SOIL QUALITY MONITORING ACROSS LAND USES IN FOUR REGIONS: IMPLICATIONS FOR REDUCING NUTRIENT LOSSES AND FOR NATIONAL REPORTING

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Abstract

This paper reports on indicators of soil nutrients and soil compaction from soil quality monitoring undertaken as part of State of the Environment monitoring by regional councils in the Auckland, Waikato, Hawke's Bay and Wellington regions of New Zealand. Several regional councils have been monitoring soil quality since 2000. This paper presents soil quality data for land uses including drystock, dairy, market gardening (vegetable production), cropping (arable), horticulture (orchards, viticulture, nursery) exotic forest and native vegetation at sites sampled to 2014. To avoid any confounding effects of changes in land use, sites that had land use changes were excluded from the analysis.

Indicators of soil nutrients included anaerobic mineralisable N (AMN), total nitrogen, C:N ratio, Olsen P, organic carbon (OC) and for some regions extractable NO_3-N and NH_4-N. Soil physical indicators were bulk density and macroporosity (-10 kPa). Low OC and AMN for market gardens, low macroporosity for dairy, and Olsen P values exceeding upper targets for market gardens > dairy > horticulture > arable were the indicators of most concern by land use, i.e. outside or exceeding recommended target values. Sites with indicators well outside targets may represent an increased risk of soil erosion and soil nutrient loss from land to water via surface runoff, or reduced production.

Regional councils are contributing to the development of the land-based component of the Environmental Monitoring and Reporting (EMaR) project with the Ministry for the Environment and other agencies. The EMaR project relates to legislation called the *Environmental Reporting Bill* that was introduced to Parliament in 2014. In this paper we highlight some observations and recommendations of interpretation and methods between regional councils which should be considered for robust nationally-based analyses and reporting.

Keywords: Soil quality, Olsen P, nitrogen, bulk density, macroporosity, water quality.

Introduction

Regional councils regularly monitor soil quality in State of the Environment (SOE) monitoring. Monitoring the state of the environment is a specific requirement for regional councils under the Resource Management Act 1991. Specific requirements are to report on the "life supporting capacity of soil" and to determine whether current practices will meet the "foreseeable needs of future generations" (Gray 2010).

A series of research projects which became popularly known as the "500 Soils Project" developed and tested a set of soil chemical, physical and biological indices to detect changes in soil quality (Sparling et al. 2004). At the completion of the research phase many regional councils established their own soil quality monitoring programmes. Methods were established by Landcare Research and other experts and published in a manual (Land Monitoring Forum 2009). Soil quality indicators from regional council monitoring have been reported on at a regional basis either annually, less often (often five-yearly), or for an extended period (e.g. Stevenson 2008; Taylor et al. 2010; 2011; 2013; Gray 2010; Curran-Cournane et al. 2014; Lawrence-Smith et al. 2014).

Targets for soil quality indicators for SOE monitoring have been published in Land Monitoring Forum (2009) and subsequent revisions (Mackay et al. 2013). Many regional council soil quality SOE reports have compared results with these targets, or from other relevant publications. Several regional council soil quality SOE reports have reported soil quality indicator values within their region being outside recommended targets. High soil nutrient status, for example, may represent a greater source risk to waterways.

Since the 500 Soils Project, there have been few published comprehensive studies combining soil quality indicator datasets from regional councils. Some studies have combined soil quality indicators from regional councils' soil quality monitoring (e.g. MfE 2007; MfE 2010), as a 'snapshot', but these presented few details. Other studies have combined other datasets for certain trace elements such as cadmium which are more comprehensive (e.g. McDowell et al. 2013; Cavanagh 2014). Recently, regional councils are contributing to the development of the land-based component of the Environmental Monitoring and Reporting (EMaR) project with the Ministry for the Environment and other agencies. The EMaR project relates to legislation called the *Environmental Reporting Bill* that was introduced to Parliament in 2014. It should be noted that a recent study (Drewry et al. 2013) highlighted that there are some key method differences between laboratories and approaches in New Zealand for some aspects of soil quality indicators which should be considered when developing and interpreting soil quality data. The Land Monitoring Forum (a group of unitary and regional council soil and land scientists) has commenced discussion of these issues for the EMaR project.

This paper reports on soil quality indicators including soil nutrients from the monitoring undertaken by four regional councils in New Zealand, and provides interpretation and recommendations for improved reporting of soil quality data, and implications for management of nutrient losses. The paper also highlights some issues in methodology and interpretation between regional councils and laboratories which should be considered for nationally-based analyses and reporting including issues which may be valuable for national Environmental Monitoring and Reporting by central and regional government.

Overview of soil quality indicators

Soil chemical and biological indicators in this paper include anaerobic mineralisable N (AMN), total nitrogen (TN), organic carbon (OC), C/N ratio, KCl-extractable NO_3-N and NH_4-N, Olsen P and pH. AMN is a measure of how much organic nitrogen can become available to plants and is an indicator of microbial biomass. NO_3-N and NH_4-N are indicators of inorganic N in the soil. Olsen P is an indicator of plant-available P. Soil physical properties are bulk density and macroporosity (the percentage of large soil pores responsible for soil drainage). Macroporosity is a useful indicator of soil compaction.

Methods

Overview of soil quality monitoring programmes

This section presents a brief overview of the four regional SOE programmes and land uses sampled. Soils were classified according to the New Zealand Soil Classification (Hewitt 2010). Only the most recent sampling round per land use is included in this study. Methods related to the data analysis in this paper are presented in the statistical analysis section.

Auckland Council's soil quality monitoring programme includes over 160 sites from various land uses including horticulture, market gardening, pastoral (dairy, drystock and lifestyle blocks), urban, plantation forestry and native bush. Further information can be found in Curran-Cournane and Taylor (2013). For the purposes of this paper soil quality across horticulture, market gardening, dairy and native bush sites are reported.

Waikato Regional Council's soil quality monitoring programme consists of about 150 sites each sampled over a period of 5 years. Land use classes were dairy pasture, pasture not in dairy, cropping (annual cultivation), horticulture, forestry (production forests), and native forest (background). Further information can be found in Taylor (2013). Data from sites sampled generally over the last 5 years are presented.

Hawke's Bay's soil quality monitoring programme began in its current format in 2010. Currently there are 57 sites covering vineyards, extensive and intensive pasture, and cropping. Only the cropping, intensive pasture and extensive pasture sites have been considered in this paper. The number of sites will be increased to about 100 sites. These extra sites will cover orchards, native bush and commercial forestry. Sites will be revisited between every 3-5 years depending on land use. Further information can be found on:
(http://www.hbrc.govt.nz/Services/Environment/SOE/Pages/SOE-Annual-Reports.aspx).

Greater Wellington Regional Council's soil quality monitoring programme includes over 100 monitoring sites on soils under different land uses. The frequency of sampling is dependent on the intensity of the land use; dairying, cropping and market garden sites are sampled every 3-4 years, drystock, horticulture and exotic forestry sites are sampled every 5-7 years, while indigenous vegetation sites are sampled every 10 years. Further information can be found in Drewry (2013) and Sorenson (2012).

Measurements – soil chemical

Details of field methods are reported in the respective SOE reports and Land Monitoring Forum report (Hill and Sparling 2009). Briefly, at each site a 50 m transect was used to take soil cores. Soil cores 2.5 cm in diameter and 10 cm in depth were taken approximately every 2 m along the transect. The individual cores were bulked and mixed in preparation for chemical and biological analyses. Soil chemical measurements, including Olsen P for the Auckland, Waikato, and Wellington regions were analysed at the Landcare Research laboratory in Palmerston North. Note that Olsen P measurements undertaken by Landcare Research are on a gravimetric (weight) basis and therefore avoid the confounding influence of soil field bulk density. For the Wellington region samples, in the years 2012, 2013 and 2014 composite samples from the transect were split to send a second (additional) subsample to Hill Laboratories, Hamilton to measure Olsen P (volumetric preparation basis). Note this was in addition to the normal routine sample sent to Landcare Research laboratory as described above. Further details on soil chemical field methods are presented in Land

Monitoring Forum (2009). For the Hawke's Bay region soil chemical measurements, including Olsen P were analysed at Hill Laboratories in Hamilton.

In New Zealand, several large commercial laboratories measure soil by volume and fertiliser industry guidelines for Olsen P also use the volumetric method. Further information and interpretation of Olsen P measurement methods are discussed in Drewry et al. (2013). Potassium chloride extractable NO_3-N and NH_4-N were measured by the Landcare Research laboratory in Palmerston North for the Auckland, Waikato, and Wellington regions only.

Measurements – soil physical

Three undisturbed (intact) soil samples were obtained from each site (details in Land Monitoring Forum 2009). The intact soil cores were collected at 15, 30 and 45 m intervals along the transect by pressing steel liners (10 cm in diameter and 7.5 cm in depth) into the top 10 cm of soil. From these intact cores a 3 cm subsample ring was used in the Landcare Research soil physics laboratory in Hamilton to determine bulk density and macroporosity (percentage of pores > 30 microns, measured at -10 kPa). Samples from Hawke's Bay were analysed by the Landcare Research soil physics laboratory in Palmerston North. Note: refer to the statistical section regarding laboratory and terminology differences.

Targets

Soil quality indicators can be used to assess how land use and management practices influence soil for plant growth or for potential risks to the environment. Targets for indicators were developed and are now commonly used by regional councils (Hill and Sparling 2009). For this paper, the target range for indicators is the reporting 'by exception' as recommended by Hill and Sparling (2009). Olsen P targets have been revised with new target values now reported in Mackay et al. (2013) based on expert workshops. Olsen P targets, for example, in pasture, cropping, horticulture are 20-50 for volcanic soils and 20-40 for sedimentary and volcanic soils, and forestry 5-30 (units not stated; likely mg/L); further details for other classes are in Mackay et al. (2013). AMN targets are >20 for cropping, horticulture, forestry and >50 for pasture as updated by Mackay et al. (2013). Macroporosity targets were updated, now 10-30% for pasture, cropping, horticulture and 8-30% for forestry (Mackay et al. 2013).

Statistical analysis and classification notes per region

Statistical analysis

AMN, TN, OC, C/N, NO_3-N, NH_4-N, Olsen P, pH, bulk density and macroporosity were tested for normality and log transformed if necessary before being subjected to analysis of variance (ANOVA), fitting terms for land use and soil order. The factorial interaction of land use and soil order was not possible because of the uneven number of land use and soil order combinations. Where used, the mean standard error of difference (SED) and F-statistic are presented in tabular form. All analysis were carried out using the statistical package Genstat 17 (2014) and graphical package SigmaPlot 12.0 (2008). For boxplots, the boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within the 10th and 90th percentile. Outliers are illustrated with black circles. The median and mean are shown as a straight and dashed line, respectively, in each box.

Olsen P analyses

Given the methodology differences described above and in Drewry et al. (2013), we undertook several statistical analyses and present two analyses here. Analysis (A) *reported as gravimetric results*, had the laboratory gravimetric Olsen P data (mg/kg) from Auckland, Wellington and Waikato regions combined, with the ‘corrected’ Hawke’s Bay region data (volumetric lab value ‘corrected’ to equivalent gravimetric units by dividing by undisturbed field bulk density). Analysis (B) *reported as volumetric results*, had the Hawke’s Bay volumetric lab data (mg/L) as is, Wellington region volumetric lab data as is, plus the remaining gravimetric lab data for Wellington with Auckland and Waikato gravimetric data ‘corrected’ to volumetric equivalent units by multiplying by undisturbed field bulk density.

Soil order
Of the 15 soil orders in New Zealand, 11 representative soil orders were used as follows: Allophanic (n=56), Brown (n=55), Gley (n=38), Granular (n=30), Melanic (n=4), Organic (n=12), Pallic (n=39), Podzol (n=4), Pumice (n=32), Recent (n=40) and Ultic (n=12).

Land use classification
Some land use classification varied a little between regional councils in their datasets. Some land uses were re-categorised to develop more detail, or to group similar land uses, for the statistical analysis (Table 1). There were 50 sites that had a change of land use since the monitoring period began (e.g. conversion to lifestyle blocks) so these were excluded from the analysis to maintain consistent land use. Several urban sites were also excluded. The number of sites per region was Auckland 44, Waikato 131, Hawke’s Bay 53, and Wellington 94.

Table 1: Land use classification used in this analysis.

Land use	Number of sites, n	Notes
Arable	40	Includes cropping
Dairy	76	
Drystock	88	Includes bull beef
Forestry	26	Exotic forestry
Horticulture	36	Includes, kiwifruit, orchards, vineyards, nurseries
Market gardens	16	Includes intensive vegetables
Native bush	40	

Auckland Council – land use
In 2014, dairy (n=12; excludes 13 converted sites) and native bush sites (n=13; excludes two urban forest sites) were the focus of soil quality monitoring and, in 2013 (excludes several land use converted sites), horticulture (n=12) and market garden (n=7) sites were sampled.

Hawke’s Bay Regional Council - macroporosity
It was observed that the macroporosity data that had been reported previously for Hawke’s Bay region had been determined at -5 kPa. For this study and for consistency with Land Monitoring Forum guidelines and other publications, macroporosity at -10 kPa was re-calculated from the original laboratory porosity and volumetric water content data at -10 kPa.

Results

Overview
The mean values and analysis for the soil quality indicators for each land use are presented in Table 2. The effect of land use was significant ($P<0.001$) for all the soil quality indicators presented. The mean values and analysis for the soil quality indicators for each soil order are presented in Table 3. The percentage of sites outside the target range described earlier (i.e. below lower target or above upper target) per land use for selected soil quality indicators is

presented in Table 4. Further details for selected indicators are presented below. Several land use mean values were outside recommended targets.

Anaerobic mineralisable N (AMN) and total nitrogen (TN)

AMN and TN for each land use and soil order are presented in Figure 1.

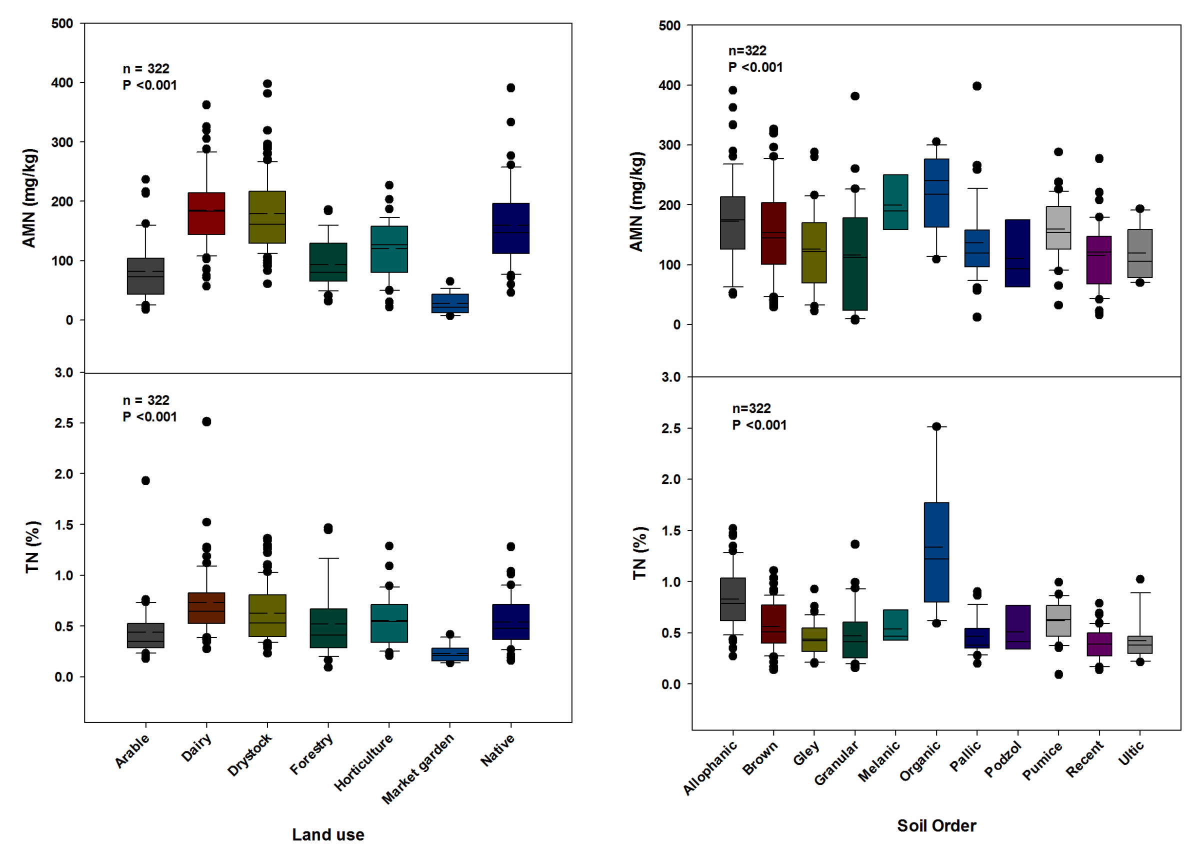

Figure 1: Anaerobic mineralisable N (AMN) and total nitrogen (TN) grouped by (A) land use and (B) soil order, for the Auckland, Waikato, Hawke's Bay and Wellington regions.

Mean AMN and mean TN were greatest in the dairy and drystock land uses with lowest values under market gardening (Figure 1 and Table 2). AMN and TN for each soil order are also presented in Figure 1. Mean AMN and mean TN values were greatest in the organic soil order. However, the average bulk density of Organic soils was 0.58 Mg/m^3 and therefore it is sometimes more appropriate to consider the volumetric values for soil parameters; otherwise presenting data on a gravimetric basis can potentially overestimate (or underestimate) the true levels of certain soil parameters. The Granular, Podzol, Recent and Ultic soil orders had the lowest ANM mean values (Figure 1). The Recent and Ultic soil orders had the lowest TN mean values. The percentage of sites that did not meet AMN target values was greatest in the market garden sites (44%; Table 4). Of the land uses assessed against targets, dairy had the greatest percentage of sites (41%) that did not meet targets for TN (Table 4).

Organic carbon (OC)

Organic carbon for each land use is presented in Figure 2 and Table 2. Mean OC was greatest in the native, dairy, forestry and drystock land uses with lowest values under market gardening. The percentage of sites that did not meet OC target values was greatest in the market garden sites (75%; Table 4). Dairy sites met OC targets; 5% of arable sites did not meet targets.

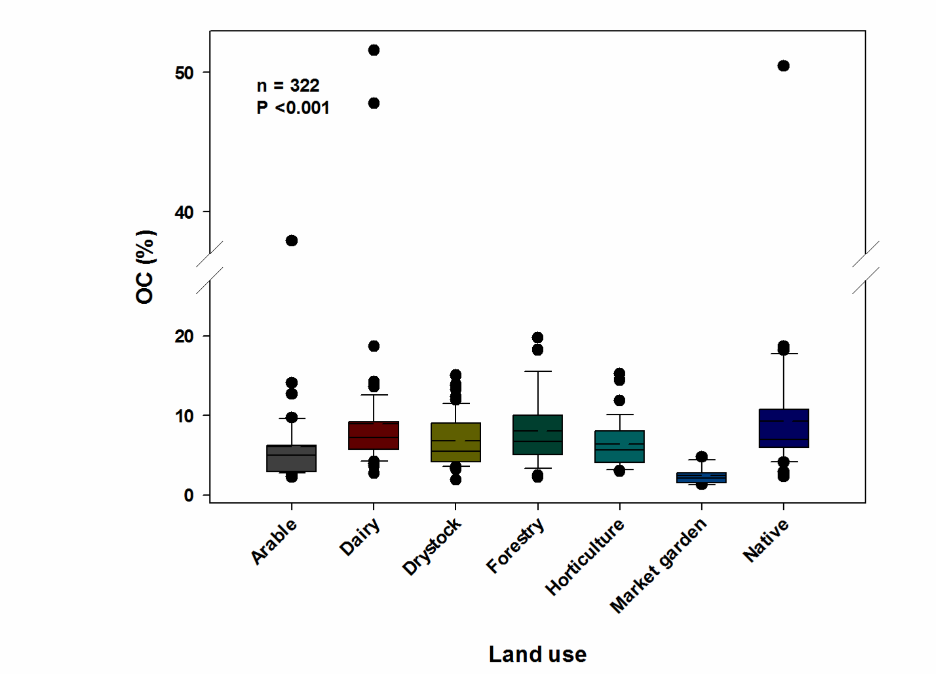

Figure 2: Organic carbon (OC) grouped by land use for the Auckland, Waikato, Hawke's Bay and Wellington regions.

Olsen P

Analysis (A) gravimetric results (mg/kg)

Olsen P values reported in gravimetric units for each land use are presented in Figure 3 (A) and Table 2. Mean Olsen P values were greatest in the market gardening and dairy land uses with lowest values under native vegetation (Table 2). Other land uses also had some values well in excess of recommended target values. The percentage of sites that did not meet Olsen P target values (gravimetric) was greatest in the market garden sites (100%; Table 4).

Analysis (B) volumetric results (mg/L)

Olsen P values and means reported in volumetric units for each land use are presented in Figure 3 (B) and Table 2. For analysis (B), mean Olsen P values were greatest in the market gardens followed by horticulture, arable and dairy land uses. The percentage of sites that did not meet Olsen P target values (volumetric) was greatest in the market garden sites (94%), followed by horticulture (75%) and dairy (72%; Table 4). The percentage of sites that exceeded Olsen P upper target values (volumetric) was greatest in market gardens (94%), followed by dairy (63%), horticulture (61%), arable (55%), drystock and forestry (both 23%). Additionally, volumetric values of Olsen P were also compared with industry-based targets, e.g., as in Roberts and Morton (2009) for dairy. There were 67% of dairy sites that exceeded upper industry targets (e.g. 40 mg/L for ash and sedimentary soils).

Table 2: Mean value of land use for soil quality indicators for the Auckland, Waikato, Hawke's Bay and Wellington regions. Standard errors of the difference (SED) are given for comparisons between land uses.

Indicator	Unit	Land use							SED	F-Stat, *P*
		Arable	Dairy	Drystock	Forestry	Horticulture	Market garden	Native		
AMN	(mg/kg)	82	185	179	93	120	28	159	8.9	<0.001
Bulk density	(Mg/m^3)	1.05	0.86	0.99	0.81	0.98	1.21	0.82	0.034	<0.001
C/N		10.4	11.6	10.9	16.9	13.2	18.4	16.3	0.6	<0.001
Macroporosity	(% v/v)	15	9	12	24	11	18	20	1.1	<0.001
pH		6.27	5.98	5.84	5.28	6.41	6.47	5.65	0.072	<0.001
TN	(%)	0.44	0.73	0.62	0.52	0.56	0.23	0.54	0.046	<0.001
OC	(%)	6.0	8.9	6.8	8.1	6.4	2.4	9.3	0.84	<0.001
Olsen P[1]	(mg/kg)	63	77	37	27	70	169	19	7	<0.001
Olsen P[2]	(mg/L)	59	57	33	24	68	159	15	6	<0.001
NH_4-N[3]	(mg/kg)	2.0	5.1	3.7	10.3	2.4	0.8	6.0	1.36	<0.001
NO_3-N[3]	(mg/kg)	51	66	54	23	35	16	19	7.04	<0.001

[1] mg/kg. [2] mg/L, See methods for explanation. [3] Excludes HBRC. Macroporosity is at -10 kPa.

Table 3: Mean value of soil order for soil quality indicators for the Auckland, Waikato, Hawke's Bay and Wellington regions. Standard errors of the difference (SED) are given for comparisons between soil orders.

Indicator	Unit	Soil order											SED	F-stat, *P*
		Allophanic	Brown	Gley	Granular	Melanic	Organic	Pallic	Podzol	Pumice	Recent	Ultic		
AMN	(mg/kg)	172	154	126	116	199	217	136	110	159	115	119	13.5	<0.001
Bulk density	(Mg/m^3)	0.76	0.96	1.07	0.95	1.12	0.58	1.15	0.60	0.71	1.14	0.96	0.033	<0.001
C/N		11.6	12.6	11.9	16.6	10.9	15.7	10.8	21.1	13.5	11.3	16.7	0.81	<0.001
Macroporosity	(% v/v)	13	15	9	15	12	15	13	28	20	13	10	1.55	<0.001
pH		6.07	5.87	6.05	6.01	6.06	6.22	5.94	5.12	5.71	6.00	5.78	0.105	0.008
TN	(%)	0.83	0.56	0.44	0.47	0.54	1.34	0.47	0.51	0.62	0.39	0.42	0.048	<0.001
OC	(%)	9.5	6.9	5.0	5.9	5.7	26.0	5.3	10.6	8.0	4.6	5.7	0.78	<0.001
Olsen P[1]	(mg/kg)	55	51	59	92	35	63	40	21	73	58	20	10.5	0.004
Olsen P[2]	(mg/L)	43	42	54	97	36	43	38	15	52	52	18	9.3	<0.001
NH_4-N[3]	(mg/kg)	5.2	4.9	3.8	2.8	1.0	6.7	5.7	10.3	6.2	2.7	2.9	0.16	ns[4]
NO_3-N[3]	(mg/kg)	66	36	27	36	21	76	40	16	70	34	16	8.08	<0.001

[1] mg/kg. [2] mg/L, See methods for explanation. [3] Excludes HBRC, [4] ns denotes not significant. Macroporosity is at -10 kPa.

Table 4: Percentage of sites outside target range (i.e. below lower target or above upper target) per land use for selected soil quality indicators for the Auckland, Waikato, Hawke's Bay and Wellington regions.

Indicator	Unit	Land use					
		Arable	Dairy	Drystock	Forestry	Horticulture	Market garden
AMN	(mg/kg)	5	0	0	0	0	44
Bulk density	(Mg/m^3)	3	14	6	19	3	19
Macroporosity	(% v/v)	30	49	44	35	44	19
pH		5	4	6	0	0	0
TN	(%)	excl	41	36	19	excl	excl
OC	(%)	5	0	1	8	0	75
Olsen P[1]	(mg/kg)	63	80	67	42	81	100
Olsen P[2]	(mg/L)	60	72	64	50	75	94

[1] mg/kg. [2] mg/L, See methods for explanation. Macroporosity is at -10 kPa. Excl, targets are dependent on crop type or are not well defined.

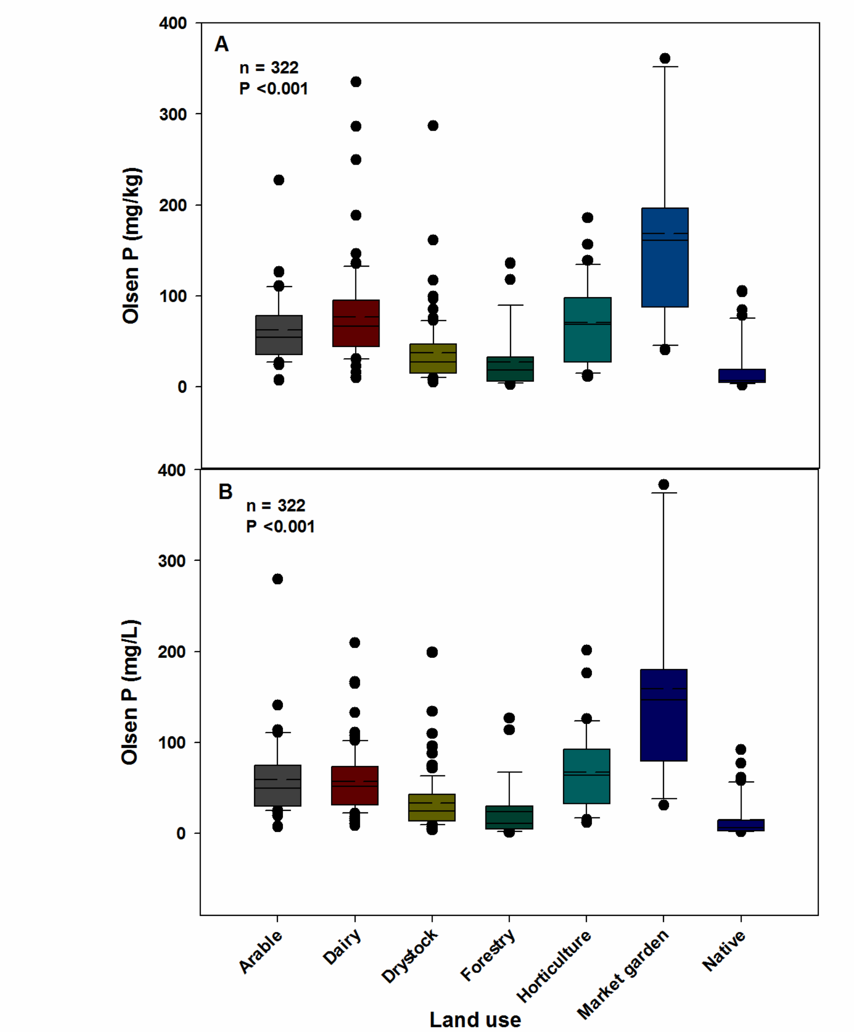

Figure 3: Olsen P grouped by land use for (A) analysis A, (gravimetric units) for the Auckland, Waikato, and Wellington regions but with Hawke's Bay data 'corrected'; and (B) analysis B, (volumetric units). See methods statistical section for explanation.

Bulk density and macroporosity

Bulk density for each land use is presented in Table 2 and by soil order in Table 3. Mean bulk density was greatest in the market garden and arable land uses with lowest values for native and forestry. Macroporosity for each land use is presented in Figure 4 and Table 2. Mean macroporosity was greatest forestry, native and market garden land uses with lowest values for dairy land use. The percentage of sites that did not meet bulk density target values was greatest in the forestry and market garden sites (19% each), followed dairy (14%; Table 4). The percentage of sites that did not meet macroporosity target values was greatest in the dairy (49%), drystock (44%) and horticulture (44%) sites (Table 4).

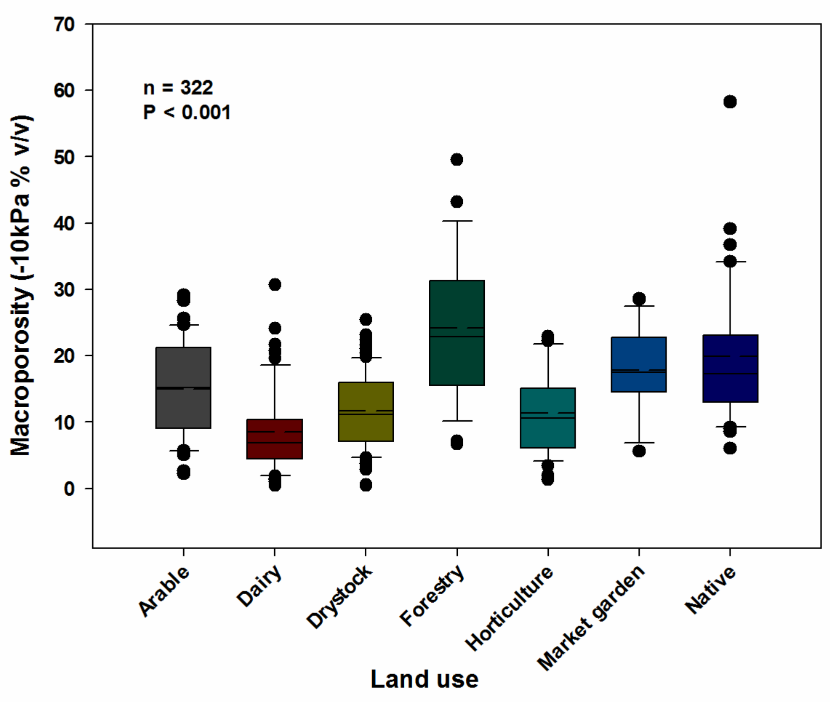

Figure 4: Macroporosity (-10 kPa % v/v) grouped by land use for the Auckland, Waikato, Hawke's Bay and Wellington regions. (Hawke's Bay data re-calculated, see methods).

Discussion

Market gardening sites tended to have high nutrient concentrations with correspondingly very low OC levels (Table 2 and Figures 2 and 3). Low OC contents for the market gardening sites as a result of continuous cultivation practice, is a cause for concern because a lack of carbon in the soil renders the soil vulnerable to nutrient leaching and runoff losses (Cathcart, 1996; Haynes and Tregurtha, 1999; Hollinger et al. 2001). Average nitrate leaching, for example, from dairy paddocks was about an eighth of that leached from potato paddocks in Pukekohe reported by Francis et al. (2003). Average nitrate leaching losses from leafy green crops were intermittent of the two. Similar findings were observed by Crush et al. (1997) in Pukekohe. Although potato crops receive the larger amounts of N fertiliser, the higher N leaching losses under this crop was largely attributed to the lack of soil OC in these intensive systems.

Low OC levels in soil also decrease the microbial activity in the soil which is supported by the low AMN values (Table 2, Figure 1). Soil organic matter can be an important source of food for microbial activity. Soils recently converted from forest to pasture, which resulted in a large loss of OC and low AMN, have regained much of the lost OC since 2009 with a corresponding increase in AMN (Taylor 2015, Hedley et al. 2009). Cover crops will act as a protective cover against rainfall as well as subsequent sediment and pollutant runoff when land is fallow. This will also facilitate an increase in microbiological activity and subsequently enhance the OC content of the soil ecosystem (Haynes and Tregurtha, 1999).

Some laboratories and researchers measure and report some indicators, e.g. Olsen P, on a volumetric basis or gravimetric basis. Olsen P when quoted on a gravimetric basis negates the influence of bulk density (McDowell and Condron 2004). The pastoral yield nutrient response curves and fertility targets (e.g. Sinclair et al. 1997; Roberts and Morton 2009) were developed from the volumetric method (Drewry et al. 2013). Vegetable production targets reported by Clarke et al. (1986) used the volumetric method and vary depending on soil P retention properties or crop type. For average values of P retention, Clarke et al. (1986) recommended an Olsen P value of 46-55 mg/L for brassicas and 36-75 mg/L for spinach and silverbeet. Prasad et al. (1988) reports in gravimetric units, for example, target values of Olsen P for cabbage of 40-49 mg/kg with upper limit of 76-82 mg/kg. Targets in Mackay et al. (2013) also account for environmental effects based on recent environmental research. Some caution should be applied if comparing with some guidelines or methods, and an awareness of methods, units and implications is needed. Our study has shown that Olsen P values are very high at some sites regardless of method.

New Zealand and international research has shown that an increase in soil nutrient indicator values is associated with an increase in nutrients in drainage water or surface runoff (e.g. McDowell and Condron 2004; Curran-Cournane et al. 2011). Our study shows that some sites are heavily compacted as indicated by low macroporosity. Soil compaction may result in reduced soil air permeability, water infiltration and increased runoff to waterways (Drewry et al. 2004; 2008). Runoff can carry contaminants and may result in increased peak-flows causing localised flooding and bank erosion (McDowell et al. 2001; Taylor et al. 2009). Conversely, an increase in macroporosity can be associated with a reduction in contaminant loads to water (e.g. nutrients and sediment) via surface runoff (e.g. Curran-Cournane et al. 2011). Therefore, if compacted sites also happen to coincide with nutrient concentrations exceeding target values (such as in some land uses in this study), such sites could be at greater risk to contaminate surface run-off. Potentially there could be reductions in contaminant loads to waterways and improvements in pasture production at some land uses and sites by improving soil physical condition where it is compacted. Optimum macroporosity values for maximum pasture and crop yield range from about 6% to 17% v/v (Drewry et al. 2008), so potential yield gains could be made on sites with very low values.

Evaluation of datasets from the four regions in this paper was an opportunity for evaluating lessons from the different datasets and methods, for potential development of the land-based component of the national EMaR project. From our observations and analyses, we observed differences between councils and laboratories for some soil chemical and physical terminology or methods. Clear distinction between volumetric and gravimetric measurement and reporting needs to be made. Ambiguity in reporting can arise in some literature. Care may also be needed with other soil measurements, e.g. AMN. Variations in soil preparation, such as sieving and root removal methods for AMN measurement between New Zealand laboratories were reported in Drewry et al. (2013). However, the effect on AMN has not yet been fully reported. Clear distinction needs to be made for matric potential of macroporosity. Ambiguity may arise with other terms (e.g. air-filled porosity) or macroporosity measured at other matric potentials. Awareness and distinction is needed during interpretation for intact undisturbed field bulk density measurements versus the very different sieved soil volume weights which may be reported by a laboratory. Lastly, land use changes over time (e.g. Curran-Cournane et al. 2013), and land use classification can be interpreted differently by researchers, so clear statements are needed to minimise ambiguity.

Conclusions

From our investigations of four regional soil quality datasets, we conclude:

- That low OC and AMN for market gardens, low macroporosity for dairy, and Olsen P values exceeding upper targets for market gardens > dairy > horticulture > arable were the indicators of most concern by land use;
- Some interpretation inconsistencies and method differences need to be carefully considered for robust cross-region and nationally-based analyses;
- Raising awareness of soil quality interpretation and implications is a key issue; and
- Some land uses, particularly market gardening and dairy, may pose greater risk of nutrient transfer to waterways than other land uses.

In relation to soil quality from this study we recommend:

- That further attention is prioritised for raising awareness of soil quality, its interpretation and potential implications for resource management decisions; and
- That resource and land managers consider appropriate management to reduce environmental risks land uses and sites that pose greatest risk.

In relation to lessons from this study for potential national soil quality reporting we recommend:

- Method differences and inconsistencies between regional councils, other agencies and laboratories need to be considered for robust nationally-based analyses;
- Interpretation of land use change and classification needs to be considered;
- That raising awareness of these issues to minimise ambiguity is encouraged; and
- That the differences in methodology are taken into consideration for resource management decisions, when developing policies such as for managing to limits for freshwater management, and when interpreting soil quality data and monitoring programmes.

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