Soil Quality in the Bay of Plenty: 2010 Update

Prepared by Danilo Guinto, Environmental Scientist

Bay of Plenty Regional Council
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Cover Photo: Soil quality sampling in a kiwifruit orchard.

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Executive summary

Temporal changes in topsoil qualities of drystock (sheep/beef and deer) and kiwifruit orchard sites were monitored periodically over a 10-year period. Results indicate that for the land uses monitored, many of the topsoil quality indicators were being maintained and these are within the provisional target values set by Landcare Research New Zealand for production and/or environmental criterion. These target values have been adopted by many regional councils representing the Land Monitoring Forum.

However, the current high level of anaerobically mineralisable N (close to 200 mg/kg) at the sheep/beef and deer sites is a concern because further increase could lead to significantly higher nitrate leaching and subsequent eutrophication of water bodies. In the case of kiwifruit land use, there was an increasing temporal trend in Olsen P values. The current Olsen P mean value exceeded the 100 mg/kg target and is a cause for concern because high Olsen P levels could lead to P-laden sediment polluting streams and other water bodies. Since kiwifruit does not require high P input for high productivity, application of P fertilisers can be reduced significantly.

The soil quality monitoring programme is invaluable in informing land managers of changes in soil quality on their properties over time particularly when there are clear trends in declining soil health so that remedial actions can be promptly undertaken. Soil quality monitoring should therefore continue well into the future with a view towards expansion into areas that are undergoing land use intensification (e.g. recent forest to dairy farm conversions) or expansion (e.g. maize cropping); and inclusion of more biological measures of soil quality such as soil microbial biodiversity (earthworms, microbiological activity etc), respiration, microbial biomass, soil enzyme activity, etc. as an indication of soil well-being.

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Tables and Figures

Part 1: Introduction

As part of its Natural Environment Regional Monitoring Network (NERMN) programme, the Bay of Plenty Regional Council has been collecting soil quality or soil health data since the late 1990's when it participated in the 500 Soils Project involving various regional councils in New Zealand (Sparling and Schipper 2002; 2004). Over the years, a total of more than 70 soil quality sites have been progressively established under various land uses. The sites were categorised by land use which include: cropping (maize), dairy, sheep and beef, deer, kiwifruit and forests (indigenous and plantation). Sampling frequencies differ and depend on the degree of soil disturbance or cultivation. Thus, cropping sites are sampled every three years, dairy, sheep and beef, deer, and kiwifruit sites every five years, and forest sites every 10 years. The status of soil quality in the region has been reported periodically by Landcare Research (Sparling 2001; Sparling and Rijkse 2003; Sparling 2004; Sparling 2005; Sparling 2006a; Sparling 2006b) for all land uses and more recently by Guinto (2009) for dairy pasture and maize cropping sites. This report focuses on the results of the 2010 soil quality sampling which covered drystock (sheep/beef and deer pastures) and kiwifruit orchard sites.

Part 2: Materials and methods

2.1 Soil sampling and analyses

The standard protocol for New Zealand soil quality sampling was followed (Hill and Sparling 2009). A 50 m transect was established in each site. For chemical analyses, topsoil samples (0-10 cm) were collected with a step-on soil sampler at 2 m intervals along the 50 m transect. The individual samples collected were bulked and mixed thoroughly in a plastic bag. For physical analyses, three stainless steel soil cores (10 cm diameter, 7.5 cm high) were taken at 15, 30 and 45 m along the transect. It should be noted that the standard 0-10 cm topsoil sampling depth represents a compromise for pasture and horticultural land uses since pasture soils are normally sampled at 0-7.5 cm while kiwifruit soils are sampled at 0-15 cm.

In samplings previously conducted by Landcare Research on these three land uses (Sparling 2001; 2005), there were a total 19 soil quality sites consisting of 10 sheep/beef pasture sites, four deer pasture sites and five kiwifruit orchard sites (Figure 1 and Appendix 1). However, for the 2010 resampling, one sheep/beef landowner and one deer farm landowner did not allow access to their farms which reduced the total number of sites sampled to 17.

The samples were submitted to Landcare Research laboratories (Hamilton for physical analyses and Palmerston North for chemical analyses) for the analysis of seven standard soil quality indicators, namely: pH, total carbon (C), total nitrogen (N), anaerobically mineralisable N, Olsen phosphorus (P), bulk density and macroporosity. The C/N ratio was obtained by dividing total C with total N (Hill and Sparling 2009). Descriptions of the seven soil quality standards are provided in the Glossary (Appendix 2).

2.2 Data analysis

Mean values of topsoil qualities by land use class were compared with the “target” or “desirable” qualities set as provisional soil quality target values for New Zealand (Sparling et al. 2008). These provisional standards have been adopted by many regional councils represented by the Land Monitoring Forum (LMF). The standards are grouped according to land use and/or soil classification. Previous results from drystock and kiwifruit sites sampled in 1999/2000 and 2004/2005 reported by Landcare Research (Sparling 2001; 2005) were also presented in order to show trends over time. For each land use, analysis of variance was employed to detect if there are statistically significant changes in topsoil qualities over time ($P<0.05$).

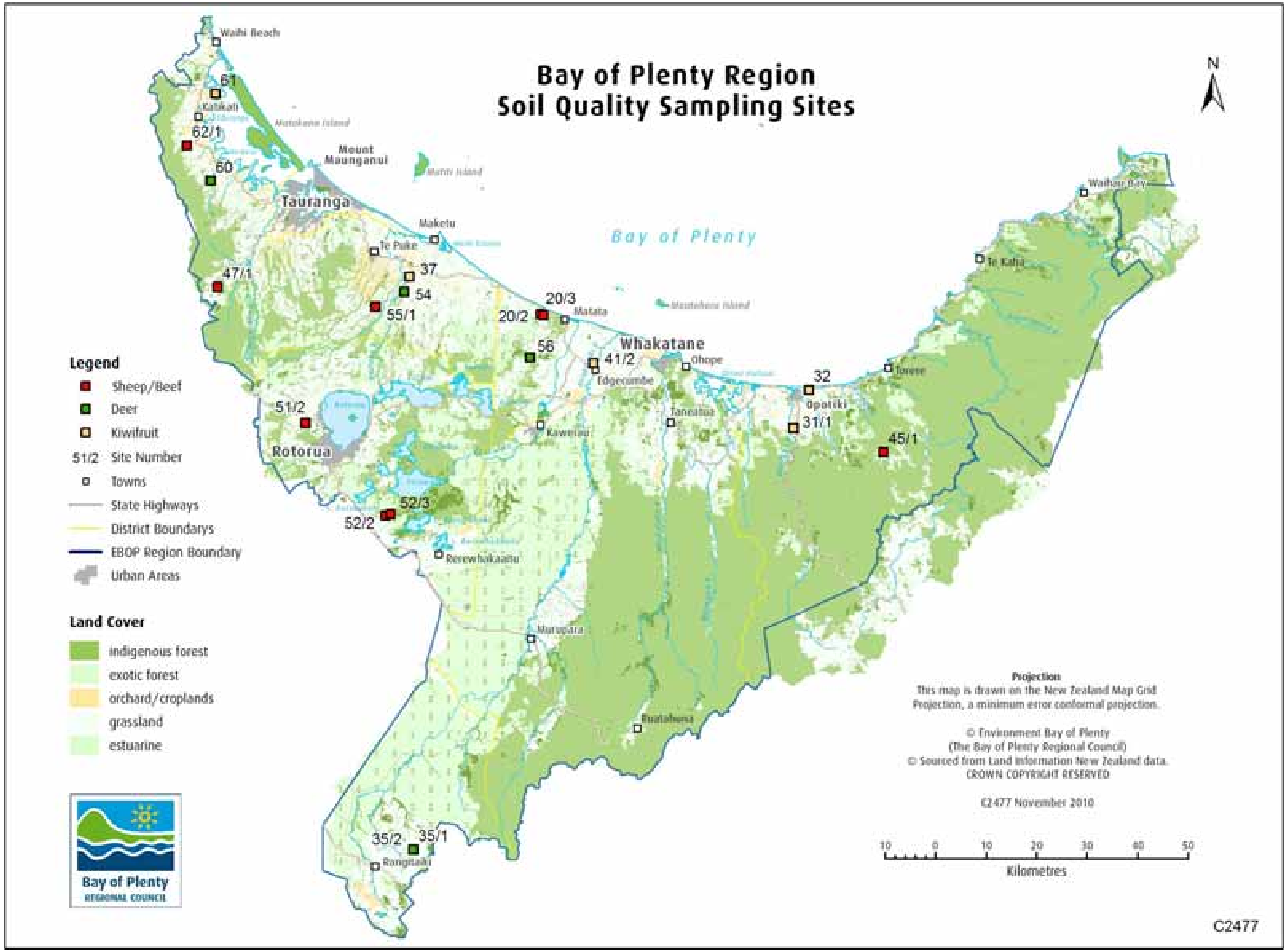

Figure 1 *Sheep/beef, deer and kiwifruit soil quality sampling sites.*

Part 3: Results and discussion

3.1 Topsoil quality of sheep and beef pasture sites

Table 1 shows the mean topsoil qualities of sheep and beef pasture sites sampled in 2010. Mean soil pH (5.8) was within the 5.0-6.6 soil quality target. In fact, all of the sites also met this target so soil acidity is not an issue in these soils.

The mean total C was 7.7% with all sites meeting the >2.5% total C target. For total N, the mean value of 0.64% was within the target range of 0.25-0.70%. More than 55% of the sites met this target. Those sites that did not meet the target have total N values above the 0.70% limit. High total N concentrations are generally desirable from a productivity standpoint since it represents the stock of soil N that could potentially mineralise during the growing season. However, very high total N levels in pasture soils are becoming a concern for environmental goals because of its potential to contribute to elevated nitrate levels in soil and to increase leaching losses and eutrophication of water bodies (Sparling et al. 2008).

The mean C/N ratio of 12.1 was slightly above the 8-12 target range from a production standpoint. More than 55% of the sites have C/N ratios within the production target range. About 44% of the sites that did not meet the target range. Using the environmental criterion, however, all sites have C:N ratio within the 7-30 target range.

Mean anaerobically mineralisable N (189 mg/kg) was within the 50-250 mg/kg target range. Majority of the sites (8 out of 9 samples) met the target range. The site not meeting the target range had anaerobically mineralisable N above the 250 mg/kg upper limit. As with total N, the main risk to the environment from high anaerobically mineralisable N is the increased chance of nitrate leaching and eutrophication of receiving waters (Sparling et al. 2008).

The mean Olsen P concentration of 44 mg/kg was within the target range of 15-100 mg/kg. About 67% of the sites met this target range while those not meeting the target range have either Olsen P values below the 15 mg/kg lower limit (22%) or above the 100 mg/kg upper limit (11%). Topsoils with low Olsen P reflect an under-investment in pasture production. On the other hand, applying phosphate fertilisers in excess of plant requirements represents not only a monetary loss to farmers but also contributes to eutrophication of rivers and lakes when P is carried in sediment during runoff events.

The mean bulk density of 0.77 t/m^3 was within the target range of 0.5-1.4 t/m^3. All of the sites have bulk density values within the target range thus ruling out any compaction issue as far as this physical soil quality indicator is concerned.

For macroporosity, the mean value of 19.8% was within the target range of 6-30%. Majority of the sites (78%) were well within this target range. About 22% of the sites have macroporosity values above the 30% indicating very porous soils represented by sandy pumice soils (Kāingaroa and Ohinepanea soil series, Appendix 1). Extremely high macroporosity values can be undesirable because of the higher risk of leaching of nutrients such as nitrate.

Table 1 Topsoil qualities of sheep and beef pasture sites sampled in 2010 and their comparison with the provisional target soil qualities for pasture soils.

Soil Quality	pH	Total C (%)	Total N (%)	C/N Ratio	Mineral-isable N (mg/kg)	Olsen P (mg/kg)	Bulk Density (t/m^3)	Macro-porosity (%)
Mean	**5.8**	**7.7**	**0.64**	**12.1**	**189**	**44**	**0.77**	**19.8**
Std Error	0.1	0.8	0.07	0.5	16	12	0.10	3.1
Pasture soil quality targets	**5.0-6.6**	**>2.5**	**0.25-0.70**	**8-12 (prodn) 7-30 (env'l)**	**50- 250**	**15-100**	**0.5-1.4**	**6-30**
Total no. of sheep/beef sites	9	9	9	9 9	9	9	9	9
No of sites meeting target	9	9	5	5 9	8	6	9	7
No. of sites not meeting target	0	0	4	4 0	1	3	0	2
No. of sites below target	0	0	0	0 0	0	2	0	0
No. of sites above target	0	na	4	4 0	1	1	0	2
Percentage of sites meeting target	100	100	55.6	55.6 100	88.9	66.7	100	77.8
Percentage of sites not meeting target	0	0	44.4	44.4 0	11.1	33.3	0	22.2
Percentage of sites below target	0	0	0	0 0	0	22.2	0	0
Percentage of sites above target	0	na	44.4	44.4 0	11.1	11.1	0	22.2

Note: Where target is not a range (e.g. >2.5%), number and percentage of sites above target are set to 'not applicable' (na) since there is no set upper limit.

3.2 Topsoil qualities of deer pasture sites

Table 2 shows the topsoil qualities of deer pasture sites sampled in 2010. Mean soil pH (5.7) was within the 5.0-6.6 soil quality target range. All of the sites (100%) also met this target range.

The mean total C was 7.7% with all sites meeting the >2.5% total C target. The same is true for total N, with a mean value of 0.65%. The mean C/N ratio of 11.9 was within the 8-12 target range for production and 7-30 range for environmental criterion. However, one site had a C/N ratio above the upper range of 12 for production.

The mean concentration of anaerobically mineralisable N was 179 mg/kg and lies within the 50-200 mg/kg target range. All soils have anaerobically mineralisable N values within this target range

The mean Olsen P concentration of 67 mg/kg was within the target range of 15-100 mg/kg. As with mineralisable N, all sites met this target range.

The mean bulk density of 0.75 t/m^3 was within the target range of 0.5-1.4 t/m^3. In fact, all of the sites attained this target range. As regards macroporosity, the mean value of 24.1% lies within the target range of 6-30%. Two out of three sites were also within this target range and this shows that compaction is not an issue on the deer pasture soils. In fact, macroporosity for one deer site (Kāingaroa series, Appendix 1) slightly exceeded the 30% target value.

Mean values for pH, total C, total N, C/N ratio and bulk density are very similar between sheep/beef beef farms and deer farms (Tables 1 and 2) indicating similar intensity of land use. However, mean Olsen P was higher in the deer farms compared with the sheep/beef farms (67 vs. 44 mg/kg). On the other hand, mean mineralisable N of deer farms was slightly lower than with the sheep/beef farms (179 vs. 189 mg/kg). Macroporosity of deer farms was slightly higher than sheep/ beef farms (24.1% vs. 19.8%). This is most likely a reflection of the pumiceous, coarse-textured nature of the soils of most of the sample sites under deer pasture (Appendix 1).

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Table 2 *Topsoil qualities of deer pasture sites sampled in 2010 and their comparison with the provisional target soil qualities for pasture soils.*

Soil Quality	pH	Total C (%)	Total N (%)	C/N Ratio	Mineral-isable N (mg/kg)	Olsen P (mg/kg)	Bulk Density (t/m^3)	Macro-porosity (%)
Mean	**5.7**	**7.7**	**0.65**	**11.9**	**179**	**67**	**0.75**	**24.1**
Std Error	0.1	0.6	0.01	0.8	18	9	0.10	3.9
Pasture soil quality targets	**5.0-6.6**	**>2.5**	**0.25-0.70**	**8-12** **(prodn)** **7-30** **(env'l)**	**50-250**	**15-100**	**0.5-1.4**	**6-30**
Total no. of deer sites	3	3	3	3 3	3	3	3	3
No of sites meeting target	3	3	3	2 3	3	3	3	2
No. of sites not meeting target	0	0	0	1 0	0	0	0	1
No. of sites below target	0	0	0	0 0	0	0	0	0
No. of sites above target	0	na	0	1 0	0	0	0	1
Percentage of sites meeting target	100	100	100	66.7 100	100	100	100	66.7
Percentage of sites not meeting target	0	0	0	33.3 0	0	0	0	33.3
Percentage of sites below target	0	0	0	0 0	0	0	0	0
Percentage of sites above target	0	na	0	33.3 0	0	0	0	33.3

Note: Where target is not a range (e.g. >2.5%), number and percentage of sites above target are set to 'not applicable' (na) since there is no set upper limit.

3.3 Topsoil qualities of kiwifruit orchard sites

Table 3 shows the topsoil qualities of kiwifruit orchard sites sampled in 2010. Mean soil pH (6.6) was within the 5.0-7.6 soil quality target range. All of the sites (100%) also met this target range.

The mean total C was 6.4% with all sites meeting the >2.5% total C target. This mean value, however, is slightly lower compared with the mean total C of pasture soils (7.7%) discussed earlier. For total N, the mean value was 0.58%. No target range for total N in cropping and horticulture soils was set in Sparling et al (2008). However, when ratings set by the old New Zealand Soil Bureau (Blakemore et al 1987) and Hill Laboratories (Hill Laboratories undated) are used for reference, this value lies within the medium range (0.3-0.6%) of the New Zealand Soil Bureau rating and within the high range (0.5-1.0%) for the Hill Laboratories rating.

The mean C/N ratio of 11.2 was within the 8-20 target range for production and 7-30 range for environmental criterion. All sites had C/N ratio that fell within these target ranges.

The mean concentration of anaerobically mineralisable N was 140 mg/kg and lies within the 20-200 mg/kg target range. All soils have anaerobically mineralisable N values within this target range.

The mean Olsen P concentration of 106 mg/kg was well above the target range of 20-100 mg/kg. Hill Laboratories (undated) uses 30-60 mg/kg Olsen P range as medium rating and above 60 mg/kg as high. Three out of five sites (60%) have Olsen P values exceeding the 100 mg/kg upper limit. The remaining two sites (40%) met the target range. It appears that, relative to the pasture sites, kiwifruit farms receive higher phosphate application rates as reflected in the high Olsen P soil test values (range: 80-147 mg/kg vs. 49-80 mg/kg for deer and 9-120 mg/kg for sheep/beef).

In a long-term study (>10 years) on the comparison of conventional and organic kiwifruit orchard systems mostly located in the Bay of Plenty, Carey et al. (2009) also showed Olsen P values exceeding 100 mg/kg in some kiwifruit orchard topsoils (at 0-15 cm sampling depth). In the nutrient balance part of this study, they indicated that inputs of P (as well as N and potassium (K)) massively exceeded removals in fruit in all kiwifruit systems they considered and that a crop response to P is unlikely to occur for any of them. Thus, inputs of P in the form of phosphate fertilizer may be excessive considering that the annual phosphorus uptake of mature kiwifruit vines is small (less than 25 kg/ha) (Smith 1996). Therefore, Carey et al. (2009) have suggested that nutrient inputs (N, P and K) can be reduced without affecting productivity. In the long term, reducing nutrient inputs in kiwifruit production would be advantageous both economically and environmentally if this recommendation is followed.

The mean bulk density of 0.90 t/m^3 was within the target range of 0.5-1.4 t/m^3. In fact, all of the sites attained this target range. As regards macroporosity, the mean value of 13.1% lies within the target range of 6-30%. All sites were also within this target range and this shows that compaction is not an issue on the kiwifruit orchard soils although when compared with the pasture soils, macroporosity values are much lower. This can be attributed to the less porous nature of the kiwifruit soils (finer textured Recent, Pumice and Allophanic soils, Appendix 1) and the probable compaction of soils caused by orchard vehicles/machinery.

Table 3 Topsoil qualities of kiwifruit orchard sites sampled in 2010 and their comparison with the provisional target soil qualities for cropping/horticulture soils.

Soil Quality	pH	Total C (%)	Total N (%)	C/N Ratio	Mineral-isable N (mg/kg)	Olsen P (mg/kg)	Bulk Density (t/m^3)	Macro-porosity (%)
Mean	**6.6**	**6.4**	**0.58**	**11.2**	**140**	**106**	**0.90**	**13.1**
Std Error	0.1	0.7	0.06	0.1	15	12	0.04	1.2
Cropping-horticulture soil quality targets	**5.0-7.6**	**>2.5**	**No std**	**8-20 (prodn) 7-30 (env'l)**	**20- 200**	**20-100**	**0.5-1.4**	**6-30**
Total no. of kiwifruit sites	5	5	5	5 5	5	5	5	5
No of sites meeting target	5	5	na	5 5	5	2	5	5
No. of sites not meeting target	0	0	na	0 0	0	3	0	0
No. of sites below target	0	0	na	0 0	0	0	0	0
No. of sites above target	0	na	na	0 0	0	3	0	0
Percentage of sites meeting target	100	100	na	100 100	100	40	100	100
Percentage of sites not meeting target	0	0	na	0 0	0	60	0	0
Percentage of sites below target	0	0	na	0 0	0	0	0	0
Percentage of sites above target	0	na	na	0 0	0	60	0	0

Note: Where target is not a range (e.g. >2.5%), number and percentage of sites above target are set to 'not applicable' (N/A) since there is no set upper limit. Where there is no set soil quality standard or target (e.g. total N for cropping and horticulture soils), the 'na' symbol was also used.

3.4 Temporal trends in topsoil qualities of sheep/beef sites

Table 4 shows the trends in topsoil qualities of sheep/beef sites over a ten-year period. Changes in all topsoil quality indicators were not statistically significant (P>0.05). Soil pH increased slightly over time. The mean pH values in each sampling year lie within the provisional target range of 5.0 to 6.6.

The increases in total C and total N were not significant (ns) as is the decrease in C/N ratio. Mean values for each year for these three indicators were all within their respective provisional targets.

Mean anaerobically mineralisable N was high (193 mg/kg) during the initial sampling in 2000, declined in the 2005 sampling (137 mg/kg), and increased again in 2010 close to the initial mean value (189 mg/kg). These changes, however, were not statistically significant (P=0.084) and the mean values lie within the 50-250 mg/kg provisional target for pasture soils. In the soil quality monitoring results obtained under dairy farming (Guinto 2009), the initial and intermediate mean mineralisable N values were much lower (72 mg/kg in 1999/2000 and 155 mg/kg in 2004) relative to the sheep/beef results. However, in the latest sampling in 2009, it jumped to 256 mg/kg which exceeded the upper limit of the target range so that concern for increased nitrate leaching is a more significant issue in dairy farming compared with sheep/beef farming.

Mean Olsen P values increased from 26 mg/kg in 1999/2000 to 44 mg/kg in 2010. This represents a 69% increase and reflects the continual application of phosphate fertilisers in these sheep/beef farms. However, this change was not statistically significant (P=0.430). This build up of P is also below the upper target Olsen P level of 100 mg/kg. However, if this increasing trend continues into the future, this would clearly be a more significant issue for this land use since excessive levels of phosphate in the soil may contribute to the eutrophication of rivers and lakes through sediment-laded runoff.

There was little change in bulk density with time. Mean bulk density values in each sampling year lie within the provisional target range of 0.5 to 1.4 t/m^3. Macroporosity decreased slightly in 2005 but recovered to just above the initial mean value in 2010. Mean values for each sampling year lie within the provisional target range of 6 to 30%.

3.5 Temporal trends in topsoil qualities of deer sites

Table 5 shows the trends in topsoil qualities of deer sites over a ten-year period. Similar to the sheep/beef sites, changes in all topsoil quality indicators were not statistically significant (P>0.05). Soil pH remained stable over time. The mean pH values in each sampling year lie within the provisional target range of 5.0 to 6.6.

Relative to their initial mean values, both mean organic carbon and total nitrogen increased over time. However, the increases were not considered as statistically significant (P=0.086 for total C and P=0.055 for total N). Mean values for each year for both total C and total N were all within their respective provisional targets. The mean C/N ratios were all close to 12 and remained fairly constant through time (P=0.823).

Mean anaerobically mineralisable N was high (158 mg/kg) during the initial sampling, declined in the 2005 sampling (139 mg/kg) and increased again in 2010 exceeding the initial mean value (179 mg/kg). These changes, however, were not statistically significant (P=0.222).

Mean Olsen P values increased from 42 mg/kg in 2000 to 67 mg/kg in 2010 with percentage change similar to the sheep/beef sites (60% increase). This change was also not statistically significant (*P*=0.314). This build-up of P is still below the upper target Olsen P level of 100 mg/kg but if this trend continues, deer farming may potentially contribute more to the eutrophication of water bodies relative to sheep/beef farming due to the higher Olsen P values involved.

Table 4 *Temporal changes in topsoil qualities of sheep/beef pasture sites with respect to pH, total C, total N, C/N ratio, anaerobically mineralisable N, Olsen P, bulk density, and macroporosity (n=10 in 1999/2000 and 2005; n=9 in 2010)*

Soil Quality	**Year**			
	1999/2000	**2005**	**2010**	***P* value**
pH	5.6	5.7	5.8	0.631 ns
Total C (%)	6.7	7.7	7.7	0.542 ns
Total N (%)	0.51	0.61	0.64	0.340 ns
C/N ratio	13.2	12.5	12.1	0.500 ns
Mineralisable N (mg/kg)	193	137	189	0.084 ns
Olsen P (mg/kg)	26	38	44	0.430 ns
Bulk Density (t/m^3)	0.79	0.81	0.77	0.905 ns
Macroporosity (%)	18.9	16.4	19.8	0.707 ns

Table 5 *Temporal changes in topsoil qualities of deer pasture sites with respect to pH, total C, total N, C/N ratio, anaerobically mineralisable N, Olsen P, bulk density, and macroporosity (n=4 in 2000 and 2005; n=3 in 2010)*

Soil Quality	**Year**			
	2000	**2004/2005**	**2010**	***P* value**
pH	5.8	5.8	5.7	0.892 ns
Total C (%)	5.9	8.6	7.8	0.086 ns
Total N (%)	0.48	0.72	0.65	0.055 ns
C/N ratio	12.4	12.0	11.9	0.823 ns
Mineralisable N (mg/kg)	158	139	179	0.222 ns
Olsen P (mg/kg)	42	50	67	0.314 ns
Bulk Density (t/m^3)	0.70	0.78	0.75	0.746 ns
Macroporosity (%)	22.7	20.0	24.1	0.772 ns

Table 6 *Temporal changes in topsoil qualities of kiwifruit orchard sites with respect to pH, total C, total N, C/N ratio, anaerobically mineralisable N, Olsen P, bulk density, and macroporosity (n=5)*

Soil Quality	**Year**			
	2000	**2005**	**2010**	***P* value**
pH	6.5	6.6	6.6	0.341 ns
Total C (%)	8.9	6.1	6.4	0.088 ns
Total N (%)	0.60	0.57	0.58	0.719 ns
C/N ratio	14.6	11.2	11.2	0.026 *
Mineralisable N (mg/kg)	117	100	140	0.150 ns
Olsen P (mg/kg)	71	71	106	0.051 ns
Bulk Density (t/m^3)	0.85	0.89	0.90	0.765 ns
Macroporosity (%)	16.1	14.1	13.1	0.540 ns

* = significant at 5% level; ns = not significant

Like the sheep/beef sites, there was little change in bulk density over time on the deer sites (means ranged from 0.70 to 0.78 t/m^3) and these values lie within the provisional target range of 0.5 to 1.4 t/m^3. Macroporosity was also maintained close to 20% with mean values for each sampling year which are within the provisional target range of 6 to 30%.

3.6 Temporal trends in topsoil qualities of kiwifruit sites

Table 6 shows the trends in topsoil qualities of kiwifruit sites over a ten-year period. Similar to the sheep/beef and deer sites, there were no statistically significant changes in soil quality indicators with the exception of the C/N ratio and a nearly significant change in Olsen P.

Soil pH was fairly stable (6.5-6.6) throughout the ten-year period and are within the provisional target range of 5.0-7.6. There was some decline in mean total C and total N values but the changes were not statistically significant. Both soil quality indicators remain high under kiwifruit land use.

There was a statistically significant decrease in the C/N ratio (P=0.026) indicating that N mineralisation is progressively dominating over N immobilisation (net N mineralisation). Nevertheless, the mean values for all sampling periods still lie within the provisional target range of 8 to 20 for cropping/horticulture soils (production criterion) and 7-30 (environmental criterion).

The changes in anaerobically mineralisable N were not statistically significant (P=0.150) with mean values ranging from 100-140 mg/kg. These values are within the 20-200 mg/kg provisional target for cropping/horticulture soils.

An increasing trend in mean Olsen P values was observed (71 to 106 mg/kg) which proved to be almost statistically significant (P=0.051). Further analysis using a linear polynomial contrast showed that the linear trend was significant (P=0.033) indicating a projected build-up of Olsen P into the future if kiwifruit growers continue to add superphosphate fertiliser. The 2010 mean Olsen P value already exceeds the 100 mg/kg upper limit of the provisional Olsen P target range. As noted earlier (Section 3.3), the inputs of P (and N and K) in many kiwifruit farms in New Zealand are excessive (Carey et al. 2009) and it would it would be in the growers' best interest to reduce fertiliser input for both economic and environmental reasons.

There were no statistically significant changes in bulk density (P=0.765). The bulk density values (0.85-0.90 t/m^3) lie within the 0.5-1.4 t/m^3 provisional target. The macroporosity values declined over the ten-year period (from 16.1% in 2000 to13.1% in 2010) but this reduction was not statistically significant (P=0.540).

Part 4: Conclusion and recommendations

For the land uses considered in this report (sheep/beef, deer and kiwifruit), many of the topsoil quality indicators were within the provisional target values set by Landcare Research for production and/or environmental criterion and have not changed significantly over the ten-year period. However, the current high level of anaerobically mineralisable N (close to 200 mg/kg) in the sheep/beef and deer sites will need to be monitored closely because further increase could lead to significantly higher nitrate leaching and subsequent eutrophication of water bodies. In the case of kiwifruit land use, the increasing trend in Olsen P and the current Olsen P mean value exceeding the 100 mg/kg target is a cause for concern because high Olsen P levels could lead to P-laden sediment polluting streams and other water bodies. A recent report on the water quality status of Bay of Plenty rivers and streams (Scholes and McIntosh 2009) has shown that while there are a number of significant improving trends, the water quality of many rivers and streams is deteriorating. Mention was made of the Rotorua and Central rivers having elevated nitrogen and phosphorus levels attributed to nitrate leaching on pumice soils and phosphorus leached from the underlying geology.

In all land uses, farmers should continue to periodically test their soil's fertility levels and employ farm nutrient budgeting to optimise fertiliser application in order to reduce input cost and minimise nutrient pollution impacts on the environment.

Where feasible, adoption of precision agriculture techniques to optimise water and nutrient application rates to realise savings in energy, water and nutrients particularly in intensive land uses such as kiwifruit should be considered.

The soil quality monitoring programme is invaluable in informing land managers of changes in soil quality on their properties over time particularly when there are clear trends in declining soil health so that remedial actions can be promptly undertaken. Thus, soil quality monitoring should continue well into the future with a view to the following:

- Soil changes are perceived to be slow but where soil quality declines are observable, future research should focus on expanding soil quality monitoring sites to areas where land use is intensifying (e.g. recent forest to dairy conversions, etc.) so that impacts can be assessed more readily. For example, additional maize sites have been added as part of the regional soil quality monitoring to better represent this land use in the region (Guinto 2009).

- Trace elements will now be included in the regular soil quality monitoring as opposed to when the need arises only (e.g. as part of MfE's requirements in State of the Environment reporting). Unintended effects of long-term fertiliser applications (e.g. potential cadmium accumulation as an impurity in superphosphate fertilisers) can be monitored through this.

- Inclusion of more biological measures of soil quality such as soil microbial biodiversity (earthworms, microbiological activity, etc.), respiration, microbial biomass, soil enzyme activity, active carbon etc. as an indication of soil well-being. For example, the decomposition and bioavailability of dissolved organic matter (i.e. dissolved organic carbon and dissolved organic nitrogen) and its implications for nutrient cycling in grazed pastures are currently being investigated by Agresearch.

It is understandable that applying maintenance N and P fertilisers in pastures and orchards is a risk aversion strategy by many farmers to protect them from potential economic failure. However, as these nutrients progressively accumulate and become mobilised to enter our groundwater, streams, rivers and lakes, this practice becomes economically wasteful and will eventually contribute to a degraded quality of our water bodies.

On excessively fertile sites, one potential researchable area is to test if the non-application or reduced application of N and/or P will significantly reduce pasture or orchard yields over time. The trial (or trials) can be initially conducted in experimental farms and the results communicated to the farming community. If results show no significant yield decline, farmers may want to investigate this further and experiment on small sections of their properties before deciding whether this practice warrants adoption or not.

Part 5: References

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Appendices

Appendix 1 – Summary information for sheep/beef, deer and kiwifruit sample sites

Site*	Sample No.	Year Established	Land Use	Soil Type	NZ Soil Classification (Order Level)	Remark
45	1	2000	Sheep/beef	Ōpōtiki hill soil	Allophanic	
35	2	2000	Sheep/beef	Kāingaroa gravelly sand	Pumice	
52	2	2000	Sheep/beef	Rotomahana mud	Recent	
52	3	2000	Sheep/beef	Ōkaro steepland soils	Recent	
51	2	2000	Sheep/beef	Waiowhiro sandy loam	Pumice	
20	2	1999	Sheep/beef	Ohinepanea loamy coarse sand	Pumice	
20	3	1999	Sheep/beef	Ohinepanea hill soils	Pumice	
55	1	2000	Sheep/beef	Oropi loamy sand	Pumice	
47	1	2000	Sheep/beef	Whakamarama sandy loam	Podzol	
62	1	2000	Sheep/beef	Katikati sandy loam	Allophanic	Not sampled in 2010
35	1	2000	Deer	Kāingaroa gravelly sand	Pumice	
56	1	2000	Deer	Manawahe hill soil	Pumice	
54	1	2000	Deer	Paengaroa sandy loam	Pumice	
60	1	2000	Deer	Katikati sandy loam	Allophanic	Not sampled in 2010
32	1	2000	Kiwifruit	Ōpōtiki sandy loam	Pumice	
31	1	2000	Kiwifruit	Opouriao fine sandy loam	Recent	
41	2	2000	Kiwifruit	Awakaponga silt loam	Recent	
37	1	2000	Kiwifruit	Paengaroa loamy sand	Pumice	
61	1	2000	Kiwifruit	Katikati sandy loam	Allophanic	

*****For location of sample sites, please refer to Figure 1.

Appendix 2 – Glossary of soil quality terms

Anaerobically mineralisable nitrogen (AMN) is a laboratory measure of the amount of nitrogen that can be readily supplied to plants from the decomposition of soil organic matter under ideal conditions. Since the actual amount of N that will mineralise in the field depends on factors such as soil temperature and moisture, caution must be exercised when interpreting the results.

Bulk density gives a measure of how densely a soil is packed (dry mass divided by total volume). Soils typically have about half of their volume comprised of voids (pore spaces). If these voids are lost through compaction, bulk density increases. The voids hold water and air and also allow water and air to move through soil. Compacted soils have poor aeration, are slow draining, and roots find it difficult to grow and push through such soil. Bulk density is influenced by the amount of soil organic matter, soil texture, constituent minerals and porosity. Soils with very low bulk density are open textured and porous but may be so loose they are susceptible to erosion, dry out quickly, and roots find it difficult to absorb water and nutrients.

C/N ratio Obtained by dividing the soil's total C with total N, this ratio provides a measure of organic matter quality. In soils with wide C/N ratios, (>30) net immobilisation of N by soil micro-organisms occur while in soils with narrow C/N ratios (<10), net mineralisation of N occurs releasing ammonium and nitrate. Thus, a high risk of nitrate leaching is perceived in soils with very narrow C/N ratios.

Macroporosity is a measure of the number of large pores in soil. Large pores are defined as those with a diameter greater than 60 micrometers (µm). Macropores are important for air penetration into soil, and are the first pores to be lost when soils are compacted. Low macroporosity reduces soil aeration, resulting in less clover growth and N-fixation and decreased pasture yields.

Olsen P is the standard method used in New Zealand to assess soil phosphorus (P) availability to plants. Phosphate is the only form of P taken up by plants. However, there is very little phosphate in the soil solution as most 'available' phosphate is adsorbed onto clays and organic matter. The Olsen extractant tries to mimic the ability of a plant to remove solution and adsorbed phosphates from soil, and hence get a measure of the P status for plant nutrition. Olsen P has been measured in many agronomic tests for crop production, and is used to calculate rates of P fertiliser application.

Provisional (soil quality) targets refer to the numerical ranges of soil quality indicators deemed desirable either from a production or from an environmental protection standpoint as detailed in the Landcare Research publication "Provisional Targets for Soil Quality Indicators in New Zealand" (Sparling et al. 2008).

Soil pH is an indication of the acidity or alkalinity of the soil. It is a measure of the number of hydrogen (H^+) ions in solution. A pH of 7 is termed neutral, below 7 is acidic, and above 7 is alkaline or basic. Most plants and soil animals have an optimum pH range for growth, and the pH of soil affects which species will grow best by influencing the availability of soil nutrients. Most forest soils in New Zealand are acidic, and indigenous forest species are generally tolerant of acid conditions. Introduced exotic pasture and crop species require a more alkaline soil. Excess soil acidity is normally corrected by topdressing with lime (ground limestone) to raise the pH.

Soil quality (or soil health) is the capacity of a specific kind of soil to function within natural or managed ecosystems to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation. Changes in the capacity of soil to function are reflected in soil properties that change in response to management or climate. These soil quality indicators are important in focusing conservation efforts or maintaining and improving the condition of the soil and in evaluating soil management practices.

Indicators are also important to relate soil quality to that of other natural resources. It helps to determine trends in the health of soils and it can also serve as a guide in land management decisions.

Total Carbon (C) measures the amount of carbon in soil. This includes carbonates and soil organic matter C, but New Zealand soils typically contain very little carbonate, so total C is a good measure of organic matter C. Organic matter is important for soil quality because it helps soils retain moisture and nutrients, and gives good soil structure for water movement and root growth. Once depleted, organic matter takes many years to replace, and its careful conservation is recommended by most agronomists and soil scientists.

Total Nitrogen (N) is a measure of the total amount of all forms of nitrogen in soil. Typically, in topsoils, organic matter N makes up more than 90% of the total N. Nitrogen is an essential major nutrient for plants and animals, and the store of organic matter N is an important measure of soil fertility. Organic N needs to be mineralised to inorganic forms (ammonium and nitrate) by soil micro-organisms before it can be used by plants.