Industry Perceptions of the Role of Soil Carbon in Farm Greenhouse Gas Emissions

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Executive Summary

Internationally increasing soil carbon in agricultural soils has the potential to offset greenhouse gas emissions. This project evaluates the role of soil carbon in relation to farm greenhouse gas emissions in New Zealand. Agricultural soils in NZ have naturally higher levels of carbon than those overseas because they are typically younger and our practices include more restorative pasture and animal phases. Therefore we may not be able to increase soil carbon in the same way as international studies suggest.

The aim of this project was to examine the role of soil carbon in NZ and in relation to farm greenhouse gas emissions and policy. Key groups industry stakeholders were identified and interviewed. From the results themes were identified and analysed to answer the study questions.

The key learnings of this project were:

- It is unlikely that soil carbon will play a role in the offsetting of greenhouse gas emissions in New Zealand agriculture because levels on farms are already high.
- The complexity of including soil carbon in an emission scheme could be inaccurate and lead to unwarranted costs for farmers.
- It is more important that farmers focus on retaining and avoiding losses of soil carbon.
- Soil carbon contributes to soil health by improving soil physical properties such as water and nutrient holding capacities.
- More research is needed on soil carbon in NZ, where it is practical to increase it and how.
- Farms are businesses and need emissions reduction solutions that are going to be both practical and ensure that their businesses remain financially viable.

The recommendations from this project are that:

- More research be done on management practices that could increase soil carbon.
- Information be presented to farmers on the benefits of soil carbon.
- Tools be made available so that farmers can compare the effect of different practices on soil carbon.
- Farmers need help to better understand their greenhouse gas emissions and a range of solutions on how to reduce them.
- The industry and the broader society need to support farmers as they adapt their businesses to account for and reduce emissions.

Introduction

Soil carbon is a component of soil organic matter which in turn makes up 2-10% of the soil (Western Australia, Agriculture and Food, 2020). Carbon enters the soil through photosynthesis. It is incorporated into plant material which is then eaten by animals and the dung is returned to the soil. Plant roots also release exudates and these alongside organic matter, from plant residue, are returned to the soil. Microbes in the soil then partially break down these inputs of soil carbon and release carbon back to the atmosphere as they consume it for energy and respire. These processes are displayed in Figure 1, below. The carbon pool changes as microbes break down these inputs. It goes from being labile, in the form of plant residues and particulate organic matter, to humus which contains carbon which is more resistant to microbial decomposition (Queensland Government, n.d.), (Lange et al., 2015).

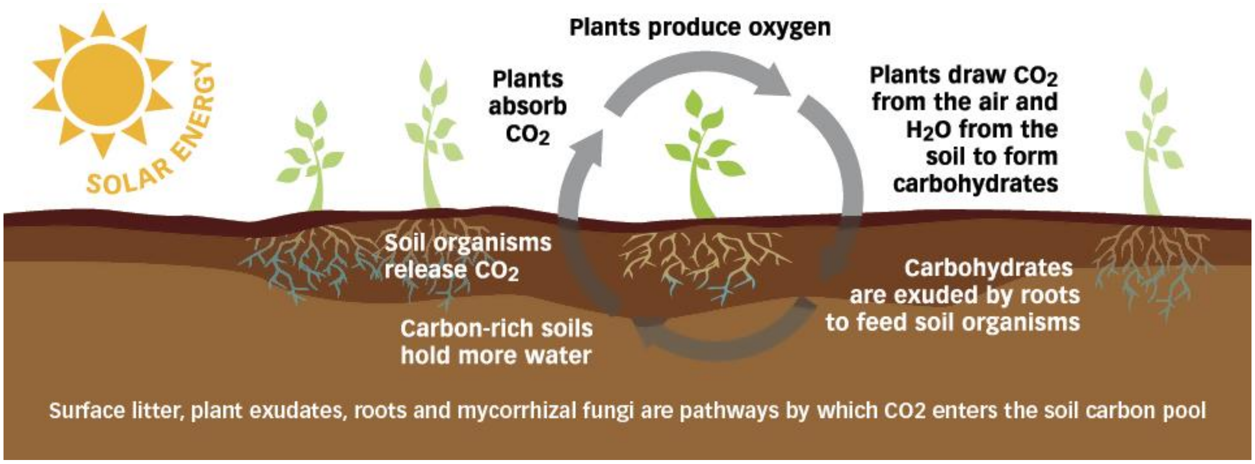

Figure 1: Formation of soil carbon pools (Community Environmental Council, 2020)

Soil carbon plays an important role in soil structure, helping keep soil aggregates together and contributing to porosity, water holding capacity and the supply and retention of nutrients (Schwartz, 2014). There is more carbon in the soil than in terrestrial plants and the atmosphere combined. Changes in the soil organic carbon pool can play a significant role in net GHGs (GHGs) globally (Lar, 2020). It is broadly recognised overseas that improved farm practices can increase soil carbon and help to offset GHGs (Lal, 2004).

In New Zealand soil organic carbon (SOC) makes up about 58% of soil organic matter (SOM), the soil inorganic carbon pool is only small in NZ. In this report the pools of carbon are not referred to individually but just as soil carbon (soil C). In New Zealand soil carbon in the top 30 cm of the soil profile can vary widely based on factors such as soil type and land use and ranges; exotic forests are generally found to have the lowest soil carbon levels and grazed pastures the highest. In general NZ has relatively high average soil carbon levels. These are a result of high C inputs from previous native forests, small areas of intensive cropping, highly productive pastoral land and favorable climatic conditions for plant growth (Sparling & Schipper, 2009).

The world is facing a climate crisis that is going to require a wide range of solutions to implement enough change to make a difference. Countries have made commitments under protocols and agreements in the past and are now working towards meeting their targets under the Paris Climate Agreement which has superseded previous policy attempts (Centre for Climate and Energy Solutions, n.d.). Domestic targets have been established to reduce GHGs to achieve these targets. New Zealand has also committed to reducing emissions and this includes reductions in agricultural emissions (Ministry for the Environment, 2019).
Could increasing soil carbon through changes in farm management practices in New Zealand help to reduce offset our GHGs?

This report analyses whether or not increasing soil carbon could help to reduce and offset farm GHGs in NZ. Information is collected for this project from relevant players in the farming industry: farmers, industry bodies, policy makers and researchers. Policy on and the requirement to reduce farm GHGs is still relatively new in NZ. This project also explores with interviewees their opinions on GHGs and reductions.

Aims & Objectives

The aims of this project are to:

- Examine the role of soil carbon in NZ.
- Learn, from literature, about what practices increase soil carbon overseas and what research has been done domestically.
- Understand the opinions in the agricultural sector on farm GHGs, recent policy and the importance of soil carbon in relation to these.

The objectives of this project are to:

- Review the climate change targets set in NZ, how they relate to agriculture, what is being done and what still needs to be done to help prepare the industry to meet these.
- Assess the attitudes of farmers on these targets and how other players in the industry see these affecting farmers.

Literature review

This literature review was carried out to provide context on soil carbon, what influences it naturally as well as what farming management practices could increase it. The review focuses on what research is available internationally and, where possible, when studies have been done in New Zealand. Current policies on GHGs in NZ are reviewed alongside the industry targets and recommendations.

Climate and texture

The climate and soil texture (silt, sand and clay content) have been found to have the greatest impact on soil carbon and this relationship varies with area and soil depth (Mei-Yan et al., 2013; Amelung et al., 1998).

Amelung et al. found that soil carbon was the highest in the clay fraction and this increased with increasing temperature and decreasing precipitation. This relationship reverses with increasing particle size, soils with higher sand contents have lower soil carbon.
Sequestration of stable soil carbon has been attributed to a number of mechanisms. The total surface area of the fine mineral fraction is the most significant contributor. Soil carbon associated with the fine mineral fraction is regarded as very stable with a high turnover time and therefore has a slow response to changes in management (Beare et al., 2014).

Soil type has been found to have more of an impact on soil carbon (contributing to 50% of the variability) than land use type (only 27%) in general there was higher soil carbon under pastures and indigenous vegetation than in arable and plantation forests (Sparling & Schipper, 2002). Allophanic soils have large surface areas from the fine mineral fraction and correspondingly high carbon concentrations. The specific surface area and extractable aluminium were the most important properties for explaining carbon variability. It is the fine fraction which influences the number of surface areas for carbon to bind to. The ability of different soil types to sequester additional carbon (their saturation deficit) was estimated on a national scale and Melanic soils (which have a high fine mineral fraction) were found to have the greatest saturation deficit. However when land area of the different soil types was modelled Brown soils had the greatest sequestration potential due to their national dominance (McNally et al., 2017).

Land use and soil type

The soil quality monitoring programme carried out in Canterbury found that soil carbon at the surface (0-15 cm) was correlated to land use with cropping having a lower soil carbon than pastoral land uses and within pastoral classes dairy had higher carbon contents than sheef/beef paddocks. The subsurface soil (15-30 cm) only showed a difference between cropping and pasture when the two were compared on a volumetric basis. Here there was higher soil carbon under cropping, potentially due to the effect of burying soil carbon with tillage. For both surface and subsurface there was a notable effect of soil group on soil carbon with the soil groups within the Gley Soils order having higher carbon contents than those in the Pallic Soils order; organic matter accumulates under anaerobic conditions in Gley Soils whereas Pallic's only contain moderate amounts of OM (Lawrence-Smith et al., 2014, 47; Mclaren & Cameron, 2012).

Management practices

Agricultural practices aim to increase plant productivity and generally involve harvesting the edible biomass and therefore may not lead to an increase in soil carbon. If plant removals are decreased or if more carbon is partitioned into the roots then soil carbon can increase. There are various management practices and inputs such as water and nutrients that help to increase plant biomass and could also increase soil carbon (Whitehead et al., 2018). This section will review soil carbon changes from the following management practices: changing to diverse pasture species, inputs such as manure and biochar, tillage and silvopasture.

Diverse species

Diverse pasture species are being recommended as an option to help reduce N loss especially on dairy farms where the increasing regulatory pressure is making increasing sward diversity economically viable and has been shown to reduce N loss by 44% (Romera et al., 2017). Increasing pasture diversity has been found to increase carbon inputs due to increased rooting depth and changes in the microbial communities which are a source of stable carbon. In NZ comparison between a diverse sward and a typical ryegrass, white clover mix showed a greater root mass and root depth for the diverse sward down to a 300 mm depth (McNally et al., 2015). Lucerne was found to have the greatest rooting density at depth although it is noted that root C input at depth does not necessarily mean stabilisation and increase in soil carbon (McNally et al., 2015).

At a long term biodiversity site called the Jena Experiment soil carbon was found to increase with plant diversity due to an increase in the soil microbial community. Soil carbon storage is influenced by root exudates which in turn have an impact on the soil microbial community and it was the stable microbial carbon resulting from this that was found to increase over time (Lange et al., 2015).

It is suggested that mixed species swards will increase soil carbon over a period of more than 5 years with careful management and selection of species with high rooting depth and density (Whitehead et al., 2018). More research is needed in this field to determine plant traits that could lead to greater resilience and production as well as soil carbon gains (Whitehead et al., 2018).

Biochar

The addition of inputs such as biochar and manure to soil has been found to have mixed effects on soil carbon. Biochar is suggested to have positive impacts on soil carbon however it is currently uneconomic in NZ to apply it at the rates needed to have a worthwhile impact. Manure on the other hand does increase carbon inputs but as little as 4% of these inputs are retained and there is concern over the increase of nitrogen and phosphorus from these effluent applications (Whitehead et al., 2018).

Tillage

No tillage has been considered as a way to increase soil carbon and mitigate GHGs (Pacala & Socolow, 2004, 971). However Ogle et al (2019) suggest that there is not enough data on soil carbon changes at depth to substantiate any claims that no-till practices lead to an increase in soil carbon. It was suggested that no-till instead has a number of positive impacts outside of increasing soil carbon such as reducing erosion, improving water use efficiency and N mineralisation. All of which have a positive impact on GHGs.

In Canterbury NZ no-till was also found to decrease macroporosity and increase bulk density in the top 75 mm of the soil in comparison to conventional tillage. No-till did not increase SOM under continual cropping but did reduce the decline in SOM with change from pasture to cropping in comparison to conventional tillage (Francis & Knight, 1993).

Full inversion tillage has been cited as a way of increasing soil carbon as there is generally more carbon in the surface than subsurface and this could be buried and retained at depth with the new surface material then able to bind additional carbon (Alcantara et al., 2016).
In New Zealand inversion tillage was found to increase soil carbon from 50 mm depth. Carbon rich soil from the surface was replaced with previously sub-surface soil which had additional carbon storage capacity. The ability of this new surface soil to absorb carbon needs to be monitored over time (Pereira et al., n.d.).
In the same trial inversion tillage was found to reduce peak nitrous oxide emissions after urine applications, reduce total mineralisation of N during the pasture/ crop cycles and increase yields (Pereira et al., n.d.).
In a review of studies in a paper published by the Rodale Institute in the US they suggest that no-till alone doesn't necessarily increase soil carbon but needs to be a part of a systems approach (Moyer et al., 2020). A systems approach employing other practices such as increased sward diversity, cover cropping and synthetic fertiliser reduction is recommended alongside no-till management in order to have a positive impact on soil carbon.
Another US study states that shallow depth (less than 25 cm) inversion tillage gave the best result for increasing soil carbon, maintaining yield and controlling weeds in comparison to deep inversion tillage and non-inversion tillage practices. similarly they state that inversion tillage does have positive benefits for soil sequestration (Cooper et al., 2016).

Irrigation

Irrigation has been suggested to have little impact on soil carbon in humid areas where levels prior to irrigation are already reasonable. In arid environments where production was initially low irrigation can dramatically increase production and plant inputs of soil carbon (Whitehead et al., 2018). Soil carbon increased in a study of dairy farm systems until a water availability of 750 mm/year, further increases resulted in a decline due to increased use of carbon by the system and lack of moisture limitations on decomposition in the summer months (Kirschbaum et al., 2017, 68). Similarly Laubach et al (2019) found that lucerne biomass production increased with irrigation alongside net carbon losses mainly over summer. This was due to reduced constraints on decomposition in comparison to a non-irrigated treatment. Maintaining a moisture deficit was suggested as a way of managing this. In a pasture based study comparing irrigated and non irrigated sites across New Zealand soil carbon to 30 cm decreased with irrigation with a high proportion lost from deeper horizons (Mudge et al., 2016).

Silvopasture

Silvopasture has been employed for a long time, originally as a way of growing grass in between pine trees. Increasingly it is employed as a way of: stabilising land on farms, reducing nutrient loss and to provide leaf matter for partial grazing of unproductive areas that are better utilised as carbon sinks (Benavides et al., 2009).

Willow and poplar silvopasture zones have been researched in Canterbury, NZ as a means of reducing nitrate leaching due to their deep root zones, high growth rates and being themselves low nutrient emitters. The biomass can then be harvested and the trees can be kept below the pivot line (Franklin et al., 2016).

In a NZ hill country study total carbon pool estimates, from topsoil and plants, over the lifetime of a poplar-pasture site suggested greater accumulation of carbon than for the pasture only site (Guevara-Escobar et al., 2002). However results showed that one of the poplar-pasture sites actually had lower soil carbon than a pasture only site. Silvopasture sites need to be evaluated for a range of benefits, such as improving soil properties, reducing erosion and increasing grass growth, as immediate increases in carbon sequestration alone may not offer enough to justify the system (Guevara-Escobar et al., 2002).

Native trees

A study carried out in the north-east of the north island evaluated Maori land ownership and cultural values alongside planting native trees for carbon farming. It found that the value of carbon sequestration alone was not enough to justify changes in land use and that care was needed to ensure that landowner values were recognised such as the right of future generations for self-determination over the land use. When other land services were recognised such as habitats for natural species, soil protection, expansion of honey production and tourism/ recreation the value of planting marginal areas increased and justified the change over just the value of the carbon credits (Funk & Kerr, 2007).

New Zealand GHG Policy

Under the Paris Agreement New Zealand is committed to reducing GHGs to 30% below 2005 levels by 2030. To provide a framework for climate change policies to meet the country's requirements under the Paris Agreement and to prepare for the effects of climate change New Zealand implemented the Zero Carbon Amendment Act. The Act puts into place both long term domestic GHG targets and emissions budgets to help reach these targets (New Zealand Agricultural Greenhouse Gas Research Centre, n.d.). The long term domestic targets embedded in The Act are net zero emissions of carbon dioxide and nitrous oxide by 2050 and reductions in biogenic methane to between 24-47% below 2017 levels by 2050 with a 10% reduction by 2030 (Ministry for the Environment, 2019). Agriculture sector emissions account for 48% of New Zealand's gross emissions in 2018 with the energy sector contributing 41%, see Figure 2 below (MFE, 2020).

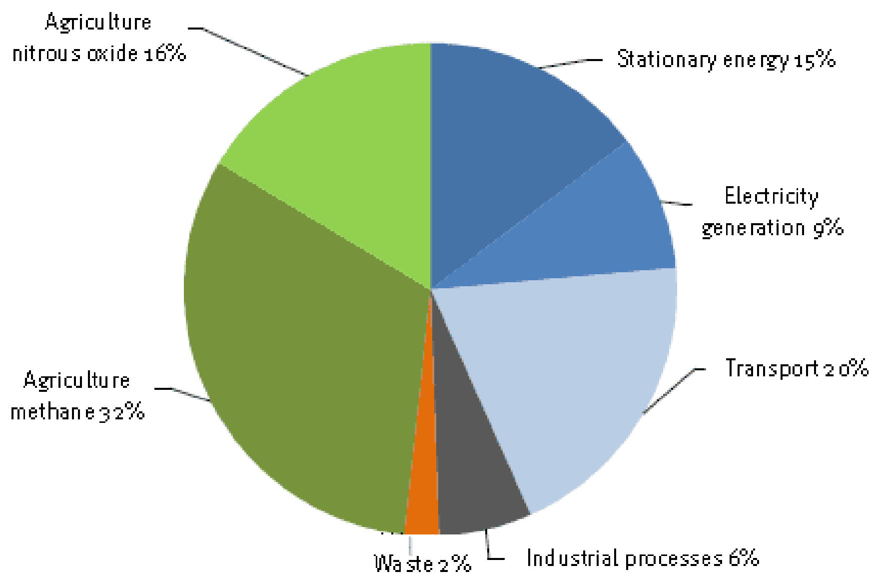

Figure 2: New Zealand GHGs per sector

Since the Zero Carbon Act was introduced the agriculture sector and the government have worked together to produce He Waka Eke Noa “Our Future in Our Hands”. It aims to build a framework for the sector to reduce farm GHGs (He Waka Eke Noa, 2020). Currently a strategy is in place till 2025 to deliver various targets, the key ones include:

- December 2021, 25% of farmers know their emissions and have a plan to manage them
- December 2022, 100% of farmers know their farm emissions
- December 2024, 100% of farmers have a written plan to measure and manage emissions
- 2025 development of an appropriate mechanism for emissions pricing

The Climate Change Commission is an independent Crown Entity whose purpose is to provide evidence-based advice to the Government. Recently it produced a report to advise the government on actions to achieve our Nationally Determined Contribution (NDC) under the Paris Agreement and advice on biogenic methane emissions (Climate Commission, 2020). In the report The Commission suggests a way to meet the 10% reduction of 2017 biogenic methane levels by 2030.

The Commission assumes no new technology or developments are made and instead relies on decreasing stock numbers of dairy, sheep and beef by around 15% of 2018 levels by 2030. It does account for genetic breeding of sheep in helping to reduce emissions of sheep and beef farming by 1.5% by 2030. Furthermore, 2,000 ha a year of dairy land will be turned into horticulture per year from 2025 (Climate Change Commission, 2021). The Commission states that if farmers are able to continue achieving productivity improvements in line with historic trends then the 2030 biogenic methane target could be met without reducing production.

The role that soil carbon has to play in these emission reductions is still to be determined and this could make up part of the recommendation from the He Waka Eke Noa Farm Sequestration workstream. The Climate Change Commission refers to soil carbon and regenerative agriculture practices as potential other ways to reduce agriculture emissions. However it makes it clear that evidence of the effectiveness of these practices in Aotearoa is required (Climate Change Commission, 2021).

Overseas

According to a review paper from Cornell University GHGs from soils are not regulated by countries worldwide. There is no legislation around soil carbon however the paper suggests that there are opportunities for soil carbon management to earn credits (Woodbury & Wightman, n.d.). Two examples of this already happening are in Australia and Canada.
In Australia GHGs from agriculture made up 13% of total emissions in 2019 (Australian Government, 2019). They have a Carbon Farming Initiative (CFI) which allows land managers to earn carbon credits for storing carbon or reducing GHGs on the land (FAO, n.d.). Australia has a ghg reduction target of 80% below 2000 levels by 2050 and reducing emissions, as well as increasing carbon storage, is key in achieving this.

In Canada GHGs from agriculture made up 8% of total emissions in 2018 (Government of Canada, 2021). It is noted that this does take into account the carbon which is sequestered by agricultural soils (Government of Canada, 2020) . From 2000 onwards canadian agricultural soils have sequestered more carbon than they have released and it is expected that until 2040 it will be practical to increase soil carbon levels. After this time they will be maintaining rather than further increasing. Practices that have been employed to increase soil carbon include, reducing fallow periods (the time without any crop in the ground), reducing tillage, better residue management and incorporating animal manure into the system. Provinces in Canada have either had (in the case of Alberta) or are starting carbon credit programs. Sequestration amounts are set based on management practices and soil zones and carbon credits are then paid out accordingly by the provincial government. There are many issues associated with the process such as the amount of time needed for little reward and the risk that growers can then be charged taxes due to inaccurate accounting (Cross, 2021).

In Australia total organic carbon is usually less than 8% and under rainfed farming typical soil carbon ranges from 0.7-4% (Carson, n.d.). Soil carbon levels in the Ontario province of Canada are similar with cropping farms having an average of 2-3% soil carbon depending on the rotation and the presence of cover cropping increasing levels (Laamrani et al., 2020).

Methods

The inspiration for this project originally came from an interest in regenerative agriculture and changes in soil carbon from regenerative management practices. It developed into an interest in farm GHGs which have had an increasing amount of attention recently. The literature review was started to help the author gain insight on the topic and was finished after the interviews. Allowing them to identify additional areas of reading.

Interviews

Carrying out interviews was chosen as the method of data collection to allow for additional insights to come out. For this reason a semi structured interview method was chosen to allow for conversations outside of the set questions. These questions were set prior and were slightly different for the groups interviewed, as shown in Appendix 1 - Interview questions. Interviewees were booked for a time and, at the start of the interview, were asked for their permission to record. Informed that no names would be used alongside their content and that the Chatham House Rule would be applied by default. They were also asked if the author would be able to send them any follow up questions via email if the need arose.

Interviewees

The author decided that approaching a range of stakeholders would offer the most interesting insight on the range of opinions and understanding on the topic.
The following groups were decided on:

- Industry bodies
- Researchers
- Policy makers
- Farmers (from sheep & beef, dairy and cropping sectors)

As a result of time restraints the groups were narrowed down, as explained in the Limitations section, and the list of interviews are as follows:

- Industry bodies & policy makers (n=3)
- Researchers (n=4)
- Farmers:
    - Cropping n=5
    - Dairy n=3
    - Sheep & beef n=3

More cropping farmers were interviewed than other farming sectors due to the variety of cropping operations. Some were a crossover between cropping and sheep & beef farming while others were a cross between dairy grazing and cropping.
There was an initial desire to include a subset of larger farming groups and of regenerative farmers but in the end these interviews were too few to be separated out and so were allowed to add diversity to the results and are mentioned if applicable.

Responses were analysed by transcribing the interviews and identifying the overarching themes. Data was numbered to group ideas within these themes. Mind maps were produced for each group, themes formed the main branches and ideas were the leaves off these. Often there were a number of similar responses within groups which made identifying themes easy. Any additional comments to the main ideas were noted so that they could be mentioned.

Results

This section highlights the results that came out of the interviews. Where relevant, reference is made to agreement by all interviewees or some on a topic.

Policy/ industry body themes

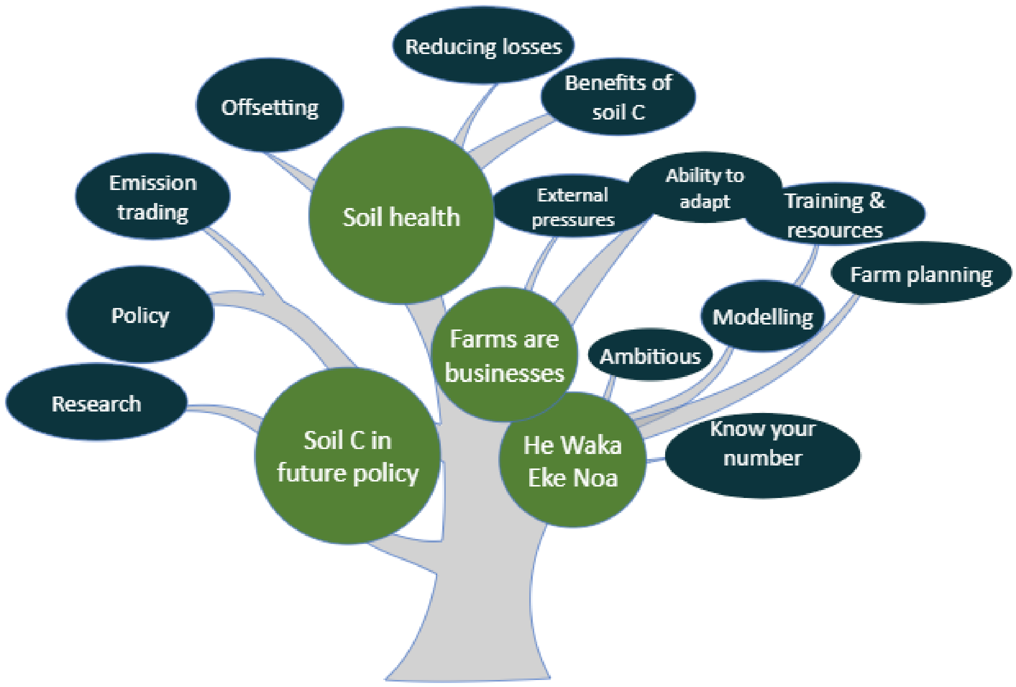

Figure 3: Mind Map of policy/ industry body themes and ideas

1. Soil C in future policy

1.1. Research

There was an agreement by interviewees that more research is needed to increase our understanding of soil carbon in NZ as well as the links between our farm systems and GHGs. The main reasons for research were:

To understand changes in soil carbon as a response to changes in land use

To understand what land management practices might influence soil carbon.

This was to inform farmers as to the impact of various practices on soil carbon. The group also noted that this would be more important in terms of reducing losses. In addition, for cropping farmers, soil carbon could play a role as an offsetting tool, because they often will not have a large animal element contributing to emissions on their farm.

For all farming types there was consensus on the need for more tools to support farmers in their everyday decisions, these need to be reputable and delivered through all media/ information channels. The importance of visual demonstrations was noted. The national soil carbon accounting survey which is being carried out by Landcare Research and the University of Waikato (Landcare Research, 2020) was mentioned as being positive in informing our overall picture on soil carbon and improving existing models. In the future interviewees agreed that more farmers would likely measure carbon at a farm scale especially if measurements get easier.

1.2. Policy

Soil carbon is not currently recognised in policy in NZ, overseas or in international agreements such as the Paris Agreement, due to difficulties in obtaining enough data at an appropriate scale. Interviewees noted that when and how soil carbon is incorporated into policy in the future will also depend on our ability to collect accurate data at an appropriate scale.

1.3. Emission Trading

Under He Waka Eke Noa there is a work stream that is focusing on on-farm emission pricing and another for on-farm sequestration. It is unlikely at this stage that soil carbon will form a part of emission trading or offsetting for farmers due to the complexity of doing this. Especially in NZ, where we already have high levels of soil carbon, it could be difficult to tell if there is an overall increase or decrease in soil carbon and farmers could be liable for the cost of losing soil carbon.

2. Farms are businesses

2.1. Ability to adapt

Farms will have varying abilities to reduce their emissions while remaining profitable. The message was very clear from all interviewees that farms needed to stay profitable, there is a cost to the initial accounting of GHGs. There is also likely to be costs associated with reducing farm emissions in the future. Some businesses would be able to make changes to increase efficiency while still remaining profitable however for others there would be very little ability to make more changes. As businesses, operating during periods of good returns, it will be difficult to make changes that could decrease profit.

Where we are at now is just a starting point and the consensus was that these farm businesses are realising the role they have to play and will adapt to these changes, as they have already to requirements under nitrate leaching regulations.

2.2. External pressures

Farms are facing increasing pressure from society and the interviewees saw this as an expectation that products would become more environmentally friendly. They did not think that farmers would see increased value from their products in the long run however there could be short term benefits if we can move quickly to demonstrate that our products are environmentally friendly or make the changes required. Examples of this are the Beef & Lamb and Dairy NZ reports released over the last 6 months which state the efficiency of their respective farming systems. There was also an underlying theme that these changes would be good for the whole NZ image rather than just primary exports.

3. Soil health

3.1. Offsetting

Across all of the interviewees there was a consensus that soil carbon needs to be recognised in terms of overall soil health rather than as a tool for offsetting. Soil carbon is very complex and we do not currently have adequate understanding of it to be used as an offsetting tool.

3.2. Reducing losses

Some of our pastoral systems rely on pasture renewal and when there is no plant cover soil carbon will be lost. The focus needs to be on how we reduce losses of carbon from farms. We have areas where the potential for erosion is high, reducing erosion would reduce losses of soil carbon.

3.3. Benefits of soil C

Farmers are visual learners and demonstrating the benefit of retaining or building soil carbon needs to be in terms of the flow on benefits such as: increased water holding capacity and visually better structure.

4. He Waka Eke Noa

4.1. Know your number

The first step for farms to meet under He Waka Eke Noa is to know their farm GHG emission number. Achieving these targets and future changes will take time but some interviewees did not think it would be as difficult as nitrate accounting and reductions because now farmers are familiar with the process.

The dairy industry already has a large number of farms in the sector reporting on GHGs through reporting done by the milk companies. This is as a result of work that the industry had already done under the Dairy Action for Climate Change (DAC).

For the arable sector there was a sense that this would be a bit daunting.

4.2. Farm planning

This is the next step outlined in He Waka Eke Noa where farms will need to integrate their GHG reporting into a farm environment plan (FEP) alongside other environmental aspects such as nitrate losses and identify management options. Interviewees considered this to be the more difficult step and especially considering at the moment management options for GHG reductions are slim. The implication of any potential system changes on other parts of the system was also seen as very important by all interviewed.

4.3. Modelling

Deciding on and developing a modelling framework for GHGs is one of the work streams in He Waka Eke Noa. All interviewees agreed that it was very important for this model to be accurate so that farmer faith in the model was not compromised. Farmers lost faith in Overseer as an accounting model for N loss and it is still a work in progress to regain that confidence. Some interviewees felt that Overseer was the best tool we have to account for GHGs.

4.4. Training and resources

Interviewees agreed that training of rural professionals was needed in both farm GHGs and soil carbon. Some interviewees felt that the role of industry bodies was in providing information on management practices to reduce GHGs and the overall benefits that could be seen from increasing soil carbon.

4.5. Ambitious

There was consensus that the targets set out in He Waka Eke Noa were ambitious but good. There was a recognition of the urgency of this topic and that it would be better to set ambitious targets and set the goals high rather than make it too easy. There was a recognition by some that ministers were understanding of the situation and the difficulty for agriculture to adapt rapidly.

Farmer/ grower themes

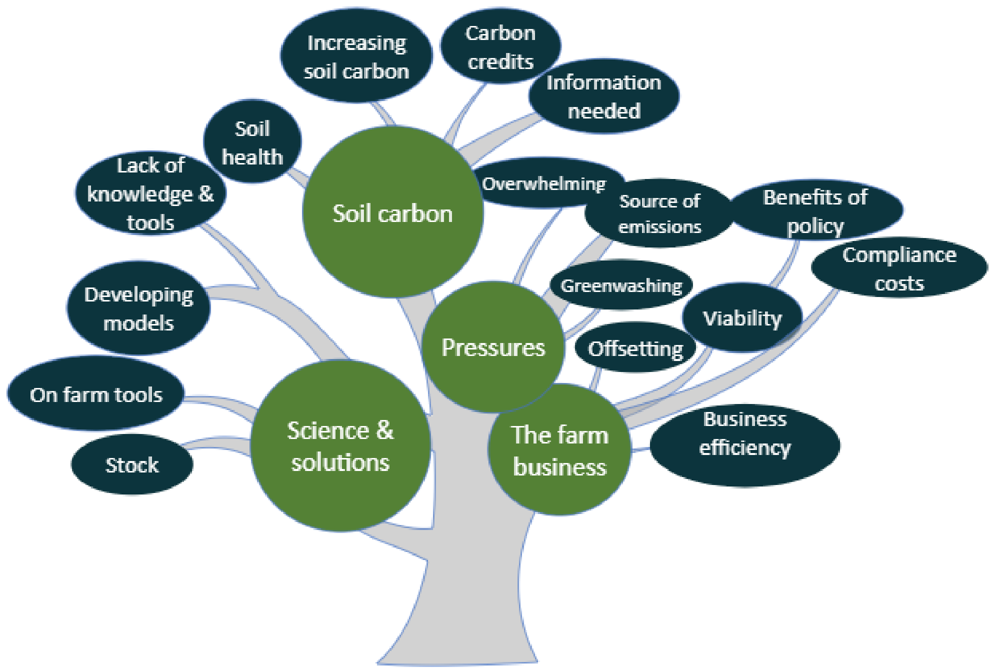

Figure 4: Mind Map of farmer/ grower themes and ideas

1. Science and solutions

1.1. Lack of knowledge/ tools

There was an overwhelming agreement amongst all farmer groups that there is currently not enough science or resources on the role of soil carbon in the farm system and in relation to farm GHGs. Furthermore, what our current levels of soil carbon are and how they could change with different management practices. This translated to an agreement that there is a lack of solutions on how to reduce farm GHGs.

1.2. Stock

The dairy farmer group noted that the only option available currently to decrease GHGS is destocking and they needed other options.

1.3. Developing models

The cropping farm group, in particular, thought that there needed to be more accurate data for accounting and informing models if soil carbon was going to form a part of GHG accounting in the future.

1.4. On farm tools

The cropping and sheep & beef farmer groups both mentioned the need for simple tools to assist with decisions on farms to help to reduce emissions.

2. Soil Carbon

2.1. Information needed

All groups agreed that it is important to be able to measure soil carbon to understand starting points on individual farms. From there what happens to carbon as management practices are changed.

2.2. Carbon credits

All farming groups agreed that there was the risk that if we measure carbon with the goal of creating a carbon credit system then there would be the risk of being charged if there were any losses. Also there was not enough science and too much variability around soil carbon in NZ and that it was difficult to measure on an accurate enough scale. Some from the cropping group also mentioned that there was a slim chance that the government would roll out a credit system that would benefit farmers doing good things for the environment as the investment didn’t seem to be there. They mentioned it would be good if low emitters could be rewarded somehow.

2.3. Increasing soil carbon

The majority of the sheep & beef and some of the dairy and cropping interviewees noted that soil carbon is already high in NZ and that there may not be many chances to increase it.
The cropping farmer group recognised the benefit of pasture and this phase of their rotation with many using this as a way to allow paddocks to recover or to improve low performers. They mentioned that this phase allowed them to increase soil organic matter and to recover from previous cropping phases.

2.4. Soil health

All groups and interviewees agreed that soil carbon would be more important in terms of overall soil health in the future rather than for the sake of offsetting GHGs. There was an acknowledgment by a number of interviewees across the farming groups that there was a lack of knowledge on soil carbon and what it could provide to the system however most suggested that it could contribute to a range of the following: soil structure, aeration, microbes, water holding capacity and nutrient retention. The cropping group felt that cultivation did not help the overall soil carbon/ health picture but that often it was a necessary tool and were interested in what was better in terms of spraying versus cultivating. Some from the sheep & beef farming group recognised the value of visual soil assessments (VSAs) and the role that these may have going forward to add value and understanding to their system.

3. The farm business

3.1. Compliance costs

Some interviewees from each group noted the cost of the administration associated with compliance and that this was already there with the nitrate regulations in place and only expected to increase. It is particularly noticeable in smaller businesses.

3.2. Offsetting

All interviewees mentioned that trees are not a solution to tackling farm GHGs for a range of reasons:

- They are a waste of productive spaces
- It is just buying the way out of the problem
- Offsetting is not the solution to the problem.

It was noted that natives wouldn't be a bad option but pines were no good. In general offsetting was not seen as a viable option but some of the cropping group mentioned that they may factor any emission pricing cost into their business structure because it might be their most viable option.

3.3. Business efficiency

Some interviewees from each group mentioned that some farm businesses were already more efficient than others. They were worried about how the need to reduce emissions further would impact the financial sustainability, really the overall sustainability, of the business. Some of both the cropping and sheep & beef interviewees noted that they had already made changes to their system to increase efficiency.

3.4. Viability

The overwhelming consensus from the groups was that farms need to be profitable because they are a business. No matter if they are organic or regenerative they need to be profitable. The cropping and sheep & beef farmer groups were united in that there is very little financial wiggle room in their systems right now and that maintaining current production levels is important. The cropping farmer group noted that banks need to see that they are sustainable. The sheep & beef farmer group noted that some farms will be sold. Some interviewees from all the farmer groups noted that age and role in the business was a factor in terms of financial ability to weather the situation and future changes.

3.5. Benefits of policy

Interviewees from all groups believed that the changes required by farmers, in terms of first accounting for and then reducing GHGs, would not result in a higher price for their products on the international market. It would just maintain access to various markets and maintain the NZ's clean, green image. They noted that consumers are expecting this from farmers and in some cases ie organics consumers already expect farms to be operating carbon neutral.

4. Pressures

4.1. Source of emissions

For most of the interviewees across the farmer groups stock was the main source of their GHGs and reducing them is currently the only real option to reducing their number. This was a source of pressure as interviewees were not sure how they would remain profitable while reducing stock numbers.

4.2. Overwhelming

Various interviewees throughout the farmer groups noted felt like their voting power had been diminished by the urban consumer who sometimes did not know where their food had come from. Likewise what has gone into producing it but are increasingly demanding more from their producers. They felt like they were an easy target and that there are other sectors that could be encouraged to reduce and for whom it might be easier for than the agriculture industry.

4.3. Greenwashing

Some interviewees from all farming groups mentioned that consumers were pointing the finger at them and their practices, including livestock production, but that these consumers aren't fully aware of the carbon footprint of a vegetarian or vegan diet yet. It is too easy for these diets to be advertised as environmentally friendly when the evidence is not necessarily there. They also noted the importance of animals in farming systems and diets and that this has always existed.

Researcher themes

Figure 5: Mind Map of researcher themes and ideas

1. Research needed into farm GHGs

1.1. Communication

Most interviewees agreed that communication on solutions and policy needed to be done through a range of avenues as all farmers get their information from different sources and learn differently. Emphasis was placed on visual demonstrations so that farmers can see the results of system changes.

1.2. Science based solutions

All interviewees agreed that there was a real need for science based solutions with tangible benefits. Solutions must be practical on the farm and there will be many rather than just one golden solution. There needs to be decision support tools where farmers can quickly evaluate the pros/ cons of everyday management decisions on the go and determine their impact on emissions. Some interviewees also mentioned that farmers were great innovators and often science was struggling to keep up with them. Options for reducing GHGs such as the methane vaccine, nitrification inhibitors and changes to animal diets were all mentioned as important research streams.

1.3. Whole system thinking

Interviewees all mentioned that solutions to reduce GHGs needed to consider any potential flow on impacts in terms of nitrate leaching, production and soil carbon. Nothing happens in isolation on farms.

1.4. Changing soil carbon

Interviewees all agreed that research was needed into how soil carbon changed with changes in land use and on different soil types. Research is needed into management practices to identify any potential ways to increase soil C. Management practices mentioned as having potential were: full inversion tillage, regenerative grazing techniques, diverse pasture swards with a range of rooting depths and silvopasture. Research into the impact of these practices on soil carbon will need to be carried out over long time periods.

1.5. Accounting and modelling

Interviewees mentioned that when the process for GHG accounting has been decided on by the He Waka Eke Noa work stream it will be extremely important that there is consistency and transparency on how farms are modelled so that farmers can trust the process. Including soil carbon in this accounting process might not be a priority at the start. In the future however, soil carbon could be modelled at some level. A consideration mentioned was that soil carbon was most likely to be affected when there was a change in land use so there could be a land use change factor in the model.

2. Soil carbon in New Zealand

2.1. Naturally high soil carbon

All interviewees agreed that soil carbon is already very high in NZ as a result of our relatively young soils and prevalence of pastoral systems. There is skepticism about how much we are able to increase our soil carbon. For us it is more about reducing losses of soil carbon and maintaining our current levels.

2.2. Maintaining soil carbon

Interviewees agreed that there may be some practices, mentioned above, that can increase soil carbon. There is a lot of room to increase soil carbon when land use change occurs for example changing from cropping to pasture systems. Otherwise it is important to maintain soil carbon through: reducing erosion, supporting soil structure through avoiding fallow periods and ensuring plants are in the ground as much as possible. Not draining wetlands or peat soils is also very important as they have very high soil carbon levels which decrease dramatically when exposed to oxygen.

2.3. Offsetting

The consensus was that although at a global scale sequestering carbon in the soil will play a significant role in offsetting GHGs, in NZ this is not a reality. There may be the ability to offset some emissions if the practices mentioned above can increase soil carbon however it will not be significant. If soil carbon was included in an offsetting programme, it would be very difficult to measure and prove and would open farmers up to the risk of paying for losses in soil carbon. In terms of other types of offsetting emissions through planting trees, some interviewees mentioned that we do not have the land area in NZ to offset in this way. Pines were not considered to be a solution.

2.4. Upper limit

The ability to increase soil carbon would be area specific based on soil types and maybe land uses with each having its own upper limit. Identifying these areas would be beneficial on a national scale and farm scale testing would help to identify specific paddocks or areas on farms where soil carbon could be increased.

3. Pressures on farmers

3.1. The consumer

Some interviewees identified that consumers are placing pressure on the farmer as they have high expectations while being disconnected from the reality of how and where their food is produced. Consumers need to support farmers rather than place blame on them. This is not helped by the fact that negative news stories always have a bigger presence and influence than positive ones do.

3.2. Alternative diets

Some of the interviewees mentioned the need to fully understand the emissions and environmental impacts associated with alternative diets such as vegan and vegetarian. There is the potential for the consumer to be greenwashed by these diets when their impact hasn't been proven.

3.3. Overwhelming

All interviewees felt that the current social and political environment would be overwhelming for farmers. They felt a range of factors were contributing to this: farmers not having enough solutions to address the reductions in GHGs that they would be facing, not yet knowing the full implications of the situation, the need to maintain their social license and feeling like they were scapegoats.

Insights

The author felt that some very wise statements were made during the interviews outside of responses to the questions a few of these have been noted below:

- This is a very real problem and we need to stop thinking about it in the abstract and start seeing it as something that we are dealing with right now and something that we are going to have to throw everything at. All solutions and all possible changes need to because there is no silver bullet.
- The hope that every individual will do their bit and with a good heart try their hardest. The hope that around the world everyone puts their best foot forward.
- The belief that there is still time for us to change, adapt and do what is best for the environment and our planet.

Discussion

The results from the interviews emerged as a few main ideas which will be analysed in more detail in this section:

- The role of soil carbon
- Carbon and greenhouses gases on farms
- The pressures on the farming business

Soil carbon in New Zealand

There has been a lot of talk internationally about how sequestering carbon in the soil can help to offset GHGs. For countries such as Canada and Australia, where cropping practices have depleted soil carbon over the years and where pasture has not been included in the system, soil carbon levels are low. The amount of carbon that could be sequestered by these depleted soils is significant and changes in management have been suggested to increase inputs. Changes include introducing cover crops and animals into the system.

New Zealand has far higher soil carbon levels than seen internationally. This is a result of our comparatively young soils and systems which often include pasture and animals, if only for parts of the rotation.

It does not appear that soil carbon will have the same importance in NZ as it will do overseas in offsetting GHGs. A sentiment that came out strongly from the researcher group and was supported by the industry and policy groups was the importance of avoiding losses of soil carbon. We may be able to increase soil carbon depending on the soil type, land use and management practice. However our focus should be on retaining and mitigating losses of soil carbon. Interviewees from the cropping farmer group recognised the importance of pasture in their rotation as a way to recover soil organic matter and carbon losses that occurred during the cropping phase.

Soil health

From the farmer interviewees there was a consensus that the role of soil carbon in the future would be more in improving soil health rather than GHG offsetting. Soil carbon contributes to important soil properties such as structure and within that water and nutrient holding capacity. The sheep & beef farmer group tended to have a deeper understanding of the importance of soil carbon due to either personal interests and being encouraged to by their certification scheme. The industry and policy groups agreed that the soil carbon was more important in terms of soil health rather than offsetting. They saw a need for increased knowledge and awareness on the benefits of soil carbon.

There are many benefits that can be observed on farms from improving soil health. Establishing initial soil health and from there how to maintain or improve it. There are multiple pressures and requirements on farmers. Focusing on soil health may not be a focus other than where it is required for certification. However, if industry bodies are able to increase awareness and information on what practices improve soil health and demonstrate the benefits then it could gain recognition.

Management practices

All groups wanted more research on how to increase soil carbon. Currently there are no management practices that have enough data and over a long enough time period to reliably say that they will increase soil carbon. Various interviewees across the groups noted that either they themselves were seeing benefits from regenerative farming practices or that there is value in further investigating regenerative practices such as regenerative grazing management and sward diversity.

Carbon offsetting

None of the groups considered that it was currently viable to include soil carbon in a farm scale emission trading scheme. With enough data we may be able to identify soil types, land uses and management practices which may increase soil carbon. This data could be included into the farm GHG accounting model in the future and could be used to identify areas where carbon could be increased and could allow for farm specific tests to add detail.
In the current research climate however there are a couple of reasons why offsetting would be difficult:

- Given the nature of soil carbon variability testing would have to be carried out on each farm and continually measured over time to determine if increases were part of the stable soil carbon fraction or labile and likely to be lost.
- If changes in soil carbon are being measured and or modelled then there is the risk that farmers might be charged for losses and that this might not be accurate.

Science on soil carbon

All interviewees agreed that more research was needed on soil carbon to increase understanding and better inform what our current levels are across the country and which areas may have the ability to increase. The 500 soils project that is being carried out by Landcare Research and the University of Waikato will help to inform this. Also where changes in land management could result in increases in soil carbon in the future. This can be used to inform models that have been developed to determine the amount of carbon a soil can store (saturation deficit) and what the losses or gains in soil carbon could be with a change in land use. Some farmer interviewees were interested in information on the role of soil carbon and the effect of management on it. Others, with existing background knowledge, were interested in data to back up the impact of management practices over time.

Knowledge and tools

Across the groups most interviewees agreed that there was a lack of knowledge on both soil carbon and farm GHGs. Farmer interviewees were very interested in tools, other than reducing stocking rates, to help them reduce their emissions. The industry and policy and researcher groups agreed that simple decision making tools were needed for farmers to quickly compare the impact of management practices on their emissions. There needs to be science backed solutions. They also agreed that farmers get their information from a range of sources such as trusted advisors, events, print and online media. Any information on these topics needs to be communicated through all of these sources.

Farmers are often visual learners and making sure information is presented in a visual way, preferably in the field where the results are tangible, is valuable. There is no simple fix for emission reduction and there needs to be a variety of tools to reduce emissions as well as different ones to suit different systems. Solutions such as the methane vaccine could be very powerful however, until it is confirmed, other tools need to be implemented.

If practical solutions are not available or if tools are not accepted by farmers then businesses may decide to build the cost of offsetting emissions into their costs. One of the He Waka Eke Noa work streams is looking into an emission pricing framework which will be ready by 2025. It needs to be structured to allow farmers to offset emissions where necessary while encouraging them to try and reduce as much as possible.

Models

Providing accurate data for emission modelling is important to create the most accurate representation of what is happening on farms. A number of interviewees mentioned that Overseer modelling of nitrate losses in the past had not been accurate and farmer trust was still being rebuilt. Whatever model is decided on by the He Waka Eke Noa work stream needs to be backed by data. Farmers also need to have an understanding of how their emission number is produced and what factors are influencing it. The role of industry bodies alongside consultancies producing FEPs needs to be on educating on this number so it does not seem like it has just been pulled out of the air.

Greenhouse gas whole system thinking

Everything is intertwined in farm systems and making changes to one factor can have an impact on another. Finding solutions to reduce farm emissions needs to pay careful attention to the impact that these changes could have on other environmental and production factors such as nitrate leaching, animal health and soil carbon. Including GHG accounting into FEPs will hopefully help this environmental concern to be seen alongside the range of other factors at play.

Compliance costs

There are already significant costs associated with preparing nutrient budgets and FEPs. Farmer interviewees noted that, with the new regulations, there would be additional compliance costs for their business. Most Canterbury farmers have had some form of compliance cost for a number of years now. For other regions compliance costs associated with N loss are only coming into effect now. Add to this the cost of accounting for GHGs and this could be a significant cost for some farm businesses to adjust to.

Viability

All farmer interviewees emphasised that they were running businesses and that they need solutions that are going to be financially viable. There was concern that the primary solution currently is to reduce stocking numbers and that this would impact their financial viability. Businesses have different margins and for some there is a real threat that they may not be able to remain in business. Furthermore some businesses are already operating on a far more efficient and environmentally sustainable level than others and this needs to be recognised in reduction targets.

Marketing

The ability to charge more for products has been discussed for a while. Interestingly very few interviewees thought that they would see an increase in the price they receive for their products as they start to account for and reduce emissions. Instead they thought that consumers were already expecting this from products. However on a larger scale accounting for and reducing GHGs would help to promote brand NZ which benefits everyone. There may be value in producing and promoting low emission products however this will be short lived as other brands catch up and it becomes the normal. For example Fonterra's carbon zero milk, to be released to the NZ market in 2021, may be worth more but in the long term as competition increases we would expect to see the price of it driven down (Anchor Dairy, n.d.).

Consumers

There are often negative news stories around farming. This is the nature of news in general but this can still taint the opinion of the consumer and make them think that all farmers are polluting the environment. Farmers feel like things are against them and that the consumer has unachievable expectations for their business. There has been a lot of talk about the rural/urban divide and how this is increasing as the proportion of our population growing up in cities increases. Various programmes try to address this such as Dairy NZ's School Farm Visits, AgProud and Bush Farm School. All are aimed at either getting kids out on farms or educating the urban population on farming practices.

Another role of these groups in the future could be in informing about what GHGs are produced by what farm practices, what farmers are doing about them and the true differences in environmental impacts between alternative diets and more conventional diets.

Adaptation

There are not many people who like change and farmers are no exception. Canterbury farmers have already, for the most part, adapted to regional council regulations around nitrate leaching. Adapting to requirements around GHGs will be a similar process. It will take time for farmers across the country to adapt but they will.

Conclusions

Soil carbon has a different role to play in New Zealand than it does overseas. In New Zealand the role of soil carbon is less in mitigating GHGs and in maintaining and improving soil health. The high levels of soil carbon in New Zealand soils mean that the focus is on avoiding losses, retaining and identifying areas where we may be able to increase.

Soil carbon will not have a role in policy in the near future, there is a need for much more research to be carried out to produce reliable models and ensure that increases or decreases in carbon on farms are accurate.

The threat of climate change is very real and requires us to use all the tools available to tackle it. In the last few years agricultural climate change policy has come to the forefront in New Zealand. Farmers now need more knowledge on their emissions, a reliable way of accounting for them and practical tools to help to reduce them.

Currently there is a lack of these and this is contributing to the pressure farmers are feeling alongside those from consumers and financially. Farms are businesses and they are facing a number of uncertainties that could have a big impact on their operation. They need support from the industry, research organisations and the consumer to adapt to these changes and stay viable.

Limitations

Due to limitations on the author's time not all the desired interviews were possible.

Originally the author had hoped to have both an industry body and a policy group however small numbers of available interviewees at the time of the study meant that these two groups were merged.

Furthermore while a range of farmers were sought out there were not enough to distinguish between farming practices and management types for example large farming groups and regenerative or organic farmers.

Most interviewees were from around Canterbury because this is where the author had most of her contacts.

Recommendations

- Identify farm practices that increase soil carbon or that don't reduce soil carbon.
- Educate farmers on the benefits of soil carbon and give them quick ways to compare the effect of different practices on soil carbon.
- Provide farmers with information to understand their emissions and a range of practical tools and solutions to help them reduce.
- Support farmers as they adapt.

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References

Alcantara, V., Don, A., Well, R., & Nieder, R. (2016). Deep ploughing increases agricultural soil organic matter stocks. *Global Change Biology*, *22*, 2939-2956. https://doi.org/10.1111/gcb.13289

Amelung, W., Zech, W., Zhang, X., Follett, R. F., Tiessen, H., Knox, E., & Flach, K. W. (1998). Carbon, Nitrogen, and Sulfur Pools in Particle-Size Fractions as Influenced by Climate. *Soil Science Society of America Journal*, *62*(1), 172-181. doi.org/10.2136/sssaj1998.03615995006200010023x

Anchor Dairy. (n.d.). *Our Specialty Milk has gone carbonzero*. Anchor Dairy. Retrieved 18th Feb, 2021, from https://www.anchordairy.com/nz/en/sustainability/carbon-zero-milk.html?gclid=CjwKCAiAmrOBBhA0EiwArn3mfJ8T0CaLFUB3Afz6PogQE7hT-EKTqdrHqPO_RFvVw7u-3nGu51iq2xoCUToQAvD_BwE

Australian Government. (2019). *Australia's National Greenhouse Accounts*. Environment Australia. https://www.environment.gov.au/system/files/resources/6686d48f-3f9c-448d-a1b7-7e410fe4f376/files/nggi-quarterly-update-mar-2019.pdf

Beare, M. H., McNeill, S. J., Curtin, D., Parfitt, R. L., Jones, H. S., Dodd, M. B., & Sharp, J. (2014). Estimating the organic carbon stabilisation capacity and saturation deficit of soils: a New Zealand case study. *Biogeochemistry*, *120*, 71-87. DOI 10.1007/s10533-014-9982-1

Benavides, R., Douglas, G. B., & Osoro, K. (2009). Silvopastoralism in New Zealand: review of effects of evergreen and deciduous trees on pasture dynamics. *Agroforest Systems*, *76*(2), 327-350. DOI 10.1007/s10457-008-9186-6

Carson, J. (n.d.). *How much carbon can soil store*. Soil Quality. Retrieved 13th Feb,, 2021, from http://www.soilquality.org.au/factsheets/how-much-carbon-can-soil-store

Centre for Climate and Energy Solutions. (n.d.). *History of UN Climate Talks*. Centre for Climate and Energy Solutions. Retrieved 20th Feb, 2021, from https://www.c2es.org/content/history-of-un-climate-talks/

Climate Change Commission. (2021, January 31). *2021 Draft Advice for Consultation*. Climate Change Commission. https://ccc-production-media.s3.ap-southeast-2.amazonaws.com/public/evidence/advice-report-DRAFT-1ST-FEB/ADVICE/CCC-ADVICE-TO-GOVT-31-JAN-2021-pdf.pdf

Climate Commission. (2020). *Reviewing Aotearoa's ND and biogenic methane*. Climate Comission. https://www.climatecommission.govt.nz/our-work/advice-to-government-topic/reviewing-new-zealands-nationally-determined-contribution-and-biogenic-methane/

Community Environmental Council. (2020). *Carbon Farming and Regenerative Agriculture*. https://www.cecsb.org/rethink-food/carbon-farming/

Cooper, J., Baranski, M., Stewart, G., Lange, M., & Barberi, P. (2016). Shallow non-inversion tillage in organic farming maintains crop yields and increases soil C stocks: a meta-analysis. *Agronomy for Sustainable Development*, *36*(22). https://doi.org/10.1007/s13593-016-0354-1

Cross, B. (2021, 1 28). Alberta farmers lose carbon credit program. *The Western Producer*. https://www.producer.com/news/alberta-farmers-lose-carbon-credit-program/

FAO. (n.d.). *Australia's Carbon Farming Initiative*. FAO. http://www.fao.org/fileadmin/templates/agphome/documents/faooecd/australia.pdf

Francis, G. S., & Knight, T. L. (1993). Long-term effects of conventional and no-tillage on selected soil properties and crop yields in Canterbury, New Zealand. *Soil & Tillage Research*, *26*(3), 193-210. G.S. Francis; T.L. Knight (1993). Long-term effects of conventional and no-tillage on selected soil properties and crop yields in Canterbury, New Zealand. , 26(3), 193–210. doi:10.1016/0167-1987(93)90044-p

Franklin, H., McEntee, D., & Bloomberg, M. (2016). The potential for poplar and willow silvopastoral systems to mitigate nitrate leaching from intensive agriculture in New Zealand. *Integrated Nutrient and Water Management For Sustainable Farming*, *29*. http://flrc.massey.ac.nz/publications.html.

Funk, J., & Kerr, S. (2007). Restoring Forests Through Carbon Farming on Maori Land in New Zealand/Aotearoa. *Mountain Research and Development*, *27*(3), 202-205. http://dx.doi.org/10.1659/mrd.0921

Government of Canada. (2020, 1 30). *Greenhouse gases and agriculture*. Agriculture. https://www.agr.gc.ca/eng/agriculture-and-the-environment/agricultural-practices/climate-change-and-agriculture/greenhouse-gases-and-agriculture/?id=1329321969842#e

Government of Canada. (2021, 1 19). *Greenhouse gas source and sinks*. Government Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2020.html

Guevara-Escobar, A., Kemp, P. D., Mackay, A. D., & Hodgson, J. (2002). Soil properties of a widely spaced, planted poplar - pasture system in a hill environment. *Australian Journal of Soil Research*, *40*(5), 873-886. doi:10.1071/sr01080

He Waka Eke Noa. (2020, October). *5-Year Programme Overview*. He Waka Eke Noa. https://hewakaekenoa.nz/wp-content/uploads/2020/12/HWEN-Programme-Overview-Oct-2020.pdf

Kirschbaum, M., Schipper, L., Mudge, P., Rutledge, S., Puche, N., & Campbell, D. (2017). The trade-offs between milk production and soil organic carbon storage in dairy systems under different management and environmental factors. *Science of the Total Environment*, *577*, 61-72. http://dx.doi.org/10.1016/j.scitotenv.2016.10.055

Laamrani, A., Voroney, P. R., Berg, A. A., Gillespie, A. W., March, M., Deen, B., & Martin, R. C. (2020). Temporal Change of Soil Carbon on a Long-Term Experimental Site with Variable Crop Rotations and Tillage Systems. *Agronomy*, *10*(840). https://doi.org/10.3390/agronomy10060840

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, *123*(1-2), 1-22. https://doi.org/10.1016/j.geoderma.2004.01.032

Landcare Research. (2020). *A new national soil carbon monitoring system for agricultural land*. Landcare Research. https://www.landcareresearch.co.nz/news/a-new-national-soil-carbon-monitoring-system-for-agricultural-land/

Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., Mellado-Vazquez, P. G., Malik, A. A., Roy, J., Scheu, S., Steinbeiss, S., Thomson, B. C., Trumbore, S. E., & Gleixner, G. (2015). Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications*, *6*(6707). https://doi.org/10.1038/ncomms7707

Lar, R. (2020). Managing soils for negative feedback to climate change and positive impact on food and nutritional security. *Soil Science and Plant Nutrition*, 1-9. doi:10.1080/00380768.2020.1718548

Laubach, J., Hunt, J. E., Graham, S. L., Buxton, R. P., Rogers, G. N.D., Mudge, P. L., Carrick, S., & Whitehead, D. (2019). Irrigation increases forage production of newly established lucerne but enhances net ecosystem carbon losses. *Science of the Total Environment*, *689*, 921-936. https://doi.org/10.1016/j.scitotenv.2019.06.407

Lawrence-Smith, E., Mojsilovic, O., Meenken, E., Cuff, J., Tregurtha, C., & Beare, M. (2014). *Arable & pastoral soil quality monitoring programme - analysis of 1999-2013 dataset*. Plant & Food Research.

Mclaren, R. G., & Cameron, K. C. (2012). Soil Organic Matter. In *Soil Science* (Second ed., pp. 150-151). Oxford.

McNally, S., Beare, M., Curtin, D., Meenken, E., Kelliher, F., Pereira, R., Shen, Q., & Baldock, J. (2017). Soil carbon sequestration potential of permanent pasture and continuous cropping soils in New Zealand. *Wily*, *1*(12), 1-12. DOI: 10.1111/gcb.13720

McNally, S. R., Laughlin, D. C., Rutledge, S., Dodd, M. B., Six, J., & Schipper, L. A. (2015). Root carbon inputs under moderately diverse sward and conventional ryegrass-clover pasture: implications for soil carbon sequestration. *Springer International*, *392*, 389-399. DOI 10.1007/s11104-015-2463-z

Mei-Yan, W., Xue-Zheng, S., Dong-Sheng, Y., Sheng-Xiang, X., Man-Zhi, T., Wei-Xia, S., & Yong-Cun, Z. (2013). Regional Differences in the Effect of Climate and Soil Texture on Soil Organic Carbon. *Pedosphere*, *23*(6), 799-807. doi:10.1016/S1002-0160(13)60071-5

MFE. (2020, 4 15). *New Zealand's Greenhouse Gas Inventory*. Ministry for the Environment. https://www.mfe.govt.nz/climate-change/state-of-our-atmosphere-and-climate/new-zealands-greenhouse-gas-inventory

Ministry for the Environment. (2019, November 25). *About New Zealand's emissions reduction targets*. Climate Change. Retrieved January 18, 2021, from https://www.mfe.govt.nz/climate-change/climate-change-and-government/emissions-reduction-targets/about-our-emissions#:~:text=Domestic%20targets,-A%20credible%20long&text=In%202019%2C%20the%20Climate%20Change,a%20new%20domestic%202050%20target%3A&text=24%20

Moyer, J., Smith, A., Rui, Y., & Hayden, J. (2020). *Regenerative agriculture and the soil carbon solution [white paper]*. https://rodaleinstitute.org/wp-content/uploads/Rodale-Soil-Carbon-White-Paper_v11-compressed.pdf)

Mudge, P. l., Kelliher, F. M., Knight, T. L., O'Connell, D., Fraser, S., & Schipper, L. A. (2016). Irrigating grazed pasture decreases soil carbon and nitrogen stocks. *Global Change Biology*. doi.org/10.1111/gcb.13448

New Zealand Agricultural Greenhouse Gas Research Centre. (n.d.). *Government and climate change*. Ag Matters. Retrieved 1 20, 2021, from https://www.agmatters.nz/topics/government-and-climate-change/

Ogle, S. M., Alsaker, C., Baldock, J., Bernoux, M., Breidt, F. J., McConkey, B., Regina, K., & Vazquez-Amabile, G. G. (2019). Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions. *Scientific Reports*, *9*(11665). https://doi.org/10.1038/s41598-019-47861-7

Ogle, S. M., Alsaker, C., Baldock, J., Bernoux, M., Breidt, F. J., McConkey, B., Regina, K., & Vazquez-Amabile, G. G. (2019). Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions. *Scientific Reports*, *12*(9), 1-8. https://doi.org/10.1038/s41598-019-47861-7

Pacala, S., & Socolow, R. (2004). W Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*, *305*(5686), 968-972. DOI: 10.1126/science.1100103

Pereira, R. C., Hedley, M. J., Hanly, J., Hedges, M., Bretherton, M., Beare, M. H., & McNally, S. R. (n.d.). Full inversion tillage pasture renewal offers greenhouse gas mitigation options: The Manawatu experience. *Nutrient loss mitigations for compliance in agriculture. (Eds L.D. Currie and C.L. Christensen)*, 11. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.htm

Queensland Government. (n.d.). *Organic Carbon Pools*. Soil Quality. Retrieved January 9, 2021, from http://soilquality.org.au/factsheets/organic-carbon-pools#:~:text=Soil%20organic%20matter%20is%20made,carbon%20and%20recalcitrant%20organic%20carbon.&text=Management%20is%20capable%20of%20altering,present%20in%20these%20different%20pools.

Romera, A. J., Doole, G. J., Beukes, P. C., Mason, N., & Mudge, P. L. (2017). The role and value of diverse sward mixtures in dairy farm systems of New Zealand: An exploratory assessment. *Agricultural Systems*, *152*, 18-26. http://dx.doi.org/10.1016/j.agsy.2016.12.004

Schwartz, J. D. (2014, March 4). *Soil as a Carbon Storehouse*. Yale Environment 360. Retrieved December 20, 2020, from https://e360.yale.edu/features/soil_as_carbon_storehouse_new_weapon_in_climate_fight

Sparling, G., & Schipper, L. (2009). Carbon in Soils. *NZ Science Teacher*, (12), 13-15. http://earth.waikato.ac.nz/staff/schipper/download/soilcarbon.pdf

Sparling, G. P., & Schipper, L. A. (2002). Soil Quality at a National Scale in New Zealand. *Ecological Risk Assessment*, *31*(6), 1848-1857. doi: 10.2134/jeq2002.1848.

Western Australia, Agriculture and Food. (2020). *What is Soil Organic Carbon*. What is Soil Organic Carbon. Retrieved December 20, 2020, from https://www.agric.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon

Whitehead, D., Schipper, L. A., Pronger, J., Moinet, G. Y.K., Mudge, P. L., Pereira, R. C., Kirschbaum, M. U.F., McNally, S. R., Beare, M. H., & Camps-Arbestain, M. (2018). Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study. *Agriculture, Ecosystems and Environment*, *265*, 432-443. https://doi.org/10.1016/j.agee.2018.06.022

Woodbury, P., & Wightman, J. (n.d.). Soil Carbon Management & Greenhouse Gas Mitigation Opportunities. *Soil Carbon GHG Mitigation*, (6), 11. http://climatesmartfarming.org/wp-content/uploads/2019/02/Soil-Carbon-Management.pdf

Appendices

Appendix 1 - Interview questions

Introduction

- Can I please record our interview? Completely private and for project use only.
- The Chatham House Rule will be used by default
- Can I send you some follow-up questions if I need to?

These questions are to provide a semi structured interview format and further discussion is encouraged. Interviews will be kept to 30 minutes unless you have time to talk for longer.

Farmers (3 x S&B, 3 dairy, 5 crop)

I want to start by saying that there is absolutely no judgement or expectations associated with any of these questions and they are purely to gain an understanding of the current situation on farms.

1. What have you heard being talked about relating to farm GHGs?
2. What would be the most intensive part of your operation?
3. How practical would it be for you to reduce emissions?
4. Do you think accounting for and then reducing emissions will help us to sell our products or allow us to meet regulations and market requirements? What else will it achieve?
5. What is the financial ability of your businesses to make reductions in GHGs?
6. What do you think about earning carbon credits for carbon stored in the soil?
7. How do you think you could go about increasing soil carbon on your farm?
8. Do you think soil carbon will be important in offsetting farm emissions in the future?
9. What would be your main difficulties in reducing GHGs or increasing soil C?

Industry bodies/ policy makers (2 x industry bodies, 1 x policy maker):

1. What do you see as being the biggest challenges for farms in accounting for GHGs?
2. What do you think will be the most successful way for farms to reduce/ mitigate GHGs (actual number)?
3. Does He Waka Eke Noa set out realistic time frames for accounting for GHGs on farm and incorporating reductions into FEPs?
4. Do you see soil carbon being recognised in GHG policy? (policy only question)
5. Do you see reductions in agricultural GHGs as helping us to sell our products or just allowing us to meet regulations and market requirements?
6. What is the impact of the current environmental situation and pressure on farmers?
7. Within your farming sector (or overall for policy maker interview) do you think GHG accounting, mitigating and offsetting requirements will be viable for farmers?
8. What are your thoughts on what an emission pricing framework will look like/ how it will work for farmers in your sector?
9. What role do you see soil carbon playing in farm GHG offsetting potentially in the future?
10. What do you think are the best ways of increasing soil C in (farms) in NZ?

Researchers (n=4):

1. How can we best engage farmers and review progress towards meeting the targets set out in He Waka Eke Noa and on a broader scale the Zero Carbon Climate Change Act?
2. Do you see soil carbon playing a role in farm GHG emission accounting?
3. Do you see soil carbon being recognised in GHG policy?
4. Is its role in ghg offsetting or in overall soil health?
5. What is the impact of the current environmental situation and pressure on farmers?
6. What specific research needs to be done to support farmers with GHG accounting, mitigating and offsetting?
7. Do you think with the tools available farmers will be able to remain productive and financially viable while decreasing GHGs in the future

8. What role do you see soil carbon playing in farm GHG offsetting? More important to factor in when land use change happens ie into forestry
9. Do you think understanding and accounting for soil carbon on farms will be important in developing an emission pricing framework?
10. What are the ways that we can avoid carbon loss?
11. What research is still needed to better understand soil C in NZ?