Soil Quality of Intensive Pasture in Hawke's Bay – 2012/13

Prepared for

Hawke's Bay Regional Council

Prepared by

LOWE Environmental Impact

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Hawke's Bay Regional Council

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1 EXECUTIVE SUMMARY

Hawke's Bay Regional Council (HBRC) are responsible for monitoring the soil quality of the Hawke's Bay region as part of their obligations for State of the Environment (SoE) reporting. HBRC reviewed their soil monitoring programme in 2006 (Pearson & Reid, 2006). This provided a framework on which to base a selection process for sites that represent Hawke's Bay based on land form, soil order, soil types and land use. It also prioritized the soil quality indicators.

In 2009 the National Land Monitoring Forum (NLMF) produced robust guidelines from which councils can produce nationally consistent land monitoring procedures and reporting. In accordance with the identified reporting requirements HBRC have engaged LEI to undertake field work and report on soil quality parameters. Information presented here examines soil quality of intensive pastoral land use in the Hawke's Bay. Soil quality is assessed in accordance with the recommendations of Pearson and Reid (2006) and the NLMF guidelines.

Intensive pastoral land use can be defined as land under high producing exotic grassland. The land has been modified by development of a pastoral system and establishment of exotic grass cover, often ryegrass and clover. Intensive pastoralism is distinguished from extensive pastoralism by a greater level of inputs of fertiliser, supplements and pasture improvement. Stocking rates are high and stock types (dairy cows and bull beef) have a high management input.

Sampling for soil quality monitoring for the intensive pasture sampling round occurred in January 2013. Site were visited by LEI staff and HBRC staff. Some locations, particularly the southern areas, inland from the coast, had received around 25 mm rainfall around Christmas/New Years. However in general the sites sampled were dry to very dry.

It should be noted that some sites visited appeared to be managed with a comparatively low level of intensity. It was considered appropriate to sample these locations never-the-less since the results could be directly compared the results of the 2007 sampling round, and in some cases, the 200/2001 sampling round.

Nineteen sites were sampled from intensive pastoral properties used for bull beef or dairy farming throughout Hawkes Bay. Results from the analysis of soil from each site enabled the following conclusions to be made:

- In general soil quality in the Hawke's Bay intensive pasture sites is good, although some care should be taken in interpretation of the results since soil moisture content was generally very low due to particularly low rainfall in the preceding weeks.
- Intensive pasture sites are expected to have higher C, N and fertility status compared to other land uses (cropping, extensive pasture) and may be expected to change rapidly due to the effect of inputs such as fertiliser and effluent. Changes over time are likely to be important, however a point in time review is a useful tool for this land use type.
- Soil physical condition is a concern for intensive pasture, in particular those sites with fine textured soils and high stocking rates.
- A high number of sites had P status outside of the target range. This was also the indicator of most concern for the previous (extensive pasture) sampling round and so P management is considered to be a key issue for soil quality and sustainability of land sue for the Hawke's Bay.
- Elevated fluoride further indicate the management of P fertiliser addition is needed to minimise the risk of soil contamination through poor fertiliser selection or over-application.

- Closer management of the N status of soils may be needed to limit the risk of N leaching from intensive pasture sites and particularly the coarser textured soils such as Pumice Soils.

Recommended actions coming from this report include:

- Managers of the properties sampled should be informed of the soil quality on their properties and where remedial activity is recommended HBRC may provide advice on potential management strategies.
- Land managers and advisors, including fertilizer representatives, may require information regarding the management of P on intensively managed soils. Specifically, the adoption of P forms best suited to soil type, and application regimes designed to optimise P use.
- Management and monitoring of dairy effluent irrigation should include consideration of P accumulation in soil to avoid saturating the soil with P, and the associated risk of discharge to water.
- Further evaluation of risks from N leaching under intensive pasture may be warranted.
- The same sites should be resampled within 5 years and at ongoing intervals to develop a long term record of soil quality indicator performance over time.

2 INTRODUCTION

2.1 Purpose

This report provides Hawkes Bay Regional Council (HBRC) with an interpretive soil quality report based on laboratory and field data collected. This information is intended to contribute to the council's State of the Environment reporting obligations.

2.2 Background

The HBRC is developing a database of soil condition from different land uses representative of the Hawke's Bay region. This database began with the "500 Soils Project" cofounded with the Ministry for the Environment (MfE) during 1999-2000. The MfE ceased involvement in the project in 2001 with the understanding that regions would continue monitoring and at a future date the 500 Soils Project sites would be resampled.

The HBRC reviewed their soil monitoring programme in 2006 (Pearson & Reid, 2006). This provided a framework on which to base a selection process for sites that represent Hawke's Bay based on land form, soil order, soil types and land use. It also prioritized the soil quality indicators. Previously sampled land uses were divided into intensive cropping, dairying and bull beef land use. The current report focuses solely on intensive pastoralism and is compared to data identified for bull beef and dairying properties in the 2007 report.

In 2009 the National Land Monitoring Forum (NLMF) produced robust guidelines from which councils can produce nationally consistent land monitoring procedures and reporting. In accordance with the identified reporting requirements HBRC have engaged LEI to undertake field work and report on soil quality parameters. Information presented here examines soil quality of intensive pastoral land use in the Hawke's Bay. Soil quality is assessed in accordance with the recommendations of Pearson and Reid (2006) and the NLMF guidelines.

2.3 Scope

This report follows on from a previous soil quality report produced for extensive pastoralism in the Hawke's Bay (LEI, 2011). For consistency this report maintains a similar format and methodology for assessing soil quality as that used in the previous report. The scope of this report is to describe the soil quality of land used for intensive pastoralism in the Hawkes Bay region. In particular it details:

- Section 3: Methods used to collect data.
- Section 4: Results from data collected with brief written interpretation.
- Section 5: Discussion
- Section 6: Conclusion
- Section 7: Recommendations

3 SOIL QUALITY AND LAND USE

3.1 Soil Quality Monitoring in the Hawke's Bay

As previously reported (LEI, 2011), soil quality and land use impacts on soil quality are important indicators of the state of the environment. A clear procedure for the investigation of soil quality in New Zealand has been established. This report uses guidelines prepared by the National Land Monitoring Forum (2009) for the measurement and interpretation of soil quality. It is complimented by information from previous reports on soil quality for the Hawke's Bay region, which have been reviewed and referenced through this report.

3.2 Land Use Definition

The adoption of intensive pasture as a land use is in line with the NLMF guidelines which group pastoral land stocked with dairy or bull beef as intensive pastoralism. The land use categories are defined so that they can be aggregated back to the New Zealand Land Cover Database.

In most cases the land has been modified by the development of a high producing exotic grassland system using exotic grass cover, often ryegrass and clover. Intensive pastoralism is distinguished from extensive pastoralism by a greater level of inputs of fertiliser, supplements and pasture improvement. Stocking rates are high and stock types (dairy cows and bull beef) have a high management input.

3.3 Soil Quality Indicators

Much investigation has been undertaken into the measurement of soil quality. In line with the recommendations of the Pearson and Reid (2006), the adopted indicators for the Hawke's Bay region follow the convention of the "500 Soils Project" (Sparling, *et al.*, 2001). The identified soil quality indicators are as follows:

Priority One: The Minimum Data Set

- Soil pH or soil acidity;
- Olsen P;
- Total C and N;
- Potentially mineralisable N;
- Bulk density;
- Macroporosity; and
- Aggregate stability (not analysed in this study).

Priority Two: Visual Soil Assessment (VSA; Shepard, 2000)

- % bare ground;
- % area of crusted soil and crust thickness;
- % area damaged soil surface; and
- Thickness of organic matter thatch.

Priority Three: Extra Measurements

- Exchangeable cations and cation exchange capacity;

- Trace elements (As, Cd, Cr, Cu, Pb, Hg, Ni);
- DDT; and
- Hot water extractable C.

3.4 Trace Element & Organochlorine Pesticide Monitoring

Trace element and organochlorine pesticide measurement corresponds to the Priority Three indicators. While not considered fundamental to the measurement of soil quality they give important information about soil health on an individual property, and may identify sites where previous land use has had a detrimental effect on soil quality. If data from several properties exceeds guidelines for trace elements it is recommended to pursue further investigation (Chapter 5: NLMF, 2009). Organochlorines are an indicator of land use impacts since they do not occur naturally. In addition the presence of elevated levels of organochlorine pesticides and trace elements indicates a limitation to land uses on the site.

Trace elements of particular interest are cadmium, fluorine and uranium that are known to accumulate in the soil when superphosphate has been applied. Use of a range of zinc containing products such as in antibiotics and fungicides are also common practice on pastoral farms, particularly facial eczema preventative remedies (Kim & Taylor, 2009).

3.5 Historical State of Hawke's Bay Soils

Previous reports and the New Zealand Soil Health Report Card (NZSHRC; MOE, 2010) have identified the soil management challenges for the Hawke's Bay region as:

- Poor aggregate stability (all land uses);
- Low macroporosity (intensive pasture);
- Low carbon reserves (cropping)
- General fertility (extensive pasture); and
- Phosphorus status (extensive pasture).

The above indicates that properties of concern for intensive pasture sites are predominantly soil physical properties likely to be impacted by large stock and higher stocking rates. Intensive pastoralism monitored for this report is best compared to soils used for bull beef and dairying production that were monitored in the 2007 report (Sparling and Stevenson, 2007).

4 METHODOLOGY

4.1 Site Selection

The method for site selection follows the recommendation of NLMF (2009). The selection of sites follows the recommendation of Pearson and Reid (2006). In order to determine locations for the establishment of soil quality monitoring sites HBRC utilized existing soil and land use maps of the region. Overlays of land use and soil type were applied to property boundaries. Sites that were visited in the 2007 study (Sparling, 2007) were given preference where detail for relocating those sites was known. The term intensive pasture was not in use for sites sampled in the 2007 round. However, sites identified as Bull Beef of Dairy were taken as equivalent to intensive pasture.

For the soil types not previously sampled, and where information was insufficient to relocate a previously sampled site, HBRC identified a representative property for each soil type. An approach was made to the property owner followed by a land management questionnaire as given in Appendix B.

Where the property was deemed to have met criteria for the establishment of a soil quality monitoring site (e.g. Section 5.1; Pearson and Reid, 2006), the site was selected for monitoring site establishment.

4.2 Establishment of a Monitoring Site

Monitoring sites were established in accordance with NLMF (2009) procedures and Section 5.2 of Pearson and Reid (2006). In brief, the site was located so that no part of the sampling transect was affected by tracks, fence lines, shelter belts, stock camps, water troughs, streams, drainage ditches, buildings, fire sites, erosion scars or other disturbed areas.

A 50 m transect was marked out. GPS co-ordinates were taken at 0 m, 25 m and 50 m. Soil pits were excavated at approximately 0 m, 25 m and 50 m along the transect. Soil was described to a depth of around 50 cm for two pits and to around 100 cm at one pit. Details of each site are given in Appendix A.

4.3 Observations on Site Selection and Site Establishment

Sampling for soil quality monitoring for the intensive pasture sampling round occurred in January 2013. Some locations, particularly the southern areas, inland from the coast, had received around 25 mm rainfall around Christmas/New Years. However, in general the sites sampled were dry to very dry.

It should be noted that some sites visited appeared to be managed with a comparatively low level of intensity. It was considered appropriate to sample these locations never-the-less since the results could be directly compared to the results of the 2007 sampling round, and in some cases, the 2000/2001 sampling round.

4.4 Sampling and Analysis

Soil sampling and analyses followed the guidelines prepared by the NLMF (2009). The draft NLMF guidelines are based the protocols established by the 500 Soils Project (Hill et al., 2003). A summary of the procedure for sampling and analysis is as follows.

4.4.1 Sampling for Soil Physical Indicators

An intact core of approximate dimensions 100 mm (diameter - ∅) x 75 mm (long - L) was taken from three locations at each transect. The sampling locations corresponded to the soil pits at 0 m, 25 m and 50 m.

4.4.2 Sampling for Soil Chemical and Microbiological Indicators

A foot corer of dimensions 20 mm ∅ x 100 mm L was used to obtain one soil core approximately every 2 m along the transect. The cores were combined to provide a composite sample for analysis of soil chemical parameters.

The procedure above was repeated to provide a second composite sample. This second sample was used for analysis of trace elements and persistent organic contaminants.

4.4.3 Sample Handling and Transport

Samples were packed in sealed bags and placed in chilly bins where necessary and transferred to a storage fridge, if not conveyed immediately to a laboratory for analysis. Intact cores were stored and transported in padded crates.

Intact cores for soil physical indicators were sent to the Landcare Research Laboratory in Palmerston North for analysis. Composite samples for chemical analysis were sent to Hill Laboratories in Hamilton.

4.4.4 Sample Analysis

As indicated above, samples were sent to Hill Laboratories for chemical analyses, being:

- Basic soil test: pH, Olsen P, exchangeable cations, CEC, base saturation;
- Organic soil profile: Available N, anaerobically mineralisable N (AmN), organic matter, total C, total N, C/N ratio, AmN/N ratio;
- Heavy metal screen: As, Cd, Cr, Cu, Ni, Pb, Zn, Hg;
- Organochlorine pesticide screen;
- Total uranium (Ur); and
- Total fluoride (Fl^-).

Analyses conducted at the Landcare Research laboratory were:

- Bulk density;
- Macroporosity;
- Particle density;
- Total porosity;
- Field capacity: soil moisture content when all macropores have drained; and
- Available water capacity (AWC).

4.5 Data Presentation

All data is expressed as received from Hills Laboratories. Where necessary, recalculation of data to different units was made to enable comparison to historical data.

5 RESULTS

5.1 Soils & Sites

Nineteen sites were sampled from intensive pastoral properties used for dairying and bull beef throughout Hawkes Bay. Table 1 lists the soil types at each sample site and the soil order/group to which they belong.

The 8 soil orders chosen to represent the region (Pearson & Reid, 2006) have at least one representative soil in this sampling investigation. The order listed is that identified for the soil type by Pearson & Reid (2006), except four Pumice soils they did not analyse, being the Kaingaroa, Otamatea, Waikoau and the Pakarae.

Table 1: Soil Quality Monitoring Sites

Site No	Soil Type	Order	Stock Type
1	Wanstead	Pallic	Bull beef
2	Pukehou	Gley	Bull beef
3	Te Aute	Mellanic	Bull beef
4	Matamau	Brown	Bull beef
5	Takapau	Allophanic	Dairy
6	Okawa	Gley	Dairy
7	TeOnepu	Mellanic	Bull beef
8	Twyford	Recent	Bull beef
9	Matapiro	Pallic	Bull beef
10	Hastings	Gley	Bull beef
11	Atua	Pallic	Bull beef
12	Poukawa	Organic	Bull beef
13	Kaingaroa	Pumice	Dairy
14	Otamatea	Pumice	Dairy
15	Gisborne	Pumice	Dairy
16	Waikoau	Pumice	Dairy
17	Taupo	Pumice	Dairy
18	Awamate	Gley	Dairy
19	Pakarae	Pumice	Bull beef

Soil profile and site descriptions are provided in Appendix A. Soil chemistry, physical data, trace element levels and agrichemical contaminants are shown in Tables 2 to 5 below. Analysis results as received from the analysing laboratories are given in Appendix C.

Table 2: Soil chemical characteristics of Hawke's Bay sites sampled in 2013

Site	Soil Type	pH	CEC	Total Carbon	Total Nitrogen	C/N	Olsen P	Base Saturation	Mineral-isable N	Potassium	Calcium	Magnesium	Sodium
			me/100g	mg/cm³	mg/cm³	ratio	mg/L	%	µg/cm³	Exchangeable cations me/100g			
01-13-10cm	Wanstead	5.9	27	65.5	6.55	10.0	24	70	243	1.12	15.30	1.99	0.28
02-13-10cm	Pukehou	6.2	17	39.7	4.09	9.7	34	73	151	0.35	10.60	1.01	0.23
03-13-10cm	Te Aute	5.7	17	59.5	5.21	11.4	28	54	237	0.64	7.00	1.17	0.25
04-13-10cm	Matamau	6.1	24	52.9	5.29	9.8	16	73	323	0.60	14.90	1.93	0.25
05-13-10cm	Takapau	6.0	23	71.4	6.53	10.9	82	66	199	0.92	11.90	2.49	0.18
06-13-10cm	Okawa	6.4	20	56.8	5.80	9.8	12	81	334	0.51	13.40	2.20	0.25
07-13-10cm	TeOnepu	6.1	23	55.0	5.15	10.6	48	67	220	2.30	11.10	1.97	0.21
08-13-10cm	Twyford	5.9	24	55.0	5.28	10.5	19	62	229	0.61	11.70	2.36	0.13
09-13-10cm	Matapiro	6.0	23	50.8	4.60	11.0	24	73	156	0.51	15.00	1.35	0.10
10-13-10cm	Hastings	5.7	21	47.6	4.76	10.1	16	54	184	0.76	8.70	1.80	0.12
11-13-10cm	Atua	5.6	18	44.2	4.68	9.3	27	64	203	0.31	9.30	1.35	0.30
12-13-10cm	Poukawa	5.3	48	118.5	9.95	12.0	25	48	221	0.54	19.70	2.25	0.29
13-13-10cm	Kaingaroa	5.9	22	64.8	5.67	11.4	90	42	147	0.31	6.40	2.14	0.12
14-13-10cm	Otamatea	5.8	21	47.6	4.09	11.6	55	36	102	0.66	5.20	1.32	0.12
15-13-10cm	Gisborne	5.8	30	70.4	6.40	11.1	18	48	157	0.57	12.60	1.31	0.20
16-13-10cm	Waikoau	5.8	26	72.1	5.91	12.1	13	29	172	0.47	5.80	0.96	0.24
17-13-10cm	Taupo	5.3	27	70.5	6.08	11.7	57	22	156	0.40	4.90	0.70	0.15
18-13-10cm	Awamate	5.8	19	55.5	5.78	9.5	70	64	232	1.07	9.00	1.66	0.11
19-13-10cm	Pakarae	5.7	22	54.3	4.46	12.2	10	34	128	0.55	5.70	1.08	0.32

Table 3: Soil chemical characteristics of Hawke's Bay sites sampled in 2013(units utilised for target range)

Site	Soil Type	pH	CEC	Total Carbon	Total Nitrogen	C/N	Olsen P	Base Saturation	Mineral-isable N	Available N (10 cm depth)	Potassium	Calcium	Magnesium	Sodium
			me/100g	%	%	ratio	mg/L	%	µg/g	mg/kg	Exchangeable cations me/100g			
01-13-10cm	Wanstead	5.9	27	5.5	0.55	10.0	24	70	204	289	1.12	15.30	1.99	0.28
02-13-10cm	Pukehou	6.2	17	3.2	0.33	9.7	34	73	122	188	0.35	10.60	1.01	0.23
03-13-10cm	Te Aute	5.7	17	4.8	0.42	11.4	28	54	191	294	0.64	7.00	1.17	0.25
04-13-10cm	Matamau	6.1	24	4.3	0.43	9.8	16	73	**263**	398	0.60	14.90	1.93	0.25
05-13-10cm	Takapau	6.0	23	7.0	0.64	10.9	**82**	66	195	203	0.92	11.90	2.49	0.18
06-13-10cm	Okawa	6.4	20	4.9	0.50	9.8	**12**	81	**288**	388	0.51	13.40	2.20	0.25
07-13-10cm	TeOnepu	6.1	23	4.7	0.44	10.6	48	67	188	257	2.30	11.10	1.97	0.21
08-13-10cm	Twyford	5.9	24	5.0	0.48	10.5	19	62	208	252	0.61	11.70	2.36	0.13
09-13-10cm	Matapiro	6.0	23	4.2	0.38	11.0	24	73	129	189	0.51	15.00	1.35	0.10
10-13-10cm	Hastings	5.7	21	3.9	0.39	10.1	16	54	151	225	0.76	8.70	1.80	0.12
11-13-10cm	Atua	5.6	18	3.4	0.36	9.3	27	64	156	264	0.31	9.30	1.35	0.30
12-13-10cm	Poukawa	5.3	48	15.0	1.26	12.0	25	48	**280**	175	0.54	19.70	2.25	0.29
13-13-10cm	Kaingaroa	5.9	22	8.0	**0.70**	11.4	**90**	42	182	119	0.31	6.40	2.14	0.12
14-13-10cm	Otamatea	5.8	21	7.1	0.61	11.6	55	36	152	68	0.66	5.20	1.32	0.12
15-13-10cm	Gisborne	5.8	30	8.8	**0.80**	11.1	18	48	196	125	0.57	12.60	1.31	0.20
16-13-10cm	Waikoau	5.8	26	8.9	**0.73**	12.1	**13**	29	212	139	0.47	5.80	0.96	0.24
17-13-10cm	Taupo	5.3	27	9.4	**0.81**	11.7	57	22	208	117	0.40	4.90	0.70	0.15
18-13-10cm	Awamate	5.8	19	4.7	0.49	9.5	**70**	64	197	274	1.07	9.00	1.66	0.11
19-13-10cm	Pakarae	5.7	22	6.7	0.55	12.2	**10**	34	158	104	0.55	5.70	1.08	0.32

* Items in bold fell outside the target range for that land use and soil order (Hill & Sparling, 2009)

Table 4: Soil physical characteristics of Hawke's Bay sites sampled in 2013

Site	Soil Type	Dry bulk density	Particle density	Porosity	Macro-porosity	Field capacity	AWC
		(g/ cm^3)	(g/cm^3)	(%)	(%)	(%)	(%)
01-13-10cm	Wanstead	1.19	2.49	52	11	45	19
02-13-10cm	Pukehou	1.24	2.56	52	14	37	19
03-13-10cm	Te Aute	1.24	2.55	51	16	39	22
04-13-10cm	Matamau	1.23	2.53	51	10	42	23
05-13-10cm	Takapau	1.02	2.49	59	18	41	24
06-13-10cm	Okawa	1.16	2.51	54	13	45	24
07-13-10cm	TeOnepu	1.17	2.54	54	16	40	21
08-13-10cm	Twyford	1.10	2.58	57	11	46	17
09-13-10cm	Matapiro	1.21	2.54	52	15	41	20
10-13-10cm	Hastings	1.22	2.54	52	16	38	20
11-13-10cm	Atua	1.30	2.49	48	**6**	42	22
12-13-10cm	Poukawa	0.79	2.18	64	17	52	18
13-13-10cm	Kaingaroa	0.81	2.30	65	18	45	27
14-13-10cm	Otamatea	**0.67**	2.32	71	**31**	41	29
15-13-10cm	Gisborne	0.80	2.27	65	21	45	29
16-13-10cm	Waikoau	0.81	2.32	65	20	41	27
17-13-10cm	Taupo	0.75	2.22	66	20	46	32
18-13-10cm	Awamate	1.18	2.49	53	9	43	24
19-13-10cm	Pakarae	0.81	2.28	65	30	42	27

* Items in bold fell outside the target range for that land use and soil order (Hill & Sparling, 2009)

Table 5: Trace element levels of Hawke's Bay sites sampled in 2013

Site	Soil Type	Individual Tests		Heavy metals , screen As, Cd, Cr, Cu, Ni, Pb, Zn, Hg							
		Total Recoverable Uranium	Fluoride	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
01-13-10cm	Wanstead	1.01	270	3	0.41	10	7	8.6	<0.10	6	46
02-13-10cm	Pukehou	1.06	240	3	0.31	12	8	12.1	<0.10	7	61
03-13-10cm	Te Aute	0.94	240	<2	0.26	12	5	8.1	<0.10	5	34
04-13-10cm	Matamau	1.05	220	<2	0.36	11	8	7.7	<0.10	5	32
05-13-10cm	Takapau	0.8	230	3	0.23	13	12	10	<0.10	6	75
06-13-10cm	Okawa	0.98	270	<2	0.28	13	9	9.7	<0.10	5	37
07-13-10cm	TeOnepu	1.1	280	3	0.66	16	16	11.3	<0.10	8	73
08-13-10cm	Tueyford	1.05	510	7	0.25	25	31	25	<0.10	20	98
09-13-10cm	Matapiro	1.02	260	4	0.51	18	14	11.2	<0.10	11	61
10-13-10cm	Hastings	0.74	370	3	0.22	14	15	12.6	<0.10	11	65
11-13-10cm	Atua	1	270	3	0.22	10	7	12.1	<0.10	4	28
12-13-10cm	Poukawa	1.62	420	4	0.43	18	25	12	<0.10	14	72
13-13-10cm	Kaingaroa	1.48	600	<2	0.79	18	7	2.6	<0.10	14	55
14-13-10cm	Otamatea	0.83	460	<2	0.34	4	7	3.2	<0.10	3	21
15-13-10cm	Gisborne	1.34	510	<2	0.67	7	10	6	<0.10	3	35
16-13-10cm	Waikoau	1.16	320	<2	0.53	7	15	4.4	<0.10	3	33
17-13-10cm	Taupo	1.38	400	<2	0.65	5	12	4.6	<0.10	<2	27
18-13-10cm	Awamatu	1.09	290	<2	0.47	11	7	6.1	<0.10	7	46
19-13-10cm	Pakarae	0.6	330	<2	0.22	3	3	4.6	<0.10	2	29

5.2 Priority One Indicators

The results from the soils analysed have been compared to the interpretative frameworks developed by the NLMF expert panel (Hill & Sparling, 2009) (referred to in this report as the Framework). The Framework provides terms to categorise the results and target ranges or critical limits.

5.2.1 Soil pH

Soil pH results are shown in Figure 1. The target range is shown as pH 5.0 to 6.6. All the sampled soils were within the target range for soil pH. The Organic soil (Site 12) has a wider target range and falls well inside this. One soil was near to the high limit corresponding to an Okawa soil (Site 6). Unmodified Okawa Soils tend to be slightly acidic. It is not known what the cause of elevated pH is at the Site however, liming of the soil may have occurred. One soil was near the low pH limit corresponding to the Taupo Pumice soil (Site 17) and that is in-line with a typical pumice soil.

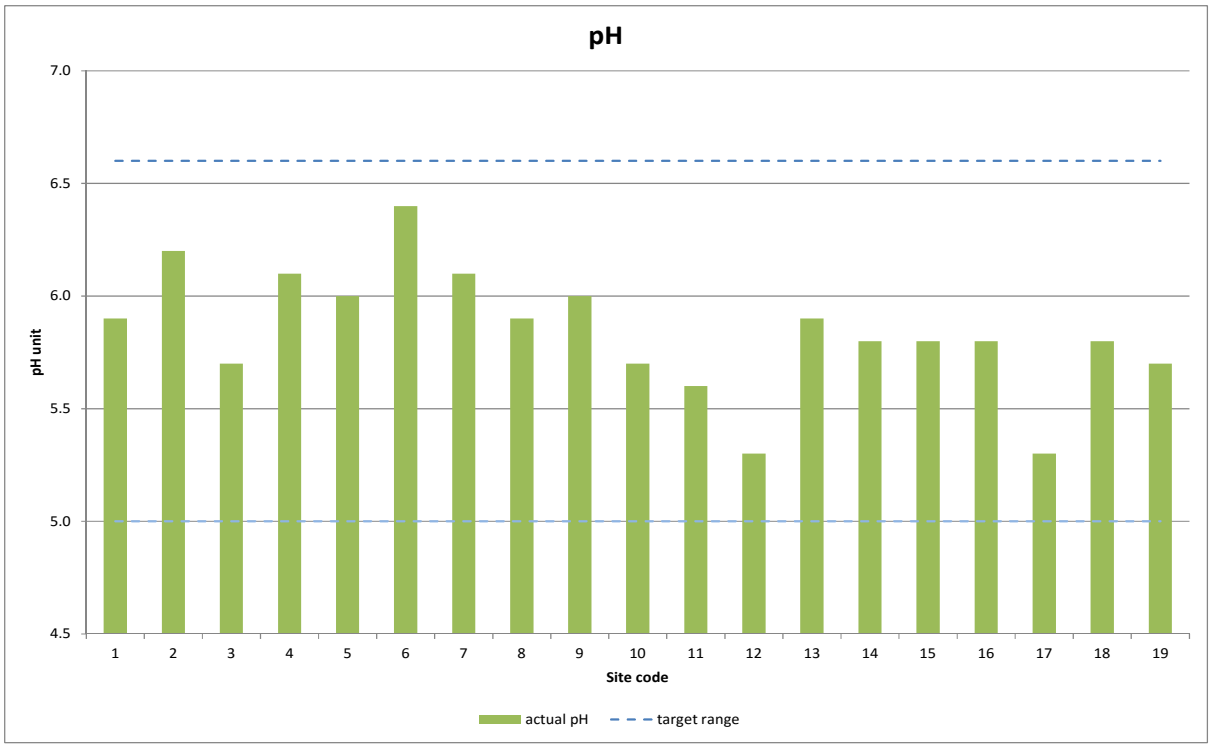

Figure 1: Soil pH for Hawke's Bay sites sampled in 2013

5.2.2 Total Carbon

The range recorded of total C (% w/w) is 3.2 to 9.4 with the organic soil at 15. For comparative purposes the results have been expressed on a weight per volume basis (mg/cm^3). Figure 2 shows the results that range from 39.7 to 72.1 mg/cm^3 and 118.5 mg/cm^3 for the organic soil. The organic soil by definition must have >15% carbon and is excluded from the target range required. Utilising the 2009 framework all sites are above the critical limit with the majority in the normal range. All pumice soils had carbon levels above the normal range.

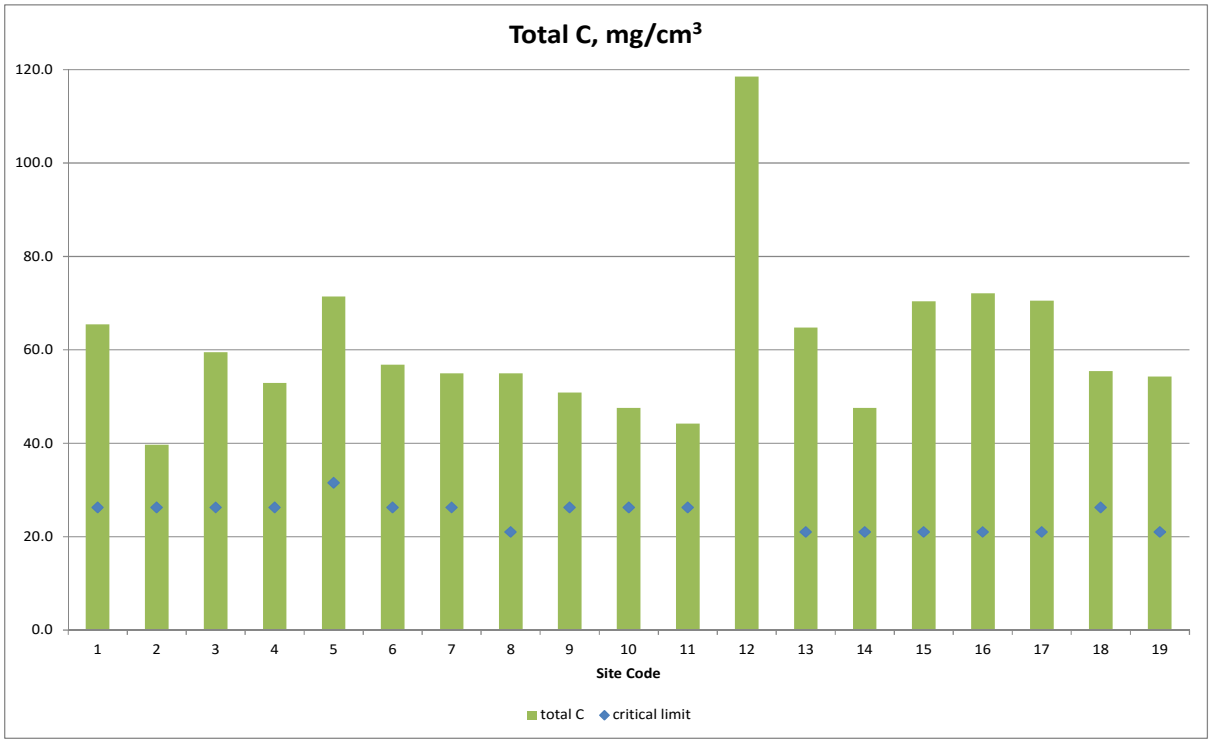

Figure 2: Total C for Hawke's Bay sites sampled in 2013

5.2.3 Total Nitrogen

All sites total nitrogen results were between 4.09 and 6.55 mg/cm^3, with the exception of the organic soil that had 12.95 mg/cm^3. In general the trend for total N follows the total C observed. There is no clear trend based on soil order and it is likely that the total N status of the soils is related to land management practices such as fertilisation history, pasture development and tillage. Utilising the Framework, four dairy properties had nitrogen levels above the target range. Figure 3 shows total N for the sites measured.

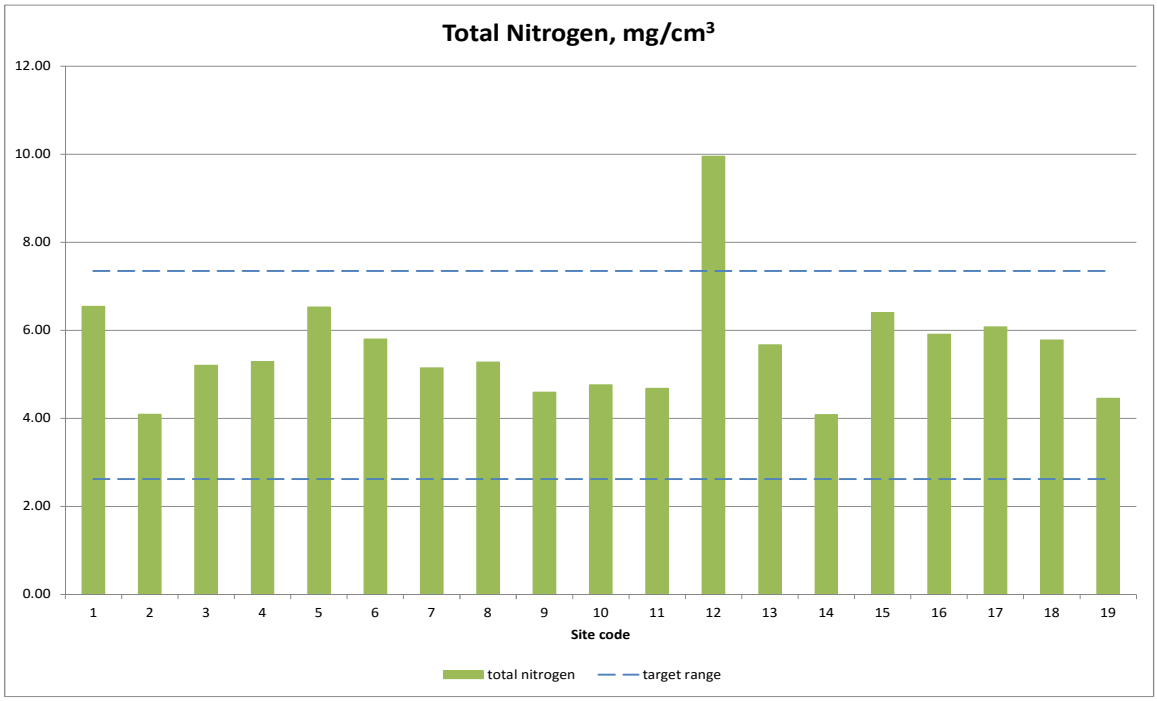

Figure 3: Total N for Hawke's Bay sites sampled in 2013

5.2.4 Anaerobically Mineralisable Nitrogen

The concentration of anaerobically mineralisable N (AmN) is a function of the C:N ratio and of the soil microbial health. Figure 4 shows the AmN results. In general soils sampled were within the target range for AmN. Three sites had high AmN which is an indicator of nitrate leaching risk. Sites at the low end of the range may be at risk of limiting the potential for plant growth, but no site indicated particularly low levels.

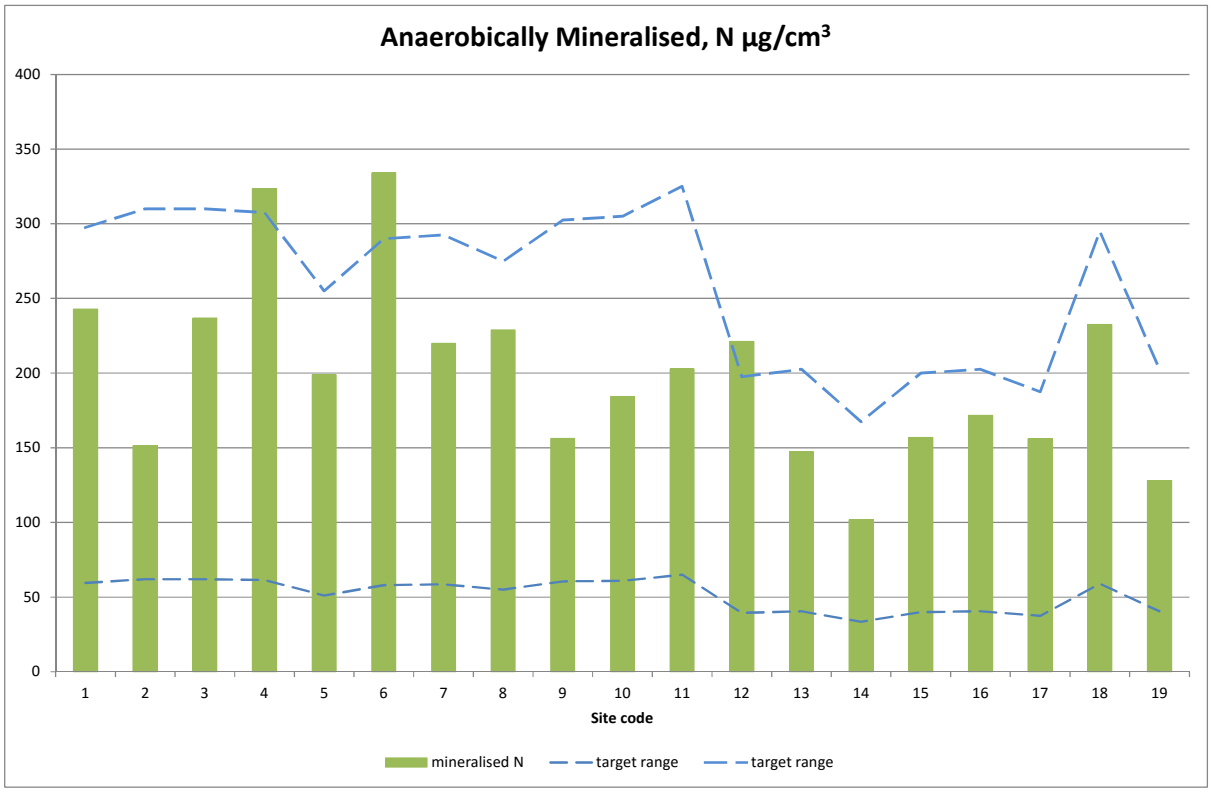

Figure 4: Mineralisable N content (µg/cm^3) of Hawke's Bay soils sampled 2013

5.2.1 Available Nitrogen

When the anaerobically mineralisable N results are adjusted for each sites bulk density and expressed on a per ha basis the results can be expressed as Available N. Available N is shown in Figure 5 below for the intensive pasture sites. It can be seen that in comparison with the results shown in Figure 4 above, when adjusted based on depth, 11 of the 19 sites visited have available N in the surface soil which is in excess of the target values. This may indicate a risk of leaching, however the values reported are not far in excess of the limit. It is likely that under an intensively managed pasture the available N may translocate downwards in the soil but is likely to be accessed by roots and utilised for plant growth.

No sites measured were below the target limits, which is to be expected in intensive pasture systems. The coarser textured soils (particularly Pumice Soils) tended to have lower Available N than the heavier textured soils. This most likely reflects N accumulation in heavy soils at a rate in excess of pasture production, while the coarser textured soils are more likely to lose N via leaching if it is not taken up by pasture.

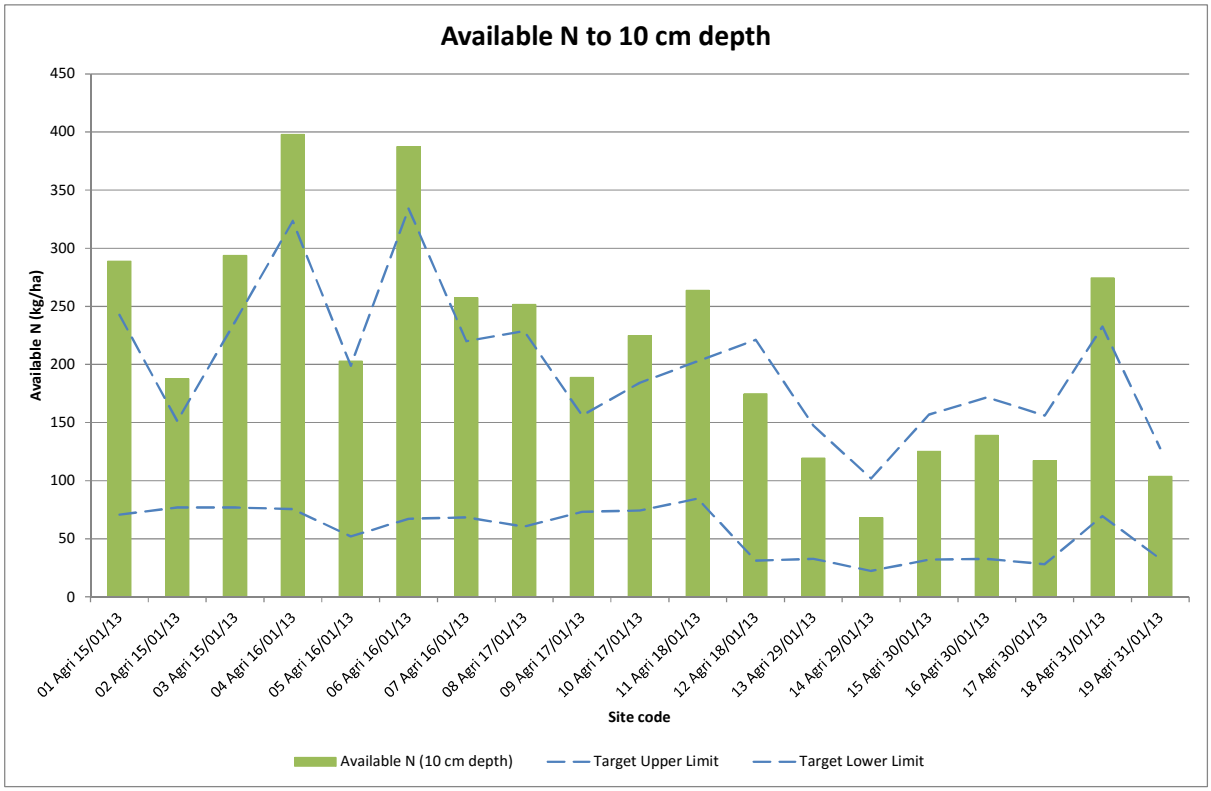

Figure 5: Available N content (kg/ha) of Hawke's Bay soils sampled 2013

5.2.2 Olsen Phosphorus

Figure 6 gives the Olsen P results. Three sites showed very low levels from the Olsen P test, therefore operating below potential growth rate for the pasture and outside the target range. Four other sites were only slightly above the lower limit. Three sites were well above the upper limit and three additional sites close to the upper limit.

For Sites 4, 6, 8, 10, 15, 16 and 19 the Olsen P level may be, or become limiting to the sustainability of the current land use. There was no clear relationship between the stock type (3 dairy, 4 bull beef) and low P status. For two of the sites with low P status, a different soil type measured on the same properties returned elevated P levels. This is likely due to differing management occurring on different soil types within a property, for instance where move free draining soils are managed more intensively than imperfectly drained soils.

For Sites 5, 13 and 18 with topsoil Olsen P in excess of the target range the risk of P reaching waterways is considered greater but dependent on the site and degree of soil loss by erosion. All three sites were on dairy farming properties and soil types likely to have a high P retention capacity (not measured). There are a couple of potential reasons for elevated P; one being if farm dairy effluent, particularly with high solids content, is being applied rapid P accumulation may occur. Alternatively, a high rate of P fertilisation may have occurred.

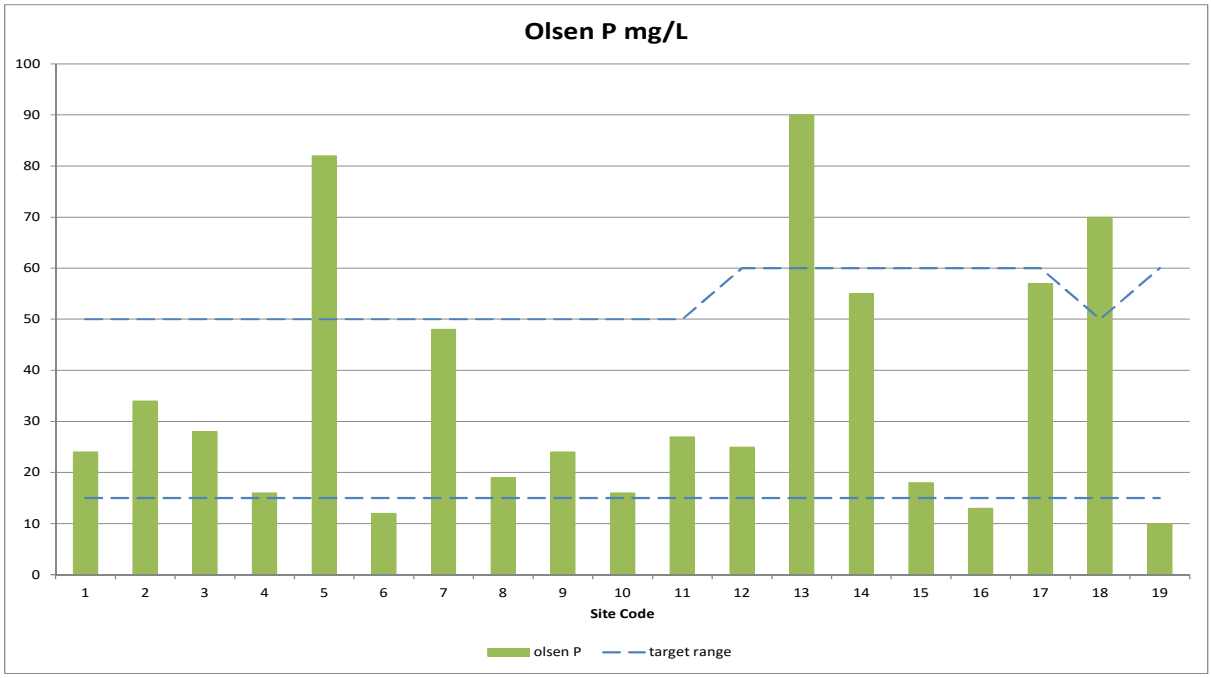

Figure 6: Olsen P content (mg/L) of Hawke's Bay soils sampled in 2013

5.2.3 Carbon : Nitrogen Ratio

The C/N ratio is consistent with the Total C and N measures. A C/N ratio below 9 is considered too low to store N in organic forms, favouring mineralisation and elevated risk of leaching. All sites had results above 9 but five sites are getting low with ratios between 9.3 and 9.8. All other sites range between 10.0 to 12.2. Figure 7 gives the C/N ratio for each site.

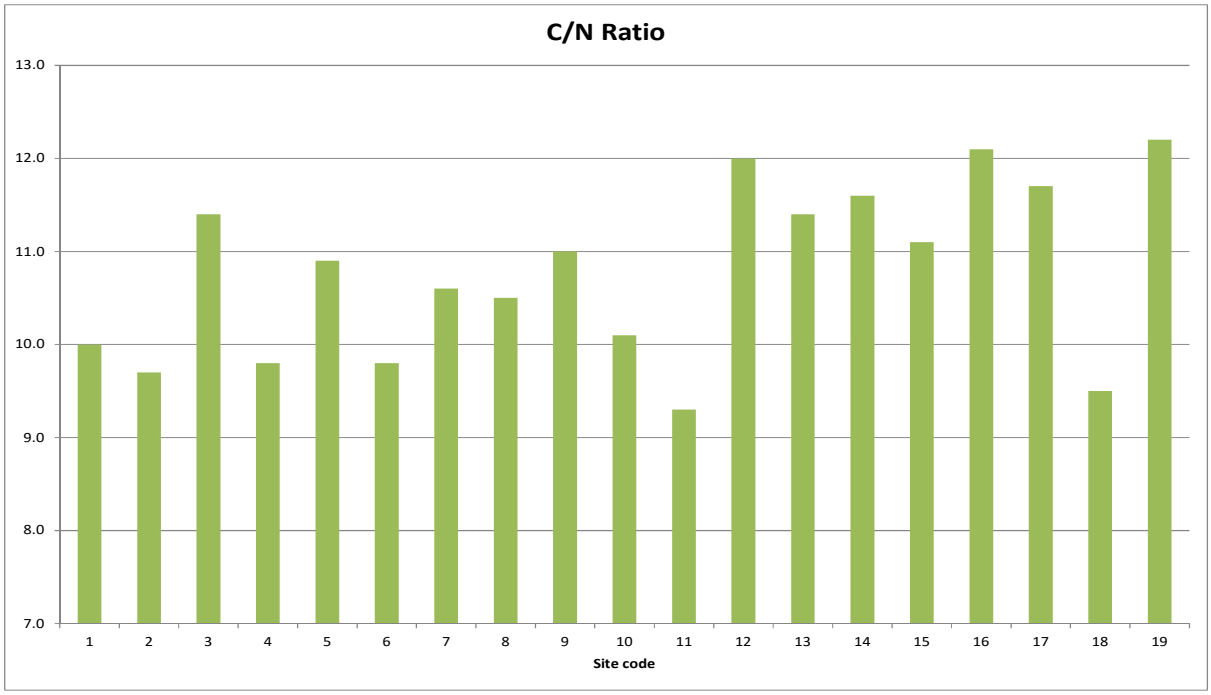

Figure 7: C/N ratio of Hawke's Bay soils sampled 2013

5.2.4 Dry Bulk Density

Figure 8 shows the bulk density results including target ranges. All sites were within the target range except Site 14, a pumice soil with very low bulk density.

No soil sampled is expected to be subject to impeded root growth from reduced aeration and drainage. All pumice soils had a low bulk density, likely due to high macroporosity in the coarse textured pumice material. At the time of sampling Site 14 it was noted that a large proportion of very vesicular (air filled) pumice was observed at the site and this is likely to have caused the low bulk density. The low bulk density soils have a greater risk of increased water and nutrient loss. These results are generally consistent with 2007 results for intensive pasture that indicated only one site with signs of compaction outside the target range.

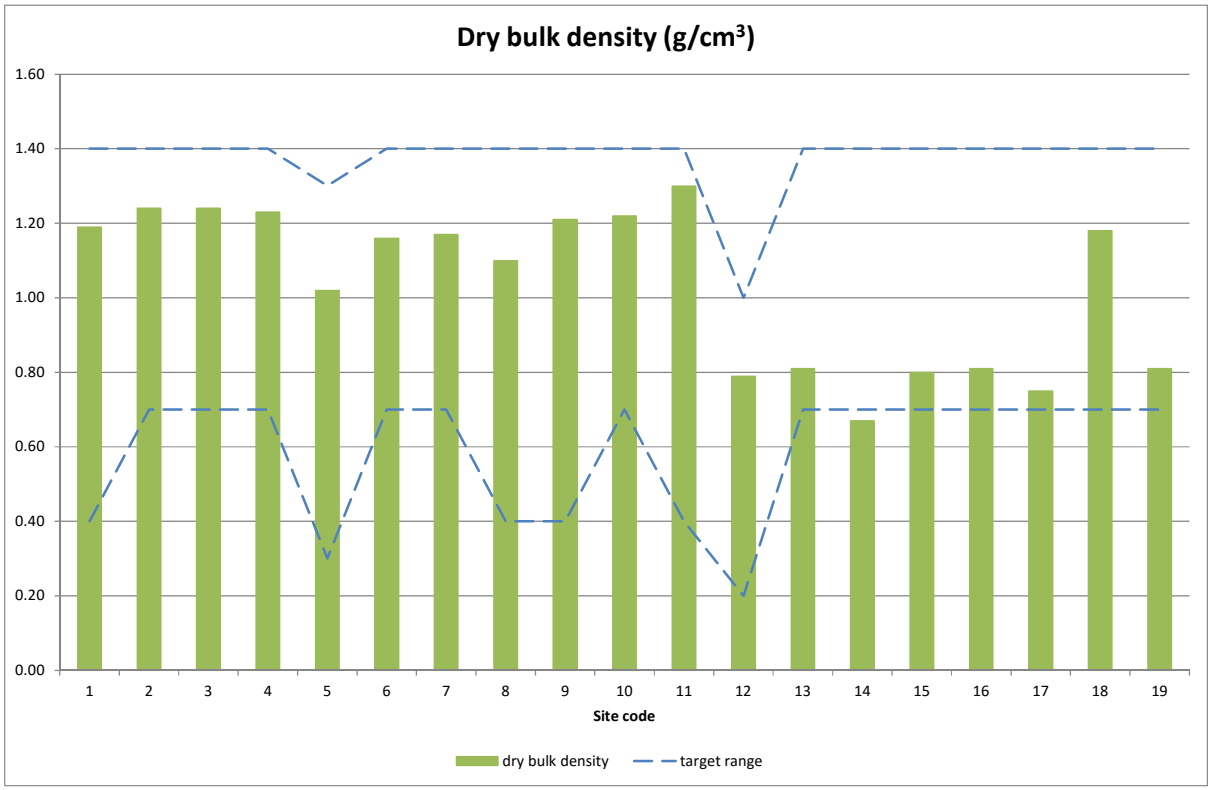

Figure 8: Dry bulk density (g/cm^3) of Hawkes Bay soils sampled 2013

5.2.5 Macroporosity

Figure 9 shows macroporosity for the sampled soils. All sites except Site 11 (low) and Site 14 (high) indicate macroporosity is inside the target range that will contribute to adequate aeration and plant growth. Unsurprisingly the macroporosity is inversely related to the bulk density.

Sites with lower measured macroporosity tend to correspond to higher clay contents (Sites 1, 4, 6 and 11) which are more likely to compact under high stocking rates. Given the dry soil state at the time of sampling the values for macroporosity are likely to be maximums. Therefore there may be some concern about the sustainability of stocking rates on those soil with low measured macroporosity.

The high macroporosity measured for Site 14, and also Site 19 reflect that these soils have high pumice content. The coarse particle size associated with these soils increase the amount of macropores present and reflect a potential for excessive drainage from these sites.

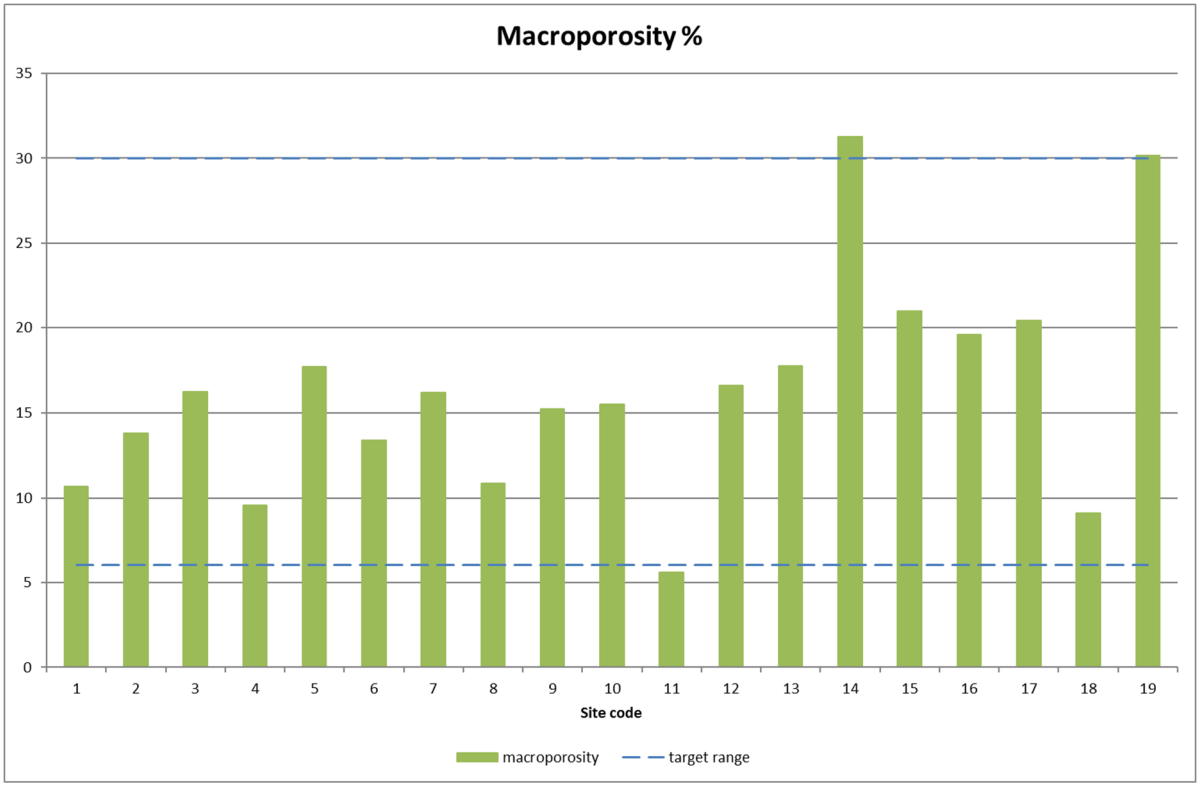

Figure 9: Macroporosity % of Hawkes Bay soils sampled 2013

5.3 Priority Two Indicators

Priority Two indicators where determined are detailed in the soil descriptions given in Appendix A.

5.4 Priority Three Indicators

5.4.1 Organochlorine Pesticides

For most sites all measured organochlorine pesticides were below detectable limits. Of the measured organoclorine pesticides only DDT or it's metabolites (DDD, DDE) were detected. DDT/DDD/DDE was detected in soils at 2 sites, being:

- Site 5, Takapau series (0.038 mg/kg);
- Site 17, Taupo series (0.092 mg/kg);

In the absence of a New Zealand guideline for the protection of soil health the measured values were compared to the Canadian Council of Ministers of the Environment (CCME, 1999) guideline. The CCME guideline for soil quality for protection of environmental and human health is 0.7 mg/kg ΣDDT+DDE+DDD.

No sites exceeded the soil quality guideline adopted for agricultural soils. Presence of DDT is likely to be due to the coating of grass seed for protection against grass grub at pasture establishment prior to the 1970s.

5.4.2 Trace Elements

Measured levels of As, Cd, Cr, Cu, Pb, Hg, Ni and Zn were below levels corresponding to risk to environmental or human health for all sites.

Cd is of particular interest in agricultural soils due the use of phosphate fertilisers. No sites exceeded soil limit for Cd of 1mg/kg (NZWWA, 2003).

5.4.3 Fluoride

Three sites had fluoride results above the expected range for NZ soils (200-500 mg/kg, FLRC, 2009), being:

- Site 8, Twyford soil (510 mg/kg);
- Site 13, Kaingaroa soil (600 mg/kg)
- Site 15, Gisborne soil (510 mg/kg).

An additional two sites have fluoride close to the upper end of the limit, being:

- Site 12, Poukawa soil (420 mg/kg);
- Site 14, Otamatea soil (460 mg/kg).

As with P results, high values may reflect phosphate fertiliser addition, however there appears to be no clear correlation between the results for these three elements other than for Site 13 and 14 that have both high P and Fl.

Another potential source of Fl is a volcanic ash shower which passed over the Hawke's Bay in August 2012.

5.4.4 Uranium

Measured U varied from 0.60 to 1.62 mg/kg. In general, levels are low and below the proposed Canadian soil limit of 23 mg/kg (CCME, 1999). Further information is required to determine a New Zealand limit (Taylor *et al.*, 2007).

5.5 Overall Soil Quality

The results from the soils analysed have been compared to the interpretative Framework which provides terms to categorise the results and target ranges or critical limits.

Six sites met all soil quality targets, 10 met all but one target and 3 sites had two targets unmet.

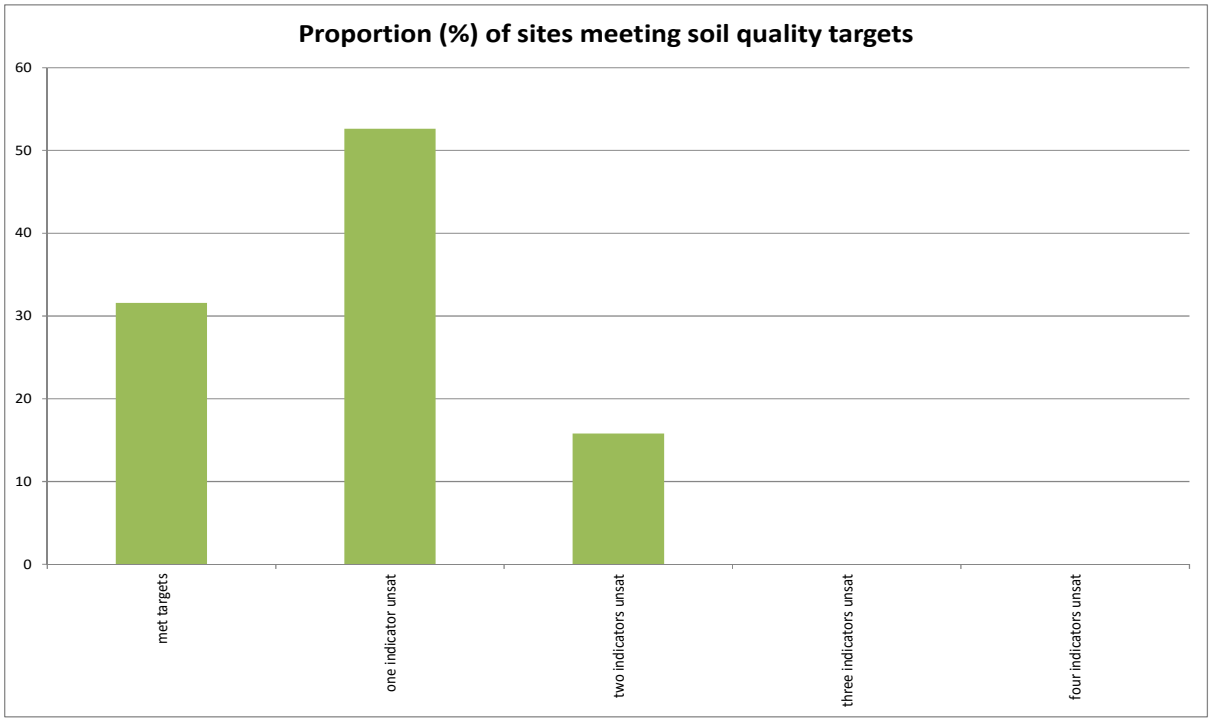

Figure 9: Proportion of Hawke's Bay intensive pasture soils not meeting soil quality targets for 7 quality indicators in 2013

As shown in Figure 10 the most common indicator that was failed was the Olsen P. 32 % of sites in total were outside the P target range with, 16 % below target levels, and 16 % above). Other commonly failed indicators were total N (21 % above target range), AmN (16 % above target range) and macroporosity (11 % sites above target range).

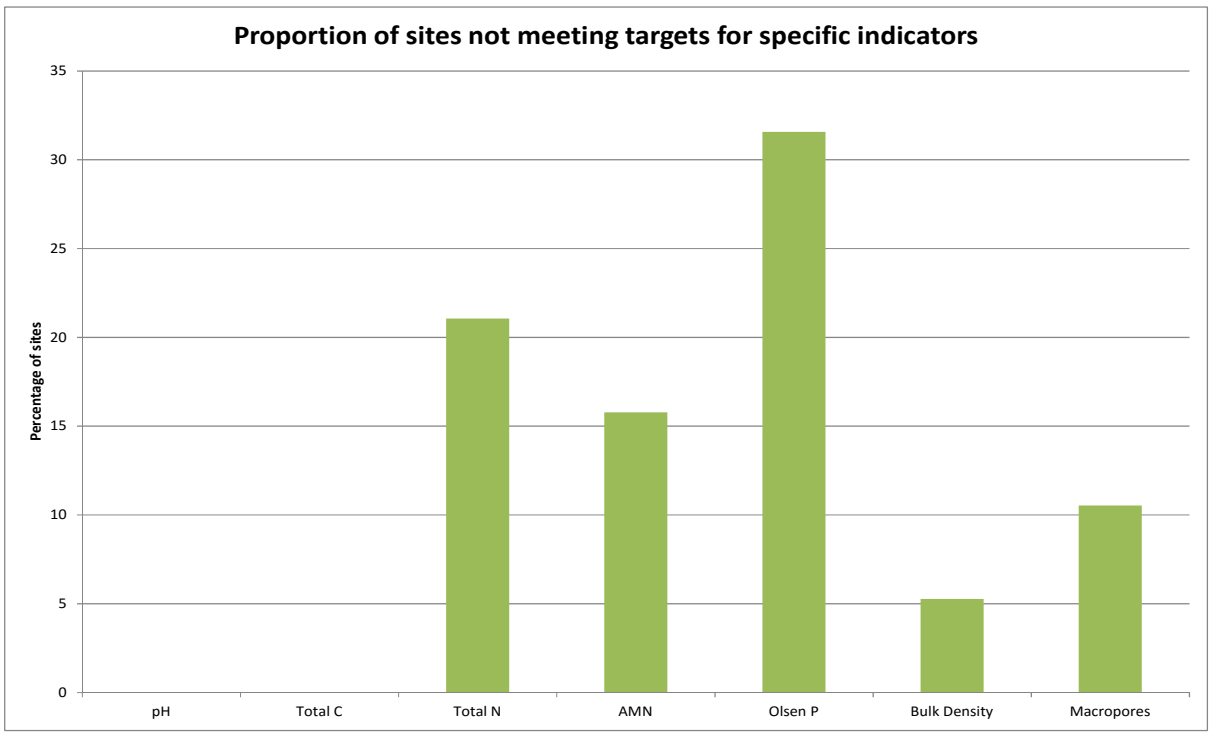

Figure 10: Proportion of Hawke's Bay soils not meeting suggested targets for specific soil quality indicators in 2013

5.6 Changes in Soil Quality Over Time

Fifteen of the properties visited in 2013 were also visited in 2007 (Table 6). The actual sampling location may have varied in some cases, with slight variations recorded in soil order. Direct comparison to previous results is not accurate but general observations can still be made regarding the changes over time.

Table 6: Comparative soil sites from 2007 and 2013

2013 Soil Sites			2007 Soil Sites		
Site No	**Soil Type**	**Order**	**Client Code**	**Soil Type**	**Order**
1	Wanstead	Pallic	MNE-07	Wanstead	Pallic
2	Pukehou	**Gley**	CLO-07	Pukehou	Pallic
3	Te Aute	Melanic	VDA-07	Te Aute	Melanic
4	Matamau	**Brown**	JGU-07	Matamau	Pallic
5	Takapau	**Allophanic**	500S-18	Takapau	Brown
6	Okawa	**Gley**	MPA-Ok-07	Okawa	Pallic
7	TeOnepu	Melanic	HCA-07	TeOnepu	Melanic
8	Twyford	Recent	AM-Tw-07	Twyford	Recent
9	Matapiro	Pallic	AM-Ma-07	Matapiro	Pallic
10	Hastings	**Gley**	GWI-07	Hastings	Recent
11	Atua	Pallic	EDE-07	Atua	Pallic
12	Poukawa	Organic	GHA-07	Poukawa	Organic
13	Kaingaroa	Pumice			
14	Otamatea	Pumice			
15	Gisborne	Pumice	AMA-07	Gisborne	Pumice
16	Waikoau	Pumice			
17	Taupo	Pumice	WAI-07	Taupo	Pumice
18	Awamate	Gley	500S-07	Awamate	Gley
19	Pakarae	Pumice			

- Bold 2013 soil order indicates variation in recorded soil order

It should be noted that datasets prior to 2007 may not be directly comparable as described by Sparling and Stevenson (2008) which states:

> *"The current and archive data may not be directly comparable for all measured characteristics because analytical methods may have differed from those used previously. Two earlier sites had been sampled for the Crop and Food SQM project to a 15 cm depth, rather than the 10 cm depth of the 500 Soils protocol, which also causes problems when trying to compare soil characteristics that are strongly stratified with depth (i.e. properties that can be more or less concentrated in the surface soil). The depth of 10 cm is adequate for most non-tilled soils and is consistent with the IPCC recommendations for estimating C storage in surface soils."*

Some general observations regarding change over time in the soil quality observed for intensive pastoral land use can be made. Table 7 itemises the data from the comparable sites.

It should be noted that general observations have been made here and no statistical evaluation of significant difference has been made. Due to the heterogeneous nature of soils, both spatially and seasonally, a change of ±15 % is considered to indicate a change in soil quality. It is unlikely that the measured results indicate a change. However general discussion is given since it will assist with identifying trends in the future.

Table 7: Changes in soil quality characersitics

Location	Site ID/Client Code	Date	Land Use	pH	Olsen P	C:N ratio	Anaerobically Mineralied N	Anaerobically Mineralied N	Total Carbon	Total Carbon	Total Nitrogen	Total Nitrogen	Bulk Density	Macroporosity
				pH units	mg/L		µg/cm^3	µg/g	mg/cm^3	%	mg/cm^3	%	g/cm^3	%v/v
				5.8-6.3	20-30							0.30-0.60		
Wanstead	MNE-07	2007	Bull beef	5.6	19	10.2	154	151	57.1	5.6	5.61	0.55	1.02	9.1
Wanstead	01 Agri 15/01/13	2013	Bull beef	5.9	24	10.0	226	204	61.1	5.5	6.11	0.55	1.11	10.9
Te Aute	VDA-07	2007	Bull beef	5.8	17	10	165	188	38.7	4.4	3.87	0.44	0.88	15.2
Te Aute	03 Agri 15/01/13	2013	Bull beef	5.7	28	11.4	237	191	59.5	4.8	5.21	0.42	1.24	9.97
TeOnepu	HCA-07	2007	Bull beef	5.7	31	8.7	199	183	44.8	4.1	5.14	0.47	1.09	9.3
TeOnepu	07 Agri 16/01/13	2013	Bull beef	6.1	48	10.6	220	188	55.0	4.7	5.15	0.44	1.17	10.24
Twyford	AM-Tw-06	2007	Bull beef	5.8	23	9.7	193	172	64.0	5.7	6.63	0.59	1.12	7.78
Twyford	08 Agri 17/01/13	2013	Bull beef	5.9	19	10.5	229	208	55.0	5.0	5.28	0.48	1.10	10.08
Matapiro	2H15	2003	Bull beef	6.0	*24				*41.1		*3.99		1.14	
Matapiro	AM-Ma-07	2007	Bull beef	5.8	**^10**	9.8	159	139	49.9	4.4	5.11	0.45	1.14	**^4.6**
Matapiro	09 Agri 17/01/13	2013	Bull beef	6.0	24	11.0	156	129	50.8	4.2	4.60	0.38	1.21	8.75
Atua	EDE-07	2007	Bull beef	6.0	21	10.6	148	121	41.6	3.4	3.91	0.32	1.22	**^2.7**
Atua	11 Agri 18/01/13	2013	Bull beef	5.6	27	9.3	203	156	44.2	3.4	4.68	0.36	1.30	**4.11**
Poukawa	GHA-07	2007	Bull beef	5.2	20	11.2	251	**^359**	108.5	15.5	9.72	1.39	0.70	10.7
Poukawa	12 Agri 18/01/13	2013	Bull beef	5.3	25	12.0	221	**^280**	118.5	15.0	9.95	1.26	0.79	8.33
Gisborne	AMA-07	2007	Dairying	5.7	33	11.2	153	222	62.6	9.1	5.57	0.81	**^0.69**	19.5
Gisborne	15 Agri 30/01/13	2013	Dairying	5.8	18	11.1	157	196	70.4	8.8	6.40	0.80	0.80	13.9
Taupo	WAI-07	2007	Dairying	5.8	36	12.0	219	**^350**	46.8	6.6	3.90	0.55	0.71	12.5
Taupo	17 Agri 30/01/13	2013	Dairying	5.3	57	11.7	156	208	70.5	9.4	6.08	0.81	0.75	14.78
Awamate	500 soil 07	2000	Dairying	5.2	**^68**		130		41.6		3.65		1.05	8.6
Awamate	500S-07	2007	Dairying	5.6	**^65**		135	119	46.9	4.2	4.24	0.38	1.13	8
Awamate	18 Agri 31/01/13	2013	Dairying	5.8	**^70**	9.5	232	197	55.5	4.7	5.78	0.49	1.18	7.53

*samples taken to 15cm therefore not directly comparable
^result is outside the target range
Red indicates any increase in 2013 from the 2007 results
Green indicates any decrease in 2013 from the 2007 results

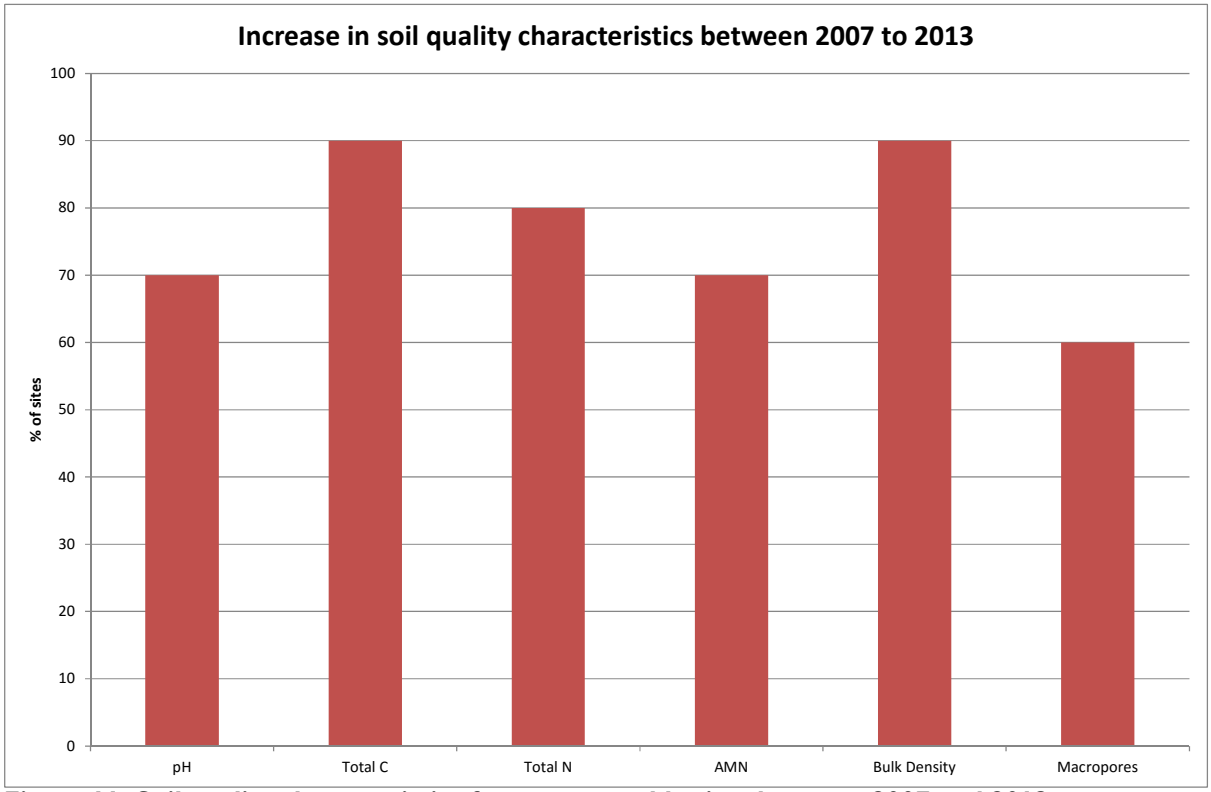

Figure 11: Soil quality characteristics from comparable sites between 2007 and 2013

Figure 11 graphically depicts the percentage of sites that showed an increase in soil quality indicator values.

- pH is stable and within the target range;
- Total C was higher for all sites except one;
- Total N is similar for all sampling events;
- Olsen P has increased from 2007 to 2013 for most sites. Some increases are quite high but still fall inside the target range. Site 18 continues to have an Olsen P result above the target range and has increased slightly since 2007. Site 13 has increased Olsen P from below to inside of the target range;
- The shift in anaerobically mineralisable N varied for each site. The two sites above the target range in 2007 have decreased their anaerobically mineralisable N, with one site now inside the target range. Other sites have recorded significant increases and for some sites little change has occurred but all results are inside the target range.
- Bulk density has slightly increased for all sites except one.
- Macroporosity has varied across the sites with some increases and some decreases.
- Other measured parameters were not previously reported.

Data produced from the sites generally have increased between the two time periods. All parameters for all sites fall inside the target range, with the exception of two sites each with one parameter outside the target range.

No targets have been specified and no data from previous years for comparative purposes is available for the following data collected: Porosity, particle density, field capacity, AWC and all trace element tests.

6 DISCUSSION

In previous soil quality monitoring for pasture soils the primary concern identified was low macroporosity, indicating soil compaction was occurring under pastoral land uses. The current dataset suggests that macroporosity continues to be an issue for 11 % of sites sampled. Low macroporosity result is considered to be a due to a combination of the land management at the site and the soil texture, in particular clay content. Further monitoring over time is warranted to detect whether changes are continuing over time. In general macroporosity under intensive pasture tended to be lower than for other land uses monitored.

Soil chemical indicators relating to fertility varied widely amongst sites sampled. The Olsen P status of the intensive pastoral sites is the indicator of most concern for the current dataset, with 32 % of sites falling outside the target range. The soil Olsen P can be increased by the application of phosphate fertilisers or other P containing soil amendments.

Where P is above the target range there is a concern that further P additions have a higher risk of being lost to surface water due to saturation of soil sorption sites. Elevated P should be monitored and P additions be minimised until Olsen P tests return to levels suitable for the land use (typically 20-30 mg P/L for bull beef and 20-4- mg P/L for dairy).

Total N and AmN both tended towards the upper end of the target range. This is in-line with general trends under land use intensification. Fertiliser inputs, contribution from animal excreta at higher stocking rates, and for dairy farms, effluent irrigation are likely to result in the high N status of the soils. There is potential to increase leaching loss of N if the soil levels are too high, and this should be monitored in the future. This is particularly the case for the coarser textured soils such as Pumice Soils.

Differences between sampling events (2000, 2007, 2013) cannot be determined to be significantly different due to the dataset size and to differing time of year sampled.

Fluorine close to the limit for five sites, 3 being over the limit. This may warrant further study, and may require a review of P fertiliser use at these sites.

7 CONCLUSIONS

- In general soil quality in the Hawke's Bay intensive pasture sites is good, although some care should be taken in interpretation of the results since soil moisture content was generally very low due to particularly low rainfall in the preceding weeks.
- Intensive pasture sites are expected to have higher C, N and fertility status compared to other land uses (cropping, extensive pasture) and may be expected to change rapidly due to the effect of inputs such as fertiliser and effluent. Changes over time are likely to be important, however a point in time review is a useful tool for this land use type.
- Soil physical condition is a concern for intensive pasture, in particular those sites with fine textured soils and high stocking rates.
- A high number of sites had P status outside of the target range. This was also the indicator of most concern for the previous (extensive pasture) sampling round and so P management is considered to be a key issue for soil quality and sustainability of land sue for the Hawke's Bay.
- Elevated fluoride further indicate the management of P fertiliser addition is needed to minimise the risk of soil contamination through poor fertiliser selection or over-application.
- Closer management of the N status of soils may be needed to limit the risk of N leaching from intensive pasture sites.

8 RECOMMENDATIONS

- Managers of the properties sampled should be informed of the soil quality on their properties and where remedial activity is recommended HBRC may provide advice on potential management strategies.
- Land managers and advisors, including fertilizer representatives, may require information regarding the management of P on intensively managed soils. Specifically, the adoption of P forms best suited to soil type, and application regimes designed to optimise P use.
- Management and monitoring of dairy effluent irrigation should include consideration of P accumulation in soil to avoid saturating the soil with P, and the associated risk of discharge to water.
- Further evaluation of risks from N leaching under intensive pasture may be warranted.
- The same sites should be resampled within 5 years and at ongoing intervals to develop a long term record of soil quality indicator performance over time.

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10 APPENDICES

Appendix A: Soil Descriptions

Soil	Wanstead
	Clay loam
Transect length and direction	50 m, SW
Classification	Typic Argillic Pallic
Land use	Intensive pasture
Date sampled	15/01/2013
Land use history	Bull beef
Present vegetation	Ryegrass pasture
Slope degrees	8
Landform	Rolling, midslope concave.
Annual rain (mm)	1050 mm
Elevation (m)	160 m
Parent material	Mudstone
Drainage	Imperfect
Topsoil depth (cm)	25
Limiting horizon	
Sampled by	KB/BL

Horizon	Depth (cm)	Description
Ap	0 - 25	Very dark greyish brown (10YR 3/2) loamy clay; slightly sticky; moderately plastic; few medium pores; moderately pedal; fine polyhedral peds; firm soil strength; many fine roots; distinct smooth boundary; dry.
Bt	20 - 50+	Light olive brown (2.5Y 5/3) clay; moderately sticky; moderately plastic; many coarse pores; strongly pedal; coarse blocky peds; very firm soil strength; common fine roots; dry.

Soil	Pukehou
	Clay loam
Transect length and direction	50 m
Classification	Mottled Argillic Pallic
Land use	Intensive pasture, brassica crop pre pasture renewal
Date sampled	15/01/2013
Land use history	Intensive pasture
Present vegetation	Brassica
Slope degrees	0-4°
Landform	Elevated floodplain
Annual rain (mm)	1150 mm
Elevation (m)	100
Parent material	Loess and Alluvium
Drainage	Poor
Topsoil depth (cm)	20
Limiting horizon	Fragipan
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 20	Very dark grey (10YR 3/1) clay loam; slightly sticky; slightly plastic; weakly pedal; very fine polyhedral peds; weak soil strength; many fine roots; indistinct smooth boundary; dry.
AB	20 - 26	Very dark grey (10YR 3/1) clay loam; moderately sticky; moderately plastic; weakly pedal; fine polyhedral peds; slightly firm soil strength; common very fine roots; indistinct irregular boundary; dry.
Bt	26 - 34	Greyish brown (2.5y 5/2) clayey silt; common very fine yellowish brown (10YR 5/6) mottles; moderately sticky; moderately plastic; weakly pedal; fine blocky peds; few very fine roots; distinct smooth boundary; dry.
Bt2	34 - 55+	Light brownish grey (2.5Y 6/2) clay; few coarse (light orange) mottles; moderately sticky; moderately plastic; weakly pedal; columnar peds; few very fine roots; dry.

Soil	Te Aute
	Silt loam
Transect length and direction	50 m S
Classification	Mottled Orthic Melanic
Land use	Intensive pasture
Date sampled	15/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Pasture
Slope degrees	5-8
Landform	Rolling hill, convex midslope
Annual rain (mm)	1180 mm
Elevation (m)	320 m
Parent material	Limestone
Drainage	Imperfectly drained
Topsoil depth (cm)	8
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 20	Dark grey (10yr 4/1) silt loam; non-sticky; slightly plastic; moderately pedal; medium polyhedral peds; slightly firm soil strength;many fine roots; distinct wavy boundary; dry.
Bw	20 - 30	Very dark grey (10yr 3/1) silt loam slightly sticky; slightly plastic; moderately pedal; medium blocky peds; slightly firm soil strength; few fine roots; indistinct wavy boundary; dry.
Bg	30 - 55+	Light brownish grey (10yr 6/2) clayey silt; common medium orange mottles; moderately sticky; moderately plastic; moderately pedal; medium blocky peds; slightly firm soil strength; dry.

Soil	Matamau
	Clay loam
Transect length and direction	50 m, E to NW
Classification	Perch-gley Pallic
Land use	Intensive pasture
Date sampled	16/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	8-15
Landform	Rolling, planar midslope
Annual rain (mm)	1000 mm
Elevation (m)	245 m
Parent material	Mudstone
Drainage	Imperfect
Topsoil depth (cm)	20
Limiting horizon	Argillic horizon at 60 cm
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 20	dry very dark greyish brown (10YR 3/2) clay loam; slightly sticky; slightly plastic; weakly pedal; polyhedral peds; weak soil strength; many fine roots; indistinct wavy boundary; dry.
Bw	20 - 25	dry light yellowish brown (2.5Y 6/3) loamy clay; moderately sticky; moderately plastic; apedal massive; firm soil strength; common fine roots; diffuse irregular boundary; dry.
Bg1	25 - 43	dry light yellowish brown (2.5Y 6/3) clay; few fine (dark orange) mottles; moderately sticky; moderately plastic; apedal massive; firm soil strength; few fine roots; indistinct smooth boundary; dry.
Bg2	43 - 60+	Light yellowish brown (2.5Y 6/3) silty clay; common coarse (orange) mottles; moderately sticky; moderately plastic; apedal massive; slightly firm soil strength; dry.

Soil	Takapau
	Silt loam
Transect length and direction	50 m, NE
Classification	Typic Allophanic Brown
Land use	Intensive pasture
Date sampled	16/01/2013
Land use history	Intensive pasture, dairy
Present vegetation	Ryegrass pasture
Slope degrees	0-3
Landform	Alluvial plain, hummock
Annual rain (mm)	950 mm
Elevation (m)	210m
Parent material	Tephra over greywacke alluvium
Drainage	Well drained
Topsoil depth (cm)	15
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 15	Very dark greyish brown (10yr 3/2) slightly gravelly silt loam; non-sticky; non-plastic; friable; apedal earthy; weak soil strength; many fine roots; distinct smooth boundary; dry.
Bw	15 - 30	Very dark greyish brown (10yr 3/2) very slightly gravelly silt loam; non-sticky; non-plastic; friable; apedal earthy; weak soil strength; many fine roots; distinct smooth boundary; dry.
Bw2	30 - 50	Dark yellowish brown (10yr 3/4) slightly gravelly silt loam; non-sticky; non-plastic; apedal earthy; weak soil strength; common fine roots; indistinct smooth boundary; dry; gravel is subrounded greywacke alluvium.
BC	50 - 120+	Dark yellowish brown (10yr 3/4) very gravelly silt loam; non-sticky; non-plastic; apedal earthy to single grain; weak soil strength; very few fine roots; gravel is subrounded greywacke alluvium.

Soil	Okawa
	Clay loam
Transect length and direction	50 m, NE
Classification	Typic Recent Gley
Land use	Intensive pasture
Date sampled	16/01/2013
Land use history	Intensive pasture, irrigated dairy
Present vegetation	Ryegrass pasture
Slope degrees	0-3
Landform	Alluvial plain
Annual rain (mm)	950 mm
Elevation (m)	220 m
Parent material	Mudstone (papa)
Drainage	Loess and greywacke alluvium
Topsoil depth (cm)	13 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 13	Dark greyish brown (10YR 4/2) silt loam; non-sticky; slightly pastic; slightly firm soil strength; weakly pedal; fine polyhedral peds; common fine roots; distinct wavy boundary; moist.
Bg1	13 - 20	Dark greyish brown (10YR 4/2) silt loam; few fine (7.5y 5/8) mottles; slightly sticky; slightly plastic; firm soil strength; weakly pedal; coarse blocky peds; few fine roots; indistinct wavy boundary; moist.
Bg2	20 - 34	Grey (2.5Y 6/1) slightly gravelly clayey silt; many coarse (7.5y 5/8) mottles; very sticky; very plastic; firm soil strength; weakly pedal; coarse blocky peds; few faint clay coatings; very few fine roots; indistinct wavy boundary; very moist.
Bxg	34 - 60+	Light grey (2.5Y 7/2) moderately gravelly loam; many coarse (7.5y 5/8) mottles; non-sticky; weak soil strength; weakly pedal; coarse blocky peds; wet.

Soil	Te Onepu
	Silt loam
Transect length and direction	50 m, SE
Classification	Argillic-calcareous Orthic Melanic
Land use	Intensive pasture
Date sampled	16/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	8
Landform	Broad planar crest of limestone hills
Annual rain (mm)	1250 mm
Elevation (m)	310 m
Parent material	Limestone
Drainage	Well drained
Topsoil depth (cm)	23
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 23	Very dark grey (7.5YR 3/1) silt loam; slightly sticky ;slightly plastic; weak soil strength; fine polyhedral peds; common fine roots; distinct wavy boundary; dry.
Bw1	23 - 45	Dark brown (7.5YR 3/3) clayey silt; moderately sticky; very plastic; firm soil strength; weakly pedal; fine polyhedral peds; few fine roots; indistinct wavy boundary; dry.
Bw2	45 - 60+	Brown (7.5YR 5/4) clay; very sticky; very plastic; weakly pedal; very coarse blocky peds; very firm soil strength; dry.

Soil	Twyford
	Clay loam
Transect length and direction	50 m, NE
Classification	Typic Recent Gley
Land use	Intensive pasture
Date sampled	17/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	0-3
Landform	Lower terrace, hummock and swale.
Annual rain (mm)	900 mm
Elevation (m)	160 m
Parent material	Alluvium
Drainage	Imperfectly drained
Topsoil depth (cm)	30
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 26	Very dark greyish brown (10YR 3/2) non-gravelly clay loam; moderately sticky; slightly plastic; firm soil strength; strongly pedal; medium polyhedral peds; common fine roots; distinct wavy boundary; dry.
Bw	26 - 55+	Grey (10YR 5/1) non-gravelly slightly silty clay; common fine (7.5YR 5/6) mottles; moderately sticky; slightly plastic; very firm soil strength; moderately pedal; medium polyhedral peds; few fine roots; dry.

Soil	Matapiro
	clay loam
Transect length and direction	50 m, NE
Classification	Duric Perch-Gley Pallic
Land use	Intensive pasture
Date sampled	17/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	12
Landform	Steep east facing midslope below limestone bluffs
Annual rain (mm)	900 mm
Elevation (m)	210 m
Parent material	Loess
Drainage	Imperfectly drained
Topsoil depth (cm)	30
Limiting horizon	Duripan at 45 cm
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 30	Black (10YR 2/1) clay loam; slightly sticky; slightly plastic; weak soil strength; apedal earthy, friable; many fine roots; distinct wavy boundary; dry.
Bw	30 - 45	Dark yellowish brown (10YR 4/4) silty clay; few medium distinct (yellow) mottles; moderately sticky; moderately plastic; weak soil strength; common fine roots; indistinct wavy boundary; dry.
Bt	45 - 80+	Pale brown (10YR 6/3) silty clay; moderately sticky; moderately plastic; firm soil strength; moderately pedal; polyhedral peds; few fine roots; few faint clay coatings; dry.

Soil	Hastings
	Silt loam
Transect length and direction	50 m, N
Classification	Typic Recent Gley
Land use	Intensive pasture
Date sampled	17/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	0-5
Landform	Low lying alluvial plain
Annual rain (mm)	850 mm
Elevation (m)	162 m
Parent material	Greywacke alluvium
Drainage	Poorly drained
Topsoil depth (cm)	20
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 20	Very dark greyish brown (10yr 3/2) silt loam; very slightly sticky; slightly plastic; moderately pedal; coarse and medium polyhedral peds; weak soil strength; many fine roots; distinct smooth boundary; dry.
Bw	20 - 30	Very dark greyish brown (10yr 3/2) silt loam; ; very slightly sticky; slightly plastic; moderately pedal; fine polyhedral peds; weak soil strength; many fine roots; distinct smooth boundary; dry.
Bg1	30 - 44	Dark brown (10YR 3/3) silt; common medium (orange) mottles; very slightly sticky; very plastic; weakly pedal blocky, breaking to fine nut and crumb structure; few fine roots; indistinct smooth boundary; dry.
Bg2	44 - 63+	Brown (10yr 4/3) silt; common medium (light orange) mottles; ; very slightly sticky; very plastic; apedal massive; dry

Soil	Atua
	Light silt loam
Transect length and direction	50 m, SW
Classification	Mottled Argillic Pumice
Land use	Intensive pasture
Date sampled	18/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	3-8
Landform	Rolling hills, wide planar crest.
Annual rain (mm)	1200 mm
Elevation (m)	170 m
Parent material	Argillite
Drainage	Imperfectly drained
Topsoil depth (cm)	22 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 22	Very dark greyish brown (10YR 3/2) clay loam; common fine (orange) mottles; moderately sticky; moderately plastic; moderately pedal; medium polyhedral peds; firm soil strength; common fine roots; distinct smooth boundary; dry.
Bt1	22 - 45+	Light brownish grey (2.5Y 6/2) clay; common medium (orange) mottles; moderately sticky; very plastic; very firm soil strength; apedal massive; breaking to fine polyhedral peds; few fine roots; dry.

Soil	Poukawa
	Peaty loam
Transect length and direction	50 m, N
Classification	Mellow Mesic Organic
Land use	Intensive pasture
Date sampled	18/01/2013
Land use history	Intensive pasture, bull beef
Present vegetation	Ryegrass pasture
Slope degrees	0-3
Landform	Low lying plain adjacent to waterway
Annual rain (mm)	1200 mm
Elevation (m)	170 m
Parent material	PM of sedimentary origin comes from tertiary mudstone
Drainage	Poorly drained
Topsoil depth (cm)	20
Limiting horizon	
Sampled by	KB/BL

Horizon	Depth (cm)	Description
Ap	0 - 20	Dark brown (7.5YR 3/3) very slightly gravelly silt loam; common medium (orange) mottles; non-sticky; slightly plastic; moderately pedal; fine polyhedral peds; common fine roots; indistinct smooth boundary; dry.
Bw1	20 - 40	Dark brown (7.5YR 3/2) slightly gravelly silt loam; common medium (orange) mottles; non-sticky; slightly plastic; moderately pedal; coarse blocky peds; common fine roots; distinct smooth boundary; dry.
BC	40 - 44	Pale yellow (2.5Y 7/3) silty sand; apedal single grain; weak soil strength, few fine roots; distinct smooth boundary; moist.
Om	44 - 55+	Mesic peat

Soil	Kaingaroa
	sand
Transect length and direction	50 m, E
Classification	Welded Impeded Pumice
Land use	Intensive pasture
Date sampled	29/01/2013
Land use history	Intensive pasture, dairy
Present vegetation	Ryegrass pasture
Slope degrees	5-8
Landform	Low rolling hills
Annual rain (mm)	1350 mm
Elevation (m)	745 m
Parent material	Pumiceous Tephra
Drainage	Imperfectly drained
Topsoil depth (cm)	8 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 8	Very dark greyish brown (10YR 3/2) very slightly gravelly sandy loam; non-sticky; non-plastic; weak soil strength; apedal earthy; common fine roots; distinct wavy boundary; dry.
Ap	8 - 14	Very dark brown (10YR 2/2) sandy loam; non-sticky; non-plastic' weak soil strength; apedal earthy; common fine roots; indistinct wavy boundary; dry.
Bw	14 - 35	Dark yellowish brown (10YR 4/4) loamy sand; non-sticky; non-plastic; weak soil strength; apedal earthy; few fine roots; distinct wavy boundary; dry.
BC	35 - 45	Very pale brown (10YR 7/4) coarse pumiceous sand; non-sticky; non-plastic; apedal single grain; weak soil strength; few fine roots; indistinct wavy boundary; dry.
C	45 - 70+	Light grey (10YR 7/2) coarse pumiceous sand non-sticky; non-plastic; apedal single grain; weak soil strength; few fine roots; dry.

Soil	Otamatea
	Gravelly sand
Transect length and direction	50 m, E
Classification	Typic Orthic Pumice
Land use	Intensive pasture
Date sampled	29/01/2013
Land use history	Intensive pasture, dairy
Present vegetation	Ryegrass pasture
Slope degrees	0-5
Landform	Floodplain, hummock and swale topography
Annual rain (mm)	1350 mm
Elevation (m)	740 m
Parent material	Pumiceous Tephra
Drainage	Moderately well drained
Topsoil depth (cm)	10 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 10	Dark yellowish brown (10YR 3/6) very slightly gravelly loamy sand; non-sticky; non-plastic; weak soil strength; apedal earthy; common fine roots; distinct wavy boundary; dry.
Bw	10 - 22	Very dark brown (10YR 2/2) moderately gravelly sand; non-sticky; non-plastic; apedal single grain; weak soil strength; few fine roots; indistinct wavy boundary; dry.
BC	22 - 70+	Dark yellowish brown (10YR 4/4) very gravelly sand; faint mottles (iron staining); few iron concretions; non-sticky; non-plastic; weak soil strength; apedal single grain; very few fine roots; dry.

Soil	Gisborne
Transect length and direction	50 m, NE
Classification	Mottled Orthic Pumice
Land use	Intensive pasture
Date sampled	29/01/2013
Land use history	Intensive pasture, dairy
Present vegetation	Ryegrass pasture.
Slope degrees	5-8
Landform	Low rolling hills, planar midslope.
Annual rain (mm)	1400 mm
Elevation (m)	200 m
Parent material	Mudstone
Drainage	Imperfectly drained
Topsoil depth (cm)	15 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 15	Black (10YR 2/1) sandy loam; non-sticky; non-plastic; weak soil strength; apedal earthy; common fine roots; distinct wavy boundary; dry.
Bw	15 - 30	Very dark greyish brown (10YR 3/2) sandy loam; non-sticky; non-plastic; weak soil strength; apedal earthy; common fine roots; indistinct wavy boundary; dry.
Bw2	30 - 50	Brown (10YR 4/3) loamy sand; non-sticky; non-plastic; weak soil strength; apedal earthy; few fine roots; distinct occluded boundary; dry.
A2	50 - 80+	Dark yellowish brown (10YR 3/6) clay loam; moderately sticky; moderately plastic; weak soil strength; apedal earthy; dry.

Soil	Waikoau
Transect length and direction	50 m, SW
Classification	Buried Allophanic Orthic Pumice
Land use	Dairy pasture
Date sampled	29/01/2013
Land use history	Pasture, dairy
Present vegetation	Ryegrass pasture
Slope degrees	15+
Landform	Strongly rolling hillslope on on concavo, convex transect
Annual rain (mm)	1500 mm
Elevation (m)	350 m
Parent material	Pumiceous tephra
Drainage	Well drained
Topsoil depth (cm)	10 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 10	Very dark grey (10YR 3/1) sandy loam; non-sticky; non-plastic; weak soil strength; apedal earthy; many fine roots; indistinct wavy boundary; dry.
Bw	10 - 20	Very dark greyish brown (10yr 3/2) sandy loam; non-sticky; non-plastic; weak soil strength; apedal earthy; peds; many fine roots; indistinct wavy boundary; dry.
Bw2	20 - 45	Very dark greyish brown (10yr 3/2) loamy sand; non-sticky; non-plastic; weak soil strength; apedal earthy; peds; many fine roots; distinct wavy boundary; dry.
BC	45 - 70	Dark brown (10yr 3/3) silty coarse sand; non-sticky; non-plastic; weak soil strength; apedal single grain; peds; common fine roots; indistinct wavy boundary; dry.
C	70 - 80+	Dark yellowish brown (10yr 4/6) slightly gravelly clayey sand; non-sticky; non-plastic; weak soil strength; apedal earthy; few fine roots; dry.

Soil	Taupo
Transect length and direction	50 m, NE
Classification	Immature Orthic Pumice
Land use	Intensive Pasture
Date sampled	29/01/2013
Land use history	Intensive pasture, dairy
Present vegetation	Recently harvested maize
Slope degrees	4-7
Landform	Planar toe slope
Annual rain (mm)	1500 mm
Elevation (m)	300 m
Parent material	Pumiceous tephra
Drainage	Well drained
Topsoil depth (cm)	15 cm
Limiting horizon	
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 15	Dark brown (7.5YR 3/2) sandy loam non-sticky; non-plastic; weak soil strength; many fine roots; many fine roots; distinct wavy boundary; dry.
Bw	15 - 20	Black (10YR 2/1) sandy loam non-sticky; non-plastic; weak soil strength; many fine roots; indistinct wavy boundary; dry.
Bw2	20 - 35	Dark brown (10YR 3/3) loamy sand; non-sticky; non-plastic; weak soil strength; many fine roots; distinct wavy boundary; dry.
BC	35 - 60	Yellowish brown (10YR 5/6) silty coarse sand; non-sticky; non-plastic; weak soil strength; apedal earthy; common fine roots; indistinct wavy boundary; dry.
C	60 - 80+	Yellowish brown (10YR 5/6) clayey sand; slightly sticky; slightly plastic; weak soil strength; apedal earthy; few fine roots; dry.

Soil	Awamate
	Silt loam
Transect length and direction	50 m, W
Classification	Mottled Fluvial Recent
Land use	Intensive pasture
Date sampled	319/01/2013
Land use history	Intensive pasture, dairy
Present vegetation	Ryegrass pasture
Slope degrees	0-3
Landform	Floodplain
Annual rain (mm)	Around 1550 mm
Elevation (m)	15 m
Parent material	Fine grained mudstone alluvium
Drainage	Poorly drained
Topsoil depth (cm)	10 cm
Limiting horizon	
Sampled by	KB/BL

Horizon	Depth (cm)	Description
Ap	0 - 10	Dark greyish brown (10YR 4/2) silt loam; moderately sticky; slightly plastic; very firm soil strength; peds and ; pores; weakly pedal; fine polyhedral peds; common fine roots; indistinct smooth boundary; slightly moist.
Bw	10 - 32	Grey (10YR 5/1) clayey silt; common fine (7.5YR 5/8) mottles; moderately sticky; moderately plastic; firm soil strength; weakly pedal; coarse blocky peds; few medium roots; indistinct smooth boundary; dry.
Bg	32 - 70+	Dark grey (10YR 4/1) clayey silt loam; common fine (7.5YR 5/8) mottles; moderately sticky; moderately plastic; firm soil strength; weakly pedal; coarse blocky peds; few medium roots; dry.

Soil	Pakarae
	Sandy loam, hill phase
Transect length and direction	50 m; N
Classification	Typic Orthic Pumice
Land use	Extensive pasture
Date sampled	31/01/2013
Land use history	Extensive pasture, beef drystock.
Present vegetation	Pasture, ryegrass and clover
Slope degrees	15-25
Landform	Steep midslope, convex face
Annual rain (mm)	Around 1550 mm
Elevation (m)	58 m
Parent material	Pumiceous tephra over argillite
Drainage	Moderately drained
Topsoil depth (cm)	25 cm
Limiting horizon	None
Sampled by	KB/KH

Horizon	Depth (cm)	Description
Ap	0 - 25	Black (10YR 1/1) sandy loam; slightly sticky; moderately plastic; slightly firm soil strength; weakly pedal; fine polyhedral peds; common fine roots; distinct irregular boundary; dry.
Bw	25 - 34	Yellowish brown (10YR 5/6) silty sand; non-sticky, slightly plastic; weak sol strength; apedal single grain; common fine roots; indistinct irregular boundary; dry.
Bw2	34 - 50	Yellowish brown (10YR 5/4) silty fine sand; slightly sticky; moderately plastic; weak sol strength; apedal earthy; few fine roots; indistinct irregular boundary; dry.
Ww3	50 - 70+	Light brownish grey (2.5Y 6/2) sandy silt; common fine (2.5Y 6/8) mottles; slightly sticky; moderately plastic; slightly form soil strength; apedal massive; few fine roots; dry.

Appendix B: Land Manager Questionnaire

Appendix C: Analytical Results

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