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ON-FARM SOIL HEALTH ASSESSMENT PROTOCOL TO AID DECISION MAKING

Nicole Schon[1] and Alec Mackay[2]

[1]AgResearch, Lincoln, New Zealand
Email: Nicole.Schon@agresearch.co.nz
[2]AgResearch Grasslands, Palmerston North, New Zealand

Abstract

Soil is the farm's greatest asset. When the soil ecosystem is working effectively it is the provider and regulator of many ecosystem services. However, soil is vulnerable to degradation, and this can reduce its ability to continue to provide ecosystem services. To ensure that soils are well-functioning, we require methods for monitoring and assessing soil health. Currently, on-farm soil assessment is typically limited to soil nutrient fertility, to inform nutrient management plans. The addition of indicators of soil organic matter, soil physical condition and biological activity can provide a more complete picture of the overall health of a soil and provide targets to maximise soil functioning. We detail a soil health assessment protocol that expands the suite of parameters measured while continuing to utilize established soil fertility monitoring transects. The use of specific indicators with target ranges that can also be linked to management recommendations, provides an opportunity for assessing soil condition and support actions that can address any potential issues. We applied the soil health assessment protocol to case study farms. In instances where indicators do not meet targets, management changes have been recommended to improve soil health. However, some aspects of soil health are difficult to manage and accordingly slow to respond to management. Linking soil health to farm performance data and expected environmental outcomes will assist in helping to realise the value of soil to farm performance.

Introduction

Soil with good structure, appropriate water storage and drainage, readily available nutrients, and diverse populations of beneficial macro- and microorganisms provides and regulates numerous ecosystem services (Dominati, 2011). However, management and changing landuse can cause degradation, which can impact the ability of the soil to function. Further guidance is required which supports farmers monitoring and managing soils to maintain and/or improve soil health.

Currently, on-farm soil assessments are typically limited to soil fertility to inform nutrient management plans. The addition of indicators of soil organic matter, soil physical condition and biological activity can provide a more complete picture of soil health. In New Zealand indicators established for soil quality monitoring, with defined target ranges, may be useful. Indicators include soil pH, Olsen P, mineralisable nitrogen, total soil carbon, total soil nitrogen, bulk density and macroporosity (Lilburne *et al.*, 2004; Sparling *et al.*, 2008; Drewry *et al.*, 2017). However, soil bulk density and macroporosity are difficult to assess on farms because measurement protocols require additional equipment and expertise. We propose combining standard laboratory tests for soil nutrient fertility and organic matter properties with an on-farm

Visual Soil Assessment (Shepherd, 2000a) that simultaneously assesses biological activity using earthworms (Schon *et al.*, 2020) as a means of assessing soil health. We report on data obtained from commercial dairy farms where we have applied this approach with the aim to advance an on-farm assessment protocol to improve decision making on pastoral land-use in New Zealand.

Methods

A soil health assessment protocol was implemented across ten commercial dairy farms in Waikato, Canterbury and Otago. On each farm, land management units (LMU) were identified, and monitor transects assigned to each LMU. Along each monitor transect, indicators of soil fertility, organic matter properties, soil physical condition and biological activity were assessed. We have listed potential soil health indicators and their target ranges to meet production and environmental outcomes for pasture soils in Table 1 and have grouped these into Tiers 1-3. Tier 1 and Tier 2 indicators can be assessed using the same sampling methods. Tier 1 tests are a basic starting point to give an indication of soil health and include measures of soil fertility routinely being measured on-farm. Tier 2 indicators break down this information further to help ensure management recommendations are specific and targeted. We continue to explore potential Tier 3 indicators that may be useful for specific situations or once targets and calibrations have been developed. Tier 3 indicators may require additional sampling and may be used to address an issue unique to a farm. However, it is noted that for Tier 3 indicators target ranges and associated management actions may be lacking and, as such, their purpose needs to be well understood before committing the resources to measuring them.

A total of 30 monitor transects were sampled in winter 2021 (with farms joining the project later sampled in summer) and again in winter 2022 across the 10 farms. Twenty soil fertility cores (25 mm diameter × 75 mm deep) were collected along each monitor transect and bulked together. Soil was air dried, sieved to 2 mm and analysed. Samples were analysed for soil pH, Olsen P, potassium, calcium, and magnesium. soil total nitrogen (N) and carbon (C), anaerobically mineralizable nitrogen, and hot water extractable C and N were also determined. All analyses were carried out by a commercial soil testing laboratory (RJ Hill Laboratories). Visual soil assessments were conducted on soil turves (200 × 200 × 200 mm) along each transect in triplicate (at the beginning, middle and end) following the methods of Shepherd (2000a). The soil turves used for the VSA were collected and hand-sorted for soil invertebrates from each site. Earthworms and insect pasture pests were identified and counted.

Soil health scores were calculated (Table 1) as described by Schon and Roberts (2020). If indicators were at or within their optimal range a score of 1 was given. If values were not at target, their distance from the target range was calculated. Scores were plotted in radar plots to represent proximity to target ranges.

Table 1. Potential soil health indicators and their target ranges for pasture soils.

Tier	Indicator	Target range	Reference
	Soil fertility		
1	Soil pH	5.8-6.0 except 5-5.5 for peat or 5.5-6.3	(Roberts and Morton, 2016) (Sparling *et al.*, 2008)
	Olsen P	20-30 and 30-40 for high producing, 35-45 for peat and pumice soil	(Roberts and Morton, 2016)
	Exchangeable cations	K QT 5-8 sedimentary, 7-10 allophanic and pumice and 5-7 for peat Mg QT 8-10 and 25-30 for animals Ca QT >1.5	(Roberts and Morton, 2016) (Edmeades and Perrott, 2004)
	Sulphate-Sulphur	10-12 mg/kg	(Roberts and Morton, 2016)
2	Organic Sulphur	15-20 mg/kg	(Roberts and Morton, 2016)
3	Trace elements		
	Heavy metals	As <20 mg/kg, Cd <0.6 mg/kg, Cu <100 mg/kg, Zn <300 mg/kg	(Drewry *et al.*, 2017)
	Cation exchange capacity	CEC low <12%, high >25%	
	Anion storage capacity	ASC low <30%, high >60%	
	Organic matter properties		
1	Soil organic carbon	>4% allophanic, >3% pumice, recent and semi-arid, other >3.5%. Excludes peat.	(Sparling *et al.*, 2008)
2	Soil total nitrogen	0.35-0.65 % or 0.25-0.7%	(Sparling *et al.*, 2008)
	Soil C:N ratio	8-12:1	(Sparling *et al.*, 2008)
	Available nitrogen	AMN 100-200 kg/ha or 50-250 kg/ha	(Sparling *et al.*, 2008)
3	Available carbon	Provisional HWEC >1400 mg/kg	(Drewry *et al.*, 2017)
	Potentially mineralisable nitrogen		
	Soil physical condition		
1	Visual soil assessment	Score >20	Shepherd (2000a)
2	Bare soil and surface relief	Each individual score =2	Shepherd (2000a)
	Colour and mottles	Each individual score =2	Shepherd (2000a)
	Structure and porosity/	Each individual score =2	(Shepherd, 2000b)
	Bulk density and macroporosity	Macroporosity 8-30% or 10-15% Bulk density soil type dependent	(Sparling *et al.*, 2008) (Houlbrooke *et al.*, 2011)
3	Water infiltration		
	Aggregate stability		
	Water holding capacity		
	Rooting depth		
	Soil biological activity		
1	Earthworm abundance	>400 m^{-2}	(Schon *et al.*, 2020)
2	Earthworm diversity	3 ecological groups	(Schon *et al.*, 2020)
	Pasture pests*	Porina <20 m^{-2}	(Ferguson *et al.*, 2019)
		Grassgrub <150 m^{-2}	(Ferguson *et al.*, 2019)
		Clover root weevil <130 m^{-2}	(Ferguson *et al.*, 2019)
		Black beetle <20 m^{-2}	(Ferguson *et al.*, 2019)
3	Microbial biomass		
	Microbial diversity		
	Microbial respiration		
	Soil diseases		
	Decomposition		

Note some target ranges are provisional and may change as science and understanding improves. Some measured properties do not have a target range. Where two target ranges are given (not soil type dependent) the first target will be used going forward.

Results and discussion

Assessment of soil health across ten commercial dairy farms show that all soils were at, or near to, the Tier 1 indicator targets across at least 70% of transects (Figure 1), with the exception of soil pH, magnesium and sulphate-sulphur. Similarly, most Tier 2 indicators were often at target with a few exceptions. Exceptions included organic-sulphur, individual scores for soil colour and mottles and soil structure and porosity (although the total visual soil assessment score was often >20) and earthworm diversity. While soil fertility may be relatively straight forward to adjust with nutrient input, other aspects of soil health may be difficult or slow to change (e.g., organic sulphur and earthworm diversity) and require a significant change to farm operations to reach target ranges. For such indicators it will be important to show the potential cost on both farm and environmental performance for longer term investment towards improved soil health.

Assessment of soil health should be conducted at the same time of year (ideally late winter/early spring) along the same farm monitor transects to ensure results can be compared through time. Additional assessments may be desired for particular paddocks. Initially annual sampling is recommended to gain a good understanding of the soil health. Results from the commercial farms in the current study show that while there were instances when measurement varied between the two years, in general indicators were consistent between years. Hence, sampling effort may be able to be reduced to once every two to three years, implementing changes in management, and monitoring trends as required.

The application of the soil health assessment using one of the case study farms in Canterbury shows the greater detail, and potential understanding of the soil resource using both the Tier 1 and Tier 2 indicators (Figure 2). However, this information is not useful beyond a static measure of health, without the provision of recommendations detailing how to maintain or improve the soil health status. Recommendations need to be specific to each monitor transect depending on whether an indicator is either above or below target. Many recommendations are based on best practice and may already be used by farmers. Ensuring indicators and management actions can be prioritised within a management plan will improve decision making going forward, and this may include the potential of incorporating soil health scores within a geospatial context. Work is currently underway to better link soil health with management practices, and farm and environmental performance. Improved soil health improves soil functions and the expectation of improved farm and environmental performance. Overseas mobile applications are already available to link global and local data to provide soil health advice (e.g. SQAPP).

The targets that are reported here are based on published optimal ranges for the pastoral sector. However, it may be timely to consider whether any of these targets need to be revised. To progress soil health monitoring on-farm it will be important to get consistency both in terms of the indicators used as well as their targets within a sector. Targets, where possible, should be sector specific and soil type dependant. Further, there are numerous tests (e.g., Cornell Soil Health test, Soil Carbon Initiative) being developed overseas to assess soil health, sometimes within a larger framework (e.g., Savory Institute). It is worth understanding which frameworks may be important for New Zealand markets and working towards ensuring these can be applied within a New Zealand context in the future.

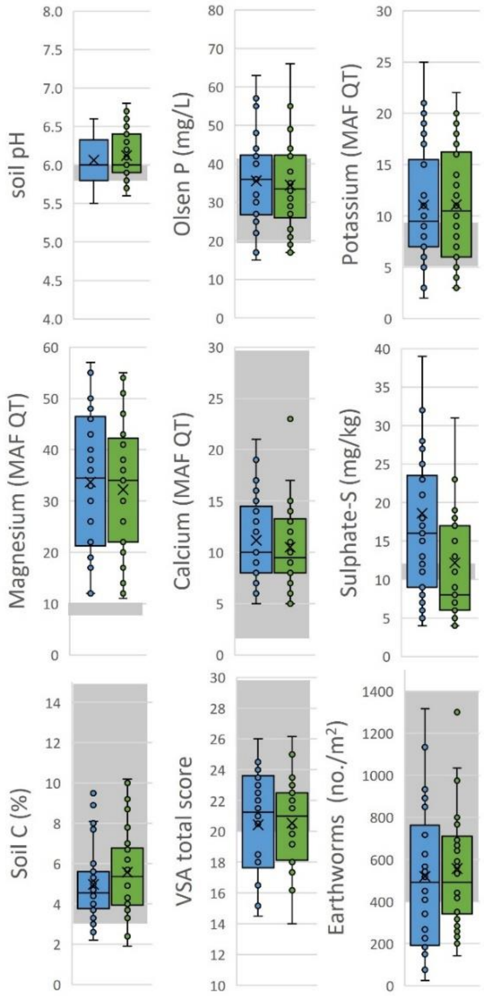

Figure 1. Box plots showing mean (x), median (horizontal midline), quartiles and minimum and maximum values for soil health indicators across 30 transects in 2021 (blue) and 2022 (green) from the 10 farms. Each indicator shown in relation to target ranges (light grey).

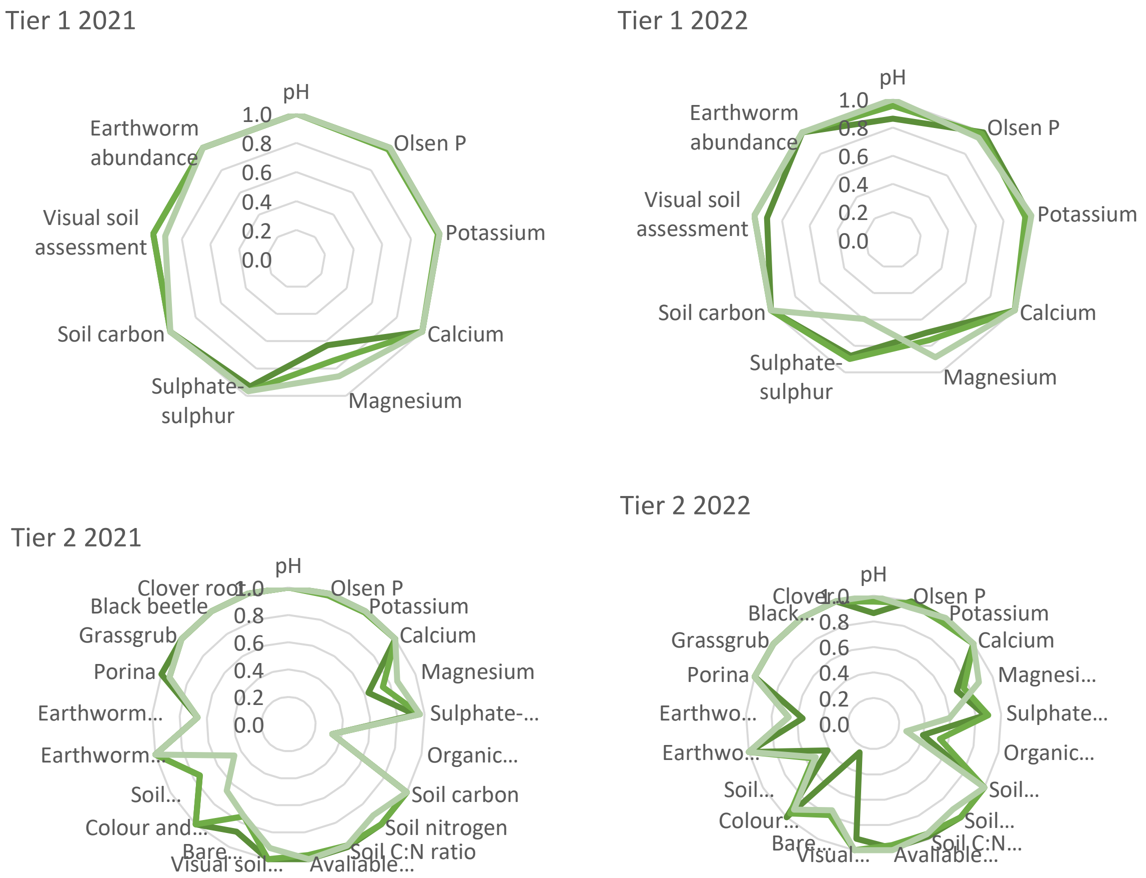

Figure 2. Tier 1 and 2 indicators of soil health as measured in 2021 and 2022 across case study commercial dairy farm in Canterbury. The optimal range is represented by 1.0, and if all indicators are at their target range a full circle would be shown, representing optimal soil health. If values were not at target their distance from the target range was calculated (Schon and Roberts, 2020). Indicators not at 1.0 may be either above or below their target range.

Conclusions and recommendations

The assessment of soil health can be employed on-farm along existing soil nutrient fertility monitor transects. Indicators selected should be those that have a target range and are responsive to management or land use change. Work on presenting soil health values and linking indicators to farm performance and environmental outcomes is on-going.

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