

Determination of the level of soil N and P storage and soil health at the Rotorua Land Treatment site

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EXECUTIVE SUMMARY

Background

The Rotorua District Council (RDC) established a land-based municipal effluent irrigation scheme at Whakarewarewa Forest, Rotorua in 1991, with the dual aims of reducing the nitrogen and phosphorus loads entering Lake Rotorua. Consent conditions limit scheme origin inputs to the Waipa stream to 3 tonnes of total phosphorus and 30 tonnes of total nitrogen. An average of 19,000m³/day of municipal waste water is treated at the sewage treatment plant in Rotorua. The tertiary effluent is sprinkler-irrigated onto 193 ha of plantation forest at Whakarewarewa. The allophanic soils at Whakarewarewa are volcanic in origin, sandy and well drained, with a large capacity for retention of applied P. Removal of applied N in the upland soils was expected to occur as a result of plant uptake while removal further downstream was expected to occur as a result of microbial denitrification processes along stream margins, and receiving wetlands.

In 2012 the RDC commissioned Scion to implement a soil assessment programme to measure nitrogen (N) and phosphorus (P) stocks at pre-determined soil depth intervals in six permanent plots. These same plots had been measured in 1995, to estimate the change in N and P stocks within the soil profile since that time. The current sampling programme included an assessment of soil health.

Objective

- Determine the levels of N and P storage in the soil in 2012 and compare these with levels determined in 1995 for irrigated and control sites.
- Assess soil health in irrigated and non-irrigated control plots and compare findings against published soil health criteria as per the Ministry for the Environment Soil Health review.

Key Results

N and P stocks and changes

- The soil profile measurements in irrigated and non-irrigated control plots at Whakarewarewa allowed N and P stocks and changes to be estimated in 1995 and 2012. Key results are summarised in the tables below.

Changes in nitrogen

- N stocks to 100 cm depth were 601 and 762 kg/ha higher in irrigated than control plots in 1995 and 2012, respectively, which indicates that soil N stocks have not increased much since 1995.
- The annual storage rate of N decreased over time, averaging 150 kg/ha/year (corresponding to 29 t/year at the LTS assuming an area of 193 ha) from 1991-1995 and 9 kg/ha/year (corresponding to 2 t/year at the LTS) from 1995-2012 to 100 cm depth. N will have leached below 100 cm depth, so the change in rate over time to 200 cm depth cannot be determined.
- N storage appears to have occurred in the surface soil, where carbon levels increased due to effluent treatment.

Differences in total nitrogen stocks (kg/ha) and periodic mean annual storage rate by depth layer and over all depths between control and irrigated plots sampled in December 1995 and resampled in December 2012.

| Depth interval | 1995 Difference N kg/ha | 2012 Difference N kg/ha | 1991-1995 Storage Rate N kg/ha/year | 1995-2012 Storage Rate N kg/ha/year |
|----------------|-------------------------|-------------------------|-------------------------------------|-------------------------------------|
| 0-20 cm | 313 | 864 | 78 | 32 |
| 20-40 cm | 229 | 104 | 57 | -7 |
| 40-100 cm | 242 | -206 | 61 | -2 |
| 100-150 cm | - | -77 | - | - |
| 150-200 cm | - | 285 | - | - |
| 0-100 cm | 601 | 762 | 150 | 9 |
| 0-200 cm | - | 970 | - | - |

Changes in phosphorus

- P stocks to 100 cm depth were 531 and 2694 kg/ha higher in irrigated than control plots in 1995 and 2012, respectively, which indicates that soil P stocks have increased by 5-fold relative to the increase that had occurred by 1995.
- The surface 0-20 cm of soil P increased by 3-fold since 1995, and the 20-40 cm of soil P increased by 12-fold since 1995.
- The annual storage rate of P has not changed appreciably over time, averaging 133 kg/ha/year (corresponding to 25.6 t/year at the LTS) from 1991-1995 and 127 kg/ha/year (corresponding to 24.5 t/year at the LTS) from 1995 and 2012 to 100 cm depth.
- Assuming that P fixation in 1995 occurred within the top 100 cm of soil, the periodic mean P storage rate was 132 kg/ha/year (corresponding to 25.5 t/year at the LTS) from 1995 to 2012 to 200 cm depth.

Differences in total phosphorus stocks (kg/ha) and periodic mean annual storage rate by depth layer and over all depths between control and irrigated plots sampled in December 1995 and resampled in December 2012.

| Depth interval | 1995 Difference P kg/ha | 2012 Difference P kg/ha | 1991-1995 Storage Rate P kg/ha/year | 1995-2012 Storage Rate P kg/ha/year |
|----------------|-------------------------|-------------------------|-------------------------------------|-------------------------------------|
| 0-20 cm | 430 | 1202 | 108 | 45 |
| 20-40 cm | 81 | 950 | 20 | 51 |
| 40-100 cm | 20 | 542 | 5 | 30 |
| 100-150 cm | - | 92 | - | 5 |
| 150-200 cm | - | -11 | - | -1 |
| 0-100 cm | 531 | 2694 | 133 | 127 |
| 0-200 cm | - | 2775 | - | 132 |

- Differences in P stock changes occurred between irrigated plots, with plots 1 and 4 showing large increases in soil P down to 70 cm compared to plot 7 where changes were smaller (half that in the other two irrigated plots) and were confined to the top 40 cm of soil. This could be attributed to lower effluent loading rate.
- P retention capacity decreased mostly in the surface, although decreases occurred at all depths.
- Olsen P concentrations were high in the surface down to 70 cm depth. Olsen P concentrations were low below 70 cm depth, which suggests that effluent-origin P did not move below 70 cm. The small increase in Olsen P below 70 cm depth is likely to be due to higher soil pH's below 70 cm mobilising native soil P.

Soil health

Effluent irrigation resulted in increased soil levels for Olsen P, Total C, Total N, Anaerobic and Aerobically Mineralisable N, pH, electrical conductivity, and moisture content. Effluent irrigation decreased soil C:N ratio, bulk density (<2 mm fraction), and macroporosity but had no effect on total bulk density.

Key indicators used to describe aspects of soil health included bulk density, macroporosity for soil physical structure, Olsen P and anaerobic and aerobically mineralisable N for chemical fertility, Total C, Total N, mineralisable N for organic and fertiliser resources and pH for soil acidity. Soil health was assessed by applying a value judgement for forestry to the set of measured indicators. The value judgement was based on the range of values obtained for a large set of soil samples and expert knowledge (Sparling *et al.* 2008).

Comparisons showed that non-irrigated and irrigated soils were classified in the optimal range for soil physical structure, organic resources and soil acidity. Within this optimal range, irrigation improved organic resources in terms of total C and N and C:N ratio and increased soil pH and thus lowered soil acidity and decreased soil macroporosity. Olsen P as a measure of chemical fertility was classified as very low in the non-irrigated soil. This level was improved by effluent irrigation but levels were classified as excessive for productivity. It is unknown whether the excessive levels of plant available P were affecting plant productivity. However, after 5 years of irrigation, foliar P levels were well below the foliar limit above which excessive P would be expected to impact on plant productivity. Further foliage sampling will be necessary to determine the current impact of irrigation on foliar P levels.

Soil heavy metal levels in irrigated soils were well below heavy metal limits (NZWWA, 2003) and only Cu, Zn and Cr were higher in the irrigated than the non-irrigated soils. Nevertheless, more than 250 years of irrigation at current rate would not cause the irrigated soils to reach the current heavy metal limits for these elements.

Implications of Results/Conclusions

- Only minor changes in soil N storage are likely to occur at the LTS in future.
- Large increases in soil P stocks were expected to occur in irrigated plots since 1995 and were indeed found, although variation between plots was large.
- The capacity to store P at the LTS is still appreciable, although investigations of variation in irrigation rates across the LTS will be needed to improve spatial matching of future irrigation rates with the remaining P fixation capacity.
- Remaining P fixation capacity at the LTS will vary spatially, depending on factors such as depth to Rotorua lapilli, harvest related soil disturbance and compaction, past effluent loading rates, and future effluent loading rates, among other factors.
- In terms of soil health for productivity, effluent irrigation had an overall positive effect on soil quality except for soil macroporosity and Olsen P. Soil macroporosity, despite being classified as optimal, had decreased over time from the top of the range to the middle of the range. This will need occasional monitoring.
- Soil Olsen P levels were classified as excessive and would make these soils more prone to contaminate surface water if soil erosion should occur, causing P rich suspended solids to reach surface waters. In order to determine whether the excessive soil P levels currently impact on plant productivity, foliar P, Zn, Mn and Fe levels will need to be measured.
- Soil heavy metals levels would not pose any environmental risk based on current practices.

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INTRODUCTION

Land-based irrigation treatment of municipal wastewater was established in Rotorua, New Zealand in 1991, to decrease the nutrient load to Lake Rotorua. The land-based irrigation scheme has been described by Tomer *et al.* (2000). In summary; an average 19,000 m³/day of effluent is tertiary treated and then sprinkler irrigated onto 193 ha of land in the Whakarewarewa Forest, which is predominantly planted in *Pinus radiata* trees. The soils in the plantation forest are volcanic in origin, sandy and well drained, with a large capacity for retention of phosphorus (P).

As part of its commitment to minimise nitrogen and phosphorus export from the irrigated catchment and to assess possible impacts of effluent on soil health, the Rotorua District Council (RDC), approached Scion to undertake specific soil assessments on nominated blocks within the Land Treatment System (LTS), in the Whakarewarewa forest to answer the following specific questions:

1. Has nitrogen soil storage in irrigated plots decreased compared with a previous study (McLay *et al.* 2000)?
2. Have phosphorus levels in nominated blocks increased down the soil profile compared with a previous study (McLay *et al.* 2000)?
3. Have soil health/quality indicators, as defined by the MfE guidelines for healthy soils, changed positively or negatively as a result of effluent irrigation?
4. Have heavy metals levels changed as a result of effluent irrigation and do levels meet the New Zealand Biosolids Guidelines (NZWWA 2003)?

Soil storage of nitrogen and phosphorus at the Rotorua land treatment system were measured in 1995 (McLay *et al.* 2000) and the treatment performance assessed in 1997 (Tomer *et al.* 2000). The research plots irrigated at the standard rate and non-irrigated control plots were revisited in December 2012, to determine soil N and P chemistry throughout the profile and changes since 1995, and to assess soil health/soil quality.

Objectives

- Using a field based approach, determine the levels of total N and P in the soil in 2012 and compare these with levels determined in 1995, for irrigated and control sites.
- Assess soil health within irrigated and non-irrigated control sites and compare the findings against published soil health criteria as per the MfE Soil Health and soil limits for heavy metals within the New Zealand Biosolids Guidelines.

METHODS

Site sampling

Site and soil descriptions for Whakarewarewa were reported by Tomer *et al.* (2000); McLay *et al.*, (2000); Gielen *et al.* (2000); and Thorn *et al.* (2000). The three standard irrigated plots and three controls sampled in 1995 were relocated and geo- referenced in 2012 using a handheld Garmin 60CSX GPS (Table 1).

Table 1. Plots soil sampled in December 1995 and re-sampled in December 2012

| Treatment | Plot ID | Elevation (m) | NZTM East | NZTM North |
|-----------|---------|---------------|-----------|------------|
| Irrigated | 1 | 378 | 1887723 | 5769319 |
| | 4 | 385 | 1887548 | 5769271 |
| | 7 | 403 | 1887478 | 5769657 |
| Control | 10 | 393 | 1887789 | 5769617 |
| | 11 | 388 | 1887635 | 5769749 |
| | 12 | 347 | 1887374 | 5769090 |

Measurement of soil N and P levels in 1995

Treated sewage effluent from Rotorua has been irrigated onto 193 ha of predominantly *Pinus radiata* forest since October 1991. At that time, 3 irrigated plots (Plots 1, 4, 7) and 3 non-irrigated control plots (Plots 10, 11, 12), each 0.16 ha in area, were established in spray irrigation blocks 3 (Plot 4, 7) and 4 (Plot 1). These blocks received similar effluent loadings to the rest of the irrigation scheme, and averaged 69 mm/week by December 1995 when the soils from the 3 irrigated plots and the 3 non-irrigated control plots were sampled to determine the amount and vertical distribution of N and P in the soil profile to 1 m depth.

Twenty eight cores were sampled per plot. The cores were collected by vertical layers: 0-10, 10-20, 20-40, and 40-100 cm. Cores were analysed individually (4 depths x 28 cores) by depth layer (McLay *et al.*, 2000). Soil chemical analysis included total P and total N, and a range of other parameters. Soil bulk density data from typical profiles from within the LTS (Tomer *et al.*, 1997) were applied to the soil N and P concentration data to determine stocks of N and P in the soil by depth layer. Plot means of soil N and P concentrations and stocks were calculated by vertical layer from the 1995 data.

Measurement of soil N and P levels in 2012

Soil in the 3 irrigated plots and 3 non-irrigated control plots were re-sampled from 5-10th December, 2012. By this date, the effluent application rate averaged 80 mm/week. Soil samples were taken at the intersects of an approximately 6 m square grid laid across each 20 x 20 m measurement plots, which gave 9 soil sampling points per plot. At each of these points, an undisturbed soil core of known volume was extracted using a motorized auger to 1 m depth. Soils below 1 m were sampled at the same 9 grid points per plot using a Dutch auger to a total depth of 2 m by layer (1.0-1.5, and 1.5-2.0 m). Volumetric soil sampling was not possible below 1 m depth.

Prior to core sampling, fresh litter was removed from the soil surface. It was intended that the FH layer also be removed, however it was difficult to distinguish from the mineral soil, so some FH was left on surface of the soil.

Using the motorised auger it was possible for surface soil to be transported down the profile by roots not cleanly cut by the corer. Each core was therefore carefully inspected and any soil contamination evident was removed with a knife. Each core was photographed in the field.

Sample processing and analyses

In the laboratory, soil cores were processed fresh as follows. Intact cores were split lengthwise into two halves – one for bulk density determination and the other for chemical analysis. The bulk density half was re-photographed as a collection per plot in the laboratory (Appendix 1). Each half core was then divided into 4 samples representing the depth layers 0-20, 20-40, 40-70, and 70-100 cm. The depth layers 1.0-1.5, and 1.5-2.0 m sampled using a Dutch auger were not suitable for bulk density measurements. Soils for

bulk density analyses were partially dried, sieved to pass through a 2 mm mesh, and then oven dried at 105° C.

The core samples were bulked by depth layer for each plot, and sent in fresh condition to an accredited laboratory (LCR). Samples were analysed for pH, electrical conductivity, Olsen P, total P, P retention, total carbon, total nitrogen, and KCl extractable ammonium and nitrate N (See Appendix 3 for detailed methodology).

Calculation of N and P stocks and changes

Soil N and P concentration data (mg/kg) acquired in 2012 were converted to N and P stocks (t/ha) by applying N and P concentrations to soil bulk density measurements for each soil layer to 1 m depth per plot. As mentioned above, Dutch auger samples were not suitable for bulk density measurements. The bulk density for soil layers below 1 m depth was therefore estimated to be 900 kg/m³, irrespective of treatment.

Changes in N and P stocks were calculated using two methods – Method 1 calculates changes over time per plot, while method 2 calculates differences between treatments at each measurement date (December 1995 and repeated in December 2012).

Sampling for soil health

Additional soil cores were acquired to assess soil health using key soil quality indicators identified in “The 500 Soils Project” (Sparling *et al.* 2003). The 500 Soils Project was a national study across New Zealand soil types and covered a variety of land uses and was therefore useful for benchmarking and interpreting the results from the land treatment site.

Twenty five surface cores (0-10 cm) were collected systematically across each plot using a Hoffer sampler, and the cores bulked into a single sample per plot. In addition, three randomly located bulk density samples (0-10 cm) were collected per plot and fine earth bulk density determined as described above. A set of three undisturbed core samples (0-3 cm), from adjacent to the bulk density samples, was collected per plot and sent to the laboratory as undisturbed cores for individual macroporosity and bulk density determination.

Fresh samples were sent to accredited laboratories (LCR and RJ Hills Laboratories) and analysed for soil health indicators, including 56-day aerobically and 7-day anaerobically mineralisable N, total carbon, total nitrogen, pH and Olsen P (chemical soil health) and macroporosity (physical soil health). These soils were also analysed for extractable ammonium and nitrate, EC and heavy metals including As, Cr, Cd, Cu, Hg, Ni, Pb and Zn. The heavy metal contents in the soils were then compared with heavy metal soil limits for “Guidelines for the safe application of biosolids to land in New Zealand” (NZWWA, 2003) in order to put these contents in perspective.

Statistical analysis

The 1995 soil chemistry samples were analysed by depth on an individual core basis previously (McLay *et al.*, 2000) whereas in 2012 soil chemistry samples were analysed by depth but using bulked samples per plot. Plot means were calculated using the 1995 data to allow comparisons with the 2012 data. The significance of irrigation effects and soil depth on the means and 95% confidence intervals (CI) of nitrogen (N) and phosphorus (P) concentrations and stocks in 1995 and 2012 were determined using SAS version 9.2.

RESULTS AND DISCUSSION

Soil chemical analysis results in 2012

Results of soil pH, electrical conductivity, Olsen P, total P, P retention, total Carbon, total N, and ammonium and nitrate forms of N for soil cores to 2 m depth are given in Appendix 4.

We first present the soil profile information and bulk density data, followed by P retention data and N and P concentrations and stocks.

Soil profiles

Full descriptions of typical soil profiles at the LTS are given in Tomer et al. (1997). Inspection of soil photographs in the three irrigated and three control plots we measured (Appendix 1) shows the presence of a grey horizon (gleyed soil) near the surface of irrigated plots 1 and 4, but not in plot 7. The Moisture content in the top 70 cm of soil was also significantly higher in plots 1 and 4 compared to plot 7. These results suggest that effluent loading rates varied spatially across the LTS. Plot 7 was at a higher elevation than plot 1 and 4 (Table 1), which may explain why loading rates varied spatially. No coarse lapilli layer was present in the 0-100 cm of soil although scattered lapilli were evident in some cores. Rotorua lapilli were found below 100 cm depth using the Dutch auger.

Bulk density

Bulk density increased with depth ($P < 0.0001$), but did not differ significantly with treatment ($P = 0.902$), however a significant treatment effect was evident in the 0-10 cm depth layer (Table 2). In 1995 bulk density was assumed to be the same for all plots, so treatment effects on N and P stocks reflect treatment effects on soil N and P concentrations. In 2012 bulk density was measured for each plot, so treatment effects on N and P stocks reflect both concentration and bulk density effects. It is not known if bulk density in the top 10 cm of soil differed by treatment in 1995.

Soil below 1.0 m depth was assumed to have a basic density of 900 kg/m^3 in both irrigated and control plots. This was lower than measured in the 70-100 cm depth layer, to make some allowance for the effect of coarse lapilli present below 1 m depth in some plots.

Table 2. Bulk density (<2mm fraction) mean (and 95% CI) by depth layer in control plots and irrigated (80 mm/week) plots sampled in December 2012, and estimated change by difference.

| Depth interval | Control BD (kg/m^3) | Irrigated BD (kg/m^3) | Difference (Irrigated-control) |
|----------------|-----------------------------------|-------------------------------------|-----------------------------------|
| 0-10 cm | 662 (572:752) | 460 (370:550) | -202 |
| 0-20 cm | 641 (485:797) | 619 (463:775) | -21 |
| 20-40 cm | 764 (608:920) | 755 (599:911) | -9 |
| 40-70 cm | 876 (720:1032) | 886 (730:1041) | 10 |
| 70-100 cm | 964 (808:1120) | 998 (842:1154) | 34 |

Phosphorus retention data

Soil P retention tended to increase with depth in all plots, and was overall still very high in 2012. P retention to 2 m depth averaged 70% in irrigated plots and 78% in control plots, which is a statistically highly significant difference ($P = 0.003$), however a significant soil depth by treatment interaction effect ($P = 0.031$) was also evident. The interaction occurred because P retention capacity decreased more-so in the surface soil than in the subsoil of irrigated plots (Table 3) relative to control plots. Soil at 150-200 cm depth tended to have a lower P retention than immediately overlying soil layers, possibly owing

to the presence of Rotorua lapilli at this depth. Lapilli were encountered more-so in control plots than irrigated plots - the latter plots were by chance located in areas with deep overlying ash layers.

Table 3. Phosphorus retention mean (and 95% CI) by depth layer in control plots and irrigated (80 mm/week) plots sampled in December 2012, and estimated change by difference.

| Depth interval | Control P ret (%) | Irrigated P ret (%) | Difference (Irrigated-control) |
|----------------|-------------------|---------------------|--------------------------------|
| 0-20 cm | 70 (57:83) | 45 (32:58) | -25 |
| 20-40 cm | 78 (65:91) | 67 (54:80) | -11 |
| 40-70 cm | 89 (76:102) | 82 (69:95) | -7 |
| 70-100 cm | 88 (75:101) | 82 (69:95) | -6 |
| 100-150 cm | 86 (73:99) | 81 (68:94) | -5 |
| 150-200 cm | 60 (47:73) | 66 (53:79) | +6 |

The relationship between P retention test results and actual soil pH is shown in Figure 1. Soil pH was higher in irrigated plots compared with control plots at all depths measured. P retention decreased significantly with increasing soil pH ($P = 0.0028$), while allowing for significant soil depth layer effects ($P < 0.0001$). By convention, the P retention test is made at pH 4.6, whereas actual soil pH values are appreciably higher than this, averaging 6.1 in control plots (points clustered on left hand side of Fig. 1) and 6.9 in effluent irrigated plots (clustered on right hand side), with a highly significant effluent treatment effect on pH evident ($P > 0.0001$). Clearly, a history of effluent treatment has reduced the P retention capacity of the volcanic ash soil at all depths assessed.

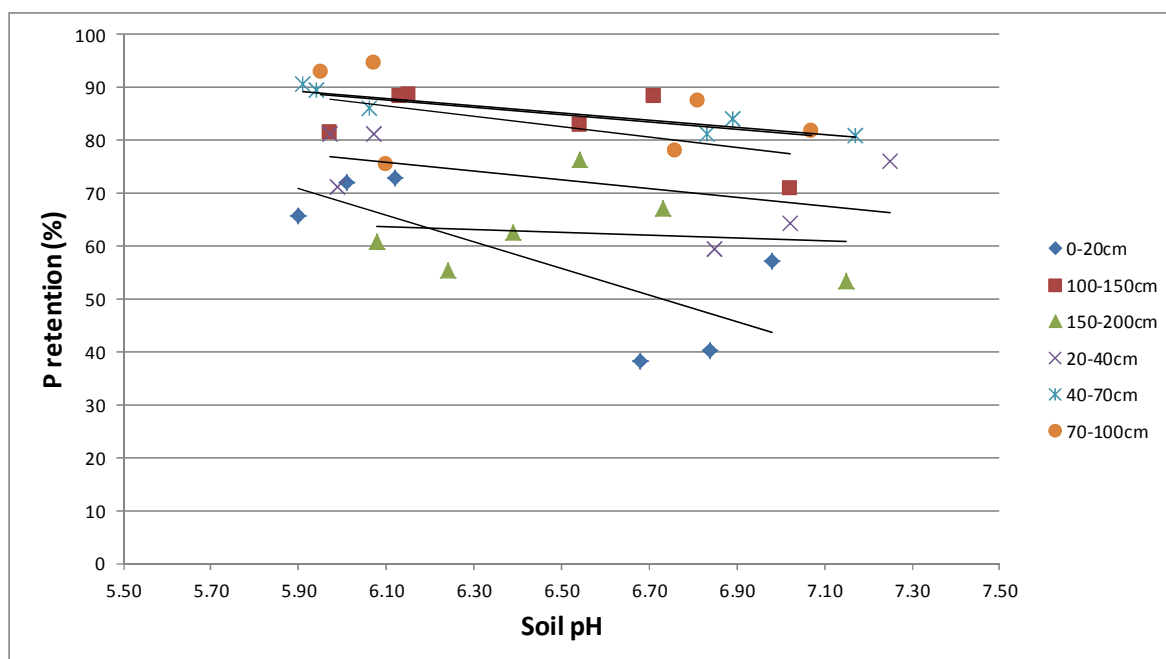


Figure 1. Phosphorus retention in relation to soil pH by soil depth interval given in the key. Unirrigated soils have pH values below 6.5, while irrigated soils have pH values above 6.5.

The reduction in P retention owing to irrigation was strongly positively correlated with soil Olsen P concentration. While cause/effect is difficult to determine using these data, it can be expected that P retention of soil to 100 cm depth will have been reduced by the large

supply of effluent derived P. Below 100 cm depth other factors will likely have reduced P retention with increasing pH, for example the relative abundance of base cations such as Na, Mg, Ca, and Al on exchange sites.

The reduction in P retention capacity indicates that the soil has a reduced ability to remove P rapidly from the soil solution, increasing the potential for solution P to move down the profile. The retention test gives P removal over a 16 hour period (Appendix 3). P retention is followed by much slower chemical reactions in the soil that eventually result in P fixation. Other factors that determine P retention, for example the amount of Rotorua Lapilli in the soil, may also be of practical significance.

Soil P retention capacity is measured at pH 4.6 because P retention capacity is generally at a maximum at this pH, and decreases at higher and lower pH values. Hence the actual P fixation power of the soil at field pH's will likely be less than suggested by the P retention test results, particularly for irrigated soils with an average pH approaching 7.0. For example, P-fixing power (amount of fertiliser P that was fixed) of three naturally acidic New Jersey soils (with an average pH of 3.6) approximately halved following liming of soil to a pH of 6.5 (Buckman & Brady 1971).

The actual P fixation power of the LTS soil can best be assessed by examining the trends in soil total P stocks over time, which is covered in the following section.

Soil total N and total P data acquired in December 1995 and stock calculations

The mean concentration of total N and total P averaged across 28 core samples from each of 3 plots are given by depth and treatment in Table 4. In 1995 irrigation related N and P concentration differences are mostly in the top 10 cm of soil, with smaller increases lower down the profile.

Table 4. Total nitrogen and total phosphorus mean (and 95% CI) concentration by depth layer in control plots and irrigated (approximately 70 mm/week) plots sampled in December 1995.

| Depth interval | Control N mg/kg | Irrigated N mg/kg | Control P mg/kg | Irrigated P mg/kg |
|----------------|------------------|-------------------|-----------------|-------------------|
| 0-10 cm | 2001 (1893:2108) | 2330 (2222:2437) | 279 (242:316) | 722 (685:759) |
| 10-20 cm | 1413 (1305:1520) | 1489 (1381:1596) | 237 (201:274) | 351 (315:388) |
| 20-40 cm | 917 (809:1024) | 1071 (964:1179) | 188 (151:224) | 242 (205:278) |
| 40-100 cm | 552 (444:659) | 594 (487:702) | 146 (109:183) | 149 (112:186) |

The corresponding total N and total P mean stocks by depth and summed over all depths by treatment are given in Table 5. Increases in stocks of N and P are greatest in the surface 10 cm of soil, even though this layer represents only 10% of the profile depth assessed. Soil BD in 1995 was based on a site mean and hence CI's of stock estimates cannot be determined, however the CI on concentrations may give an indication of the significance of treatment effects on stocks.

Table 5. Total nitrogen and total phosphorus mean stocks by depth layer and over all depths measured in control plots and irrigated plots sampled in December 1995.

| Depth interval | Control N kg/ha | Irrigated N kg/ha | Control P kg/ha | Irrigated P kg/ha |
|------------------------|-----------------|-------------------|-----------------|-------------------|
| 0-10 cm | 1542 | 1796 | 215 | 557 |
| 10-20 cm | 1089 | 1148 | 183 | 271 |
| 20-40 cm | 1361 | 1590 | 278 | 359 |
| 40-100 cm | 3133 | 3375 | 827 | 847 |
| Total to 100 cm | 7126 | 7909 | 1504 | 2034 |

Soil total N and total P data acquired in December 2012 and stock calculations

The mean concentration of total N and total P based on the 9 bulked core sample from each of 3 plots are given by depth interval and treatment in Table 6. In 2012 irrigation related N concentration differences are again mostly in the surface layer. However, P concentration increases were evident at greater depths in the profile than found previously.

Table 6. Total nitrogen and total phosphorus mean (and 95% CI) concentrations by depth layer in control plots and irrigated plots sampled in December 2012.

| Depth interval | Control N mg/kg | Irrigated N mg/kg | Control P mg/kg | Irrigated P mg/kg |
|----------------|------------------|-------------------|-----------------|-------------------|
| 0-20 cm | 2076 (1699:2452) | 2839 (2462:3215) | 249 (34:465) | 1221 (1005:1437) |
| 20-40 cm | 1067 ((691:1443) | 1148 (771:1524) | 178 (-38:393) | 794 (578:1009) |
| 40-70 cm | 765 (388:1141) | 796 (420:1173) | 140 (-75:356) | 308 (92:523) |
| 70-100 cm | 645 (268:1021) | 505 (128:881) | 148 (-68:364) | 167 (-48:383) |
| 100-150 cm | 455 (78:831) | 438 (61:814) | 144 (-72:360) | 165 (-51:380) |
| 150-200 cm | 198 (-178:575) | 262 (-114:638) | 157 (-59:372) | 154 (-61:370) |

For example, soil P concentration increased significantly at 0-20 and 20-40 cm depth, but not significantly at 40-70 cm (Table 6). However there were clearly large differences at 40-70 cm depth among irrigated plots (Fig. 2). These differences among plots introduced variability, which reduced the power of the statistical analysis. However the differences among plots are nevertheless of practical importance, with P moving deeper down the soil profile at sites where presumably more effluent had been applied.

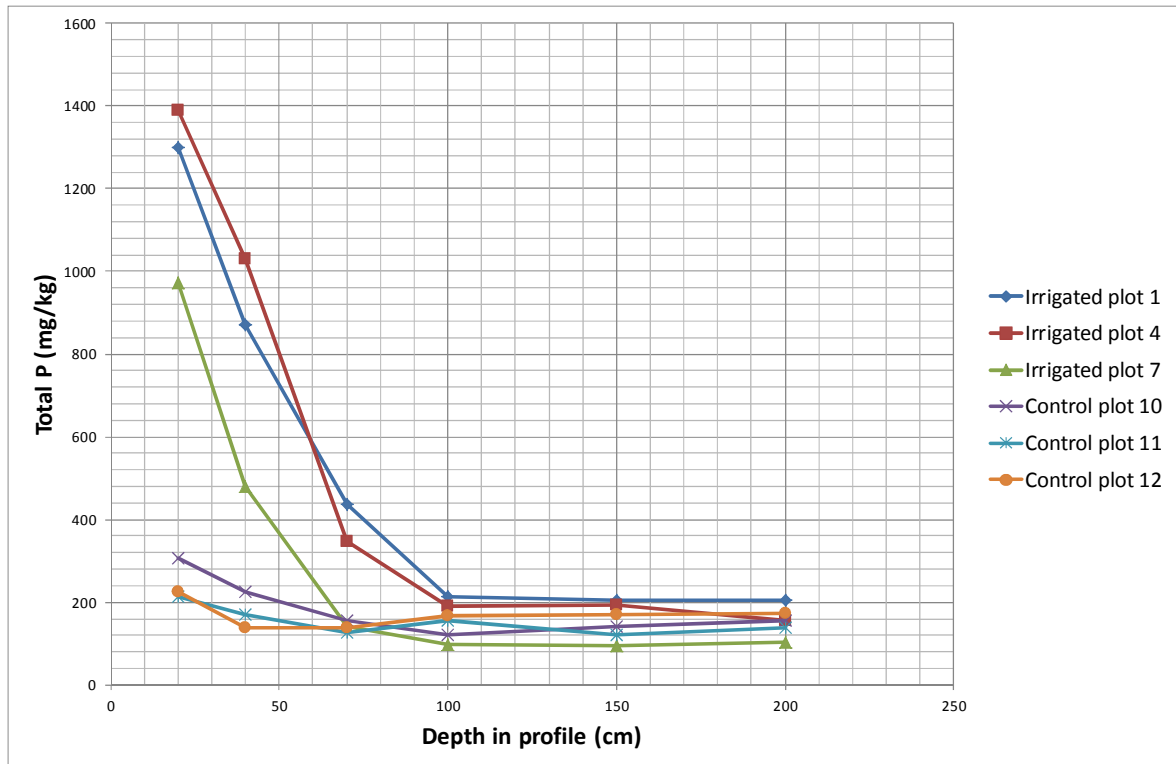


Figure 2. Relationship between total P concentration and depth for each plot.

The corresponding total N and total P mean stocks by depth and sum over all depths by treatment in 2012 are given in Table 7. N stocks increased significantly at 0-20 cm depth, but not in other layers, nor overall depths. P stocks increased significantly at 0-20, 20-40, and 40-70 cm depths, and also to 200 cm depth (Table 7).

Table 7. Total nitrogen and total phosphorus mean (and 95% CI) stocks per ha by depth layer and over all depths measured in control plots and irrigated plots sampled in December 2012.

| Depth interval | Control N kg/ha | Irrigated N kg/ha | Control P kg/ha | Irrigated P kg/ha |
|------------------------|---------------------------|----------------------------|-------------------------|-------------------------|
| 0-20 cm | 2645 (1940:3350) | 3509 (2804:4214) | 317 (-138:772) | 1519 (1064:1975) |
| 20-40 cm | 1619 (914:2324) | 1723 (1018:2428) | 269 (-186:724) | 1218 (763:1674) |
| 40-70 cm | 2002 (1297:2708) | 2114 (1408:2819) | 370 (-85:825) | 827 (372:1282) |
| 70-100 cm | 1816 (1111:2522) | 1498 (793:2203) | 423 (-32:878) | 508 (52:963) |
| 100-150 cm | 2046 (1341:2751) | 1969 (1264:2674) | 649 (194:1104) | 741 (286:1197) |
| 150-200 cm | 893 (188:1598) | 1178 (473:1884) | 705 (250:1161) | 694 (239:1149) |
| Total to 100 cm | 8082 | 8844 | 1379 | 4073 |
| Total to 200 cm | 11021 (9666:12378) | 11991 (10632:13350) | 2733 (1890:3576) | 5508 (4668:6348) |

The differences in P stocks among plots are evident in Figure 3. This figure suggests that P stocks may also have increased below 70 cm depth down the profile at some but not all irrigated sites. The Olsen P data is the best indicator of solution P movement down the profile.

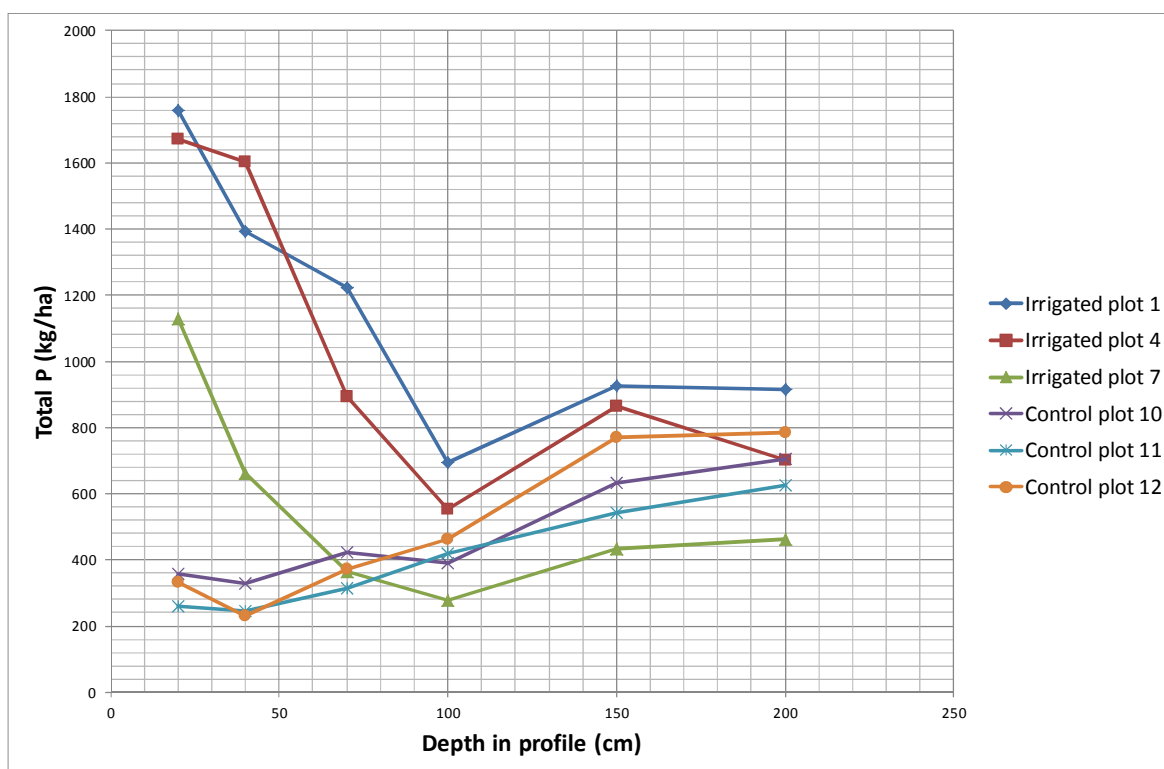


Figure 3. Relationship between total P stock and depth for each plot.

Effect of effluent irrigation on soil total N and total P stocks over time

Irrigation effects can be obtained from the change in stocks from repeated measurements over time (Method 1), or alternatively, from the difference between control and irrigated plots at a given sampling date (Method 2).

Method 1

The stock changes obtained by subtracting the stocks in 1995 from the stocks in 2012 are given in Table 8. Changes are shown to 100 cm depth because sampling in 1995 extended down to that depth.

While inherently a superior approach to method 2, method 1 suffers from having an assumed average bulk density data for all plots in 1995. It would be expected that controls will remain unchanged, which suggests that the difference over time is a result of bias in the estimates due to BD errors (i.e. use of assumed BD in 1995 versus measured BD in 2012). No difference to 100 cm depth was expected in controls, however there were large differences (956 kg N/ha, -124 kg P/ha) calculated using Method 1. The apparent bias in stocks is sizable for N relative to expected changes. The bias is relatively small for P because P stocks have increased markedly since 1995. Assuming that the bias is consistent between treatments, these results indicate that N stocks in irrigated plots in 2012 have not increased since 1995. We note that bulk density in the top soil (0-10 cm) was significantly lower in irrigated than control plots in 2012, and it would be reasonable to expect some reduction would have occurred by 1995 (so the consistency assumption may not be entirely valid).

Because of the BD issues with Method 1, we will focus on the stock change calculations based on Method 2.

Table 8. Changes in total nitrogen and total phosphorus stocks (kg/ha) by depth layer and to 1 m depth in control plots and irrigated plots sampled in December 1995 and re-sampled in December 2012.

| Depth interval | Controls change N kg/ha | Irrigated change N kg/ha | Control change P kg/ha | Irrigated change P kg/ha |
|------------------------|-------------------------|--------------------------|------------------------|--------------------------|
| 0-20 cm | 13 | 565 | -81 | 682 |
| 20-40 cm | 258 | 133 | -9 | 859 |
| 40-100 cm | 685 | 237 | -34 | 488 |
| Total to 100 cm | 956 | 935 | -124 | 2029 |

Method 2

The differences between stocks obtained by subtracting the stock estimates for control plots in 1995 from the stock estimates for irrigated plots in 1995 are given in Table 9. Comparable calculations for 2012 are also given in Table 9. Depth intervals have been harmonized to allow comparisons over time.

The table also shows total differences to 100 cm because sampling in 1995 extended down to that depth and to 200 cm because sampling in 2012 extended down to that depth. The difference in totals to 100 cm depth was 601 kg N/ha and 531 kg P/ha in 1995 and 762 kg N/ha and 2694 kg P/ha in 2012. In other words, since 1995 N stocks increased moderately, due primarily to significant increases in the surface 20 cm of soil. In contrast, total P stocks in irrigated plots increased by approximately 5-fold to 100 cm depth, primarily due to large increases in P below 20 cm depth. In 2012 the total difference to

200 cm depth was 970 kg N/ha and 2775 kg P/ha. In 2012, soil from 100-200 cm depth in irrigated plots may have stored additional N but probably no additional P relative to controls.

While inherently less precise than method 1, method 2 uses directly measured bulk density data in 2012 so can be expected to be more accurate than method 1. The negative difference for some layers therefore presumably reflects random sampling variation, and not bias. To help clarify whether effluent origin P has moved below 100 cm depth, we examined Olsen P data.

Table 9. Differences in total nitrogen and total phosphorus stocks (kg/ha) by depth layer and over all depths between control and irrigated plots sampled in December 1995 and again in December 2012.

| Depth interval | 1995 Difference N kg/ha | 2012 Difference N kg/ha | 1995 Difference P kg/ha | 2012 Difference P kg/ha |
|------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 0-20 cm | 313 | 864 | 430 | 1202 |
| 20-40 cm | 229 | 104 | 81 | 950 |
| 40-100 cm | 242 | -206 | 20 | 542 |
| 100-150 cm | - | -77 | - | 92 |
| 150-200 cm | - | 285 | - | -11 |
| Total to 100 cm | 601 | 762 | 531 | 2694 |
| Total to 200 cm | - | 970 | - | 2775 |

Soil Olsen P

Olsen P test results (used as an indicator of effluent P movement in soil solution down the profile) are given in Table 10. Olsen P is very low in control plots, with values around 2 in the surface and 1 at other depths, but high in irrigated plots. Olsen P concentrations were obviously appreciably higher in irrigated plots to 70 cm depth (although statistically significantly so down to 40 cm). At all depths below 70 cm, concentrations in irrigated plots were low but nevertheless averaged 2-3 fold the concentrations in control plots. Some effluent-origin P clearly moved into the 40-70 cm depth layer. However the increase in Olsen P below 70 cm may be indirectly related to the increase in pH, due to effluent treatment, increasing the availability of native soil P below 70 cm, as shown in Figure 1.

Table 10. Olsen P concentration (and 95% CI) by depth layer in control plots and irrigated plots sampled in December 2012.

| Depth interval | Control Olsen P mg/kg | Irrigated Olsen P mg/kg |
|----------------|-----------------------|-------------------------|
| 0-20 cm | 2.4 (-28:33) | 137.8 (107:169) |
| 20-40 cm | 1.6 (-29:32) | 75.4 (45:106) |
| 40-70 cm | 1.1 (-30:32) | 12.0 (-19:43) |
| 70-100 cm | 0.7 (-30:32) | 2.3 (-29:33) |
| 100-150 cm | 0.7 (-30:32) | 2.2 (-29:33) |
| 150-200 cm | 1.1 (-30:32) | 1.8 (-29:33) |

Soil Health Indicators (based on 0-10 cm soil samples)

Effluent irrigation for 21.2 years significantly ($P < 0.05$) increased soil Olsen P, pH, Total C, Total N, and decreased the bulk density (<2 mm fraction) compared to values in non-irrigated controls (Table 11). Furthermore the irrigated soils were significantly higher in moisture content and electrical conductivity (EC) while the C:N ratio was lower in the irrigated soil than in the non-irrigated control soils (Table 12).

Table 11. Soil health indicators measured in non-irrigated controls and irrigated plots

| Treatment | Plot ID | Olsen P | pH | Anaerobically Mineralisable N | Total C | Total N | Bulk density (<2 mm) | Macroporosity |
|-----------|---------|---------|------|-------------------------------|---------|---------|----------------------|---------------|
| | | mg/kg | | mg/kg | % | % | g/cm ³ | % |
| Control | 10 | 4.7 | 5.91 | 56 | 4.72 | 0.19 | 0.70 | 27.8 |
| | 11 | 3.8 | 5.81 | 63 | 4.83 | 0.21 | 0.66 | 31.2 |
| | 12 | 4.2 | 5.84 | 51 | 4.33 | 0.21 | 0.63 | 29.4 |
| Irrigated | 1 | 161 | 6.76 | 108 | 6.99 | 0.37 | 0.45 | 14.3 |
| | 4 | 147 | 6.82 | 84 | 6.58 | 0.37 | 0.45 | 11.7 |
| | 7 | 100 | 6.83 | 89 | 5.79 | 0.28 | 0.47 | 27.1 |
| Control | Mean | 4.2 | 5.85 | 57 | 4.62 | 0.20 | 0.66 | 29.5 |
| Irrigated | Mean | 136 | 6.80 | 94 | 6.45 | 0.34 | 0.46 | 17.7 |

Table 12. Soil parameters measured in non-irrigated controls and irrigated plots

| Treatment | Plot ID | Moisture content | EC | C:N ratio | KCl extr NO ₃ -N | KCl extr NH ₄ -N | Aerobically Mineralisable N |
|-----------|---------|------------------|-------|-----------|-----------------------------|-----------------------------|-----------------------------|
| | | % wet wt | µS/cm | | mg/kg | mg/kg | mg/kg |
| Control | 10 | 0.28 | 4.4 | 24.2 | 0.0 | 1.0 | 56 |
| | 11 | 0.29 | 4.3 | 23.4 | 0.3 | 0.9 | 63 |
| | 12 | 0.30 | 4.0 | 20.8 | 0.6 | 4.0 | 51 |
| Irrigated | 1 | 0.56 | 17.2 | 18.7 | 33.5 | 1.1 | 108 |
| | 4 | 0.51 | 15.6 | 17.8 | 28.5 | 0.4 | 84 |
| | 7 | 0.43 | 13.0 | 20.3 | 22.2 | 0.7 | 89 |
| Control | Mean | 0.29 | 4.2 | 22.8 | 0.3 | 2.0 | 36 |
| Irrigated | Mean | 0.50 | 15.3 | 19.0 | 28.0 | 0.7 | 79 |

Soil Health Interpretation

In order for a parameter to be effective as an indicator for soil health/quality, it is important to know optimal values for such parameters. These may differ by soil type and land use. As part of the MfE soil quality indicators project, 500 soils around New Zealand were investigated for a series of soil parameters indicative of soil health (Sparling *et al.* 2004; Sparling and Schipper 2004, Land Monitoring Forum 2009). This dataset has become a benchmark against which the sampled top soils at the LTS were evaluated. These

evaluations are shown for each parameter in Figure 3 for forest soils and interpreted individually below.

Olsen P

Phosphorus is an essential plant nutrient but only a small fraction of total phosphorus in the soil is available for plant uptake. Olsen P is a measure of plant available P and is often used to determine P fertiliser requirements. In the non-irrigated control soils, Olsen P levels were very low. Allophanic and pumice soils adsorb and retain phosphorus very well. This therefore resulted in low Olsen P levels, which means that higher levels of Olsen P are required to get equivalent levels of P availability compared to other soil types. In the irrigated soils, Olsen P increased considerably through the addition of effluent derived phosphorus. The level of Olsen P in the irrigated soils was classified as excessive (Fig. 3) because this level of Olsen P is considerably higher than required for plant uptake, and would increase the risk that if soil erosion occurs, this form of P could contaminate surface waters. Nutritional stress due to high P levels in tomato plants has been documented when P levels in the leaves exceeded 1.0% foliar P (Jones 1998). At these levels P is known to promote manganese uptake and inhibit zinc and iron uptake even if there is enough in the soil. In 1996, after 5 years of irrigation foliar P levels were 0.22% (Thorn *et al.* 2000) which was well below the toxic limit indicating that at that stage soil P levels did not have a toxic effect on the plants. Foliage levels have not been resampled therefore current foliar P levels in the irrigated areas are unknown.

pH

Soil pH is a measure of soil acidity and can influence the solubility of a wide range of elements in the soil. Different crops have different pH requirements for optimum growth, for example *Pinus radiata* trees are able to grow at much lower soil pH than pasture species. The optimal pH range for allophanic soils under forestry land use was considered by Sparling *et al.* (2008) to be between 4 and 7. Both the non-irrigated and irrigated soil pH fell within the optimal range despite pH of irrigated soils being about 1 pH unit higher than in non-irrigated soils. A soil pH of near 7 would be suitable if the land use changed to cropping and horticulture. Pasture as a land use prefers a soil pH between 5.5 and 6.3 for optimal growth.

Mineralisable N

Anaerobically mineralisable N indicates how much organic N is available for plant uptake and also corresponds with microbial carbon in the soil therefore giving an indication of the biological soil health. A large proportion of nitrogen in a soil is present in the form of organic nitrogen. Plants however are only able to take up inorganic N such as ammonium and nitrate. Therefore it is important to determine how much organic N can be mineralised and become plant available. Allophanic soils often contain high levels of organic matter and thus frequently have relatively high levels of mineralisable N. In this case anaerobically mineralisable N levels were adequate in both the control and irrigated soils. The anaerobically mineralisable N levels were higher in the irrigated than the control soil indicating an increase of soil organic matter due to effluent irrigation.

In addition to the mineralisable N, effluent-irrigated soils receive nitrate and ammonium nitrogen on a regular basis therefore making the plants less dependent on the mineralisation process for their nitrogen demand. The KCl extractable levels were 28.0 mg/kg nitrate N and 0.7 mg/kg ammonium N in the irrigated soil compared to 0.3 mg/kg nitrate N and 2.0 mg/kg ammonium N in the control soil. This indicated that in the irrigated soils 28 mg/kg of nitrate N was already available without the need for mineralisation of organic matter to occur.

Aerobic mineralisable N is measured over 56 days as opposed to anaerobic mineralisable N which is measured over 7 days. The aerobic mineralisable N levels reflect N supply over a growing season better than anaerobic mineralisable N levels. For both the control

and irrigated soils, the aerobic mineralisable N (Table 12) were lower than the anaerobic mineralisable N (Table 11). The control soils incubated aerobically resulted in a mineralisable N level 64% of that incubated anaerobically while in the irrigated soils, mineralisable N level was 84% of that incubated anaerobically. This suggested that under aerobic soil conditions less N would become available through mineralisation than under anaerobic soil conditions.

Total C

Carbon is one of the basic components of organic matter and is easier to measure accurately than organic matter. Therefore, carbon is used as an indicator of the level of organic matter in the soil. Organic matter is relevant to all biological, chemical and physical processes in the soil. Biologically, soil organic matter is a source of energy for soil micro-organisms, chemically it is a source of plant nutrients either through degradation or desorption processes and physically soil organic matter stabilises soil structure and soil pores therefore improving aeration, water storage capacity and water infiltration. In the non-irrigated control soil, total C levels were within the normal range but at the lower end indicating that C levels could be increased for optimal functioning. Effluent irrigation increased the C levels to the middle of the normal range therefore improving soil C levels. This agreed with the mineralisable N results which also indicated that effluent irrigation increased soil organic matter levels.

Total N

Total N measures the total amount of N in the soil. This generally consists of a majority of organic matter N that has been accumulated over time through N fixing or organic matter incorporation. As discussed in the mineralisable N section, the proportion of inorganic nitrogen is often low in a non-irrigated soil. Overall, total N levels in the non-irrigated soil were on the boundary between low and adequate.

The C:N ratio was 23. This is generally considered high and is more commonly associated with a low total soil N than adequate soil N. An adequate soil C:N ratio would range from 15 to 17. Nevertheless, *Pinus radiata* trees have a lower nitrogen demand than pasture allowing them to grow in low N soils and soils with a moderately high C/N ratio. Effluent irrigation resulted in total N levels in the irrigated soils that were classified in the middle of the adequate range. Consequently, the C:N ratio of the irrigated soils decreased to 19 which is consistent with a more fertile soil, and higher growth rate.

Bulk density

Bulk density can be used as an indicator of soil compaction whereby compacted soils have a reduced porosity and stability of aggregates resulting in reduced aeration for plant roots, reduced infiltration and increased resistance to penetration. Soils with low bulk densities on the other hand may be subject to increased risk of erosion. Total bulk densities in both the non-irrigated and irrigated soil were in the adequate range. The bulk density (<2 mm fraction) of irrigated soil was significantly lower than that of non-irrigated soil. The reduction in bulk density in irrigated plots is consistent with the increase in soil carbon concentration.

Macroporosity

Macroporosity measures the proportion of large pores in the soil. These large pores drain quite rapidly after rainfall or irrigation and provide oxygen to plant roots. Soil macroporosity was lower in the irrigated soils than the non-irrigated soils but both values fell within the adequate range. A low macroporosity may lead to limited root extension and a limited ability for water drainage. Due to the relatively large difference between non-irrigated and irrigated values, it will be important to continue monitoring macroporosity over time.



Figure 3 Soil Health Indicators Expert Interpretation based on Sparling *et al.* (2008)

Moisture Content and EC

In addition to soil health indicators, moisture content measurements showed that as expected all irrigated soils were wetter than the non-irrigated soils. The soil from Plot 7 seemed to be drier than from Plot 1 and 4 suggesting that Plot 7 received less effluent. This highlights that there is some variability in effluent distribution within the irrigated area and even within a spray block depending on the topography of the land.

Electrical conductivity is an indirect measure of the salt content within the soil. Soil EC values around the central plateau were in the range 10 to 30 $\mu\text{S}/\text{cm}$, indicating that soil EC values observed in the irrigated soils (average 15 $\mu\text{S}/\text{cm}$) were common even though soil EC values were higher than in the non-irrigated soils (4 $\mu\text{S}/\text{cm}$). The sewage effluent irrigated typically had an average EC of 381 $\mu\text{S}/\text{cm}$ while rainwater typically ranges from 3 - 33 $\mu\text{S}/\text{cm}$. It is therefore expected that soil EC values were somewhat higher in the irrigated soils making it a useful tracer. Like for the moisture contents, EC was lower in Plot 7 than in Plot 1 and 4, confirming that Plot 7 received a slightly lower effluent loading than Plots 1 and 4.

Heavy metals

Because soil health indicators give an indication of soil quality for crop production, it is also important to obtain an indication of soil quality for environmental protection. Therefore heavy metals were investigated on the same soil samples and compared with soil limits published in the "Guidelines for the safe application of biosolids to land in New Zealand"

(NZWWA, 2003). These soil limits were also used by Taylor *et al.* (2010) to evaluate 340 soils from the Waikato region.

After 21.2 years of effluent irrigation, arsenic, cadmium, lead mercury and nickel contents in the top 10 cm of soil were similar to those in the non-irrigated control soils (Table 13) indicating that effluent did not contain significant levels of these heavy metals. Only soil chromium, copper and zinc contents were greater in the irrigated than the non-irrigated soils. However, the increase in soil content due to effluent irrigation was small for Cr, Cu and Zn when comparing these to the heavy metal soil limits (Table 13) published in the “Guidelines for the safe application of biosolids to land in New Zealand” (NZWWA, 2003).

Based on the increase in soil content for Cr, Cu and Zn and assuming similar irrigation rates as for the past 21.2 years, it would take between 259 and 4755 years of irrigation to reach the heavy metals soil limits in the NZWWA (2003) Guidelines. This indicates that the contributions of Cr, Cu and Zn in the sewage effluent were very small and that the heavy metal contents within the irrigated soils were well within the Guidelines. Furthermore soil values for Cr, Cu and Zn were well within the range and close to the average values reported for Waikato soils by Taylor *et al.* (2010).

Table 13. Heavy metal soil contents at 0-10 cm depth, heavy metal soil guideline limits and years of irrigation left until soil limits be reached.

| Treatment | Plot ID | As | Cd | Cr | Cu | Pb | Hg | Ni | Zn |
|---------------------------------|---------|-------------------|------|------|-----|------|-------|------|-----|
| (mg/kg) | | | | | | | | | |
| Control | 10 | 6 | <0.1 | <2 | 7 | 5.3 | <0.1 | <2 | 19 |
| | 11 | 5 | <0.1 | 2 | 5 | 5.8 | <0.1 | <2 | 12 |
| | 12 | 6 | <0.1 | <2 | 7 | 6.1 | <0.1 | <2 | 17 |
| Irrigated | 1 | 5 | <0.1 | 4 | 16 | 5.8 | 0.15 | <2 | 43 |
| | 4 | 6 | <0.1 | 5 | 16 | 6.1 | <0.1 | <2 | 46 |
| | 7 | 5 | <0.1 | 3 | 10 | 5.7 | <0.1 | <2 | 25 |
| Control | Mean | 6 | <0.1 | <2 | 6 | 5.7 | <0.1 | <2 | 16 |
| Irrigated | Mean | 5 | <0.1 | 4 | 14 | 5.9 | <0.15 | <2 | 38 |
| Difference | | n.s. ¹ | n.s. | 2.7 | 7.7 | n.s. | n.s. | n.s. | 22 |
| Soil limits ² | | 20 | 1 | 600 | 100 | 300 | 1 | 60 | 300 |
| Years to reach limit | | ∞ | ∞ | 4755 | 259 | ∞ | ∞ | ∞ | 273 |

¹ n.s: non-significant P<0.05

² NZWWA (2003)

CONCLUDING SUMMARY

After 21 years of effluent irrigation at the Rotorua LTS, N storage to 100 cm depth has not changed appreciably relative to N additions. In contrast to N, the soil has stored the large amount of added P over this period, and can be expected to continue to do so for many years. The remaining P fixation capacity at the LTS varies spatially, depending on factors such as depth to Rotorua lapilli, harvest related soil compaction, past effluent loading rates, and future effluent loading rates, among other factors. Spatial mapping of factors associated with P fixation capacity could be undertaken in future with the aim to utilise the large capacity to continue to fix P at the LTS while minimising losses of P from sensitive micro-sites.

The use of soil health or soil quality indicators is a way to describe the overall condition of the soil by investigating key indicators that describes aspects of soil physical structure (bulk density, macroporosity), chemical fertility (Olsen P, anaerobic mineralisable N), organic resources (Total C, Total N, anaerobic mineralisable N) and soil acidity (pH).

However, these indicators in themselves do not measure soil health/quality. The level of soil health/quality is a value judgement for a particular use that has been applied to a set of measured indicator values. The value judgement was based on the range of values obtained for a large set of soil samples and expert knowledge (Sparling *et al.* 2008).

Irrigation increased the fertility of the soils in terms of available P and it also improved organic resources in terms of total C and N, C:N ratio and mineralisable N. Furthermore it increased soil pH thus lowering soil acidity and decreased soil macroporosity although values of these indicators were all in the optimal or adequate range except for plant available P which was classified as excessive.

This indicated that in terms of soil health for productivity, effluent irrigation had an overall positive effect on soil quality except for the excessive levels of soil Olsen P which would make these soils more prone to contaminate surface water if soil erosion should occur, through P rich suspended solids entering surface waters. After 5 years of irrigation, foliar P levels were well below the limit where excessive P is expected to impact plant productivity. Currently it is unknown whether the excessive level of plant available P is affecting plant growth and in order to determine this, foliage samples would need to be analysed.

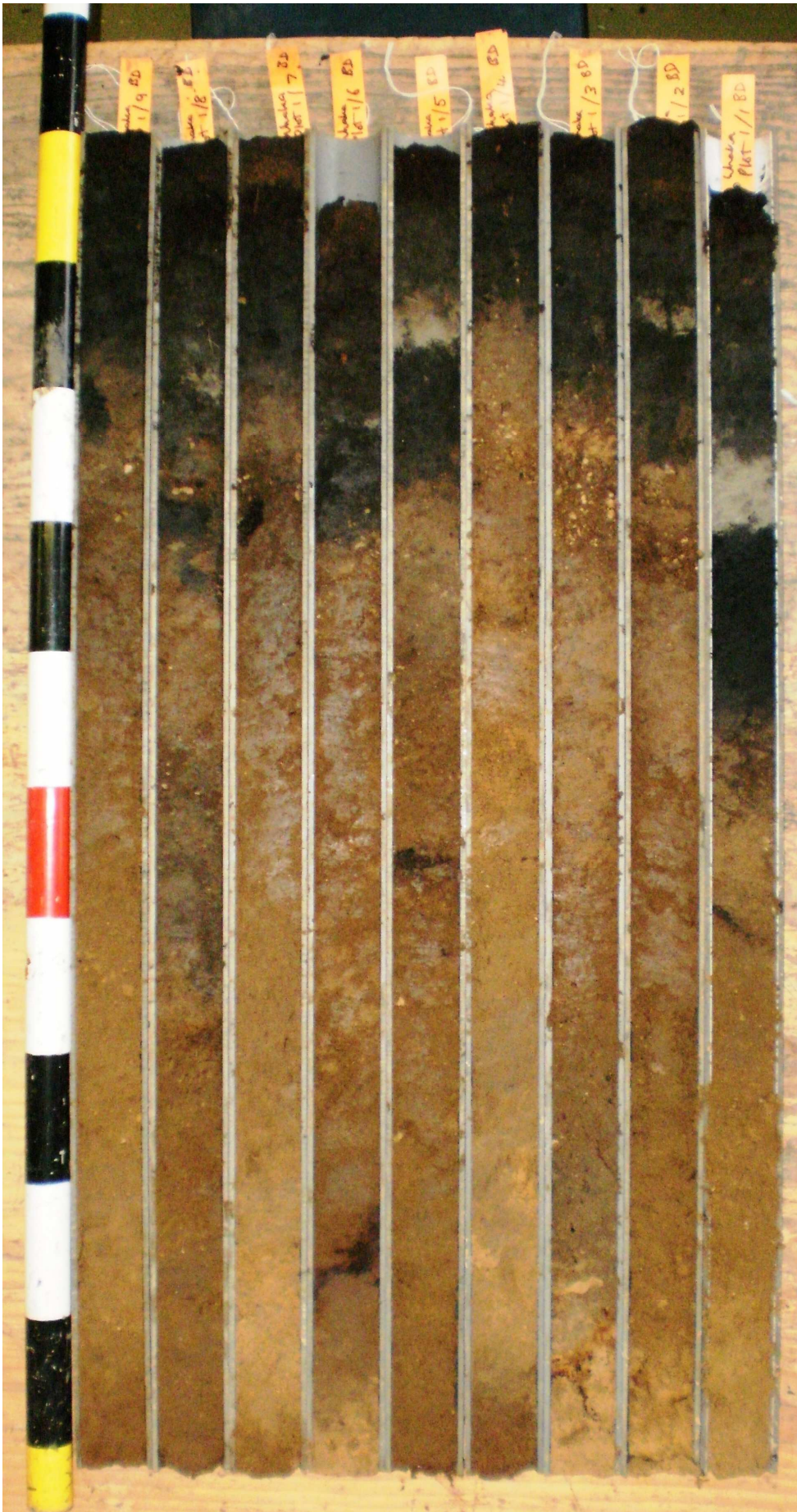
Also from an environmental perspective in terms of soil heavy metal limits, the irrigated soil was well below the heavy metal limits and only Cu, Zn and Cr were higher in the irrigated than the non-irrigated soils. Nevertheless, more than 250 years of irrigation at current rate would not cause the irrigated soils to reach the current heavy metal limits for these elements.

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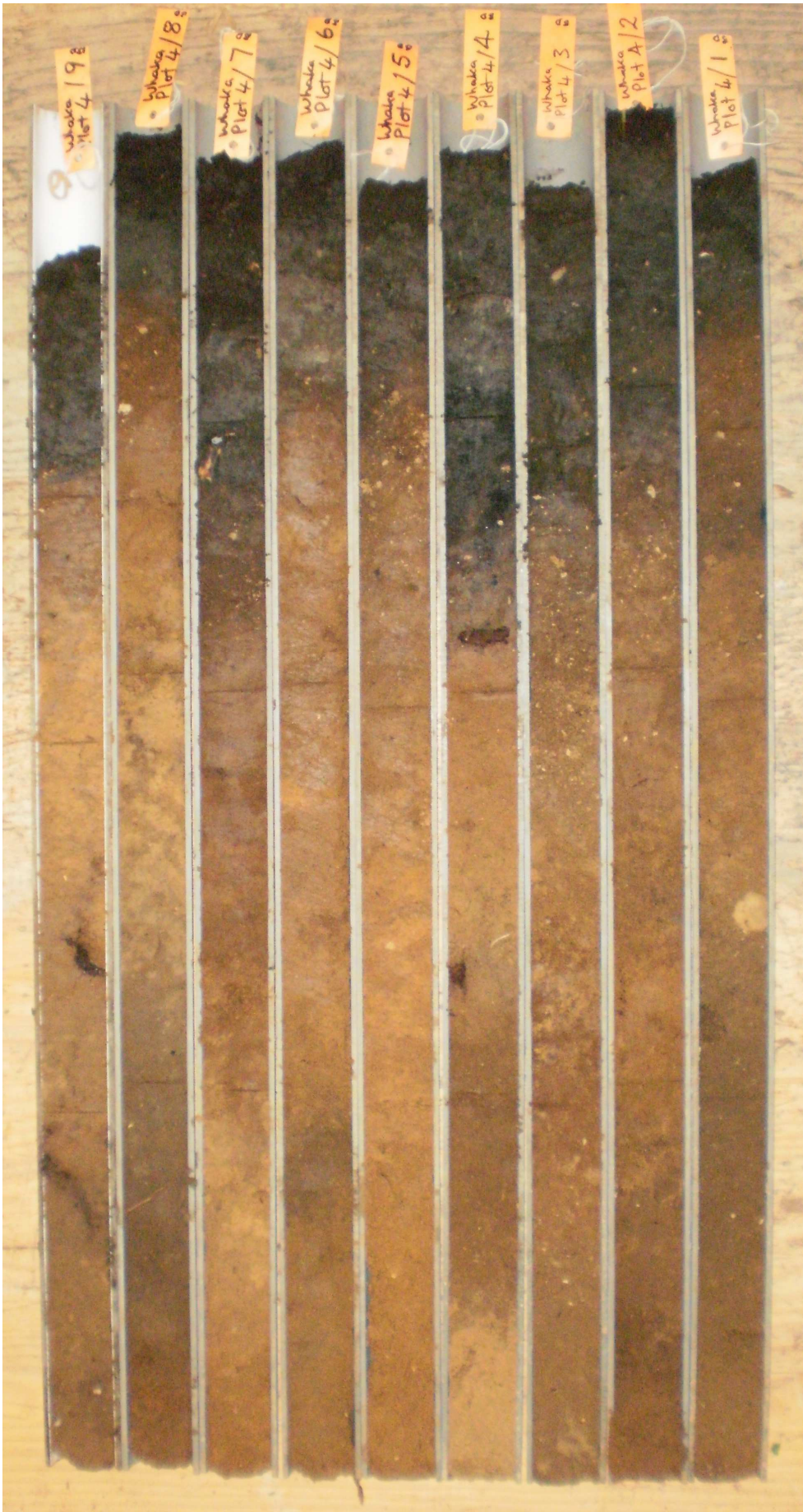
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application at Whakarewarewa Forest, New Zealand. In *"The Forest Alternative: Principles and Practice of Residuals Use"*. College of Forest Resources, University of Washington, Seattle, Washington. Chapter 25, Pp 155-162.

APPENDIX 1. PHOTOS OF SOIL PROFILES



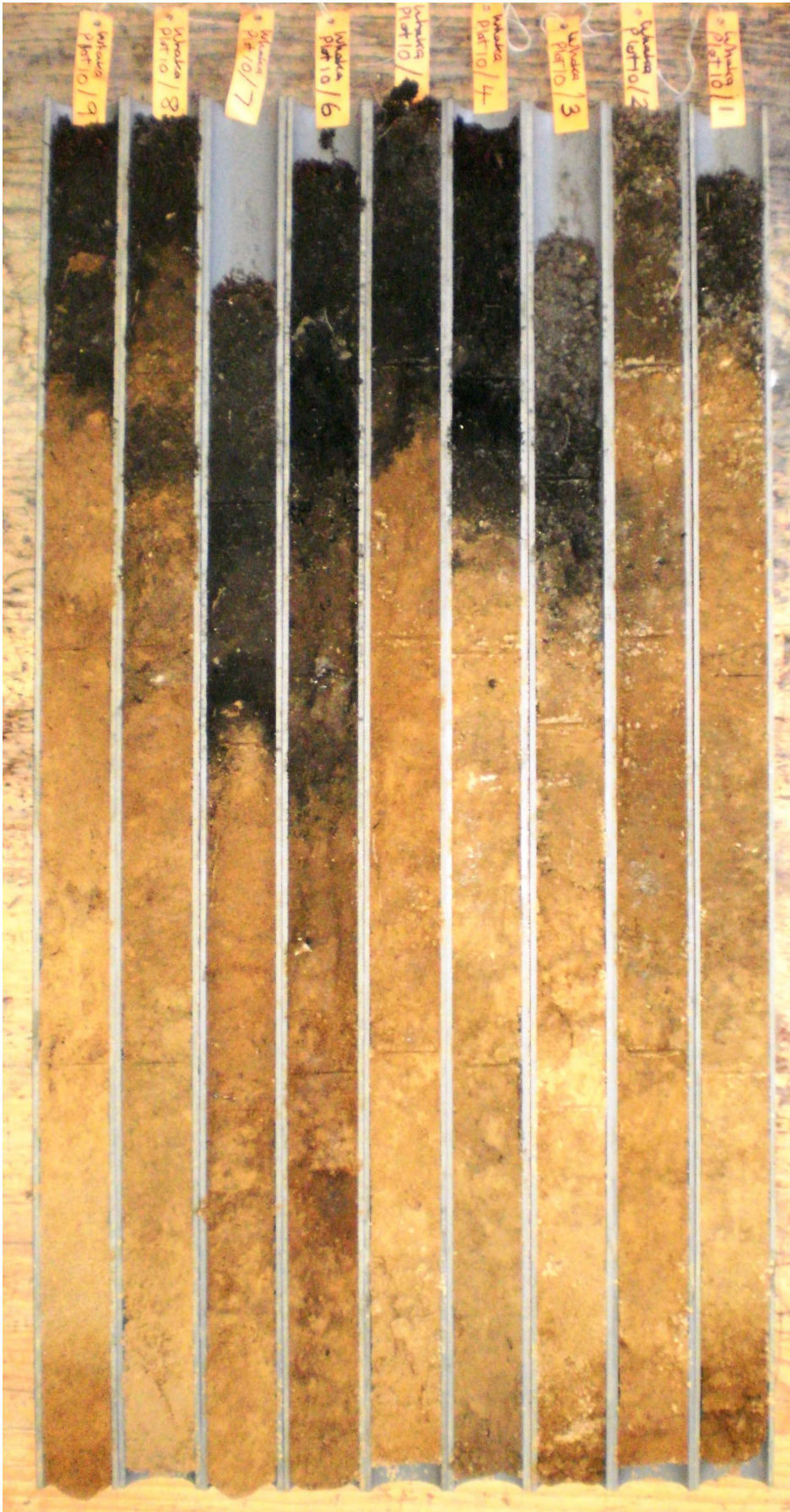
Plot 1. Power auger cores to 1 m depth - irrigated treatment



Plot 4. Power auger cores to 1 m depth - irrigated treatment



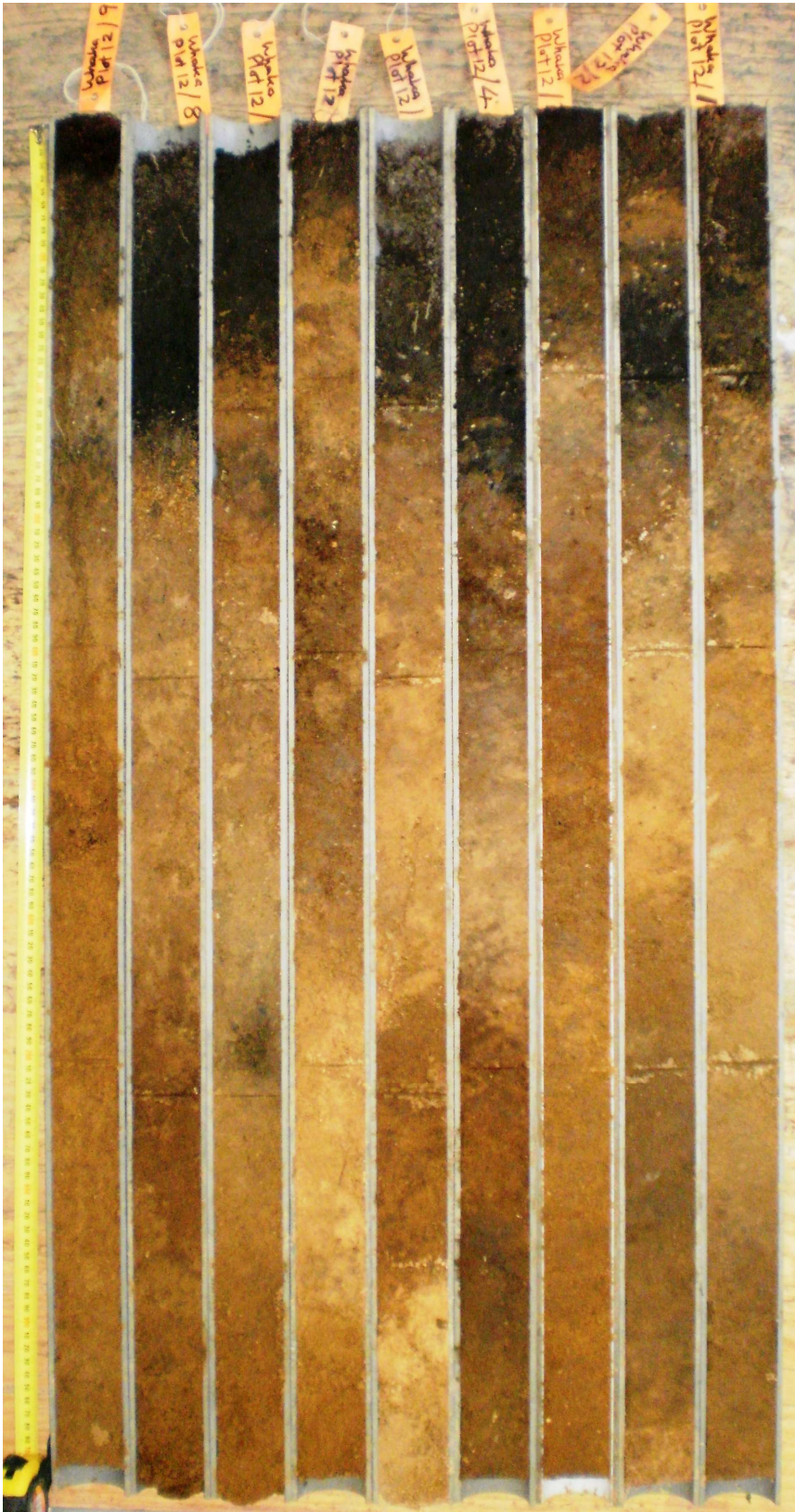
Plot 7. Power auger cores to 1 m depth - irrigated treatment



Plot 10. Power auger cores to 1 m depth - control treatment



Plot 11. Power auger cores to 1 m depth - control treatment



Plot 12. Power auger cores to 1 m depth - control treatment

APPENDIX 2. BULK DENSITY

Soil bulk density (BD < 2mm fraction) means by treatment and depth layer to 1 m depth in control plots and irrigated (80 mm/week) plots sampled in December 2012.

| Depth layer | Control BD (kg/m ³) | Irrigated BD (kg/m ³) |
|-------------|------------------------------------|--------------------------------------|
| 0-10 cm | 662 (572:752) | 460 (370:550) |
| 0-20 cm | 641 (485:797) | 619 (463:775) |
| 20-40 cm | 764 (608:920) | 755 (599:911) |
| 40-70 cm | 876 (720:1032) | 886 (730:1041) |
| 70-100 cm | 964 (808:1120) | 998 (842:1154) |

APPENDIX 3. DETAILED ANALYTICAL METHODOLOGY FROM LCR WEBSITE

Phosphate Retention

Phosphate retention is an empirical measure of the ability of a soil to remove phosphorus rapidly from solution. The process is considered to be a precursor to the much slower process of phosphorus fixation, which renders phosphorus unavailable to plants. The test is sometimes referred to as anion storage capacity (ASC), particularly in the soil fertility context where it is used as a measure of the possibility of rapid leaching of mobile anions.

Samples are shaken for 16 hours with a 1,000 mg/L P solution at pH 4.6. The method was devised by Saunders (1965) so that the concentration of phosphorus used gives a high degree of differentiation between soils of low and high phosphorus retention ability, and the pH used is close to the point of maximum phosphate retention in many soils. After centrifuging the phosphorus left in solution is determined using flow injection analysis. Orthophosphate (PO₄-P) in the extract reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions then a molybdenum blue complex is formed after ascorbic acid reduction (Lachat 1998g).

Lachat Instruments, Milwaukee, WI, USA. 1998g Quik Chem Method 12-115-01-1-J.
Saunders, W.M.H. 1965. Phosphate retention in New Zealand soils and its relationship to free sesquioxides, organic matter and other soil properties. *New Zealand Journal of Agricultural Research* 8:30 – 57.

Organic Phosphorus

The organic phosphorus fraction is determined from the increase in 0.5M H₂SO₄-soluble phosphorus caused by ignition of the soil at 550 °C for 60 minutes, which converts organic phosphorus to inorganic phosphate. The ignited soil is then extracted by shaking end-over-end with 0.5M H₂SO₄ at a ratio of 1:200 soil:extractant for 16 hours. The extraction is that described by Blakemore et al (1987). Using flow injection analysis, orthophosphate, PO₄-P, in the extract reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions then a molybdenum blue complex is formed after ascorbic acid reduction (Lachat 1998f).

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. *Methods for Chemical Analysis of Soils*. New Zealand Soil Bureau Scientific Report 80. 103 p.
Lachat Instruments, Milwaukee, WI, USA. 1998f Quik Chem Method 12-115-01-1-A.

Olsen-Available Phosphorus

Available phosphorus tests attempt to extract a similar fraction of phosphate to that accessible to plants. This method is based on that of Olsen et al (1954), as described by Blakemore et al (1987). In this method, soils are shaken end-over-end at a 1:20 ratio, with 0.5M sodium hydrogen carbonate adjusted to pH 8.5, for 30 minutes, then filtered. This process is carried out at 25°C. Using flow injection analysis, orthophosphate, PO₄-P, in the extract reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions then a molybdenum blue complex is formed after ascorbic acid reduction (Lachat 1998e).

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. *Methods for Chemical Analysis of Soils*. New Zealand Soil Bureau Scientific Report 80. 103 p.
Lachat Instruments, Milwaukee, WI, USA. 1998e Quik Chem Method 12-115-01-1-G.

Olsen, S.R.; Cole, C.V.; Watanabe, F.S.; Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Department Circular 939.

Mineral Nitrogen

Mineral nitrogen (i.e. NH₄-N and NO₃-N) levels represent immediately plant-available nitrogen and are often used as indicators of biological activity and soil fertility. However, as these forms are extremely labile levels can fluctuate rapidly and results must be interpreted with caution.

In this method, ammonium and nitrate are extracted with 2M KCl using a 1:10 soil:extractant ratio and a 1 hour end-over-end shake followed by filtration. The procedure is that described by Blakemore et al (1987). NH₄-N is determined colorimetrically using the indophenol reaction with sodium salicylate and hypochlorite (Lachat 1998c) and NO₃-N by Cd reduction and NEDD colorimetry (Lachat 1998d), both using a flow injection analyser.

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 80. 103 p.

Lachat Instruments, Milwaukee, WI, USA. 1998c Quik Chem Method 12-107-06-3-A.

Lachat Instruments, Milwaukee, WI, USA. 1998d Quik Chem Method 12-107-04-1-B.

Organic carbon and total nitrogen

Soils are analysed using a Leco CNS2000 Analyzer (Leco, 2003) which utilises the Dumas dry combustion principle. Samples are combusted in a stream of pure oxygen at 1050 °C. Moisture is removed from the combustion gases via a thermo-electric cooler and the gases are routed into a ballast to equilibrate. An aliquot is subsampled and passed through a heated copper catalyst which converts the various forms of nitrogen to N₂ which is then measured by a thermal conductivity detector. At the same time the CO₂ produced from carbon present is measured in an infrared detector cell.

Inorganic carbon (e.g. carbonate and bicarbonate) is not combusted at the temperatures used in this method. For most New Zealand soils with a pH below 7, the free carbonate content is negligible (Miller, 1968) and therefore the total carbon content obtained using Dumas combustion without acid pretreatment may be taken as the total organic carbon content of the soil (Metson et al, 1979.) Charcoal, however, is measured by this technique and if present will contribute to the result.

A conversion factor of 1.72 can be used to convert organic carbon to organic matter, based on the assumption that organic matter contains 58% organic C (Nelson and Sommers, 1996).

Leco, 2003. Total/organic carbon and nitrogen in soils. LECO Corporation, St. Joseph, MO, Organic Application Note 203-821-165.

Metson, A.J., Blakemore, L.C. and Rhoades, D.A. 1979. Methods for the determination of soil organic carbon: a review, and application to New Zealand soils. NZ Journal of Science 22:205 -228.

Miller, R.B. Soil pH, calcium carbonate and soluble salts. Soils of New Zealand, Part 2. NZ Soil Bureau Bulletin 26(2):50 – 54.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, 2nd ed., A.L. Page et al., Ed. Agronomy. 9:961-1010. Am. Soc. of Agron., Inc. Madison, WI.

pH in Water 1:5 ratio

In this method, a 1:5 suspension is shaken for 30 minutes then measured with a pH electrode. The extract can also be used for the measurement of conductivity. The method is based on that described by Blakemore et al (1987).

In this report pH was measured in a 1:5 suspension while as part the soil health indicators project soil was measured in a 1:2.5 suspension. However, variation of the ratio of soil to water within the range 1:1 to 1:10 does not alter the pH much, values being around 0.1 to 0.3 pH unit higher for the more dilute suspensions (Piper, 1942) probably owing to dilution of CO₂ absorbed in the soil sample (Whitney & Gardner, 1943).

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 80. 103 p.

Piper, C.S. 1942. Soil and plant analysis. University of Adelaide, Adelaide. 368p.

Whitney, R.S. and Gardner, R. 1943. The effects of carbon dioxide on soil reaction. Soil Science 55:127 – 141.

Electrical Conductivity

In this method, a 1:5 soil:water mixture is shaken for 30 minutes, allowed to settle then the conductivity measured with a temperature-compensated probe. An approximate soluble salts value may be derived from the conductivity using the empirical relationship:

$$\text{Soluble salts (\%)} = \text{Conductivity (dS/m)} \times 0.35$$

The method is based on that described by Blakemore et al (1987). Reporting is now in line with SI convention and uses units of dS/m rather than the historic mS/cm. Numerically though, dS/m and mS/cm are equivalent.

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 80. 103 p.

APPENDIX 4. CHEMICAL AND PHYSICAL ANALYSES FROM LCR LABORATORY.

Job Number: LJ12071

Date Received: 12th December 2013

Customer: Dr Ir Gerty Gielen, Industrial Ecology, Scion
49 Sala Street, Private Bag 3020
Rotorua 3046

Date Reported: 18th March 2013

| Client ID | Sample No. | Water Content (method 104(III)) (% dry wt) | pH (1:5 Water) (method 106(III)) | EC (1:5) (method 110) (dS/m) | Organic C (method 114) (%) | Total N (method 114) (%) | KCl-extractable | |
|------------------|------------|--|--|---------------------------------------|----------------------------------|--------------------------------|-----------------------|------------------|
| | | | | | | | NO3-N (method 118) | NH4-N (mg/kg) |
| Whaka/1/0-10 | M12/2387 | 125.8 | 6.76 | 0.17 | 6.99 | 0.37 | 33.5 | 1.1 |
| Whaka/4/0-10 | M12/2388 | 104.6 | 6.82 | 0.16 | 6.58 | 0.37 | 28.5 | 0.4 |
| Whaka/7/0-10 | M12/2389 | 76.3 | 6.83 | 0.13 | 5.79 | 0.28 | 22.2 | 0.7 |
| Whaka/10/0-10 | M12/2390 | 38.9 | 5.91 | 0.04 | 4.72 | 0.19 | 0.0 | 1.0 |
| Whaka/11/0-10 | M12/2391 | 41.5 | 5.81 | 0.04 | 4.83 | 0.21 | 0.3 | 0.9 |
| Whaka/12/0-10 | M12/2392 | 41.9 | 5.84 | 0.04 | 4.33 | 0.21 | 0.6 | 4.0 |
| Whaka/1/0-20 | M12/2393 | 82.7 | 6.68 | 0.12 | 5.46 | 0.26 | 0.2 | 1.7 |
| Whaka/1/20-40 | M12/2394 | 60.8 | 6.85 | 0.07 | 2.67 | 0.10 | 9.1 | 0.7 |
| Whaka/1/40-70 | M12/2395 | 55.9 | 6.83 | 0.08 | 1.92 | 0.08 | 2.5 | 0.7 |
| Whaka/1/70-100 | M12/2396 | 41.9 | 6.76 | 0.07 | 1.09 | 0.04 | 1.9 | 0.7 |
| Whaka/1/100-150 | M12/2397 | 49.3 | 6.54 | 0.08 | 0.85 | 0.04 | 1.3 | 0.6 |
| Whaka/1/150-200 | M12/2398 | 45.0 | 6.54 | 0.07 | 0.67 | 0.03 | 1.8 | 1.5 |
| Whaka/4/0-20 | M12/2399 | 95.8 | 6.84 | 0.14 | 6.14 | 0.34 | 1.5 | 0.5 |
| Whaka/4/20-40 | M12/2400 | 55.6 | 7.02 | 0.08 | 2.13 | 0.11 | 14.2 | 0.7 |
| Whaka/4/40-70 | M12/2401 | 52.0 | 6.89 | 0.09 | 1.65 | 0.09 | 2.4 | 1.1 |
| Whaka/4/70-100 | M12/2402 | 47.9 | 6.81 | 0.08 | 1.52 | 0.08 | 2.3 | 0.7 |
| Whaka/4/100-150 | M12/2403 | 50.3 | 6.71 | 0.08 | 1.22 | 0.06 | 2.3 | 0.7 |
| Whaka/4/150-200 | M12/2404 | 39.0 | 6.73 | 0.06 | 0.55 | 0.03 | 1.9 | 0.9 |
| Whaka/7/0-20 | M12/2405 | 63.8 | 6.98 | 0.10 | 4.97 | 0.25 | 1.3 | 0.3 |
| Whaka/7/20-40 | M12/2406 | 44.3 | 7.25 | 0.08 | 2.70 | 0.13 | 5.1 | 0.8 |
| Whaka/7/40-70 | M12/2407 | 40.0 | 7.17 | 0.08 | 1.42 | 0.08 | 0.1 | 0.7 |
| Whaka/7/70-100 | M12/2408 | 38.1 | 7.07 | 0.08 | 0.78 | 0.04 | 1.3 | 1.0 |
| Whaka/7/100-150 | M12/2409 | 37.4 | 7.02 | 0.07 | 0.54 | 0.03 | 1.2 | 0.9 |
| Whaka/7/150-200 | M12/2410 | 36.4 | 7.15 | 0.06 | 0.35 | 0.02 | 1.5 | 0.6 |
| Whaka/10/0-20 | M12/2411 | 43.9 | 6.12 | 0.04 | 5.22 | 0.23 | 0.5 | 0.7 |
| Whaka/10/20-40 | M12/2412 | 42.6 | 6.07 | 0.03 | 2.60 | 0.12 | 0.1 | 1.7 |
| Whaka/10/40-70 | M12/2413 | 37.4 | 6.06 | 0.03 | 1.33 | 0.07 | 0.1 | 1.0 |
| Whaka/10/70-100 | M12/2414 | 31.5 | 6.10 | 0.02 | 0.64 | 0.04 | 0.1 | 0.9 |
| Whaka/10/100-150 | M12/2415 | 46.3 | 6.15 | 0.02 | 0.68 | 0.04 | 0.2 | 0.5 |
| Whaka/10/150-200 | M12/2416 | 34.9 | 6.39 | 0.02 | 0.38 | 0.02 | 0.9 | 2.2 |
| Whaka/11/0-20 | M12/2417 | 41.1 | 5.90 | 0.04 | 4.75 | 0.20 | 0.8 | 1.9 |
| Whaka/11/20-40 | M12/2418 | 41.4 | 5.97 | 0.02 | 2.31 | 0.11 | 0.1 | 1.1 |
| Whaka/11/40-70 | M12/2419 | 41.9 | 5.91 | 0.02 | 1.82 | 0.09 | 0.2 | 1.0 |
| Whaka/11/70-100 | M12/2420 | 45.2 | 5.95 | 0.02 | 1.56 | 0.07 | 0.1 | 1.0 |
| Whaka/11/100-150 | M12/2421 | 41.3 | 5.97 | 0.02 | 0.82 | 0.04 | 0.2 | 0.9 |
| Whaka/11/150-200 | M12/2422 | 36.7 | 6.08 | 0.02 | 0.46 | 0.01 | 0.2 | 0.8 |
| Whaka/12/0-20 | M12/2423 | 46.8 | 6.01 | 0.03 | 3.74 | 0.19 | 0.1 | 0.4 |
| Whaka/12/20-40 | M12/2424 | 42.3 | 5.99 | 0.03 | 1.73 | 0.09 | 0.3 | 1.6 |
| Whaka/12/40-70 | M12/2425 | 42.8 | 5.94 | 0.03 | 1.63 | 0.08 | 0.4 | 1.3 |
| Whaka/12/70-100 | M12/2426 | 48.0 | 6.07 | 0.02 | 1.88 | 0.08 | 0.2 | 0.7 |
| Whaka/12/100-150 | M12/2427 | 44.5 | 6.13 | 0.02 | 1.05 | 0.05 | 0.1 | 0.7 |
| Whaka/12/150-200 | M12/2428 | 32.0 | 6.24 | 0.02 | 0.36 | 0.03 | 0.1 | 0.4 |

| Client ID | Sample No. | Anaerobic Mineralisable-N (method 120) (mg/kg) | 56-day Aerobic Mineralisable-N (method 121) * (mg/kg) | Nitrate % of 56-day extract. N (calc) | Olsen P (method 124) (mg/kg) | Total P (method 130) (mg/kg) | Phosphate Retention (method 132) (%) |
|------------------|------------|--|---|---------------------------------------|------------------------------|------------------------------|--------------------------------------|
| Whaka/1/0-10 | M12/2387 | 108 | 72.2 | 99 | 161 | not requested | not requested |
| Whaka/4/0-10 | M12/2388 | 84 | 76.0 | 100 | 147 | not requested | not requested |
| Whaka/7/0-10 | M12/2389 | 89 | 88.6 | 99 | 100 | not requested | not requested |
| Whaka/10/0-10 | M12/2390 | 56 | 26.4 | 98 | 5 | not requested | not requested |
| Whaka/11/0-10 | M12/2391 | 63 | 16.3 | 96 | 4 | not requested | not requested |
| Whaka/12/0-10 | M12/2392 | 51 | 65.8 | 93 | 4 | not requested | not requested |
| Whaka/1/0-20 | M12/2393 | not requested | not requested | not requested | 161 | 1300 | 38 |
| Whaka/1/20-40 | M12/2394 | not requested | not requested | not requested | 84 | 871 | 60 |
| Whaka/1/40-70 | M12/2395 | not requested | not requested | not requested | 15 | 435 | 81 |
| Whaka/1/70-100 | M12/2396 | not requested | not requested | not requested | 3 | 212 | 78 |
| Whaka/1/100-150 | M12/2397 | not requested | not requested | not requested | 2 | 206 | 83 |
| Whaka/1/150-200 | M12/2398 | not requested | not requested | not requested | 2 | 204 | 76 |
| Whaka/4/0-20 | M12/2399 | not requested | not requested | not requested | 160 | 1390 | 40 |
| Whaka/4/20-40 | M12/2400 | not requested | not requested | not requested | 114 | 1030 | 64 |
| Whaka/4/40-70 | M12/2401 | not requested | not requested | not requested | 17 | 346 | 84 |
| Whaka/4/70-100 | M12/2402 | not requested | not requested | not requested | 3 | 191 | 88 |
| Whaka/4/100-150 | M12/2403 | not requested | not requested | not requested | 3 | 192 | 88 |
| Whaka/4/150-200 | M12/2404 | not requested | not requested | not requested | 2 | 156 | 67 |
| Whaka/7/0-20 | M12/2405 | not requested | not requested | not requested | 93 | 973 | 57 |
| Whaka/7/20-40 | M12/2406 | not requested | not requested | not requested | 29 | 480 | 76 |
| Whaka/7/40-70 | M12/2407 | not requested | not requested | not requested | 4 | 142 | 81 |
| Whaka/7/70-100 | M12/2408 | not requested | not requested | not requested | 1 | 98 | 82 |
| Whaka/7/100-150 | M12/2409 | not requested | not requested | not requested | 1 | 96 | 71 |
| Whaka/7/150-200 | M12/2410 | not requested | not requested | not requested | 1 | 103 | 53 |
| Whaka/10/0-20 | M12/2411 | not requested | not requested | not requested | 3 | 307 | 73 |
| Whaka/10/20-40 | M12/2412 | not requested | not requested | not requested | 2 | 225 | 81 |
| Whaka/10/40-70 | M12/2413 | not requested | not requested | not requested | 1 | 156 | 86 |
| Whaka/10/70-100 | M12/2414 | not requested | not requested | not requested | 1 | 120 | 76 |
| Whaka/10/100-150 | M12/2415 | not requested | not requested | not requested | 1 | 141 | 89 |
| Whaka/10/150-200 | M12/2416 | not requested | not requested | not requested | 1 | 157 | 63 |
| Whaka/11/0-20 | M12/2417 | not requested | not requested | not requested | 2 | 215 | 66 |
| Whaka/11/20-40 | M12/2418 | not requested | not requested | not requested | 1 | 169 | 81 |
| Whaka/11/40-70 | M12/2419 | not requested | not requested | not requested | 1 | 128 | 91 |
| Whaka/11/70-100 | M12/2420 | not requested | not requested | not requested | 1 | 155 | 93 |
| Whaka/11/100-150 | M12/2421 | not requested | not requested | not requested | 1 | 120 | 81 |
| Whaka/11/150-200 | M12/2422 | not requested | not requested | not requested | 1 | 139 | 61 |
| Whaka/12/0-20 | M12/2423 | not requested | not requested | not requested | 2 | 227 | 72 |
| Whaka/12/20-40 | M12/2424 | not requested | not requested | not requested | 1 | 139 | 71 |
| Whaka/12/40-70 | M12/2425 | not requested | not requested | not requested | 1 | 137 | 89 |
| Whaka/12/70-100 | M12/2426 | not requested | not requested | not requested | 1 | 168 | 95 |
| Whaka/12/100-150 | M12/2427 | not requested | not requested | not requested | 1 | 171 | 88 |
| Whaka/12/150-200 | M12/2428 | not requested | not requested | not requested | 1 | 174 | 56 |

Soil Physics Laboratory Analytical Report

Job Number: PJ12019

Date Received: 19/12/2012

Customer: SCION, Gerty Gielen

Date Reported: 15/01/2013

| Core # | Plot | R e p | Remarks | Sample ID | Particle density (g/cm ³) | Dry bulk density (g/cm ³) | Porosity (%) | Macro-porosity (%) | Gravimetric water content | | | Volumetric water content | | |
|--------|------|-------|---------------|-----------|--|--|-----------------|-----------------------|---------------------------|----------------------|------------------|--------------------------|----------------------|------------------|
| | | | | | | | | | Field (%w/w) | Saturation (%w/w) | -5 kPa (%w/w) | Field (%v/v) | Saturation (%v/v) | -5 kPa (%v/v) |
| 54 | 1 | a | | PP12-0313 | 2.48 | 0.86 | 65 | 12 | 64 | 76 | 62 | 55 | 65 | 54 |
| 4 | 1 | b | core 4 not 63 | PP12-0314 | 2.54 | 0.99 | 61 | 20 | 38 | 62 | 42 | 37 | 61 | 41 |
| 25 | 1 | c | | PP12-0315 | 2.35 | 0.76 | 68 | 11 | 75 | 89 | 74 | 57 | 68 | 56 |
| 33 | 4 | a | | PP12-0316 | 2.50 | 1.00 | 60 | 12 | 49 | 60 | 49 | 48 | 60 | 48 |
| 39 | 4 | b | | PP12-0317 | 2.40 | 0.83 | 65 | 4 | 75 | 79 | 75 | 62 | 65 | 62 |
| 67 | 4 | c | | PP12-0318 | 2.38 | 0.72 | 70 | 20 | 67 | 97 | 69 | 49 | 70 | 50 |
| 69 | 7 | a | | PP12-0319 | 2.36 | 0.64 | 73 | 30 | 51 | 113 | 66 | 33 | 73 | 43 |
| 64 | 7 | b | | PP12-0320 | 2.34 | 0.70 | 70 | 28 | 37 | 101 | 61 | 26 | 70 | 42 |
| 66 | 7 | c | | PP12-0321 | 2.40 | 0.70 | 71 | 24 | 65 | 102 | 68 | 46 | 71 | 47 |
| 10 | 10 | a | | PP12-0322 | 2.43 | 0.85 | 65 | 22 | 41 | 77 | 51 | 35 | 65 | 43 |
| 11 | 10 | b | | PP12-0323 | 2.35 | 0.75 | 68 | 29 | 38 | 91 | 52 | 28 | 68 | 39 |
| 6 | 10 | c | | PP12-0324 | 2.32 | 0.64 | 72 | 32 | 40 | 113 | 63 | 25 | 72 | 40 |
| 40 | 11 | a | | PP12-0325 | 2.31 | 0.72 | 69 | 24 | 51 | 96 | 63 | 36 | 69 | 45 |
| 31 | 11 | b | | PP12-0326 | 2.36 | 0.73 | 69 | 35 | 33 | 95 | 47 | 24 | 69 | 34 |
| 53 | 11 | c | | PP12-0327 | 2.34 | 0.71 | 70 | 35 | 23 | 98 | 49 | 16 | 70 | 35 |
| 43 | 12 | a | | PP12-0328 | 2.33 | 0.67 | 71 | 33 | 37 | 107 | 57 | 25 | 71 | 38 |
| 28 | 12 | b | | PP12-0329 | 2.42 | 0.75 | 69 | 33 | 32 | 92 | 49 | 24 | 69 | 36 |
| 21 | 12 | c | | PP12-0330 | 2.37 | 0.79 | 67 | 23 | 35 | 85 | 56 | 28 | 67 | 44 |

APPENDIX 5. CHEMICAL ANALYSIS RESULTS FROM HILL'S LABORATORY.

| Sample Type: Soil | | | | | | |
|--|---------------|--------------|--------------|---------------|---------------|--------|
| Sample Name: | Whaka/1/0-10 | Whaka/4/0-10 | Whaka/7/0-10 | Whaka/10/0-10 | Whaka/11/0-10 | |
| Lab Number: | 1080465.1 | 1080465.2 | 1080465.3 | 1080465.4 | 1080465.5 | |
| Heavy metals, screen As,Cd,Cr,Cu,Ni,Pb,Zn,Hg | | | | | | |
| Total Recoverable Arsenic | mg/kg dry wt | 5 | 6 | 5 | 6 | 5 |
| Total Recoverable Cadmium | mg/kg dry wt | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Total Recoverable Chromium | mg/kg dry wt | 4 | 5 | 3 | < 2 | 2 |
| Total Recoverable Copper | mg/kg dry wt | 16 | 16 | 10 | 7 | 5 |
| Total Recoverable Lead | mg/kg dry wt | 5.8 | 6.1 | 5.7 | 5.3 | 5.8 |
| Total Recoverable Mercury | mg/kg dry wt | 0.15 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Total Recoverable Nickel | mg/kg dry wt | < 2 | < 2 | < 2 | < 2 | < 2 |
| Total Recoverable Zinc | mg/kg dry wt | 43 | 46 | 25 | 19 | 12 |
| Sample Name: | Whaka/12/0-10 | | | | | |
| Lab Number: | 1080465.6 | | | | | |
| Heavy metals, screen As,Cd,Cr,Cu,Ni,Pb,Zn,Hg | | | | | | |
| Total Recoverable Arsenic | mg/kg dry wt | 6 | - | - | - | - |
| Total Recoverable Cadmium | mg/kg dry wt | < 0.10 | - | - | - | - |
| Total Recoverable Chromium | mg/kg dry wt | < 2 | - | - | - | - |
| Total Recoverable Copper | mg/kg dry wt | 7 | - | - | - | - |
| Total Recoverable Lead | mg/kg dry wt | 6.1 | - | - | - | - |
| Total Recoverable Mercury | mg/kg dry wt | < 0.10 | - | - | - | - |
| Total Recoverable Nickel | mg/kg dry wt | < 2 | - | - | - | - |
| Total Recoverable Zinc | mg/kg dry wt | 17 | - | - | - | - |