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IMPLEMENTATION OF A NATIONAL SOIL CARBON BENCHMARKING AND MONITORING SYSTEM FOR AGRICULTURAL LAND IN NEW ZEALAND

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Introduction

Soil organic carbon (SOC) is a critical component of terrestrial ecosystems for two key reasons. First, SOC is important for overall soil health, through the role it plays in processes and properties such as nutrient cycling and maintaining soil structural stability. Second, soils contain more than double the amount of carbon as the atmosphere and therefore any gains in SOC will contribute to reducing atmospheric CO_2 concentrations, while losses will exacerbate increases in atmospheric CO_2 concentrations (Smith et al. 2020).

Under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, New Zealand reports annually on its anthropogenic greenhouse gas (GHG) emissions and removals, including changes in soil carbon stocks due to land-use change (Ministry for the Environment 2021). National-scale changes of soil carbon stocks in mineral soils are currently predicted based on transitions of land use (e.g. forest to pasture) using a statistical model (SoilCMS) calibrated with historic data (McNeill et al. 2014). The model follows the default IPCC assumption that SOC can be considered at steady state 20 years after a land-use change that is known to cause a significant change in SOC) (Penman et al. 2003), and that SOC does not change, through time, if land use does not change.

A recent study (Whitehead et al. 2021) demonstrated that between 1990 to 2016 most of the total land area of New Zealand remained within the same land-use class (91.6%), for which the SoilCMS model assumes there were no changes in SOC stocks. However, there is limited data from direct measurements of SOC change through time to test this assumption. Furthermore, the data that were available was often collected for purposes other than SOC monitoring and not fully representative of New Zealand's agricultural land. There is also increasing interest at national, primary industry sector and at farm scales to improve estimates of land-use change impacts on SOC and whether differences in management within a broad land use influence changes in SOC stocks (e.g., high producing grassland contains dairy and drystock grazing systems).

The objective of the national soil carbon benchmarking and monitoring (NSCM) system is to provide a robust benchmark of SOC stocks across agricultural land in New Zealand and then monitor through time to determine whether SOC stocks are changing.

Methods

Study design

The NSCM system for agricultural land involves benchmark/baseline soil sampling of field plots and then repeated sampling of the same plots through time to detect whether changes in SOC have occurred. The study involves representative sampling across five broad agricultural land use classes (cropland, perennial horticulture, dairy pasture, flat-rolling drystock pasture, hill country drystock pasture). The number of sampling sites within each land-use class was chosen using a statistical design to ensure enough power to detect a change in soil carbon stocks of at least 2 tonnes/ha, should such a change occur. Using this approach, 500 sites have been selected for sampling, with about 100 in each of the five land-use classes (Fig. 1). To spread the sites evenly within each land use class, the design used spatial balanced sampling (Robertson et al. 2013). Where a random balanced sampling position was within a specified distance (e.g. 8 km for grassland classes, or 250 m for cropping land) of a node of the existing national 8-km national grid (Holdaway 2017) in the same land-use class, the site was moved to this grid location. Moving the sampling position to a nearby 8-km grid position will help enable synergies with potential future studies where the grid system is used for sampling of other environmental indicators such as biodiversity on agricultural land (Holdaway 2017).

A key feature of the design was that there should be sufficient samples within each land-use class to ensure an experimental power of 80% for detection of a change in soil carbon stocks, including sampling additional sites to account for any future land-use change between measurements; for example, if changes in infrastructure mean the site cannot be used again (e.g. a farm building constructed on a sampling site after the first sampling) or a drystock farm is converted to intensive cropping. These changes would invalidate the use of this site for the main objective of the study (change in SOC stocks through time under consistent land use). To account for this potential loss of sites, the probability of change in land use was estimated from historical land use mapping, and additional sites were then incorporated within each land-use class.

Sampling

The intent is to complete the benchmark sampling by 2023 and then resample each site on a 4-year rolling schedule (FAO 2020) with three sampling rounds completed by 2031. At each site, samples are collected from a 20 × 20 m plot laid out in a Latin square design (Fig. 2). In this Latin square approach, 10 core (or 2 pit) samples within a given sampling round are taken from an array, where each core (or pit) sample is taken from a unique row and column of a 10-by-10 spatial arrangement. This approach ensures samples are spatially balanced across the plot.

Samples are collected in 10-cm increments to 60-cm depth using soil cores, or quantitative pits for stony soils (see Mudge et al. 2020 for details). Replicate core samples from each depth are combined to provide one bulk sample per depth for each site, which are then processed and analysed using standard laboratory procedures (FAO 2020; Mudge et al. 2020). Post analysis, air-dry subsamples are retained in the national soil archive to enable repeat analysis (if required) and provide a valuable future resource for analyses of other soil properties.

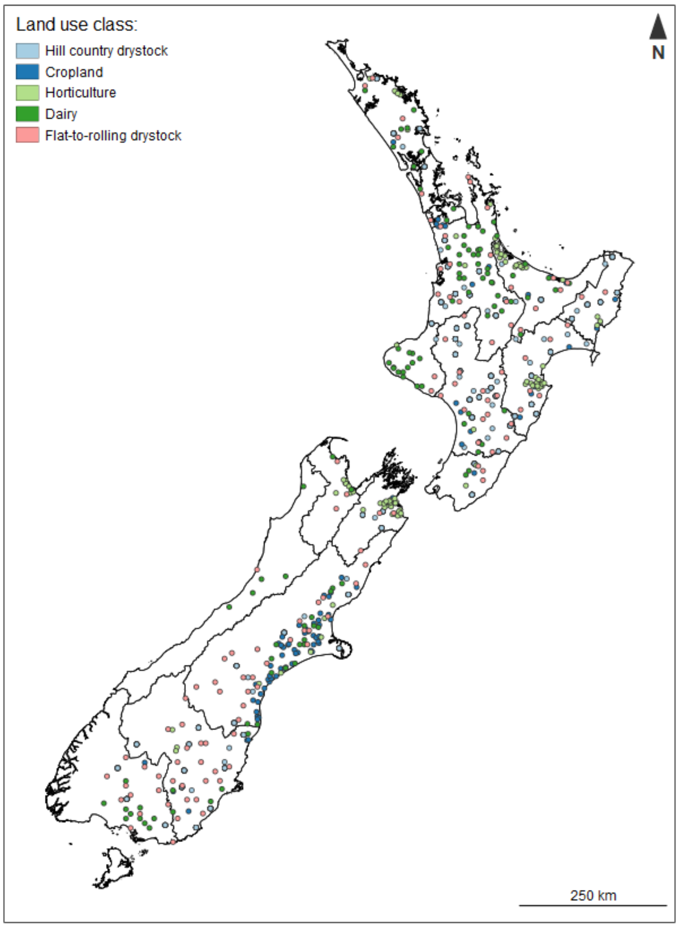

Figure 1. Distribution of 500 sites for soil organic carbon monitoring of agricultural land in New Zealand. Internal lines are Regional Council boundaries, and the different coloured dots indicate different Land Use class.

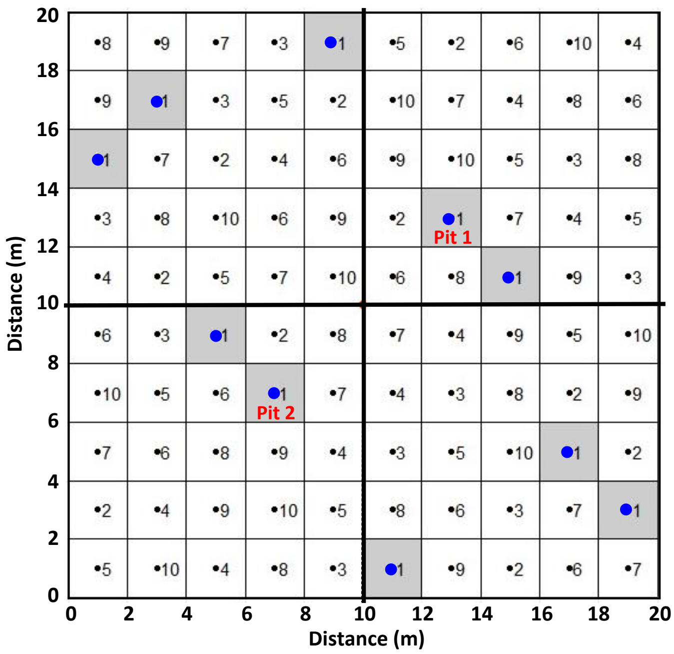

Figure 2. Latin square desgin of the 20 × 20 m sampling plot showing the location of 100 uniqe soil sampling points. The shaded cells indicate the 10 sampling points for the benchmark sampling round. One core is collected at each of the 10 points in non-stony soils, while two pits are dug in stony soils. The design provides unique sampling points for a total of 10 sampling rounds (i.e. numbers 1–10).

Results and discussion

To date, a total of 215 of the 500 sites have been sampled (43%), with sampling of remaining sites on-going. Preliminary estimates of the SOC stocks within each land use class are provided in Figure 3. Interpretation of these results should be made with caution given only 43% of the baseline sampling is completed. On average, the highest SOC stocks are found in soils under dairy pasture and lowest stocks under cropping land. However, these results must be treated with caution and cannot be interpreted as a land-use effect because the location of different land uses is often related to soil type and climate. For example, there are proportionally more dairy sites on Allophanic Soils, which have naturally high SOC stocks, due to the soil's specific mineralogy (Parfitt 1990). When benchmark sampling of all 500 sites has been completed, inferences about the effect of some key land use/soil order interactions on SOC stocks should be possible, particularly within grassland classes. However, the key longer-tern focus of this study is to determine whether SOC stocks are changing through time within the different land use classes and the answer to this question will be obtained after resampling the sites in future. We are also gathering detailed soil and site descriptions (e.g. topsoil depth, slope, aspect), plus land use and management information that will help with understanding and interpretation of results (both for benchmark stocks and stock change).

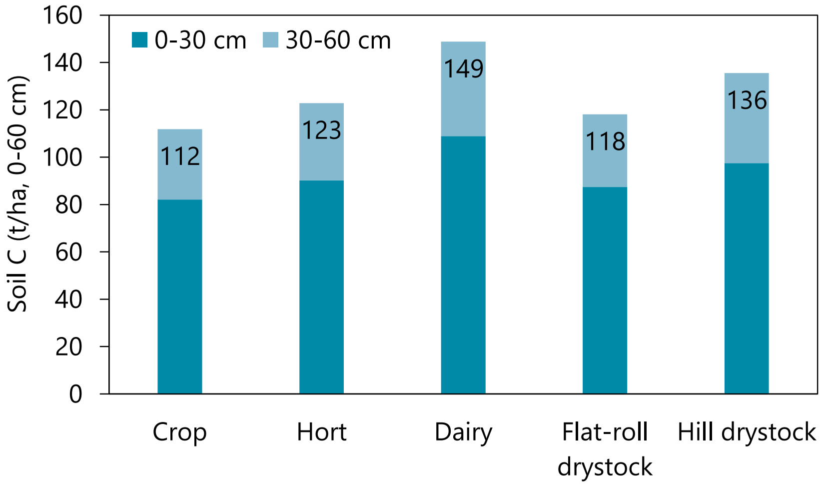

Figure 3. Soil organic carbon stocks (t/ha) for the five different land use classes, for interim data. The different colors in each bar are for the 0–30 cm and 30–60 cm depth increments, while the numeric values on each bar are for the full 0–60 cm depth.

In addition to archiving all soil samples for potential future analyses, there are a number of existing instances where this project is adding value to, and gaining value from, aligned projects. For example, data will be used to improve national GHG inventory reporting (Ministry for the Environment 2021) and update the national soil carbon map (Manaaki Whenua – Landcare Research 2022). Samples are being used to improve a calibration library for near-infrared (NIR) and mid-infrared (MIR) spectroscopy, which is an efficient method to quantify soil carbon, nitrogen, and a range of other properties. Sub-samples of surface soils will be analysed by the Fertiliser Association of NZ for long-term monitoring of metals and fluorine, plus other basic soil properties (e.g. pH, cation exchange capacity, phosphate retention and nutrients). Researchers at the University of Waikato will compare how the CO_2 production from soils from each of the sites varies at ~40 temperatures in a laboratory-based experiment. Last, as part of a European Joint Programme (EJP SOIL) project, carbon fractions, age, and stability will be determined on the samples alongside samples from national monitoring sites in Europe. The additional data generated from these projects will help interpret SOC stock results from the NSCM project.

Summary and conclusions

The NSCM project is primarily designed to provide a representative estimate of SOC stocks and stock changes through time, for five broad agricultural land use classes at the national scale. The project is progressing steadily with benchmark sampling of just under half the 500 sites completed as of February 2022. Benchmark sampling of all sites is scheduled to be completed in 2023, after which the plan is to begin resampling for the first monitoring round.

Results will provide much greater certainty about SOC stocks and stock changes in New Zealand and will be used to improve national greenhouse gas inventory reporting. Robust data for different land uses will also help enable the primary industry to make credible statements about SOC to international markets amid increasing emphasis on good environmental stewardship. Information from direct measurement of changes in SOC stocks under different land uses (in New Zealand conditions) will assist farmers as they consider options for how to reduce their net GHG emissions.

The NSCM system is currently designed to provide robust estimates for SOC stocks and change at the national scale for five broad agricultural land use classes. There is potential to leverage off the existing design/data and increase the number of sites via regional or industry sector initiatives to provide finer resolution results (e.g. detection of changes within specific regions, cropland types, or grazing management regimes). Other soil analyses (on both archived and newly collected soils) are also possible to address new questions that might arise in the future.

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