tasman
district council

State of the Environment Report

Soil Health Monitoring

2015 Sampling Programme

Soil Health Monitoring Programme

Soil Health Sampling 2015

Document Status: Draft

The purpose of this report is to provide information about the health status of the soils in the Region

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Cover Photo: Soil profile of a Dovedale silt loam.

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1 Introduction

The aim of this monitoring programme for Council is to collect and interpret information on soil health in the region, as required by the Resource Management Act 1991 for the purposes of State of the Environment reporting. The information will contribute to improved sustainable management by providing quantitative data to evaluate the risk to, and state of, the soil resource under intensive land use.

Monitoring of Soil Health in the Tasman District was initiated in 2000 with the collection of information at 10 sites as part of the Ministry of the Environment's "500 Soils Project". The sites selected were four pastoral (dairying) sites, three rehabilitation sites (mining and gravels extraction), two orchard sites and one market garden site (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 sampling sites to 35. These covered dairying pasture, and introduced sheep and beef grazing, viticulture, cropping and additional market gardening sites.

This report summarises the soil quality monitoring undertaken at five pastoral sites in 2015, and compares these findings with the results of the 2005 monitoring programme.

2 Method

The 2015 programme revisits five sites that were last sampled in 2005. The sites TDC15.11, TDC15.12 and TDC15.13 (a hill country site) are under pasture, with long-term sheep and beef grazing. Sites 12 and 13 received inputs of nitrogen (N) fertiliser as part of the 2004 "Wise Use of N-Fertiliser on Hill Country" trial (AgResearch NZ), which assessed the intensive use of nitrogen fertilizer (129 kg N/ha) in stimulating production on hill country. Site 11 was a control site, and received no N fertiliser inputs. The sites TDC15.14 and TDC15.15 are pastoral soils from a dairy factory farm in Takaka.

The sites and their description are listed in Table 1 below.

Table 1: Sites and Description.

Site code	Soil type	Land use
TDC15.11	Stanley silt loam	Pasture; long-term sheep/beef
TDC15.12	Stanley silt loam	Pasture; long-term sheep/beef
TDC15.13	Stanley silt loam (hill soil)	Pasture; long-term sheep/beef
TDC15.14	Karamea silt loam	Pasture; long-term dairying
TDC15.15	Dovedale gravelly loam	Pasture; bull beef grazing

At each sample site, a site description and soil profile was completed and sampling carried out to assess the following basic soil properties:

1 Total Carbon
2 Total Nitrogen
3 Mineralisable Nitrogen
4 Olsen P
5 Soil pH
6 Bulk density
7 Macroporosity

These are the soil properties used in the "500 Soils Project" and the sampling protocols for these are found in Appendix 2.

In addition to these properties, heavy metals (total recoverable); arsenic, cadmium, chromium, copper, lead, nickel, zinc were assessed.

Heavy metal analysis indicates the potential contamination risk associated with some past and present land use practises such as fertilizer application and disease control. For example, cadmium is a contaminant of super phosphate, while facial eczema treatments contain high levels of zinc, and copper is used as a fungicide in orchards. Heavy metals accumulate in the soil, hence even small inputs on a yearly basis may in the long term accumulate to detrimental levels.

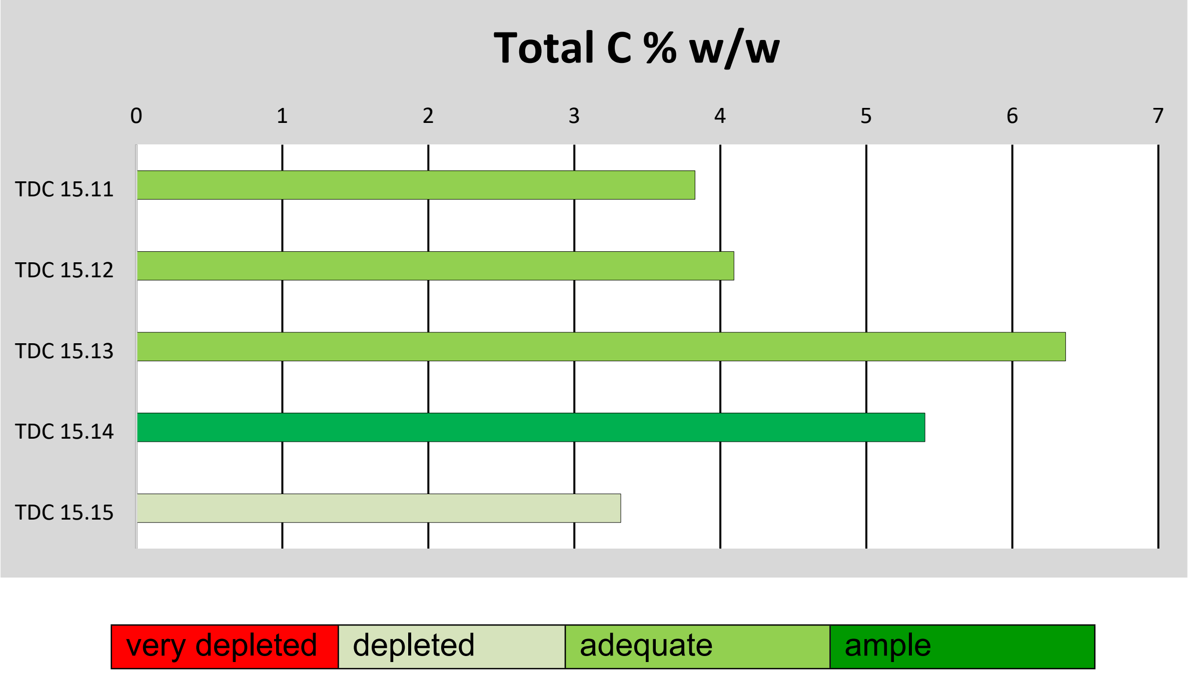
Soil properties themselves are not a measurement of soil quality; rather, soil quality is a value judgement about how suitable a soil is for its particular land use. A group of New Zealand soil scientists have developed soil response curves for each of the soil properties, and established critical values or optimal ranges for the predominant Soil Orders and land uses. The evaluations of soil quality in this report are based on the findings of that work, however as new information is gathered and our understanding of the science grows, the critical values and ranges may eventually be adjusted.

3 Results

3.1 Organic Resources

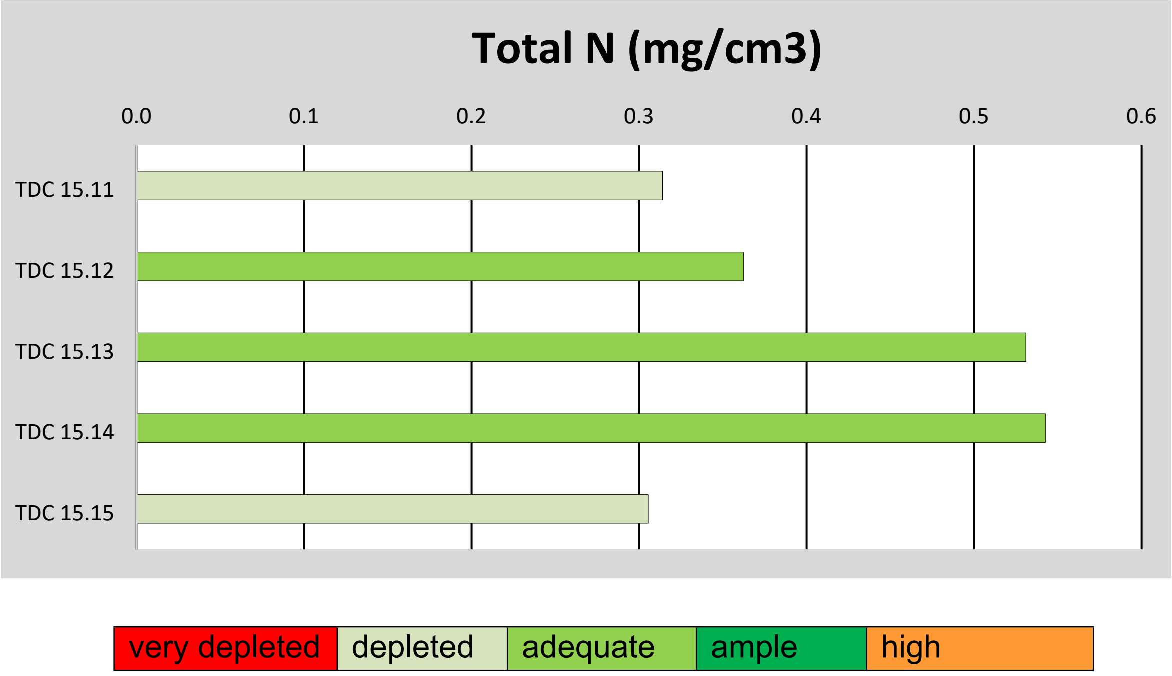
Total Organic Carbon (TOC) levels are an indication of organic matter content, which is important for moisture and nutrient retention and for good soil structure. The issues relating to TOC are soil organic matter depletion and C loss from the soil, generally as a result of intensive land use. The sample results, ranging from 3.3 to 6.4 mg/cm³, are displayed in the following chart.

Target C levels differed by Soil Order. The only Recent soil in the survey; Site TDC15.14 measured 5.4 mg/cm^3, which is *ample* for that Soil Order. The remainder of sites are on Brown Soils. The long-term sheep and beef sites (TDC15.11-13) had *adequate* C content, while *depleted* levels were measured at site TDC15.15.

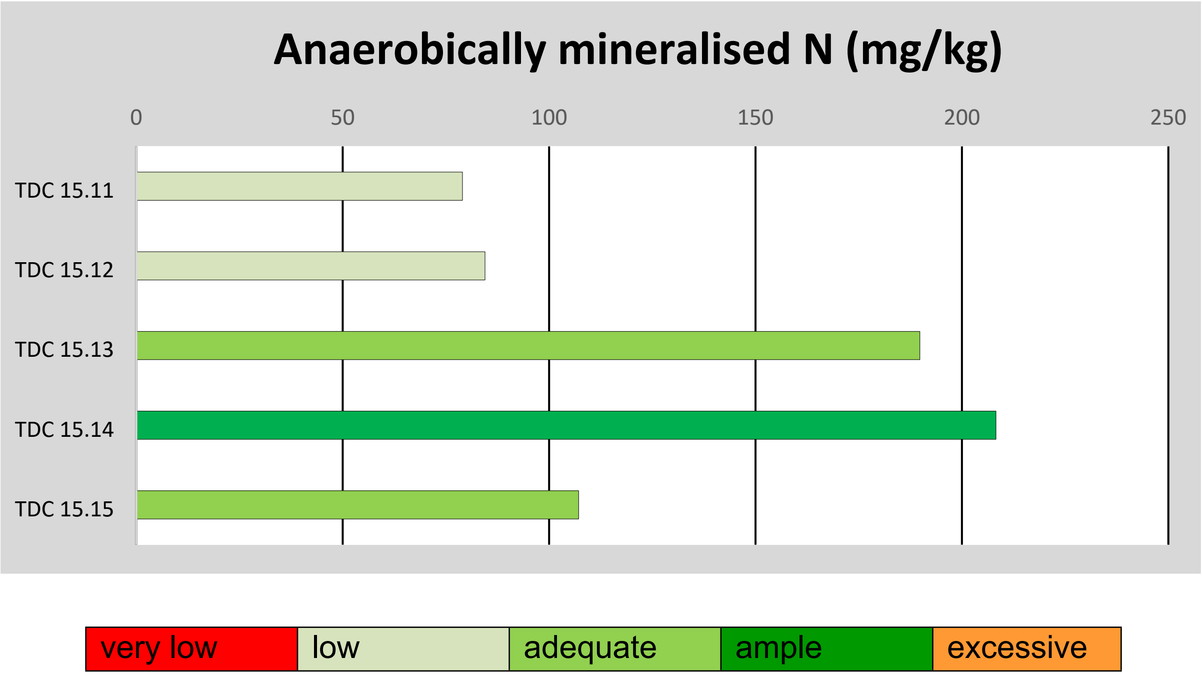


Total Nitrogen (TN) gives a measure of the reserves of organic matter in the soil as most N in soil is within the organic matter fraction. Nitrogen is an essential nutrient for plants and animals. Usually only a small fraction of the TN is immediately available for plant uptake (soluble inorganic N). While a variable proportion of the TN is potentially mineralisable to inorganic N. In general, high TN indicates the soil is in good biological condition. However, very high TN contents may increase the risk that N supply may be in excess of plant demand, and ultimately lead to leaching of nitrate to groundwater. The sample results range from 0.31 to 0.54 mg/cm^3 of TN and are displayed on the following chart.

The N trial control site; TDC15.11 and the pasture grazing site TDC15.15 were TN *depleted*. *Adequate* levels of N were measured at the sheep and beef N fertiliser trial sites TDC15.12 and TDC15.13, as well as site TDC15.14.



Anaerobic Mineralisable Nitrogen (AMN) levels measure the readily decomposed organic N. This gives a measure of the level of activity of soil organisms. Soil organism activity is important for the overall functioning of the soil as it aids nutrient availability, water and gas movement/exchange and soil structural stability. Generally, the higher the AMN content is, the healthier the soil is. The results ranged from 79 to 208 mg/kg of AMN. No sites fell below the critical lower limit of 50 mg/kg.



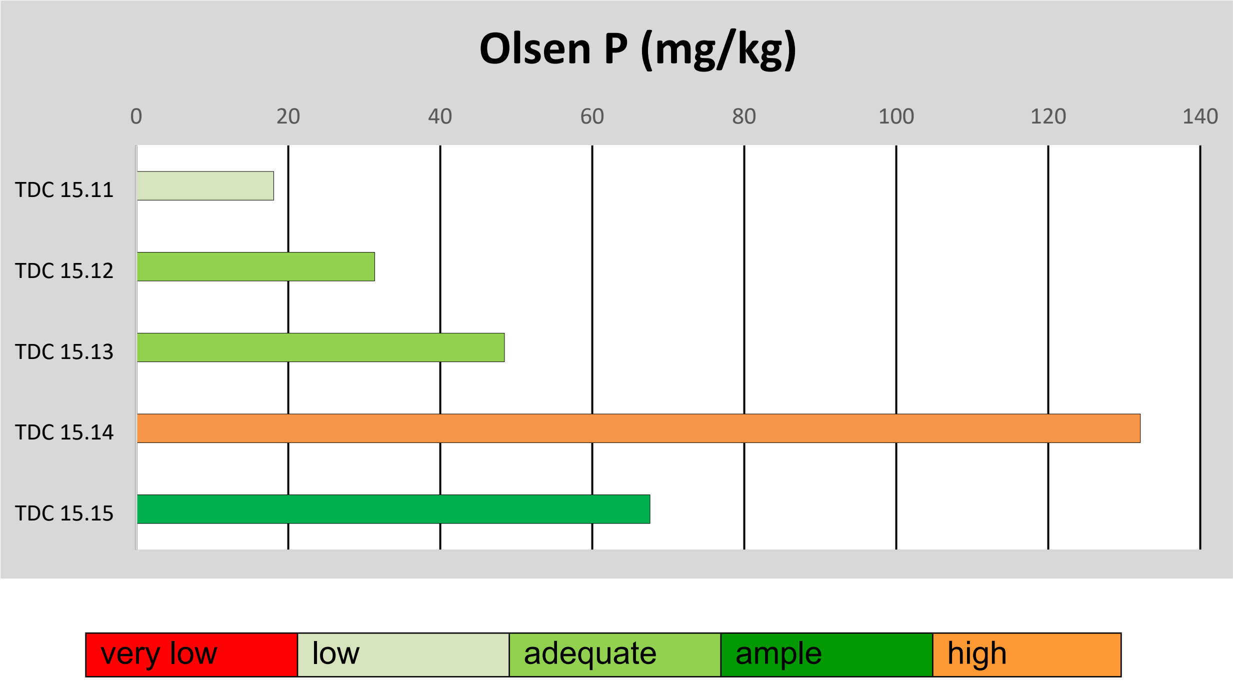
3.1.1 Discussion on the Soil Organic Resources

The results indicate that soil organic resources at the sheep and beef sites are generally adequate for total C and N. The exception being *depleted* levels of N at site TDC15.11 and TDC15.15. Site TDC15.11 was the control site for the 2004 N trial, and therefore received no N fertiliser inputs but had a similar grazing intensity. Soil organic matter is important for N storage. The *depleted* TOC and N levels detected at site TDC15.15 indicate that soil may have a poor ability to store N, resulting from a low soil C content. Compared to site 13, anaerobically mineralisable N was *low* at TDC15.11 and TDC15.12, but were in line with values expected for long-term pasture, according to the ECan 2008 Regional Environment report. This is most likely due to the reduced compaction on site 13; a hill site, as rainfall would runoff and not saturate the soil. On the flat sites; 11 and 12, pooling or saturation may occur and be more susceptible to compaction.

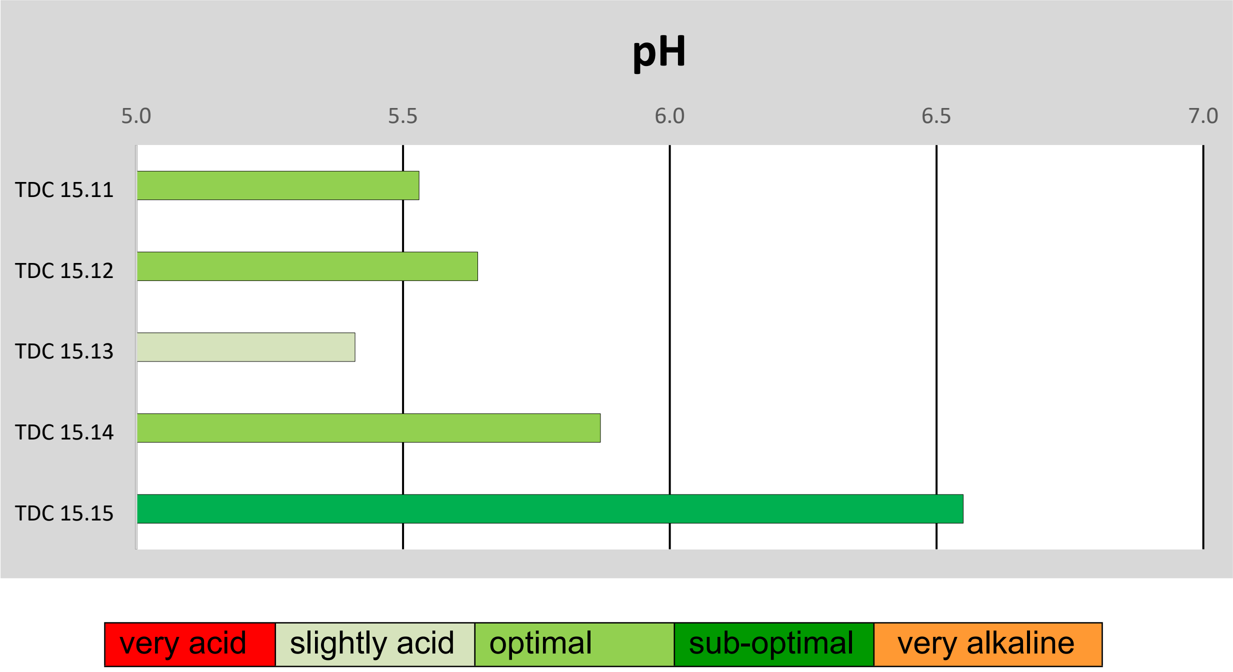
3.2 Soil Chemical Quality

Olsen P levels indicate 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 P from phosphates in soil. Many soils in New Zealand have low available P, necessitating inputs of manure, effluent or phosphates to increase suitability for intensive agricultural use. The issues associated with P inputs are the possible depletion of global rock phosphate reserves, the associated risk of increasing heavy metal content in the receiving soils ('heavy metals' may include contaminants of phosphate reserves), and excessive fertilizer use with the potential for accelerated P losses to waterways, resulting in eutrophication especially in highly weathered soils (i.e. Pakihi) or soils with a low P storage capacity. Results ranged from 18 to 132 mg P/kg.

Olsen P concentrations were varied across the data set. Site TDC15.14; a Recent soil had high concentrations at 132 mg P/kg. Site TDC15.15 had *ample* Olsen P values also (68 mg P/kg). TDC15.11 recorded *low* Olsen P levels.



pH is a measure of soil acidity. Most plants and soil animals 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 sites fall outside the favourable pH range for desired plant species. Also, some heavy metals may become soluble and bioavailable at certain pH ranges. The results were generally *optimal* for pasture growth, ranging from pH 5.4 to 6.6.

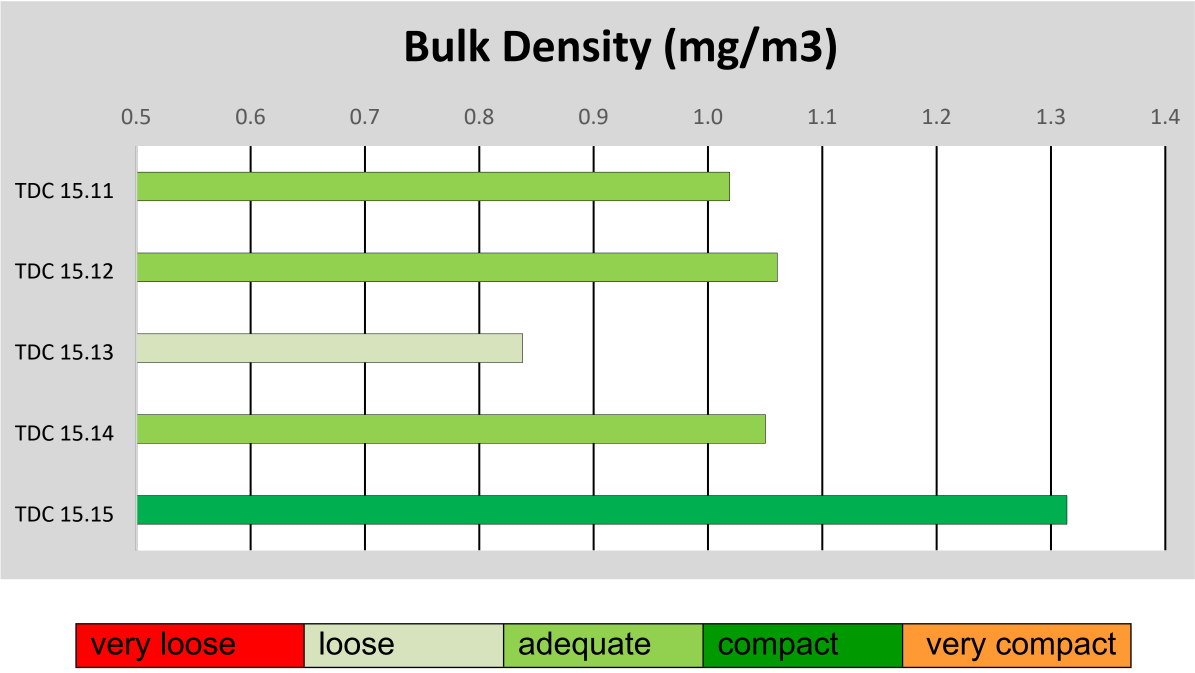


3.2.1 Discussion on Soil Chemistry

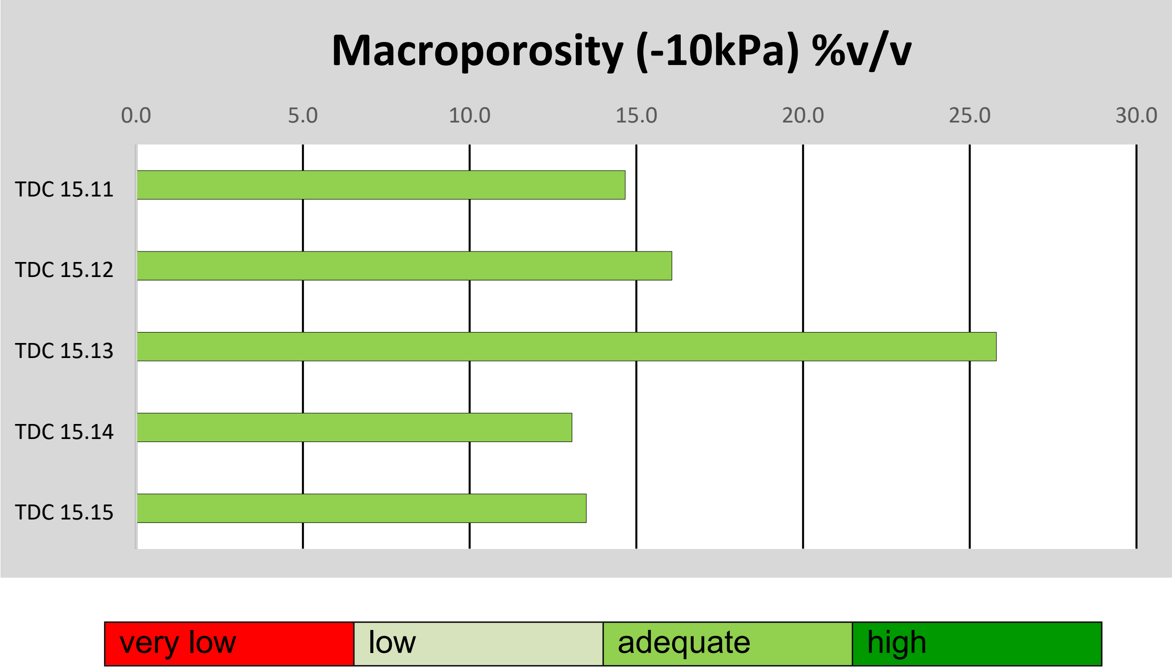
The soil chemistry properties indicate generally healthy soils at all sites. The *high* Olsen P concentration at TDC15.14 (132 mg/kg) indicates that the soil had either received fertiliser a short time before the sample was collected, or the site is subject to over-fertilisation. Similarly, TDC15.15 had an Olsen P level of 68 mg/kg, which is considered *ample* for soil fertility. At these concentrations there is a risk of environmental consequences, should runoff occur. The fertility of the sheep and beef soils were generally *adequate*, however TDC15.11 indicated some level of deficiency.

3.3 Soil Physical Characteristics

Bulk Density levels indicate the level of soil compaction. Compacted soils restrict water or air penetration into the soil profile, which restricts drainage and root growth. This in turn has the potential to increase surface water run-off and nutrient losses. The results ranged from 0.8 to 1.3 mg/m³. All sites had bulk density levels falling within the target ranges of *loose, adequate* or *compact*.



Macroporosity levels also indicate the level of soil compaction and aeration. Macropores are important for air penetration into soil, and are the first pores to collapse when soil is compacted. This can adversely affect plant growth due to poor root environment, restricted air access and N-fixation by clover roots. The results range from 13.1 to 25.8 %v/v as indicated in the chart below.



3.3.1 Discussion on Soil Physical Results

All of the sites were indicated to be at target levels for physical soil health. The bulk density of the Stanley hill soil; at the sheep and beef site was *loose*, but at 0.84 mg/m^3 it was bordering on *adequate* (0.9 mg/m^3). This site; TDC15.11 had markedly higher levels of N, AMN and C. All of which are indicators of soil organic resources and microbial content. Soils with higher organic matter content have a lower bulk density, and hill slopes are less prone to compaction, which explains the slight discrepancy between the other Stanley soil sites.

3.4 Trace Element Analysis

A deficiency or an excess of trace elements in soil can have a major bearing on soil health despite their low concentrations. Some trace elements are essential micronutrients for plants and animals. Others are not. However, both essential and non-essential elements can become toxic at higher concentrations.

A suite of the most common environment-impacting elements; arsenic, chromium, cadmium, copper, lead, nickel and zinc were measured at each site. These trace elements can accumulate in soils as a result of common agricultural and horticultural land use activities and are most likely to have a negative effect on soil quality.

The Ministry for the Environment's "Environmental Guideline Value (EGV) database" has been used to provide guidance as to which soil guideline values to use for interpretation of the data gathered. The guideline is used to assess if values for specific trace elements are at concentrations in soils that are likely to have a negative effect on soil quality. These effects specifically include factors such as soil microbial function, soil invertebrate populations, phytoxicity, animal health, the protection of groundwater and the protection of human health. The results of the trace element tests are presented in Table 2 below.

Table 2: Trace Element levels (total recoverable) of Sites Sampled in the Tasman District: 2015

Site Code	**Land Use**	**Soil Type**	**Arsenic** mg/kg dry wt	**Cadmium** mg/kg dry wt	**Chromium** mg/kg dry wt	**Copper** mg/kg dry wt	**Lead** mg/kg dry wt	**Nickel** mg/kg dry wt	**Zinc** mg/kg dry wt
TDC 15.11	Pasture	Stanley Brown	2	0.15	6	3	4	4	19
TDC 15.12	Pasture	Stanley Brown	2	0.18	10	6	7	7	36
TDC 15.13	Pasture	Stanley (hill) Brown	2	0.25	12	9	11	9	56
TDC 15.14	Pasture	Karamea Recent	13	0.28	80	30	16	51	112
TDC 15.15	Pasture	Dovedale Brown	2	0.21	11	13	22	8	36
Guideline values adapted from NZWWA (2003)			20	1	600	100	300	60	300

3.4.1 Discussion on Trace Element Analysis

Arsenic levels are well below guideline levels at all sites. This is to be expected from long-term pastoral sites, as arsenic is typically derived from pesticides and herbicides where it is measured in high quantities in the district. These sprays have been withdrawn from use in New Zealand for several decades, so levels should be declining in all areas.

Cadmium levels range from <0.15 to 0.28 mg/kg, with an average of 0.21 mg/kg. New Zealand has a national average baseline (i.e. the 'natural' background level in soils) value for cadmium of 0.16 mg/kg, which is consistent across all regions and soil types. The current national average concentration of cadmium from soils used for agricultural production is 0.35, with a range of 0-2.52 mg/kg.

Copper levels are below guideline levels at all sites. Products containing copper were historically and are still widely used in New Zealand as animal remedies (e.g. facial eczema treatment), veterinary medicines and pesticides. Soil copper concentrations that are < 5mg/kg may result in copper deficiency in plants, particularly under pasture. At 3 and 6 mg Cu/kg, the Stanley Brown pastoral sites may need Cu supplementation to optimise pasture growth.

Nickel levels were below guidelines for all sites, however the Karamea Recent soil pasture site (TDC15.14) came close at 51 mg/kg. Nickel concentrations are typically related to the parent material, and for a Karamea Recent soil, a high nickel content could be attributed to outwash from the ultramafic Dun Mountain Ophiolite belt.

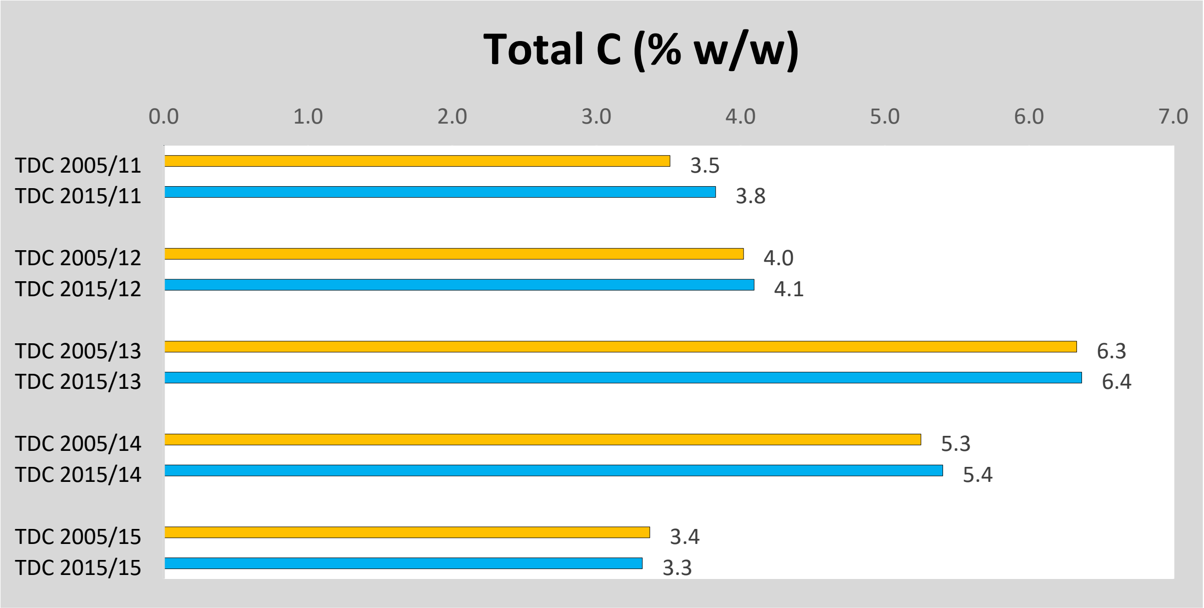
4 2005 – 2015 data comparison

The following charts represent the data collected at sites 11 to 15 in 2005 and 2015. Samples were collected from the same transects at the sites using the same sampling and testing protocol.

4.1 Organic Resources

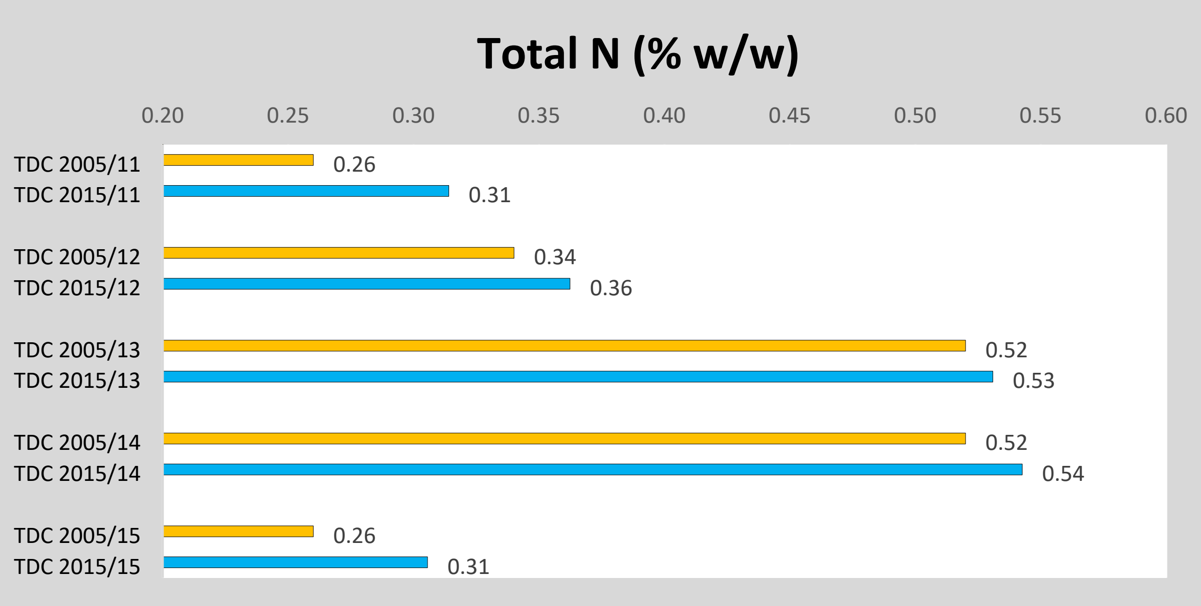
Total Carbon levels are an indication of organic matter content, which is important for moisture and nutrient retention and for good soil structure. The issues relating to total carbon are soil organic matter depletion and carbon loss from the soil, generally as a result of intensive land use.

Total Carbon has not changed significantly at the majority of sites between 2005 and 2015, increasing by an average of 0.1%. This indicates that organic matter inputs and losses have been well balanced over this time, most likely due to low-intensity grazing regimes.



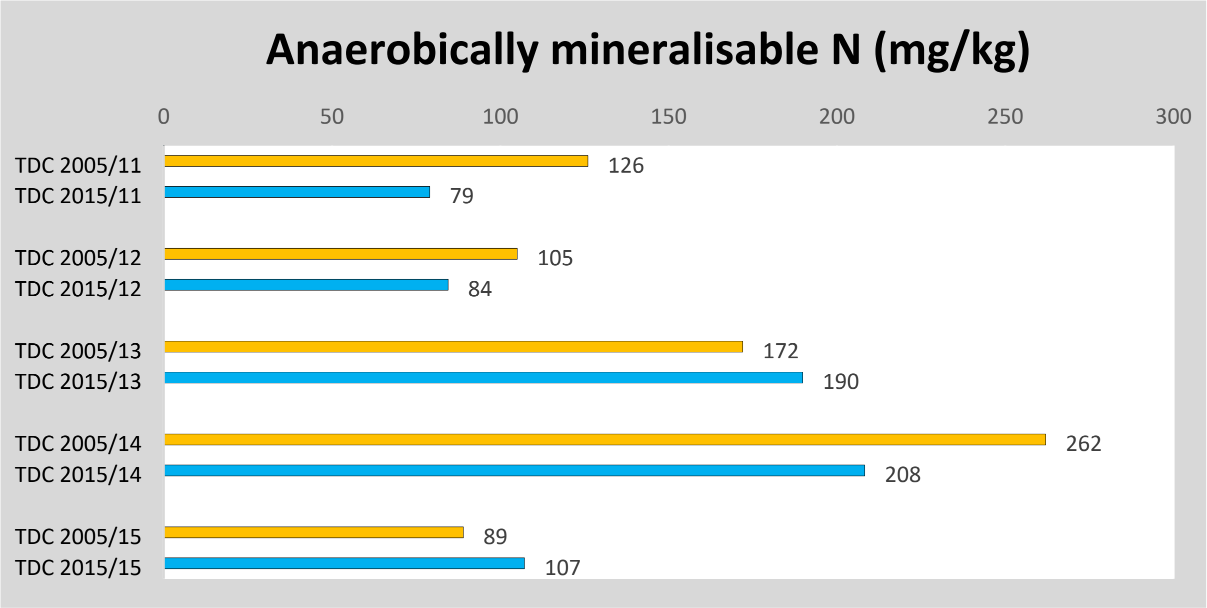
Total Nitrogen gives a measure of the reserves of organic matter in the soil as most nitrogen (N) in soil is within the organic matter fraction. Nitrogen is an essential nutrient for plants and animals. Usually only a small fraction of the total N is immediately available for plant uptake (soluble inorganic nitrogen). While a variable proportion of the total nitrogen is potentially mineralisable to inorganic N. In general, high total nitrogen indicates the soil is in good biological condition. However, very high total nitrogen contents may increase the risk that nitrogen supply may be in excess of plant demand, and ultimately lead to leaching of nitrate to groundwater.

Total Nitrogen (TN) has increased slightly at all sites. The greatest changes were sites 11 and 15 where TN increased by 16%. Despite this increase, the target range status of each site did not change, remaining within the *depleted* range (0.25 – 0.35%w/w). Sites 11, 12 and 13 were part of the same farm and were managed together. The lower TN at site 11 is expected, as during 2005 it was the control site for an N fertiliser experiment, where sites 12 and 13 received 129 and 144 kg N/ha in 2004 and 2005, respectively. The higher N fertiliser content at site 13 (Stanley Brown – hill soil) is expected, as hill country soil has a greater response to N fertiliser than highly developed flat land.



Anaerobic Mineralisable Nitrogen (AMN) levels measure the readily decomposed organic Nitrogen. This gives a measure of the level of activity of soil organisms and the potential of soil to provide nitrogen to growing plants. Soil organism activity is important for the overall functioning of the soil as it aids nutrient availability, water and gas movement/exchange and soil structural stability. Generally, the higher the AMN content is, the healthier the soil.

The status of several sites have changed. Sites 11 and 12 decreased from 126 to 79 mg/kg, and 105 to 85 mg/kg, respectively, changing from *adequate* to *low*. These decreases most likely reflect a change in land use or soil management regime following the N fertiliser trial. The land owners reportedly changed the type and stocking rate of cattle for grazing from 2006. The Stanley hill sample; site 13 remained at *adequate* levels. Site 14 decreased from *high* to *ample* levels from 2005 to 2015, while site 15 increased from *low* to *adequate*.

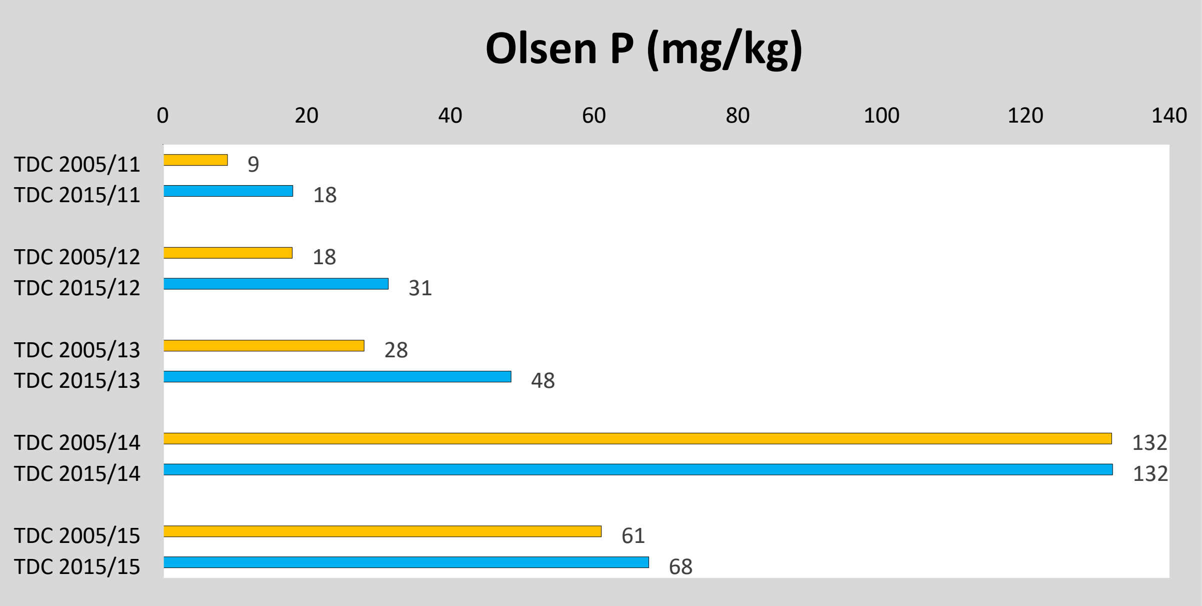


4.2 Chemical Resources

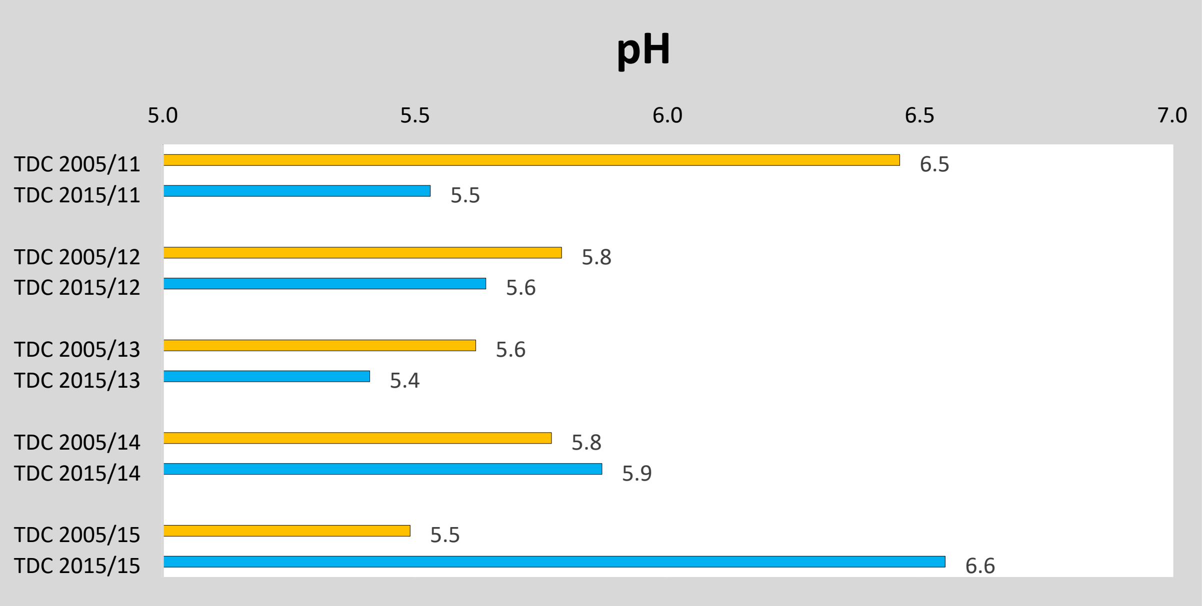
Olsen P levels indicate the level of plant available phosphorus and general fertility of the soil. The concentration of P in surface runoff is closely related to the level of available P in the soil – and hence the Olsen P test. Thus, any increase in Olsen P levels in soils could increase P runoff into rivers, streams and lakes.

Olsen P concentrations increased at all three Stanley silt loam sites. The status of site 11 increased from *very low* to *low*, site 12 increased from *low* to *adequate* and site 13 remained unchanged at *adequate* Olsen P concentrations. According to the N fertiliser trial, the three sites were to be managed as a single farm unit, suggesting they would receive similar rates of fertiliser. While the change in Olsen P concentrations was not equivalent for sites 11, 12 and 13 (with increases of 9, 13 and 20 mg P/kg, respectively), Olsen P will increase by a greater amount for a given P fertiliser rate when background soil Olsen P levels are already elevated. This is due to the soil's reduced ability to buffer phosphate inputs (having met its P sorption capacity). The concentrations measured in the Stanley silt loam soils are not likely to pose a serious environmental risk.

Olsen P did not change at site 14 and 15, remaining at *ample* and *high* status. At these Olsen P concentrations there is a risk of P losses in runoff to waterways.



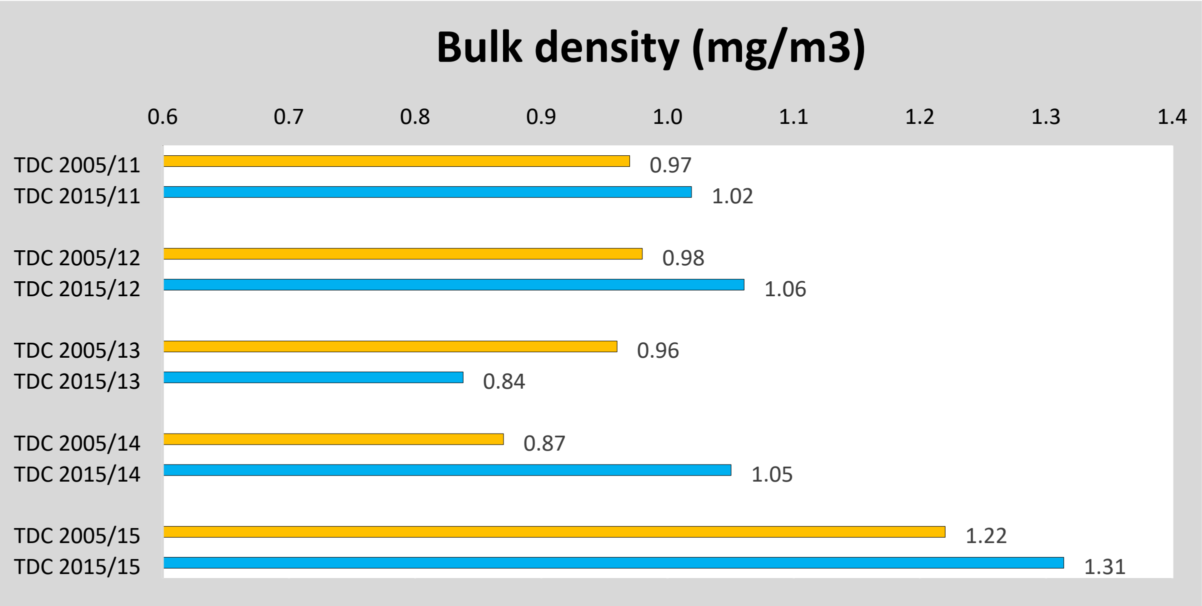
pH is a measure of soil acidity. Most plants and soil animals have an optimum pH range for growth. The pH of the Stanley silt loam soils decreased significantly from *optimal* to a mean of 5.5, verging on *slightly acid* (pH < 5.4). This indicates these soils could benefit from liming in the near future. The pH at site 14 increased by a negligible amount, however site 15 increased significantly. At pH 6.6 the site is considered *sub-optimal* to *very alkaline* for pasture.



4.3 Physical Resources

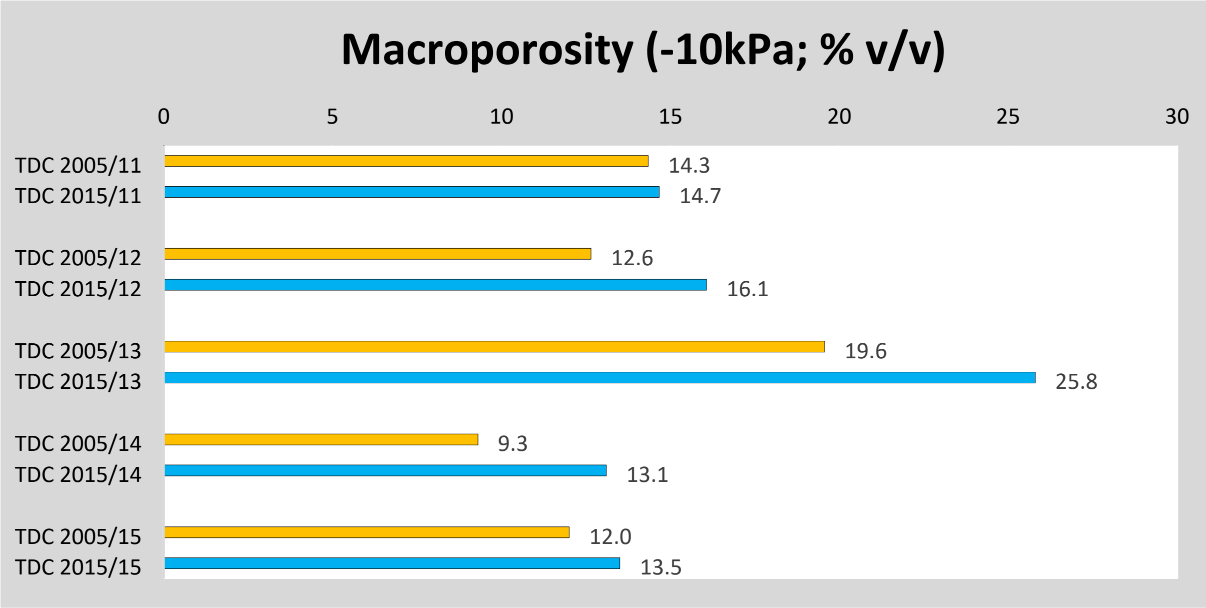
Bulk Density levels indicate the level of soil compaction. Compacted soils restrict water or air penetration into the soil profile, which restricts drainage and root growth. This in turn has the potential to increase surface water run-off and nutrient losses

There were changes in bulk density over the sampling time frame that modified the status of several sites. The three Stanley silt loam soils had similar densities in 2005, but in 2015 site 13 (hill site) had decreased by 0.12 mg/m^3. This could have been brought about by the planned changes to farm management, that included the stock type and rate. Sites 14 and 15 increased by 0.18 (*loose* to *adequate*) and 0.09 mg/m^3 (*adequate* to *compact*), respectively. These changes could also have been brought about by land use change including recent stock movement across the sample site.



Macroporosity levels also indicate the level of soil compaction and aeration. Macropores are important for air penetration into soil, and are the first pores to collapse when soil is compacted. This can adversely affect plant growth due to poor root environment, restricted air access and N-fixation by clover roots.

Macroporosity increased at all sites, but changes were favourable and not sufficient to alter the soil status beyond *adequate* levels. The most significant change was for site 13; a 24% increase in macroporosity. This, coupled with a decrease in bulk density at this site indicates the site had recovered somewhat from compaction.



5 Summary

The 2015 round of sampling included the re-sampling of all 2005 sites. The results indicate that soil quality is within target ranges for most of the measured variables.

The three sheep and beef sites on Stanley silt loam soils were in excellent condition. The soils had been the subject of a 2004 N fertiliser trial and received variable fertiliser inputs. Site 11 was a control site, whereas site 13 was a hill soil. These management and topographical differences explain much of the variability measured between the sites and the changes that were measured between sampling dates. Most notably, the comparably *low* TN measured at site 11 (fertiliser control site), and the higher bulk density and *low* anaerobically mineralisable N at the level-ground sites compared to the hill site (evidence of compaction).

The Karamea silt loam site; TDC15.14 has been used for dairy grazing and was in optimal condition for pastoral use. This was particularly evident from the *ample* anaerobically mineralisable N and total C content. There is evidence that the site is being intensively managed, as Olsen P concentrations were very high and had not changed between sampling dates – suggesting maintenance P application rates are excessive, which could pose an environmental risk. The site also had elevated nickel content, most likely attributable to outwash from the ultramafic Dun Mountain Ophiolite belt, but this did not exceed the NZWWA guideline values.

The Dovedale gravelly loam; Site TDC15.15 was used for bull grazing. The site was of moderate biological health with depleted total N and C, but had elevated Olsen P and pH levels. This suggests recent liming and P fertiliser application had occurred.

Bulk density measurements also indicated the soil was *compact*, which is not an issue in itself, but in combination with high Olsen P concentrations there may be a higher incidence of problematic surface runoff.

Comparing data from 2005 and 2015 shows general soil health has not changed a great deal, but has highlighted the effects of some soil management activities. These include the apparent recent liming at site 15 (a significant increase in pH), and the possible need for maintenance liming at the Stanley silt loam sites. Bulk density has increased at all sites, possibly indicating changes to the grazing regime or stocking rate or timing of sample collection.

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Appendix 1: 2015 Soil Physical and Chemical Characteristics Data

Table 3: Soil Physical Characteristics of Sites Sampled in the Tasman District: 2015

Site Code	Land Use	Soil Type	Bulk Density mg/m^3	Particle Density mg/m^3	Total Porosity % v/v	Macro Porosity (-5 kPa) % v/v	Readily Available Water % v/v	Total Available Water % v/v
TDC 15.11	pasture	Stanley silt loam	1.0	2.51	59.47	11.67	9.77	28.53
TDC 15.12	pasture	Stanley silt loam	1.1	2.59	59.07	13.13	9.27	31.63
TDC 15.13	pasture	Stanley (hill) silt loam	0.8	2.59	67.67	21.87	8.97	32.93
TDC 15.14	pasture	Karamea silt loam	1.1	2.59	59.40	1.00	9.27	47.77
TDC 15.15	pasture	Dovedale gravelly loam	1.3	2.57	48.83	10.50	6.83	18.70

Table 4: Soil Chemical Characteristics of Sites Sampled in the Tasman District: 2015

Site Code	Land Use	Soil Type	Total C mg/cm^3	Total N mg/cm^3	C:N Ratio	AMN mg/kg	Olsen P mg/kg	pH
TDC 15.11	pasture	Stanley silt loam	3.8	0.31	12.19	79.02	18	5.5
TDC 15.12	pasture	Stanley silt loam	4.1	0.36	11.30	84.47	31	5.6
TDC 15.13	pasture	Stanley (hill) silt loam	6.4	0.53	11.99	189.81	48	5.4
TDC 15.14	pasture	Karamea silt loam	5.4	0.54	9.95	208.25	132	5.9
TDC 15.15	pasture	Dovedale gravelly loam	3.3	0.31	10.86	107.15	68	6.6

Appendix 2: Sampling and Analytical Methods

At each site a 50 m transect is laid out. For chemical analysis 25 individual soil cores 2.5 cm in diameter to a depth of 10 cm are taken every 2 m along the transect. The cores are bulked and mixed in preparation for chemical analyses. Analysis is carried out at the Landcare Research soil chemistry and soil physics laboratories in Palmerston North.

For the physical analyses three undisturbed soil samples are also obtained from each site at 15, 30 and 45 m intervals along the transect by pressing steel liners 10 cm in width and 7.5 cm in depth into the top 10 cm of soil. Analysis is carried out at the Landcare Research soil chemistry and soil physics laboratories in Palmerston North.

For the aggregate stability measure take triplicate samples from the same transect positions as the soil cores (15-, 30- and 45 m). The sample consists of a vertical block of soil 10 cm deep, 10 cm wide and 1-3 cm thick from a fresh soil face. Analysis is carried out at the Plant & Food Research laboratories at Lincoln.

The trace element sampling procedure is a replicate of that carried out for the soil chemical analysis, with 25 individual cores bulked. Analysis is carried out at R J Hills Laboratory in Hamilton.

Recommended procedures for soil physical and chemical 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 NaHCO3 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 condition (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.
- **Water release** (used to calculate porosity) - Calculated from drainage on pressure plates at specific tensions (Gradwell and Birrell, 1979).

- **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.

- **Particle density -** Measured by the pipette method as described by Claydon (1989). The particle density information is needed to calculate total porosity (see below).

- **The total porosity -** Calculated from the formula: $S_t = 100[1- (p_b/p_p)]$ (Klute, 1986), where S_t is total porosity, p_p is the particle density and p_b is the dry bulk density.

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

- **Aggregate stability** is calculated from the mean weight diameters of aggregates remaining on 2 mm, 1 mm and 0.5 mm sieve after wet sieving.

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