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CHANGES IN SOIL QUALITY UNDER DIFFERENT LAND USES IN THE MANUKAU HARBOUR CATCHMENT AREA, 1995-2017

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Abstract

The Manukau Harbour catchment area of the Auckland region includes many of New Zealand's highly versatile soils recognised for their contribution to the region's food production and the provision of other ecosystem services. Auckland Council has monitored soil quality for the whole of the region for more than 20 years as part of its periodic State of the Environment reporting. This report summarises the monitoring of soil quality and trace element status of the Manukau Harbour catchment area from 1995 to 2017. Thirty-two soil quality sites covering various land uses [horticulture (12), pasture (9), urban (5), and native vegetation (6)] were monitored periodically for standard topsoil (0-10 cm) quality indicators used by regional councils in New Zealand. Monitoring showed that some soil quality indicators fell outside the recommended guideline ranges. Olsen P concentration, an indicator of plant-available phosphorus, was high on horticulture sites. This shows that more phosphorus fertiliser is being applied than is being taken by crops. Total nitrogen and anaerobically mineralisable nitrogen were low on outdoor vegetable production sites. Soil macroporosity was low on pasture sites indicating soil compaction that favours surface runoff of nutrients and suspended sediments to enter waterways. Different land use activities add trace elements to the soil that tend to accumulate over time. Mean concentrations of trace elements at monitored sites are mostly within guideline ranges but differed with land use. Pasture and horticulture sites had the highest mean concentrations of cadmium and arsenic. On the other hand, urban and horticulture sites had the highest mean concentrations of copper. Urban sites had the highest concentrations of chromium, nickel and zinc. Significant reductions in pH, organic C, AMN, and macroporosity, and an increase in bulk density were observed during 22 years of monitoring. Elevated Olsen P levels, low total N and AMN, and low macroporosity are common soil quality issues affecting both Manukau Harbour catchment and the whole of the Auckland region.

Background

The Manukau Harbour catchment area of the Auckland region includes many of New Zealand's highly versatile soils recognised for their contribution to the region's food production (Orbell, 1977) and the provision of other ecosystem services (Curran-Cournane et al. 2014). In particular, the Franklin district is undergoing rapid land use change owing to population growth and the conversion of farmlands with elite and prime soils (LUC classes 1 to 3) into residential and rural lifestyle blocks as documented in various studies by Curran-Cournane et al. (2014; 2018; 2021), Deloitte (2018), Silva (2018) and Richardson (2021). Auckland Council has monitored soil quality for the whole of the region for more than 20 years as part of its periodic State of the Environment (SoE) reporting (Curran-Cournane, 2020). A synthesis report of the SoE for the Manukau Harbour catchment that includes land cover, ecology, air quality, etc. was produced by Auckland Council for the first time in 2021 (Auckland Council, 2021). Soil quality

status was included but no details were provided due to summative nature of the report. This report is about the monitoring of soil quality and trace element status of the Manukau Harbour catchment area from 1995 to 2017 representing a subset of the region-wide soil monitoring (Curran-Cournane, 2020). The specific objectives include: (1) to identify any soil quality issues arising from the latest monitoring data (2013-2017); (2) analyse data trends during the periods 1995-2000, 2008-2012, and 2013-2017 for all land uses; and (3) compare soil quality issues in the Manukau Harbour catchment with the whole of Auckland region data set.

Methods

Thirty-two soil quality sites covering various land uses [horticulture (12), pasture (9), urban (5), and native vegetation (6)] were monitored periodically for standard topsoil (0-10 cm) quality indicators used by regional councils in New Zealand (Figure 1). At each site, seven soil quality indicators namely: pH, organic C, total N, anaerobically mineralizable N (AMN), Olsen P; bulk density and macroporosity were collected (Figure 2) using standard sampling procedures and analytical methods (Land Monitoring Forum, 2009). In addition, seven trace elements, namely total recoverable arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) were collected. The analysis focused on the most recent soil quality data collected (2013-2017). Mean values were compared with environmental guideline values (EGVs) and expressed as the number and percentage of sites outside the EGVs for both soil quality indicators and trace elements. To further compare the two rural land uses pasture and horticulture, they were further broken down into dairy (6 sites) and drystock (3 sites) and outdoor vegetable (9 sites) and orchard sites (3 sites), respectively. For temporal trend analysis, all data collected were grouped into three time periods: 1995-2000; 2008-2012; and 2013-2017. A comparison between Manukau Harbour and Auckland-wide soil qualities under rural land uses was also made noting that the former is a subset of the region-wide soil quality monitoring (Curran-Cournane, 2020).

The data were subjected to analysis of variance (ANOVA) using Genstat 21st edition. Due to variance heterogeneity, they were log-transformed prior to analysis (except for pH). The *P* values for log-transformed data were presented but the untransformed means were the ones presented.

Results and Discussion

Soil quality indicators and trace elements (all land uses), 2013-2017

Table 1 shows the summary of the most recent soil quality indicators and trace elements by land use in the Manukau Harbour catchment. Horticultural soils have elevated levels of Olsen P (over 3 times the upper guideline value of 50 mg/kg). This has been attributed to the heavy application of phosphate fertiliser several times a year particularly on long-term vegetable growing sites (Hicks, 2006). Excessive phosphate in soils could lead to elevated P levels in sediment carried by runoff water which leads to eutrophication of surface water bodies. On pasture and urban soils, compaction is the main issue with their macroporosity values falling below the 10% guideline value. A compacted soil increases surface runoff of nutrients and suspended sediments that can enter waterways. In the case of urban soils, many of the sites are on parklands that are subject to heavy foot traffic thus compaction has become apparent.

The mean concentrations of trace elements are within their guideline values but differed with land use with pasture and horticulture sites having high mean concentrations of Cd and As. Long-term heavy applications of phosphate fertiliser not only increases soil Olsen P levels but

also increases soil Cd levels since Cd is an unavoidable contaminant in phosphate fertilisers. Fortunately, phosphate fertilisers sold in New Zealand now have low levels of Cd as a contaminant (Abraham et al., 2016) but the issue of continuous heavy application of phosphate fertiliser on vegetable farms remains as its effect is cumulative. Urban and horticulture sites had the highest mean concentrations of copper. Copper is widely used in the horticulture sites as a fungicide particularly on orchard sites. Urban sites had the highest concentrations of chromium, nickel and zinc reflecting their proximity to industrial areas.

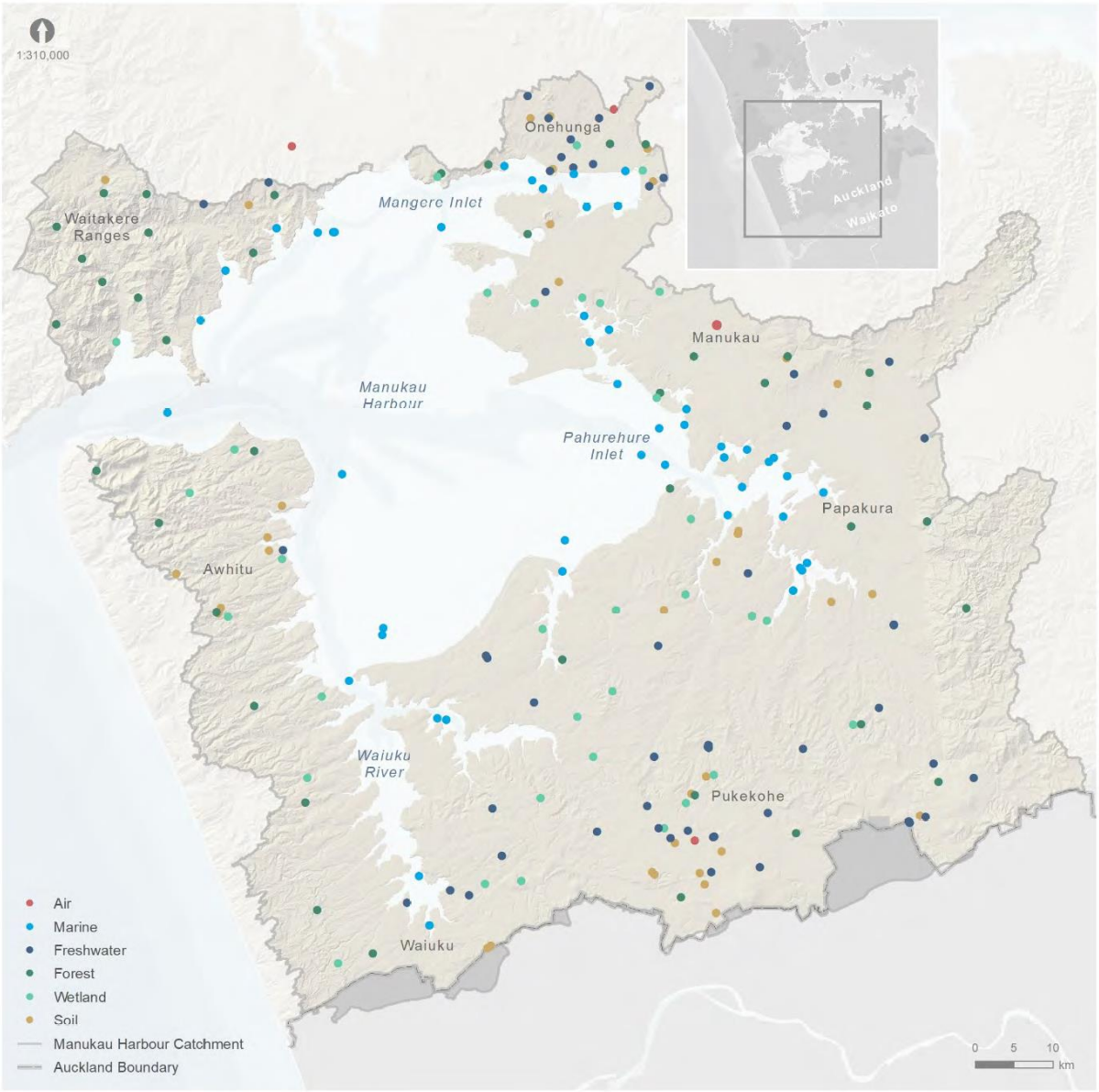

Figure 1: Manukau Harbour catchment environmental monitoring locations with the soil quality monitoring sites shown as brown circles (Auckland Council, 2021).

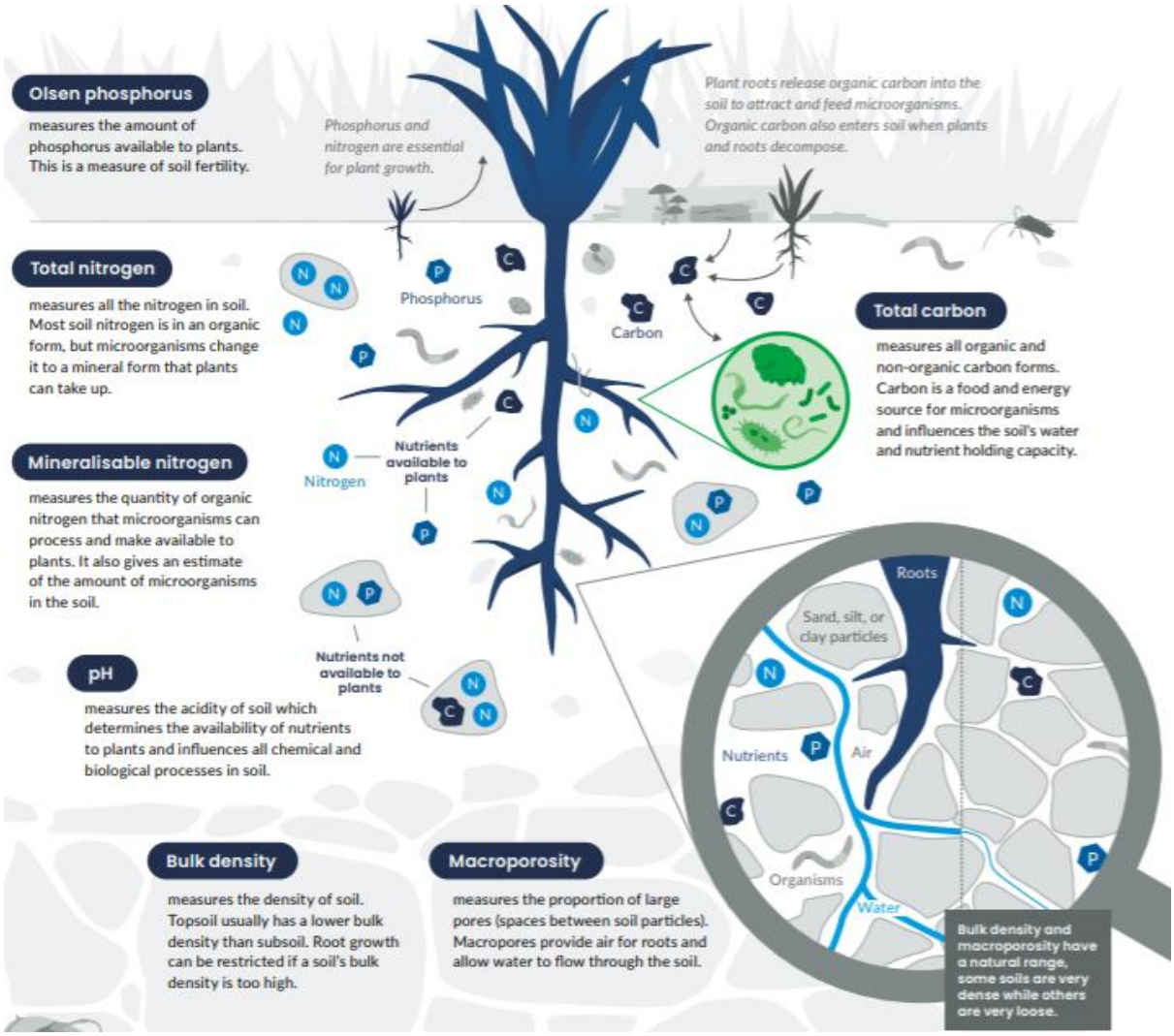

Figure 2. Soil quality infographic showing the seven soil quality indicators monitored (MfE and Stats NZ, 2021).

Table 2 which is derived from Table 1 shows the number and percentage of sites outside the target ranges for soil quality indicators and trace elements for each land use. Soil qualities showing 50% or more outside the target environmental guideline values or targets were flagged. These include the high Olsen P on the horticulture sites (83% or 10 out of 12 sites), low macroporosity of pasture (56% or 5 out of 9 sites) and urban sites (80% or 4 out of 5 sites).

Soil quality indicators and trace elements by rural land use, 2013-2017

Table 3 shows the soil quality indicators and trace elements under rural land when horticulture land use is further broken down into orchard and outdoor vegetable, and pasture land use is broken down into dairy and drystock. The outdoor vegetable and orchard sites have elevated Olsen P levels. In addition, total N and AMN are low (below 0.35% and below 40 mg/kg, respectively). This indicates that the native N supplying capacity of the soil is being compromised so that vegetable crops become highly dependent on the application of commercial N fertiliser for good production. Low macroporosity (<10%) is also an issue on outdoor vegetable sites and dairy and drystock pastures. While bulk density is also an indicator of compaction since it measures the mass of soil per unit total volume of soil (solids + pores),

Table 1. Soil quality indicators and trace elements by land use in the Manukau Harbour catchment, 2013-2017[1]

Indicator Land use	Total C (%)	Total N (%)	AMN (mg/kg)	pH	Olsen P (mg/kg)	Macro-porosity, -10kPa (%)	Bulk density (g/cm^3)
Horticulture (n=12)	3.80	0.34	49	6.4	**152**	19	1.02
Native (n=6)	7.70	0.45	139	5.4	4	16	0.81
Pasture (n=9)	8.40	0.76	175	6.0	37	**8**	0.90
Urban (n=5)	6.10	0.54	179	5.8	52	**8**	0.77
SED	1.38	0.106	24.0	0.22	41.0	2.7	0.080
LSD	2.82	0.218	49.1	0.44	84.0	5.5	0.160
P value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.01**	**<0.01**
Trace element (mg/kg)							
	As	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Horticulture (n=12)	7.5	0.53	22	31	8	28	50
Native (n=6)	4.1	0.06	14	9	4	19	26
Pasture (n=9)	6.2	0.56	16	19	5	30	45
Urban (n=5)	4.0	0.28	58	32	67	37	106
SED	1.09	0.080	3.7	6.9	7.1	12.1	9.0
LSD	2.23	0.160	7.5	14.2	14.5	24.7	18.5
P value	**<0.01**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.25 ns	**<0.001**

[1]Significant differences are highlighted in bold and ns denotes 'not significant'. Soil parameters in **red** and **blue** bold figures are mean values that are above and below recommended guidelines, respectively. The standard error of difference (SED) and least significant difference (LSD) are presented using un-transformed data and the *P*-value is presented using log transformed data, except for pH.

it did not differ statistically among land uses, and so does not appear to be a sensitive indicator compared to macroporosity.

Temporal changes in soil quality indicators and trace elements

The mean values of soil quality indicators and trace elements over three sampling periods (1995-2000; 2008-2012 and 2013-2017) for all land uses considered are shown on Table 4. It shows significant (P<0.05) declines in pH, organic C, and AMN and a highly significant (P<0.001) decline in macroporosity over a period of more than 20 years. Bulk density showed a significant (P<0.05) increase over time confirming that soil compaction has been worsening in the Manukau catchment area over the years. While mean Olsen P increased from 42 mg/kg to 55 mg/kg, this increase was not shown to be statistically significant. No significant changes in trace element concentrations were observed for the whole duration of the monitoring.

Comparison between Manukau Harbour and Auckland-wide soil quality issues under rural land uses

Table 5 shows the quality issues of the Manukau Harbour catchment soils and those of the whole of the Auckland region based on the latest monitoring data (Curran-Cournane, 2020). In general, soil quality issues in Manukau Harbour catchment are similar to those of the whole region with a few differences. In the Manukau Harbour catchment, elevated Olsen P levels are

an issue only under horticulture while it is an issue under both horticulture and dairy land uses in the whole region. For total N and AMN, both Manukau catchment and whole region soils have low values on outdoor vegetable sites but within guideline values on orchard sites. Manukau catchment soils have low macroporosity values on dairy, drystock and outdoor vegetable sites whereas whole region soils have low macroporosity values on dairy and drystock sites only.

Table 2. Number and percentage of sites (in parentheses) outside target ranges for soil quality indicators and trace elements for each land use, 2013-17. (Broad target ranges are provided in the footnotes containing specific target ranges by soil order and land use. Percentages in **bold** highlight the indicators by land use when more than half the soil samples failed to meet targets (n/a = not applicable)).

Land use	Indicator and broad target ranges						
	Total C[1]: >3%	**Total N[2]**: 0.35-0.7%	**AMN[3]**: >40 mg/kg	**pH[4]**: 5.5-7.5	**Olsen P[5]**: 15-50 mg/kg	**Macro-porosity (-10kPa)[6]**: 10-30% v/v	**Bulk density[7]**: 0.6-1.3g/cm^3
Horticulture (n=12)	8 (42%)	0	5 (42%)	1 (8%)	10 **(83%)**	1 (8%)	0
Native (n=6)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Pasture (n=9)	0	2 (22%)	0	0	3 **(**33%**)**	5 **(56%)**	0
Urban (n=5)	0	0	0	1 (20%)	2 **(**40%**)**	4 **(80%)**	0

	Trace element (mg/kg)						
	As (0.4-12)	**Cd** (<0.1-0.65)	**Cr** (2-55)[8]	**Cu** (1-45)[8]	**Ni** (0.9-35)	**Pb** (1-65)	**Zn** (9-180)[8]
Horticulture (n=12)	0	3 (25%)	0	0	0	0	0
Native (n=6)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Pasture (n=9)	0	2 (22%)	0	0	0	1 (11%)	0
Urban (n=5)	0	0	0	0	1 (20%)	1 (20%)	0

[1] **Total C:** Allophanic >4%; Recent >3%; Brown, Gley, Granular and Ultic >3.5%; Excludes Organic
[2] **Total N**: Pasture 0.35-0.7%; Excludes horticulture
[3] **AMN:** Pasture >60mg/kg; Horticulture and Forestry >40mg/kg
[4] **pH:** Pasture (excl Organic) 5.5-6.6; Pasture (Organic) 5.0-6.7; Horticulture (excl Organic) 5.5-7.5; Horticulture (Organic) 5.0-7.5;
[5] **Olsen P:** Pasture and Horticulture (Brown, Gley, Organic, Granular and Ultic) 20-35 mg/kg; Pasture and Horticulture (Allophanic and Granular) 20-50mg/kg; Hill country 15-20mg/kg
[6] **Macroporosity:** 10-30%
[7] **Bulk density:** Allophanic: 0.6-1.2 g/cm^3; Brown, Gley, Granular and Ultic 0.7-1.3g/cm^3; Organic 0.2-1.0g/cm^3; Recent 0.8-1.3g/cm^3
[8] For volcanic derived soils target ranges for **Cr** are 3-125 mg/kg; **Cu** are 20-90 mg/kg; **Ni** 4-320 mg/kg; **Zn** are 54-1160 mg/kg

Table 3. Soil quality indicators and trace elements by rural land use in the Manukau Harbour catchment, 2013-2017[1].

dicator Rural land use	Total C (%)	Total N (%)	AMN (mg/kg)	pH	Olsen P (mg/kg)	Macro-porosity -10kPa (%)	Bulk density (g/cm^3)
Dairy (n=6)	9.0	0.80	187	6.0	44	**7**	0.96
Drystock (n=3)	7.3	0.68	153	5.9	22	**9**	0.79
Orchard (n=3)	5.4	0.46	89	6.0	**86**	19	0.99
Outdoor vegetable (n=9)	3.3	**0.30**	**36**	6.5	**174**	**9**	1.03
SED	1.9	0.16	30.8	0.27	61.3	3.7	0.083
LSD	4.0	0.34	64.9	0.56	129.3	7.9	0.175
P value	**<0.001**	**<0.001**	**<0.001**	ns	**<0.05**	**<0.01**	ns

Trace element (mg/kg)							
	As	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Dairy (n=6)	5.1	0.59	15	18	5	17	41
Drystock (n=3)	8.2	0.53	18	22	6	55	53
Orchard (n=3)	6.7	0.51	18	13	7	22	48
Outdoor vegetable (n=9)	7.7	0.53	23	38	9	29	51
SED	0.97	0.11	2.4	8.4	0.8	12.2	10.2
LSD	2.04	0.24	5.0	17.7	1.7	29.8	21.6
P value	**<0.05**	ns	**<0.01**	**<0.05**	**<0.001**	ns	ns

[1]Within a column, significant differences are highlighted in bold and ns denotes 'not significant'. Soil parameters in **red** and **blue** bold figures are mean values that are above and below recommended guidelines, respectively. The standard error of difference (SED) and least significant difference (LSD) are presented using un-transformed data and the *P*-value is presented using log transformed data, except pH.

Table 4. Changes in soil quality indicators and trace elements over three sampling periods (all land uses).

Soil parameter	Sampling period			SED	LSD	*P* value	Guideline value range
	1995-2000	2008-2012	2013-2017				
Indicator							
Soil pH	6.25	6.28	6.02	0.093	0.19	**<0.05**	5.5-7.5
Organic C (%)	7.7	7.3	6.9	0.31	0.64	**<0.05**	>3
Total N (%)	0.61	0.61	0.58	0.02	0.04	ns	0.35-0.70
Olsen P (mg/kg)	42	56	55	8.1	16.4	ns	15-50
AMN (mg/kg)	159	159	131	7.0	9.9	**<0.05**	>40
Macroporosity, -5kPa (%)[1]	15	9	11	1.4	2.8	**<0.001**	8-30
Bulk density (g/cm^3)	0.87	0.94	0.93	0.03	0.05	**<0.05**	0.6-1.3
Trace element (mg/kg)							
Arsenic	6.5	5.5	6.3	0.87	1.78	ns	0.4-12
Cadmium	0.50	0.52	0.47	0.02	0.048	ns	<0.10-0.65
Chromium	16.8	16.3	17.4	1.03	2.11	ns	2-55
Copper	19	20	18	17	3.5	ns	1-45
Nickel	6	6	6	0.5	1.1	ns	0.9-35
Lead	26	27	26	4.1	5.8	ns	1-65
Zinc	50	55	45	6.1	12.5	ns	9-180

[1]Macroporosity used here is -5kPa (pores >60 microns) because -10kPa (pores >30 microns) data were not available in the 1995-2000 sampling period. Environmental guideline values appear in the last column. SED = standard error of difference; LSD – least significant difference; ns = not significant.

Table 5. Comparison between Manukau Harbour and Auckland-wide soil quality issues under rural land uses (most recent data, 2013-2017).

Soil quality indicator (Guideline value)	Manukau Harbour (n=32)	Auckland-wide (n=157)[1]
Olsen P (15-50 mg/kg)	High on orchard (86 mg/kg) & outdoor vegetable sites (174 mg/kg)	High on orchard (55 mg/kg), outdoor vegetable (206 mg/kg) & dairy sites (57 mg/kg)
Total N (>0.35%)	Low on outdoor vegetable sites (0.30%) but within guideline value on orchard sites (0.46%)	Low on outdoor vegetable sites (0.25%) but within guideline values on orchard sites (0.43%)
AMN (>40 mg/kg)	Low on outdoor vegetable sites (36 mg/kg) but within guideline values on orchard sites (89 mg/kg)	Low on outdoor vegetable sites (21 mg/kg) but within guideline values on orchard sites (84 mg/kg)
Macroporosity, 10kPa (10%)	Low on dairy (7%), drystock (9%) and outdoor vegetable sites (9%)	Low on dairy (6%) and drystock (8%) sites

[1]Curran-Cournane (2020)

Summary

The latest monitoring data show that some soil quality indicators fell outside the recommended guideline values. Olsen P high on the horticultural sites. Total C, total N and AMN were low on outdoor vegetable sites. Macroporosity is low on pasture sites and outdoor vegetable sites indicating soil compaction. The mean concentrations of trace elements are within guideline values but differed with land use with pasture and horticulture sites having high mean concentrations of Cd and As. Significant reductions in pH, organic C, AMN, and macroporosity, and an increase in bulk density were observed over a 22-year period. Elevated Olsen P levels, low total N and AMN, and low macroporosity are common soil quality issues affecting both Manukau Harbour catchment and the whole of the Auckland region.

Addressing soil quality issues identified in monitoring

Reduction in the use of phosphate fertiliser should be encouraged particularly in horticultural sites since the soils are already over-fertilised. There is also a need to evaluate and/or promote the use of slow-release P fertiliser on crops to increase P use efficiency and minimise P losses via sediment in runoff. For example, the Mangere wastewater treatment plant now produces a slow-release phosphorus fertiliser called struvite that also contains nitrogen and magnesium (Rob Tinholt, Watercare resource recovery manager, personal communication). The slow-release nature of the fertiliser suggests that it could be effective on crops with long growing cycles but less so on crops with short growing cycles like some leafy vegetables.

As regards compaction, timing of cultivation should occur in late spring or early summer, so soil is close to optimum moisture for tillage operations on horticultural sites. On pasture sites, heavy stocking in winter and spring should be avoided so that pugging does not occur. Where possible, stock needs to be moved into lighter-textured soils in the farm. Keeping the grazing rotation short should also be practised.

To maintain or increase soil organic matter in the long run, a range of practices such as minimising cultivation, maintaining ground cover, growing of cover crops, including a pasture phase in arable cropping, etc. need to be encouraged.

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