Soil Carbon Sequestration – a Contested Space in Science.

A discussion Paper

Peter Bruce-Iri, May 2018

New Zealand depends heavily on its agricultural industries, with pastoral land occupying approximately 40% of total land area (New Zealand Government, 2018). Pastoral farming, especially dairy is criticised for impacting on water quality and for greenhouse gas emissions. Soil carbon sequestration has potential to offset these emissions, but a lack of clarity and resolution in the science is hampering progress.

Soil's capacity to sequester carbon provides another strategy to reduce the impact of climate change. But there is disagreement about this capacity. Some state that soil sequestration is minimal or at least not proven while others enthuse about its potential. This paper seeks to surface this tension in the science and the pragmatic consequences of the failure to resolve it.

The carbon equilibrium argument

The report *Managing Soil Organic Carbon for Global Benefits* (Govers, Merckx, Van Oost, & Van Wesemael, 2013) extols the multiple benefits of soil organic carbon (SOC) and then describes how SOC is in equilibrium in the soil.

> Barring human disturbance, the exchange between the soil reservoir and the atmosphere is globally in near-equilibrium: about 60 Pg of soil organic carbon is added annually to the soil reservoir through litterfall, throughfall, stemflow, crop residues and root turnover while a similar amount is lost through respiration of soil organisms, roots and mycorrizhae (Raich and Schlesinger, 1992; Houghton, 2007) (p13).

The analogy of a kitchen sink reinforces the concept of SOC equilibrium, positing that increases in input from the tap results in increases in output through the drain.

Those at the forefront of advocating for carbon sequestration are proponents of organic agriculture, but while European research acknowledges some evidence of higher soil carbon concentrations in soils managed organically, they cite other studies that have not found differences between organic and conventional farms (Gattinger et al., 2012)

In New Zealand, the scientific consensus appears to be strongly in favour of the carbon equilibrium argument. Doug Edmeades (2018) states that soil cannot absorb more oganic matter, reaching equilibrium in about 20 to 50 years. Research at Landcare Research, one of the country's Crown Research Institutes concludes that "soil carbon levels in New Zealand's grazing lands are at or near steady state" (Manaaki Whenua, Landcare Research, n.d.). And research from the Waikato concludes that "different data sets suggest either no change or a gain of C, but with large uncertainties"(Schipper et al., 2017).

It would appear that this research feeds through to Government publications positioning pastoral farming as problematic. For example, the recent Low Emissions Economy (Productivity Commission, 2018) draft report confined emissions reduction strategies to breeding low-emitting animals, and methane inhibitors and vaccines. Sequestration potential was confined to forests. The 469 page document does not mention soil carbon.

The carbon sequestration argument

Of the planets global carbon stocks the majority, 39,000 gigatonnes (GT), or 93% is in the oceans. Soil contains more than half of the remainder (1,580 GT, or3.77%). The atmosphere and vegetation contain 750 GT (1.79%) and 610 GT (1.45%) respectively. Since the industrial revolution, an estimated 50 to 100 GT of carbon have been lost from the soil to the atmosphere(Ontl & Schulte, 2012). If that carbon was lost from the soil, it must be possible for it to be at least restored.

The Drawdown Project (Hawken, 2018) identifies over 80 solutions to either reduce emissions of CO_2 equivalents or sequester carbon to achieve a 1050 GT drawdown between 2020 and 2050. silvopasture ranks as the 9th solution achieving a 31.19 GT sequestration with regenerative agriculture, ranked 11th, achieving 23.15 GT. These gains are achieved through carbon sequestration: "Farms are seeing soil carbon levels rise from a baseline of 1 to 2 percent up to 5 to 8 percent over ten or more years, which can add up to 25 to 60 tons of carbon per acre" (Hawken, 2018, p 55).

A meta analysis of 74 publications identified changes in soil carbon stocks between pasture, plantation, native forest and crop. Land converted from pasture to plantation lost 10% of soil carbon and from pasture to crops lost 59%. Conversely, converting from crop to pasture increased soil carbon by 19% and native forest to pasture, 8%.

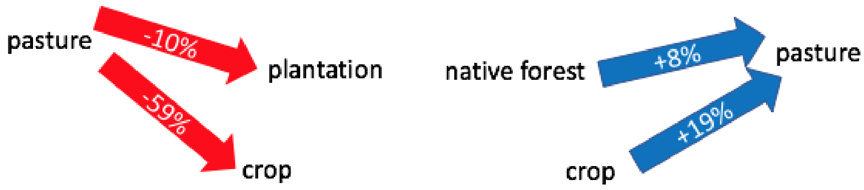

Figure 1: Changes in soil carbon stocks based on land-use changes (Guo & Gifford, 2002)

Notably for New Zealand and current policy trends, the meta analysis identifies a 12 to 15% reduction in soil carbon stocks when pine plantations displaced pasture or native forest (Guo & Gifford, 2002).

Over the last two decades many studies have attempted to quantify differences in soil carbon from differing management practices. Brazilian research, based on five dairy farms quantified carbon levels under rotational grazing at 115 tonnes per ha while no tillage management achieved 92.5 tonnes. (Seó, Filho, P, & Brugnara, 2017). The best results in recent Chinese research on multiple crop rotation systems showed " increased yields by 15.2–65.8% and C sequestration by 27.0–64.4%"(Wang et al., 2018, p 87). Another Chinese study measured increased soil organic carbon stocks on degraded arable land converted to legume based pasture over seven years. Gains of 24.1, 19.9 and 14.6 tonnes of carbon per hectare were reported under alfalfa, bush clover and milk vetch. Carbon sequestered in the one to two metre soil profile accounted for 79, 68 and 74% respectively (Wang et al., 2018).

U.S. research found that adaptive multi-paddock (AMP) grazing has the potential to offset greenhouse gas emissions achieving a net carbon sink. A four year trial achieved a 3.59 tonne of SOC per ha, per year (Stanley, Rowntree, Beede, DeLonge, & Hamm, 2018).

Even lawn can sequester carbon. Net sequestration, accounting for lawn maintenance practices, on average were 46 to 127.1 grams of carbon per m^2 per year (0.46 to 1.271 tonnes per hectare).

The action imperative

Climate change is broadly accepted as a threat to our social and economic development. While there is divergence over its impact, ranging from immanent human extinction (Waters, 2016) to claims that we are heading for colder weather, action on climate change will generate huge efforts for at least half a century.

Earlier action will accelerate mitigation. Any delays in achieving scientific consensus have potential to hamper mitigation initiatives and increase economic and social consequences. Soil carbon sequestration will reach equilibrium over decades (Edmeades, 2018). That makes it an ideal strategy to drawdown carbon while global efforts to replace fossil fuels gain momentum.

Action to mitigate climate change was successfully delayed by wealthy individuals with vested interests in fossil fuel industries. The Koch brothers have funded 84 groups denying climate change over $US100 million since 1997 (Greenpeace, n.d.). It appears New Zealanders have been particularly gullible. A University of Tasmania study found 13% of New Zealanders were climate change sceptics, following only Norway (15%) and Australia (17%) (Theunissen, 2015).

In our response to climate change, we can learn lessons from last century. The people of England were collectively traumatised by the First World War and didn't want to be involved in another. They tried to ignore the threat that Adolf Hitler posed in a "fog of denial". But Winston Churchill persisted in raising the alarm. "The era of procrastination, of half-measures, of soothing and baffling expedients, of delays is coming to its close. In its place we are entering a period of consequences" (Churchill, 1936). To extend the analogy, the big industrial wars of the 20th century, through the survival imperative, spawned exponential innovation, for example, in aviation, industrial chemistry and innovation. Fear motivation action.

The situation we face with climate change is potentially more destructive than those wars, but without tangible warning signs. There is no climate equivalent to Hitler's invasion of Poland as the dynamic nature of climate provides only confused trends. Record breaking temperatures do not seem a sufficient prompt for action from sufficient majority.

Our science seems to progress at a leisurely pace, and around the question of soil carbon sequestration in New Zealand, is currently stalled. Lessons can be learned here from the business world. In some industries, organisations can be overwhelmed by competitors if they are not innovating quickly enough. Lessons from companies such as Nokia and Kodak, blindsided by others' innovations, are that speed of innovation is now a necessary competitive asset (McGrath, 2013, Berger, 2018). How do we change our science to be better equipped with the necessary climate change mitigation timelines?

A call for citizen science

With the relatively small science community, policy derived from local science can very quickly be skewed. The impasse we face now will continue to inhibit attempts to focus energies on soil carbon sequestration. Planting more trees is an easy answer, as is scaling up pine seedling production.

Thomas Kuhn (1970) developed the paradigm concept in The Structure of Scientific Revolution. He described progress in science as episodic rather than having a steady evolutionary trajectory. Accepted theories become the orthodoxy and are defended. When sufficient disconfirming evidence accumulates a new paradigm emerges, establishing a new orthodoxy. Kuhn's classic example was the shift from a Newtonian to an Einsteinian paradigm.

Science values the principle of objectivity, but factors such as the profit motive, science or researcher personal investment in a field of enquiry, blind adherence to a Western epistemology, and political motives erode that objectivity. To effectively mitigate and adapt to climate change, we can't afford to be encumbered by the paralysis of action that the erosion of objectivity creates.

The frequent call for "more evidence" could be code for "more research funding".

A problem with soil science is the sheer complexity of factors determining its bio-chemical performance. These include parent material, topography, the soil's natural and managed history, the composition of the soil biome, its physical structure and current management practices. In Northland, one farm can have a number of soil types and each of these manifest different properties based on the interaction of the factors above. The passage of time further complicates.

This complexity makes it difficult for science to accurately measure and model sequestration potential. But there are other tools that can advance the science. A primary tool to help triangulate attempts to measure and model is farmer observation. Farmers often work the same soils for decades. While they may not have measured carbon content, they may have observed changes in top soil depth, compaction and infiltration rates, and soil structure. The observation of one farmer is insufficient to support a new consensus, but enough farmers, working as peers provide a valid source of data, especially when triangulated with valid and reliable measures of soil carbon.

Consequences of no resolution of the soil carbon question

"The science isn't there yet". This seems to be the dominant consensus in New Zealand (Edwards, 2017). Our prevailing narrative is that planting more trees is our major strategy to comply with the Paris Agreement, to the extent that the Government aims to plant one billion trees in ten years. Conversely, discursively agriculture remains a problem with the narrative focusing on when agriculture will be bought into the ETS positioning, agriculture as problematic. This narrative is supported and reinforced by Government publications such as the *Low Emissions Economy* that calls for more trees and fewer livestock (Productivity Commission, 2018).

If this narrative is misinformed by lack of clarity about the carbon sequestration potential of livestock interacting with pasture it has consequences impacting on sustainability. The further expansion of forestry in regions such as Northland further depopulates the region, especially where forestry displaces agriculture. Every one thousand hectares of forestry supports three jobs, whereas the same areas under dairy pasture supports 19.1 jobs[1]. There is a consequent erosion of incomes and their downstream impacts. The prevailing narrative is also damaging, reinforcing the perceived rural (or farmer) urban divide. Dealing effectively with climate change must be predicated by cohesive and collaborative communities.

Regional action on climate change

With a lack of consensus nationally, regions can attempt to initiate soil sequestration projects. The following calculations estimate sequestration required to offset emissions for the Northland region.

1. What is the extent of pasture in Northland?

Global grazing land (2003) = 3.3 billion ha (Roser & Ritchie, 2018)

New Zealand pasture (2008) = 13,211,000 ha. (Anastasiadis, Kerr, Zhang, Allan, & Power, 2014)

Northland region pasture (2018) = 735,400 ha (Northland Regional Council, 2018).

2. New Zealand greenhouse gas emission

New Zealand's gross greenhouse gas emissions in 2015 were 80.2 million tonnes of carbon dioxide equivalent (Mt CO2-e). Agriculture contributes 47.9 % of these emissions or 38.42 million tonnes of CO2 equivalents (Ministry for the Environment, 2018).

Converting CO2 equivalents to carbon, agriculture emissions of 38.42 million tonnes of CO2 equivalents = 10.47 million tonnes of carbon, or 0.79 tonnes c/ha.

3. Targets for Northland pasture (Top 10 cm only)

	Pasture (ha)	tonnes per hectare increase for offset/ha	total offset (tonnes C)	Additional percentage		
				0.50%	1%	2%
				7.50 tonnes/ha	15.00 tonnes/ha	30.00 tonnes/ha
Total Northland pasture	735,400	0.79	582,682	5,515,500	11,031000	22,062,000

[1] 2011 data from www.stats.govt.nz

30% Northland pasture	220,620		582,682	1,654,650	3,309300	6,618,600
20% Northland pasture	147,080		582,682	1,103,100	2,206200	4,412,400
10 % Northland pasture	73540		582,682	551,550	1,103100	2,206,200
5% Northland pasture	36770		582,682	275,775	551,550	1,103,100
2.5% Northland pasture	18385		582,682	137,888	275,775	55,1550

In this table a hectare of soil has 30 tonnes of SOC in the top 10 cm of soil based on a factor of 1.5 for bulk densty. A deeper topsoil increases this tonnage, and SOC will also be found in the subsoil. Determining the SOC in layers of soils, increases the complexity and cost of testing. It would be useful to have benchmarks for soil types to enable modelling based on topsoil tests.

In this example, increasing the SOC by one percent, from 30 tonnes to 45 tonnes, achieves a 15 tonne addition. Also, increasing topsoil depth has potential for further increases. Returning to the 0.79 tonnes/ha required to offset agricultural emissions over 30 years, effective soil husbandry can easily achieve this. If 10% of pasture land was under effective soil husbandry, this generates 1.1 million tonnes of additional carbon per hectare, offsetting Northland's agricultural emissions of 582,682 tonnes, assuming the remaining 90% is not further degraded.

Conclusion

There is enough international data to support the potential for pastoral sequestration of soil carbon. Observations by farmers who have focussed on soil health triangulates international data. New Zealand science appears ambivalent to this potential. With farmers criticised for both environmental degradation and greenhouse gas emissions, opportunities to mitigate would help us meet international obligations, and help restore the reputation of farmers.

To create forward momentum the greatest challenge is to challenge or thinking.

Further research

1. There is a continuum of farming practices from regenerative agriculture to the more intensive system 5 (Dairy NZ, n.d.). Intensification aspires to raise production and revenue. What are the drivers in the agribusiness ecosystem that cause farmers adopt more intensive practices?
2. Regenerative farmers (organic, biodynamic, biological, tikanga Māori etc) are often isolated geographically from their peers? How does this isolation impact on their ability to engage with peers and how might they better engage with neighbours to share good practice?

Author's note

I am not a soil science but have a 40-year interest in soils. I studied soil science at Diploma level and have taught it at certificate level. So often in scientific academic pursuits the veneer of objectivity is thin. W. Edwards Deeming stated that three percent of problems have figures and 97% of the problems do not. The issue of soil carbon is a multilogical problem that can't be solved by soil science alone.

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Appendix one: Reference data

1. The global carbon pool

Soil organic carbon (SOC) is the largest component of the terrestrial carbon pool at 1,580 gigatonnes (New South Wales Government, 2010) based on Kasting's estimate. Other experts estimate the range between 1395 and 1548. These figures are for the first metre of soil – a further 491 to 1456 Gt are estimated to be in the 2nd metre of soil.

vegetation	610 Gt
Atmosphere	750 Gt
Soil	1,580 Gt
Ocean	39,000 Gt
Carbon changes due to human activity	
Fossil fuel use	+ 5.5 Gt/year
Land use	+ 1.6 Gt/year
Rate of C increase in the atmosphere	
	+ 3.3 Gt/year

Table 1: Carbon pool size and changes (kasting 1998 cited in New South Wales Government, 2010)

2. Comparisons and conversions

1 Gt = 1,000,000,000 tonnes = 1 billion tonnes = 10^9 tonnes

The Drawdown project uses Gt of CO_2 or CO_2 equivalents as its base measure.

1 tonne of soil carbon is equivalent to 3.67 tonnes CO_2 equivalents (New South Wales Government, 2010). Thus when the Drawdown project calls for 16.34 Gt of CO_2 over 30 years for "Managed Grazing", that equates to 4.45 Gt of sequestered carbon, or 148 million tonnes carbon per year.

3. Converting soil organic matter (SOM) to soil organic carbon

SOM includes a range of soil elements including carbon whereas SOC is only the carbon in SOM.

To convert SOC% to SOM% multiply SOC% by 100/57 or 1.75
e.g 3% SOC is equivalent to (3 x 1.75)% SOM, i.e. 5.25%

To convert SOM% to SOC% divide SOM% by 1.75
e.g. 6% SOM is equivalent to (6/1.75)% SOC, i.e. 3.43% (New South Wales Government, 2010, p. 16)

4. Accounting for soil bulk density and soil depth

Soil bulk density is the mass of soil solid particles divided by the volume occupied. Density will be conditioned by factors such as soil texture, degree of compaction and topsoil depth. Here is an example.

> Area = 1ha = 10,000m^2
>
> Depth of 0 – 10 cm = 0.1 m
>
> Volume of soil = 10,000m^2 x 0.1 m = 1000m^3
>
> Bulk density = 1.5 tonnes/m^3
>
> SOC% = 2 which is the same as 2 tonnes SOC per 100 tonnes of soil, the mass of SOC in 1,500 tonnes of soil = 2 x 1,500/100 = 30 tonnes.
>
> This is the mass of SOC present in 0 – 10 cm of soil over one hectare of land.
>
> This same calculation can be used to work out the mass of SOC for other combinations of soil depth, bulk density and SOC% (New South Wales Government, 2010, p. 17).