Soil Quality in the Bay of Plenty: 2009 Update

Prepared by Danilo Guinto, Environmental Scientist

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Whakatane
NEW ZEALAND

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Cover Photo:
Pasture soil showing contrast in organic matter between upper and lower depths. Photo taken by Danilo Guinto.

Acknowledgements

Thanks to Wim Rijkse of Land Use Consultants Ltd for assistance during field soil sampling and characterisation; Mike Parker of the Foundation for Arable Research (Hamilton) and Chris MacKay of Environment Bay of Plenty (Tauranga) for their help in selecting additional maize sites. Wayne Smith, former Land Technical Support Team Leader, is thanked for suggesting the addition of new maize sites. Thanks to Paul Scholes (Environmental Scientist) and Simon Stokes (Manager, Land Resources - Eastern) for their helpful comments on the report. Many thanks to the farmers and landowners who allowed soil quality sampling on their properties.

Executive summary

Temporal changes in topsoil qualities of dairy pasture and maize cropping sites were monitored periodically over a 10-year period. Results indicate that for both land uses, many of the topsoil quality parameters were being maintained and these are within the provisional target values set by Landcare Research New Zealand for production and/or environmental criterion. However, the steady increase in the levels of anaerobically mineralisable N and Olsen P in dairy sites is a concern. High values of anaerobically mineralisable N could potentially lead to increased nitrate leaching while high values of Olsen P could lead to P-rich sediments polluting water bodies. Dairy farmers should therefore exercise judicious use of N and P fertilisers through periodic soil testing and farm nutrient budgeting.

Six new maize sites were established and sampled for topsoil qualities as well. With the exception of low aggregate stability values of most soils, mean soil quality values were within the desirable provisional target ranges established by Landcare Research.

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); inclusion of trace elements in the regular monitoring as opposed to when the need arises only (e.g. as part of Ministry for the Environment's (MfE's) requirements in State of the Environment reporting); 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.

Contents

Tables and Figures

Part 1: Introduction

Healthy soils underpin the Bay of Plenty's rural economy but they have the potential to be impacted by land use and soil management practices, especially where they become intensively managed. A decline in soil health or soil quality can occur gradually and it may often be masked in the short-term by changes in management practices. Ultimately, however, a reduction in soil quality will result in increased costs, loss of production and/or adverse environmental impacts.

Because of the potential adverse effects of declining soil quality, a methodology was developed to identify changes in soils in a timely manner. In 1998, the Ministry for the Environment (MfE) contracted Landcare Research to trial a series of soil quality 'indicators'. Following this trial, MfE partly funded a 3-year project called the "500 Soils Project" which aimed to establish sites to measure these indicators on 500 soils throughout New Zealand (Sparling and Schipper 2002; 2004). Environment Bay of Plenty was one of the five inaugural regional councils that participated in this project and by the completion of this project in 2001, ten regional councils had joined. Environment Bay of Plenty established 75 sample sites over this period.

Following the completion of the 500 Soils Project, the regional councils jointly supported a review of the soil quality monitoring methodology. This review confirmed with the methodology and the indicators. It also recognised that the use of a common methodology and comparison of results for similar land uses across other regions in New Zealand which would improve the ability to interpret the sampling results. The regional councils continue to work together to further document and refine the methodology and work with scientists to improve the interpretation of the indicators. The current soil quality monitoring is being run under Environment Bay of Plenty's Natural Environment Regional Monitoring Network (NERMN) programme.

Environment Bay of Plenty currently has 74 soil quality sites in the region grouped 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 3 years, dairy, deer, sheep and beef, and kiwifruit sites every 5 years, and forest sites every 10 years. In the past, 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). This report focuses on the results of the 2009 soil quality sampling which covered dairy pasture and cropping sites.

Part 2: Materials and Methods

2.1 Soil sampling and analyses

Twenty four soil quality sites consisting of 19 dairy pasture sites and 5 cropping sites from previously established sites were re-sampled in 2009 (See Figure 1 and Appendix 1). The standard protocol for New Zealand soil quality sampling was followed (Sparling and Schipper 2002; 2004). 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 25 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 both land uses since dairy pasture soils are normally sampled at 0-7.5 cm while maize soils are sampled at 0-15 cm.

The samples were submitted to Landcare Research laboratories (Hamilton and Palmerston North) 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 (See Appendix 2 for definitions of soil quality terms). The C/N ratio was obtained by dividing total C with total N. For maize sites, relatively undisturbed topsoil samples were also taken using a spade and submitted to Plant and Food Research in Lincoln for the analysis of aggregate stability. Aggregate stability was expressed as a mean weight diameter in mm. All laboratory analyses were performed following the methods described in Sparling et al. (2008).

2.2 Soil sampling and analyses in additional maize sites

For maize sites, there were only six original sites established and sampled periodically. One of these sites was recently converted to lucerne cropping reducing the number of maize sites for resampling. Due to the small number of sites originally sampled and recognising that areas devoted to maize production are increasing in the Bay of Plenty, six additional sites were selected and sampled (Figure 1). Site and soil profile descriptions were also done on each site in accordance with the New Zealand Soil Description Handbook (Milne et al. 1995). Majority of the sites selected have been continuously growing maize between 8 to 43 years. Although not an assurance, selecting sites under long-term maize cultivation may lessen the likelihood of these sites drastically changing their current land use. Results obtained from the current sampling are treated as baseline values for comparison with future samplings.

2.3 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 standards are grouped according to land use and/or soil classification. Aggregate stability results from maize sites were compared with the standard established by Beare et al. (2009). Previous results from dairy and maize sites reported by Landcare Research were also used in order to show trends over time. Analysis of variance was also applied to the data set to detect if there are statistically significant changes in soil qualities over time.

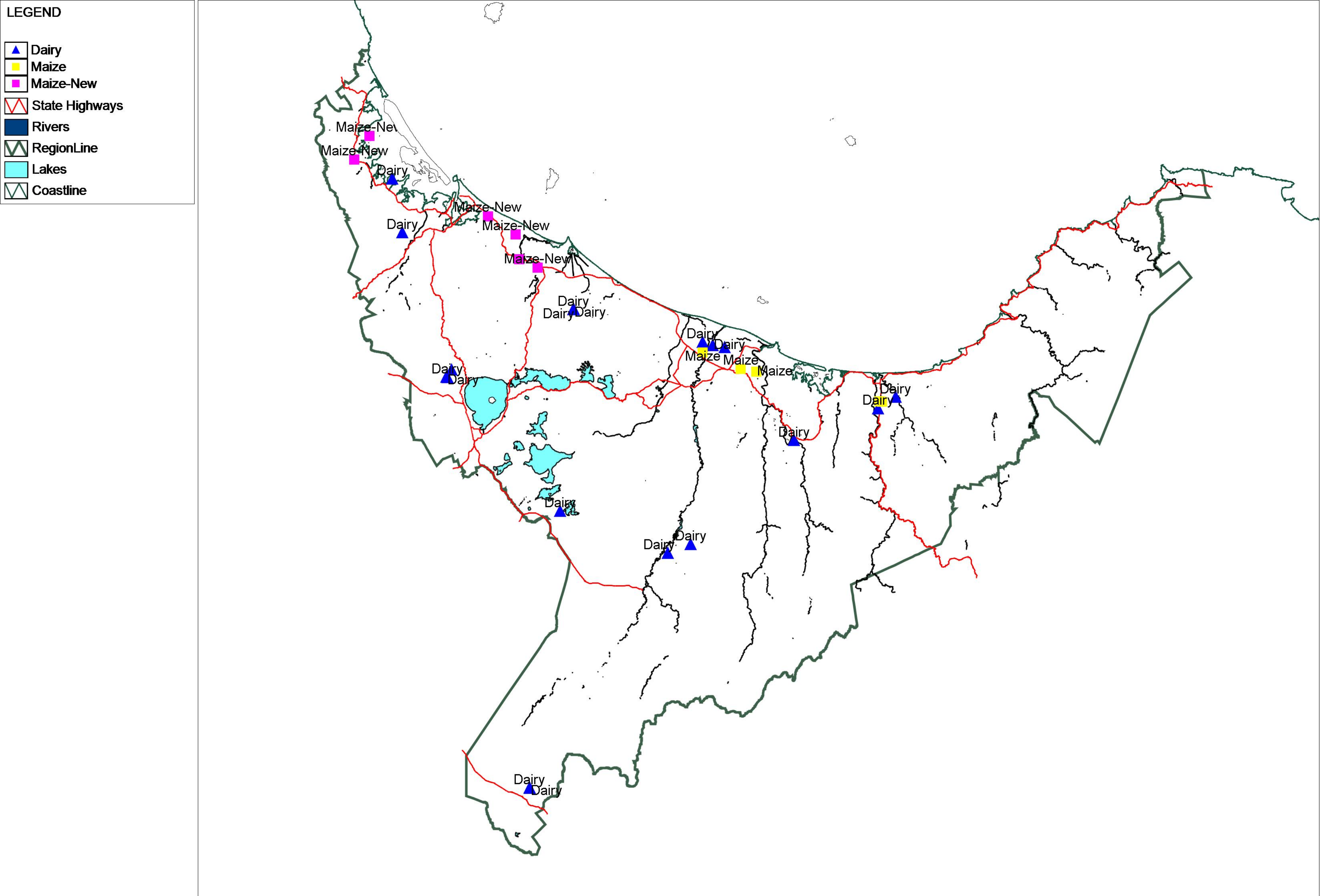

Figure 1. Dairy and maize soil quality sites

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0 7 14 21 28 56 84 112
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Part 3: Results and Discussion

3.1 Topsoil qualities of dairy sites

Table 1 shows the mean topsoil qualities of dairy sites sampled in 2009. Mean soil pH (5.79) was within the 5.0-6.6 soil quality target. Majority of the sites (95%) also met this target so soil acidity is not a problem in these soils.

The mean total C was 7.81%. All sites met the >2.5% total C target. For total N, the mean value of 0.73% slightly exceeds the target range of 0.25-0.70%. However, more than 50% of the sites met this target. Those sites that did not meet this 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 pool of soil N that could potentially mineralise during the growing season. However, very high total N levels in pasture soils are becoming of concern for environmental goals because of its potential to contribute to nitrate levels in soil and to increase leaching losses and eutrophication (Sparling et al. 2008).

The mean C/N ratio of 10.2 was within the 8-12 target range from a production standpoint. Majority of the sites (84%) have C/N ratios within the target range. About 16% of the sites that did not meet the target range have C/N ratios above 12. For environmental criterion, a C:N ratio of 7–30 is considered optimal. Most of the dairy sites also comply with this target level.

The mean concentration of anaerobically mineralisable N (256 mg/kg) exceeded the 50-250 mg/kg target range. However, about 53% of the sites met the target range. Those sites not meeting the target range have 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 97 mg/kg was within the target range of 15-100 mg/kg. About 63% of the sites met this target range while those not meeting the target range (37%) have Olsen P values above the 100 mg/kg upper limit. 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 0.85 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 which shows that there is no compaction issue as far as this physical soil quality indicator is concerned.

For macroporosity, the mean value of 9.97% is within the target range of 6-30%. Majority of the sites (79%) were well within this target range. About 21% of the sites were below the 6% macroporosity limit implying some degree of compaction occurs in these pasture soils. Macroporosity is a measure of the number of large pores (diameter >60 µm) in soil. Macropores are important for soil aeration and are the first pores to be lost when soils are compacted. Thus, macroporosity is a more sensitive indicator of soil compaction than bulk density. Low macroporosity reduces soil aeration, resulting in less clover growth, N-fixation and decreased pasture yields (Sparling et al. 2008).

Table 1 Topsoil qualities of dairy pasture sites sampled in 2009 and their comparison with the provisional target soil qualities for pasture soils.

	pH	Total C (%)	Total N (%)	C/N Ratio	Olsen P (mg/kg)	Mineral-isable N (mg/kg)	Bulk Density (t/m^3)	Macro-porosity (%)
Mean	**5.79**	**7.81**	**0.73**	**10.7**	**97**	**256**	**0.85**	**9.97**
Std Error	0.09	0.50	0.05	0.2	10	23	0.03	1.08
Pasture soil quality targets	**5.0-6.6**	**>2.5**	**0.25-0.70**	**8-12** (prodn) **7-30** (env'l)	**15-100**	**50- 250**	**0.5-1.4**	**6-30**
Total no. of dairy sites	19	19	19	19	19	19	19	19
No of sites meeting target	18	19	10	16	12	10	19	15
No. of sites not meeting target	1	0	9	3	7	9	0	4
No. of sites below target	1	0	0	0	0	0	0	4
No. of sites above target	0	na	9	3	7	9	0	0
Percentage of sites meeting target	94.7	100	52.6	84.2	63.2	52.6	100	78.9
Percentage of sites not meeting target	5.3	0	47.4	15.8	36.8	47.4	0	21.1
Percentage of sites below target	5.3	0	0	0	0	0	0	21.1
Percentage of sites above target	0	na	47.4	15.8	36.8	47.4	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' (na) since there is no set upper limit.

3.2 Topsoil qualities of maize sites

Table 2 shows the topsoil qualities of maize sites sampled in 2009. Mean soil pH was within the 5.0-7.6 soil quality target. All of the sites (95%) also met this target range.

The mean total C was 3.24% with all sites meeting the >2.5% total C target. This mean value, however, is much lower compared with the mean total C of dairy pasture soils discussed earlier. For total N, the mean value was 0.26%. No target range for total N in cropping soils was set in Sparling et al (2008). However, when earlier ratings set by the old New Zealand Soil Bureau (Blakemore et al 1987) and ratings set by Hill Laboratories (Hill Laboratories undated) are used for reference, this value lies within the low range (0.1-0.3%) of the New Zealand Soil Bureau rating and within the medium range (0.2-0.5%) for the Hill Laboratories rating. Similar to mean total C, the mean total N content of maize cropping imply less biomass is incorporated into the soil and the potential loss of organic matter due to more frequent cultivation.

The mean C/N ratio of 12.4 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 Olsen P concentration of 48 mg/kg was within the target range of 20-100 mg/kg. Most of the sites (80%) met this target range. Only one site (20%) did not meet the target range as it is below the 20 mg/kg lower limit.

The mean concentration of anaerobically mineralisable N was 46 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 bulk density of 0.98 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 20.52% 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 maize soils.

As far as aggregate stability is concerned, the mean aggregate stability value was 0.98 mm which is less than the 1.5 mm target and only 1 out of 5 sites passed the 1.5 mm target. Similar results were reported during past soil quality samplings conducted by Landcare Research (Sparling 2001; Sparling and Rijkse 2003; Sparling 2004; Sparling 2005; Sparling 2006a; Sparling 2006b).The sandy nature of the maize soils and the effect of long-term cultivation seem to be contributing factors for the soils not attaining the desirable aggregate stability value. During the actual field sampling, it was observed that some of the surface soils were so loose that it was difficult to obtain aggregate stability samples without some of the large aggregates breaking apart even under careful handling. Thus, increasing soil aggregate stability would entail the incorporation of more organic matter in the soil through crop residue management and employing minimum tillage techniques.

Table 2 Topsoil qualities of maize sites sampled in 2009 and their comparison with the provisional target soil qualities for cropping soils.

	pH	Total C (%)	Total N (%)	C/N Ratio	Olsen P (mg/kg)	Mineral-isable N (mg/kg)	Bulk Density (t/m^3)	Macro-porosity (%)	Agg-regate Stabi-lity (mm)
Mean	**6.21**	**3.24**	**0.26**	**12.4**	**48**	**46**	**0.98**	**20.52**	**0.98**
Std error	0.13	0.33	0.02	0.5	8	8	0.04	2.15	0.17
Cropping soil quality targets	**5.0-7.6**	**>2.5**	**No std**	**8-20 (prodn) 7-30 (envl)**	**20-100**	**20-200**	**0.5-1.4**	**6-30**	**>1.5**
Total no. of maize sites	5	5	5	5	5	5	5	5	5
No of sites meeting target	5	5	na	5	4	5	5	5	1
No. of sites not meeting target	0	0	na	0	1	0	0	0	4
No. of sites below target	0	0	na	0	1	0	0	0	4
No of sites above target	0	na	na	0	0	0	0	0	na
Percentage of sites meeting target	100	100	na	100	80	100	100	100	20
Percentage of sites not meeting target	0	0	na	0	20	0	0	0	80
Percentage of sites below target	0	0	na	0	20	0	0	0	80
Percentage of sites above target	0	na	na	0	0	0	0	0	na

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 Temporal trends in topsoil qualities of dairy sites

Figures 1a to 1h show the trends of topsoil qualities of dairy sites over a ten-year period. Figure 1a shows that there was no significant change in topsoil pH with time. The mean pH values in each year lie within the provisional target of 5.0 to 6.6.

There was no significant change in total C (Figure 1b). Mean values for each year are above the provisional target of >2.5%. For total N, a slight increase was observed (Figure 1c). Mean values for each year are within the provisional range of 0.25 to 0.70%.

There was a very slight decrease in the C/N ratio (Figure 1d) but this is statistically significant (*P*=0.015, Appendix 3) implying that the C/N ratio is narrowing progressively with N mineralisation dominating over N immobilisation. However, the mean values lie within the provisional optimal target range of 8 to 12 for pasture soils (production criterion) and 7-30 (environmental criterion).

A steady increase in anaerobically mineralisable N over a ten-year period was observed (Figure 1e). Mean anaerobically mineralisable N in 1999/2000 was 72 mg/kg and 155 mg/kg in 2004. These values are within the provisional target range 50 to 250 mg/kg. However, in the 2009 sampling, the mean value was 256 mg/kg exceeding the upper limit of the target range. This is 3.6 times the initial value in 1999/2000 (P<0.001, Appendix 3). If this trend continues in the future, concern for increased nitrate leaching will become a more significant issue for this land use. Excessive N and P fertility is already a concern in soils of the nearby Waikato region which has similar soils as the Bay of Plenty (Environment Waikato 2008).

Mean Olsen P value increased from 67 mg/kg in 1999 to 97 mg/kg in 2009 (Figure 1f). This represents a 45% increase and reflects the continual application of phosphate fertilisers in these dairy farms (*P*=0.095). The mean Olsen P value for 2009 is near the upper limit of the 15-100 mg/kg provisional Olsen P target range. This buildup of P can become a concern in the near future if P-laden sediment is carried away by runoff and enters waterways.

Given that fertiliser is one of the biggest single expense items in dairy farming, very high levels of soil mineral N and Olsen P from excessive fertilisation do not contribute to additional productivity and represent a waste of inputs and an unnecessary expense. Dairy farmers should therefore exercise judicious use of N and P fertilisers through periodic soil testing and farm nutrient budgeting.

There was little change in bulk density with time (Figure 1g). All mean values lie within the provisional target range of 0.5 to 1.4 t/m^3. Macroporosity decreased slightly in 2004 but recovered to near starting values in 2009 (Figure 1h) which probably reflects the dynamic nature of this soil property in response grazing pressure. Mean values for each year lie within the provisional target range of 6 to 30%.

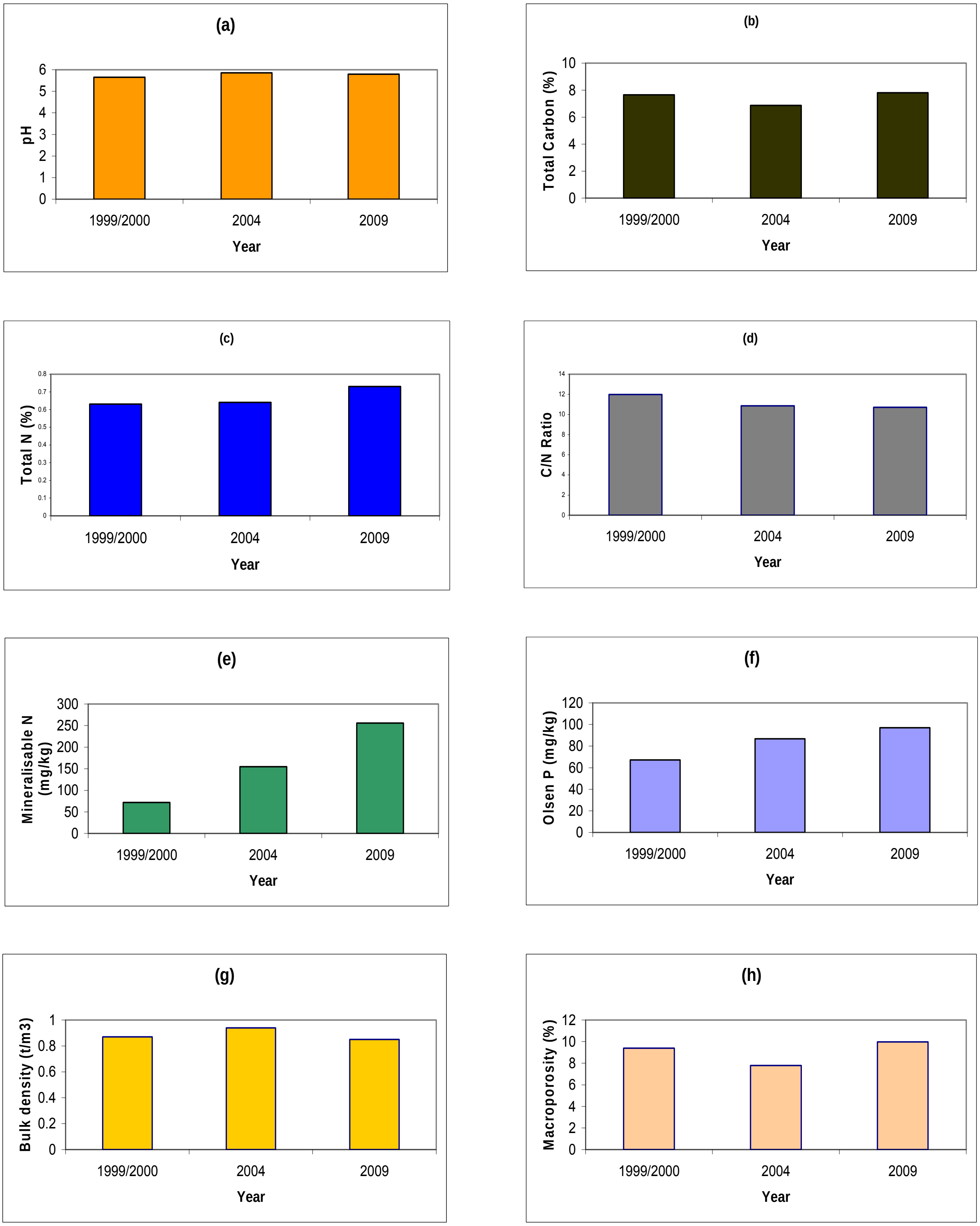

Figure 2 *Temporal trends in topsoil qualities of dairy sites with respect to (a) pH, (b) total C, (c) total N, (d) C/N ratio, (e) anaerobically mineralisable N, (f) Olsen P, (g) bulk density, and (h) macroporosity.*

3.4 Temporal trends in topsoil qualities of maize sites

Figures 2a to 2i show the trends of topsoil qualities of maize sites over a nine-year period There was little change in topsoil pH and the mean values lie within the provisional target range of 5 to 7.6 for cropping soils (Figure 2a).

There was a decline in total C from 2000 to 2003 but stable afterwards (Figure 2b). Nevertheless, all mean values were above the provisional target value of >2.5%. Similarly, there was a decline in total N from 2000 to 2003 but also stable afterwards (Figure 2c). Provisional target values are not established for cropping soils but low values are undesirable.

The declines in total C (42% decrease) and total N (38% decrease) from 2000 to 2003 were unclear. Sparling and Rijkse (2003) noted that this apparent degree of change is far greater than can be accounted for by soil management over this short time period. They attempted to explain the declines in differences in sampling methods between these two years. In the initial sampling, the samples were collected in mid-season when the crop was still in place rather than the preferred method of sampling after harvest which was done in 2003. Even so, differences of the magnitudes observed was unusually large, and suggest substantial soil disturbance, with topsoil being mixed with subsoil giving a highly variable matrix. They indicated that the anomalous results can only be satisfactorily resolved through further sampling. Subsequent samplings from 2003 through to the present show that total C and total N values remain stable suggesting that the initial sampling results are most likely in error.

The C/N ratio appears to be a stable soil property (Figure 2d). All mean values are within the 8 to 20 provisional target range for cropping soils.

Except for a decrease in 2004, there is an increasing trend in anaerobically mineralisable N (Figure 2e) but the magnitude of increase is far less than the soils of the dairy sites. All mean values lie within the 20 to 200 mg/kg provisional targets for cropping soils.

Olsen P values appear to be gradually decreasing implying that P applied as a fertiliser is being taken up by the maize crop (Figure 2f). However, all mean values are within the 20 to 100 mg/kg target values for cropping soils.

Bulk density values appear stable (Figure 2g). All mean values lie within the provisional target range of 0.5 to 1.4 t/m^3. Similar to the dairy sites, high macroporosity was maintained in maize sites (Figure 2h). Mean values are within the 6-30% provisional target range. However, macroporosity values for maize sites are generally higher than the dairy sites which is probably caused by cattle grazing the latter sites.

Aggregate stability did not appear to decline over time. The aggregate stability values were close to 1 mm. These values, however, are less than the 1.5 mm desirable target set by Beare et al. (2009). As explained earlier, the sandy nature of the maize soils and the effect of cultivation could be contributory factors for not attaining the desired aggregate stability value.

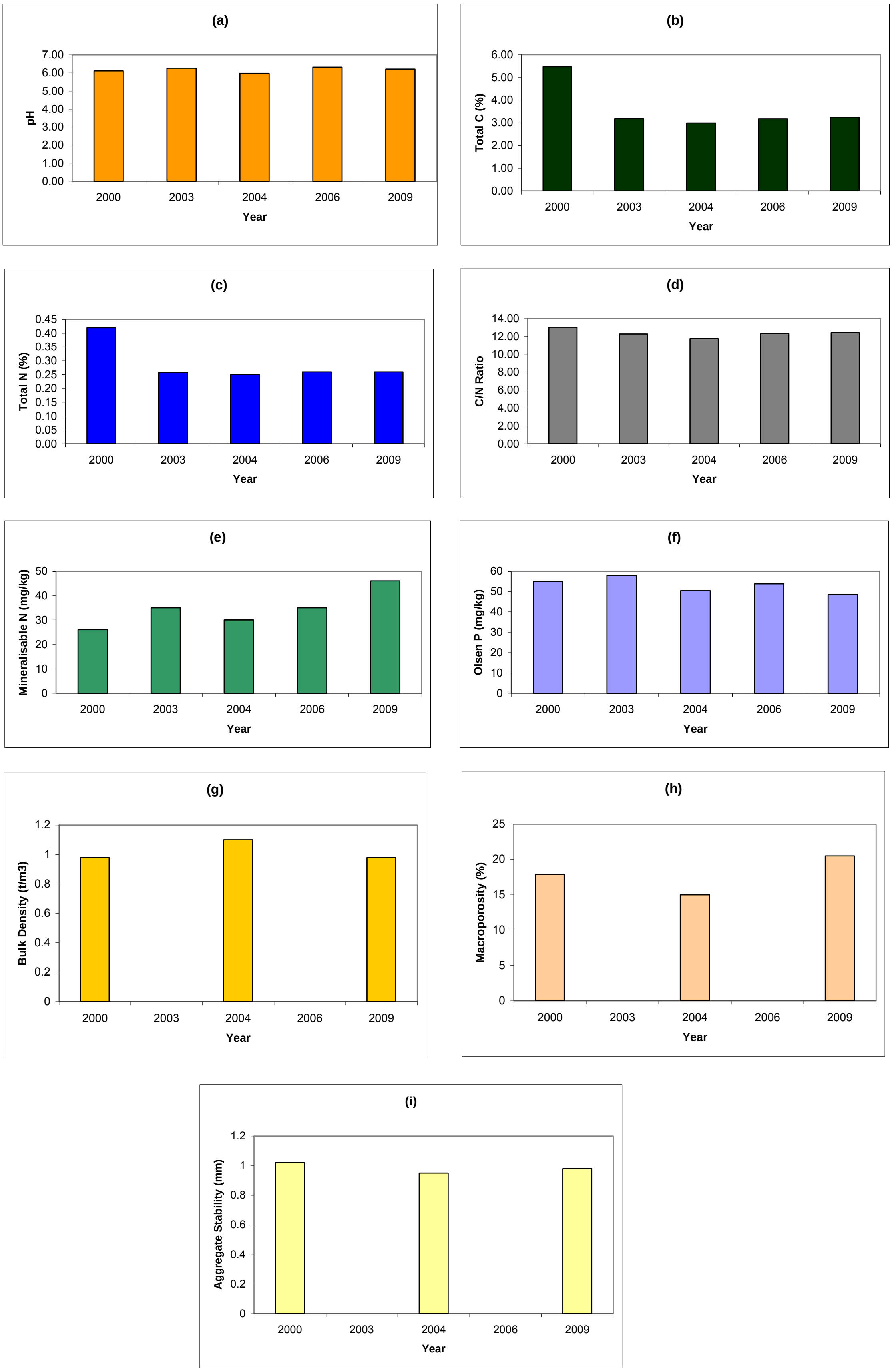

Figure 3 *Temporal trends in topsoil qualities of maize sites with respect to (a) pH, (b) total C, (c) total N, (d) C/N ratio, (e) anaerobically mineralisable N, (f) Olsen P, (g) bulk density, (h) macroporosity, and (i) aggregate stability.*

3.5 Topsoil qualities of additional maize sites

Table 3 shows the topsoil quality indicators of additional (new) maize sites (See Figure 1 and Appendix 1 for site locations). Out of six sites, four are Allophanic soils belonging to the Te Puke (two sites) and Katikati (two sites) series while two are classified as Organic soils belonging to the Parton series. Detailed site and soil profile descriptions are given in Appendix 3. The number of years the soils were used for maize production ranged from 3 to 43 years with a mean of 19.8 years.

Mean pH for the new sites was 6.36 (range 5.87-6.80) and falls within the target range for cropping soils (5.0-7.6 for mineral soils and 4.5-7.6 for organic soils).

All soils have a total C content greater than 3% (average 4.01%, range 3.31-6.96%) which is considered the desirable lowest level for Allophanic soils (Sparling et al. 2008). Very high total C (>16%) is not reflected in the topsoil of the Organic soils. In one Organic soil (Site 70), the peaty layer occurs below 30 cm. In the other organic soil (Site 71), the peaty layer occurs on the surface but the carbon content is only 6.96%. For these reasons, these organic topsoils can be treated as behaving like mineral soils and the provisional soil quality standards for mineral soils also apply to them.

Total N content averaged 0.41% (range 0.28-0.55%). Although there is no set standard for total N in cropping soils, earlier ratings set by the old NZ Soil Bureau (Blakemore et al. 1987) and ratings set by Hill Laboratories (Hill Laboratories undated) consider this value as within the medium range (0.3-0.6% for NZ Soil Bureau and 0.2-0.5% for Hill Laboratories).

The average C/N ratio of 12.6 (range 10.8-14.8) is within the provisional optimum range for cropping soils (8-20) from a productivity standpoint and also within the allowable range from an environmental protection (7-30) standpoint.

Anaerobically mineralisable N averaged 63 mg/kg (range 30-130 mg/kg) and this value falls within the 20-200 mg/kg provisional target for cropping soils.

The average Olsen P value of 30 mg/kg (range 20-40 mg/kg) falls within the 20-100 mg/kg provisional Olsen P target range for cropping soils.

The average bulk density is 0.83 t/m^3 (range 0.70-0.96 t/m^3) and lies within the 0.5-1.4 t/m^3 provisional soil bulk density range for cropping soils.

Macroporosity values are all above 10% (mean 14.92%; range 10.37-19.97%) and fall within the acceptable 6-30% provisional range.

Mean aggregate stability is 1.29 mm (range 0.98-1.93 mm). This falls short of the provisional target value of 1.5 mm However, typical values for cropping soils range from 1.2-2.0 mm (Beare et al. 2009). Only one soil (Organic soil at Site 71) had aggregate stability value above 1.5 mm. This soil also has the highest total C content among the six maize soils.

Table 3 Soil types, soil classification, number of years under maize cultivation and topsoil qualities (0-10 cm) of additional sites sampled in 2009.

Characteristic	**Site No.**						**Mean (± se)**
	66	**67**	**68**	**69**	**70**	**71**	
Soil Type	Te Puke sandy loam	Te Puke sandy loam	Katikati sandy loam	Katikati sandy loam	Parton gritty sandy loam	Parton gritty loamy peat	
Soil Classification	Typic Orthic Allophanic	Typic Orthic Allophanic	Typic Orthic Allophanic	Typic Orthic Allophanic	Acid Mesic Organic	Acid Mesic Organic	
Years in maize	15	20	30	3	43	8	19.8 (6.0)
pH	6.46	6.78	6.18	6.06	6.80	5.87	6.36 (0.16)
Total C (%)	3.31	3.72	5.46	5.95	5.63	6.96	4.01 (0.57)
Total N (%)	0.28	0.30	0.48	0.55	0.38	0.48	0.41 (0.04)
C/N ratio	11.8	12.4	11.4	10.8	14.8	14.5	12.6 (0.7)
Olsen P (mg/kg)	28	20	24	29	40	36	30 (3)
Mineralisable N (mg/kg)	30	40	56	58	66	130	63 (14)
Bulk density (t/m^3)	0.96	0.86	0.79	0.82	0.84	0.72	0.83 (0.03)
Macroporosity (%)	12.53	19.97	13.10	15.63	17.93	10.37	14.92 (1.47)
Aggregate stability (mm)	1.12	1.10	1.32	1.31	0.98	1.93	1.29 (0.14)

Part 4: Conclusion and Recommendations

For both dairy and maize sites, many of the topsoil quality parameters were within the provisional target values set by Landcare Research. However, the steady increase in the levels of anaerobically mineralisable N and Olsen P in dairy sites over a ten-year period is a concern. High values of anaerobically mineralisable N could lead to increased nitrate leaching while high values of Olsen P could lead to P-laden sediment polluting streams and other water bodies.

Since fertiliser is one of the biggest single expense items in dairy farming, very high levels of soil mineral N and Olsen P from excessive fertilisation do not contribute to additional productivity, and represent a waste of inputs and an unnecessary expense. Dairy farmers should therefore exercise judicious use of N and P fertilisers through periodic soil testing and farm nutrient budgeting.

With the exception of low aggregate stability values of most soils, mean soil quality values of the additional maize sites sampled were within the desirable provisional target ranges established by Landcare Research (Sparling et al. 2008).

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.

- Inclusion of trace elements 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, etc. as an indication of soil well-being. The impacts of the long-term use of pesticides (herbicides in particular) on soil microbial population and diversity may be assessed in this way.

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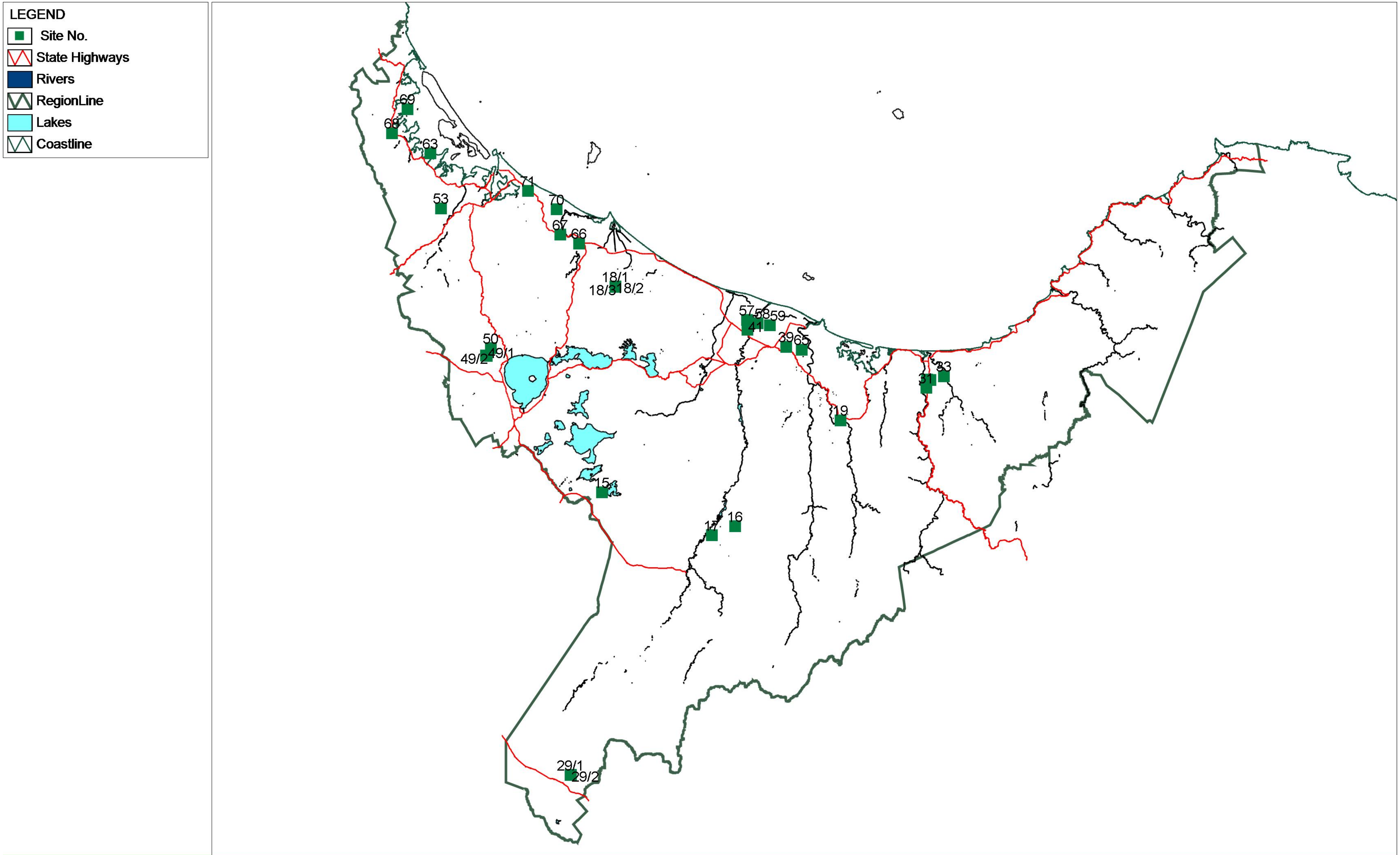
Appendices

Appendix 1 – Summary Information for Dairy and Maize Sample Sites

Site*	Sample No.	Year Established	Land Use	Soil Type	NZ Soil Classification (Order Level)
15	1	1999	Dairying	Rotomahana sandy loam	Recent
16	1	1999	Dairying	Horomanga sand	Pumice
17	1	1999	Dairying - irrigated	Galatea sand	Pumice
18	1	1999	Dairying	Oropi loamy coarse sand	Pumice
18	2	1999	Dairying	Oropi hill soils	Pumice
18	3	1999	Dairying	Kawhatiwhati sand	Pumice
19	1	1999	Dairying	Opouriao fine sandy loam	Recent
29	1	2000	Dairying - effluent	Kaingaroa gravelly sand	Pumice
29	2	2000	Dairying	Kaingaroa gravelly sand	Pumice
31	2	2000	Dairying	Opouriao fine sandy loam	Recent
33	1	2000	Dairying	Otara silt loam	Recent
49	1	2000	Dairying - effluent	Oturoa loam	Allophanic
49	2	2000	Dairying	Oturoa loam	Allophanic
50	1	2000	Dairying	Oturoa loam	Allophanic
53	1	2000	Dairying	Katikati sandy loam	Allophanic
57	1	2000	Dairying - organic	Paroa silt loam on peat	Gley
58	1	2000	Dairying - whey	Paroa silt loam on peat	Gley
59	1	2000	Dairying	Paroa silt loam on peat	Gley
63	1	2000	Dairying	Katikati sandy loam	Allophanic
34	1	2000	Maize	Opouriao fine sandy loam	Recent
39	1	2000	Maize	Pongakawa sandy loam	Gley
41	1	2000	Maize	Awakaponga silt loam	Recent
46	1	2000	Maize	Otara silt loam	Recent
65	1	2001	Maize	Paroa sandy loam	Recent
66	1	2009	Maize-New	Te Puke sandy loam	Allophanic
67	1	2009	Maize-New	Te Puke sandy loam	Allophanic
68	1	2009	Maize-New	Katikati sandy loam	Allophanic
69	1	2009	Maize-New	Katikati sandy loam	Allophanic
70	1	2009	Maize-New	Parton gritty sandy loam	Organic
71	1	2009	Maize-New	Parton gritty loamy peat	Organic

* For locations of sample sites with site numbers, refer to map on next page.



Site numbers of soil quality sites, 2009

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N

Appendix 2 – Glossary of Soil Quality Terms

Aggregate stability is a measure of the structural stability of the soil. Soil aggregates are clusters of mineral particles bound together by organic matter and chemical forces. Soil aggregates need to be of a size, shape and packing that maintains the necessary soil porosity for roots to easily access air, water and nutrients. Soils with high aggregate stability are better able to withstand the impacts of cultivation, wheel trafficking or animal treading and raindrop impact. Aggregates with low structural stability are more prone to dispersion by wind and water. Particles dispersed by water tend to fill the surrounding pores, restricting the movement of water and air into the soil profile. When this occurs at the soil surface, caps may form that can restrict seedling emergence and water infiltration. Aggregate stability is a soil quality indicator used only for cropping or arable soils.

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 organic matter in soils, their 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.

Appendix 3 – F and P Values from Analyses of Variance of Topsoil Qualities over Time

A. Dairy Sites			
Soil quality	**Degrees of freedom**	***F* value**	***P* value**
pH	2	1.76	0.181 ns
Total C	2	0.76	0.473 ns
Total N	2	1.25	0.294 ns
C/N ratio	2	4.56	0.015 *
Anaerobically mineralisable N	2	32.54	<0.001 **
Olsen P	2	2.46	0.095 +
Bulk density	2	1.59	0.214 ns
Macroporosity	2	0.99	0.377 ns
B. Maize Sites			
Soil quality	**Degrees of freedom**	***F* value**	***P* value**
pH	4	1.09	0.384 ns
Total C	4	3.35	0.027 *
Total N	4	3.58	0.021 *
C/N ratio	4	0.72	0.59 ns
Anaerobically mineralisable N	4	1.35	0.281 ns
Olsen P	4	0.15	0.962 ns
Bulk density	2	1.61	0.234 ns
Macroporosity	2	0.90	0.430 ns
Aggregate stability	2	0.044	0.957 ns

ns = not significant
+ = significant at 10% level
* = significant at 5% level
** = significant at 1% level

Note: Significant declines in total C and total N ($P<0.05$) in maize sites are not real because initial values were regarded as incorrect (See text for explanation).

Appendix 4 – Site and Soil Profile Descriptions, New Maize Sites

Site: 66

Soil Series	Te Puke sandy loam
Location	Gulliver Road, 1.5 km from intersection with SH 2
Transect length	50 m, direction NW 300°
Local contact person	William Litchfield
Classification	Typic Orthic Allophanic Soil
Land use	More than 15 years under continuous grain maize
Date sampled	31 March 2009
Land use history	15+ years under maize
Present vegetation	Maize
Slope (°)	2
Landform	Terrace in rolling country
Annual rainfall (mm)	1400 to 1600
Elevation (m)	20
Parent material(s)	Tephra: very thin Kaharoa and Taupo Tephra overlying Whakatane Tephra and older rhyolitic tephra
Erosion	None
Drainage	Well drained
Topsoil depth (cm)	20
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by	W. Rijkse, Dani Guinto

Description

Horizon	Depth (cm)	Description
Ap	0–20	Dark brown (7.5YR 3/2) gritty sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; earthy; common fine and very fine roots; indistinct smooth boundary.
Bw1	20-50	Dark yellowish brown (10YR 4/4) gritty sandy loam; slightly sticky; slightly plastic; weak soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct smooth boundary.
Bw2	50-80	Yellowish brown (10YR 5/6) gritty silt loam; sticky; slightly plastic; weak soil strength; friable failure; massive breaking to weakly pedal; few fine and very fine roots; indistinct smooth boundary.
2BC	80–120+	Yellowish brown (10YR 5/6 – 5/8) silt loam; sticky; slightly plastic; slightly firm soil strength; friable failure; massive; few fine and very fine roots.

Site: 67

Soil Series	Te Puke sandy loam
Location	Te Matai/State Highway 2 intersection, Te Puke
Transect length, direction	50 m, NW 300°
Local contact person	William Litchfield
Classification	Typic Orthic Allophanic Soil
Land use	Cropping, maize
Date sampled	31 March 2009
Land use history	Maize grain on grain yearly for approximately 20 years. Sometimes silage and oats rotation
Present vegetation	Maize
Slope (°)	Flat
Landform	Flat terrace
Annual rainfall (mm)	1400 to 1600
Elevation (m)	20

Parent material(s)	Tephra: very thin Kaharoa and Taupo Tephra overlying Whakatane Tephra and older rhyolitic tephra
Erosion	None
Drainage	Well drained
Topsoil depth (cm)	30
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by	W. Rijkse, Dani Guinto

Description

Horizon	Depth (cm)	Description
Ap	0–30	Dark brown (7.5YR 3/2) gritty sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; earthy; common fine and very fine roots; indistinct smooth boundary
Bw1	30-40	Dark brown (10YR 3/3) gritty sandy loam; slightly sticky; slightly plastic; weak soil strength; friable failure; weakly pedal; common fine and very fine roots; indistinct smooth boundary.
Bw2	40-60	Dark yellowish brown (10YR 4/4) gritty sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct smooth boundary.
Bw3	60-90	Yellowish brown (10YR 5/6) gritty sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct wavy boundary.
2Bw	90–120+	Yellowish brown (10YR 5/6) gritty silt loam; slightly sticky; slightly plastic; weak soil strength; friable failure; massive; few very fine roots.

Site: 68

Soil Series	Katikati sandy loam
Location	Main Road, Katikati
Transect length, direction	50 m, E 80°

Local contact person	Andrew Gorringe
Classification	Typic Orthic Allophanic Soil
Land use	Dairy until early 1970s, continuous maize since then (30+ years)
Date sampled	1 April 2009
Land use history	Long-term cropping
Present vegetation	Maize
Slope (°)	1
Landform	Terrace
Annual rainfall (mm)	1600
Elevation (m)	18
Parent material(s)	Tephra: very thin Kaharoa and Taupo Tephra overlying Tuhua Tephra and older rhyolitic tephra
Erosion	None
Drainage	Well drained
Topsoil depth (cm)	26
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by	W. Rijkse, Dani Guinto

Description

Horizon	Depth (cm)	Description
Ap	0-26	Dark brown (7.5YR 3/2) sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; earthy; common medium and fine roots; distinct smooth boundary.
Bw1	26-50	Dark yellowish brown (10YR 4/4) sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; weakly pedal; common fine and very fine roots; indistinct smooth boundary.

Bw2	50-80	Yellowish brown (10YR 5/6) silt loam; slightly sticky; slightly plastic; weak soil strength; friable failure; weakly pedal; few fine and very fine roots; distinct smooth boundary.
2Bw	80-120+	Yellowish brown (10YR 5/6) silt loam; sticky; slightly plastic; slightly firm soil strength; friable failure; weakly pedal; few fine and very fine roots.

Site: 69

Soil Series	Katikati sandy loam
Location	Beach Road, Katikati
Transect length, direction	50 m, E 80°
Local contact person	Kevin Leech through Andrew Gorringe
Classification	Typic Orthic Allophanic Soil
Land use	Cropping
Date sampled	1 April 2009
Land use history	Grew strawberry crop for 5 years then continuous maize cropping since 2006
Present vegetation	Maize
Slope (°)	0
Landform	Terrace
Annual rainfall (mm)	1600
Elevation (m)	18
Parent material(s)	Tephra: very thin Kaharoa and Taupo Tephra overlying Tuhua Tephra and older rhyolitic tephra
Erosion	None
Drainage	Well drained
Topsoil depth (cm)	22
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by	W. Rijkse, Dani Guinto

Description

Horizon	Depth (cm)	Description
Ap	0-22	Dark brown (7.5YR 3/2) with some dark yellowish brown mixing from Bw1 horizon; sandy loam; slightly sticky; non-plastic; very weak soil strength; friable failure; earthy; common medium and fine roots; distinct smooth boundary.
Bw1	26-50	Dark yellowish brown (10YR 4/4) loam; slightly sticky; slightly plastic; weak soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct smooth boundary.
Bw2	50-120+	Yellowish brown (10YR 5/6) silt loam; slightly sticky; slightly plastic; slightly firm soil strength; friable failure; weakly pedal; few fine and very fine roots.

Site: 70

Soil Series	Parton gritty sandy loam
Location	Bell Road, Te Puke
Transect length, direction	50 m, S 180°
Local contact person	Daniel Dovaston
Classification	Acid Mesic Organic Soil
Land use	Cropping, maize
Date sampled	2 April 2009
Land use history	Under continuous grain maize since 1966
Present vegetation	Maize
Slope (°)	Flat
Landform	Flat plain
Annual rainfall (mm)	1600
Elevation (m)	1
Parent material(s)	Organic material with fine Kaharoa Tephra in the topsoil and a thin layer of fine-textured Taupo Tephra at about 50 cm depth.

Erosion	None
Drainage	Poorly drained
Topsoil depth (cm)	20
Total rooting depth (cm)	High groundwater table occurs for at least three months a year
Limiting horizon	High, fluctuating ground water
Sampled by	W. Rijkse , Dani Guinto

Description

Horizon	Depth (cm)	Description
Ap	0–30	Black (5YR 2/1) gritty sandy loam; slightly sticky; non-plastic; very weak soil strength; friable failure; earthy; common fine and very fine roots; many fine white grains (Kaharoa Tephra); diffuse smooth boundary.
Om1	30-40	Black (5YR 2/1) loamy peat; non-sticky; non-plastic; very weak soil strength; friable failure; weakly pedal; few fine and very fine roots; sharp smooth boundary.
BCg	40-60	Dark brown (7.5YR 3/4) loamy very fine sand; slightly sticky; non-plastic; weak soil strength; friable failure; massive; few very fine roots; sharp smooth boundary (Taupo Tephra).
Om2	60-90	Dark reddish brown (5YR 2/2) loamy peat; non-sticky; non-plastic; very weak soil strength; very friable failure; massive; common old roots, no live roots; distinct smooth boundary.
Of	90–120+	Dark reddish brown (5YR 2/2) loamy peat; non-sticky; non-plastic; soft soil strength; very friable failure; massive; many old roots and tree stumps.

Site: 71

Soil Series	Parton gritty loamy peat
Location	Kairua Road, Welcome Bay
Transect length, direction	50 m, S 180°
Local contact person	Bill Webb

Classification	Acid Mesic Organic Soil
Land use	Silage maize since 2001
Date sampled	2 April 2009
Land use history	Since 2001, silage maize-annual ryegrass (for dairy cow winter grazing) cropping sequence
Present vegetation	Maize (recently harvested)
Slope (°)	Flat
Landform	Flattish valley floor
Annual rainfall (mm)	1400 to 1600
Elevation (m)	2
Parent material(s)	Organic material with fine Kaharoa Tephra in the topsoil
Erosion	None
Drainage	Poorly drained
Topsoil depth (cm)	25
Total rooting depth (cm)	High groundwater table occurs for at least three months a year
Limiting horizon	High, fluctuating ground water
Sampled by	W. Rijkse, Dani Guinto

Description

Horizon	Depth (cm)	Description
Ap	0–25	Black (7.5YR 2/0) gritty loamy peat; slightly sticky; non-plastic; very weak soil strength; very friable failure; earthy; common fine and very fine roots; many fine white grains (Kaharoa Tephra); indistinct smooth boundary
Om	25-35	Black (7.5YR 2/0) loamy peat; slightly sticky; non-plastic; very weak soil strength; very friable failure; massive; few fine and very fine roots; common old roots and few stumps; indistinct smooth boundary.

Of	35-120+	Dark reddish brown (5YR 3/2) loamy peat; slightly sticky; non-plastic; very weak soil strength; soft failure; massive; no live roots; abundant old roots and stumps.