Monitoring soil quality in intensive dairy-farmed catchments of New Zealand: implications for farm management and environmental quality

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Abstract
Soil physical and chemical quality assessments were performed for the predominant soil types within four intensively grazed dairy catchments in New Zealand during the winters of 2001, 2003, 2005 and 2007. The four catchments monitored were in the following regions: Waikato (Toenepi stream), Taranaki (Waiokura stream), Canterbury (Waikakahi stream) and Southland (Bog Burn stream). The surveys suggest that, in general, soil quality was good. Mean soil macroporosity was initially low in the Toenepi catchment but is now within the recommended range for good pasture production. All catchments, except the Bog Burn, have showed that soil macroporosity values have increased since the study began. A considerable proportion (76%) of farms within all catchments has higher than optimum concentrations of soil Olsen P. These P concentrations have been maintained despite evidence from farm surveys which suggest that P fertilization rates have decreased. However, changes in soil test status following a change in fertilization policy can be slow to manifest themselves. These high levels are likely to be uneconomic and pose increased risk of P loss to waterways.

Introduction
There is concern in New Zealand about the impacts of intensive dairy farming on soil and water quality. Concern about surface water quality is high in many regions that have seen a rapid shift from low intensity dry-stock farming to high intensity dairying. In response, the Best Practice Dairying Catchments for Sustainable Growth Project was established in summer 2001. The project aim was to quantify the benefits of integrating environmentally sustainable farming practices into a rapidly expanding dairy industry. Four predominantly dairy land use catchments were chosen for study: Waikato, Taranaki, Canterbury and Southland. In addition to providing geographical spread, the chosen catchments are typical of dairy farming climatic conditions, soil types and farm management practices for each region. Decreases in soil quality within pastoral agricultural systems have been associated with deteriorating surface water quality (Kurz *et al.* 2006). In addition to decreasing surface water quality, the loss of sediment, phosphorus and nitrogen from pastoral land represent a decrease in soil fertility and nutrient use efficiency (McDowell *et al.* 2008). Factors such as soil P concentration can determine the availability of P for loss in overland and subsurface flow (McDowell *et al.* 2003; McDowell *et al.* 2005), while others such as soil compaction by animal treading can have detrimental effects on soil physical properties that impair plant growth and enhance the transfer of contaminants in overland flow (Drewry *et al.* 2008; Houlbrooke *et al.* 2009; McDowell and Houlbrooke 2009). Some soils are particularly susceptible to treading damage under intensive grazing management (Hewitt and Shepherd 1997). Such soils are now being increasingly used for dairy farming and present a management challenge for good soil and water quality to be maintained. Soils may also deteriorate through inappropriate management of K fertility via excessive or inadequate nutrient inputs (Roberts and Morton 1999).

Methods
Transect location
The four dairy catchments are drained by the Toenepi Stream (Waikato), Waiokura Stream (Taranaki), Waikakahi Stream (Canterbury) and Bog Burn (Southland). Within each catchment, at least two transects of approximately 100 m length were sampled from each of ten different farms representing the major soil type used for dairy farming in each catchment. The soils types investigated in the Toenepi, Waiokura, Waikakahi and Bog Burn catchments were a Kereone silt loam (US soil taxonomy: Udand), a Manaia silt loam (US soil taxonomy: Udand), an Eyre very stony sandy loam (US soil taxonomy: Dystrochrept), and a Pukemutu silt loam (US soil taxonomy: Fragiochrept), respectively. In addition, within the Waikakahi catchment, ten transects were also sampled on the heavier Temuka silt loam (US soil taxonomy: Aquept).

Sampling procedure and analysis
Two sets of soil samples were taken from each transect during the winter period for each survey conducted. Soil chemical samples were obtained by collecting and bulking 20 small cores to 75 mm depth along each transect. This sampling procedure is the same as that recommended for standard soil fertility sampling on commercial dairy farms in New Zealand. Twenty 5-cm diameter core samples were also taken per transect for soil physical analyses using a coring device designed to extract an intact soil core from 1.5 to 3.5 cm depth, nominally 0 to 5 cm. All samples were analysed by an IANZ accredited commercial laboratory for the following soil properties: pH, P, Ca, K, Mg, Na, SO_4-S, total N, mineralisable N, organic S, organic C, bulk density and macroporosity (pores > 30 µm). For the purposes of this report we will present data on the following soil quality properties: Olsen P, exchangeable K (Quicktest method), organic carbon and macroporosity (pores > 30 µm at -10 kPa tension).

Statistical analyses and data presentation
Soil chemical data and paddock mean soil physical data from dairy farm sites were analysed by ANOVA using GENSTAT, with transect within farm as the block structure and catchment (with Waikakahi catchment subdivided by soil series) as the treatment. Soil quality properties from sampled dairy farms are presented as box and whisker graphs (Figure 1) to demonstrate the distribution within catchments in relation to proposed optimal criteria. Changes in soil quality over time within catchments have been determined by a change ≥ 2 SEM (Figure 2). Figures 1 and 2 compare catchment soil quality data with optimum ranges. The macroporosity and organic C criteria were based on soil quality assessment targets (Sparling & Tarbotton, 2000), while the soil K targets were from Roberts and Morton (1999). However, soil Olsen P criteria were based on values for established agronomic optimums (Roberts and Morton 1999), and the potential risk to contamination of waterways (McDowell *et al.* 2005).

Results and discussion
With the exception of the Bog Burn, mean Olsen P concentrations in all catchments, , were greater than agronomic targets for dairy farming. Furthermore, Waiokura and Toenepi Olsen P concentrations have significantly increased with time since monitoring began (P<0.05), despite a decrease in reported P fertilization rates. However, changes in soil test status following a change in fertilization policy can be slow to manifest themselves. Optimum agronomic concentrations for soil Olsen P on dairy farms are 20-30 mg/L for farms with average milk-solids (MS) production per hectare. However, higher Olsen P concentrations of 30-40 mg/L can be agronomically and economically justified at high MS/ha production if all additional pasture is utilised (top 25% milk-solids production in a supply region (Roberts and Morton 1999). Potential P losses in surface runoff to waterways can be minimised, and economic returns maximised, by maintaining soil Olsen P concentrations within the correct target ranges, depending on soil type (McDowell *et al.* 2005). From an economic perspective, excessive P fertilisation that results in soil Olsen P concentrations above the agronomic optimum has little financial merit since little additional pasture production is gained, and has a greater potential for P to be lost.

A large proportion (>25%) of soil Quicktest K concentrations for all catchments were greater than recommended targets (Figures 1 and 2). The Waikakahi, Waiokura and Bog Burn catchments showed no significant change in mean soil Quicktest K concentrations between the 2005 and 2007 surveys following a period of increasing soil Quicktest K concentrations from 2001-2005. However, the Toenepi catchment demonstrated a significant increase (P<0.05) of 2.5 Quicktest units between the 2003 and 2005 surveys. Large within-catchment variability of Quicktest K concentrations was found for all catchments (Figure 1). Trends in Quicktest K with time are presented in Figure 2. The low soil Quicktest K concentrations suggest that clover growth is likely to be restricted. Conversely, soil enriched with K can lead to high concentrations of K in pasture and subsequently cause metabolic problems such as hypomagnesaemia in grazing animals. This is commonly associated with areas receiving long term additions of farm dairy effluent (Houlbrooke *et al.* 2004).

Mean and median concentrations of soil organic carbon (SOC) were generally considered normal or enriched for all catchments (Figures 1 and 2). Well established and productive pastures are known to return large amounts of organic matter to soil via the breakdown of dead root material, litter and animal dung and these returns act as inputs into the soil organic matter pool.

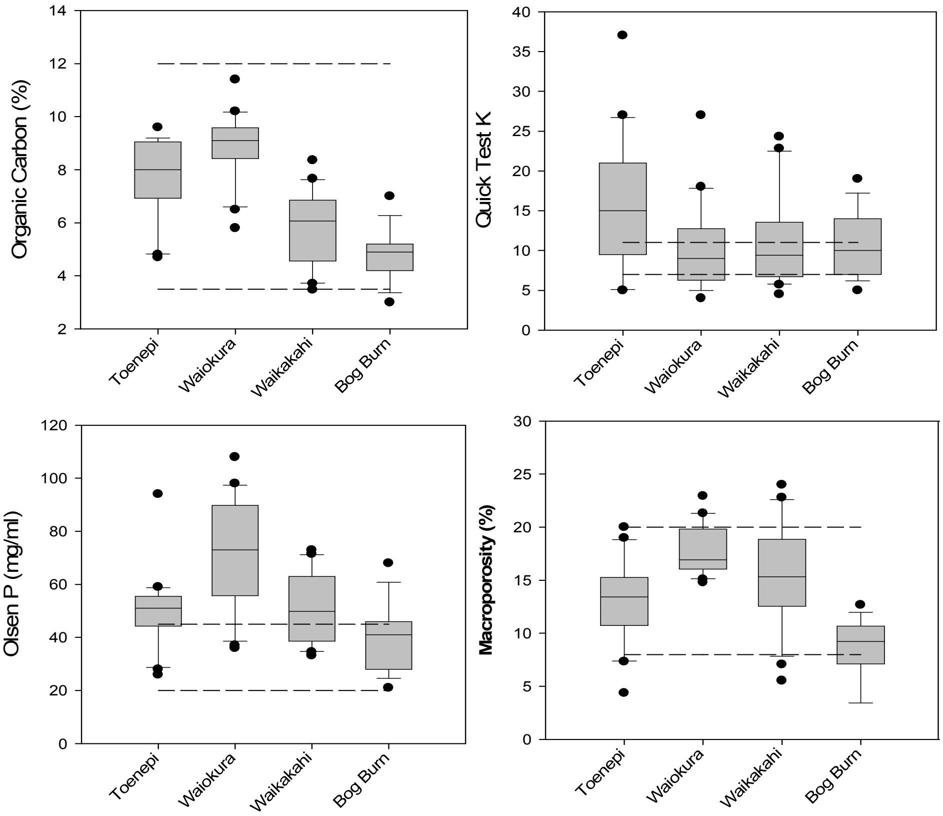

Figure 1. 2007 soil quality data showing between- and within-catchment variation compared to optimum ranges (dashed lines). To interpret a box and whisker graph, the boundaries of the box represent the 25th (lower) and 75th (upper) percentiles, and a line within the box marks the median. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, outlying points are plotted as closed circles.

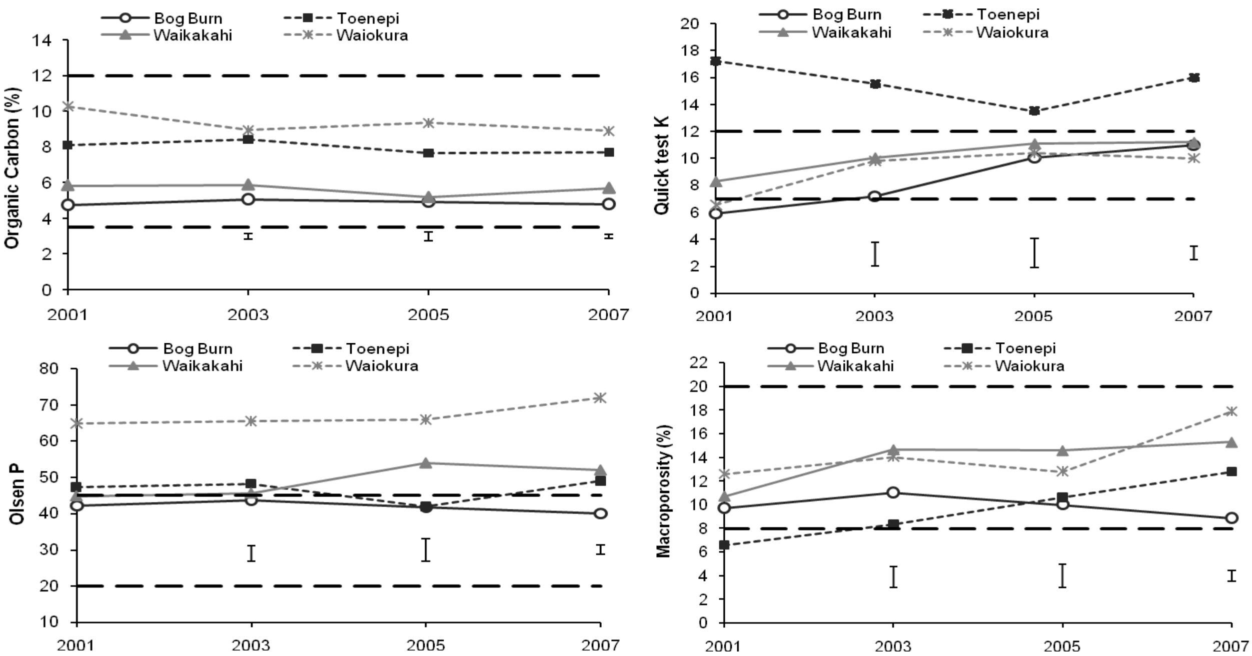

Figure 2. Changes in soil properties with time. Bars represent two SEM values for data between the current and previous year. Dashed lines represent optimum range thresholds.

Mean and median values for macroporosity were considered satisfactory for all catchments (Figure 1 and 2). The mean soil macroporosity value calculated for the Bog Burn catchment (8.7% v/v) was close to the lower end of that considered optimal for pasture production (>8%), but 33% of farms tested had a mean macroporosity value below optimum (Figure 1). Furthermore, the Bog Burn catchment demonstrated a significant ($P<0.05$) decreasing trend (c. 1% unit change) between the 2005 and 2007 surveys. The Pukemutu silt loam found in the Bog Burn catchment is highly vulnerable to degradation under intensive management (Hewitt and Shepherd 1997). We therefore recommend the strategic use of stand-off pads in this catchment for on-off grazing when the soil is very wet in order to minimise soil compaction and treading damage and associated overland flow of contaminants. It is of note that soil macroporosity consistently increased every year (P<0.05) from very low levels in the Toenepi catchment in 2001 to be well within the optimal range in 2007 (6% unit increase over 6 years). The volcanic soil in this catchment is reputedly quite resilient to treading damage so eliminating the frequency and severity of compaction events would have allowed for recovery.

Conclusion

Soil quality assessments have been performed for each of the major soil types within four New Zealand catchments that are intensively used for dairy farming. With the exception of Olsen P, mean results suggest that soil quality was generally considered 'good' overall. Enriched soil Olsen P concentrations are likely to be uneconomic and represent a potential risk to surface water quality. Recommended management strategies for dairy farmers within the catchment study are to manage nutrient inputs of K and P to keep soil concentrations within agronomically optimum levels and decrease the potential for associated animal health and environmental impacts. Farms within the Toenepi catchment have demonstrated an improving trend for soil macroporosity to well within optimum levels. However, farms within the Bog Burn catchment have, due to the presence of a soil that is vulnerable to treading and compaction damage, tended to have low macroporosities. These vulnerable soils should be strategically managed during wet periods

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