Temporal changes in topsoil qualities of dairy pasture and maize cropping sites in the Bay of Plenty Region, New Zealand

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Abstract
Temporal changes in topsoil qualities of dairy pasture and maize cropping sites were monitored periodically over a ten-year period. Results indicate that for both sites, 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.

Key Words
Soil quality, soil health, soil quality monitoring.

Introduction
Environment Bay of Plenty (the Bay of Plenty Regional Council) has been collecting soil quality or soil health data since the late 1990's when it participated in the 500 Soils Project involving the various regional councils of New Zealand (Sparling and Schipper 2004). A total of more than 70 soil quality sites have been progressively established under various land uses. The sites were categorised by land use which include: cropping (maize), dairy, sheep and beef, deer, kiwifruit and forests (indigenous and plantation). The number of sites sampled for each land use category was proportional to the area of land use. 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. 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). The objective of this report is to discuss the changes in topsoil qualities periodically sampled dairy pasture and maize cropping sites over a ten-year period.

Methods
Soil sampling and analyses
Twenty four soil quality sites consisting of 19 dairy pasture sites and 5 maize cropping sites from previously established sites were resampled in 2009. The standard protocol for New Zealand soil quality sampling was followed (Sparling and Schipper 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. The C/N ratio was obtained by dividing total C with total N. For maize sites, undisturbed topsoil samples were also taken 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).

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 by Landcare Research (Sparling *et al*. 2008).

These standards are grouped according to land use and/or soil classification with production and/or environmental criterion. Aggregate stability results from maize sites were compared with the standard given in Beare *et al*. (2009). Previous results from dairy and maize sites reported by Landcare Research were used in order to show changes over time.

Results

Temporal changes in topsoil qualities of dairy sites

Table 1 shows the trends of topsoil qualities of dairy sites over a ten-year period. 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.

Table 1. Temporal changes in topsoil qualities of dairy sites with respect to pH, total C, total N, C/N ratio, anaerobically mineralisable N, Olsen P, bulk density, and macroporosity (n=19)

Soil Quality	Year			
	1999/2000	2004	2009	P value
pH	5.65	5.86	5.79	0.181
Total C (%)	7.65	6.87	7.81	0.473
Total N (%)	0.63	0.64	0.73	0.294
C/N ratio	11.98	10.86	10.72	0.015
Anaerobically mineralisable N (mg/kg)	72	155	256	<0.001
Olsen P (mg/kg)	67	87	97	0.095
Bulk Density (t/m^3)	0.87	0.94	0.85	0.210
Macroporosity (%)	9.40	7.78	9.97	0.378

There was no significant change in total C. Mean values for each year are above the provisional target of >2%. For total N, a slight increase was observed . 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. 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. 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. This reflects a continual fertiliser N input in the pasture soils. 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 dairy pasture 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. Although the increase was not statistically significant, this represents a 45% increase and reflects the continual application of phosphate fertilisers in these dairy farms. 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.

There was little change in bulk density with time. 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 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%.

Temporal changes in topsoil qualities of maize sites

Table 2 shows the temporal changes of topsoil qualities of maize sites. 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.

There was a decline in total C from 2000 to 2003 but stable afterwards. The cause of this decline is unclear. Nevertheless, all mean values were above the provisional target value of >2%. Similarly, there was a decline in total N from 2000 to 2003 but also stable afterwards. The cause of this decline is also unclear. Provisional

target values are not established for cropping soils but low values are undesirable. 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. All mean values are within the 8 to 20 provisional target range for cropping soils.

Table 2. Temporal changes in topsoil qualities of maize sites with respect to pH, total C, total N, C/N ratio, anaerobically mineralisable N, Olsen P, bulk density, macroporosity, and aggregate stability (n=6 in 2000-2004; n=5 in 2006-2009)

Soil Quality	Year					
	2000	2003	2004	2006	2009	P value
pH	6.12	6.27	5.98	6.32	6.21	0.384
Total C (%)	5.47	3.18	2.99	3.17	3.24	0.027
Total N (%)	0.42	0.26	0.25	0.26	0.26	0.021
C/N ratio	13.04	12.28	11.76	12.33	12.43	0.590
Olsen P (mg/kg)	55	58	50	54	48	0.962
Anaerobically mineralisable N (mg/kg)	26	35	30	35	46	0.281
Bulk density (t/m^3)	0.98	no data	1.10	no data	0.98	0.234
Macroporosity (%)	17.9	no data	15.0	no data	20.5	0.430
Aggregate Stability (mm)	1.02	no data	0.95	no data	0.98	0.957

Except for a slight decrease in 2004, there is an increasing trend in anaerobically mineralisable N 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 target for cropping soils.

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

Bulk density values appear stable. 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. 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). The sandy nature of the maize soils of the Bay of Plenty and the effect of long-term cultivation could be contributory factors for not attaining the desired aggregate stability value.

Conclusion

For both dairy and maize sites, many of the topsoil quality parameters were being maintained and 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, rivers and lakes.

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