Manaaki Whenua
Landcare Research

Soil health indicators

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Soil health indicators

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Summary

Objectives and background

Soil health (and/or soil quality) indicators are defined as 'measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions'. A standard set of core indicators for all uses might be desirable, but the intended use is an important factor in choosing appropriate indicators. For state of the environment (SOE) reporting a more formal set of standardised indicators is required, whereas for farm-scale or landowner use less formal procedures (such as visual soil assessment) may suffice.

The current set of soil quality indicators were developed from a series of programmes in the 1990s and early 2000s that culminated in the 500 Soils programme. Statistical methods (e.g. multivariate techniques such as principal component analysis) were used to determine the indicators that best differentiate land uses. These included pH, total carbon, total nitrogen, anaerobic mineralisable N, Olsen P (phosphorus), bulk density, and macroporosity. These were chosen as a minimum data set for SOE reporting of soil quality indicators. Trace element analyses (such as cadmium) were also added as a further measure of anthropogenic inputs into the soil system.

This document is undertaken as part of the 'Soil health and resilience: oneone ora, tangata ora' project (C09X1613) and is intended to be a brief overview of soil quality/soil health indicators in New Zealand. It covers current soil quality indicators that are used in New Zealand SOE reporting, a comparison with other indicator approaches, indicators in development, and where there are major gaps. It is also intended as a source of reference material for those wanting more background material.

Conclusions

The current set of indicators has been important for SOE reporting at both the regional and national level and has helped inform significant land-use issues such as low macroporosity on dairy and intensive drystock land uses. Although the current set of soil quality indicators are some of the most well-accepted soil measurements internationally, currently there are gaps, especially biological data. Advances in genomics may help fill this gap for the microbial community, but though the effects of increased land-use intensification are starting to be quantified, determining what constitutes a 'healthy' microbial community has still not been defined. Worms as an indicator of soil fauna are being suggested for farm-scale soil health monitoring in pastures. A suggested method for a potentially mineralisable N test has been published, but more work on soil physical vulnerability is needed.

Broader measures that relate to how soil functions in the environment and the services it provides are desirable for SOE reporting. Recognition of the different ways in which soil is valued – not just from an instrumental viewpoint (what soil does for us) but from intrinsic and relational points of view (the relationship of different parts of society to soil) – should be incorporated into these broader measures. Acknowledgement of different relational values of soil also readily accommodates a Māori world view on soil health. Concepts such as the soil ecosystem services model and soil security can help frame these broader measures. Alternative measures for different purposes (e.g. visual soil assessment for less formal soil health evaluation) should also be encouraged.

1 Introduction

This document is undertaken as part of the 'Soil health and resilience: oneone ora, tangata ora' project (C09X1613) and is intended to be a brief overview of soil quality/soil health indicators in New Zealand. It covers current soil quality indicators used in New Zealand state of the environment (SOE) reporting, indicators in development, where there are major gaps, and how those gaps might be filled. It is also intended as a source of reference material for those desiring more background material.

Although indicators are used very broadly in SOE reporting, Arshad and Martin (2002) define soil quality indicators as 'measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions' and add that 'attributes that are most sensitive to management are most desirable as indicators'. Although this definition is relatively narrow by today's standards, it contains the core concept of what an indicator is. A broader definition of soil health is the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans.[1] In this broader definition an indicator is a measurable property that tells us something about how the soil is functioning. (Note that while some distinguish between soil quality and soil health, these terms are used interchangeably in this document.)

A standard set of core indicators for all uses might be desirable, but the intended use of the indicators is an important factor in choosing appropriate indicators. For SOE reporting a more formal set of standardised indicators is required, whereas for farm-scale or landowner use less formal procedures (such as visual soil assessment) may suffice.

2 Current New Zealand soil quality indicators

The current set of soil quality indicators were developed from a series of programmes in the 1990s and early 2000s that culminated in the 500 Soils programme (Sparling et al. 2004; Lilburne et al. 2004). These programmes began as a comparison of a set of soil properties under different land uses that were thought to be sensitive to change (Schipper & Sparling 2000). The 500 Soils programme was more ambitious and sampled a number of different land uses (dairy, drystock, plantation forestry, cropping and horticulture) on different soil types.

The larger programme tested a variety of common indicators, selected from Doran & Parkin 1994, in consultation with New Zealand soil scientists. These included such typical measures as total carbon, total nitrogen, bulk density, water-holding capacity, soil respiration, microbial biomass, and measures of nutrient content such as Olsen P (phosphorus). Statistical methods (e.g. multivariate techniques such as principal component analysis) were used to determine the indicators that best differentiated land uses. The analysis also considered which indicators were correlated (e.g. microbial biomass and anaerobic nitrogen) and/or redundant in discerning land-use classes. The programme

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[1] USDA-NRCS. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/.

also determined the variation in indicators due to land use versus that due to soil order. The conclusion of Schipper and Sparling (2000) was to eliminate several indicators from the data set, such as microbial biomass and soil respiration.

A core set of indicators were chosen as a basic minimum data set for SOE reporting of soil quality indicators (Sparling & Schipper 2002):

- pH
- total carbon
- total nitrogen
- mineralisable nitrogen, determined by the anaerobic mineralisable nitrogen (AMN) test
- Olsen P
- bulk density
- microporosity.

The indicators chosen represented different aspects of soil quality/soil health: pH as a measure of soil acidity; total carbon, total nitrogen, and mineralisable N as the soil organic status; Olsen P as soil fertility; and bulk density and macroporosity as indicators of soil physical status (see Figure 1).

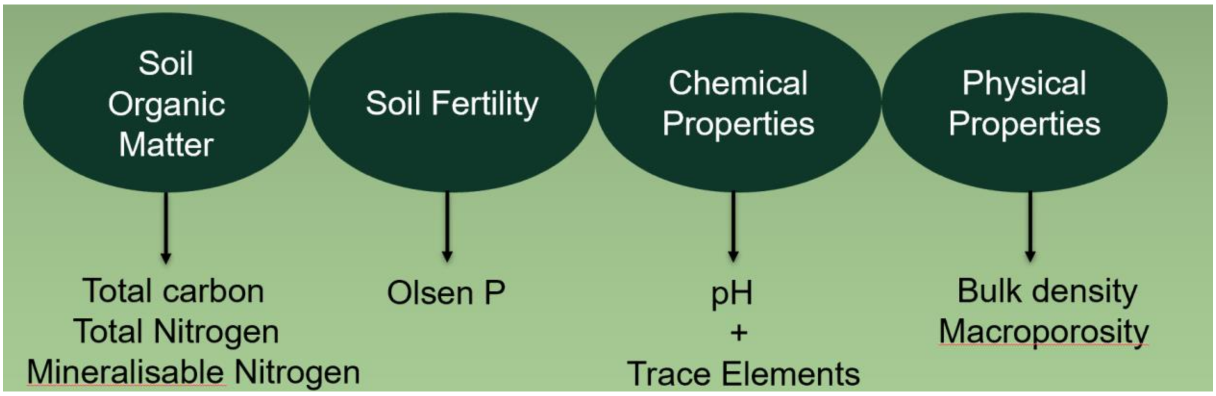

Figure 1. How the NZ State of the Environment soil quality indicators relate to soil attributes.

The sampling methods and interpretation of these indicators were reviewed (Hill et al. 2003) and laid out in a series of journal articles (Sparling et al. 2004; Lilburne et al. 2004). Procedures and sampling methods were further laid out in Hill & Sparling 2009 in the Land Monitoring Forum guide *Land and Soil Monitoring: A guide for SoE and regional council reporting*. The data gathered from the soil quality monitoring programme have not just formed the basis for regional and national SOE reporting (Drewry et al. 2021; MfE & StatsNZ 2021, 2018), but have also been a rich source of data for research (e.g. Stevenson et al. 2015, 2010; Parfitt et al. 2014).

While the original programme was focused on a relatively small set (a minimum data set) of soil measurements, other facets of soil health were also developed by regional authorities. Chief among these was trace element analysis (such as cadmium), along with several other trace elements as a further measure of anthropogenic inputs into the soil system. Guidelines for trace element concentrations (in the form of soil guideline values for contaminants) have been produced (Cavanagh & Munir 2019).

3 Overview of other programmes and approaches

There are different types of programme that monitor soil condition. Bünemann et al. (2018) reviewed a number of international programmes and found that the most common indicators were total or organic carbon, pH, available phosphorus, water storage, and bulk density. Australia has several programmes that are relatively similar to New Zealand's (Queensland Government Department of Environment & Science 2020; Cotching & Kidd 2010), but the indicators chosen include several that are not considered relevant (at present) in New Zealand, such as soil electrical conductivity.

3.1 US-based programmes

The New Zealand approach originally considered indicators suggested by Doran and Parkin (1994) based on work done in the US, which has generally followed a laboratory-based approach with well-accepted laboratory methods. The Cornell Assessment of Soil Health programme (manual.pdf (cornell.edu)) and the Soil Management Assessment Framework (Andrews et al. 2004) are examples of US programmes that evolved in this way.

The US-based Soil Health Institute published a list[2] of what they consider Tier 1 and Tier 2 indicators (Table 1). Tier 1 indicators are those that are the most common and accepted analyses that can be standardised across different laboratories. Tier 2 indicators are those that show promise but need more testing. While the New Zealand indicator set does not contain all the Tier 1 indicators, those chosen (except for macroporosity) would be considered Tier 1 indicators. Interestingly, macroporosity has been one of the more useful indicators and has demonstrated that compaction (and loss of macropores, which let air and water into the soil) is a problem on many dairy and intensively used drystock soils reported in *Our Land 2018* and *Our Land 2021* (MfE & StatsNZ 2018, 2021).

[2] National Soil Health Measurements to Accelerate Agricultural Transformation - Soil Health Institute

Table 1. Soil Health Institute Tier 1 and Tier 2 soil health indicators

Tier 1 indicators		
Organic carbon	Cation exchange capacity	Nitrogen mineralisation
pH	Electrical conductivity	Erosion rating
Water stable aggregation	Nitrogen	Base saturation
Crop yield	Phosphorus	Bulk density
Soil texture	Potassium	Available water-holding capacity
Penetration resistance	Carbon mineralisation	Infiltration rate
		Micronutrients
Tier 2 Indicators		
Sodium adsorption ratio	Soil protein index	Phospholipid fatty acid (PLFA)
Aggregate stability	Active carbon	Genomics (16S rRNA ITS and shotgun metagenomics)
Soil stability index	Enzymes: β glucosidase N-acetyl-B-D-glucosiminidase Phosphomonoesterase Aryl sulfatase	Reflectance

3.2 European programmes

There are a number of European-based programmes, but many have been derived from the Environmental Assessment of Soil for Monitoring (ENVASSO) programme, which attempted to develop a harmonised soil monitoring programme for Europe (Kibblewhite et al. 2010).

The programme identified 290 potential indicators and produced nine key soil threats: soil erosion, organic matter decline, contamination, compaction, salinisation, decline in biodiversity, soil sealing, landslides, and desertification. After consultation, 20 priority indicators covering soil erosion by water, decline in soil organic matter, soil contamination, soil sealing, compaction, salinisation, and desertification were chosen. Although the programme was very large and has not been repeated on a continental scale, individual countries have used ENVASSO as a starting point for further monitoring (Table 2).

Table 2. Suggested indicators for soil monitoring across Europe, based on soil threats

Soil threat	Main relevant indicators
Soil erosion	Estimated soil loss, measured soil loss
Decline of soil organic matter	Organic matter (or organic carbon content), bulk density, carbon:nitrogen ratio
Soil contamination	Heavy metal content, pH, nutrient content,
Soil sealing	Sealed area
Soil compaction	Bulk density, organic matter content, particle size distribution, soil water retention, saturated hydraulic conductivity, observation of soil structure
Decline of soil biodiversity	Earthworm diversity, Collembolla diversity, microbial respiration
Soil salinisation	Salt profile, electrical conductivity, exchangeable sodium percentage
Landslides	Occurrence of landslide activity
Desertification	Organic matter content, salt content, electrical conductivity

Source: Morvan et al. 2008

Some European approaches tend to be more field based, combining an array of both laboratory and field measurements, such as nutrient input data, management practices, and soil fauna data (e.g. earthworm, nematode and microarthropod abundance and diversity) (see Figure 2 for an example). While such an approach provides a much broader range of information, the sampling time and cost to obtain that information generally also tend to be greater.

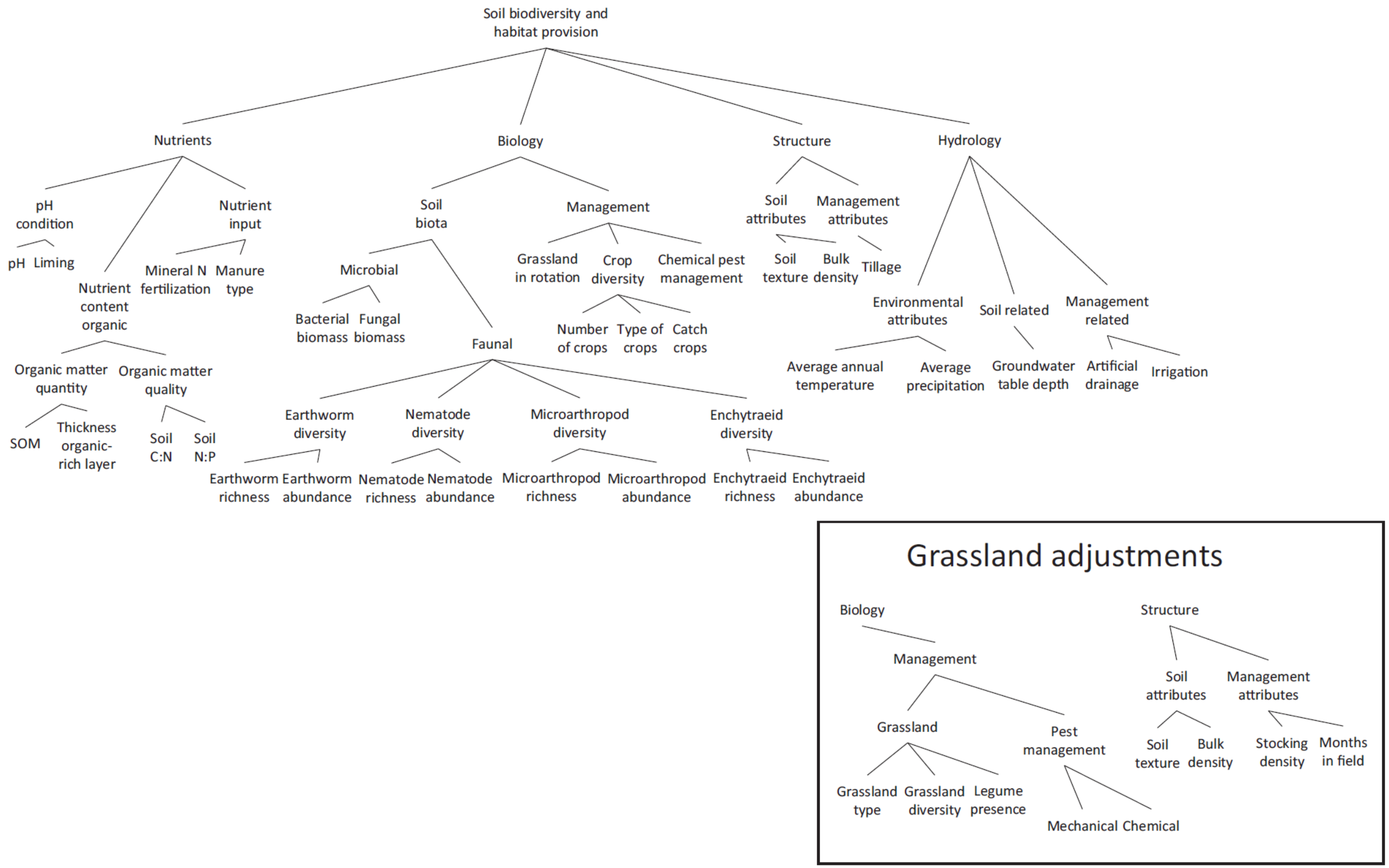

Figure 2. A suggested European approach to soil health indicators, which includes field-based measures (type of nutrient inputs, management) as well as biological indicators such as soil faunal abundance and diversity.
Source: van Leeuwen et. al. 2019.

Other programmes, such as the Wageningen Interactive 'Soil Quality Assessment in Europe and China for Agricultural Productivity and Resilience' project, are much broader in scope. They include typically measured soil indicators, but also indicators of soil threats (which include desertification, soil pollution, and erosion). As part of the project they developed a soil quality app (SQAPP), which integrates soil quality information with other soil and climate data. The steps taken to initiate the programme are detailed in Building SQAPP (isqaper-is.eu).

3.3 Visual soil assessment

A less formal way of assessing soil health is through purely field-based avenues such as visual soil assessment (VSA) (Shepherd 2003). The VSA scores different components of soil quality (soil aggregates, soil drainage, soil erosion) through field-based observations (Figure 3).

SCORE CARD

Visual indicators for assessing soil quality under cropping

SOIL INDICATORS

Land use:

Site location/Paddock name:

Date:

Soil type:

Textural qualifier: ☐ Sandy ☐ Loamy ☐ Clayey

Moisture condition: ☐ Dry ☐ Slightly moist ☐ Moist ☐ Wet

Seasonal weather conditions: ☐ Dry ☐ Wet ☐ Cold ☐ Warm ☐ Average

Visual Indicator of Soil Quality	Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS Ranking
Soil structure & consistence (Fig. 1, p.17)		× 3	
Soil porosity (Fig. 2, p.19)		× 3	
Soil colour (Fig. 3, p.21)		× 2	
Number and colour of soil mottles (Fig. 4, p.23)		× 2	
Earthworm counts (Fig. 5, p. 25)		× 2	
Tillage pan (Fig. 6, p. 27)		× 2	
Degree of clod development (Fig. 7, p. 29)		× 1	
Degree of soil erosion (wind/water) (Fig. 8, p. 31)		× 2	
RANKING SCORE (Sum of VS rankings)			

Soil Quality Assessment	**Ranking Score**
Poor	< 10
Moderate	10 – 25
Good	> 25

If your soil quality assessment is moderate or poor, guidelines for sustainable management are given in Volume 2, Part One.

Figure 3. Visual soil assessment guide, available online (for no cost) at: VSA field guide » Manaaki Whenua (landcareresearch.co.nz).

To be interpreted correctly, however, the directions must be followed closely. Also, different people may score the tests differently, so there is a degree of variability in how the tests are undertaken and interpreted. Although this method may not be quantitative enough for formal SOE reporting, it is a great practical tool for farmers and landowners to understand how the different components of the soil interact. Figure 4 gives a brief explanation of the 'drop test' to measure soil aggregates. The basic version of the visual soil assessment can be downloaded (for free) from the Manaaki Whenua – Landcare Research website (see link in Figure 3 caption).

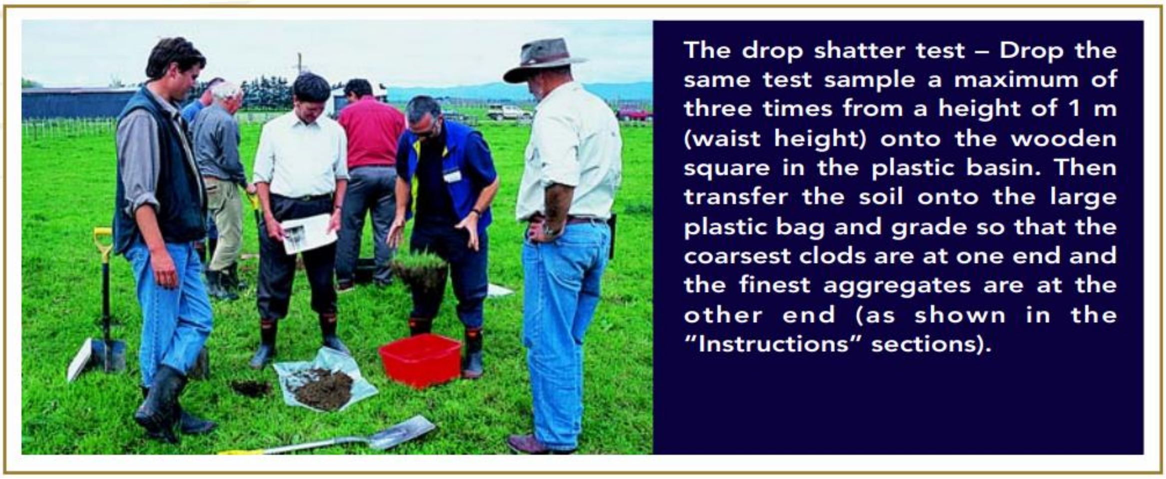

Figure 4. The drop test assesses the size of soil aggregates as a measure of soil physical structure.

4 Indicators in development and indicator gaps

Although the current set of indicators has been useful in assessing specific aspects of soil quality and soil health, there are gaps. In this section we discuss more typical soil-based measurements, but in the following sections we discuss broader indicators that go outside the normal soil measurements.

4.1 Plant-available nitrogen

The current mineralisable nitrogen test (based on a 7-day anaerobic incubation) has been criticised as not the best predictor of plant-available nitrogen. A test (based on hot-water-extractable nitrogen, HWN) has been proposed that aims to predict plant-available nitrogen better than the current (anaerobic) mineralisable nitrogen measurement. Curtin et al. (2017) found that while the anaerobic nitrogen test was good, a procedure based on the HWN extraction better correlated with long-term aerobic nitrogen mineralisation, which is used as the baseline measurement for the amount of nitrogen mineralised. The test hopes to improve nitrogen management by better predicting the quantity of nitrogen a soil can supply via nitrogen mineralisation.

4.2 Soil physical vulnerability

Soil structure is the amount and arrangement of the solid (soil minerals, organic matter), liquid (water), and gaseous (air) parts of the soil. Soil structure plays an important role in soil functions and the services the soils provide. However, soil structural degradation is observed worldwide, and is associated not only with land-use pressures from agricultural intensification, but also with soil structural vulnerability, defined as the ability of soil structure to cope with stress. Understanding soil structural vulnerability is important to identifying management practices that mitigate the risk of soil structural degradation and improve soil functions.

Currently, soil structural vulnerability assessment can be classified mainly into two groups. One is compaction vulnerability, which is based on soil strength and stress properties, and the other is vulnerability of soil aggregate breakdown to wetting or mechanical stress. However, existing compaction indicators focus on possible change in bulk density or total porosity. Although aggregates are related to the risk of wind and water erosion, the aggregate is not the best indicator of soil structure because most soil chemical and microbiological processes happen in voids rather than aggregates. Therefore, future development of methods for assessing soil structural vulnerability should focus on soil structure indicators (e.g. pore network–based hydraulic properties) that determine soil functions and ecosystem services.

There are several papers that have documented how soil organic matter, soil type, and land use affect soil physical vulnerability (Hu et al. 2022; Fu et al. 2021a,b; Hewitt & Shepherd 1997). Hu et al. (2022), for instance, found that Gley soils are more vulnerable to physical degradation under maize cropping than Allophanic soils.

4.3 Soil biology

Soil biology is an important aspect of soil health and is the largest indicator gap. The different organisms in the soil create a food web that cycles organic material and nutrients through the soil (Figure 5). The biological component of the soil is generally more costly and labour intensive to measure, and it is also more difficult to interpret the results and determine what constitutes 'healthy' levels of organisms in different land uses. Pollutants can obviously have a negative impact on soil biology (including soil fauna such worms, as well as soil microbes), but the number and diversity of these organisms can vary depending on soil pH, land use, vegetation type and diversity, soil carbon (and carbon inputs into the soil), and a host of other properties.

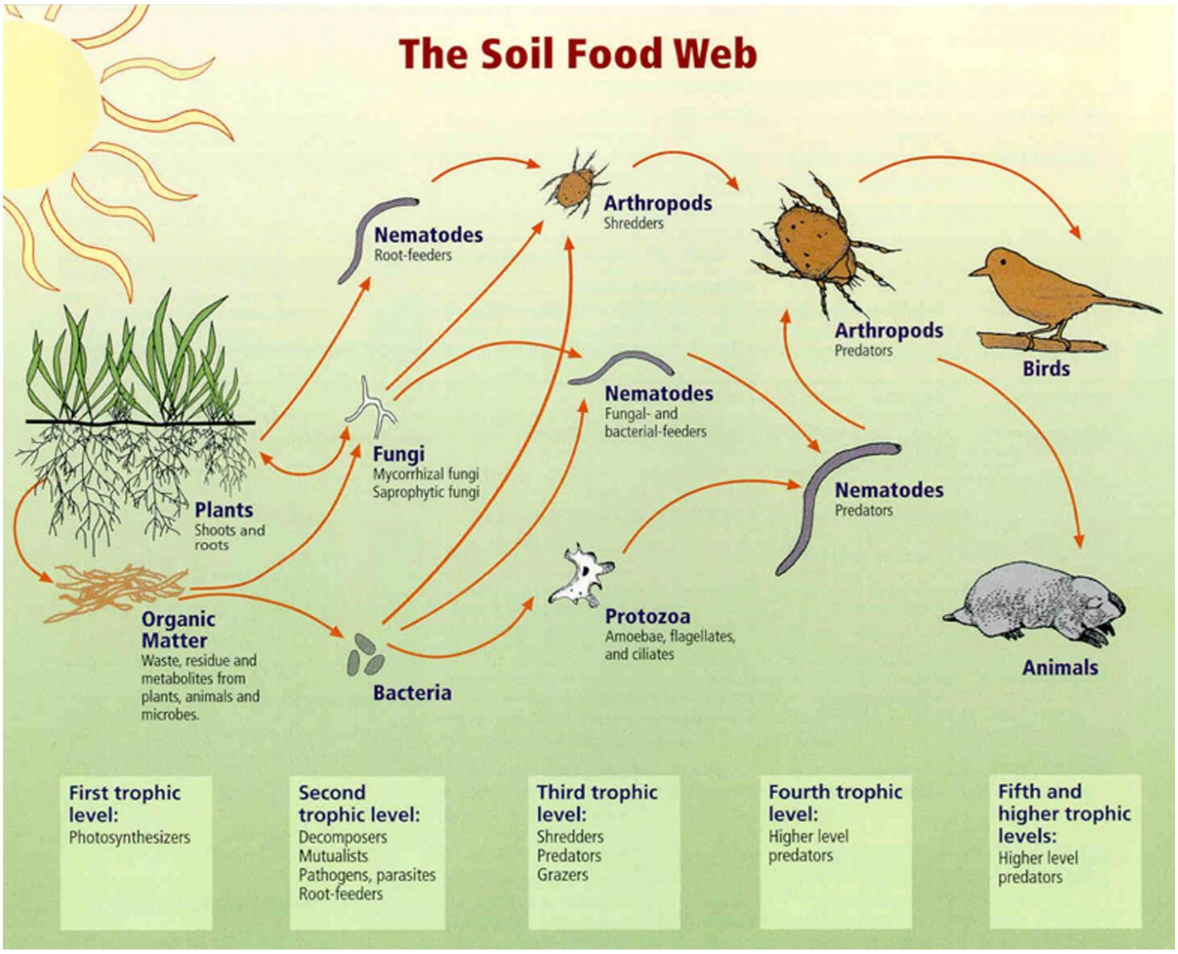

Figure 5. Some of the organisms that make up the soil food web.
Source: figure from Natural Resources Conservation Service:
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053868

4.3.1 Soil fauna

Worms are generally considered to be an indication of a healthy soil in pasture and cropping land uses. Schon et al. (2022) set out methods for counting earthworms and suggested levels of different earthworm types for pasture. Earthworms have not yet been included in formal SOE reporting because it covers land uses where worms don't normally occur in great abundance (e.g. plantation forests), and it was also felt that earthworm counts would be too variable on a year-to-year basis. Other types of soil fauna (such as mites and nematodes) can be useful indicators of change, but they require specialised expertise to identify different species and types. Also, many soil fauna found in pasture and cropping land uses are not native to New Zealand, and although many are beneficial (and already present), their non-native status is potentially a negative aspect.

4.3.2 Microbial activity

Bacteria, fungi, and other associated microbial organisms are perhaps the most difficult in which to interpret changes. Microbial biomass and activity measures, such as soil respiration and the microbial quotient (soil respiration per unit microbial biomass) tend to be variable within land uses and soil orders and difficult to interpret. While contaminant levels that are toxic to microbes certainly have a detrimental impact on microbial biomass and function, microbes actually respire more when stressed (because the oxidation of carbon provides the energy needed to survive stressful conditions), so care must be taken when evaluating changes in these measurements (Wardle & Ghani 1995).

Although on a global scale climate (as a function of latitude), pH, and soil organic carbon have a large impact on determining microbial biomass carbon (Wardle 1992), in agricultural systems where pH is largely controlled, soil carbon (and particularly available carbon) appears to have the greatest impact on microbial biomass (Stevenson et al. 2016; Sparling et al. 1998). For these reasons (and the relatively strong correlation between microbial biomass and anaerobic mineralisable nitrogen), these measurements were not included in the indicators from the 500 Soils programme (Schipper & Sparling 2000).

4.3.3 Genomics

The field of genomics applied to the soil biome is still relatively new and rapidly evolving, but it has shown promise in being able to address how microbial assemblages can indicate soil health (Astudillo-Garcia et al. 2019). Hermans et al. (2017, 2020) used 16S rRNA gene amplicon sequencing on samples from across regional council soil quality sites (over 3,000 soil samples from 606 sites across indigenous vegetation, plantation forestry, horticulture, and pastoral grasslands in the case of the 2020 paper) and found a strong positive correlation between the relative abundances of members of Pirellulaceae and soil pH, and strong negative correlations between the members of Gaiellaceae and carbon-to-nitrogen ratios, members of Bradyrhizobium and the levels of Olsen P, and members of Chitinophagaceae and aluminium concentrations. Soil bacterial community composition was strongly linked to land use, to the extent that it could correctly determine the type of land use with 85% accuracy. These relationships between specific soil attributes and individual soil taxa not only highlight ecological characteristics of these organisms, but also demonstrate the ability of key bacterial taxonomic groups to reflect the impact of specific land-use activities, even in comparisons of samples collected across large geographical areas and diverse soil types.

Although the field of genomics is rapidly expanding (and the costs for analysis are becoming more affordable), Fierer et al. (2021), in a paper entitled 'How microbes can, and cannot, be used to assess soil health', summarise the state of microbial metrics as follows:

> *given their well-established importance to many aspects of soil health, microbes and microbial processes are often used as metrics of soil health with a range of different microbe-based metrics routinely used across the globe. Unfortunately, it is our opinion that many of these pre-existing microbial measurements are not easy to interpret and may not necessarily provide credible inferences about soil health status.*

While the authors extoll the use of genomics as a suitable replacement for existing techniques, they do state that more research is needed before it can be adopted as a measure of soil health. It is important to note, however, that, particularly in managed land uses, most genomics studies have focused on bacterial communities, and that the composition and diversity of fungal communities have been much less explored.

4.3.4 The fungal community

Interest in the status of fungal communities, and in particular mycorrhizal fungal associations, has grown with the realisation of their importance to nutrient cycling and retention. Lauber et al. (2008) concluded that though soil pH is the best predictor of bacterial community composition across this landscape, fungal community composition is most closely associated with changes in soil nutrient status. De Vries et al. (2006, 2011) demonstrated that higher fungal biomass and fungal to bacterial ratios in grasslands indicate tighter nutrient cycling and less 'leaky' systems.

Mycorrhizal fungi can help plants acquire scarce nutrients, but the individual mycorrhizal species appear to have different abilities to acquire these nutrients. Treseder (2004) found that both nitrogen and phosphorus tend to supress mycorrhizal fungi in most systems. While from a soil health perspective, the ability of the soil biota to control the cycling of nutrients is ideal, the trade-off is that although ecosystems exhibiting these characteristics appear to be less 'leaky' to nutrients, they often exhibit slower cycling of nutrients (which may mean less to plants during peak growth periods).

5 Soil functions, ecosystem services, and soil security

While much of the preceding discussion has focused on specific measurements of soil, broader concepts of how soil interacts with the wider environment have also been developed. The concepts of ecosystem services and soil functions have played a role in how soil health is evolving. Ecosystem services are the services provided by the environment to humans. Food and fibre production is a major component of these services, but the environment also provides a number of other services (for more detail see section 5.1). Soil functions are described by Bünemann et al. (2018) as 'bundles of soil processes' that are responsible for nutrient cycling, greenhouse gas abatement, soil structural maintenance, etc. Soil security is another concept (developed in Australia) that tries to bring these ideas together and is further explored in section 5.2.

5.1 Soil ecosystem services

The soil ecosystem services concept (Figure 6) shows how soil stocks (which form part of natural capital) and flows affect ecosystem services. Food and fibre production is the most obvious ecosystem service soil provides, but there are others, as listed in Figures 5 and 6. The broader ecosystem services concept acknowledges that trade-offs often occur between different services, and that it is difficult to optimise all services. The framework can be used to investigate how natural capital and supporting or degrading processes affect different services. Dominati et al. (2021) used this approach to assess biodiversity enhancements on the financial and environmental performance of mixed livestock farms in New Zealand. Lilburne et al. (2020) used a similar approach (the land resource circle) to explore services and functions provided by soil.

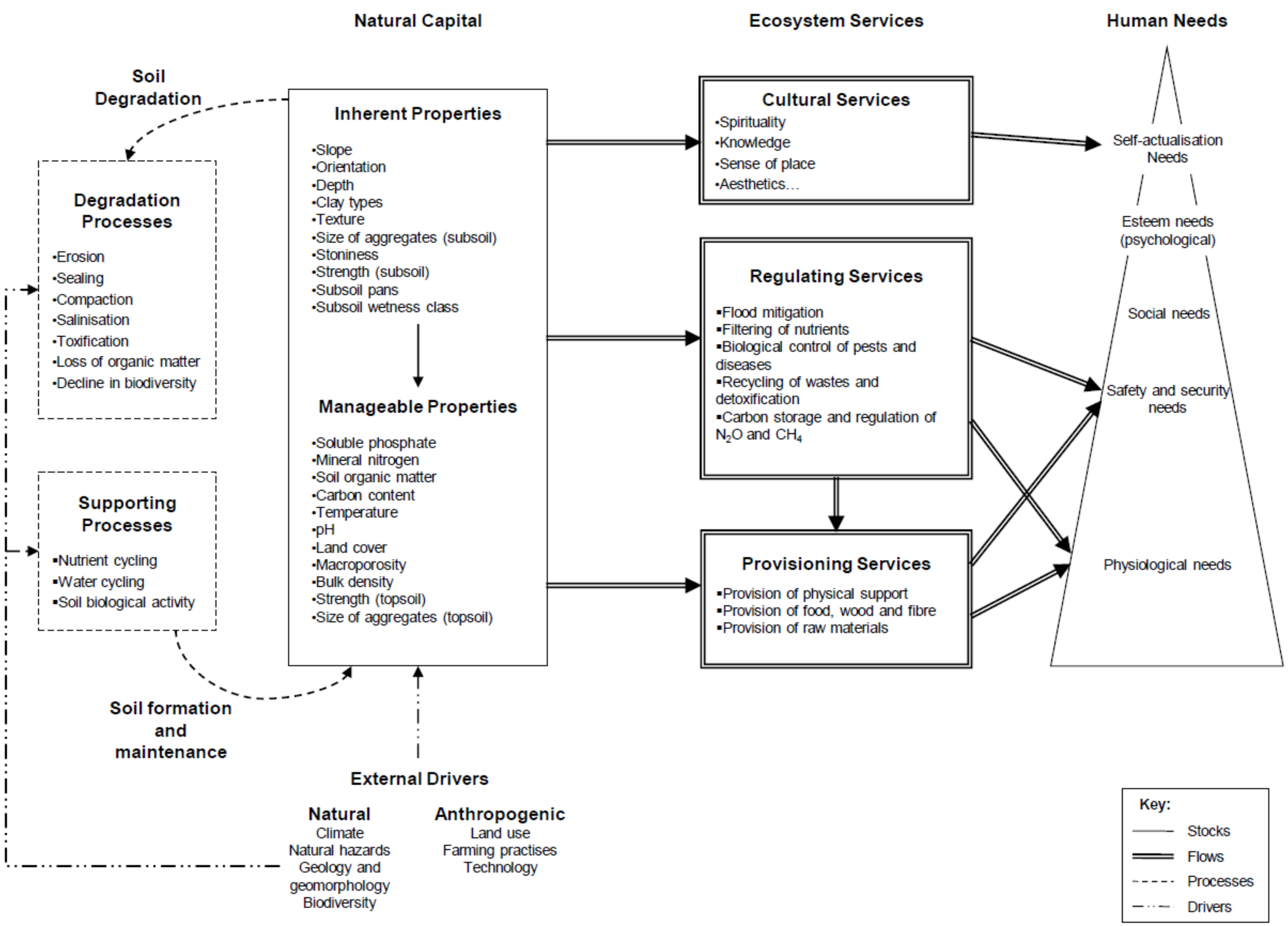

Figure 6. Conceptualisation of soil ecosystem services.
Source: Dominati 2011

5.2 Soil security

The soil security concept relates how seven soil functions (biomass production; storing, filtering, and transforming of nutrients; biodiversity pool; physical and cultural environment; sources of raw materials; acting as a carbon pool and archive of geological and cultural heritage) affect an array of global concerns such as food security, water security, climate change, and biodiversity.

The five interconnected dimensions of soil security are defined as capability, condition, capital, connectivity, and codification. Threats to each of these dimensions are listed in Table 3. Soil health is closely aligned with the condition (and capability) of a soil but is explicitly defined in comparison to a reference state. In New Zealand, codification (laws and governance) has arguably affected the development of soil quality (and natural capital) concepts through the Resource Management Act 1991. Connectivity (relationship to society) is also affecting our views on soils, particularly from a Māori perspective.

Table 3. Threats to the dimensions of soil security

Dimension	Threat to soil security
Capability	Erosion, landslides, sealing by infrastructure, source of raw materials
Condition	Contamination, loss of organic matter, compaction and other physical soil degradation, salinisation, floods
Capital	Inadequate assessment of the value of the soil asset, soil stock, and the processes that: support (e.g. nutrient and water cycling, biological activity), degrade (e.g. acidification, salinisation, loss of organic matter, compaction), and regulate (flood mitigation, erosion, control soil pests and diseases, and greenhouse gas abatement) Indiscriminate treatment of soil as a renewable resource
Connectivity	Inadequate soil knowledge of land managers Lack of recognition of soil services and soil goods by society
Codification	Incomplete policy framework Inadequate or poorly designed legislation

Source: McBratney et al. 2014

6 Soil, society, and well-being

The value society puts on soil (and what it is valued for) informs many of the policy decisions central and regional governments must make. Is soil (or land in general) worth more for housing than for agricultural production? Stronge et al. (submitted) use the Natures Futures Framework to explore the different ways soils are valued (Figure 7). This framework acknowledges that there are different sets of values we need to account for – instrumental, intrinsic, and relational (as defined in Figure 7) – and each of these values underlies the various benefits that we receive from soil.

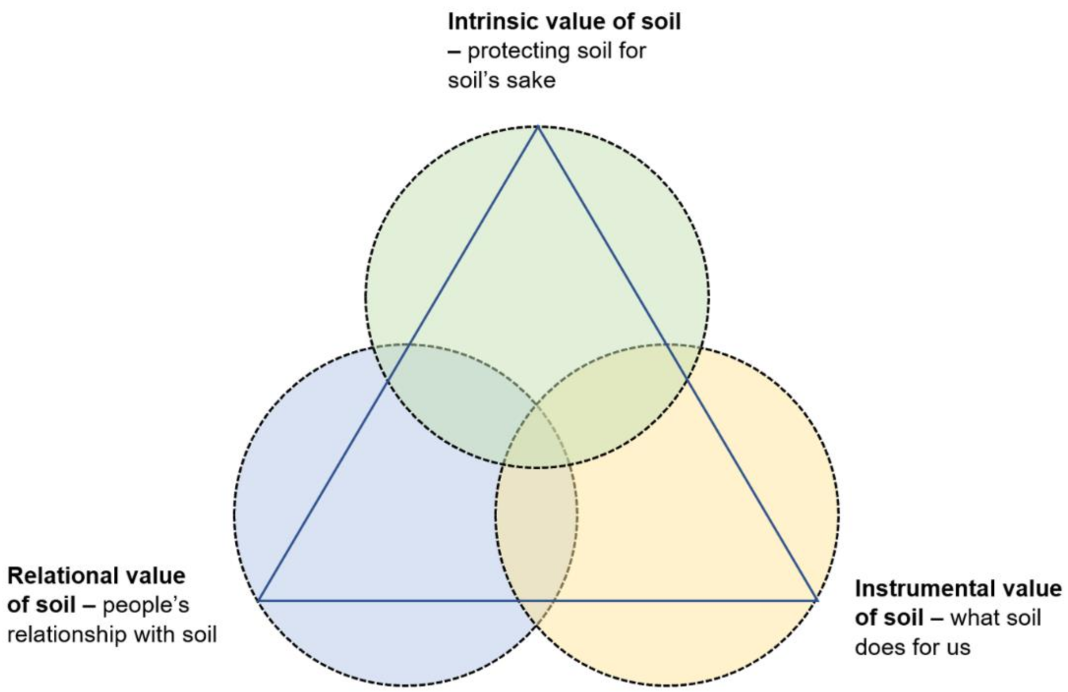

Figure 7. Application of the Natures Futures Framework to how we value soil. Source: Stronge et al. submitted.

The well-being framework put forth by Stronge et al. (Figure 8) incorporates the different values defined in the Natures Futures Framework with aspects of the Treasury's Living Standards Framework (inclusion of social, human, and natural capital as well as financial and physical capital). It also incorporates the Waka Taurua concept (the connection of overlapping goals with te ao Māori through a papanoho (bridge) (Maxwell et al. 2020) to explicitly acknowledge a Māori world view in addition to a Western science approach and broader societal view.

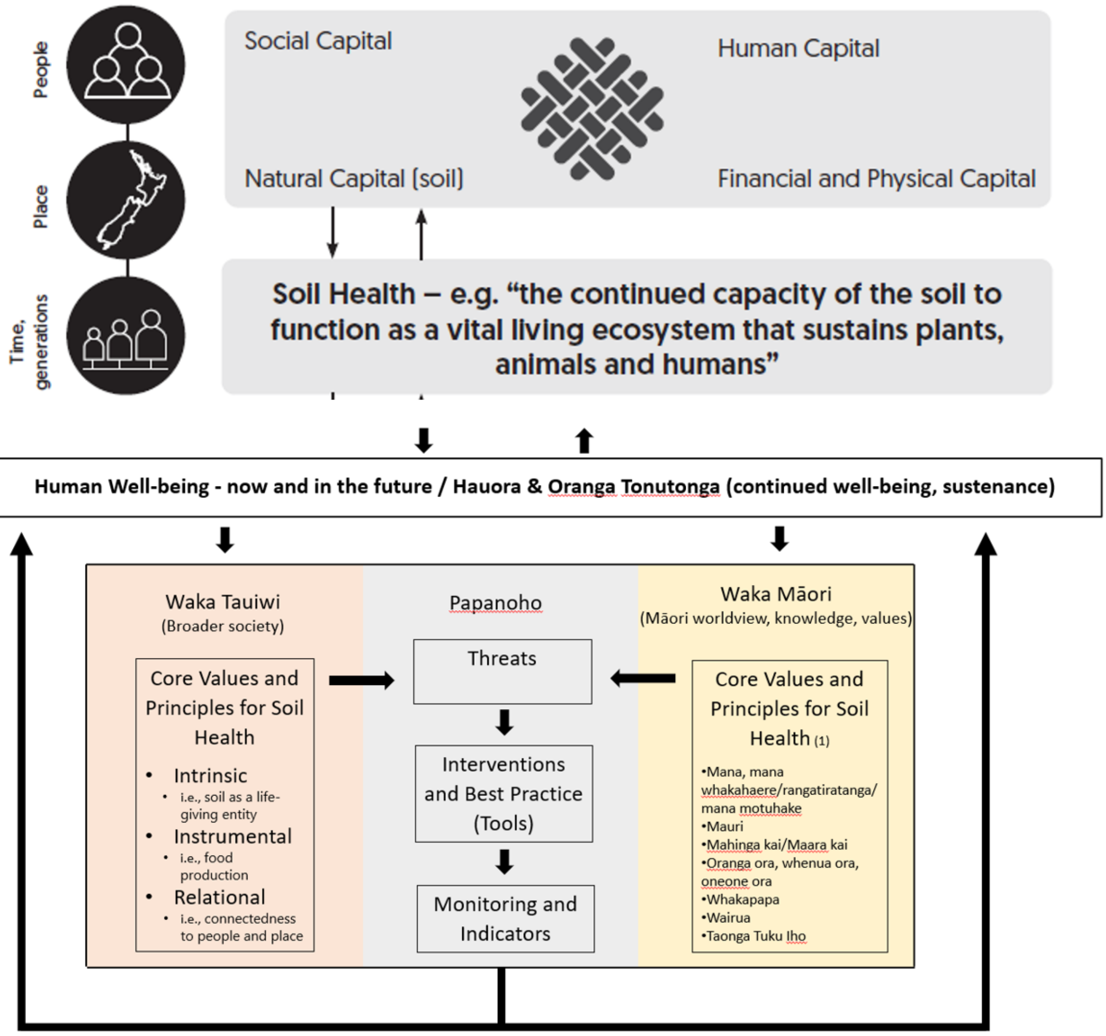

Figure 8. A well-being framework for soil health in New Zealand.
Source: Stronge et al. submitted

Progress has been made in this area, though specific indicators are still being worked out. Research summarising soil health from a Māori world view can be found at [Kaupapa Māori » Manaaki Whenua (landcareresearch.co.nz)](landcareresearch.co.nz).

7 Summary

The current set of indicators has been important for SOE reporting at both the regional and national level, and has helped inform significant land-use issues such as low macroporosity on dairy and intensive drystock land uses. While the current set of soil quality indicators are some of the most well-accepted soil measurements internationally, there are gaps.

Biological data are currently the largest gap in the current indicator list. Advances in genomics may help fill this gap for the microbial community, but although the effects of increased land-use intensification are starting to be quantified, determining what constitutes a healthy microbial community has still not been defined. Worms as an indicator of soil fauna are being suggested for farm-scale soil health monitoring in pasture. A suggested method for potentially mineralisable nitrogen has been published, but more work on soil physical vulnerability is needed.

Broader measures that relate to how soil functions in the environment and the services it provides are required for SOE reporting. Recognition of the different ways in which soil is valued – not just from an instrumental viewpoint (what soil does for us) but from intrinsic and relational points of view (the relationship of different parts of society to soil) – should be incorporated into these broader measures. Acknowledgement of different relational values of soil also readily accommodates a Māori world view on soil health. Concepts such as the soil ecosystem services model and soil security can help frame these broader measures. Alternative measures for different purposes (e.g. visual soil assessment for less formal soil health evaluation) should also be encouraged.

8 Acknowledgements

Wei Hu (Plant & Food Research) provided information on soil physical vulnerability, and discussions with Estelle Dominati (AgResearch) and Gavin Lear (Auckland University) helped to inform sections on ecosystem services and genomics respectively.

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