Manaaki Whenua
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Challenges and opportunities for soil carbon in a farm-level pricing system

Prepared for: He Waka Eke Noa C/- Beef + Lamb New Zealand Limited

September 2021

Challenges and opportunities for soil carbon in a farm-level pricing system

Contract Report: LC4063

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1 The carbon cycle

Soil carbon is ultimately formed from a small difference between two very large processes – photosynthesis and respiration (Whitehead et al. 2018). Photosynthesis captures carbon dioxide and converts it into a temporary store of fixed carbon that is later used for plant growth and maintenance, while some exits the roots stimulating the soil microbial biomass. Respiration is the release of this captured carbon back to carbon dioxide and is carried out by plants, microbes, and animals (Fig. 1). When photosynthesis is greater than respiration there is an opportunity for accumulation of soil carbon. Conversely, when photosynthesis does not keep pace with respiration, soil carbon can decline. Many factors, such as soil type, temperature, water supply, and land management, alter both photosynthesis and respiration, often in subtle ways, so predicting the overall balance can be difficult. Carbon can also be imported or exported from a system via other pathways (e.g. in supplementary feed, leaching or erosion), which can influence soil carbon stocks (Laubach et al. 2019; Wall et al. 2019).

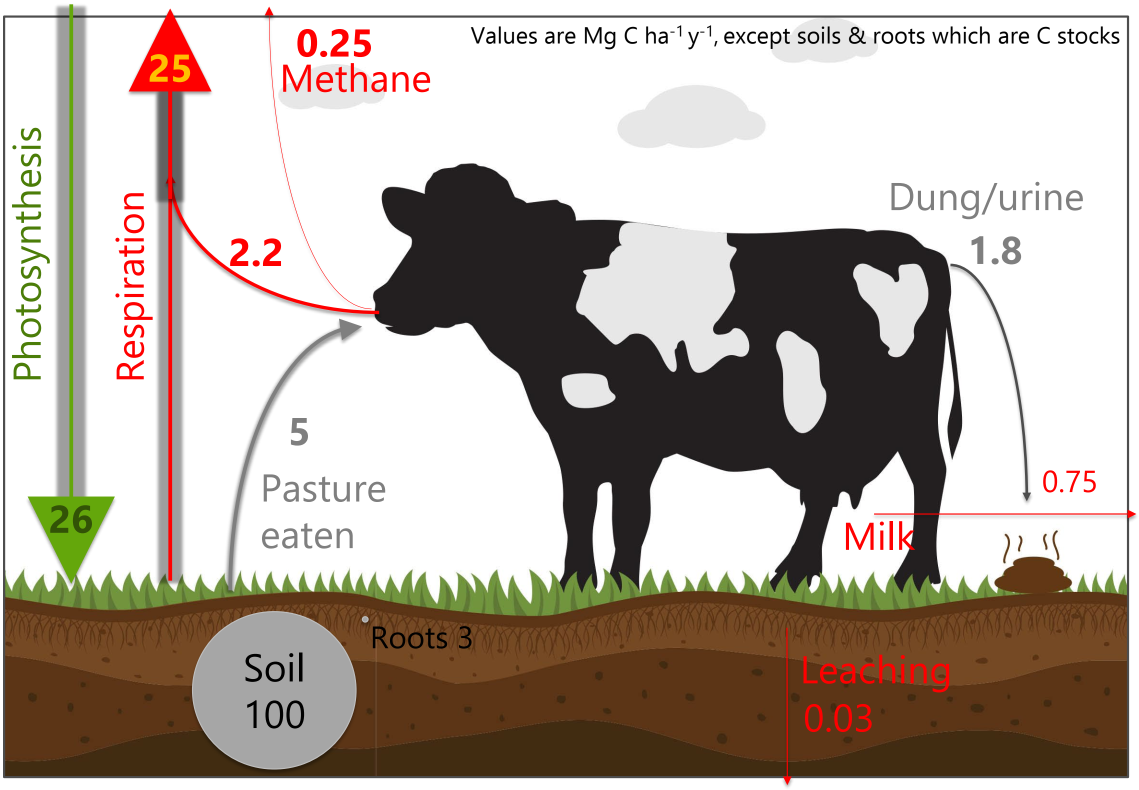

Figure 1. Simplified carbon cycle for a dairy farm paddock over a year with an example of carbon stocks and flows. The width of arrows is indicative of the size of the carbon flow, with the system set to be at equilibrium (no net gain or loss of carbon), which is the most likely situation at present for most New Zealand's pastoral systems under typical grazing management. All values are in Mg C ha^{-1} y^{-1} except for soils and roots, which are stocks.

2 Existing understanding of soil carbon stocks and stock changes in New Zealand

In general, New Zealand has high soil carbon stocks, due to a moist temperate climate and land cover dominated by perennial vegetation. Soil carbon changes associated with changes in land use and management can be difficult to predict based on first principles and can be counter intuitive. For example, lower soil carbon stocks were observed in irrigated vs adjacent unirrigated soils despite large increase in above-ground biomass production at irrigated sites (Condron et al. 2014; Mudge et al. 2021).

Research in New Zealand has shown that changes in land use (e.g. from forest to pasture) can lead to changes in soil carbon stocks (McNeill et al. 2014). Perennial pastures typically have the highest soil carbon stocks, annual cropland the lowest and forests have intermediate values. The effects of land use change on soil carbon stocks are included in New Zealand's national greenhouse gas inventory reporting obligations and are modelled using the national soil carbon monitoring system (SoilCMS) model (McNeill et al. 2014).

Data on the impact of changes in specific management practices within a land use (e.g. grazing management, tillage regime or fertiliser use) on soil carbon stocks in New Zealand's mineral soils are limited (Schipper et al. 2017; Whitehead et al. 2018) and any results are not as clear as our coarse understanding of changes in soil carbon with land use change. A current assumption behind the national soil CMS model is that if land use remains constant (e.g. pasture) for more than 20 years, soil carbon stocks will not change, even if management practices change (e.g. grazing management or crop type).

While uncertainties are high for consequences of management practices on mineral soils, it is very clear that the drainage and agricultural use of organic soils result in large but poorly constrained carbon losses (Schipper et al. 2017; Campbell et al. 2021).

3 Current challenges and opportunities associated with including soil carbon in the He Waka Eke Noa farm-level pricing system

In principle, changes in soil carbon could be included in the He Waka Eke Noa farm-level pricing system if more work were undertaken to ensure estimates of change were sufficiently robust. Two main approaches can be used to estimate changes in soil carbon: 1) modelling/lookup tables; and 2) direct measurements of change through time. Factors not directly related to soil carbon change estimates would also need to be considered in any farm-level pricing system (e.g. additionality and permanence), but are not discussed in any detail here.

3.1 Modelling changes in soil carbon

The simplest way to begin inclusion of soil carbon in the pricing system would be in relation to changes in land use, where values from the national SoilCMS model (McNeill et al. 2014) could be used in a similar manner to default lookup tables for forests. At present only *single* national-scale change factors are used for each land use transition (e.g. forest to pasture, pasture to crop). These national change factors could be further refined, and potentially made to be region (or soil) specific, like (some of) the forest lookup tables. This approach could capture both soil carbon sequestration and loss, depending on the land use transition.

Our understanding and ability to confidently model effects of different land management practices within a given land use are lower, but could be addressed. Mudge et al. (2020) concluded that:

> currently there is not sufficient New Zealand data to parameterise models to confidently predict how soil carbon will change in response to changes in management for specific, individual farms across New Zealand (due to the diversity of climate, soil type and management regimes). However, soil carbon data and modelling capability is rapidly increasing in New Zealand and this may be an avenue to pursue in the future.

One advantage of modelling compared with direct measurements is that models can enable trade-offs between different greenhouse gases and production to be determined for different land uses or management regimes (Kirschbaum et al. 2017).

3.2 Direct measurements of changes in soil carbon

Well-documented sampling methods and systems are available to enable direct measurement of farm-scale soil carbon stock changes to be made (Australian Government 2018; FAO 2020; Mudge et al. 2020). These measurements are also critical to support development of modelling as described above, that could be used for extrapolation. The Australian Government (2018) has a comprehensive system embedded in legislation, which could be adapted and applied in New Zealand (Mudge et al. 2020). The Australian system not only considers measurement of changes in soil carbon, but also covers the issues of additionality, and the implications of changes in land use or management on other greenhouse gas emissions. It also stipulates how farm-scale results must be reported to enable aggregation to contribute to national scale reporting obligations.

While direct measurement approaches to quantify changes in soil carbon stocks are well established, in the near future, widespread implementation of farm-scale measurements in New Zealand will likely be low, due to a number of related factors:

1 Unlike Australia, there is currently no Government (or industry) mandated system(s) through which farmers could directly derive financial benefit from increased soil carbon storage [recognising this short document is specifically exploring this issue]. Voluntary carbon markets and associated verification/measurement systems (e.g., VERRA 2018) are a possible avenue for farmers wanting to pursue this now.

2 As noted earlier, at present in New Zealand, no management practices within a land use have been widely proven to increase soil carbon. Therefore, even if direct financial payments were available for proven increases in soil carbon storage, there is high uncertainty regarding whether a given management practice will lead to increased soil carbon.

3 Quantifying changes in soil carbon via direct measurements requires a baseline sampling and then repeat samplings at 1–5-year intervals (e.g., Australian Government 2018; FAO 2020; Mudge et al. 2020). Therefore, results of changes in land use or management on soil carbon and potential payment for any stored carbon would take time to be realised.

4 The costs associated with implementing direct measurement approaches.

While modelling of soil carbon processes and direct measurement of soil carbon appear to be distinct approaches, it is likely that early results of ongoing soil carbon monitoring will influence the development of more complicated models. Similarly, a greater understanding of soil carbon dynamics from modelling is likely to stimulate efforts to better monitor soil carbon, whether to verify these models, or to assist with or refine their development.

4 Overview of the work that is occurring (or needs to occur) to allow for soil carbon to be included in the He Waka Eke Noa farm-level pricing system

To fully include accounting for soil carbon requires information on the rate of change of soil carbon with known uncertainty for land use change and the impact of management within these land uses. Decisions need to be made about the granularity of information required for present and future government reporting requirements, but also for the needs of industry sectors, including for demonstrating sustainability of their products. At one extreme of granularity is the use of national-scale lookup tables, at the other is direct measurements of change at the farm scale. Intermediate granularity would be at industry or regional scales via measurement or modelling (or a combination).

Some work is being conducted in this area, under a range of relatively short-term funding mechanisms. Here, we briefly outline priorities that may help enable soil carbon to be included in the He Waka Eke Noa farm-level pricing system in future. Future research also needs to be strongly cognisant of rapidly developing international efforts (Smith et al. 2020) that will likely impose expectations on New Zealand's reporting.

4.1 Development of lookup tables and modelling

Since publication of the last paper on the development and calibration of the national soil carbon monitoring system (CMS) model (McNeill et al. 2014), substantially more soil carbon data have been collected (e.g., Mudge et al. 2021). A number of legacy datasets have also been incorporated into the National Soil Database Repository (NSDR), with others still in line to be added. Further, implementation of the National Soil Carbon Monitoring System for Agricultural Land (Mudge 2019) has begun, based on direct measurement of soil carbon stocks and change at 500 sites.

Based on this existing information, we recommend:

- compiling all relevant soil carbon data into one database (we recommend the NSDR)
- updating the national SoilCMS model, initially for land use effects, but also exploring whether some management effects within land uses could be identified
- testing whether region, or soil-specific effects could be detected to enable some level of disaggregation in reporting.

Other priorities for new work in this area include:

- Prioritisation of key farming practices that require an evidence base for possible soil carbon stock changes.
- Measurement of soil carbon changes associated with the above prioritised management practices across New Zealand conditions. Measurements could include direct measurements of soil carbon (e.g. using cores at paired sites, Hewitt et al. 2012; Barnett et al. 2014; Mudge et al. 2021), and the net ecosystem carbon balance approach (Laubach et al. 2019; Wall et al. 2019), which provides invaluable information for calibration of process-based models (Kirschbaum et al. 2017).
- Developing look-up tables for changes in soil carbon for existing and proposed management practices and robust process-based modelling to extrapolate observed changes across New Zealand.
- A special category of focus is the large but variable losses of carbon that come from drained peat soils used for agriculture, which needs quantification (Campbell et al. 2021). It is also unclear to what extent and whether restoration of these soils might reduce emissions.

4.2 Direct measurements of changes in soil carbon at the farm scale

As mentioned earlier, international, well-documented sampling methods and systems are available to enable direct measurement of farm-scale soil carbon stock changes (e.g., Australian Government 2018; FAO 2020), and these have begun to be adapted to the New Zealand context (Mudge et al. 2020). A key decision is whether such a system is formally approved/adopted for use in New Zealand, with the addition of a New Zealand specific pricing mechanism.

5 Conclusion

It should be possible to include changes in soil carbon in a farm-scale pricing mechanism in the future if sufficient investment were to be made.

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