Te Kaunihera o te tai o Aorere

State of the Environment Report

Soil Quality Monitoring

The purpose of this report is to provide information about the quality status of the soils in the Tasman District from the 2023 Sampling Programme.

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2023 Sampling Programme

Soil Quality Monitoring

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Cover Photo: an excavated soil core for physical analyses.

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Acknowledgements

We wish to acknowledge all the landowners for their cooperation and for providing access to their properties for sampling.

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1. Introduction

As required by the Resource Management Act 1991, Regional (and Unitary) Councils have a responsibility for monitoring and reporting the state of the environment in their regions.

One of the most valuable resources is soil, which its health status can affect quality of other natural resources such as groundwater and surface water. Moreover, due to recent intensification of specific land uses including dairying and horticulture across New Zealand, soil quality monitoring is becoming increasingly important.

The objectives of soil quality monitoring programme are to:

- Provide information on chemical, biological and physical properties of soils, contributing to the overall soil quality.
- Track specific, identified issues relating to the effect of land use on long-term soil productivity.
- Provide an early-warning system to identify the impacts of primary land uses on long-term land versatility.
- Integrate with other resource monitoring, particularly groundwater.
- Contribute to improved sustainable management of the productive lands.
- Provide a mechanism to determine the effectiveness of regional environmental policies and plans.

In Tasman, monitoring of soil quality was started in 2000 with soil sampling of 10 sites, as part of the Ministry of the Environment's "500 Soils Project". The sites selected were four pastoral (dairying), three rehabilitation (from mining and gravel extraction), two orchards and one market garden (report: *Implementation of soil quality indicators for land in the Tasman region – a progress report for Year 1*).

Additional sites were sampled in 2005, 2009 and 2014, bringing the total number of soil monitoring sites to 35. These cover dairying pasture, drystock pasture, market gardening and perennial horticulture including orchards and vineyards. Due to increasing interests in establishment of hop farms in our district in last few years, two hop farm sites (TDC23.36 & TDC23.37) have also been added last year. All these 37 sites were sampled in 2023 to provide a comprehensive picture of current soil quality status in our district.

This report summarises the results of 2023 soil quality monitoring programme and compares them with the national target values as well as results of previous monitoring programmes. The correlations between different soil attributes and their contributions to overall soil health are also discussed.

2. Materials and Methods

2.1. Sampling Sites

In 2023 soil monitoring programme, 37 sites were sampled across the Tasman District to cover a wide range of soil types under main land uses.

“Soil order” is the broadest class of soils under the New Zealand Soil Classification (Hewitt, 2010). In Tasman, the two dominant soil orders are “Recent” and “Brown”. Recent soils are weakly-developed soils occurring on young land surfaces including floodplains, while Brown soils are more developed mature soils, covering 43% of New Zealand. Soil orders are further broken down into smaller classes including group, sub-group, family, and sibling. Soil “type” is a common name for soil “family” – such as “*Ranzau”*.

The main land uses in Tasman are dairying/drystock, perennial horticulture (orchard/vineyard), market gardening/cropping and field tree nursery.

The locations of sampled sites are indicated on below map:

The sites information including the main land use, respective soil order/type and previous sampling dates are also provided in Table 1, below.

Table 1. Descriptions of 37 sites sampled in 2023 soil quality monitoring programme.

Site Code	Land Use	Soil Order	Soil Type	Previous Sampling Year(s)
TDC 23.1	Dairy	Recent	Karamea	2001,2009
TDC 23.2	Dairy	Brown	Ikamatua	2001,2009
TDC 23.3	Dairy	Podzol	Onahau	2001,2009
TDC 23.4	Apple Orchard (grazing now)	Brown	Waimea	2001,2009
TDC 23.5	Pear Orchard (grazing now)	Ultic	Mapua	2001,2009
TDC 23.6	Market Garden	Brown	Waimea	2001,2009
TDC 23.7	Market Garden (rehabilitated)	Recent	Waimea	2001,2009
TDC 23.8	Drystock (sheep)	Recent	Waimea	2001,2009
TDC 23.9	Drystock (beef)	Brown	Ikamatua	2001,2009
TDC 23.10	Drystock (beef)	Recent	Hokitika	2001
TDC 23.11	Drystock (sheep&beef)	Brown	Stanley	2005,2014
TDC 23.12	Drystock (sheep&beef)	Brown	Stanley	2005,2014
TDC 23.13	Drystock (sheep&beef)	Brown	Stanley (hill)	2005,2014
TDC 23.14	Dairy	Recent	Karamea	2005,2014
TDC 23.15	Drystock (beef)	Recent	Dovedale	2005,2014
TDC 23.16	Dairy	Recent	Takaka	2009
TDC 23.17	Dairy	Brown	Uruwhenua	2009
TDC 23.18	Dairy	Recent	Anatoki	2009
TDC 23.19	Dairy	Brown	Ikamatua	2009
TDC 23.20	Dairy	Brown	Puramahoi	2009
TDC 23.21	Dairy	Brown	Motupipi	2009
TDC 23.22	Drystock (beef)	Ultic	Pisgah	2009
TDC 23.23	Dairy	Brown	Hamama	2009
TDC 23.24	Kiwifruit Orchard	Recent	Karamea	2009
TDC 23.25	Kiwifruit Orchard	Recent	Takaka	2009
TDC 23.26	Drystock (sheep&beef)	Gley	Motukara	2014
TDC 23.27	Apple Orchard	Brown	Waimea	2014
TDC 23.28	Apple Orchard	Brown	Waimea	2014
TDC 23.29	Drystock (horse&goat)	Pallic	Braeburn	2014
TDC 23.30	Drystock (beef)	Brown	Dovedale	2014
TDC 23.31	Cropping	Recent	Redwood	2014
TDC 23.32	Market Garden	Recent	Wai-iti	2014
TDC 23.33	Apple Orchard	Brown	Redwood	2014
TDC 23.34	Tree Nursery	Brown	Motupiko	2014
TDC 23.35	Vineyard	Gley	Cotterell	2014
TDC 23.36	Hop Farm	Brown	Tapawera	-
TDC 23.37	Hop Farm	Brown	Tapawera	-

2.2. Soil Sampling

Sampling was carried out in October 2023 over three weeks.
Two types of soil samples were taken from each site. First type was a composite sample comprising 25 individual cores (with depth of 100mm) taken by a soil tube sampler at 2m intervals along a 50m transect. The composite samples were sent to the lab for chemical and biological analyses. On the other hand, three undisturbed soil cores (100mm diameter by 75mm depth) were collected at 15m, 30m and 45m positions along the transect. The soil cores were removed by excavation around the metal liner, bagged and loaded into padded crates for transport to the laboratory for physical analyses (Fig.1).

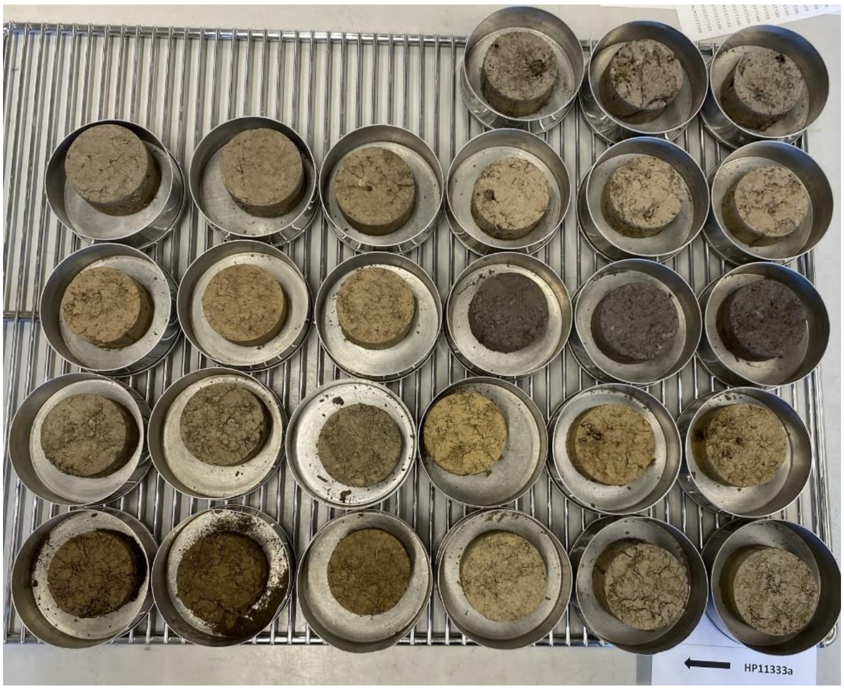

Figure 1. Soil cores prepared for physical analyses at the lab.

2.3. Soil Quality Attributes

Several different soil attributes are measured to assess overall soil quality. Soil chemical attributes include soil pH, Olsen P, and trace elements. Soil biological characteristics are determined by measuring anaerobically mineralisable nitrogen, total carbon, total nitrogen, carbon-to-nitrogen ratio, and hot water carbon. Soil physical conditions are assessed by measuring bulk density and air-filled porosity.

3. Results

3.1. Soil Biological Attributes

3.1.1. Total Carbon

Total Carbon (TC) in soils is sum of both organic and inorganic carbon. Organic carbon is present in the soil organic matter, whereas inorganic carbon is largely found in carbonates. As New Zealand soils often contain small amounts of carbonate, total carbon is often considered as an indication of organic carbon, which is important for soil structure stability as well as nutrient and moisture retention.

Organic matter accumulation is often higher under native bush and pasture, while land uses with high levels of soil disturbance (cultivation) often result in depleted soil carbon content.

Soils with a low carbon level are likely to have a weak structure and are therefore more prone to erosion and compaction. These can also result in reduction of productive capability of the respective land.

Figure 2 shows TC levels found in soil samples taken from 37 sites under different land uses including market garden, orchard/vineyard, hops, and pasture. Market garden sites, grouped with similar land uses including one cropping and one field nursery sites, had the lowest TC median of 2.1%, which is just above the minimum target value (2%) for the respective soil order (Recent).

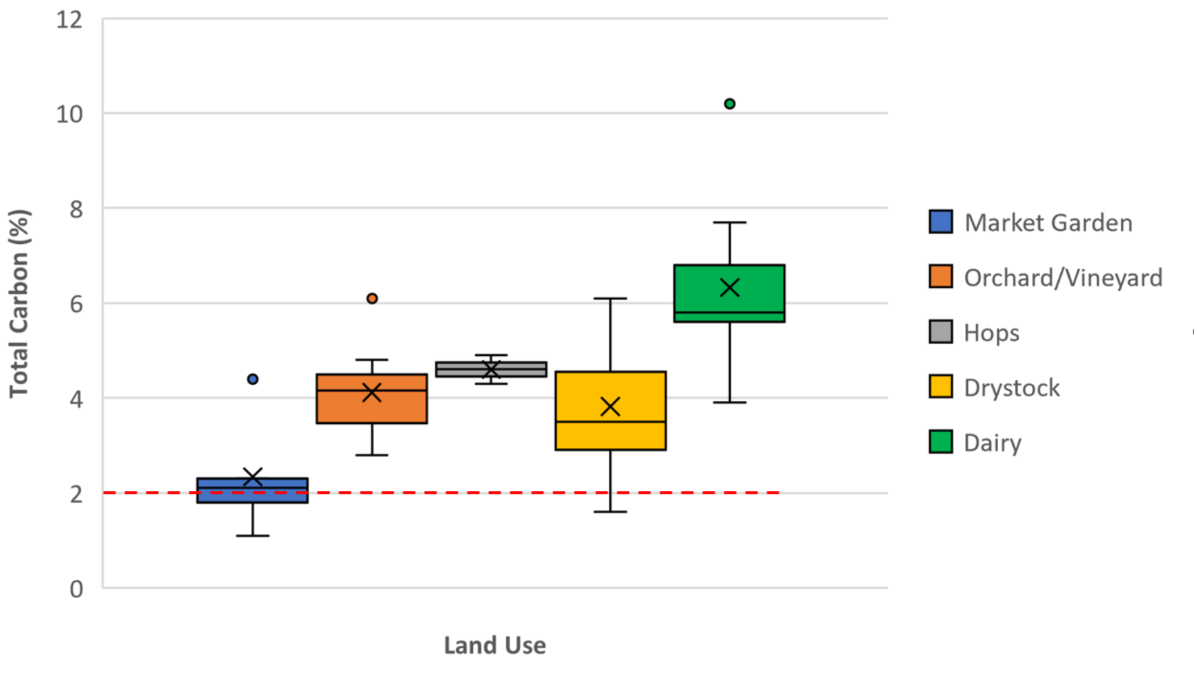

Figure 2. Total carbon values by land use for 2023 soil samples. The red dashed line is the minimum target value for Recent soils (2%). This value for other soil orders is 2.5% (not shown).

There was only one market garden site: TDC007 (the outlier) showing an acceptable TC level (4.4%), which is likely to be attributed to its anthropogenic soils - backfilled after gravel extraction. As Fig. 3 shows, there was a significant increase (~3%) in TC at this site between 2010 and 2023.

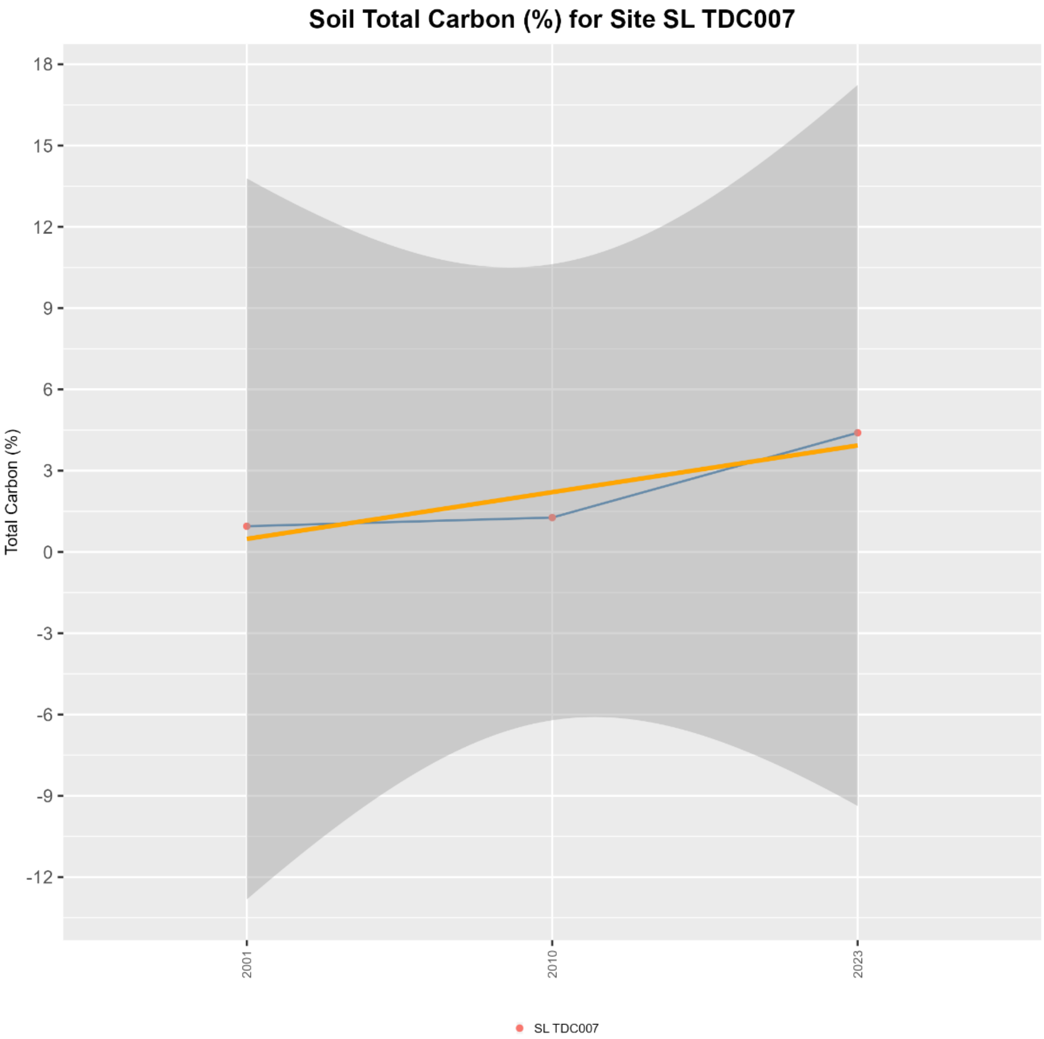

Figure 3. Overall trend of soil total carbon at a rehabilitated gravel extraction site between 2001 and 2023.

On the other hand, dairy pasture, which is often subject to no or minimal cultivation and maximal soil coverage (with grass), showed an ample TC median: 5.8%. Podzol soil samples from a dairy site (in Aorere Catchment) even showed TC as high as 10.2%, possibly attributed to interaction of *carbon-friendly* land use and well-structured weathered soil type.

Total carbon medians for other land uses including drystock pasture, orchard/vineyard and hops ranged between 3.5% to 4.6%, which are well above the minimum target value of 2%.

3.1.2. Hot Water Carbon

Hot Water Carbon (HWC) is a relatively new soil quality indicator, which can measure slowly labile carbon pool as well as labile (very active) soil carbon fraction. Labile carbon is positively correlated with soil microbial biomass, which is affected by changes in soil management practices such as fertilisation regime, cultivation, and stocking rate.

While the provisional minimum target value of HWC is set at 1900 mg carbon per kg of soils, a lower limit of 1700 mg/kg has been found more realistic for the South Island (McMillan & Oliver, 2023). However, even considering 1700 mg/kg, Orchard/Vineyard and Hops barely meet this minimum target value, while Market Garden (with median of 891 mg/kg) falls well below it. On the other hand, both Dairy and Drystock, with medians of 2527 mg/kg and 2269 mg/kg respectively, showed adequate HWC (Fig. 4). This means that grazed pastures are likely to maintain the level of labile organic carbon better, owing to their higher microbial activities.

Overall, the land use impact was far greater on HWC than TC, which is likely to be correlated with soil microbial biomass/activities. That is why hops and orchard/vineyard land uses are here distinguished from drystock pasture by HWC, while they did not show any meaningful differences in their TC levels.

Given the reasonable size of the labile carbon pool (which usually constitutes of 3 – 6% of the total organic carbon in the soils), HWC measurements can, in fact, give an early indication of organic matter loss.

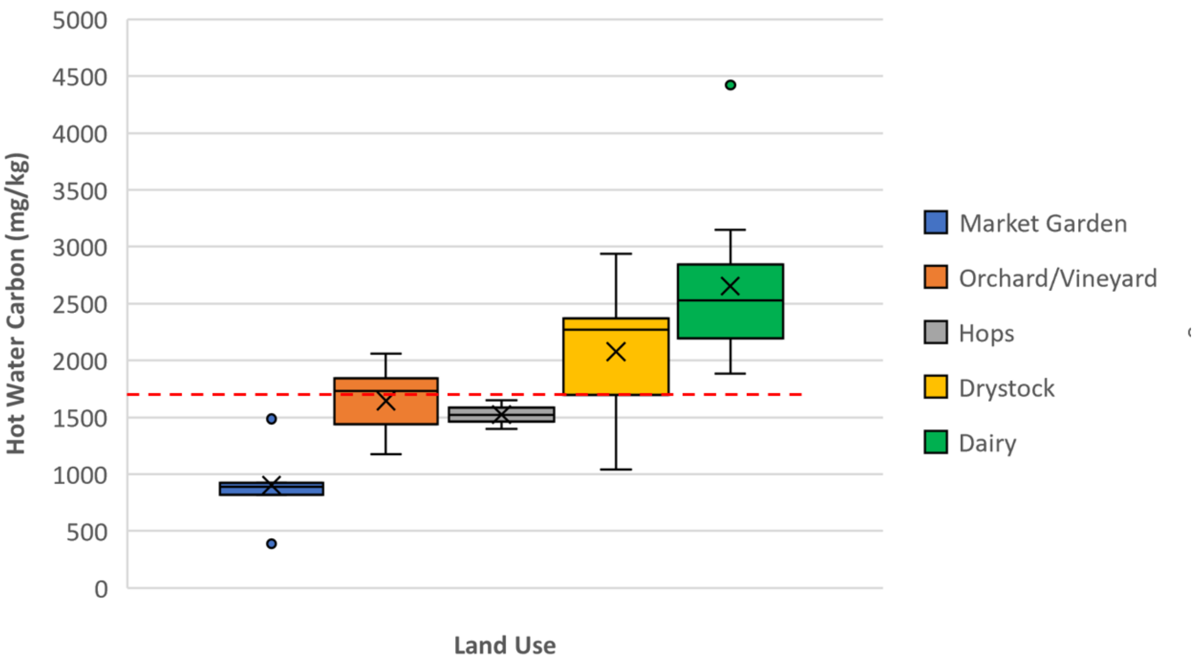

Figure 4. Hot water carbon values by land use for 2023 soil samples.
The red dashed line is the provisional minimum target value for the South Island (1700 mg/kg).

3.1.3. Total Nitrogen

Total Nitrogen (TN) gives a measure of reserve organic nitrogen in the soil as a large portion of nitrogen in soil is within the organic matter fraction. Nitrogen is an essential nutrient for plants and animals. Usually only a small fraction of the TN is immediately available for plant uptake (soluble inorganic N), while a variable proportion of TN is potentially mineralisable to inorganic N.

In general, a high TN indicates that the soil is in good biological condition. However, very high TN contents indicate that N supply is likely to be in excess of plant demand, which can potentially lead to leaching of nitrate to groundwater. On the other hand, soils with low inputs of organic matter or high N loss rates (mainly due to cultivation) often have low TN.

Among the sites sampled, median TN of sites under market gardening (0.21%) falls below the minimum target value of 0.25%, while other land uses had medians within the target range: 0.25% to 0.7% (Fig.5). As expected, dairy pasture had the highest TN median of 0.54%.

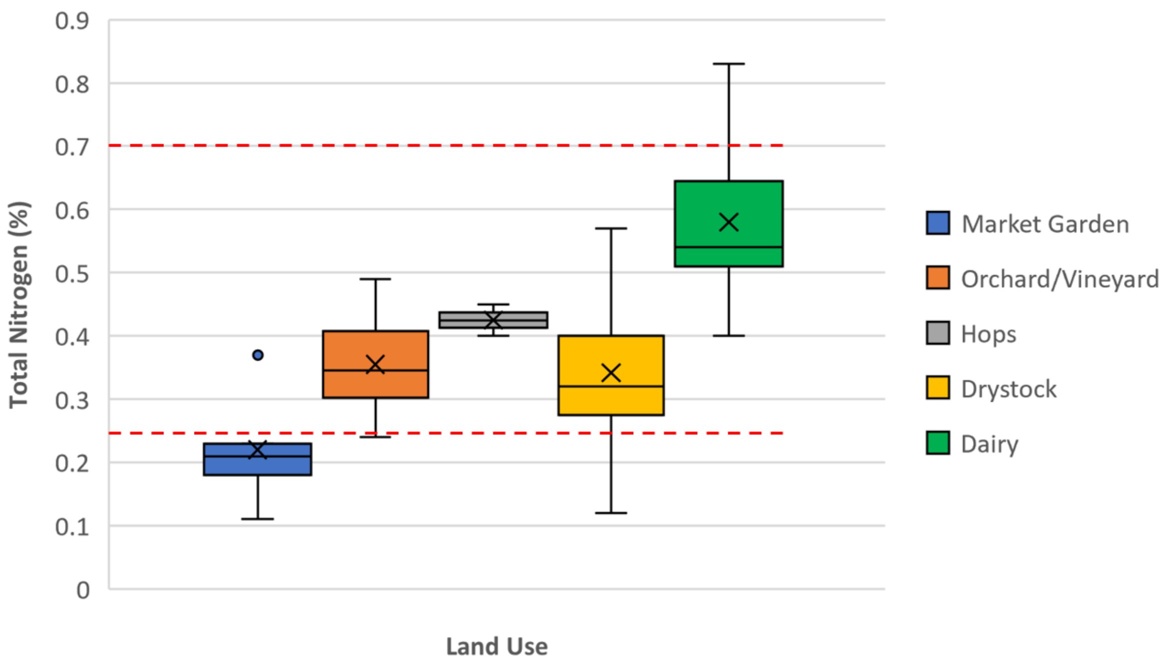

Figure 5. Total nitrogen values by land use for 2023 soil samples.
The red dashed lines show the target range: 0.25% to 0.7%.

3.1.4. Anaerobic Mineralisable Nitrogen

Anaerobic Mineralisable Nitrogen (AMN) represents the readily decomposed organic nitrogen. This gives a measure of the activity of soil organisms. Soil organism activity is important for the overall functionality of the soils as it aids nutrient availability, water and gas movement and soil structural stability.

Generally, the higher the AMN content is, the healthier the soil is. However, if the rate of mineralisation exceeds the rate of plant uptake, this can increase the risk of nitrate leaching. However, it is worth to note that nitrate losses are also controlled by other factors such as soil texture/structure, which significantly affect the water movement (drainage) in the soil and thereby nitrate leaching. In addition, because soils are only sampled to 10cm depth, this indicator may not reflect other processes happening to the nitrate-N further down the soil profile (such as denitrification).

The use of AMN as a soil quality indicator for mineralisable nitrogen is currently under review.

Unlike TN, AMN median for Market Garden (85 ug/g) is well within the target range (20 to 150 ug/g) while Orchard/Vineyard and Drystock are at the higher end of the respective optimal ranges (Fig. 6). On the other hand, dairy pasture with median of 282 ug/g falls well above the maximum optimal value of 250 ug/g, which can be an indication of excess nitrogen input.

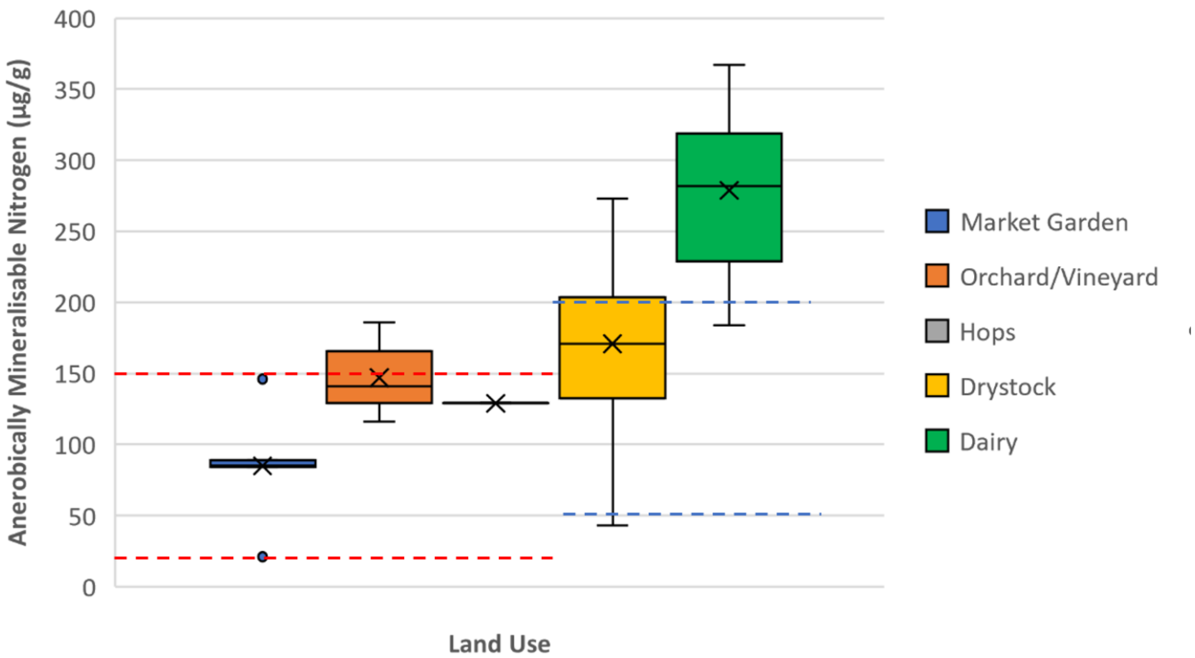

Figure 6. Anaerobic mineralisable nitrogen values by land use for 2023 soil samples.
The target range for pasture is 50 to 200 ug/g (blue dashed lines) and for other land uses is 20 to 150 ug/g (red dashed lines).

3.1.5. Carbon to Nitrogen Ratio

Carbon to Nitrogen ratio (C:N) is a useful indicator for decomposition/likely ease of decomposition of nitrates and ammonium from organic residues in soils. It is also a guide to risk of nitrate leaching from the soils.

Generally speaking, the reason behind low C:N could be either depleted carbon content or elevated nitrogen level. Among the sampled sites, only four sites had C:N below the minimum target value of 10. Three of these are under pasture. As C:N increases above 10 (nitrogen becomes scarce in relation to carbon), soluble nitrogen is immobilised (taken up) by soil microbes, and the risk of nitrogen leaching decreases (Havlin et al, 2013). Nitrogen cycling then becomes more dependent on microbial activity. The highest C:N value found was 12.9, belonging to a drystock pasture site in Upper Buller with Sandy Recent soils.

However, looking at the overall trend across the representative sites, it seems that C:N had reduced (about 1 unit) from 2005 to 2023 (Fig. 7).

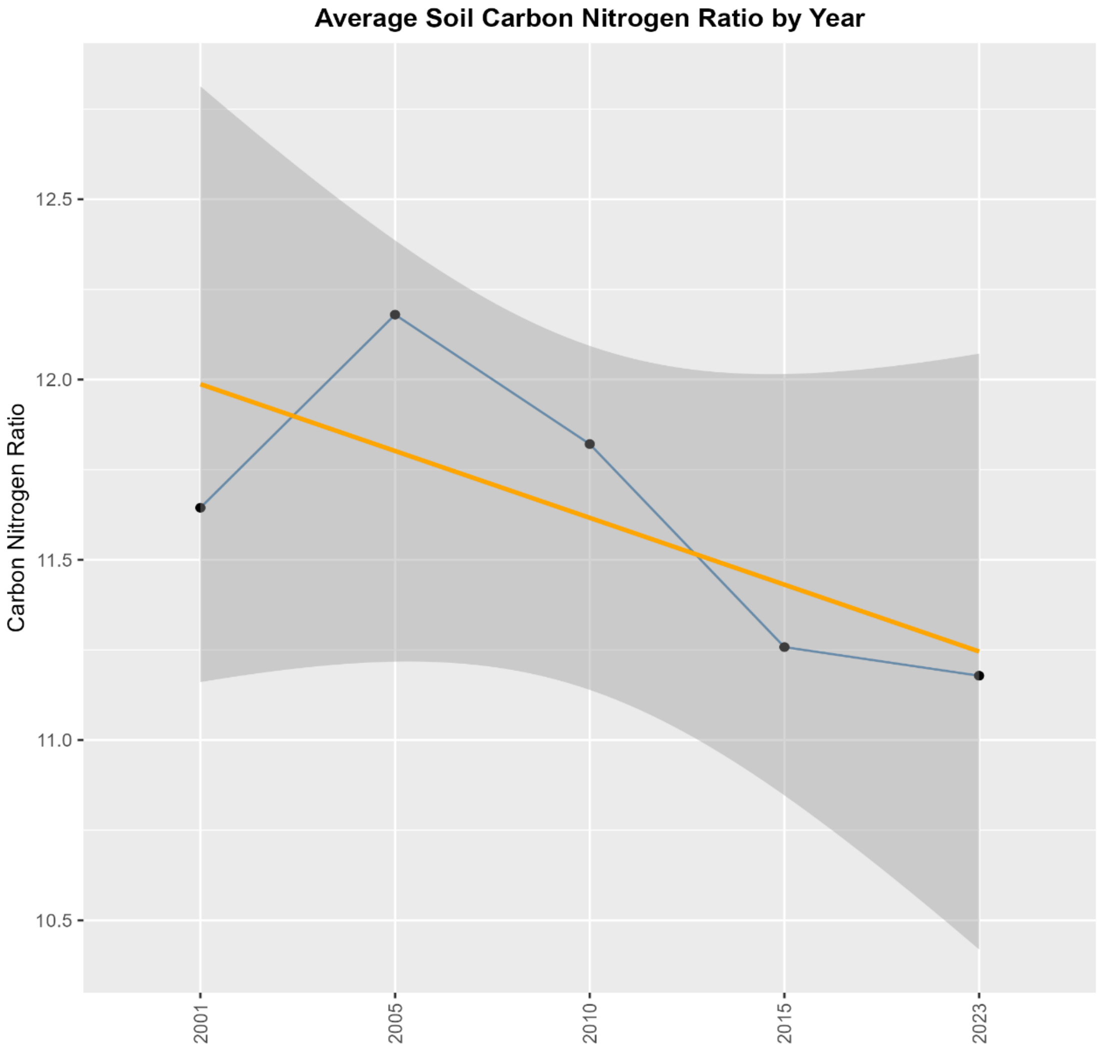

Figure 7. Overall trend of average C:N for sites monitored three times since 2001 (TDC1-9 & TDC11-15).

3.1.6. Summary of Soil Biological Results

The results show that the market garden sites, which are mainly located on Recent soils of the Waimea Plains, are relatively low in soil organic carbon. While main reason for this is likely to be high levels of soil cultivation involved, some inherent properties of subject soils such as stoniness and low water-holding capacity also play roles in this. The results also suggest that there is still room for improving organic carbon in horticultural soils (orchards, vineyards and hop farms), which can potentially benefit crop yield and quality.

On the other hand, dairy pasture sites had nitrogen levels higher than optimal, posing potential risk of nitrate leaching.

In addition, the results suggest that HWC and AMN can respectively reflect available soil organic carbon and nitrogen more realistically.

3.2. Soil Chemical Attributes

3.2.1. Olsen P

Olsen P indicates the level of plant available phosphorus (P) and general fertility of the soil. Phosphorus is an essential nutrient for plants and animals. Plants get their phosphorus from phosphates in soil. Many soils in New Zealand have low available P, necessitating inputs of manure, effluent, or phosphate fertiliser to increase suitability for intensive agricultural use.

The issues associated with P fertilisers are possible global depletion of phosphate rock reserves and risk of increasing heavy metals, particularly cadmium, in the receiving soils (cadmium is a common impurity in phosphate ores). Moreover, excessive fertiliser uses can cause accelerated P losses to waterways, resulting in eutrophication - especially in highly weathered soils or soils with a low P-retention capacity.

Results, here, ranged from 8 to 132 mg P/kg, similar to the previous range found in 2015 (18 to 132 mg/kg). While Olsen P average of market garden sites exceed the maximum target value of 50 mg/kg, it fits within the target range for other land uses. However, Hops with a median of 20.5 mg/kg was at the lower end of the target range (Fig. 8), which is probably attributed to a lower P demand of hop and respective lower P inputs, compared to perennial or pasture.

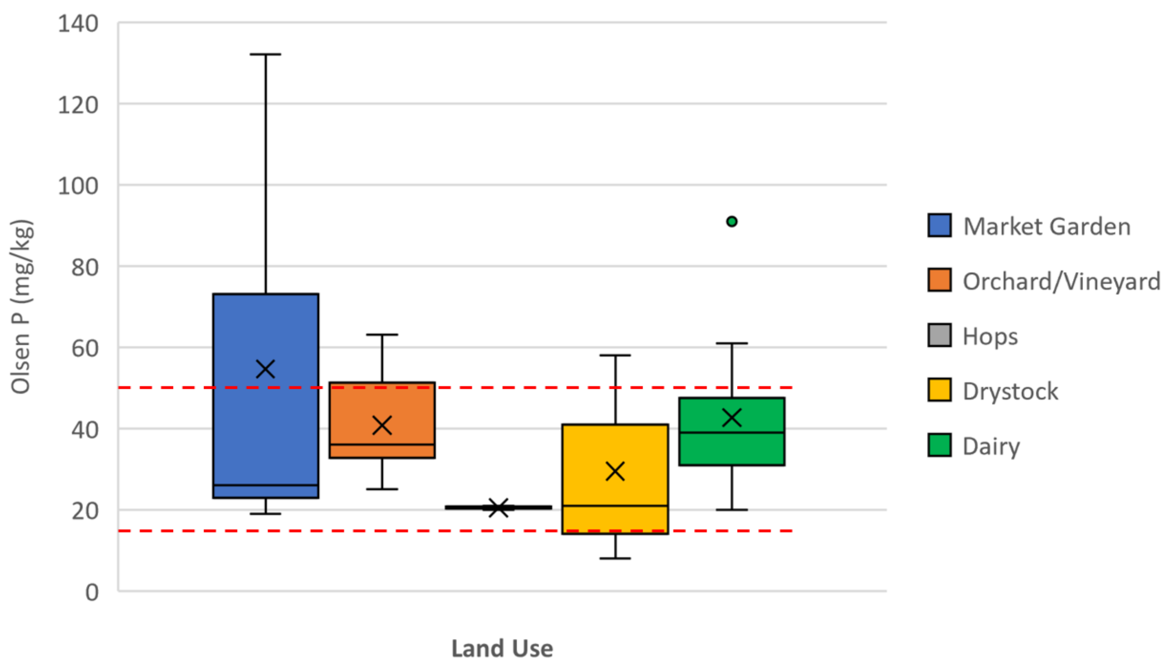

Figure 8. Olsen P values by land use for 2023 soil samples.
The red dashed lines show the target range: 15 to 50 mg/kg.

Looking at the averages of Olsen P at a market garden site (on the Waimea Plain) in 2001, 2010 and 2023 reveals a significant increase from around 70 mg/kg in 2001 to around 130 in 2023 (Fig. 9), which could be of concern.

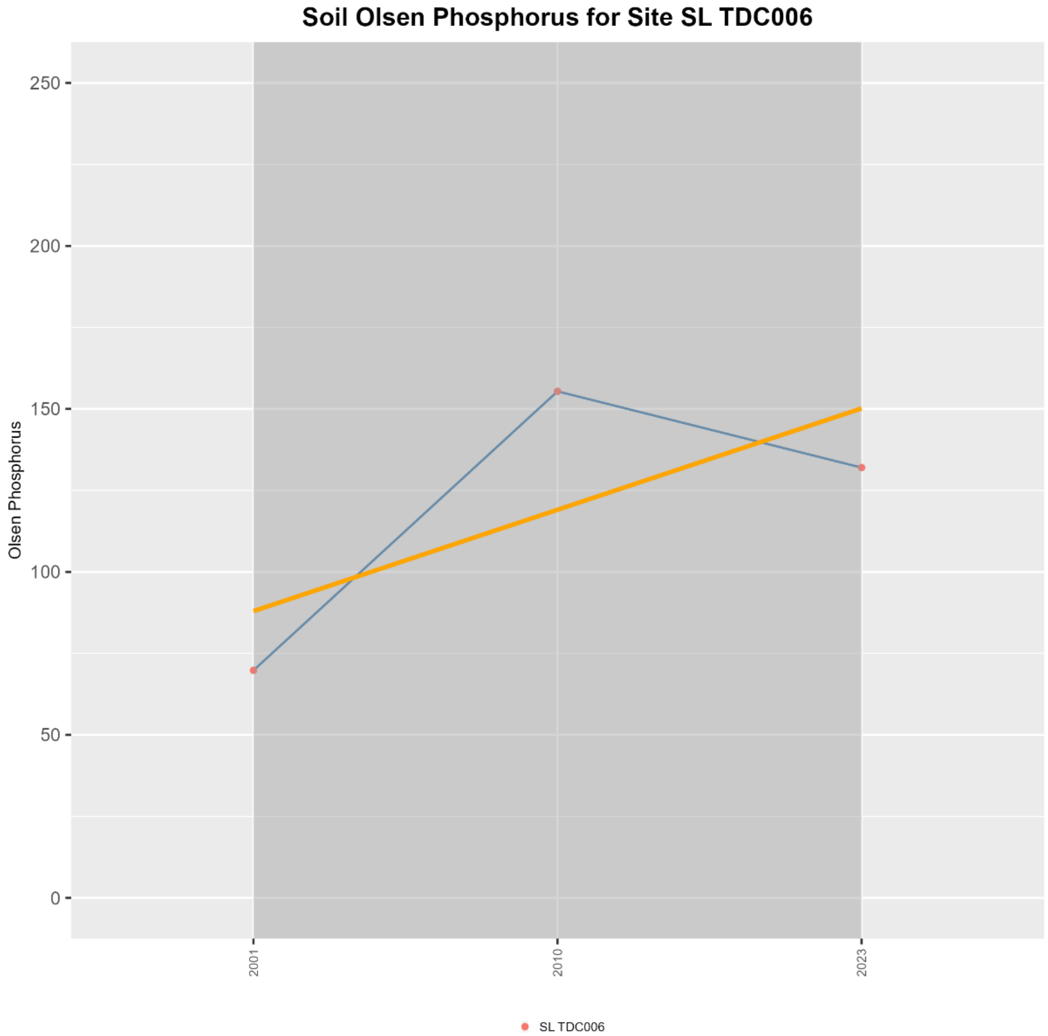

Figure 9. Overall trend of soil Olsen P for a garden market site between 2001 and 2023.

3.2.2. pH

Soil pH is a measure of acidity or alkalinity in soil. Most plants and soil organisms have an optimum pH range for growth. Indigenous species are generally tolerant of acid conditions but introduced pasture and crop species require a more alkaline soil. The issues associated with pH levels occur when site pH falls outside the favourable pH range for desired plant species. Also, some heavy metals may become soluble and bioavailable at certain pH ranges.

In 2023, the pH medians measured for all the land uses were *optimal*, ranging between 5.9 in dairy to 7 in hops (Fig. 10).

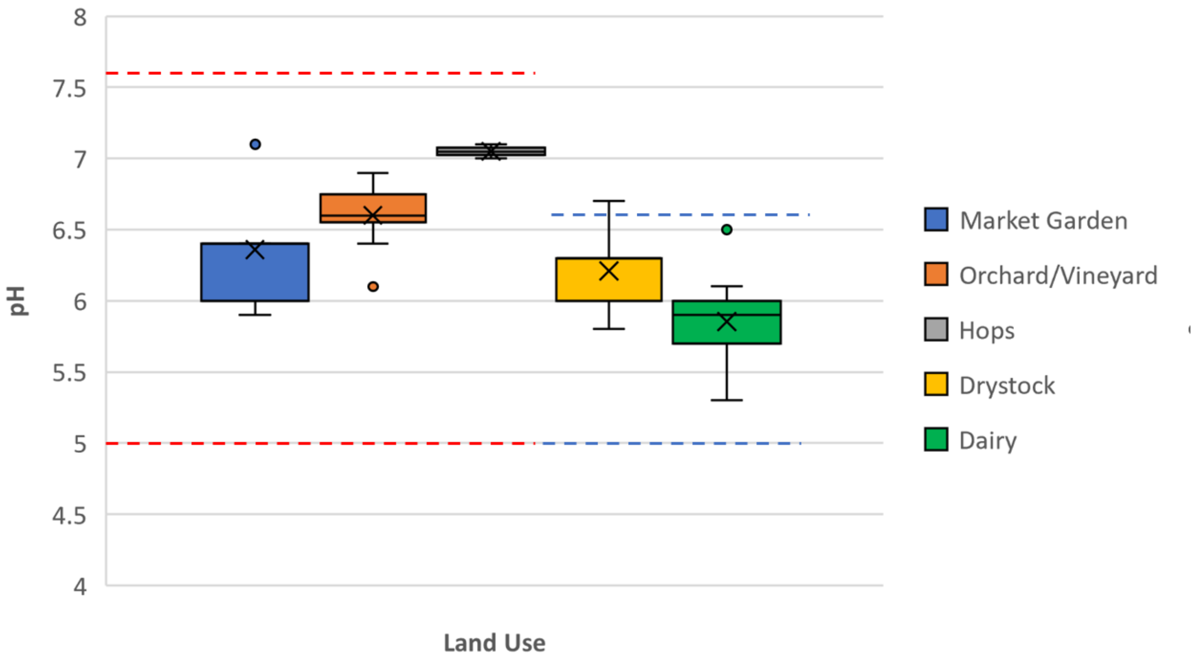

Figure 10. Soil pH by land use for 2023 soil samples.
Target range for pasture is 5 to 6.6 (blue dashed lines) and for other land uses is 5 to 7.6 (red dashed lines).

3.2.3. Summary of Soil Chemical Results

With the exception of detecting elevated Olsen P levels at some market garden sites, which can pose potential risk of phosphorus run-off into surface water, the overall chemical quality of the 2023 soil samples was found acceptable for other land uses.

3.3. Trace Elements

Trace elements accumulate in soils either naturally through weathering of minerals contained in soil parent material or from anthropogenic sources. While many trace elements such as copper and zinc are essential for plant health and animal growth, at high concentrations these can have adverse impacts on plant/animal health. Copper and zinc often accumulate in soils as a result of common agricultural/horticultural activities. On the other hand, some other trace elements including cadmium, lead and arsenic are not essential to plants/animals or soil organisms and their accumulation can have negative impacts on their wellbeing and pose a risk of entering the human food chain.

A suite of the most common environment-impacting elements including arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and mercury (Hg) was analysed for the 2023 soil samples.

The results are compared against Ecological Soil Guideline Values (Eco-SGVs), providing a useful way to assess their potential negative impacts on the most sensitive receptors on or in the soil and thereby soil quality. The results are also compared with Tasman interim ambient background concentrations, came into effect from October 2023.

The results of the trace element analyses are presented in Table 2.
The ones in “ ” are above the background level and the ones underlined are at or above the respective Eco-SGV.

Table 2. Concentrations (total recoverable) of trace elements detected in 2023 soil samples.

Site Code	Land Use	Soil Order	Soil Type	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
TDC 23.1	Dairy	Recent	Karamea	8.1	“0.41”	41	29	14.5	0.04	35	82
TDC 23.2	Dairy	Brown	Ikamatua	“20”	“0.39”	85	33	14.5	0.06	31	60
TDC 23.3	Dairy	Podzol	Onahau	0.4	“0.4”	4.4	7.9	2.4	0.04	2	10.4
TDC 23.4	Apple Orchard (grazing now)	Brown	Waimea	“31”	0.35	132	“230”	“100”	“0.28”	“180”	“99”
TDC 23.5	Pear Orchard (grazing now)	Ultic	Mapua	“20”	0.29	8.8	“64”	“124”	“0.47”	5.2	48
TDC 23.6	Market Garden	Brown	Waimea	3.6	0.189	160	30	8.7	0.05	“270”	70
TDC 23.7	Market Garden	Recent	Waimea	5.5	0.25	111	31	13.6	0.1	138	82
TDC 23.8	Drystock	Recent	Waimea	3.4	0.102	79	21	7.7	0.04	108	55
TDC 23.9	Drystock	Brown	Ikamatua	4.7	0.075	24	9.8	11.6	0.05	16.8	42
TDC 23.10	Drystock	Recent	Hokitika	5.9	0.086	15.1	16.1	12.3	0.02	20	47
TDC 23.11	Drystock	Brown	Stanley	1.4	0.0163	6.8	3	4.8	0.03	3	14.4
TDC 23.12	Drystock	Brown	Stanley	1.3	0.164	9	4.9	6	0.02	5.1	29
TDC 23.13	Drystock	Brown	Stanley (hill)	1.8	0.27	12.6	8.8	9.9	0.05	8.3	48
TDC 23.14	Dairy	Recent	Karamea	“11.3”	0.24	77	27	15.2	0.06	47	“97”
TDC 23.15	Drystock	Recent	Dovedale	1.5	0.21	10.3	8	“23”	0.02	6.5	38
TDC 23.16	Dairy	Recent	Takaka	7.8	0.35	58	23	11.8	0.02	36	71
TDC 23.17	Dairy	Brown	Uruwhenua	5.4	“0.54”	33	13.6	10	0.08	8.9	39
TDC 23.18	Dairy	Recent	Anatoki	5	“0.44”	13.1	11.4	11.4	0.03	13.8	40
TDC 23.19	Dairy	Brown	Ikamatua	“10.5”	“0.45”	48	20	9.6	0.09	22	79
TDC 23.20	Dairy	Brown	Puramahoi	6	0.35	42	49	16.3	0.1	19.5	“127”
TDC 23.21	Dairy	Brown	Motupipi	4.7	“0.48”	33	22	10.7	0.06	18.1	71
TDC 23.22	Drystock	Ultic	Pisgah	9	0.28	51	21	15.8	0.13	18.6	68
TDC 23.23	Dairy	Brown	Hamama	“10.5”	“0.38”	98	18.7	10.8	0.06	48	64
TDC 23.24	Kiwifruit Orchard	Recent	Karamea	“10.1”	0.26	50	40	11.9	0.03	24	“95”
TDC 23.25	Kiwifruit Orchard	Recent	Takaka	7	0.22	56	“57”	8.5	0.02	30	“101”
TDC 23.26	Drystock	Gley	Motukara	5.4	0.12	53	15.2	8.9	0.02	47	53

Site Code	Land Use	Soil Order	Soil Type	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
TDC 23.27	Apple Orchard	Brown	Waimea	3.4	0.29	82	29	15.2	0.05	87	"103"
TDC 23.28	Apple Orchard	Brown	Waimea	3.8	"0.4"	79	35	9.7	0.04	84	91
TDC 23.29	Drystock	Pallic	Braeburn	1.9	0.121	7.2	3.9	12.2	0.04	3	14.5
TDC 23.30	Drystock	Brown	Dovedale	0.6	0.24	5.9	19.4	3.5	0.02	2.9	17.8
TDC 23.31	Cropping	Recent	Redwood	4	0.2	103	27	9.7	0.05	146	69
TDC 23.32	Market Garden	Recent	Wai iti	3.7	0.18	116	24	8.1	0.04	"182"	57
TDC 23.33	Apple Orchard	Brown	Redwood	5.1	0.28	102	45	9	0.04	119	"147"
TDC 23.34	Tree Nursery	Brown	Motupiko	3.4	0.169	19	15.4	11.7	0.04	16.6	57
TDC 23.35	Vineyard	Gley	Cotterell	5.1	0.21	58	24	9.3	0.03	48	85
TDC 23.36	Hop Farm	Brown	Tapawera	3.2	0.165	50	12.2	13.7	0.03	59	71
TDC 23.37	Hop Farm	Brown	Tapawera	3	0.26	73	14.8	8.2	0.03	90	55
Tasman interim background (2023)				**9.5**	**0.35**	**290**	**55**	**21**	**0.1**[a]	**154**	**92**
ECO-SGV (2023)				**20**	**1.5**[b]	**200**	**95**[c]	**290**			**180**[c]

a. Median of Wellington background as no background determined for Tasman.

b. While Eco-SGV for Cd is 1.5 mg/kg, according to the Tiered Fertiliser Management Strategy, soil cadmium levels above 0.6 mg/ kg require more active management.

c. Eco-SGVs developed for sensitive soils based on the estimated median ambient concentration.

3.3.1. Arsenic

About 90 percent of samples had arsenic levels below or just above the background concentration (9.5 mg/kg). One of the historic sources of arsenic in New Zealand is pesticide treatments used in sheep dips, withdrawn from use from 1980s. However, there were three sites, including two orchards, with arsenic levels at or above the Eco-SGV (20mg/kg). One possible source of arsenic contamination in orchards is leaching from copper chrome arsenate (CCA) treated posts, which are still being used.

These orchard sites (TDC 23.4 and TDC 23.5) also showed elevated levels of other trace elements including Cu, Pb and Hg. In the previous round of monitoring, these two sites showed similar elevated levels of these elements. This can confirm the persistence of heavy metals is soils.

In New Zealand, one of the main sources of lead contamination in soils is historic use of lead-based paints, while mercury is relatively low and is often not an issue.

3.3.2. Copper

Among three orchard sites (TDC 23.4, TDC 23.5 and TDC 23.25) with Cu levels higher than the background, TDC 23.4 was the only one exceeding the Eco-SGV. All the other sites had Cu levels below the background. The main source of copper in horticultural soils is often Cu-based pesticides, which are widely used in New Zealand. On the other hand, there were three drystock sites with copper levels lower than 5 mg/kg, which can potentially result in copper deficiency in pasture in long-term, if not improved.

3.3.3. Cadmium

Cadmium concentrations ranged from <0.01 to 0.54 mg/kg, with a median of 0.26 mg/kg. Among nine sites which had levels higher than the background level (0.35 mg/kg), only one of them is an orchard and the rest are under dairy pasture. Elevated levels of Cd often come from excessive application of phosphate fertilisers. However, none of them exceeds target value of Tiered Fertiliser Management Strategy (0.6 mg/kg) or the Eco-SGV (1 mg/kg).

3.3.4. Nickel

Nickel concentrations were below background level (154 mg/kg) for all sites, except three sites on the Waimea Plains, ranging between 180 to 270 mg/kg, which is likely to be attributed to outwash from the ultramafic Dun Mountain belt.

3.3.5. Chromium

Chromium concentrations at all the sites were below the background level of 290 mg/kg. Similar to spatial accumulation of nickel, distinguished higher Cr levels were found at few sites on the Waimea plains, which are likely to be related to outwash of the ultramafic Dun Mountain belt into Fluvial Recent soils.

3.3.6. Zinc

Among 37 sites sampled, only 7 sites had zinc concentrations higher than the background level (92 mg/kg), which none of them exceeds Zn Eco-SGV for sensitive soils: 180 mg/kg. One of the main sources of zinc in orchard soils can be Zn-based pesticides such as Ziram.
On the other hand, none of the soil samples was found Zn-deficient.

3.4. Soil Physical Attributes

3.4.1. Dry Bulk Density

Dry Bulk Density (DBD) is the weight of soils in a specified volume, indicating the level of soil compaction. Compaction reduces water or air penetration into the soil profile, which restricts drainage and root growth. This can, in turn, increases surface water run-off and nutrient losses. Here, DBD medians, ranging from 0.9 to 1.2 Mg/m³, were all within the target ranges of 0.7 to 1.4 Mg/m3 (Fig. 11). However, Market Garden was at the high end, having the densest soils among all the land uses.

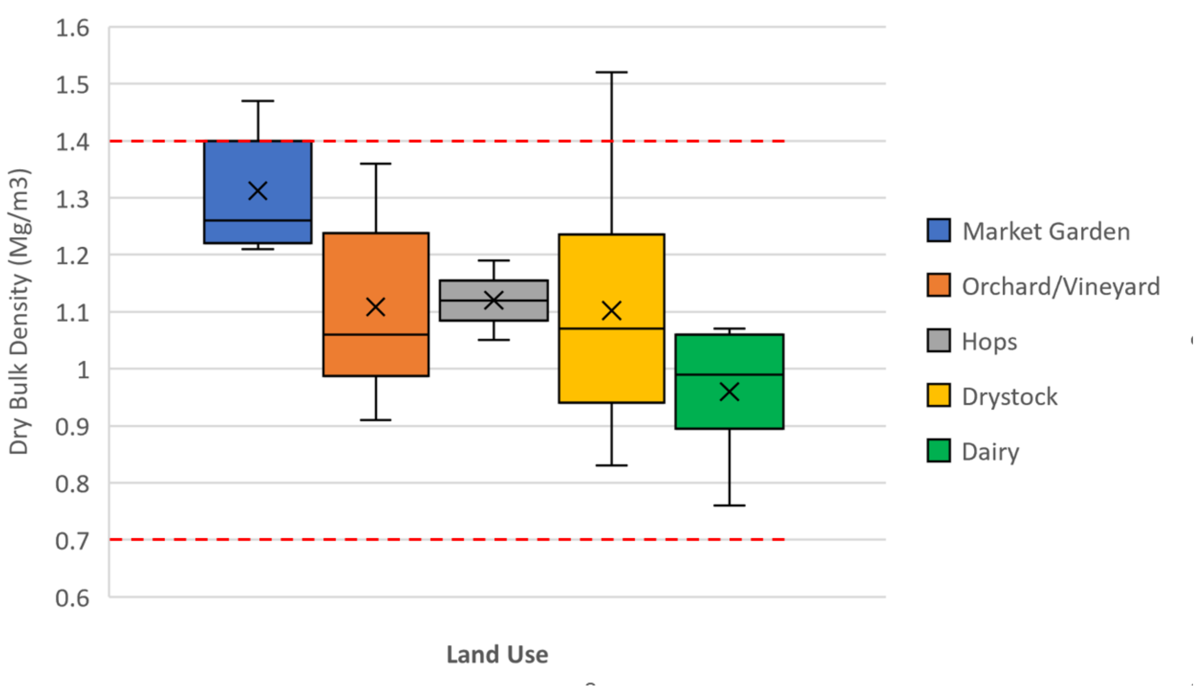

Figure 11. Dry bulk density values by land use for 2023 soil samples.
The red dashed lines show the target range: 0.7 to 1.4 Mg/m3.

3.4.2. Air Filled Porosity

Air Filled Porosity (AFP) also indicates the level of soil compaction and aeration. Macropores are important for air penetration into the soil and are the first pores to collapse when compaction happens. This can adversely affect plant growth due to restriction of root penetration and air access.

It is believed that AFP levels lower than 10 percent can adversely affect plant growth. Here, among all the land uses, dairy pasture and orchard/vineyard had significantly lower AFP (5.2%) (Fig.12). The possible reasons are high stocking rates and excessive use of heavy machinery, respectively.

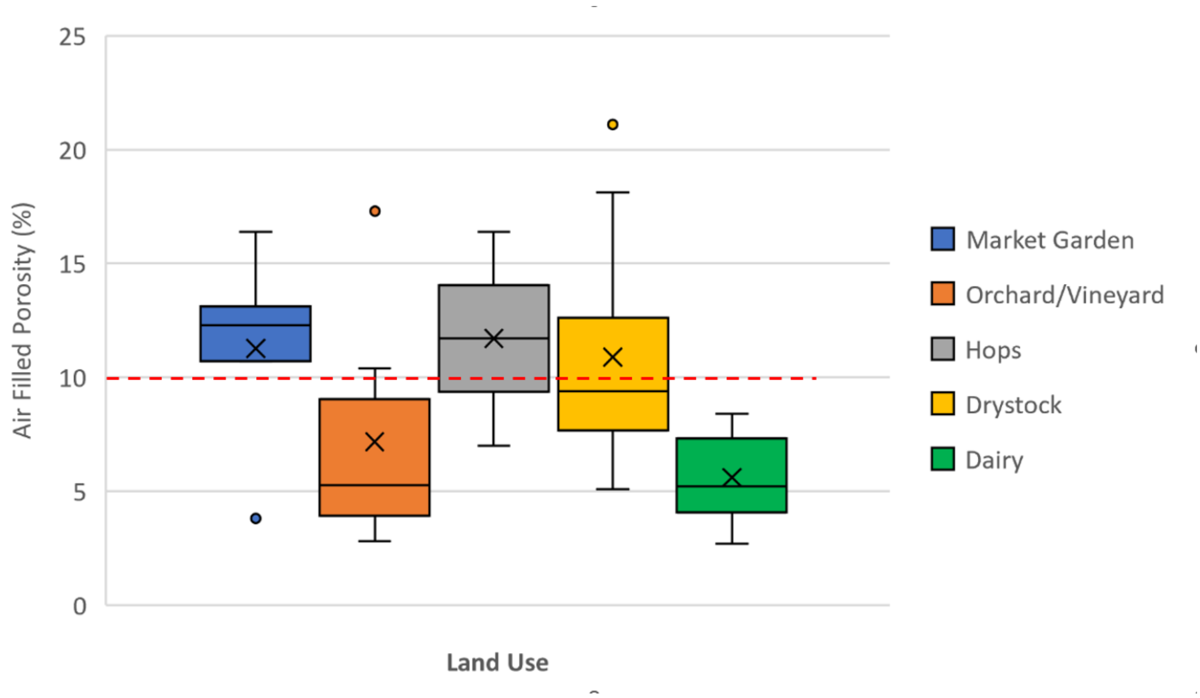

Figure 12. Air-filled porosity percentage by land use for 2023 soil samples.
The red dashed line shows the minimum target value: 10%.

Looking at the average AFPs of the representive sites between 2001 to 2023 shows that although the overal trend is increasing (mainly due to low number of sites sampled in 2001), there had been a significant drop (about 4 kPa) from the last round of monitroing in 2015 (Fig. 13).

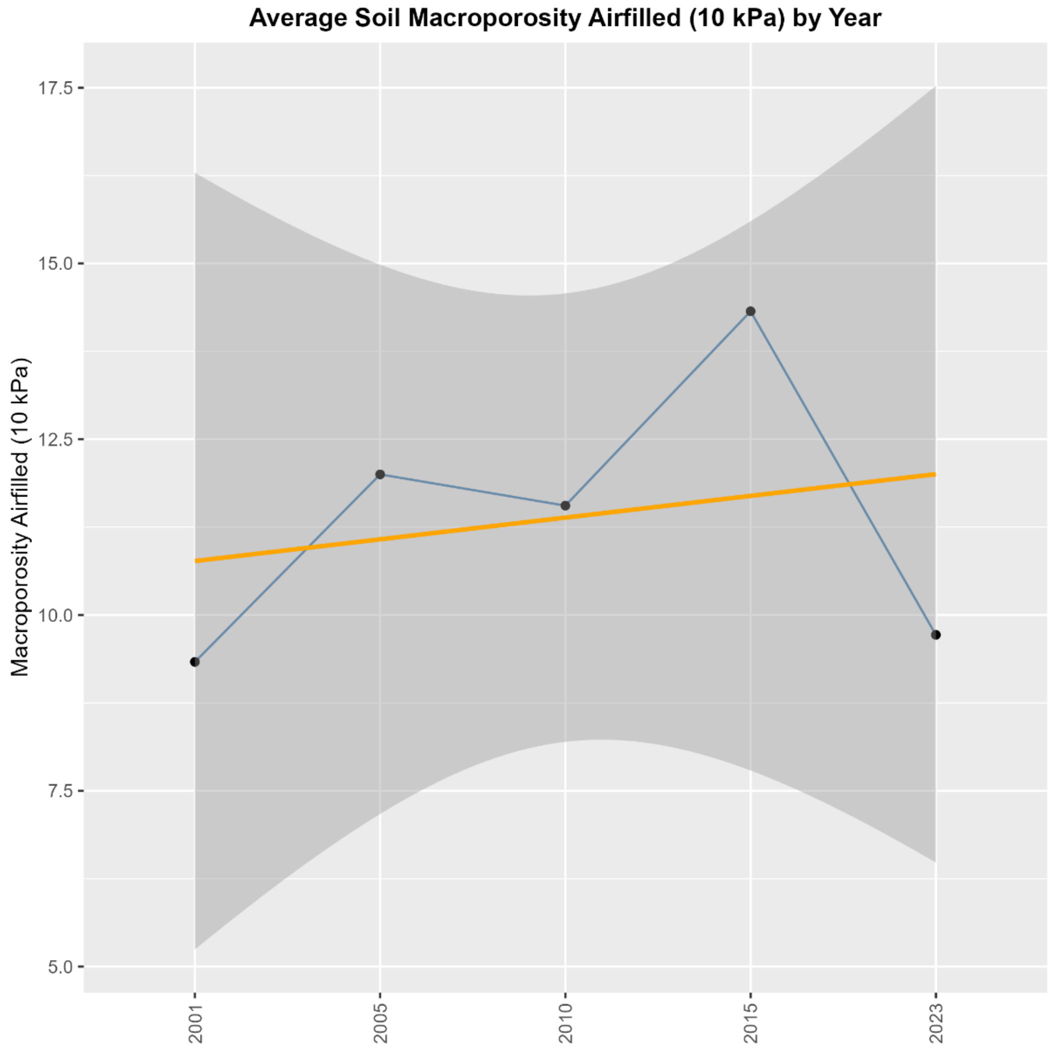

Figure 13. Overall trend of AFP for sites sampled three times between 2001 and 2023 (TDC1-9 & TDC11-15).

3.4.3. Summary of Soil Physical Results

Interpretation of physical attributes is more complex than other attributes, as they are often correlated with soil biological properties including organic matter. As a rule of thumb, soils with higher organic matter content have a lower bulk density. This can explain bulk densities observed here, showing Dairy with the lowest bulk density and Market Garden with the highest.

On the other hand, the results confirm that AFP can be a reliable indicative for soil compaction, which is not masked by organic matter impact. AFM results, here, show some degrees of soil compaction in Dairy and Orchard/Vineyard, where animal treading and machinery use can be the possible causes, respectively. Market garden sites had acceptable AFP, which is probably because of temporal impacts of cultivation on surface soil integrity. However, comparing the overall AFP results of the last two rounds of monitoring suggests that further compaction of agricultural soils can significantly affect soil health in near future.

4. Conclusion

All in all, comparing the soil quality under different land uses, drystock and hops represent the healthiest status in which all the soil attributes measured fit within the national target ranges.

On the other hand, some soil attributes fell out of the optimal target ranges for other land uses. For instance, soils under market gardening were often found low in organic carbon, which can adversely affect soil structure and integrity. This can potentially be addressed by reducing/improving cultivation and increasing soil organic matter *via* soil improvers. To support this, TDC is leading a research project with Manaaki Whenua - Landcare Research to investigate efficiency of potential soil conditioners such as compost, green manure, sawdust, and biochar.

The other finding was relatively high nitrogen levels in dairy soils, which can be attributed to excessive nitrogen input. Dairy farmers need to be aware of and manage elevated nitrogen levels to reduce the risk of nutrient losses to water as well as reduce soil compaction risks by imbalanced animal treading.

Likewise, orchard/vineyard sites also showed a degree of soil compaction, which is mainly under/around wheel tracks between the rows.

The soil quality issues identified in Tasman, including the risk of nutrient loss to water, soil compaction and loss of organic matter, are also of concern in some other regions such as Marlborough. The recommendations include a series of practice changes by respective land users including changing practice to lift soil carbon levels, minimise excess nutrient levels and reduce soil compaction. Some of these changes may have far-reaching consequences for farm practice.

In particular, market gardens need to lift soil carbon levels to improve soil structure and reduce erosion risks.

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Appendix 1: Sampling and Analytical Methods

At each site, a 50m transect was laid out as below:

For chemical/biological analyses, 25 individual soil cores with 2.5cm diameter to a depth of 10cm are taken every 2m along the transect. The cores were bulked and sent as a composite sample for chemical and biological analyses. Analyses were carried out at Hills Lab in Hamilton.

For the physical analyses, three undisturbed soil samples were obtained from each site at 15m, 30m, and 45m intervals along the transect by pressing steel liners, with 10cm width and 7.5cm depth, into the top 10cm of soils, as below.

Analyses were carried out at the Landcare Research Soil Physics Laboratories in Hamilton.

Recommended procedures for soil biological, chemical and physical analyses are:

- **Total C and N** – analyses using high temperature combustion methods.

- **Soil pH** – measured by glass electrode in a slurry of 1 part by weight of soil to 2.5 parts water.

- **Olsen P** – extraction by shaking for 2 h at 1:20 ratio of air-dry soil to 0.5 M $NaHCO_3$ at pH 8.5, filtered, and the phosphate concentration measured by the molybdenum blue reaction using Murphy-Riley reagent.

- **Potentially mineralisable N** – estimated by the anaerobic incubation method. Moist soil is incubated under waterlogged conditions (5 g equivalent dry weight with 10 ml water) for 7 days at 40°C. The increase in ammonium-N extracted in 2 M KCl over the 7 days gives a measure of potentially mineralisable N.

- **Dry bulk density –** measured on a sub-sample core of known volume dried at 105°C (Gradwell and Birrell, 1979). The weight of the oven-dry soil expressed per unit volume, gives the bulk density. The bulk density is also needed to calculate porosity.

- **Macroporosity –** is calculated from the total porosity and moisture retention data: $S_m = S_t - \theta$, where S_m is macroporosity, and S_t is total porosity and θ is the volumetric water content at -10 kPa tension (Klute, 1986).

- **Trace elements –** use the total recoverable trace element extraction method - US EPA 200.2.