount of carbon fixed in photosynthesis, so increasing soil carbon is inevitably a slow process. By contrast, the processes that cause carbon to be released back into the atmosphere – microbial and plant respiration – are relatively unconstrained, so soil carbon levels can decline very quickly when not managed correctly.

HOW ARE CHANGES IN SOIL CARBON DETERMINED?

A combination of repeated soil sampling, net carbon exchange measurements, and process and modelling studies are needed to determine management practices that protect and potentially increase soil carbon.

To estimate the amount of soil carbon in a given area and its changes over time, scientists need to know:

- how much carbon each soil type contains
- how much land is covered in each soil type
- how the amount of soil carbon changes over time

For consistency's sake in international greenhouse gas measurements, the amount of carbon in the soil is taken to be the amount of carbon in the top 30 centimetres of the soil. This is where most, but not all, the carbon in soil is stored.

Carbon makes up about 50% of organic matter. Where studies cite the amount of soil organic matter, a reasonable approximation of the actual soil carbon content can be gained by dividing the figure for soil organic matter by two.

SOIL SAMPLING

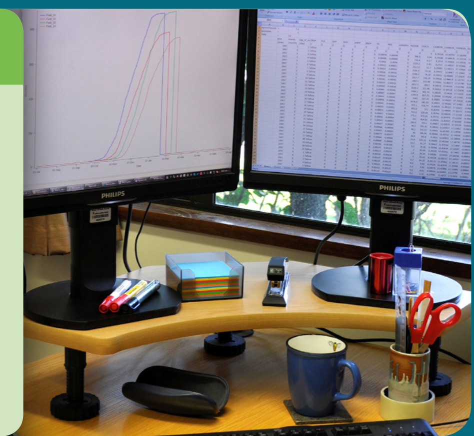
The classification of soils, knowledge of their formation and morphology, is the domain of a specialist branch of soil science known as pedology. New Zealand's soil is highly variable, so a pedologist will often need to take more than one sample to classify the soil type(s) even in a single paddock. Records from soil samples taken across the country are submitted to New Zealand's National Soils Database[2].

Even within a single soil type, each layer (known as a 'horizon') will have a distinct composition, so samples must be taken and analysed to determine the percentage of carbon in each horizon. In order to calculate the total amount of carbon, scientists must take into account how dense each soil horizon is by volume (soil 'bulk density'). Soil bulk density is measured by extracting, weighing and drying columns of soil. Repeat samplings over time can determine whether soil carbon is increasing or decreasing, but because the amount of carbon in New Zealand soils is large and the expected annual changes are small it can take more than ten years to observe changes.

MODELLING

There are many different variations of management practices that could result in increases in soil carbon and testing all of these is not feasible. Therefore computer models are developed to test a wider range of options.

The models are developed using knowledge gained from field studies and then models used to identify promising management practices that can be tested in field studies. Models can also be used to predict the long-term trends of soil processes as climate changes.



[2]soils.landcareresearch.co.nz

NET CARBON EXCHANGE MEASUREMENTS

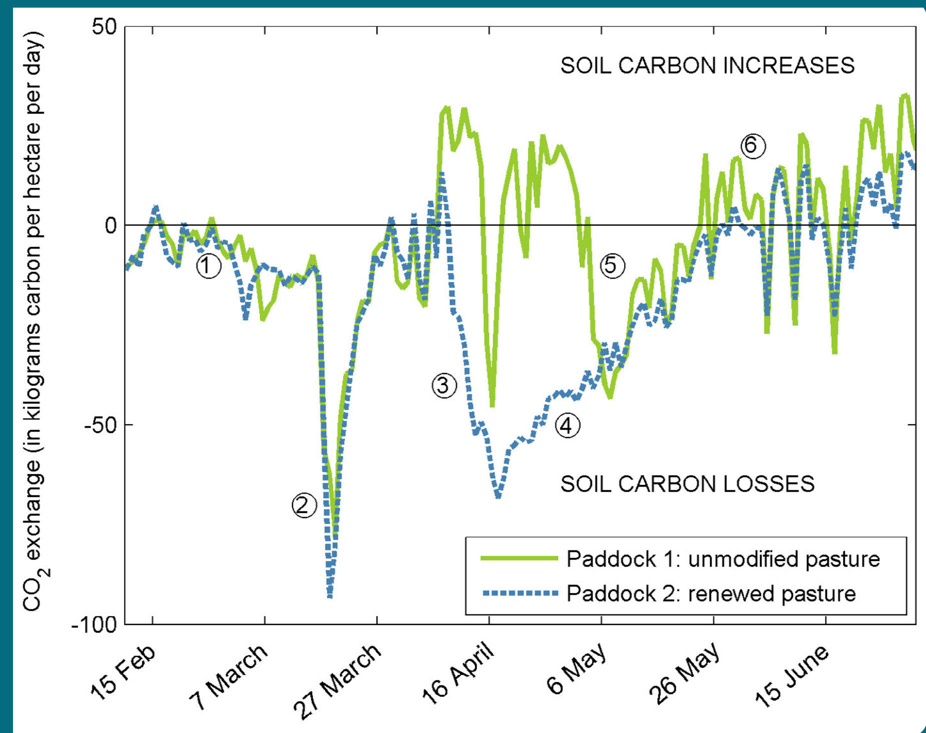
An alternative approach is to measure all the inputs and outputs of carbon to a farm to calculate whether the farm is gaining or losing carbon. The hardest part is measuring the daytime uptake of carbon dioxide by photosynthesis and continuous losses by respiration. Both of these processes are very large and a small difference generally dictates whether a site is gaining or losing carbon.

New Zealand scientists are currently using micrometeorological techniques known as eddy covariance techniques to measure this exchange[3]. Their equipment measures the concentration of carbon dioxide in the air and the direction of air movement above a paddock ten times per second over a year. This vast amount of data is summed to determine whether the paddock was a source or sink of carbon dioxide for the year. For this method, it is also important to have detailed records of the carbon exported in milk or imported in feed.

In contrast to soil sampling, changes can be detected within a few years and comparisons can be made between different management practices. Unfortunately, these measurements are expensive and technically challenging, which constrains the number of management comparisons that can be made. Carbon exchange can also be measured using small chambers, which allow a cost effective approach to simultaneously measuring the shorter-term effects of different management factors, for example different concentrations of livestock urine or different irrigation rates.

MEASURED CARBON DIOXIDE EXCHANGE FOR TWO NEIGHBOURING PADDOCKS

This graph shows increases and losses of soil carbon in two paddocks on the same farm during and after a drought.



1. The two sites lost soil carbon (released CO_2) in modest amounts during the drought
2. After the first rainfall, both paddocks released a large amount of CO_2, as soil microbes became active again
3. Paddock 2 was sprayed off and dies releasing CO_2
4. After sowing, plants in Paddock 2 regrow taking up CO_2
5. Paddock 1 was grazed, decreasing photosynthesis and CO_2 uptake
6. Eventually, the CO_2 dynamics of the two paddocks were similar again

[3]NZAGRC-PGgRc fact sheet: How we measure emissions

WHAT INFLUENCES THE AMOUNT OF SOIL CARBON STORED IN AGRICULTURAL SOILS?

Many factors interact to determine the balance between carbon inputs and processes that release carbon back into the atmosphere.

TYPE OF LAND-USE

Grasslands that are in permanent pasture tend to be large and potentially stable stores for soil carbon. This is in contrast to arable soils, which can be frequently cultivated and where the amount of carbon decreases with time to a lower stable store.

Intensive cropping systems are designed to promote fast growth of the productive part of the crop, which is generally biomass above ground, and may not invest energy in developing large rooting systems. Arable crops, therefore, tend to put less carbon into the soil and more of the carbon that has been fixed through photosynthesis will be harvested and removed from the site. Consequently, less leaf litter and other plant material enters the soil. Arable soils are also frequently disturbed when the crop is established, which can enhance microbial respiration.

Plants in a pasture system, on the other hand, generally have greater root mass and soils are less frequently disturbed.

In New Zealand, it also seems that there is more carbon in soil under pasture than under forests. Possible contributing factors include more root inputs (more carbon exuding into the soil), more root turnover (more dead plant matter rotting in the soil).

CLIMATE

Temperature and precipitation affect chemical, physical and biological processes in the soil – all of which interact in complex ways to determine the average stock of stable carbon in the soil and the dynamic exchange of CO_2 into and out of the soil.

Higher temperatures and abundant moisture generally promote both lush plant growth and rapid microbial activity. This may create good conditions for increasing soil carbon but whether warm, wet conditions lead to increased storage of carbon overall is entirely dependent on the delicate balance between plant inputs and degradation back to carbon dioxide through respiration by microbes and plants.

The overall effect of drought on soil carbon is similarly complex. In drought conditions, plant growth slows down and photosynthesis eventually stops, so the amount of carbon going into the soil declines. Microbes continue their work for a while longer though, continuing to respire and release carbon into the atmosphere. Initially, therefore, we can expect soil carbon levels to drop during a drought. When rain comes again, dying roots may be incorporated into soil organic carbon and plants will grow relatively quickly but microbial respiration also increases and some soil may be washed away.

Climate change has the potential to influence soil carbon levels over time as the frequency and intensity of drought and heavy rain periods affect the balance of carbon inputs to the soil and microbial processes that release it again.

SOIL TYPE

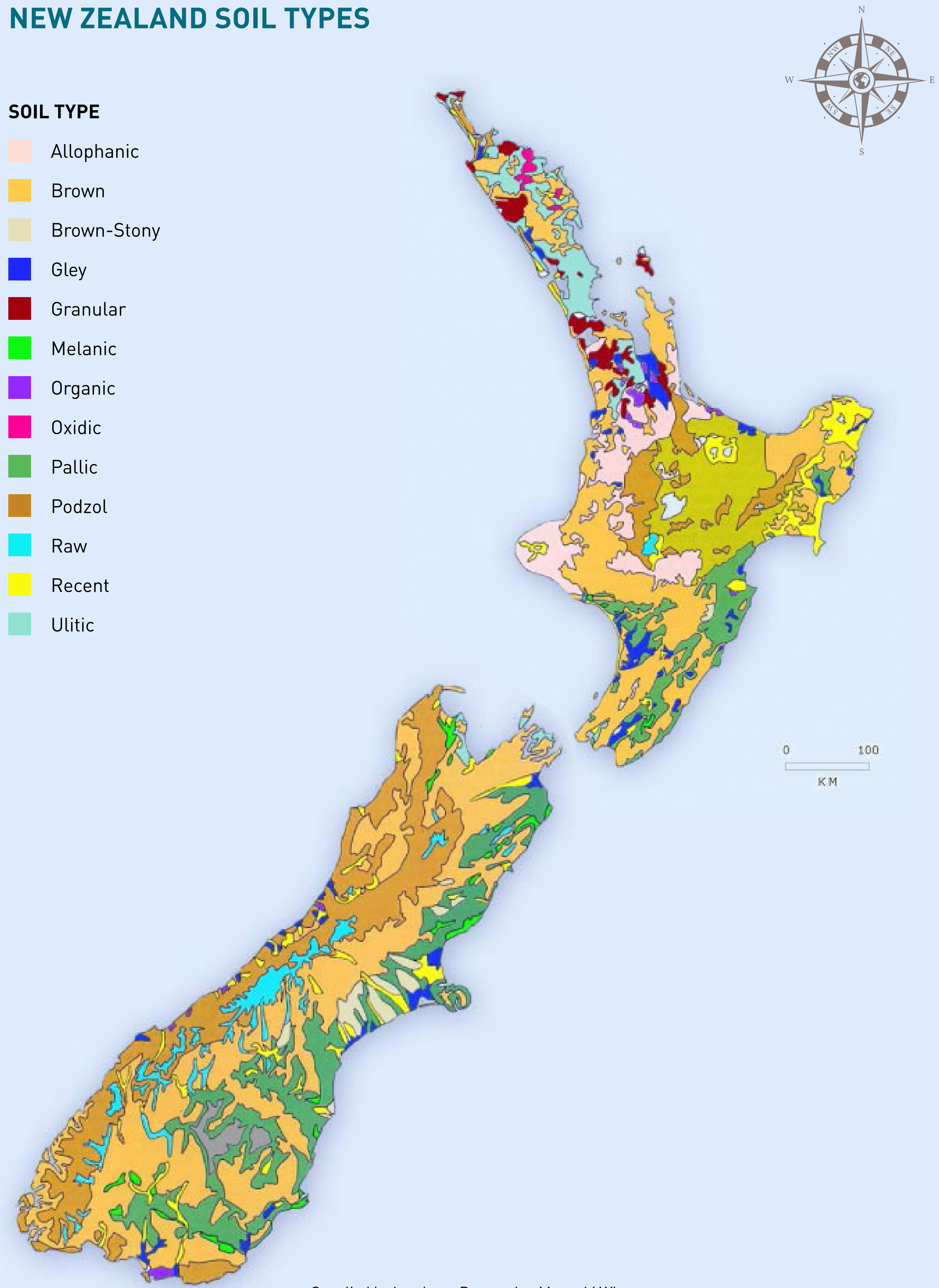
The amount of surface area of the soil is important for binding of organic matter.

Other things being equal, light soils with a high sand content contain less soil carbon than medium to heavy soils with more clay particles that have high surface areas.

Many of New Zealand's volcanic soils have very high surface area and so can store more organic matter than soils in other parts of the world.

Peat soils, formed by the partial decomposition of vegetation in wetlands, can be 40-60% carbon. Organic carbon can persist for thousands of years in such water-logged, acid, anaerobic (oxygen-deprived) conditions, but is lost rapidly if peat soils are drained. In parts of New Zealand, peats soils can be more than ten metres in depth, but this peat is vulnerable to loss when drained and used for agriculture, where measurements have shown peat soils declining at about two centimetres in height per year.

NEW ZEALAND SOIL TYPES



Supplied by Landcare Research – Manaaki Whenua

Source: Les Molloy, Soils in the New Zealand landscape: the living mantle. 2nd ed. Lincoln: New Zealand Society of Soil Science, 1998, p. 230

WHAT IS THE CURRENT STATE OF SOIL CARBON IN NEW ZEALAND?

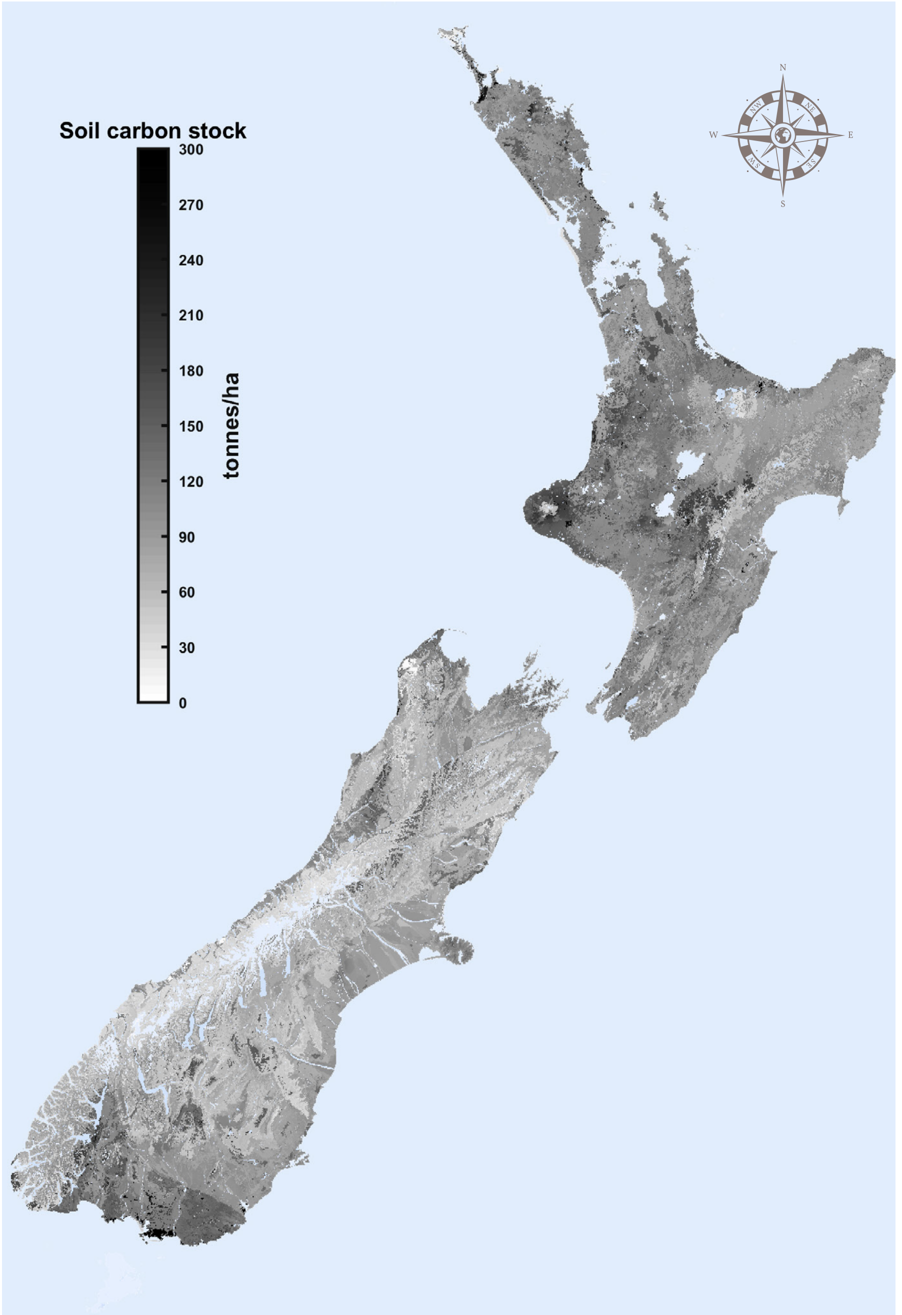
In New Zealand, the climate is temperate and agriculture is dominated by permanent pasture with high carbon inputs. As a result, measurements show that New Zealand soils tend to have accumulated relatively high carbon contents.

Available evidence suggests that on average, the soil carbon content of flat pasture land in New Zealand has changed very little over the past two to three decades, although the carbon content of pastures on some soil orders (including allophanic and peat soils) may have declined. This is a tentative conclusion – long-term datasets are required to distinguish short-term fluctuations from persistent changes in soil carbon stores. Explanation of these observed losses in soil carbon is challenging because of complex interactions between soil properties, farm management practices and the weather that all affect carbon inputs and losses. There is some evidence of short-term losses in soil carbon under animal urine patches for some soils and conditions but further investigations are needed to confirm any long-term effects at the paddock scale.

On the other hand, there is evidence that soil carbon in some parts of New Zealand's hill country has tended to increase over the past 30 years. It is unclear as yet whether this is the result of pastures gradually recovering after the initial deforestation and soil perturbation decades to centuries ago, or whether changed management practices in hill countries are contributing to this result (and the reasons could differ from location to location). It is not yet clear whether these changes are continuing or whether these soils have now reached a new steady state.

There is a limit to the amount of carbon a specific soil can absorb, which is related to the surface area of the soil particles. At that point a soil is said to have reached carbon saturation. There is evidence that most New Zealand soils under long-term pasture are not at their theoretical carbon saturation point, but it is not clear whether this point is readily achievable.

MAP OF SOIL CARBON STOCKS FOR NEW ZEALAND MAINLAND IN 2012 FOR 0-30cm



Supplied by Landcare Research – Manaaki Whenua

Note: Soil carbon stocks do not indicate whether carbon is increasing or decreasing in the soil

HOW IS SOIL CARBON TREATED IN NEW ZEALAND'S GREENHOUSE GAS INVENTORY?

The default assumption in New Zealand's Greenhouse Gas Inventory is that soil carbon does not change where land remains in a constant land use over time. Changes in carbon are only taken into account when there is a change in land-use.

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For mineral soils (which cover more than 99% of New Zealand's land area), the New Zealand Soil Carbon Monitoring System uses New Zealand soil data, climate and soil type to provide estimates of soil organic carbon stocks for each land use (forest land, croplands, wetlands, grasslands, settlements) in steady state. Following land-use change, the soil carbon is assumed to transition by the same amount each year to its new steady state value (depending on the new land-use) over a default period of 20 years. After 20 years, and in the absence of further land-use change, the soil carbon stocks are assumed to remain at the steady state level for the new land-use class.

Carbon is accounted for in this way because of uncertainties and technical difficulties of deriving accurate national estimates within land-use classes, and the requirement to estimate only those changes that are occurring directly as a result of local human activities.

Based on this accounting approach, soils as a whole have been a net source of emissions since 1990, mainly due to net conversions from grassland (which generally holds more soil carbon than forest soils) to forest land.

[4]www.mfe.govt.nz/climate-change/reporting-greenhouse-gas-emissions/nzs-greenhouse-gas-inventory

OPTIONS FOR INCREASING SOIL CARBON

Despite a wealth of theories and ongoing research, there are not yet any robust general rules about how to reliably and sustainably increase soil carbon in New Zealand pasture soils.

Soils can lose carbon quickly and recover it only slowly, so it is important, firstly, to protect current stocks. Beyond that, options to increase soil carbon fall into two categories:

- add more carbon and stabilise that carbon in the soil, and/or
- stabilise more of the existing carbon input and reduce carbon turnover.

From international research, it is clear that overgrazing can reduce soil carbon as it reduces overall plant cover and carbon inputs via roots, but undergrazing may also have such an effect as carbon inputs might decline.

Here we list some other pointers that have been proposed and that have some evidence or theoretical basis to support them. However for most options, additional tests are needed to confirm that they do indeed increase soil carbon levels in the long term under New Zealand conditions, and whether the options are restricted to particular soil types, climatic conditions or management practices.

ADD NITROGEN

In low fertility grasslands, the addition of nitrogen fertiliser or through clover fixation might increase soil carbon in the short term, but in the longer term, the amount of soil carbon reaches a plateau where additional nitrogen inputs do not yield any extra benefit. Whether adding further nitrogen to New Zealand pastures will increase soil carbon has yet to be fully tested. It is also important to be aware of undesirable side-effects, such as the production of nitrous oxide, which is also a greenhouse gas, and would likely outweigh any benefit of extra carbon storage[5].

OPTIMISE IRRIGATION

Theoretically, optimised irrigation should increase soil carbon stocks due to increased plant growth and greater inputs of carbon into soil, and hence remove carbon dioxide from the atmosphere. However, irrigation will also support greater soil microbial activity, converting soil carbon back into carbon dioxide that would be released back into the atmosphere. The role of irrigation and the net effect of these competing processes on the storage of soil carbon in the long term remains an area of active research.

INCREASE ROOT INPUTS OF CARBON

Increasing the amount and turnover of roots should deposit more carbon into the soil, where some of it would be incorporated into stable soil organic matter. This line of research is currently being explored, testing traditional ryegrass clover pasture against a mixed sward that includes chicory, plantain and lucerne. Some mixed swards and plant species have previously been shown to have greater root biomass and turnover. Further research is needed, not least to assess the effect of different pastures on milk and meat production.

ADD BIOCHAR

There is good evidence that biochar (organic matter carbonised under controlled conditions) represents a very stable form of carbon, so it could be used to store more carbon in soils. Research has indicated that specific biochars could also help reduce nitrous oxide emissions although the specific mechanisms are not yet clear; other potential benefits for improving soil functions and reducing emissions from pastures are also being tested. However, the main challenge at present to any widespread use of biochar in a pastoral system remains its cost and the large area that would need to be covered, which makes this strategy not economically feasible for New Zealand farmers.

[5] NZAGRC-PGgRc fact sheet: What we are doing

WORKING TOGETHER

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

More information

This fact sheet has been produced by NZAGRC and PGgRc, with substantial input from the University of Waikato.

There is more information on our websites, or contact us:

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