Taylor, M.D., Hill, R.B. 2018. The 20 Year Evolution of the Waikato Region Soil Quality Monitoring Programme In: *Farm environmental planning – Science, policy and practice*. (Eds L. D. Currie and C. L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.8 pages.

THE 20 YEAR EVOLUTION OF THE WAIKATO REGION SOIL QUALITY MONITORING PROGRAMME

MD Taylor[1] and RB Hill[1]

[1] *Waikato Regional Council, Private Bag 3038, Waikato Mail Centre, Hamilton*

Abstract

Soil quality monitoring in New Zealand started in 1995 with a national project to test methods and provide data about sustainable land use for state of the environment reporting. Results from the original project and subsequent regional soil quality monitoring programmes have provided a simple sampling strategy, basic indicators and interpretive framework that has enabled New Zealand to obtain and report on soil quality information where none existed prior to 1995.

The monitoring programme developed in the national research project had limitation; inadequate site representativeness due to the uneven regional participation, the intensity of sampling undertaken, and whether sampling was targeted towards certain land uses perceived to be at risk.

However, the programme succeeded in developing a pragmatic national soil quality monitoring programme capable of providing sufficient data to identify soil quality issues for “State of the Environment” reporting at a national scale. In 2003 a review of the national programme guided the establishment of the ongoing regional soil quality monitoring programmes in the Waikato and other regions. There are currently 13 regions with soil quality monitoring programmes, while the number of sites has increased from the original 511 sites (across nine regions) to over 1000 across the 13 regions.

The Waikato soil quality monitoring programme now has data (including data from the original national project) for 148 sites, across nine Soil Orders and six major landuses. The resampling of the same sites over a 20-year period (some up to four times) provides trend data and insights into the strengths and weaknesses of the established regional programme and the original national project.

Collectively, the regional monitoring programmes have contributed to regional and national state of the environment reporting for soil quality, established trends by measuring changes on the same sites, provided the opportunity to improve site representation and methods, and increased communication between regional authorities and scientists. This paper revisits the original design and objectives of the soil quality monitoring programme, assesses the reasons for the programme’s success, how it has responded to issues with consistent methodology, development of new measurements of soil properties, and addressed research gaps.

Introduction

Background

Over the last 60-70 years radical changes in agricultural practices and an unprecedented growth in human population globally have intensified the pressure on soil resources in the Waikato region and the world. Plant and animal improvement programs, increasing mechanisation, irrigation, broad-scale application of mineral fertilisers, and agrochemicals for weed and pathogen control, have all contributed to higher production per unit area for the full range of foods and fibres produced from soil. Competition for land resources has resulted in loss of high quality soils and potentially productive land to urban and infrastructure development. At the same time, expansion of agricultural and other human activities into the ‘natural’ environment has generated major concerns about ecological sustainability, the role of biodiversity, and the condition of rivers, lakes, groundwater, the coastal environment and oceans (MacEwan 2007).

The economy and people’s wellbeing of the Waikato region depend on our natural capital, including soils, and Waikato Regional Council (WRC) has legislative responsibility to manage the soil resource. An established soil quality monitoring programme provides information for State of the Environment (SOE) reporting, policy development, and helps in understanding the interactions between soil and water. The soil quality trend measurements enable assessment of the sustainability of current land use management practices and the effectiveness of WRC policy by providing evidence of change or stability.

Soils with high soil quality are considered healthy as they support important functions such as agricultural production, water filtration and storage, flood mitigation, nutrient and carbon storage, plant growth and biological diversity, and can act as a barrier to below surface contamination (MPI 2015). Soils with high soil quality are more resilient and durable to the pressures associated with man’s activities, and are quick to recover if damaged. Typically, a soil with high soil quality has low leakage of nutrients and contaminants, low rates of erosion, has high biodiversity, will capture and hold water, and can sustain high levels of production. Such soils are also resistant to disturbance from intense storms and land use change.

Soil quality monitoring has been carried out continuously in the Waikato region as part of national reporting for more than 20 years. This programme is aligned with national soil quality monitoring as established and administered through the Land Monitoring Forum (LMF), a Special Interest Group of regional council soil and land scientists. The quality of the regions soils are assessed by calculating the proportion of sites meeting seven soil quality targets and the direction of trends (Taylor et al. 2017).

Prior to 1995, there was no consistent programme to provide data on sustainable land use or soil quality for state of the environment reporting. Starting in the early 1990’s, Graham Sparling and others at Landcare Research developed pilot soil quality studies funded by the Sustainable Farming Fund in 1995 and 1996. This work lead to the national “500 soils” project (1998-2001), which carried out three years of trial on potential soil quality indicators. Once funding ceased, monitoring was continued and expanded by several regional councils coordinated by Reece Hill and the LMF. Under the LMF, new objectives and detailed documentation (LMF 2009) were produced, and the approach shifted to repeated inventory of an item benchmarked to a location and time.

An international perspective

Although many indicators and indices of soil quality and soil health have been proposed, a globally acceptable and applicable definition and methodology of assessment of soil quality or soil health are still not in place (Laishram et al. 2012). The concept of soil quality has been regularly criticised for bias towards one land management system or soil function, detaching soil properties from environmental aspects and interpretation of indicators and derived indices being unclear and failing to inform management action (Schröder et al. 2016). However, soil quality has become connected with the ecosystem services provided by soils, which has enhanced communication between scientists and stakeholders (Bünemann et al. 2018).

The choice of relevant soil attributes and interpretation of measurements are not straightforward, because of the complexity and site-specificity of soils, legacy effects of previous land use, and trade-offs between ecosystem services (Bünemann et al. 2018). Compared to air and water quality, soil performs multiple functions: (i) providing physical support to terrestrial plants, (ii) supplying fundamental resources, (iii) providing habitat to a variety of soil organisms, (iv) regulating hydrological and mineral/nutrient cycling, with significant impacts on global climate, (v) detoxification of organic and inorganic substances, leading to purification of water resource and (vi) resisting erosion. Regulation of each function is determined by a large number of soil attributes. A minimum number of indicators is needed as a single measurable soil attribute is unlikely to be correlated with soil function(s) and measurement of 'all' soil attributes is not practical (Laishram et al. 2012).

So, standardisation of methods is needed to empower decision-making processes. Also, soil quality indicators are useful only if we know their critical limits, i.e., the desirable range of values of a given indicator that must be maintained for normal functioning of the soil. Soil quality indicators are not "ends in their own rights" but need to be evaluated in the context of climate, geology and land management options (Schröder et al. 2016, Laishram et al. 2012).

This paper revisits the original design and objectives of the soil quality monitoring programme in the light of this international perspective, assesses the reasons for the programme's success, how it has responded to issues with consistent methodology, development of new measurements of soil properties, and addressed research gaps.

Comparison of the current and the original programmes

There are differences and similarities between the original "500 soils" and present soil quality monitoring. The importance of someone to champion and lead is clear in both cases. The "500 soils" was led by Graham Sparling at Landcare Research and sort to test the suitability of the stratified sampling technique, a range of soil parameters and provide a strong foundation for a national monitoring programme. In comparison, the present soil quality monitoring programme has built on the foundation of the "500 soils", and primarily seeks to provide information on the effects of land use and management. However, the current programme only came about because some regional councils funded the programme in their areas with the coordination of the LMF. The lack of central government ownership at this stage could easily have led to the cessation of this form of soil monitoring. The LMF has provided a forum for Regional councils to develop soil quality monitoring in ways that better suit their requirements; methodology was documented and new objectives produced (Tables 1 & 2, Hill & Sparling 2009).

A key feature of soil quality monitoring is it has standardised methods that ensure consistency and ease of uptake. Sampling sites are selected through a stratification process to ensure all major soil and land use types are included in sufficient numbers to allow for meaningful statistical analysis. The "500 soils" project resulted in the identification of seven key indicators; soil pH, total C, total N, Olsen P, anerobically mineralised N, bulk density and macroporosity (at -10kPa) (Hill et al. 2003). These are relatively simple and standard measurements in soil science. This simple approach allows for the interpretation of data against target values and trend reporting - essential components of soil quality monitoring.

Table 1. Comparing the objectives of the “500 soils” and present soil quality monitoring.

500 Soils	**Soil Quality Monitoring**
• Increase SQ understanding • Test suitability of indicators • Test impacts of land use on soil quality • Test representativeness of sampling sites	• Provide an early warning system on the effects of land use & management • Identify and track long-term soil issues • Track effectiveness of policy • Provide information for SoE reporting • Integrate with other regional monitoring (water, groundwater, sediment, air) • Dynamic so allowing for addition of new indicators
Nationally representative	Regionally representative
Strong foundation for national monitoring	

Soil quality monitoring also allows for new properties to be added as indicators during subsequent surveys. These are added as chapters to the Land and Soil Monitoring manual (LMF 2009). This approach has allowed a wider range of soil and land properties to be included in monitoring then originally envisaged in the “500 soils”. Within the WRC, aspects normally considered part of soil quality overseas are separated out as separate programmes, e.g. soil quality, diffuse contamination (including trace elements), contaminated land, peat soils, and soil stability. This division has allowed specialised focus on each of these issues rather than a one size meets all approach. The separation of the Land and Soil Monitoring manual (LMF 2009) into chapters is along these lines. Each chapter can be a programme of work added on to the basic set of seven key indicators and referred to for the specific methods, e.g. Hill & Sparling (2009) for soil quality monitoring (based on “500 soils”), Kim & Taylor (2009) for trace element monitoring.

Several physio-chemical, biodiversity and pollution measurements are currently under investigation as potential soil indicators by the LMF for target values associated with the soils ability to provide specific services.

Using stratified sampling for selecting sites has both advantages and disadvantages. It increases precision and reduces variance. It can be used to ensure inclusion of all sites of interest in numbers that can be considered statistically valid. Cavanagh et al. (2017) described this, “For valid statistical analysis, perfect representativeness across all soil order and/or land-use combinations is not necessarily required. A minimum number of sites are needed to provide sufficient statistical power to determine differences, for example, a relatively rare element (assuming that element is considered important enough to be sampled) may need to be over-represented in the data set. On the other hand, elements that make up a large area can be somewhat under-represented, as there will be enough samples to provide sufficient statistical power. Nonetheless, one implicit requirement for representativeness is that a data sample should be taken from the widest spatial coverage available, rather than close proximity sampling in one region”. So, investigations within each strata are statistically valid although there is now overrepresentation of these sites within the whole dataset.

Success
Soil quality monitoring meets conceptual and practical criteria, while indicator measurements are suitably sensitive and are interpretable. Bünemann et al. (2018) lists various requirements for soil quality indicators and these are compared with soil quality monitoring (Table 3). A major reason for the success of soil quality monitoring is its affordable financially, personally and temporally. This affordability along with the clear protocols for a simple sampling strategy and basic set of parameters (Hill & Sparling 2009) that can be expanded to include wider aspects of soil quality depending on the circumstances of a particular council, makes it a practical, yet scientifically valid option for regional councils to assess changes in the state of the soil environment and the effects of policy.

Table 2. Comparing characteristics of the “500 soils” and present soil quality monitoring

500 Soils and preliminary trials	**Soil Quality Monitoring**
Funded by MfE, MAF and councils - Funding ceased ~2001	Ongoing funding by individual Councils
Central Government (MfE, MRST)	Local Government but national reporting likely in the future (EMAR)
Research programme	State of the Environment reporting
Output focused – publications, milestones etc.	Procedure and assessment focused Targets & Trends – what’s good and what’s not
Agronomic production + expert knowledge based targets	Evidential change in soil properties, functions and services
Results interpreted against target values	Results interpreted against target values and the direction of trends
Scientifically robust + able to change quickly in response to developing knowledge	Standard sampling and analytical methods. Procedures documented
No subsequent surveys planned	New locations and new properties can be added during subsequent surveys
No archiving of soil samples	Soil sample archiving recommended
Samples analysed at	Samples analysed at multiple laboratories
One-off SOE on a 3 year timeframe (largely based on production targets due to the lack of ecological information)	Ongoing repeated monitoring (about 5 yearly). Environmental and production orientated targets
Multi-regional scale	Regional scale

Table 3. Comparison of for the seven key indicators in Soil Quality Monitoring with the list of criteria in Bünemann et al. (2018)

Criteria		Soil Quality Monitoring
Conceptual	Related to soil function and/or ecosystem processes; Relevant, representative of key variables controlling soil quality, correlated to long-term response, allowing evaluation of assessment criteria; Significant at the appropriate scale; Integrates soil physical, chemical, biological properties; Allows estimation of soil properties or functions which are more difficult to measure directly.	Targets increasingly related to soil function and/or ecosystem processes as knowledge of critical values and thresholds increases; Main soil issues identified, long-term, act as early warning system and allows assessment of policy effectiveness; Provide regionally relevant data; Properties reported separately, but developing issue based methods, e.g. compaction directly effects soil physical and biological properties and leads to increased transport of contaminants Provides estimation of changes in SOM and risk of nutrient loss but this is still developing
Practical	Easy to sample and measure (simplicity, practicality, provide information in short timeframe, high throughput of analysis, wide applicability, small amount of soil needed, reliability and reproducibility of measurement, standard operating procedures); Sample storage before analysis; Reference material for quality control available; Cost (sampling, hardware, analysis, labour).	Simple, reliable, reproducible, established, standard methods that require relatively little soil, analysis commonly done in most soil laboratories. Operating procedures documented in LMF manual; Protocols ensure samples are stored safely and transported quickly to the laboratory; Registered laboratories with established quality control including internal standard references; Low cost due to method selection.
Sensitive	To spatial variation, temporal variation (not influenced by short-term weather patterns), changes in management, or land use, responds to perturbation as well as corrective measures.	Established in early studies ("500 soils").
Interpretable	Comparable with routine sampling and monitoring programs (context data available, part of standard tests; baseline available); Easy to interpret, interpretation criteria available. Generic or diagnostic value. Does not become redundant; Able to be archived, capable of being assessed at a later date; Mappable trend indicators.	Relatively man unimpacted native sites provide true background. Initial "500 soils" provided baselines for different land uses and soil types; Interpretation of data against target values, background/baseline and trends; Excess air-dried sample archived; Sites spatially located so able to be mapped.

As a result, soil quality information has been produced where none existed prior to 1995, e.g. the Waikato soil quality monitoring programme now has data (including data from the original tional project) for 148 sites, across nine Soil Orders and six major landuses. The resampling of the same sites over a 20-year period (some up to four times) has provided bench marking and trend data. The main soil quality issues of compaction, excessive nutrients and loss of organic matter identified and strong evidence of land use impacts acknowledged. The long-term nature of the programme enable the detection of the components of temporal change, allowing it to act as an early warning of emerging issues and contamination and a validation tool for assessing the success of policy. The programme is close to being truly national. There are currently 13 regions with soil quality monitoring programmes, while the number of sites has increased from the original 511 sites (across nine regions) to over 1000 across the 13 regions. Collectively, the regional monitoring programmes have contributed to regional and national state of the environment reporting for soil quality, established trends by measuring changes on the same sites, provided the opportunity to improve site representation and methods, and increased communication between regional authorities and scientists.

Limitations and research gaps

Perhaps the greatest limitation in the past has been the lack of central government participation. Although lead by regions and coordinated by the LMF, there has been no national coordination. This has led to a confusion in focus between regional and national issues. Other resulting concerns include the lack of centralised storage of data and samples, and inconsistent methodology by laboratory service providers, e.g. Olsen P (Taylor et al. 2018). Also, the monitoring programme developed in “500 soils” had inadequate site representativeness due to the uneven regional participation, the intensity of sampling undertaken, and whether sampling was targeted towards certain land uses perceived to be at risk.

Soil quality monitoring remains regional or larger in scale. It is not representative of local conditions and certainly not of specific field conditions. Care is needed in intermitting data beyond its intended scale.

Further research is needed to refine some targets to enable them to relate more strongly to soil functions, e.g. nitrogen loss risk is poorly related to the total N indicator and its current targets.

The future

The Environmental Monitoring and Reporting (EMaR) Project will lead to a nationally consistent monitoring programme for SoE reporting at a national scale. It involves exploring the standardisation of methods and sharing of data collection, management and exchange protocols to allow national scale interpretation of regional data (MfE 2017). Soil quality monitoring will remain administrated by the regions and will remain relevant at a regional scale. The end goal of the EMaR Project is to have environmental data collected by regional councils more widely available through Land, Air, Water Aotearoa (LAWA).

Conclusions

A simple affordable approach with the clear protocols for a simple sampling strategy and basic set of parameters with the capability to be expanded depending on individual council circumstances makes soil quality monitoring a practical, yet scientifically valid option for regional councils to assess long-term changes in the state of the soil environment and the effects of policy. In addition, soil quality monitoring informs SoE reporting, and provides early warning of emerging issues and the effects of land use and management.

Champions are needed at the critical times, such as at emergence and transfer from research programme to SoE programme.

The Environmental Monitoring and Reporting (EMaR) Project will lead to nationally coordinated soil quality reporting

Acknowledgements
The past and present members of the Land Monitoring Forum have contributed to the development of the ongoing soil quality monitoring programmes across the regions, the review of the "500 soils" programme to develop regional Soil Quality Monitoring and ongoing improvements in soil indicators and methods. Thanks to the many farmers who have supported monitoring on their farms over the years. Manaaki Whenua Landcare Research are thanked for their continual soil quality research alongside LMF.

References

Bünemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P. and Pulleman, M. 2018. Soil quality–A critical review. Soil Biology and Biochemistry, 120, 105-125.

Cavanagh J.E., Munir K., McNeill S., Stevenson B. 2017. Review of soil quality and trace element State of the Environment monitoring programmes. Landcare Research Report for Envirolink Advice Grant 1757-HBRC226.

Hill, R.B., Sparling, G., Frampton, C., Cuff, J. 2003. National soil quality review and programme design. Technical Paper No. 75. Ministry for the Environment. Wellington.

Hill, R.B., Sparling, G.P. 2009. Soil quality monitoring. Land and soil monitoring: A guide for SoE and regional council reporting. Land Monitoring Forum. pp. 27-86.

Kim, N.D., Taylor, M.D. 2009 Trace element monitoring A guide for SoE and regional council reporting. Land Monitoring Forum. pp. 117-166.

Land Monitoring Forum. 2009. Land and soil monitoring: a guide for SoE and regional council reporting. Land Monitoring Forum. Available at http://www.mfe.govt.nz/publications/land/land-and-soil-monitoring-guide-soe-and-regional-council%C2%A0reporting Accessed 26/2/2018.

Laishram, J., Saxena, K.G., Maikhuri, R.K. and Rao, K.S., 2012. Soil quality and soil health: A review. International Journal of Ecology and Environmental Sciences, 38(1), pp.19-37.

MacEwan R.J.2007 Soil Health for Victoria's agriculture context, terminology and concepts. MIS 07898 Finial Report. Department of Primary Industries, Bendigo, Australia.

Ministry for the Environment. 2017. Improving environmental reporting data. Available at http://www.mfe.govt.nz/more/environmental-reporting/data-improvement/data-improvement-initiatives Accessed 26/2/2018.

Ministry of Primary Industries. 2015. Future Requirements for Soil Management in New Zealand. National Land Resource Centre, Palmerston North.

Schröder, J.J., Schulte, R.P.O., Creamer, R.E., Delgado, A., Leeuwen, J., Lehtinen, T., Rutgers, M., Spiegel, H., Staes, J., Tóth, G. and Wall, D.P., 2016. The elusive role of soil quality in nutrient cycling: a review. Soil Use and Management. 32, 476-486.

Taylor, M.D., Drewry, J.J., Stevenson, B., Cavanagh, J.E., Foster, N., Curran-Cournane, F. 2018. How closely do different Olsen P measures correlate? In: *Farm environmental planning – Science, policy and practice*. (Eds L. D. Currie and C. L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand

Taylor, M.D., Cox, N., Littler, R., Drewry, J. (2017) Trends in soil quality monitoring data in the Waikato region 1995-2015. Waikato Regional Council Technical Report 2017/26, Waikato Regional Council, Hamilton.