COMPARISON OF SOIL CARBON AND NITROGEN STOCKS OF ADJACENT DAIRY AND DRYSTOCK PASTURES

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Abstract

The largest terrestrial store of carbon (C) is in soil and research has shown that anthropogenic land use change and management practices can alter soil C stocks. A concern is that small losses of soil C can contribute to large increases in atmospheric CO_2. Research has focused on identifying which land use conversions modify soil C dynamics and more recently, how management practices influence soil C stocks, with particular emphasis on croplands and forests but less on grazed pasture systems. The soil nitrogen (N) cycle has also been modified with increased N inputs, especially under agriculture where N fertilisers and N-fixing plants are used.

About 33% of New Zealand's total land area is used for grazing. A previous study observed that between the 1980s and 2000s soils on flat land under dairy farming had lost significant amounts of C and N, while soils under drystock farming on flat land had not. A conclusion drawn from the previous study was that a dairy farm was likely have a lower soil C stock than an adjacent drystock farm on the same soil, on flat land. The reasons for the reported soil C and N losses from dairy farm soils are not well understood and require further testing and verification using other approaches.

The objectives of this thesis were to firstly, determine if there was a difference in soil C and N between adjacent dairy and drystock farms on the same soil and secondly, if differences were detected whether they were dependant on differences in farming intensity, as defined by stocking rate.

A synthesis of recent literature showed that when differences in soil C have been observed under various grazing intensities, soil C was generally always lower under higher stocking rates. However, many of the grazing intensity studies were based in semi-arid regions and not particularly applicable to New Zealand's pastoral grazing systems.

I sampled 25 adjacent dairy and drystock farms (paired sites) on flat land in the Waikato Region to 0.6 m depth and analysed samples for C, N and soil dry bulk density by horizon. Sampling sites at each paired site were an average of 108 m apart and located on the same soil with a similar slope, aspect and topography. The estimated average stocking rate for dairy farms (24 ± 0.8 SU ha^{-1}) was higher ($P<0.01$) than drystock farms (14 ± 2.0 SU ha^{-1}). The mean soil C and N stocks for the whole soil profile (0–0.6 m) were 173.1 ± 12.4 t C ha^{-1} and 18.5 ± 0.9 t N ha^{-1} for the dairy farms and 182.7 ± 15.0 t C ha^{-1} and 19.1 ± 5.7 t N ha^{-1} for the drystock farms. The soil C and N stocks for the whole soil profile were not significantly different between dairy and drystock farms. However, when soil horizons were considered separately there was a significant difference in C stocks of the A horizon ($P<0.05$). The mean soil C in the A horizon under dairying was 94.7 ± 5.7 t C ha^{-1} and 103.3 ± 6.1 t C ha^{-1} under drystock, with dairy farms having an average of 8.6 ± 4.1 t C ha^{-1} less than the drystock farms ($P<0.05$). No significant difference in soil N stock of the A horizons was detected. The increased variability of soil C and N with depth meant that the significant difference in soil C of the A horizon was not evident when the whole soil profile was considered. The A horizon thickness under dairy farming was shallower ($P<0.05$) and the soil dry bulk density was higher ($P<0.05$) than the drystock farms, indicating soil compaction. The total mass of soil sampled from the A horizons was similar for both types of grazing (0.14 ± 0.01 t m^{-2}). Therefore, the significant difference in soil C of the A horizon was likely to be a consequence of land management rather than sampling different masses of soil.

My result that dairy farms had less topsoil C than adjacent drystock farms aligned with the conclusion drawn from a previous study of New Zealand pastoral grazing systems. The result also supported the general trend of less soil C under higher stocking rates than lower stocking rates observed in the literature synthesis. Further work is required to understand what has driven the difference in topsoil C under dairy and drystock farming on flat land in New Zealand. Future research should include exploring how important stocking rates and the type of livestock being grazed are on soil C and N dynamics, as this may be useful information for future farming management decision making.

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Chapter 1. Introduction

1.1 Background

Soil is the largest terrestrial store of carbon (C). Globally, there is some 2000 Pg of C in soil, to 1 metre depth, compared to 760 Pg in the atmosphere and 500 Pg in above-ground biomass (Janzen, 2004). Soil C stocks are a balance of net inputs (e.g. organic matter) and net outputs (e.g. respiration, erosion and leaching of dissolved C) (Smith, 2008). Research has shown that anthropogenic land use change and management practices can alter this balance and either increase or decrease soil C stocks, which in turn can modify atmospheric carbon dioxide (CO_2) concentrations (Foley *et al.,* 2005; Ogle *et al.,* 2005; Batlle-Aguilar *et al.,* 2011). A concern is that even small losses from soil C stocks can contribute to large increases in atmospheric CO_2. For example, a 5% change in soil C could potentially alter CO_2 concentrations by up to 16% (Mackay, 2008). Conversely, there may be an opportunity to decrease CO_2 concentrations by sequestering C (removing it from the atmosphere) into the soil by altering land use or management (Smith, 2008; Fitton *et al.,* 2011).

Strong evidence of the relationship land use change has with soil C stocks was presented in a global meta-analysis by Guo and Gifford (2002). They surmised that land use changes which generally increase soil C include the conversion of native forest to pasture (+8%), cropping to plantation forest (+18%) and cropping to pasture (+19%). Whereas, land use changes that decrease soil C include pasture to plantation forest (-10%) or to cropping (-59%) and native forest to plantation forest (-13%) or to cropping (-42%). Similar trends have also been found in more recent meta-analyses of the literature (Don *et al.,* 2011; Poeplau *et al.,* 2011).

Many fundamental soil properties are dependent on the amount of C or soil organic matter (SOM) present. Soil organic matter helps regulate soil moisture, nutrient cycling, microbial activity, soil structure and aggregation (Six *et al.,* 2004; McLauchlan, 2006). Thus, soil C is an important component of any soil, especially those used for agriculture.

As a result of the importance of the soil C pool, it is crucial to understand not only how land use changes influence the soil C cycle but also how differing land management practices, within a land use class, may affect soil C. In the last decade, since the adoption of the Kyoto Protocol, there has been interest in comprehending and then utilising management practices that sequester CO_2 in soil, with a particular emphasis on forest and cropland management worldwide (Freibauer *et al.,* 2004; McLauchlan, 2006). Forest ecosystems store more than 70% of all soil organic carbon (SOC) and research has shown that management practices, such as harvesting and thinning, can directly influence the movement of C into the underlying soil (Jandl *et al.,* 2007). Likewise, conventional cropping practices have been confirmed to cause significant losses of soil C and as a result substantial effort has been directed into understanding alternative cropping practices that either will lessen the loss of soil C or sequester CO_2 (West and Marland, 2002; Ogle *et al.,* 2005; McLauchlan, 2006; Maia *et al.,* 2010). Less is currently known about how different management practices influence soil C stocks under grazed pasture systems.

A first step in understanding soil C stocks is to determine C inventories at regional and national scales. The first comprehensive terrestrial C inventory for New Zealand was completed by Tate *et al.* (1997). Using soil maps and the National Soils Database, Tate *et al.* (1997) estimated that there was 2500 ± 77 Mt C in the top 0.25 m of soil and 4260 ± 19 Mt C in the top 1 m of soil in New Zealand. They also estimated the average soil C stock for New Zealand to be 168 t C ha^{-1} (to 1 m depth) which is higher than the estimated global average of 130 t C ha^{-1} (to 1 m depth) (Tate *et al.,* 1997).

While it is necessary to be able to report national soil C stocks, it is becoming increasingly important for landowners or managers to comprehend the soil C stocks of their land and how stocks may change in response to various management practices. As an example, the New Zealand Emissions Trading Scheme was recently established and as a result the Waikato Regional Council is proposing a Regional Carbon Strategy where land use and management may be required to change in an effort to enhance CO_2 sequestration to soils (West *et al.,* 2011). Legislation and strategies such as those listed above signify the need for practical and efficient sampling and reporting approaches on soil C at regional and potentially farm scales.

Several studies have attempted to link changes of soil C with land use and land management in New Zealand (Tate *et al.,* 1997; Schipper *et al.,* 2007; Schipper *et al.,* 2010). The re-sampling of soils under pasture 50 years after initial sampling by Tate *et al.* (1997) showed no change in soil C stocks in the top 0.15 m of soil. This led Tate *et al.* (1997) to conclude that between the 1950s and 1990s pastoral soils were at steady state for soil C. More recently, Schipper *et al.* (2010) undertook an in-depth study to investigate whether changes in soil C stocks of grazed pasture were dependent on land management. Schipper *et al*. (2010) re-sampled 83 soils that were under dairy or drystock on flat land and drystock on hill country or tussock grasslands, with an average of 27 years between sampling (1980s to 2000s). They detected that soil on flat land under dairy farming had lost significant amounts of C, 0.73 ± 0.16 Mg C ha^{-1} y^{-1}, while there was no significant difference of soil C under drystock farming also on flat land (to 0.3 m depth).

Another environmental concern of changing soil C stocks is the effect on soil nitrogen (N) storage. There is a strong link between SOC and soil organic nitrogen (SON) and it is estimated that for every 1 tonne of C stored, 100 kg of N could be stored (Schipper *et al.,* 2004; Gardenas *et al.,* 2011; Knicker, 2011). It is not known how long soils can continue to immobilise N. If soil N storage is exceeded in New Zealand's pastoral farming systems the typical N inputs of fertiliser, N-fixation by clover and stock excreta could potentially increase nitrate leaching and nitrous oxide emissions (Schipper *et al.,* 2004).

A previous study of New Zealand soils created a simple model to indicate when N saturation may occur. Using the assumption that soil C is at steady state, the model demonstrated that many New Zealand soils may reach their maximum N storage within the next 50 years (Schipper *et al.,* 2004). The more recent study by Schipper *et al.* (2010) found that soils under drystock farming on flat land appeared to be at steady state, therefore the N saturation model could be applicable and these soils may not be able to accumulate much more N. However, on flat land under dairy farming soils Schipper *et al.* (2010) found that soils had lost N, at an average rate of 57 ± 16 kg N ha^{-1} y^{-1} (to 0.3 m depth). Further information on how N is stored and cycled in soils both in New Zealand and internationally is necessary so that any adverse environmental effects from N saturation can be mitigated or avoided.

Reasons for the losses of soil C and N found in Schipper *et al.* (2010) are poorly understood and require further testing and verification using other approaches. Schipper *et al.* (2010) were able to utilise archived soil samples to allow for temporal sampling but access to multiple and suitable archived samples is not always available. Therefore, there is a need for other sampling approaches that can detect changes in soil C and N.

A conclusion drawn from Schipper *et al*. (2010) was that a dairy farm was likely have a lower soil C stock than an adjacent drystock farm on the same soil, on flat land. I hypothesised that dairy farms would have less soil C and N stocks relative to adjacent drystock farms.

This thesis used paired sites of dairy and drystock farms to investigate soil C and N stocks under the two different types of grazing. The dairy and drystock farms which made a paired site were directly adjacent to one another. At each paired site, a soil pit was dug on both the dairy and drystock farms on matching soil and soil samples were collected from the pits. An experienced pedologist assisted with matching soils across a paired site, the soil description and soil classifications. The rational for using paired sites was that this sampling strategy would allow for differences in land management to be shown by minimising the natural variation in the soil. Detailed management questionnaires were completed by farmers so that grazing intensity, as defined by stocking rate, could be explored with the aim of linking any differences in soil C and N with grazing intensity.

1.2 Aims and objectives

The overall aims of this study were to firstly, test the findings of Schipper *et al.* (2010) and examine if soils on flat land had less C and N stocks under dairy farming than adjacent drystock farming and secondly, to further the understanding of soil C and N stocks under dairy and drystock grazing in New Zealand.

The specific objectives were:

1. To determine if there was a difference in soil C and N between adjacent dairy and drystock farms on the same soil.
2. To determine whether any differences in soil C and N were dependant on differences in grazing intensity, as defined by stocking rate.

The key hypothesis was that dairy farms would, on average, have less soil C and N than adjacent drystock farms.

1.3 Thesis layout

Chapter 2 reviews literature on the effects of land use and land management changes on soil C and N globally and specifically in New Zealand. The review also considers the methods used to investigate these effects.

Chapter 3 describes the full methods used for site selection, soil sampling, laboratory analysis and statistical analysis undertaken for this thesis.

Chapter 4 contains the main experimental part of this thesis as it presents the data gathered during the study and discusses the differences in C and N stocks of soils under dairy and drystock farming. This chapter has been written in the form of a paper for subsequent submission to a peer reviewed journal. Hence, there is some repetition of the introductory, literature review and methods material. As brevity was required additional material including detailed data on the soil descriptions and raw data are in the appendices.

Chapter 5 then presents the summary and conclusions for the study and recommendations for future research.

The appendices hold the following information:

- Appendix A contains a template of the farm management questionnaire for the dairy and drystock farms.
- Appendix B has stocking rate information.
- Appendix C contains the soil profile descriptions.
- Appendix D lists the raw data used to calculate soil C and N for each horizon.

Chapter 2. Literature Review

2.1 Introduction

Carbon (C) and nitrogen (N) are essential elements for sustaining life. Soil provides a large store of C and a smaller store of N (Janzen, 2004; Ollivier *et al.,* 2011). Research over the last century has recognised that anthropogenic land use change can alter the C and N cycles causing increases in soil C and N or losses of C and N from soils that potentially contribute to increased atmospheric CO_2 emissions and N leaching to water (Galloway *et al.,* 2003; Smith, 2008; Ollivier *et al.,* 2011). More recently, studies have analysed how particular land management practices may alter soil C and N stocks, with a particular focus on the management of croplands (e.g. West and Marland, 2002, Ogle *et al.,* 2005 and Maia *et al.,* 2010). How soil C and N stocks respond to stock grazing management practices is less well understood.

This literature review explores the relationship that soil C and N has with land use conversions and with land management practices. It is broken into three main sections that address different questions: (1) What is soil C and N and how can it be measured? (2) How can land use change alter soil C and N? (3) How can management of grazing land alter soil C and N stocks?

2.2 Soil carbon

The largest terrestrial store of C is found in soils (2000 Pg down to 1 m depth; Janzen, 2004). Soil C stocks are a result of C inputs (e.g. organic matter) less C outputs (e.g. respiration, erosion and leaching of dissolved C) (Smith, 2008). In soils, C is found in three forms – elemental C (e.g. charcoal), inorganic C and organic C. In most soils, C is predominately found in the form of soil organic carbon (SOC), which is composed of living and dead soil organisms (e.g. earthworms, nematodes, fungi and bacteria), un-decomposed plant matter or animal remains and humus, all of which can be collectively referred to as soil organic matter (SOM). Humus is organic material that is decomposed to the extent that is has none of its original structural arrangement and in most soils it makes up a majority of the SOM. Approximately 55% of SOM is SOC, with the remaining 45% of SOM being comprised of other essential elements such as nitrogen, oxygen, phosphorus and hydrogen (Amundson, 2001; Blanco-Canqui and Lal, 2004). As Blanco-Canqui and Lal (2004) note, SOM and SOC are often used interchangeably in studies of soil C but they should not be as SOM is not solely composed of C.

Organic C has different residence times in soil and fractions do not all cycle at the same rate. SOC can be broadly split into three pools that describe its cycling or turnover rate – the labile (active), stabilised (slow) and recalcitrant (passive) pools (Prior, *et al.,* 2007; von Lutzow *et al.,* 2007; Allen *et al.,* 2011). The labile pool has a relatively quick turnover rate of less than 5 to 10 years and includes microbes and particulate organic C. The stabilised pool includes soil C fractions of humus and clay-complexed C and has a turnover rate of decades. The recalcitrant pool has a turnover rate of millennia and includes soil C fractions of carbonates and phytoliths (Allen *et al.,* 2011). The turnover rate of SOC is related to how well protected the C is from decomposition. Soil C can be protected from mineralisation biochemically, by silt and clays or by microaggregates, which is essentially protection via either chemical reactions with mineral surfaces or physical barriers (Christensen, 2001; Six *et al.,* 2002; von Lutzow *et al.,* 2007). It appears that in general the physical protection of SOM is more important than chemical protection, which highlights the importance of soil aggregation (Balesdent, 1996). A majority of SOM is stabilised in the recalcitrant pool (von Lutzow *et al.,* 2007). The general response of soil C pools to management change ranges from rapid for the labile fraction to intermediate for the stabilised fraction and slow to very slow for the recalcitrant fraction (Allen *et al.*, 2011).

Many fundamental soil properties are dependent on the amount of SOC and SOM present. SOM helps regulate soil moisture, nutrient cycling, microbial activity, structure and aggregation (Six *et al.,* 2004; McLauchlan, 2006). Thus, soil C is an important component of any soil, especially those used for agriculture.

2.2.1 The relationship between soil carbon and allophane

New Zealand has 15 soil orders described in the New Zealand Soil Classification and C content varies between soil orders (Hewitt, 1998; Parfitt, 2009). Aside from Organic soils, Allophanic soils, which are characterised by relatively high allophane content, have the highest C contents. Allophane describes a group of clay-sized minerals that are commonly associated with volcanic ash soils (Parfitt, 2009). Soils high in allophane can sometimes contain twice as much C as other soils (Percival *et al.,* 2000). It is thought that the large surface area of allophane allows SOM to bind strongly to it which in turn makes the decomposition of SOM (the mineralisation of C and N) slower (Parfitt, 2009). However, there is debate and on-going research into the reasons why soils high in allophane tend to hold more C (Parfitt, 1990; Parfitt, 2009; Chevallier *et al.,* 2010).

There are two New Zealand examples which highlight the complex relationship between allophane and soil C. Parfitt *et al.* (1997) found more soil C in an Allophanic soil than a non-allophanic soil (0–0.2 m depth) but in contrast, Percival *et al.* (2000) found a poor correlation between allophane content in Allophanic soils and soil C (0–0.2 m depth). Percival *et al.* (2000) suggested that the high soil C stocks in Allophanic soils could be due to suitable soil physical properties, high phosphorus content or previous land use that provided initial high C inputs rather than high allophane content being the cause. Whatever the reasons for Allophanic soils having a high C content, there may be the potential for greater C sequestration in these soils compared to other soil orders (Calabi-Floody *et al.,* 2011).

2.3 Soil nitrogen

Nitrogen (N) is an essential element for many plants but almost 95% of the total N found in soils is held in the SOM fraction as soil organic nitrogen (SON) and, in general, is not directly available to plants. Nitrogen is also found in soils as mineral forms held in soil solution as ammonium, nitrite and nitrate (1–2% of total soil N), and ammonium held by clay minerals (1–6% of total soil N). Nitrogen-fixing microorganisms, often in association with plants, can transform gaseous N_2 into ammonia. Other microbes can mineralise the N in SOM to make it ammonium or nitrate which then becomes available to plants (Ollivier *et al.,* 2011). N will covalently bind to C and so SON storage in soils can be dependent on the size of the SOC pool (Schipper *et al.,* 2004; Knicker, 2011).

Anthropogenic land use and management changes have altered soil N dynamics. Soil organic nitrogen stocks are a balance of inputs (e.g. N atmospheric deposition and biological N-fixation) and outputs (e.g. N volatilisation, leaching and biological N fixation), and any changes to this balance can alter soil N stocks (Pineiro *et al.,* 2010). Nitrogen inputs have increased globally from many sources including the increased use of N-fertilisers, crops that biologically fix N and the combustion of fossil fuels. One of the issues arising from the increase in N inputs is the increased N outputs that are causing eutrophication of freshwater and N pollution of coastal water. Agroecosystems (croplands and grazing land) have been identified as one of the key contributors of N leaching to water (Vitousek *et al.,* 1997; Galloway *et al.,* 2003; Zhang *et al.,* 2012).

Previous studies in New Zealand suggest that soil N stocks under different management practices and land forms have behaved in range of ways – declined under dairy on flat land ($P<0.05$), increased under drystock on hill country ($P<0.01$) and were at steady state under drystock on flat land and on tussock-land, all to 0.1 m depth. It is unknown how long some soils may continue to immobilise N, and if soil N storage is exceeded there is potential for increased losses via volatilisation or leaching (Schipper *et al.,* 2004). If soils become saturated in N it is not known if C is able to accumulate, given that most organic N is covalently bonded to organic C.

2.4 C:N ratio

The C:N ratio of soil is often influenced by the land use. As an example, in New South Wales, Australia, the C:N ratio of soils was lowest under cropland, higher under pasture and then highest under woodland (Wilson *et al.,* 2011).

The mean C:N ratio of topsoil's worldwide ranges from 9.9 to 25.8 (Batjes, 1996). The C:N ratio of soils under pastoral grazing in New Zealand has been found to be around 11.5 to 11.7, which is at the lower end of the scale compared with topsoil's worldwide (Schipper *et al.,* 2004; Schipper *et al.,* 2010). Schipper *et al.* (2010) found that after about 27 years of grazing, the C:N ratio of soils sampled had declined, likely due to increases in N inputs from N-fertilisers and N-fixing legumes (Schipper *et al.,* 2004). The soil C:N ratio can provide an indication of how much more N can accumulate in that soil. On the basis that New Zealand's pastoral soils are unlikely to have a C:N ratio of less than 9, the current low C:N ratios indicate that some soils may be getting close to maximum N storage as SON (Schipper *et al.,* 2011).

2.5 Methods used to measure soil carbon and nitrogen

Given the concern about environmental pollution caused by the anthropogenic-induced loss of soil C and N stocks, it is important to be able to effectively measure and monitor any changes in these stocks. As a result, a number of methods have been developed to quantify soil C and N stocks and rates of change due to land use or management changes. Each method has strengths and weaknesses which will make particular methods more suited to some studies than others. Field studies of soil C and N have used methods such as temporal sampling, the use of chronosequences, C balance techniques (e.g. eddy covariance) and paired site sampling, and in more recent times modelling and remote sensing techniques have been developed. I will briefly summarise the methods of temporal sampling, chronosequences and paired sites, as these approaches have often been used to measure soil C and N stocks following land use change in recent decades (Guo and Gifford, 2002). A summary of the differences between the three approaches used to measure soil C and N stocks is in Table 2.1.

Table 2.1. Summary of temporal, chronosequence and paired site sampling methods used to measure the effect of land use or management changes on soil C and N stocks (adapted from Breuer *et al.,* 2006).

	Temporal sampling	**Chronosequence sampling**	**Paired site sampling**
Investigation method uses	Single site with changes of land use or management during experiment	Several sites in same area with known different land use or management	Two adjacent sites with different land use
Assumption	None	Sites had same land use at some point in the past and had similar soil properties	Sites had same land use at some point in the past and had similar soil properties
Site properties to be checked	None – as same site is used throughout experiment	Soil type, climate conditions	Soil type, aspect, topography, climate conditions
Amount of sampling required	Multiple samplings over a period of years	Single sampling (in general)	Single sampling (in general)
Measurements	Soil C & N stocks and rates of change	Soil C & N stocks and rates of change	Soil C & N stocks
Restrictions	Long term experiment, need records of change in land use or management	Need to know land use history	Need to know land use history

2.5.1 Temporal sampling

Temporal sampling is where soil C and N stocks are measured at the same site at multiple points through time, allowing not only static stocks to be measured but for rates of change over time to be calculated. Because the same site is sampled, variability such as soil type and land use is minimised. If records are kept on variables such as land management and climate any changes in soil C and N stocks may be able to be linked to those variables. Because changes in soil C and N may happen quickly or slowly, depending on the stage of land use change or management, the time between sampling should be set appropriately for the particular study (Oliver *et al.,* 2004; Breuer *et al.,* 2006). The length of time required to show changes in soil C and N stocks is not simple to quantify, as illustrated by Sanjari *et al.* (2008) whose study did not show a significant difference in soil C stocks under two grazing management regimes over a 6 year period. It is interesting to note that sampling periods of greater than 20 years are limited in the literature (Breuer *et al.,* 2006).

Recent research has involved comparing historical sampling with contemporary sampling either via the re-analysis of archived soil samples or via the re-analysis of previous data (Meersmans *et al.,* 2009; Schipper *et al.,* 2010; Schipper & Sparling, 2011). A common issue with analysing historical archived soils or data is that soil dry bulk density samples were not always taken at the initial sampling. Soil dry bulk densities were often not measured because original experiments had different objectives, such as measuring soil fertility changes and changes in production (Schipper *et al.,* 2010). To fill the gap, assumptions of soil dry bulk density must be made to enable mass correction of historical samples for comparison with contemporary sampling (e.g. Meersmans *et al.,* 2009).

2.5.2 Chronosequence sampling

Chronosequences have long been used to measure changes in soil C and N stocks. The basic principle of chronosequences is that 'space' substitutes for 'time'. A chronosequence consists of a series of separate sites that are at different stages of development or time elapsed since land use change, but that all have the same climatic history, parent material, topography and land use. The assumption used is that the sites, although in different locations, were initially similar and that sampling of sites of different time since a change is equivalent to re-sampling the same site through time, as in temporal sampling (Amundson, 2001; Sparling *et al.,* 2003).

Sparling *et al.* (2003) sampled a 59 year chronosequence of recovering land slip scars in hill country pasture under sheep grazing. Rates of land slip scar topsoil recovery were estimated from the chronosequence as sampled in 1987. Fourteen years later, in 2001, a subset of the sites were re-sampled to test whether the estimated rates of recovery were in line with those from temporal sampling. Sparling *et al.* (2003) were able to confirm that, for their study, the chronosequence sampling was consistent with the temporal sampling. While temporal sampling has the distinct advantage of the same site being sampled, it is not always possible to access or sample through time and static sampling approaches, such as chronosequences, are valuable.

2.5.3 Paired site sampling

The paired site approach is used to compare two different land uses or management practices. The methodology requires two nearby sites that have the same climatic conditions, topography and type of soil. The assumption used is that both sites were previously under the same land use with similar soil physical and chemical properties. Therefore, knowledge of the land use history at both sites is important to validate the underlying assumption (Oliver *et al.,* 2004; Breuer *et al.,* 2006). To minimise differences in local climatic conditions and soil variability, paired sites which are immediately adjacent rather than kilometres apart are preferable. Soil samples are taken from matching soils (the same type of soil) on both sites within a pair, so that any difference in soil C or N stocks may be attributed to different land use or management practices rather than the soils natural properties.

Site selection is critical to the success of the paired site approach given the natural variability of soils in the landscape. Although seemingly straight forward, matching up adjacent sites can be difficult primarily due to spatial variability of soil (Oliver *et al.,* 2004; Breuer *et al.,* 2006).

2.5.4 Other considerations when measuring soil carbon and nitrogen stocks

No matter which sampling approach is used (e.g. temporal sampling, chronosequences or paired sites) to assess soil C and N stocks, soil sampling methods, in particular the number of samples taken, measurement of bulk densities and sampling depth, are also important and can impact on the outcome of the soil stocks.

i. Number of samples taken

As with any scientific investigation, it is important to take samples from a sufficient number of replicates in order to achieve sufficiently high statistical power to detect change in the variable of interest. In the case of soil C and N stocks, the number of individual sites and/or the number of replicates taken at a single site are important.

Kucharik *et al.* (2003) sampled 14 sites that had been cropland for at least 50 years paired with cropland converted to grassland for at least 8 years. For this study, they found it difficult to find 14 paired sites with the same soil series due to the natural spatial variation of soils. Even though this study used sites with similar elevation, slope, soil and sampling locations an average of 73 metres apart within a paired site, they did not find any significant difference in SOC across the paired sites, in the top 0.05 m of soil nor down to 0.25 m depth. They highlighted the importance of undertaking an ad hoc power analysis prior to sampling to estimate the required number of paired sites necessary to detect a significant difference of SOC. In this case, a post hoc power analysis suggested that 40 to 65 paired sites would have been needed to detect a change of interest at $P<0.05$.

Kravchenko and Robertson (2011) note that ad hoc or post hoc power analyses are rare for soil C studies. However, in the case of Kucharik *et al.* (2003), and many other studies, it would have been beneficial to undertake an ad hoc power analysis prior to any sampling to obtain an estimate of the number of sites or replicates necessary to detect a significant difference in soil C or N stocks of a certain size. This type of pre-sampling analysis will help ensure that the number of sites or samples taken is adequate for the particular study and decisions can be made on the cost-benefit of the study's possible outcomes.

ii. Analytical methods

Goidts *et al.* (2009) highlighted how the choice of determination method can also impact whether changes in soil C and N are detected. The precision of common analytical laboratory methods used to determine C and N varies from about 1.2 to 15.8% for loss-on-ignition, 1.6 to 4.2% for the Walkley and Black method and 1.3 to 7.1% for dry combustion and each method has slightly different detection limits.

Analytical errors will have an impact on the final result of soil C and N, so it is important to select a method appropriate for the study and detection limits required with the highest precision available (Kucharik *et al.,* 2003; Goidts *et al.,* 2009; Conyers *et al.,* 2011).

iii. Soil dry bulk density measurements

Soil dry bulk density measurements are a fundamental part of assessing soil C and N stocks on an area basis. The method of bulk density collection can impact the soil C and N stocks calculated, as illustrated in Parfitt *et al.* (2010) where they compared soil core collection via carving and a slide hammer. It was common practice in New Zealand to use a slide hammer to force cylinders into soil where the primary objective was to collect cores for measuring water release curves for a soil profile. A more time consuming method is where a pedestal of soil is carved with a knife to allow a cylinder to be carefully pressed into the soil to minimise disturbance. Parfitt *et al.* (2010) concluded that compared to carving, the slide hammer approach could underestimate bulk density by an average of 5%, but underestimation varies depending on the particular soil order and horizon. Goidts *et al.* (2009) also emphasise the importance of direct measurements of bulk density (such as collection via a carved cylinder) because indirect estimates have been shown to produce errors from 9–36% of the SOC stock.

iv. Sampling depth

When considering the impact that alterations of land use or land management have had on soil C and N, it is important to identify the depth to which the land use or management is likely to impact the C or N stocks for sampling purposes.

Soil C and N are not evenly distributed down a soil profile, in general a majority of the SOM is held in the topsoil and the variability of soil C increases with depth (Blanco-Canqui and Lal, 2004; Kravchenko and Robertson, 2011). The type of long term vegetation can also influence the vertical distribution of SOC, for example the proportion of SOC held in the upper 0.2 m relative to 1.0 m depth ranged from ~33% for shrublands, ~42% for grasslands and ~50% in forests (Jobbagy and Jackson, 2000). Consequently, the depth to which samples are taken should consider both the type of land use or management change and to what depth the soil is likely to be modified by the land use.

Many studies only report on SOC to shallow depths of less than 0.3 m, but depth varies from 0.04 m to 1.0 m depth (Poeplau *et al.,* 2011). The reason for these relative shallow samplings may be because guidelines from the Intergovernmental Panel on Climate Change (IPCC) specify reporting on soil C stocks to 0.3 m depth, and many studies are used for IPCC reporting purposes. The IPCC 0.3 m sampling depth recommendation is based on the suggestion that land use and management changes have the greatest impact on soil down to 0.3 m depth (Oliver *et al.,* 2004). A recent study by Schipper *et al.* (2010) suggests that there can be substantial changes in soil C and N stocks in subsoils (down to 0.9 m depth) and that it may be prudent to measure these stocks as well.

Kravchenko and Robertson (2011) note that there are two important considerations for soil C studies: (1) shallow sampling may miss significant changes of soil C at depth, and (2) reporting whole profile changes in soil C may mask soil C changes at smaller depth increments. DeGryze *et al.* (2004) illustrated the impact sampling depth can have on the outcome of a study. DeGryze *et al.* (2004) found that 10 years after a land use change (afforestation), differences in soil C could be found down to 0.07 m but if the soil profile down to 0.5 m depth was considered no change in soil C was shown. In this case, if only the 0–0.5 m depth was considered, the significant change in soil C in the topsoil would have not been evident. Furthermore, Schipper and Sparling (2011) found significant increases in soil C socks at 0–0.075 m depth at nine sites but when considering C stocks to 0.3 m depth only two soils still showed significant increases. Again the significant increase in soil C stocks found at the shallower depth would have been obscured if the sampling only considered the 0–0.3 m depth. Conversely, VandenBygaart *et al.* (2011) reported significantly greater changes in soil C stocks for 0–0.30 m depth but not for 0–0.15 m depth when comparing soils under conventional tillage to no-till practices. Thus, shallow sampling for this study would have missed the significant difference in SOC at greater depth. Overall, soil should be analysed separately by horizon or relatively small increments to have the best chance of detecting the variable soil C stocks.

2.6 Soil sampling methods

Two common approaches to collect samples for soil C and N stock analysis are by soil horizon to a fixed depth and by equivalent soil mass (ESM). Sampling by horizon is as the name suggests. For soil C and N analysis, a sample of the whole horizon is taken and for soil dry bulk density measurements, a subsection of the horizon is also taken and assumed to be representative of the whole horizon. Soil pits are often used when sampling by horizon and pedological knowledge is essential. The method for ESM sampling requires the same mass of soil to be sampled at sites, often by successive layers. As Ellert and Bettany (1995) observed, the actual soil mass selected is not as important as the fact that ESM is sampled at each site sampled. The strength of the ESM method is that 'unjustifiable' differences in soil masses amongst sites can be corrected, especially in studies of cultivated or eroded land where the soil has been redistributed (Ellert and Bettany, 1995). The methods for sampling by fixed depth and ESM are clearly explained in Whitehead *et al.* (2010).

2.7 Land use change and carbon and nitrogen cycling

Land use change has occurred for centuries and as a result has altered the planet in many ways. Land uses can be broadly split into four categories – forest, cropland, grassland and native vegetation. From 1700 to 1980, the total area of cropland land increased 466% (Matson *et al.,* 1997). Now croplands and pastures cover roughly 40% of the global land area, making them one of the dominant terrestrial ecosystems (Janzen, 2004; Foley *et al.,* 2005). As the world's population increases, it is likely that land use change will need to continue to support the growing need for food production and that intensive use of agricultural land will increase. There are a number of far reaching effects of land use change such as alterations in regional climate, soil physical and chemical properties and surface hydrology (Postel *et al.,* 1996; Kalnay and Cai, 2003). In this section of the literature review, I will only focus on the modification of C stocks in mineral soils and, to a lesser extent, soil N.

`Many studies have confirmed that land use change can significantly affect soil C stocks and release CO_2 into the atmosphere (Guo and Gifford, 2002). It has been estimated that about 35% of anthropogenic CO_2 emissions since 1850 are a consequence of land use change (Foley *et al.,* 2005). In the 1990s, land use change was the second largest contributor of anthropogenic CO_2 (1.6 ± 0.8 Pg C y^{-1}), with fossil fuel combustion being the first (5.3 Pg C y^{-1}) (Smith, 2008).

Studying the impacts of land use change on soil C and N is complex. Land use change may alter the amount and/or quality of soil C and N inputs, outputs or both, leading to an imbalance. There are many inherent factors that will affect soil C and N stocks at a given location such as soil type and texture, vegetation type, temperature, precipitation and other environmental conditions. The interactions between different variables mean that that the magnitude of changes on soil C and N following land use change can often vary between regions (Bellamy *et al.,* 2005; Poeplau *et al.,* 2011).

Different land uses provide differing amounts of C and N inputs to soil. In general terms, the largest annual C inputs to SOM are found in forest systems (with inputs all year round), less inputs in grassland ecosystems and then the smallest inputs in croplands (Smith, 2008). The overall amount of C and N input to a soil is the product of factors such as the length of time of inputs (forests can grow year round whereas inputs from croplands are usually periodic), the quality of input (recalcitrant or labile type), removal of biomass (more frequent in croplands than forests), land management practices (tillage in croplands destroying aggregation and exposing protected SOC), and the productivity of the vegetation growing (Smith, 2008; Poeplau *et al.,* 2011).

In the last few decades, there appear to be different trends for the response of soil C to land use change in temperate and tropical regions of the world. In temperate regions, forested area and intensive agriculture are both increasing whereas, land in tropical regions is changing from forest ecosystems to agricultural land at a current rate of ~13 million ha y^{-1} (Don *et al.,* 2011; Poeplau *et al.,* 2011). Two recent meta-analyses were undertaken by Poeplau *et al.* (2011) for the world's temperate regions and Don *et al.* (2011) for the tropical regions (Table 2.2)

Table 2.2. Summary of the effects of land use conversions on SOC stocks for tropical and temperate climatic zones. Negative values indicate losses and positive values are gains. Results are reported as mean ± standard error of the mean, unless specified otherwise. LUC denotes land use change.

Land use change	**Climatic zone**	**SOC change following LUC (%)**	**SOC prior to LUC (Mg ha^{-1})**	**Sampling depth (m)**	**Time after LUC (years)**	**Reference**
Forest to grassland	Tropics	-12.1 ± 2.3^{A}	73 ± 7.0^{A}	0.36 ± 0.03^{A}	25 ± 3	Don *et al.* (2011)
Forest to cropland	Tropics	-25.2 ± 3.3^{A}	83 ± 9.0^{A}	0.36 ± 0.04^{A}	28 ± 4	Don *et al.* (2011)
	Temperate	-31.4 ± 20.4^{A}	147 ± 52.2^{B}	0.28 ± 13.5^{B}	20	Poeplau *et al.* (2011)
Grassland to forest	Tropics	17.5 ± 8.0^{A}	60 ± 9.0^{A}	0.35 ± 0.06^{A}	28 ± 4	Don *et al.* (2011)
	Temperate	-4.3 ± 3.7^{A}	77.2 ± 43.0^{B}	0.23 ± 0.16^{B}	20	Poeplau *et al.* (2011)
Grassland to cropland	Tropics	-10.4 ± 6.1^{A}	64 ± 15.0^{A}	0.38 ± 0.11^{A}	22 ± 5	Don *et al.* (2011)
	Temperate	-36.1 ± 4.6^{A}	115 ± 66.3^{B}	0.27 ± 0.11^{B}	20	Poeplau *et al.* (2011)
Cropland to grassland	Tropics	25.7 ± 11.1^{A}	61 ± 17.0^{A}	0.40 ± 0.10^{A}	21 ± 6	Don *et al.* (2011)
	Temperate	39.8 ± 11.0^{A}	46.2 ± 20.7^{B}	0.24 ± 0.11^{B}	20	Poeplau *et al.* (2011)
Cropland to forest	Tropics	50.3 ± 11.9^{A}	70 ± 9 .0^{A}	0.44 ± 0.06^{A}	32 ± 7	Don *et al.* (2011)
	Temperate	16.0 ± 7.4^{A}	55.5 ± 33.5^{B}	0.40 ± 0.25^{B}	20	Poeplau *et al.* (2011)

^{A} ± 95% confidence interval
^{B} ± standard deviation

In both temperate and tropical regions, SOC increased when cropland was converted to grassland. In temperate regions the SOC increase was relatively slow and continuous, leading to an estimated increase of 128 ± 23% after 100 years (to 0.24 ± 0.11 m depth). Conversely, the land use change from grassland to cropland caused a decrease of SOC in both temperate and tropical regions, with the loss being relatively greater for temperate regions (Don *et al.,* 2011, Poeplau *et al.,* 2011).

For conversions of forest to cropland, SOC decreased for both temperate and tropical regions. The SOC losses were around the same magnitude (~25–32%) to similar soil depths and time elapsed since conversion for both regions (Don *et al.,* 2011, Poeplau *et al.,* 2011). Afforestation of cropland led to SOC increases in temperate and tropical regions, but the increase was over three times greater for tropical regions. However, the larger increase of SOC for tropical regions could be due to the mean sampling depth being deeper (0.44 m depth) compared to temperate regions (0.28 m depth) (Don *et al.,* 2011, Poeplau *et al.,* 2011).

In temperate regions, the afforestation of cropland caused an increase in SOC, but the afforestation of grassland resulted in a small loss of SOC (4 ± 4%) for the upper ~0.3 m of soil after 20 years (Poeplau *et al.,* 2011). In the tropics, grassland afforestation to secondary forest increased SOC by 18 ± 8% for the top 0.35 ± 0.6 m of soil, 28 ± 4 years after the conversion. Deforestation to grassland was not included in Poeplau *et al.*'s (2011) review, presumably because there was insufficient data available. However, primary forest conversion to grasslands in the tropical regions led to SOC loss of 12 ± 2 % (0.36 ± 0.03 m). The SOC stocks of the forested land only include the mineral soil (not the litter layer) for both the tropical and temperate regions.

In summary, land use change can alter soil C stocks. In general, SOC is lost when converting forest to agricultural land (grassland or cropland) but is gained when converting cropland to grassland or forest. The conversion of grassland to cropland often results in losses of SOC, whereas the conversion of grassland to forest may increase or decrease SOC (Table 2.2). The relative amount of lost or gained SOC is dependent on many variables but is important to comprehend given the trends of land use change in different parts of the world.

2.8 Land management practices of grazed land

Research has provided insight into how land use change can have major impacts on soil C and N stocks, but it is also important to consider how different land management practices, within a land use class, may influence the soil stocks. A substantial amount of the global land area is in managed ecosystems; approximately 10% of the global land area is in cropland, 25% in managed grassland grazing and 28% in forests (Asner *et al.,* 2004; Janzen, 2004). In general, more than 90% of organic C in grassland ecosystems is stored in the soil, which means management practices that cause losses of soil C could significantly reduce the C within this ecosystem and provide a large source of CO_2 (Wright *et al.,* 2004; Ganjegunte *et al.,* 2005; Guodong *et al.,* 2008). Thus, recent research has been directed at understanding the influences that different management practices have on soil C and N stocks, especially potential methods that sequester C. This section of the literature review focuses on management practices of land used for grazing, firstly worldwide and then focusing on New Zealand examples.

Here, grazing land refers to native rangelands or grasslands and land converted to pasture which is used for grazing livestock. At 1990, the countries with the most land area in grazing were Australia (4.4 million km^2), China (4.0 million km^2), USA (2.4 million km^2), Brazil (1.7 million km^2) and Argentina (1.4 million km^2) (Asner *et al*., 2004). Grazing systems are managed in a wide variety of ways, which makes the study of and the comparison across grazing management practices difficult. Consideration of all the possible different variables must be given when comparing studies of grazing systems worldwide (Soussana *et al.,* 2004).

2.8.1 How grazing influences soil carbon and nitrogen stocks

In grazing land, factors that can influence soil C and N stocks include: livestock consumption of aboveground vegetation which may change litter quality and decomposition rates and in turn alter SOM formation; change in the belowground input of C and N (mainly from roots); increase of SOM mineralisation from the disruption of aggregates via livestock trampling; increases in soil temperature caused by a decrease in vegetation cover; and increase N leaching and volatilisation from livestock dung and urine (Soussana *et al.,* 2004; Li *et al.,* 2007; Pineiro *et al.,* 2009).

The intensity of grazing (as defined by stock unit per unit area) can have a major impact on the amount of C and N that can enter the soil. In high intensity grazing systems, the consumption of aboveground vegetation can be up to 60% of the net primary production (NPP), with only 25–40% of NPP being returned to the soil as excreta and the rest respired by the animal, which can lead to larger losses of C than inputs of C (Soussana *et al.,* 2004; Dawson and Smith, 2007). The response of soil C and N to the intensity of grazing is not simple to measure, which has led some studies to find light or moderate grazing intensity increased soil C and N stocks (Ganjegunte *et al.,* 2005; Ingram *et al.,* 2008), other studies to find that intensive or heavy grazing decreases C and N stocks (Abril and Bucher, 2001; Ganjegunte *et al.,* 2005; Guodong *et al.,* 2008; Ingram *et al.,* 2008; Steffens *et al.,* 2008) and one study where more intensive farming practices increased C stocks (Conant *et al.,* 2003). Other studies have not been able to show a significant difference in soil C and N stocks under varying grazing intensities (Savadogo *et al.,* 2007; Li *et al.,* 2008; Sanjari *et al.,* 2008).

2.8.2 Soil carbon and nitrogen stocks response to grazing intensity

Some studies undertaken the last decade on the relationship of grazing intensity and soil C and N have been unable to detect any statistically significant differences in soil C and N under different stocking rates. Other studies that were able to detect a difference have generally found lower soil C stocks under higher grazing intensity (stocking rates) compared to lighter grazing intensity or no grazing (Table 2.3).

Conant *et al.* (2003) noted that most grazing impact studies have compared grazed areas with ungrazed areas (exclosures) and/or were undertaken in semi-arid or tropical areas. When considering studies published in the last decade (Table 2.3), it is evident that many studies are still based in semi-arid regions but now often several grazing intensities are examined, rather than a comparison of a single grazing rate to a grazing exclosure. In the last decade, there has been a great deal of research on grazing of rangelands in semi-arid regions for example the USA rangelands (Ingram *et al.,* 2008), Inner Mongolia steppe rangelands (Cui *et al.,* 2005; Guodong *et al.,* 2008) and Argentina (Abril and Bucher, 2001) (Table 2.3), with less information published for temperate regions. This may be explained by land in temperate regions such as Europe and North America being increasingly utilised for forestry (Poeplau *et al.,* 2011). Whilst there are examples of older literature relating to grazing influence on soil C and N (e.g. Jackman, 1964), the focus of this section of the literature review is only on papers published in the last decade.

A study undertaken at a research station in semi-arid Wyoming, USA concluded that compared to grazing exclosures, continuous light stocking rate increased SOC and total N (0–0.05 m) (Ganjegunte *et al*., 2005). SOC and total N were significantly higher under light grazing than the grazing exclosure by about 3.8 Mg C ha^{-1} and 0.29 Mg N ha^{-1} after 21 years of grazing or no grazing ($P<0.05$) (Ganjegunte *et al.,* 2005). As concluded in other studies (Augustine *et al.,* 2003; Frank *et al.,* 2003), light grazing may stimulate above-ground vegetation production and enhance nutrient cycling to sequester C while also helping to maintain biodiversity (Guodong *et al.,* 2008). Quantifying soil C accumulation under light grazing is important because the common practice for light grazing of rangeland environments may be a useful approach to sequester CO_2.

Table 2.3. Summary of studies on grazing intensity impacts on soil C and N from the last decade.

Reference	Location & climatic zone	MAT. (°C)	MAP (mm)	Elevation (m.a.s.l)	Vegetation	Soil	Methods used	Management/ grazing intensity	Soil depth (m)	Soil C (SOC unless otherwise stated)	Soil N (Total N unless otherwise stated)	Overall findings
Abril and Bucher, 2001	Argentina Semi-arid	Hottest: 28.8 Coldest: 16.6	550	-	Grasses, cacti, woodland trees	Aridic Haplustoll	Grazing intensity gradient (6 km long) Bulk density was measured	No livestock grazing for previous 20 years (stock exclusion)	0–0.2	7.05 kg m^{-2} *	Not measured	SOC was significantly different at each site ($P<0.05$) with the least SOC stock under heavily overgrazed
								No livestock grazing for previous 10 years (stock exclusion)	0–0.2	3.10 kg m^{-2} *		
								Heavily overgrazed by cattle and goats for previous 60 years	0–0.2	1.50 kg m^{-2} *		
Ammann *et al.*, 2007	Switzerland Temperate	9.5	1100	450	Grassland	Eutri-Stagnic Cambisol	Eddy covariance 3 years since conversion from cropland to grassland	Extensive – Grass cut 3 times a year & no fertiliser	N/A	Net C loss of 57 (+130/-110) g C m^{-2} y^{-1}	Not measured	C budget mean difference of 204 ±110 g C m^{-2} y^{-1} over 3 years was significantly different, but the P value was not recorded
								Intensive – Grass cut 4 times a year & fertilised with 200 kg N ha^{-1} y^{-1}	N/A	Net C gain of 147 ± 130 g C m^{-2} y^{-1}		
Conant *et al.*, 2003	Virginia, USA	13–14.3	992–1157	-	-	Typic Hapludult & Typic Hapludalf	Paired sites (4 paired sites) Bulk density was measured	Extensively grazed	0–0.5	Average 39.5 Mg ha^{-1} total C	Average 4.52 Mg ha^{-1} total N	3 of 4 paired sites had significantly greater soil C under SRG and 2 of 4 significantly greater soil N under SRG ($P<0.05$)
								Short rotation grazing (SRG)	0–0.5	Average 48.3 Mg ha^{-1} total C	Average 5.28 Mg ha^{-1} total N	
Cui *et al.*, 2005	Inner Mongolia, China	0.2	350	1100	Grassland (natural & degraded)	Mollisol	Paired sites 3 paired sites, 2 on natural and 1 on highly degraded grassland Bulk density was measured	2 paired grazing with no grazing (exclosure) for 20 years on natural grassland	0–0.6	Difference of <0.25 kg m^{-2} for both paired sites	Not measured	Significantly less SOC in the grazing site of the degraded grassland than the exclosure, 1 paired site ($P<0.05$ to 0.001)
								1 paired grazing with no grazing (exclosure) for 10 years on degraded grassland	0–0.6	~2 kg m^{-2}* difference for paired site		
Ganjegunte *et al.*, 2005	Cheyenne, Wyoming, USA Semi-arid	-	425	1910–1950		Aridic Argiustolls	Temporal experimental trial Trial sites established in 1982 & sampled in 2003 Bulk density was measured	No grazing since 1982 (exclosure for 21 yr.)	0–0.05	10.8 ± 0.8 Mg ha^{-1}	0.94 ± 0.04 Mg ha^{-1}	Significantly more SOC and N in the continuous light grazing treatment than the exclosure or heavy grazing treatments ($P<0.05$)
								Continuous light grazing 0.16–0.23 steers ha^{-1} for 21 years	0–0.05	13.8 ± 0.2 Mg ha^{-1}*	1.23 ± 0.03 Mg ha^{-1}*	
								Continuous heavy grazing 0.56 steers ha^{-1} for 21 years	0–0.05	10.9 ± 0.3 Mg ha^{-1}	0.94 ± 0.04 Mg ha^{-1}	

** significantly different at $P<0.10$ * significantly different at $P<0.05$ MAT Mean annual temperature MAT Mean annual temperature

Table 2.3. Continued

Reference	Location & climatic zone	MAT. (°C)	MAP (mm)	Elevation (m.a.s.l)	Vegetation	Soil	Methods used	Management/ grazing intensity	Soil depth (m)	Soil C (SOC unless otherwise stated)	Soil N (Total N unless otherwise stated)	Overall findings
Golluscio *et al.*, 2009	Argentina Semi-arid	Monthly mean varies between 2 & 7	150	-	Steppe grasses and shrubs	-	Experimental sites 5 sites, each with 3 levels of grazing intensity Bulk density not measured	No grazing (exclosure for 5, 10, 21, 32 or 50 years prior to sampling)	0–0.05	~6 g kg^{-1}	~0.55 g kg^{-1} SON	No significant difference of SOC. SON under heavy grazing was significantly less than no grazing and moderate grazing (P<0.05)
								Moderate grazing (0.1–0.3 sheep ha^{-1})	0–0.05	~6 g kg^{-1}	~0.52 g kg^{-1}SON	
								Heavy grazing (same paddock as moderately grazed but closer to water source)	0–0.05	~5 g kg^{-1}	~0.45 g kg^{-1}* SON	
Guodong *et al.*, 2008	Inner Mongolia, China Semi-arid	1	350–450	762–768	-	Haplustoll	Grazing intensity gradient 0.8–0.86 dairy cows ha^{-1} over 7 month grazing period Bulk density not measured	Light grazing	0–0.1 0.1–0.2 0.2–0.3	35.5 g kg^{-1} 25.5 g kg^{-1} 21.7 g kg^{-1}	3.23 g kg^{-1} 2.24 g kg^{-1} 1.95 g kg^{-1}	SOC was significantly less under heavy grazing than light or moderate grazing for two depths (P<0.05) SON was significantly less under heavy grazing than light or moderate grazing for all depths measured (P<0.05)
								Moderate grazing	0–0.1 0.1–0.2 0.2–0.3	34.2 g kg^{-1} 24.6 g kg^{-1} 20.8 g kg^{-1}	3.19 g kg^{-1} 2.23 g kg^{-1} 2.00 g kg^{-1}	
								Heavy grazing	0–0.1 0.1–0.2 0.2–0.3	25.9 g kg^{-1}* 14.9 g kg^{-1}* 15.0 g kg^{-1}	2.53 g kg^{-1}* 1.54 g kg^{-1}* 1.56 g kg^{-1}*	
Ingram *et al.*, 2008	Cheyenne, Wyoming, USA Semi-arid	-	425	1910–1950	Native, northern mixed-grass rangeland	Aridic Argiustolls	Temporal experimental trial Trial sites established in 1982, sampled in 1993 and in 2003 Bulk density was measured	No grazing since 1982 (exclosure for 21 yr.)	 0–0.15 0–0.3 0–0.6	Difference from 1993 to 2003: -0.9 Mg ha^{-1} -0.6 Mg ha^{-1} -7.6 Mg ha^{-1}	Difference from 1993 to 2003: 0.25 Mg ha^{-1} 0.42 Mg ha^{-1} 0.53 Mg ha^{-1}	The only significant difference between 1993 and 2003 was in SOC under heavy grazing (P<0.10)
								Continuous light grazing 0.16–0.23 steers ha^{-1} for 21 years	 0–0.15 0–0.3 0–0.6	Difference from 1993 to 2003: -3.1 Mg ha^{-1} -3.8 Mg ha^{-1} 0.6 Mg ha^{-1}	Difference from 1993 to 2003: -0.01 Mg ha^{-1} -0.21 Mg ha^{-1} 0.93 Mg ha^{-1}	
								Continuous heavy grazing 0.56 steers ha^{-1} for 21 years	 0–0.15 0–0.3 0–0.6	Difference from 1993 to 2003: -10.0 Mg ha^{-1} ** -15.8 Mg ha^{-1} ** -30.8 Mg ha^{-1} **	Difference from 1993 to 2003: -0.33 Mg ha^{-1} -0.54 Mg ha^{-1} -0.57 Mg ha^{-1}	
Li *et al.*, 2007	Inner Mongolia, China Semi-arid	-	250–350	2650–2660	-	Mollisol	Experimental sites Bulk density was measured	Extensive grazing / Conventional grazing 0.3 adult sheep ha^{-1}	0–0.2	52.9 Mg ha^{-1} *	1.9 g kg^{-1}*	SOC was significantly greater (7 Mg ha^{-1}) under intensive grazing/ rotational grazing than extensive/ conventional grazing (P<0.05)
								Intensive grazing / Rotational grazing for 22 years (Grazing pressure less than conventional grazing)	0–0.2	59.9 Mg ha^{-1} *	2.0 g kg^{-1}*	

** significantly different at P<0.10 * significantly different at P<0.05 MAT Mean annual temperature MAT Mean annual temperature

Table 2.3 Continued.

Reference	Location & climatic zone	MAT. (°C)	MAP (mm)	Elevation (m.a.s.l)	Vegetation	Soil	Methods used	Management/ grazing intensity	Soil depth (m)	Soil C (SOC unless otherwise stated)	Soil N (Total N unless otherwise stated)	Overall findings
Li *et al.,* 2008	Inner Mongolia, China Semi-arid	-	280	1440–1510	Short desert steppe species	Mollisol	Experimental sites Bulk density was measured	No grazing for 4-6 years previous (exclosure)	0–0.2	35.56 Mg ha^{-1}	4.02 Mg ha^{-1}	No significant differences found
								Light grazing (3 sheep-unit-month ha^{-1})	0–0.2	35.86 Mg ha^{-1}	4.12 Mg ha^{-1}	
								Moderate grazing (5 sheep-unit-month ha^{-1})	0–0.2	29.64 Mg ha^{-1}	3.50 Mg ha^{-1}	
								Heavy grazing (10-15 sheep-unit-month ha^{-1})	0–0.2	32.38 Mg ha^{-1}	3.88 Mg ha^{-1}	
Sanjari *et al.,* 2008	Queensland, Australia Semi-arid	-	645	675	Native perennial grasses	Clay to clay loams	Paired site & temporal 2 different grazing regimes sampled in 2001 & 2006 Bulk density was measured	Time controlled grazing / short rotation grazing (12.6 ± 6 dry-sheep-equivalents ha^{-1})	0–0.1	In 2001: ~26 t ha^{-1} In 2006: ~27 t ha^{-1}	In 2001: ~2.2 t ha^{-1}SON In 2006: ~2.3 t ha^{-1}SON	No significant differences found through time or between grazing intensities
								Continuous grazing/ Extensive grazing (1.6 dry-sheep-equivalents ha^{-1})	0–0.1	In 2001: ~26 t ha^{-1} In 2006: ~26 t ha^{-1}	In 2001: ~1.9 t ha^{-1}SON In 2006: ~1.9 t ha^{-1}SON	
Savadogo *et al.,* 2007	Burkina Fasco, West Africa	Lowest: 16 Highest: 40	841	300	Tree & bush savannah	Lixisols	Experimental sites Different grazing intensities with no fire treatment	No grazing for 11 years (exclosure)	0–0.1	1.8%	0.07 mg kg^{-1}	No significant difference between grazing intensities
								Light grazing 2 AUD^{-1} ha^{-1} ^{A}	0–0.1	1.7%	0.06 mg kg^{-1}	
								Moderate grazing 4 AUD^{-1} ha^{-1} ^{A}	0–0.1	1.6%	0.06 mg kg^{-1}	
								Heavy grazing 6 AUD^{-1} ha^{-1} ^{A}	0–0.1	1.6%	0.06 mg kg^{-1}	
								Very heavy grazing 8 AUD^{-1} ha^{-1} ^{A}	0–0.1	1.2%	0.05 mg kg^{-1}	
Steffens *et al.,* 2008	Inner Mongolia, China Semi-arid	0.7	343	1270	Steppe	Calcic Chernozems	Chronosequence & paired site Grazed by sheep (70-90%) & goats (10-30%) Bulk density was measured	No grazing since 1979 (exclosure)	0–0.04	1.15 ± 0.11 kg m^{-2} *	0.12 ± 0.01 kg m^{-2} *	Heavy grazing had significantly lower SOC and total N stocks than the ungrazed area The lower intensity grazing was not significantly different to the ungrazed area
								No grazing since 1999 (exclosure)	0–0.04	1.08 ± 0.16 kg m^{-2}	0.11 ± 0.02 kg m^{-2}	
								Winter grazing only (0.5 sheep units ha^{-1} y^{-1})	0–0.04	1.12 ± 0.14 kg m^{-2}	0.12 ± 0.01 kg m^{-2}	
								Continuous grazing (1.2 sheep units ha^{-1} y^{-1})	0–0.04	1.06 ± 0.14 kg m^{-2}	0.11 ± 0.01 kg m^{-2}	
								Heavy grazing (2 sheep units ha^{-1} y^{-1})	0–0.04	0.86 ± 0.16 kg m^{-2} *	0.09 ± 0.01 kg m^{-2} *	

** significantly different at P<0.10   * significantly different at P<0.05   MAT Mean annual temperature   MAT Mean annual temperature ^{A} animal unit per day and per hectare (AUD^{-1} ha^{-1})

Another example of the influence that heavy grazing can have on soil C is a study undertaken in a semi-arid rangeland of Argentina that was heavy grazed for a period of 10 and 20 years (Abril and Bucher, 2001). Abril and Bucher (2001) detected a significant loss of SOC (0–0.2 m) under heavy grazing compared with land that was excluded from grazing over the same time period ($P<0.05$). Two studies of heavy grazing on the steppe landscape of Inner Mongolia have also found significant losses of SOC and total N compared to no, light and moderate grazing (Cui *et al.,* 2005; Guodong *et al.,* 2008). In all three studies, grazing stocking rates were not quantified but relied on a relative grazing intensity along a gradient from a water source or animal housing. Consequently, identifying stocking numbers that lead to changes in soil C is difficult for these examples.

Reasons given to explain the losses of soil C and N from heavily grazed grasslands include, that vegetation changed composition and provided less C and N inputs, soil temperature increased and annual precipitation decreased over the sampling period contributing to a faster rate of SOM decomposition and that the consumption of aboveground biomass by livestock decreased the litter availability for SOM production (Cui *et al.,* 2005; Guodong *et al.,* 2008; Ingram *et al.,* 2008).

Almost half of the studies listed in Table 2.3 were unable to report significant differences between grazing intensities. Kravchenko and Robertson (2011) remind us that the absence of a significant difference does not imply that the soil C or N content are not different but may simply reflect insufficient replication to detect differences against a background of high spatial variability. Studies reporting no significant difference in soil C and N are, again, mostly from semi-arid environments including Inner Mongolia (Li *et al.,* 2008), Queensland, Australia (Sanjari *et al.,* 2008) and West Africa (Savadogo *et al.,* 2007).

The reasons that some studies have reported no significant difference in C and N stocks under different grazing intensities, may include that the measurement period was not sufficient to detect any differences (Sanjari *et al.,* 2008), that most of the soil C and N was held in the humus fraction which was not greatly affected by the grazing (Li *et al.,* 2008) or that the difference in grazing intensities was not sufficient enough to lead to a difference in soil C and N stocks.

A study that appears to be inconsistent with the observed trend of less soil C under heavy grazing intensity is where compared to extensive grazing, higher soil C stocks were found under short rotation grazing (Conant *et al.,* 2003). Short rotation grazing involves short periods of intense grazing followed by a long rest period for the pasture before the next grazing cycle. In the USA, Conant *et al.* (2003) used 4 paired sites of extensive grazing/haying and short rotation grazing (stocking rate was not quantified) and found that soil C stocks were significantly higher ($P<0.05$) for short rotation grazing compared to extensive grazing by an average of 8.4 Mg C ha^{-1} or 22% more (0–0.5 m depth). Soil N was only significantly greater ($P<0.05$) under short rotation grazing at 2 of the 4 paired sites, but the trend for all sites was less soil N under extensive grazing, by an average of 0.76 Mg N ha^{-1} (0–0.5 m depth). As stocking rates were not quantified it is difficult to compare the findings of Conant *et al*. (2003) with other studies.

Similarly, Li *et al.* (2007) found significantly ($P<0.05$) more SOC under short rotation grazing of sheep than under extensive grazing, 13.2% more SOC to 0.2 m depth. However, Li *et al.* (2007) noted that grazing pressure was higher under the extensive grazing than the short rotation grazing, again stocking rates were not quantified. Thus, in the case of Li *et al.* (2007) the short rotation grazing could be more aligned with the light grazing intensity of other studies, and the extensive grazing more similar to a moderate to heavy grazing intensity. It would be interesting to be able to compare the stocking rates of Li *et al.* (2007) and Conant *et al.* (2003) not only between each other, but against the other studies listed in Table 2.3. If the short rotation grazing was considered a heavy grazing intensity the management practice of pasture rest periods may enable higher stocking rates with minimal loss of soil C and N to be sustained in some environments rather than continuous heaving grazing that may cause losses of soil C and N. Compared to extensive grazing, short rotation grazing may allow for a higher proportion of plant material to be incorporated into SOM leading to more soil C and N and also allow for soil to recover from physical disturbances from livestock trampling (Li *et al.,* 2008; Sanjari *et al.,* 2008). Further studies need to be undertaken to investigate the impact of short rotation grazing as it is becoming a popular management technique among graziers around the world, especially in

Australia (Sanjari *et al.,* 2008) and for at least the last half century in New Zealand.

Comparing studies of grazing intensity on soil C and N is difficult due to the non-standardised reporting of stocking rates. A variety of stocking rate descriptors have been used such as dry sheep equivalent ha^{-1}, steers ha^{-1}, adult sheep ha^{-1}, sheep months ha^{-1}, cow-calf pairs ha^{-1} and ha animal-equivalent^{-1} (defined as a 450 kg steer). Because no standard stock units are used it is impossible to easily and accurately compare results across studies. There are also many studies that do not quantify grazing intensity but instead use a relative stocking rate which makes it further impossible to compare across sites. To ensure studies are useful to others it would be helpful to convert the stocking rate to a standard stocking unit per area unit.

Another aspect that makes comparison across studies difficult is how soil C and N stocks are reported. Stocks are most commonly reported to a fixed depth (e.g. 0.2 or 0.5 m) but grazing livestock can often cause soil compaction which can lead to over- or under-estimating C or N concentrations at a fixed depth. It is common for ungrazed sites to have lower soil dry bulk density and to fairly compare ungrazed sites to grazed sites with a higher soil dry bulk density the soil mass should be corrected (Ellert and Bettany, 1995).

Further studies on the impact of grazing on soil C and N stocks need to incorporate farming systems in temperate regions, as these areas do not appear to be well represented in the literature. Understanding how grazing systems influence soil C and N stocks will enable the possible use of management options to either mitigate the loss of soil C and N or sequester C. There can also be other environmental benefits of well managed grazing land such as increased resilience to erosion and maintenance or enhancement of biodiversity (if grazing natural grassland) (Dawson and Smith, 2007).

2.8.3 Soil carbon and nitrogen stocks of New Zealand's grazed land

In New Zealand, grazing land is predominately used for sheep and beef farming or dairy cow farming. Sheep and beef farming are jointly referred to as drystock farming in this literature review and dairy farms are defined as systems that use lactating cows to produce milk. New Zealand's temperate environment is not a dominant climatic zone used for grazing in comparison to the rest of the world, as 78% of grazing land worldwide is on savannahs, grasslands, shrublands and desert ecosystems (Asner *et al.,* 2004). However, pastoral grazing has become a vital part of the New Zealand economy and covers 11.1 million ha of land, almost half of New Zealand's total land area. Approximately half of pastoral farming land (5.4 million ha) in New Zealand is on flat to gently rolling topography. Drystock farming dominates much of the flat to gently rolling land throughout the country (3.6 million ha) with dairy farming occupying around 30% of the flat land (1.5 million ha) (Tate *et al.,* 2005; Schipper *et al.,* 2010). Most of the land occupied by pastoral farming was previously indigenous forest or scrubland that has been converted to grass and clover dominated pasture (Williams and Haynes, 1990).

In New Zealand, dairy and drystock farms have year-round grazing. Both types of farming on flat land are generally managed with rotation grazing, but hill country drystock farms would most often be considered extensively grazed. Dairy farms are generally more intensively managed than drystock farms, with greater inputs of N fertiliser and feed supplements to support higher stocking rates and intensive use of pasture (MacLeod and Moller, 2006; Schipper *et al.,* 2010). In the last few decades, since N fertiliser use became common and other supporting technologies have been developed, some of the land that was traditionally used for drystock farming has been converted to dairy farming. For example, N fertiliser use has increased from minimal quantities in the early 1980s to an average of 115 kg N ha^{-1} in 2005 (Clark *et al.,* 2007).

In the 1960s, Jackman (1964) undertook a study of the cycling of nutrients under pastoral farming in New Zealand. In Jackman's (1964) study, chronosequences for 10 soils converted from scrub to pasture were identified and sampled, incrementally, to 0.3 m. The chronosequence of soils demonstrated that SOM was accumulating in the top 0.075 m and that below this depth there was little or no change in SOM. Jackman (1964) also highlighted that soils containing the clay mineral allophane had more SOM than those which did not.

To aid the understanding of how different land use and management practices influence soil C, a detailed terrestrial C inventory was completed by Tate *et al.* (1997). They estimated that the top 0.25 m of soil held 2500 ± 77 Mt C and the top 1 m held 4260 ± 19 Mt C. Tate *et al.* (1997) also estimated the average soil C stock for New Zealand to be 168 t ha^{-1} (to 1 m depth) which is slightly higher than the estimated global average of 130 t ha^{-1} (to 1 m depth) (Tate *et al.,* 1997).

Following on from the national inventory, efforts were put in to understand how land use and management may influence soil C stocks. Tate *et al.* (1997) compared soil C stocks in the top 0.15 m of pastoral soils from 1950 to 1992. Tate *et al.* (1997) concluded that there was no change in soil C between 1950 and 1992 and that soils were at steady state. However, soil dry bulk density measurements had not been collected and so volumetric comparisons could not be made. Schipper *et al.* (2010) noted that the sampling in 1992 by Tate *et al.* (1997) was prior to the intensification of pastoral farming that included increased N fertiliser use and increased stocking rates which occurred in the 1990s. The assumption of pastoral soils being at steady state for soil C from Tate *et al*. (1997) was utilised by Tate *et al.* (2005) to develop a Carbon Monitoring System to quantify the effects of land use change on SOC. The objective was to provide a tool for policy makers to estimate changes in soil C stocks following the current land use conversions trends of pasture to exotic forests or native shrubland, and to a lesser extent the conversion of drystock to dairy farming.

A more recent study by Schipper *et al.* (2010) of soil C and N stocks under grazing land in New Zealand suggested that not all soils may be at steady state. Schipper *et al.* (2010) re-sampled 83 soils under dairy or drystock on flat land, drystock on hill country and tussock grasslands with an average of 27 years between sampling. They found that soils under dairy farming had lost significant amounts of C and N, 0.73 ± 0.16 Mg C ha^{-1} y^{-1} and 0.057 ± 0.016 Mg N ha^{-1} y^{-1}, to

0.3 m depth ($P<0.005$). The loss of soil C and N was significant ($P<0.05$) throughout the soil profiles to 0.9 m depth. However, drystock farms on flat land had no significant change of soil C and N stocks over the same period. The rates of soil C and N change reported by Schipper *et al.* (2010) indicated that the soils under drystock farming may have remained at steady state through to the 2000s as reported by Tate *et al.* (1997), but that flat land dairy farms had not. Reasons for the loss of soil C and N under dairy farms compared to drystock farms was suggested to be caused by the different management practices of the two farming systems. The recent knowledge that not all soils may be at steady state could impact on previous assumptions used by Tate *et al.* (2005) to develop the Carbon Monitoring System.

To summarise, investigations of soil C and N stocks on New Zealand soils under grazing have been on-going since the 1960s. Research from the 1950s through to the 1990s suggests that pastoral soils may have been at steady state for soil C. From the 1980s to 2000s, Schipper *et al.* (2010) suggest that soils on flat land under dairy farming lost significant amounts of soil C and N right through the soil profile to 0.9 m depth, while soils on flat land under drystock farming had no significant losses or gains and may be at steady state for soil C and N.

2.9 Conclusions

Soil C and N are essential components of soil, especially that used for agricultural purposes. Research has confirmed that land use change and land management practices can alter the soil C and N dynamics and the concern is that practices which lead to losses of soil C and N stocks can cause increases in atmospheric CO_2 emissions and N leaching to waterways.

In the last several decades, research has focused on understanding ‘big picture’ land use change implications and impacts. Large scale land use change is continuing to occur worldwide, and will only continue with the need to support growing demands for food production as will more intensive management practices of current agricultural land. It is important to understand how land management practices will affect soil C and N stocks, so that detrimental effects can be mitigated or avoided. The relationship of soil C and N stocks with management practices of grazed land are not particularly well understood and it is difficult to quantify the complex relationship of soil C and N with grazing intensity.

Chapter 3. Methods

3.1 Introduction

The focus of this study was to compare soil C and N stocks in adjacent dairy and drystock farms. The general approach was to:

- Estimate the number of replicates likely needed to find a difference in soil C and N, if a difference exists, using a paired site methodology (section 3.2.1).
- Identify paired sites in the Waikato region (section 3.2.3) that met specific site requirements (section 3.2.2).
- Use the sampling methodology described in Schipper *et al.* (2010) to collect soil samples and analyse these for total C, total N and soil dry bulk density (section 3.3).
- Calculate stocking rates from the information collected from farm management questionnaires (section 3.4).

This chapter gives a full description of the methods used which are also summarised in Chapter 4, where the methodology is provided in a format more suited to publication in a journal. Thus, there is some repetition between Chapter 3 and the methods section of Chapter 4.

3.2 Sites

3.2.1 Number of paired sites

Detecting changes in soil C and N stocks either temporally or in side-by-side site comparisons is difficult because of the naturally high spatial variability of soil. Kravchenko and Robertson (2011) recommend that an ad hoc power analysis be undertaken prior to sampling to estimate the number of replicates or samples required to achieve a specific level of certainty and change to be detected.

An ad hoc power analysis was completed by the late Dr Greg Arnold, a statistician at Landcare Research, Hamilton, in 2007. The actual variability of the difference in C and N stocks between dairy and drystock paired sites was not known. The power analysis assumed that a paired sampling approach would have similar variability to the Schipper *et al.* (2007) temporal study, where the average loss of C was 2.1 ± 4.8 kg m^{-2} (mean ± standard deviation), to 0.77–1.28 m depth. Dr Greg Arnold also used variability measured in a paired site comparison of soil C contents between pine and pasture soils to select standard deviations (SD) of the difference for the power analysis. SD of 2 and 3 kg C m^{-2} (or 20 and 30 t ha^{-1}) were selected to estimate the number of paired sites needed to be 80% likely to detect a difference of 2 kg C m^{-2} at $P<0.05$. A curve of SD = 3 kg C m^{-2} suggested that a sample size of about 20 paired sites could detect a total difference of 2 kg m^{-2} or 20 t ha^{-1} (Figure 3.1).

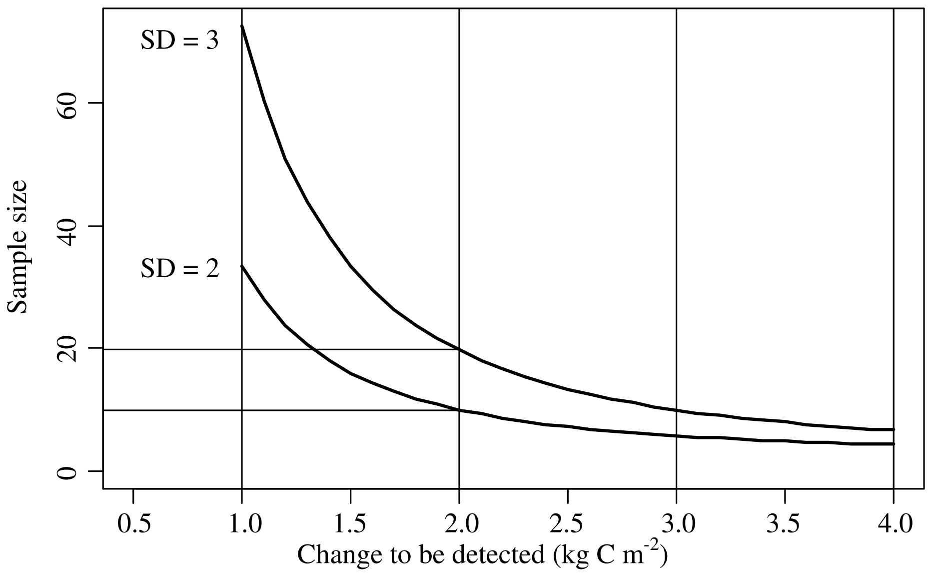

Figure 3.1. Ad hoc power analysis of the number of paired sites estimated to detect a change of 2.0 kg C m^{-2} using different standard deviations. Power analysis provided by Dr Greg Arnold, Landcare Research, Hamilton.

From the information provided by the ad hoc power analysis, it was decided to sample 25 paired sites for this study.

3.2.2 Site selection criteria

To ensure that farms sampled were representative of their farming type and that they would align with sites used by Schipper *et al.* (2010), a set of site selection criteria was established. The criteria were decided following discussions with farmers, a fertiliser scientist (Dr Ants Roberts) and soil science experts from the University of Waikato, AgResearch and Landcare Research.

As one of the aims of this project was to test the findings of Schipper *et al.* (2010), it was important to keep site selection requirements of landscape form and soil properties as similar as possible so that comparisons could be made between the studies. Therefore, only paddocks on the boundary between a dairy and drystock pair with flat to gently rolling topography (<15°) were considered for sampling (Figure 3.2). Potential sampling paddocks on farm boundaries were excluded from selection if they contained organic soils, had been cultivated (grass re-sown or cropped) in the previous two years, had substantial artificial drainage or other recent mass disturbance within the paddock (e.g. hump and hollow, mole or tile drainage) or if they received regular dairy effluent irrigation or water irrigation. It was determined that each farm must have been in dairy or drystock farming for at least 10 years to allow the soils enough time to be influenced by the particular management practices of that type of farming.

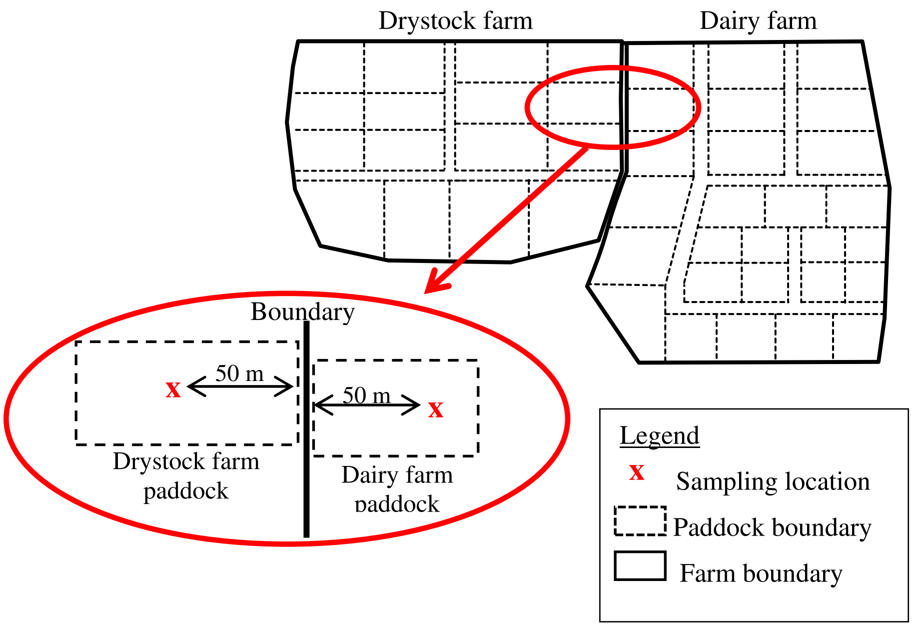

Figure 3.2. Example schematic of the sampling location at a paired site (not to scale).

The breed of cows milked at a dairy farm was not considered, but for the drystock farms only sheep and/or beef farms were considered. Deer farms and dry (non-lactating) dairy cow grazing farms were excluded.

3.2.3 Site selection

Sites were selected in the Waikato region, which is one of the largest dairy farming areas farming areas in New Zealand and a majority of the flat to gently rolling grazing land is land is under dairy farming (

Figure 3.3).

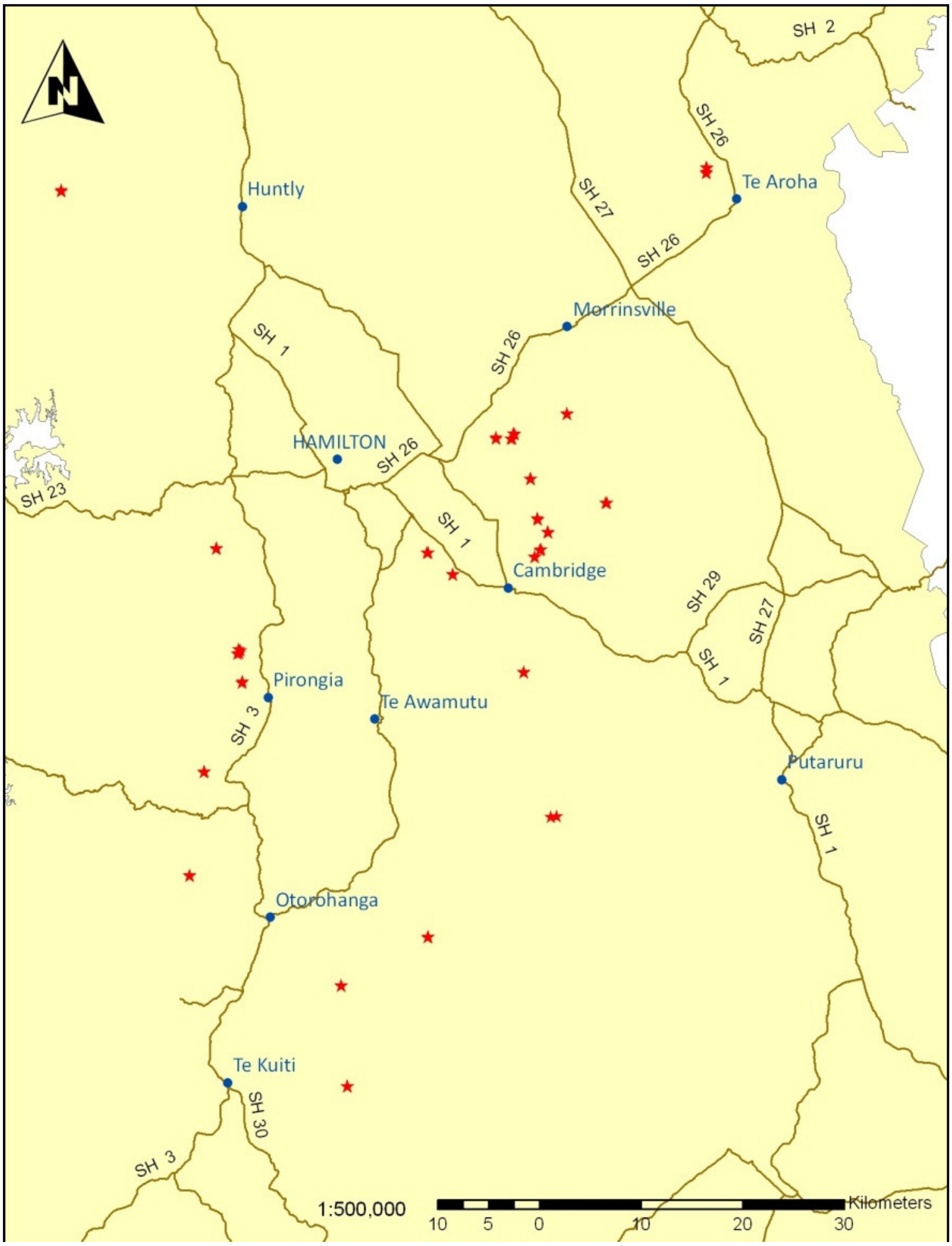

Figure 3.3. Location of paired sites in the Waikato Region, New Zealand.

Potential paired sites were identified several ways, including from information provided by the Waikato Regional Council, word of mouth and searching areas with prospective sites using Google Earth or by physical reconnaissance. The Waikato Regional Council provided a list of the locations of dairy farms that either shared a property boundary or were directly across the road from a drystock farm and on flat land (<15°). From this list, 100 paired sites were randomly selected and land owners were contacted via mail.

As farmers and industry representatives were spoken to about the project, some people were able to suggest other suitable farms. This proved to be a successful method of finding sites, especially once sampling had started in an area with a number of drystock farms.

Areas around the region that were dominated by flat to rolling topography with some drystock farms were searched using Google Earth or physical reconnaissance. From the Google Earth satellite images it was often simple to ascertain whether a farm was dairy or drystock due to the layout of races, if there was a milking shed and images of the stock grazing. The addresses of potential paired sites were then put into QuickMap (Custom Software Ltd, Wellington, New Zealand) which showed farm boundaries and size, and then land owners were contacted.

Initial phone interviews with farmers helped to identify if their farm would meet the necessary requirements of this study (as described in section 3.2.2). Farms were then visited to locate potential sampling sites within boundary paddocks of each farm that had a slope of less than 15°, similar aspect, no obvious in-paddock artificial drainage or recent cultivation. Soils on both farms were checked with a hand-auger to at least 0.7 m depth to ensure the soil was similar (e.g. similar horizon depths, colour, texture and drainage) and that there was no peat present.

3.3 Soil sampling

Sampling occurred between October 2010 and December 2011 (Figure 3.4). In total, 25 paired sites were sampled (50 individual farms). Each paired site was sampled on the same day so that preceding weather conditions were similar for both farms.

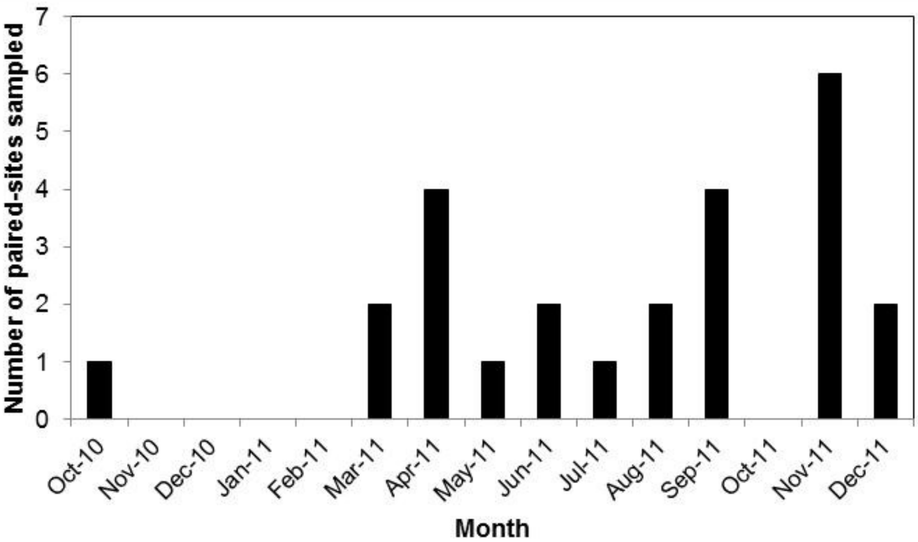

Figure 3.4. Timing of soil sampling of the paired dairy and drystock farms.

At a paired site, a soil pit was dug on each farm to expose the soil profile for description and to take samples for total C, total N and soil dry bulk density by horizon. In general, soil profile pits were between 20 and 50 metres from the farm boundary (

Figure 3.2). The location of the pit was randomly selected within a 10 x 10 metre grid that was positioned in an area of the paddock identified as having similar topography and soil on both the dairy and drystock farms. Matching soils within a paired site and soil profile descriptions were undertaken by an experienced pedologist.

The soil profile was described down to between 0.6 and 1.0 m, following the methods of Milne (1995). A slice of each horizon (approximately 0.03 m thick and 0.25 m wide) was taken to be analysed for total C and total N (Figure 3.5). The samples were stored in plastic bags and refrigerated at 4^{o}C in the laboratory until processed and analysed.

Figure 3.5. An example of a slice of an A horizon being taken for total C and N analysis.

Two soil dry bulk density cores (each either 500.35 cm^{-3} or 577.33 cm^{-3} volume) were taken per horizon. The cores were gently carved into the soil to avoid disturbance (Figure 3.6) (Parfitt *et al.,* 2010). The cores were spaced at approximately one third and two thirds of the depth of the horizon, where the horizon thickness allowed; otherwise they were placed side by side at the same depth. During sampling, if a piece of the soil core broke off, the core was re-sampled therefore, no assumptions on volume had to be made for missing pieces of a core. Samples were stored in a refrigerator at 4°C in the laboratory until analysed.

Figure 3.6. An example of a soil dry bulk density core being carved in to an A horizon

As soil profiles were sampled to 0.6 m depth by horizon, every profile sampled included the whole A and B horizons (first and second horizons). Below the second horizon down to 0.6 m depth were a third and sometimes a fourth horizon and because of the fixed sampling depth, the third or fourth horizon was cut off at 0.6 m. To allow for simple reporting, the horizons are reported as A horizon, B horizon and below B horizon to 0.6 m.

3.4 Land management questionnaire

To obtain an understanding into specific site management practices that may influence changes in soil C and N, a detailed land management questionnaire was developed (Appendix A). The questionnaire was developed in conjunction with AgResearch and Landcare Research staff. Information on land use history, stock management, supplementary feed and fertiliser use was requested in the questionnaire as well as more specific management practices of the paddock which was sampled.

This thesis uses stocking rate as the definition of grazing intensity for this study; a higher stocking rate represented a higher grazing intensity.

3.4.1 Stocking rates

A questionnaire on farm management was completed by 16 dairy farms and 16 drystock farms. Stocking rates were determined using the effective farm area and the live weight loading stock unit system developed by Coop (1965), which is based on livestock grazing equivalents of a 55 kg breeding ewe with lamb at foot. The stock units (SU) for each drystock farm were generally based on the live weight or age and number of wintered stock and the annual peak cow number for the dairy farms over the last 1 to 5 years (Appendix B). Estimating the SU ha^{-1} of dairy farms was relatively simple, provided the breed of the lactating cows was noted. If the breed of cows was not given, the breed was guessed based on the animals seen grazing during soil sampling. Estimating SU ha^{-1} of the drystock farms was more difficult as stock tend to move on and off farm more frequently than dairy farms.

3.5 Laboratory analysis

3.5.1 Soil carbon and nitrogen

The percentage of C and N in each soil horizon was measured by combustion method at either the University of Waikato on a LECO TruSpec CN Carbon/Nitrogen Determinator or at Hills Laboratories, Hamilton on an Elementar VarioMAX CN Combustion Analyser. All soil samples from a paired site were analysed on the same machine. To prepare the soil for analysis, samples were air dried, passed through a 2 mm sieve and then ground using an agate mortar and pestle. A portion of each air dried and sieved sample has been archived at the University of Waikato.

The C and N results from the combustion analysis were presented as a percentage of air dried soil ($\%C_{AD}$ and $\%N_{AD}$).

3.5.2 Moisture factor

To correct the air dried soil mass used for %C and %N determination to oven dry soil mass, a the moisture factor (MF) of the ground samples used for soil C and N analysis was determined. Approximately 3 g of ground sample was added to a pre-weighed aluminium tray and weighed; it was then dried in a 105°C oven for 48 hours and cooled in a desiccator to constant weight. The moisture factor was determined using equation 1.

$$MF = \frac{(M_{AD} - M_t)}{(M_{OD} - M_t)} \qquad \text{(Eqn. 1)}$$

Where, M_{AD} was the mass of air dried soil and aluminium tray (g), M_t was the mass of the aluminium tray (g) and M_{OD} was the mass of oven dried soil and aluminium tray (g).

3.5.3 Soil dry bulk density

Soil dry bulk density (BD) was measured gravimetrically. The volume of soil was calculated as the volume of the stainless steel cylinder that was carved into the soil to collect the bulk density samples (cylinders used were either 500.4 cm^3 or 577.3 cm^3 volume). An aluminium tray was weighed and then a soil core (removed from the cylinder) was added and weighed again. Samples were dried in a 105°C oven for 48 hours and then re-weighed. Bulk density (g cm^{-3}) was calculated from equation 2.

$$BD = \frac{(M_{OD} - M_t)}{V_T} \qquad \text{(Eqn. 2)}$$

Where, M_{OD} was the mass of oven dried soil and aluminium tray (g), M_t was the mass of the aluminium tray (g) and V_T was the total volume of soil (cm^3). As most often two bulk density cores were sampled per horizon, the soil dry bulk density was calculated as an average of those two cores.

3.5.4 Total carbon and total nitrogen

Total C and total N for each soil horizon (TC or TN) were calculated using the horizon thickness, $\%C_{AD}$ or $\%N_{AD}$, moisture factor and soil dry bulk density. The soil dry bulk density measurements (equation 2) were changed from g cm^{-3} to t m^{-3}. To convert grams to tonnes and cubic centimetres to cubic metres a conversion factor of 10^{-6} is necessary for each.

Therefore, the equation used to calculate total C for a horizon (t ha^{-1}) was:

$$TC = HT \times \%C_{AD} \times MF \times BD \times 10^4 \qquad \text{(Eqn. 3)}$$

Where, HT was the horizon thickness (m), $\%C_{AD}$ was the percentage of C per horizon (air dried soil), MF was the moisture factor, BD was the soil dry bulk density (t m^{-3}) and 10^4 was an area conversion factor to convert m^2 in to ha^{-1}.

To calculate total N per horizon (t ha^{-1}), $\%C_{AD}$ was substituted for $\%N_{AD}$ in equation 3 to give:

$$TN = HT \times \%N_{AD} \times MF \times BD \times 10^4 \qquad \text{(Eqn. 4)}$$

Where, HT was the horizon thickness (m), $\%N_{AD}$ was the percentage of N per horizon (air dried), MF was the moisture factor, BD was the soil dry bulk density and 10^4 was an area conversion factor to turn m^2 in to ha^{-1}.

3.6 Statistical analysis

Statistical differences between the means of total C, total N, C:N ratio, horizon thickness, bulk densities and soil mass for dairy and drystock paired sites were analysed using analysis of variance (ANOVA) with site as blocking factor and land use and soil type as treatment factors. Because interaction between land use and soil type was always non-significant, the results are displayed from models with no interaction. Analyses were carried out separately for different soil horizons and for the total soil profile 0–0.6 m depth. A P-value of less than 0.05 was regarded as being statistically significant.

Assumptions of normality and equal variances were checked using standard residual plots.

Chapter 4. Comparison of soil C and N stocks of adjacent dairy and drystock farms in the Waikato Region

4.1 Abstract

A previous temporal sampling study of 83 soils under pastoral grazing in New Zealand indicated that between the 1980s and 2000s soils on flat land under dairy farming had lost significant amounts of C and N, while soils under drystock farming on flat land had not. A conclusion drawn from the previous study was that a dairy farm would have a lower soil C stock than adjacent drystock farm on the same soil. This conclusion relies on the assumption that the adjacent dairy and drystock farms would have originally had similar soil C and N stocks. A synthesis of recent literature on grazing intensity found that often soils under a higher stocking rates often had less C compared to a lower stocking rate.

To test the previous findings we sampled 25 adjacent dairy and drystock farms (paired sites) on flat land in the Waikato Region to 0.6 m depth and analysed samples for C, N and soil dry bulk density by horizon. Sampling sites at each paired site were an average of 108 m apart and located on the same soil with a similar slope, aspect and topography. Where it was possible to obtain data, the estimated average stocking rate for dairy farms (24 ± 0.8 SU ha^{-1}) was higher ($P<0.01$) than drystock farms (14 ± 2.0 SU ha^{-1}). The mean total C and total N stocks for the whole soil profile (0–0.6 m) were 173.1 ± 12.4 t C ha^{-1} and 18.5 ± 0.9 t N ha^{-1} for the dairy farms and 182.7 ± 15.0 t C ha^{-1} and 19.1 ± 5.7 t N ha^{-1} for the drystock farms. The soil C and N stocks for the whole soil profile were not significantly different between dairy and drystock farms. However, when the soil horizons were considered separately there was a significant difference in C stocks of the A horizon of 8.6 ± 4.1 t C ha^{-1} ($P<0.05$), but no significant difference in soil N. The increased variability of soil C and N of the lower horizons meant that the

significant difference in soil C of the A horizon was not evident when the whole soil profile was considered; this supported recommendations for quantifying soil C stocks by horizon.

The A horizon thickness under dairy farming was shallower ($P<0.05$) and the soil dry bulk density was higher ($P<0.05$) than the drystock farms indicating soil compaction, but the total mass of soil sampled from the A horizons was similar for both of grazing (0.14 ± 0.01 t m^{-2}). Therefore, the significant difference in soil C of the A horizon was likely to be a consequence of land management rather than as a result of sampling different masses of soil.

The difference in topsoil C that we detected between dairy and drystock farms aligned with the conclusion drawn from the previous temporal sampling, as well as other studies of grazing intensity. Further work is required to understand the management practices influencing soil C and N dynamics under dairy and drystock farming on flat land in New Zealand.

4.2 Introduction

Soil is the largest terrestrial store of carbon (C). Globally, there is some 2000 Pg of C in soil, to 1 metre depth, compared to 760 Pg in the atmosphere and 500 Pg in above-ground biomass (Janzen, 2004). Research has shown that anthropogenic land use change and management practices can alter soil C stocks, which in turn can alter atmospheric carbon dioxide (CO_2) concentrations (Foley *et al.,* 2005; Ogle *et al.,* 2005; Batlle-Aguilar *et al.,* 2011). Even relatively small losses of soil C can contribute to large increases in atmospheric CO_2. For example, a 5% change in soil C could potentially alter CO_2 concentrations by up to 16% (Mackay, 2008). Conversely, there may be an opportunity to decrease CO_2 concentrations by sequestering it into the soil C pool by altering land use or management (Smith, 2008; Fitton *et al.,* 2011). Soil C is also an important component of many fundamental soil properties and thus, is necessary for maintaining soil quality (Six *et al.,* 2004; McLauchlan, 2006).

Anthropogenic land use and management changes may have also altered soil N dynamics. Nitrogen inputs have increased globally from many sources including the increased use of N-fertiliser, crops that biologically fix N and the combustion of fossil fuels. One of the issues arising from the increase of N inputs is the increased N outputs, which is causing eutrophication of freshwater and N pollution of coastal water. Agroecosystems (croplands and grazing land) have been identified as one of the key contributors of N leaching to water (Vitousek *et al.,* 1997; Galloway *et al.,* 2003; Zhang *et al.,* 2012). It is unknown how long soils may continue to immobilise N, and it has been estimated that some New Zealand pastoral soils may exceed N storage in several decades, leading to potentially increased N losses (Schipper *et al.,* 2004).

Studies on the impact that land management practices have on soil C and/or N have had particular emphasis on forested land (Jandl *et al.,* 2007) and cropland (West and Marland, 2002; Ogle *et al.,* 2005; McLauchlan, 2006; Maia *et al.,* 2010) management worldwide, with less focus on grazing land. Approximately 25% of the global ice-free land area is in managed grazing (Asner *et al.,* 2004). Some studies report that heavily grazed sites have less soil C and/ or N compared to lighter grazing or no grazing (e.g. Abril and Bucher, 2001, Ganjegunte *et al.,* 2005, Guodong *et al.,* 2008 and Steffens *et al.,* 2008), while others are unable to report any statistically significant differences between different grazing intensities (e.g. Savadogo *et al.,* 2007, Li *et al.,* 2008 and Sanjari *et al.,* 2008). Many studies have compared grazing exclosures to a single grazing rate and/ or have been undertaken in semi-arid or tropical regions (Conant *et al.,* 2003). In the last decade, there has been a shift to studies that examine several grazing intensities, although semi-arid regions such as the USA rangelands (Ganjegunte *et al.,* 2005; Ingram *et al.,* 2008), Inner Mongolia steppe rangelands (Cui *et al.,* 2005, Guodong *et al.,* 2008; Steffens *et al.,* 2008) and Argentina (Abril and Bucher, 2001; Golluscio *et al.,* 2009) still dominate the literature, with fewer studies based in temperate regions.

New Zealand's temperate environment permits year round livestock grazing. About 33% of New Zealand's total land area is used for grazing, of which 1.9 million ha is under dairy farming (lactating cows) and 3.8 million ha under intensive, as opposed to extensive high country, drystock farming (raising sheep, beef, deer or non-lactating dairy cows). Both dairy farming and intensive drystock farming are usually on flat to gently rolling land (<15°) (Ministry for the Environment, 2007). Most of the land occupied by pastoral farming was previously indigenous forest or scrubland that has been converted to rye grass and clover dominated pasture (Williams and Haynes, 1990). A common assumption is that dairy farms are generally more intensively grazed than drystock farms (MacLeod and Moller, 2006), although the term 'intensively grazed' is not well defined in the literature.

Several studies have attempted to link changes of soil C and N with land use and land management in New Zealand pastures (e.g. Jackman, 1964, Tate *et al.,* 1997, Schipper *et al.,* 2007 and Schipper *et al.,* 2010). In the 1960s, an investigation of chronosequences of soils converted from scrub to pasture showed that SOM was accumulating in the top 0.075 m of soil, but there was little or no change below this depth to 0.3 m (Jackman, 1964). Tate *et al.* (1997) compared soil C stocks in the top 0.15 m of pastoral soils from the 1950s to 1992 and concluded that there was no change in soil C during this period and that soils were at steady state.

A more recent study by Schipper *et al.* (2010) of soil C and N stocks under grazing land in New Zealand suggested that not all soils were at steady state between the 1980s and 2000s. They found that soils on flat land (<15°) under dairy farming had lost significant amounts of C and N, 0.73 ± 0.16 t C ha^{-1} y^{-1} and 0.057 ±0.016 t N ha^{-1} y^{-1}, to 0.3 m depth (mean ± standard error, $P<0.005$). The loss of soil C and N were significant throughout the soil profiles to 0.9 m depth ($P<0.05$). However, drystock farms on flat land had no significant change of soil C and N stocks over the same period. The rates of soil C and N change reported by Schipper *et al.* (2010) indicated that the soils under drystock farming may have remained at steady state through to the 2000s as reported by Tate *et al.* (1997), but that flat land dairy farms had not. Reasons for the losses of soil C and N reported in Schipper *et al.* (2010) are poorly understood and require further testing and verification using other approaches. Schipper *et al.* (2010) were able to utilise archived soil samples to allow for temporal sampling but access to multiple and suitable archived samples is not always available. Therefore, there is a need for other sampling approaches that can detect changes in soil C and N stocks.

Our primary objective was to test the findings of Schipper *et al.* (2010) and examine if soils on flat land had less C and N stocks under dairy farming than drystock farming using a paired site approach. Our secondary objective was to determine whether any differences in soil C and N were dependant on differences in grazing intensity, as defined by stocking rate, between dairy and drystock farming systems. The key hypothesis was that dairy farms would, on average, have less soil C and N than adjacent drystock farms.

4.3 Methods[1]

4.3.1 Site selection

Sampling soils from paired sites of adjacent dairy and drystock farms was used for this study. The underlying assumption was that in the past, both sites in a pair had similar land use, soil physical and soil chemical properties (Breuer *et al.,* 2006) and that the soil C and N stocks were similar before land use was changed to pastoral grazing.

The precise variability of the difference in soil C and N stocks between dairy and drystock pairs was not known; hence an ad hoc power analysis was completed to estimate the number of paired sites needed to detect a difference in soil C, if one existed. The power analysis assumed that a paired site sampling approach would have similar variability to the temporal study of soil C and N stocks in land under pastoral grazing in New Zealand by Schipper *et al.* (2007). We determined that sampling of about 20 sites would be needed to detect a difference in total C of 20 t C ha^{-1}, 80% of the time at $P<0.05$. To be conservative, we sampled 25 paired sites.

Paired sites were selected based on the following criteria: 1) the farm had to have been a dairy or a drystock farm for at least 10 years, 2) the paired dairy and drystock farms had to be directly adjacent (e.g. share a property boundary or be situated across the road from each other), 3) the paired dairy and drystock farms had to have the same soil and similar elevation, slope and aspect in a paddock

[1] Chapter 3 contains a detailed explanation of the methods used in this study.

within 100 m of the shared property boundary, 4) paddocks were excluded if they contained organic soils, had been cultivated in the previous 2 years, had recent mass disturbance (e.g. in-paddock mole and tile or hump and hollow drainage) or received regular dairy effluent or water irrigation.

Based on the above criteria, 25 paired sites were identified in the Waikato Region (Figure 4.1). Prior to sampling, soils were checked with an auger to determine that they were the same on a dairy and drystock pair. The mean air temperature at sites was estimated to be similar to that at Ruakura, Hamilton (13.7 °C) and the estimated mean annual precipitation ranged from 1124 to 1550 mm (Table 4.1).

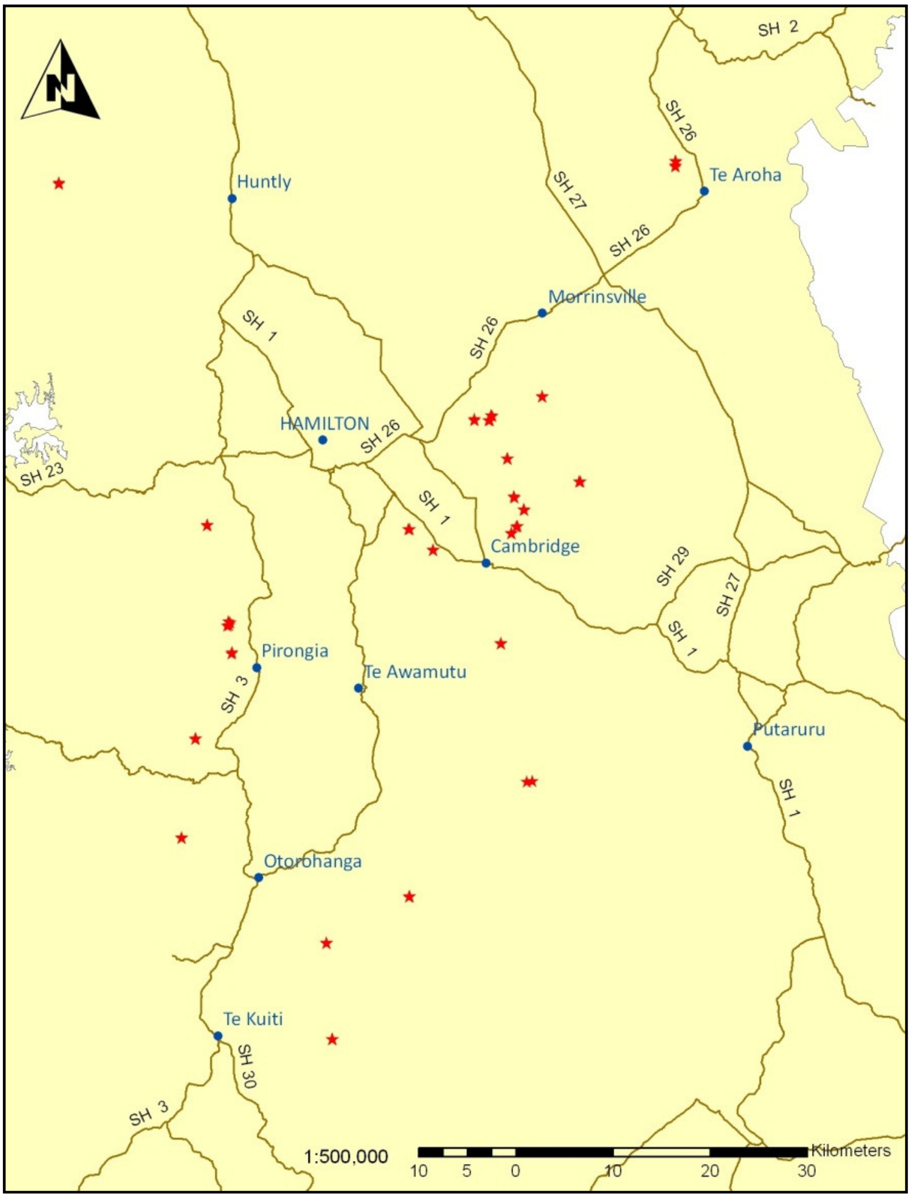

Figure 4.1. Location of paired sites (star symbol) in the Waikato Region of New Zealand.

Table 4.1. Site information for the paired sites sampled.

Site ID	Date sampled	Soil order[A]	MAP[B] (mm)	Elevation[C] (m.a.s.l)	Slope[C] (°)	Distance between sampling locations[E] (m)
01	10-2010	Allophanic	1550	110	6	53
02	03-2011	Allophanic	1211	18	0	101
03	03-2011	Allophanic	1211	18	0	125
04	04-2011	Granular	1190	46	3	125
06	04-2011	Gley	1190	73	0	156
07	04-2011	Gley	1190	58	0	101
08	09-2011	Allophanic	1550	114	0	63
09	04-2011	Allophanic	1190	65	0	66
10	04-2011	Gley	1190	82	2	86
11	09-2011	Granular	1190	68	5	78
12	06-2011	Allophanic	1127	137	6	92
13	06-2011	Allophanic	1127	89	1	193
14	07-2011	Allophanic	1190	194	0	118
15	08-2011	Gley	1550	71	0	75
16	08-2011	Allophanic	1550	230	9	94
17	09-2011	Allophanic	1550	383	6	81
18	09-2011	Allophanic	1190	119	6	72
19	11-2011	Allophanic	1190	74	2	176
20	11-2011	Gley	1190	54	0	78
21	11-2011	Granular	1190	101	4	74
22	11-2011	Gley	1190	73	0	105
23	11-2011	Allophanic	1190	53	1	177
24	11-2011	Allophanic	1190	71	2	231
25	12-2011	Brown	1190	23	0	93
26	12-2011	Allophanic	1124	63	6	85

[A]New Zealand Soil Classification

[B]Mean annual precipitation, estimated from the Waikato Regional Council's rainfall station closest to the site (http://www.waikatoregion.govt.nz) or from the Ruakura climate station NIWA (http://niwa.co.nz)

[C]Mean from the paired dairy and drystock site

[E]Distance between the sampling locations of the paired dairy and drystock farms

4.3.2 Stocking rates

A questionnaire on farm management was completed by most farmers (16 dairy farms and 16 drystock farms) to provide information on land use history, stock management, supplementary feed and fertiliser use as well as more specific management practices of the paddock which was sampled. Stocking rates were determined using the effective farm area and the live weight loading stock unit system developed by Coop (1965), which is based on livestock grazing equivalents of a 55 kg breeding ewe with lamb at foot. The stock units (SU) for drystock farms were generally based on the live weight or age of stock and the number of wintered stock and the annual peak cow number for the dairy farms, over the last 1 to 5 years (Appendix B). Estimating the stocking rate of dairy farms was relatively simple, provided the breed of the lactating cows was noted. If the breed of cows was not given, the breed was guessed based on the animals seen grazing during soil sampling. Estimating stocking rates of the drystock farms was more difficult as stock tend to move on and off farm more frequently than dairy farms.

We have used stocking rate as the definition of grazing intensity for this study; a higher stocking rate represented a higher grazing intensity.

4.3.3 Soil sampling

Soil samples were collected between October 2010 and December 2011. Each paired site was sampled on the same day so that preceding weather conditions were similar for both farms. At a paired site, a soil pit was dug on each farm to expose the soil profile to ensure soils were similar across a paired site as well as for soil description analysis and to take samples for total C, total N and soil dry bulk density by horizon.

The location of each pit was randomly selected within a 10 x 10 metre grid that was positioned in an area of a paddock identified as having similar soil and topography on both the dairy and drystock farms. The soil profile was described down to between 0.6 and 1.0 m, following the methods of Milne (1995) and the soil order was classified from the New Zealand Soil Classification (Hewitt, 1998).

A slice of each horizon (approximately 0.03 m thick and 0.25 m wide) was taken to be analysed for total C and total N.

Two bulk density cores (volume of 500.4 cm^{-3} or 577.3 cm^{-3}) were taken from each horizon. The cores were gently carved into the soil to avoid disturbance (Parfitt *et al.,* 2010). The cores were spaced at approximately one third and two thirds of the depth of the horizon, where the horizon thickness allowed; otherwise they were placed side by side at the same depth.

As soil profiles were sampled to 0.6 m depth by horizon, every profile sampled included the whole A and B horizons (first and second horizons). Below the second horizon down to 0.6 m depth was a third and sometimes a fourth horizon and because of the fixed sampling depth, the third or fourth horizon was cut off at 0.6 m. To allow for simple reporting, the horizons are reported as A horizon, B horizon and below B horizon to 0.6 m (i.e. the lowest reporting depth may include a fourth horizon).

4.3.4 Soil carbon and nitrogen analysis

The percentage of C and N in each soil horizon was measured by combustion method at either the University of Waikato on a LECO TruSpec CN Carbon/Nitrogen Determinator or at Hills Laboratories, Hamilton on an Elementar VarioMAX CN Combustion Analyser. To prepare the soil for analysis, samples were air-dried, passed through a 2 mm sieve and then ground using an agate mortar and pestle. Air dried soil $\%C_{AD}$ and $\%N_{AD}$ were corrected to oven dry weight using a moisture factor determined by drying a sub-sample at 105°C to constant weight.

Soil dry bulk density was measured gravimetrically. Soil from the bulk density cores was dried at 105°C to constant weight and then divided by the core volume. In general, two cores were taken per horizon and the soil dry bulk density was calculated as the mean of the two cores.

Total C and total N for each soil horizon (TC or TN) were calculated as the product of the horizon thickness, $\%C_{AD}$ or $\%N_{AD}$, moisture factor and soil dry bulk density. The data for each horizon was summed to give TC and TN to 0.6 m depth.

4.3.5 Statistical analysis

Evidence for statistical differences between the means of total C, total N, C:N ratio, horizon thickness, soil dry bulk densities and soil mass for dairy and drystock paired sites were analysed using analysis of variance (ANOVA) with site as blocking factor and land use and soil type as treatment factors. Because interaction between land use and soil type was always non-significant we display the results of models with no interaction. Analyses were carried out separately for different soil horizons and for the total soil profile (0–0.6 m depth). Statistical differences between stocking rates of the dairy and drystock farms was analysed using a paired t-test. A P-value of less than 0.05 was regarded as being statistically significant. Assumptions of normality and equal variances were checked using standard residual plots.

Error bounds presented are the standard error of the mean or the standard error of the difference, unless stated otherwise.

4.4 Results

Twenty-five paired sites were sampled in the Waikato Region (soil descriptions are in Appendix C and raw data is in Appendix D). The soil orders sampled were: Allophanic (15), Gley (6), Granular (3) and Brown (1). The soil profile pits in each pair were on average 108 m apart, but this distance ranged from 53 to 231 m (Table 4.1).

4.4.1 Total C, total N and C:N ratio

The mean soil C stock of the dairy farms was 173.1 ± 12.4 t C ha^{-1} and 182.7 ± 15.0 t C ha^{-1} for the drystock farms down to 0.6 m depth, with no significant difference between the two types of grazing (Table 4.2 and Figure 4.2).

However, when horizons were compared separately the soil C in the A horizon of drystock farms was greater than dairy farms, with a mean difference of 8.6 ± 4.1 t C ha^{-1} ($P<0.05$, Table 4.2). The 95% confidence interval for this difference was 0.15 to 17.05 t C ha^{-1}. There was no significant difference in C stocks between dairy and drystock farms in the B horizon or the lowest horizon (Table 4.2).

Table 4.2. Mean total C of dairy and drystock sites for different soil horizons or depth.

Soil depth	**Dairy (t C ha^{-1})**	**Drystock (t C ha^{-1})**	**Difference (t C ha^{-1})**	**SED[A] (t C ha^{-1})**	**P value**
0–0.6 m	173.1 (12.4)	182.7 (15.0)	9.6 (40[B])	7.9	0.236
A Horizon	94.7 (5.7)	103.3 (6.1)	8.6	4.1	**0.048**
B Horizon	44.5 (4.5)	43.4 (4.6)	-1.1	3.7	0.779
Below B horizon to 0.6 m	34.0 (5.3)	36.1 (6.0)	2.1	3.2	0.518

Standard error of the mean in parenthesis.
[A] Standard error of the difference between means.
[B] Standard deviation.

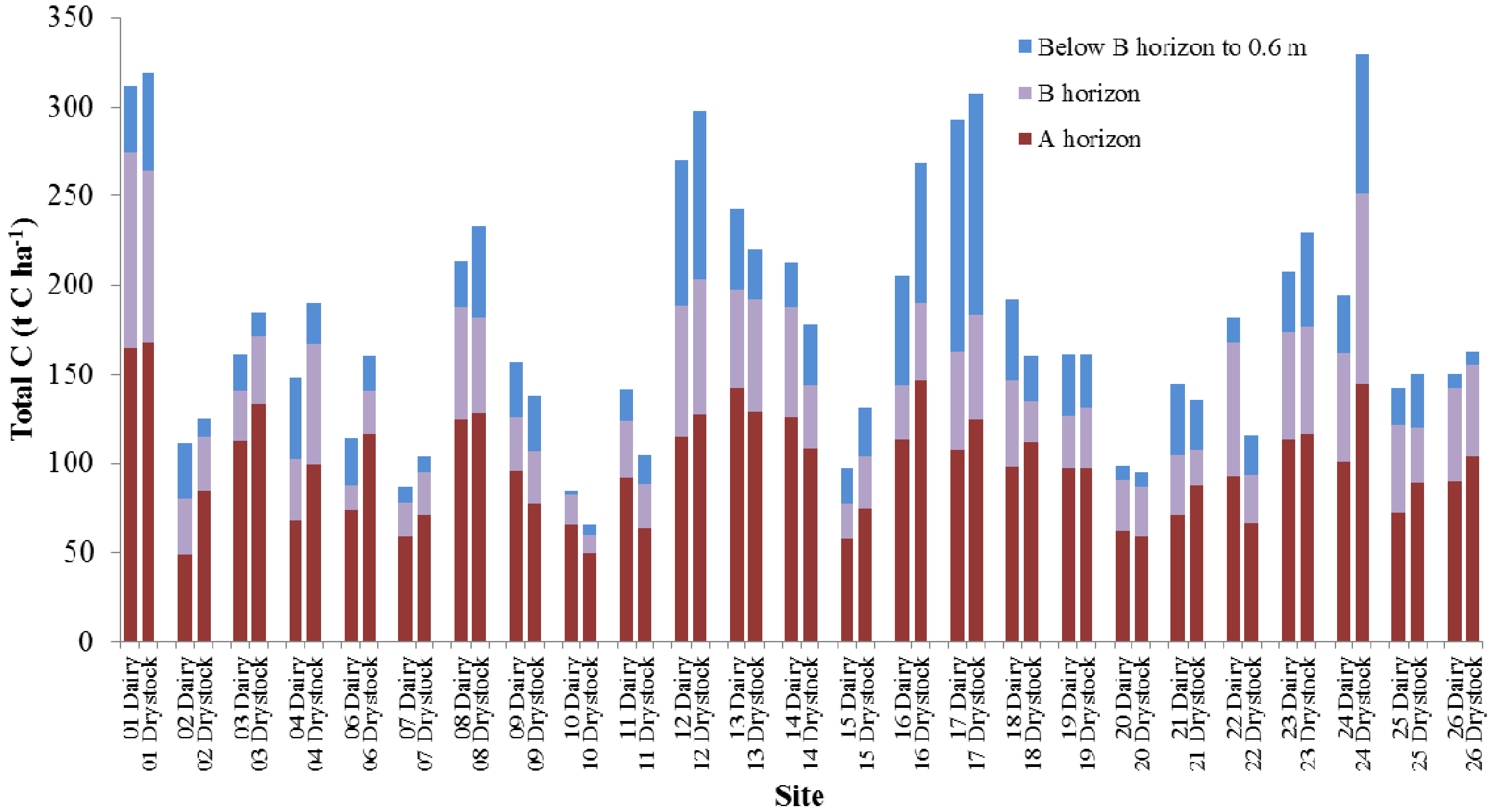

Figure 4.2. Total soil C for each site by horizon to 0.6 m depth. Graph arranged with A horizon then B horizon then below B horizon to 0.6 m depth to allow for easy visual comparison of A horizon soil C stocks.

There was no significant difference in total N between the two types of grazing for the full soil profile to 0.6 m depth or for any of the horizons considered individually (Table 4.3 and Figure 4.3).

Table 4.3. Mean total N of dairy and drystock sites for different soil horizons or depth.

Soil depth	**Dairy ($t\ N\ ha^{-1}$)**	**Drystock ($t\ N\ ha^{-1}$)**	**Difference ($t\ N\ ha^{-1}$)**	**SED[A] ($t\ N\ ha^{-1}$)**	**P value**
0–0.6 m	18.5 (0.9)	19.1 (5.7)	0.6	0.7	0.463
A Horizon	9.8 (0.5)	10.5 (0.6)	0.7	0.4	0.088
B Horizon	4.7 (0.4)	4.6 (0.4)	-0.1	0.4	0.697
Below B horizon to 0.6 m	4.1 (0.5)	4.0 (0.4)	-0.1	0.3	0.745

Standard error of the mean in parenthesis.
[A] Standard error of the difference between means.

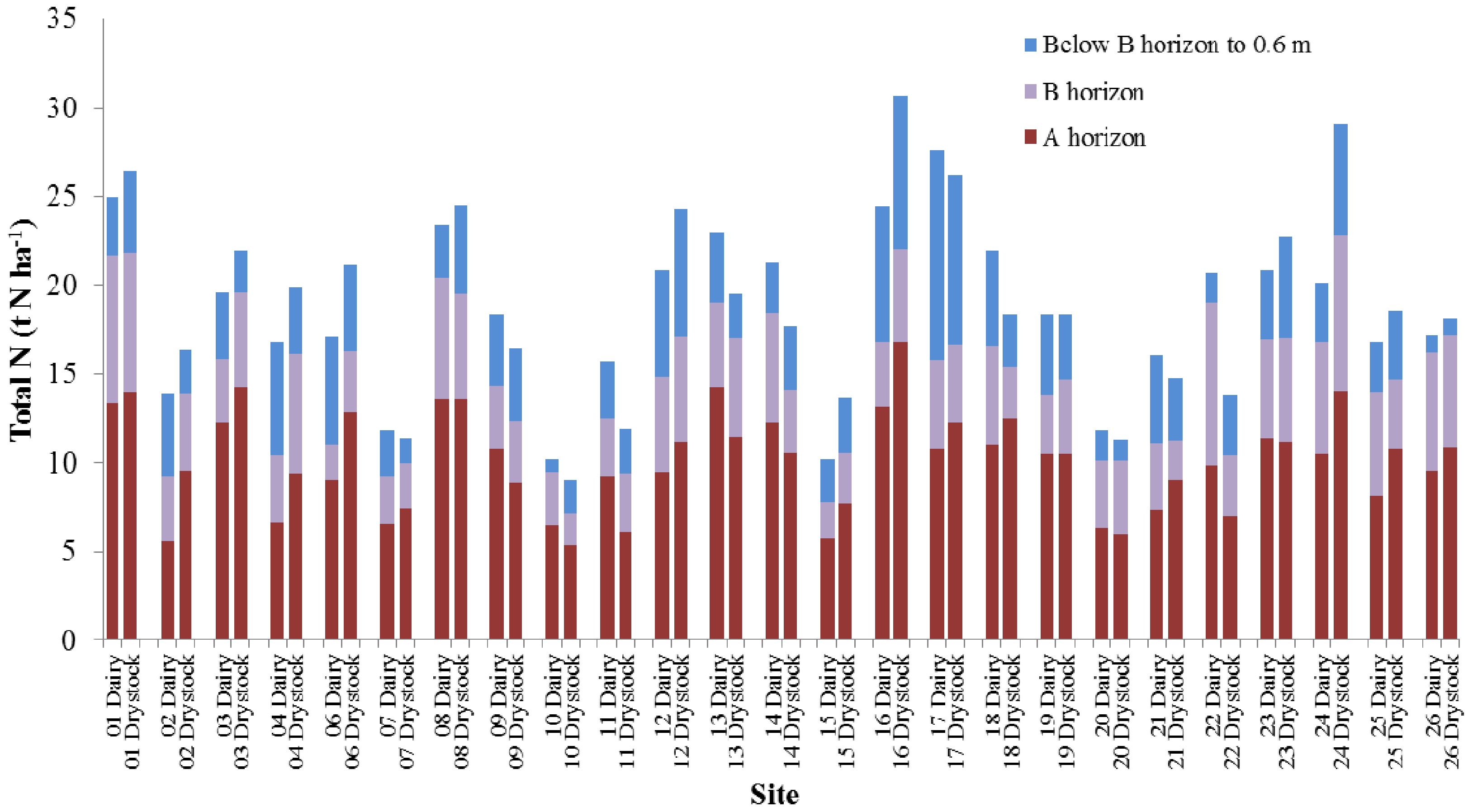

Figure 4.3. Total soil N for each site by horizon to 0.6 m depth. Graph arranged with A horizon then B horizon then below B horizon to 0.6 m depth to allow for easy visual comparison of A horizon soil N stocks.

The C:N ratio of the dairy and drystock farms was generally low with little variation between sites (Table 4.4). The difference in the C:N ratio between dairy and drystock farms at different soil depths only ranged between 0 to 0.3 and none of these differences were significant.

Table 4.4. Mean C:N of dairy and drystock sites for different soil horizons or depth.

Soil depth	Dairy	Drystock	Difference	SED[A]	P value
0–0.6 m	9.2 (0.3)	9.4 (0.3)	0.2	0.1	0.169
A Horizon	9.7 (0.2)	9.8 (0.2)	0.1	0.1	0.180
B Horizon	9.1 (0.4)	9.1 (0.4)	0	0.2	0.800
Below B horizon to 0.6 m	7.9 (0.5)	8.2 (0.6)	0.3	0.2	0.177

Standard error of the mean in parenthesis.
[A] Standard error of the difference between means.

Soil C and N stocks were higher in the Allophanic soils than non-allophanic soils (Figure 4.4). However, soil order had no significant effect on the size of the difference in soil C and N between dairy and drystock farms. Thus, the soil order effect was not further explored. The N content of soils was strongly correlated to the C content (R^2 = 0.86, Figure 4.4).

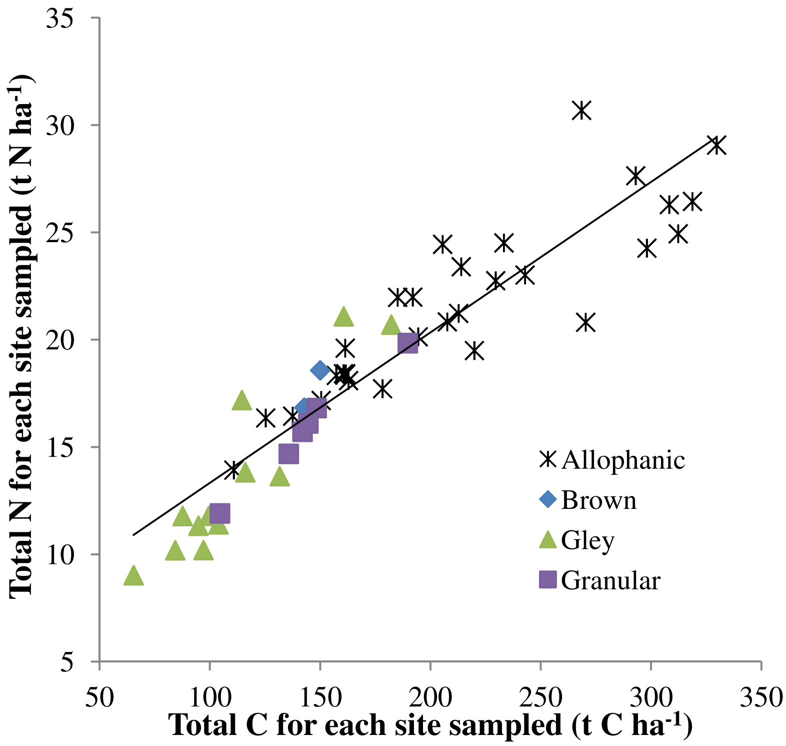

Figure 4.4. The relationship between total N and total C (0–0.6 m depth) for each site sampled and by soil order. TN = 0.07TC + 6.3, R^2 = 0.86.

4.4.2 Soil dry bulk density, horizon thickness and soil masses

Soil dry bulk densities differed between horizons but the only significant difference was found in the A horizon, with dairy farms having a slightly higher soil dry bulk density than drystock farms (P<0.05, Table 4.5).

Table 4.5. Mean soil dry bulk density of dairy and drystock sites for different soil horizons or depth.

Soil depth	Dairy ($t\ m^{-3}$)	Drystock ($t\ m^{-3}$)	Difference ($t\ m^{-3}$)	SED[A] ($t\ m^{-3}$)	P value
A Horizon	0.87 (0.04)	0.83 (0.04)	-0.04	0.019	**0.038**
B Horizon	0.86 (0.05)	0.89 (0.06)	0.03	0.015	0.177
Below B horizon to 0.6 m	0.88 (0.05)	0.90 (0.06)	0.02	0.023	0.389

Standard error of the mean in parenthesis.
[A]SED, standard error of the difference between means.

The thickness of horizons sampled varied between dairy and drystock farms, but was only significantly different in the A horizon, with drystock farms having a slightly thicker topsoil by 0.01 ± 0.006 m (Table 4.6).

Table 4.6. Mean horizon thickness of dairy and drystock sites.

Soil depth	Dairy (m)	Drystock (m)	Difference (m)	SED[A] (m)	P value
A Horizon	0.16 (0.03)	0.17 (0.03)	0.01	0.006	**0.017**
B Horizon	0.18 (0.07)	0.19 (0.06)	0.01	0.010	0.732
Below B horizon to 0.6 m	0.26 (0.08)	0.24 (0.06)	-0.02	0.014	0.177

Standard deviation in parenthesis.
[A]SED, standard error of the difference between means.

The mass of soil sampled from each horizon was calculated as the product of soil thickness and bulk density. The average soil mass of each horizon under dairy and drystock grazing was similar, especially the A horizon which averaged 0.14 ± 0.01 $t\ m^{-2}$ under both grazing types (Table 4.7).

Table 4.7. Mean soil mass for dairy and drystock sites for each soil horizon or depth.

Soil depth	Dairy ($t\ m^{-2}$)	Drystock ($t\ m^{-2}$)	Difference ($t\ m^{-2}$)	SED[A] ($t\ m^{-2}$)	P value
0–0.6 m	0.52 (0.03)	0.53 (0.03)	0.004	0.010	0.686
A Horizon	0.14 (0.01)	0.14 (0.01)	0.006	0.006	0.351
B Horizon	0.16 (0.02)	0.17 (0.02)	0.008	0.012	0.517
Below B horizon to 0.6 m	0.23 (0.02)	0.22 (0.02)	-0.010	0.015	0.511

Standard error of the mean in parenthesis.
[A]SED, standard error of the difference between means.

4.4.3 Stocking rates

The mean stocking rate of dairy farms was 24 ± 0.8 SU ha^{-1} which was significantly greater ($P<0.01$) than the stocking rate of drystock farms at 14 ± 2 SU ha^{-1} (Table 4.8). The variability of stocking rate of the drystock farms was also greater, and represented the range of stocking rates estimated (from 6 to 30 SU ha^{-1}). It was difficult to obtain information from each farmer, hence mean stocking rates were estimated from a subset of 16 dairy and 16 drystock farms.

Table 4.8. Estimated stocking rates based on the stock unit system of Coop (1965). Average stocking rates were significantly diffferent from one another at P<0.01.

	Number of farms	Average (SU ha^{-1})	Standard error (SU ha^{-1})	Range (SU ha^{-1})
Dairy	16	24	0.8	14 – 27
Drystock	16	14	2	6 – 30

4.5 Discussion

There was no significant difference in soil C and N stocks between dairy and drystock farms when the whole soil profile was considered to 0.6 m depth. However, individual horizons were analysed, there was significantly less ($P<0.05$) soil C in the A horizon of dairy farms than drystock farms (94.7 ± 5.7 t C ha^{-1} and 103.3 ± 6.1 t C ha^{-1}, respectively). There were also important differences in soil physical properties of the A horizon. The A horizon thickness was an average of 10 ± 6 mm deeper ($P<0.05$) in drystock than dairy farms but the soil dry bulk density was greater ($P<0.05$) in the A horizon of the dairy farms (0.87 ± 0.04 t m^{-3})

than the drystock farms (0.83 ± 0.04 t m^{-3}). As a result of the dairy farms having a shallower horizon depth but a higher soil dry bulk density, the mass of soil sampled in the A horizon was the same as the drystock farms, both with an average of 0.14 ± 0.01 t m^{-2}. Given the similar mass of soil sampled in the A horizon of dairy and drystock farms, the significant difference in soil C observed was likely to be a consequence of land management rather than from sampling different masses of soil. An important assumption was that both sites of a pair would have originally had similar soil C and N stocks. Multiple auger holes were done at each farm and assessed by a pedologist, with more than ten year's experience, in an effort to get the best match of soils within a paired site to satisfy the fundamental assumption as best we could.

The significant difference in soil C of the A horizon between dairy and drystock farms supported the conclusion drawn from Schipper *et al.* (2010), that dairy farms would have a lower soil C stock than adjacent drystock farms on the same soil, on flat land. However, no significant differences in soil C were detected for the B horizon or below to 0.6 m depth or for the total profile (0–0.6 m depth), nor were any differences in soil N stocks determined between the paired sites for any horizon or the total profile. This lack of difference of soil C at depth and soil N was in contrast to Schipper *et al.* (2010) who found a decline in soil C and N under dairy farms throughout the soil profile to 0.9 m depth. One potential reason for the discrepancy between the current study and Schipper *et al.* (2010) was that the variability of soil C and N was greater than expected when using a paired sampling approach compared to the temporal sampling of pastoral grazing by Schipper *et al.* (2007). The ad hoc power analysis we conducted prior to sampling suggested that 25 paired sites should have been able to demonstrate differences in soil C stocks throughout the profile. However, the difference in soil C between dairy and drystock sites used in the ad hoc power analysis was larger (20 t C ha^{-1}) than was observed in the current study (9.6 t C ha^{-1}). Furthermore, the estimated standard deviation of the difference in soil C between dairy and drystock sites used in the power analysis was set at 30 t C ha^{-1} to 0.6 m depth and this estimated standard deviation was smaller than the standard deviation we observed (40 t C ha^{-1}). As a result of the ad hoc power analysis's underestimation of both the size of the difference and standard deviation of the difference in soil C (to 0.6 m depth), sampling a larger number of paired sites may have been necessary to enable any significant differences to be detected at greater depths or the whole profile, if indeed there was a real difference.

That we could detect a difference in soil C of the A horizon but not the whole soil profile aligned with similar findings in a number of other studies, where the additional variability of soil C and N stocks of the lower horizons meant the significant differences in the topsoil was not evident when the whole soil profile was analysed (Kravchenko and Robertson, 2011). For example, DeGryze *et al.* (2004) detected significant differences in soil organic C between agricultural, afforested, natural field succession and native land uses at 0–0.07 m depth but not at 0–0.5 m depth. Schipper and Sparling (2011) reported significant increases in total C for 9 of 10 soils converted from scrub to pasture at 0–0.075 m depth but only 2 of the 10 soils still showed a significant increase of soil C at 0–0.3 m depth ($P<0.05$). The naturally high variability of soil C concentration and stock with depth means it was not surprising to be unable to detect differences in C stocks of whole soil profiles, and is why Kravchenko and Robertson (2011) recommend that each horizon should be analysed separately.

Our results also aligned with those of Schipper *et al.* (2010), who were unable to demonstrate an effect of soil order on the size of the change in soil C for dairy and drystock farms. Allophanic soils are particularly prevalent in the Waikato Region where this study was conducted and made up 60% of the paired sites sampled. Allophanic soils often have greater soil C than other soil orders and are also thought to protect C more than other soil orders (Parfitt, 2009). Consequently, Schipper *et al.* (2010) stated they initially thought that Allophanic soils under dairy farming would have lost less soil C than other soil orders. They found that Allophanic soils did lose slightly less soil C (0.6 t C ha^{-1} y^{-1}) than the other soil orders but this difference was not significant.

The mean C:N ratio of the A horizon of both dairy (9.7) and drystock (9.8) farms was lower than other reported ratios for New Zealand pastoral soils (11.5 to 11.7) (Schipper *et al.,* 2004; Schipper *et al.,* 2010), and at the lower end of the worldwide range (9.9–25.8, Batjes, 1996). The relatively low C:N ratios found likely reflect the fact that all farms sampled were managed to support clover growth and that nearly all the dairy farms and over half of the drystock farms used N fertiliser. It may have been that the drystock farms used in the current study had been more intensively managed that those reported in Schipper *et al.* (2010).

4.5.1 Grazing intensity

There are a number of important differences between the grazing management of dairy and drystock systems that might contribute to the difference in soil C stocks observed in the A horizon, which include stocking rate and stocking type. The stocking rates we estimated indicated that drystock farms on flat land in the Waikato region were generally more lightly stocked than dairy farms, and therefore less intensively grazed. The estimated stocking rate for the dairy farms (24 ± 0.8 SU ha^{-1}) was significantly greater than the drystock farms (14 ± 2 SU ha^{-1}). The larger standard error of the drystock farms in part represented the difficulty in estimating stocking rates given the frequent movement of stock on and off farms compared to dairy farms.

In general, previous studies have found that higher stocking rates have either led to lower soil C and/or N (Ganjegunte *et al.,* 2005; Li *et al.,* 2007; Steffens *et al.,* 2008) or they have been unable to detect a difference (Savadogo *et al.,* 2007; Li *et al.,* 2008; Sanjari *et al.,* 2008), which is in general agreement with our study (Table 4.9). The stocking rates we estimated for dairy and drystock farms were generally higher than those measured in other grazing studies published in the last decade, possibly because studies have predominately been undertaken in semi-arid regions with lower stocking rates reflecting the lower productivity of the land used for grazing. For example, Ganjegunte *et al.* (2005) compared stocking rates of 0.16–0.23 steers ha^{-1} (light grazing) and 0.56 steers ha^{-1} (heavy grazing) and found that soil C (0–0.05 m) was about 3 t C ha^{-1} less ($P<0.05$) under the higher stocking rate. If the stocking rates used by Ganjegunte *et al.* (2005) were converted to Coop's (1965) stock unit system, the stocking rates range from 0.7 to 1.0 SU ha^{-1} for the light grazing and 2.5 SU ha^{-1} for the heavy grazing (Table 4.9), which are considerably lower to the mean stocking rates of our study. Steffens *et al.* (2008) reported less soil C under heavy sheep and goat grazing (2 SU ha^{-1} y^{-1})

than winter only grazing (0.5 SU ha^{-1} y^{-1}) of about 2.6 t C ha^{-1} in the top 0.04 m of soil in Inner Mongolia. Again, the stocking rates of Steffens *et al.* (2008) were much less than our study.

Table 4.9. Summary of studies that investigated the effect of stocking rate on soil C and N stocks. Stocking rates were converted to stock unit system of Copp (1965) where necessary. Full details for these studies is in Table 2.3.

Reference	**Grazing intensity (SU ha^{-1})**	**Soil depth**	**Estimated difference in soil C or soil N**
Ganjegunte *et al.,* 2005[A]	0.7–1.0 & 2.5	0–0.05	2.9 t C ha^{-1}* & 0.29 t N ha^{-1}* less under higher stocking rate
Golluscio *et al.,* 2009[B]	0.1–0.3 & in same paddock but closer to water source	0–0.05	No significant difference in soil C. 0.07 g kg^{-1}* less SON under higher stocking rate
Li *et al.,* 2007[B]	<0.3 & 0.3	0–0.2	7 t C ha^{-1}* & 0.1 g kg^{-1}* total N less under higher stocking rate
Li *et al.,* 2008[C]	3¸5 & 10-15[B]	0–0.2	No significant differences detected
Sanjari *et al.,* 2008[B]	1.6 & 12.6	0–0.1	No significant differences detected
Savadogo *et al.,* 2007[A]	10, 20, 30 & 40	0–0.1	No significant differences detected
Steffens *et al.,* 2008[B]	0.5 & 2	0–0.04	2.6 t C ha^{-1}* & 0.3 t N ha^{-1}* less under higher stocking rate than two lower stocking rates
This study	14 & 24	0–0.16	9.6 t C ha^{-1}* less under higher stocking rate.

[A] Stocking rates converted to Coop (1965) stock unit system.

[B] Used a similar stock unit system as Coop (1965) therefore there was no need to convert.

[C] Estimated 1 sheep-unit-month ha^{-1} = 1 SU ha^{-1}

* $P<0.05$

Some studies do not quantify stocking rates, making direct comparisons to our study impossible. For example, Guodong *et al.* (2008) only differentiate relative grazing intensities by a gradient away from the animals' housing. However, Guodong *et al.* (2008) did detect less soil C under the relatively higher stocking rate by approximately 20 g kg^{-1} to 0.2 m depth, although bulk density was not measured and therefore results could not be corrected for area comparison. The difference we measured in soil dry bulk density between dairy and drystock farms was small but roughly 5% and if not accounted for might lead to an underestimation of the true soil C loss in the A horizon.

Recent grazing intensity studies that use a paired site approach generally have a small number of paired sites, ranging from a single comparison (Sanjari *et al.,* 2008) to three paired sites (Cui *et al.,* 2005). However, there are often multiple sampling plots in each site, for example 52 sampling sites were used across one paired site in the study by Sanjari *et al.* (2008), as opposed to sampling from a single pit for each site in our study. Sanjari *et al.* (2008) detected no difference in soil C or N between two grazing intensities on one paired site. Cui *et al.* (2005) found significantly less ($P<0.05$) soil C in one of the three paired sites investigated however, they compared a single grazing regime to a grazing exclosure. No published studies comparing grazing intensity or different stocking rates with a similar number of paired sites sampled to our study were found.

It is common for grazing intensity to be defined by the difference in stocking rates and most studies compare the same type of stock, such as steers (Ganjegunte *et al.,* 2005) or dairy cows (Guodong *et al.,* 2008) or sheep (Li *et al.,* 2008 and Golluscio *et al.,* 2009). One of the difficulties with comparing the effects of stocking rates is calculating fair comparisons for different types of grazing stock. For our study, we compared dairy cows with sheep and beef cattle, hence it was important to standardise the stocking rate. The stock unit system of Coop (1965) developed for New Zealand was used to convert the animal numbers per hectare to a standard ewe equivalent per hectare. Parker (1998) noted that the Coop (1965) stock unit system was not specifically developed for between farm comparisons and that the original sheep categories used have changed substantially and may not best represent current average stock live weights and feed consumption. However, Parker (1998) did comment that the comparison of stock units between farms was a useful first step to identify different management practices.

4.5.2 Stocking type effects

However difficult it is to compare the soil C of the A horizons for dairy and drystock of our study to other published studies, the outcome was similar. That is, in general, topsoil under a higher stocking rate had less C than topsoil under a lower stocking rate. Consequently, stocking rate may have been a contributing factor to the changes in the stocks of soil C under pastoral grazing. Nevertheless, it was also recognised that there are important differences between animal types in dairy and drystock farming that could also alter C and N dynamics of soil (Mackay, 2008; Lambie *et al.,* 2012). Two key differences between the dairy and drystock farms are the size of the animals grazing that results in a difference in physical pressure exerted on the soil and the deposition of urine (Haynes and Williams, 1993).

The pressure exerted on soil by the hooves of livestock can damage soil structure and cause compaction (Mackay, 2008). Greenwood and McKenzie (2001) demonstrated that grazing cows exerted a greater static loading pressure (138 kPa) compared to sheep (66 kPa) and these static pressures increase as the animal moves (Schon *et al.,* 2011). It is believed that the physical protection of soil organic matter in aggregates is more important than chemical protection in soils (Balesdent, 1996). Compaction will disturb soil aggregates and may allow the soil C occluded in aggregates to become available for microbial decomposition, thus decreasing the soil C content (Steffens *et al.,* 2008). Compared to the drystock farms, the dairy farms examined had a higher bulk density and shallower A horizon indicating soil compaction had occurred, with the assumption that originally the soil dry bulk density would have been similar within a paired site. The compaction and disruption of aggregates of the soils under dairy farming may have contributed to the lower soil C stocks observed.

Soil C decomposition may be enhanced under livestock urine patches (Lambie *et al.,* 2012) and dairy cows tend to have larger urine deposits than drystock cattle and sheep (Haynes and Williams, 1993; Bilotta *et al.,* 2007). Lambie *et al.* (2012) demonstrated that 25–40% of C held in air dried pastoral topsoil's may be solubilised by dairy cow urine. The fate of dissolved soil C under urine patches is unknown but may include leaching from the soil profile, mineralisation by soil microbes or reabsorption further down the soil profile (Lambie *et al.,* 2012). While the study by Lambie *et al*. (2012) was based in a laboratory, the potential loss of soil C under dairy cow urine patches may be one of the mechanisms contributing to lower soil C stocks under dairy farming.

4.6 Conclusions

The significant difference in soil C of the A horizon we detected between adjacent dairy and drystock farms supported the prediction from a temporal sampling of New Zealand pastoral soils (Schipper *et al.,* 2010), that dairy farms would have a lower soil C stock than adjacent drystock farms on the same soil. However, we did not detect any significant differences in soil N. When the full soil profile (0–0.6 m) was considered no differences in soil C or N were observed, mostly likely due to the additional variability of soil C stocks of the lower horizons which may have concealed the significant difference of soil C in the topsoil. This highlighted the importance of sampling and assessing soil C and N by horizon or incremental depths (Kravchenko and Robertson, 2011).

A synthesis of recent literature showed that when differences in soil C have been observed under various grazing intensities, soil C was generally always lower under higher stocking rates (Abril and Bucher, 2001; Ganjegunte *et al.,* 2005; Guodong *et al.,* 2008; Steffens *et al.,* 2008). The estimated stocking rate of the dairy farms was greater ($P<0.01$) than the drystock farms and indicated that dairy farms were more intensively grazed than drystock farms. Therefore, the difference in topsoil C we observed agreed with findings from recent literature; that the higher stocking rate (dairy farms) had less soil C. However, there are several other important differences between drystock and dairy grazed pastures, including the type of animals grazed.

It is important to note that stocking rates were difficult to estimate drystock farms given the frequent movement of stock on and off farms. The stocking rate system of Coop (1965) used in this study may need to be updated to reflect current farming practices and live weights of livestock. Stocking rate may be one of the factors influencing soil C and N stocks of pastoral soils, but further investigation into the management practices of dairy and drystock farms is required, and should examine the influence the different types of animals may have on soil C and N dynamics. While Lambie *et al*. (2012) were able to demonstrate the possibility of dairy cow urine inducing losses of C from soil, it would be interesting to be able to know if sheep and beef cattle urine would also solubilise soil C and to what extent.

Further work is required to understand the drivers of the difference in topsoil C under dairy and drystock farming on flat land in New Zealand and any possible implications for this difference.

Chapter 5. Conclusions and Future Research

5.1 Conclusions

A recent temporal study of soil C and N stocks under pastoral grazing in New Zealand found that between the 1980s and 2000s soils under dairy farming on flat land had lost significant amounts of C and N, while soils under drystock farming on flat land had not (Schipper *et al.,* 2010). A conclusion drawn from Schipper *et al*. (2010) was that a dairy farm would have a lower soil C stock than adjacent drystock farm on the same soil. The conclusion relies on the assumption that adjacent dairy and drystock farms would have originally had similar soil C and N stocks.

The first objective of my thesis was to further investigate C and N stocks of soil on flat land under pastoral grazing in the Waikato Region, using 25 paired sites of adjacent dairy and drystock farms. The main conclusion drawn from my study, was that dairy farms on flat land had significantly less soil C (8.6 ± 4.1 t C ha^{-1}) in the A horizon in comparison to the same soil on adjacent drystock farms ($P<0.05$). The difference in topsoil C detected between paired sites supported my key hypothesis, that dairy farms would have less soil C than adjacent drystock farms.

No significant difference in soil N was detected in the topsoil, nor could any significant differences in soil C or N be detected for the whole soil profile (0–0.6 m). This was in contrast to Schipper *et al.* (2010) who observed significant losses in soil C and N throughout the soil profile to 0.9 m depth for soils under dairy farming on flat land. In my study, the additional variability of soil C and N stocks of the lower horizons may have concealed any significant difference of C in the topsoil when the whole soil profile was considered, which highlighted the importance of quantifying soil C and N by horizon or incremental depths (Kravchenko and Robertson, 2011).

My second objective was to determine if any difference in soil C and N between paired sites were dependent on the difference in grazing intensity, as defined by stocking rate. A synthesis of recent literature on grazing intensity found that if a significant difference in soil C or N was detected under varying stocking rates, it was almost always that the higher stocking rate has less soil C (Abril and Bucher, 2001; Ganjegunte *et al.,* 2005; Guodong *et al.,* 2008; Steffens *et al.,* 2008). I estimated stocking rates based on information from 16 dairy and 16 drystock farms and used the stock unit system of Coop (1965), which had been developed for New Zealand pastoral farms. The stocking rates were significantly different from one another and averaged 24 ± 0.8 SU ha^{-1} for the dairy farms and 14 ± 2 SU ha^{-1} for the drystock farms. The difference in C observed in the topsoil agreed with findings from recent literature, that the higher stocking rate (dairy farms) had less soil C.

While stocking rate could have been one of the factors influencing C and N stocks of pastoral soils, differences in the type of animals grazing may have also played an important role. For example, a recent study suggested that urine from dairy cows can accelerate the dissolution of C from soil (Lambie *et al.,* 2012) and dairy cows tend to have larger urine deposits than drystock cattle and sheep (Haynes and Williams, 1993; Bilotta *et al.,* 2007). Further investigation into the particular management practices of dairy and drystock farms and how they influence soil C and N is required. It is also important to examine any possible implications of the difference in topsoil C observed between dairy and drystock farms on flat land.

5.2 Future research

The major question arising from this thesis was: what factors are driving the difference in topsoil C between dairy and drystock farming on flat land in the Waikato region? I attempted to explore management practices of individual farms, but it proved difficult to get all farmers to complete the questionnaire. I selected stocking rate to define grazing intensity for this thesis. While the stocking rates I estimated from 16 dairy and 16 drystock farms indicated that dairy farms had significantly higher stocking rates, the stock unit system used was developed in the 1960s. Farm management has changed considerably since the 1960s and now includes the use of N fertilisers and imported feed supplements. Stocking rate may not be the best indicator of grazing intensity. As there is currently no standard approach to defining grazing intensity, future development of a standard would be valuable.

Understanding the general management practices of dairy farms was relatively simple as individual farms operate in a similar fashion year-round. Drystock farms can have stock moving on and off the property frequently, with the number and age (live weight) of stock grazing often fluctuating annually. A more thorough analysis of individual farm management practices may have provided more insight into particular practices that may influence soil C and N dynamics. However, understanding different farm management proved to be a large undertaking. Future research could include updating the stock unit system of Coop (1965) or developing a model or system that allows for comparison of grazing intensity between farms.

International research of the relationship between grazing intensity and soil C and N proved to not be particularly relevant to the New Zealand pastoral grazing systems. This was because many of these studies were conducted in systems with much lower stocking rates and were in semi-arid regions. Also, the use of a variety of stock units in other studies made comparison of stocking rates with my study almost impossible. The development of a global standard stock unit system would be valuable for future research. It would be also be interesting to be able to compare the results of this study with research undertaken in other temperate areas with similar year round grazing systems as New Zealand.

The single pit sampling approach used in this thesis is unlikely to be the best approach to account for variability in soil C and N stocks of a particular paddock. The pit approach was valuable for enabling thorough soil profile descriptions to be done and aligned with methodologies of previous work. To obtain a clearer picture of the soil C and N stocks of a paddock, it may be better to take multiple samples and bulk by either horizon or incremental depths. In this study, the results demonstrated how differences in soil C may only be in shallow depths (about 0.16 to 0.17 m depth) of the topsoil, and I recommend that future studies of soil C and N ensure that sampling increments are sufficiently small to have the best chance at detecting differences, should differences exist. As I found dairy farms had significantly higher soil dry bulk density than drystock farms, I would also recommend that sampling by equivalent soil mass be considered to account for differences in soil mass thereby, ensuring the same mass of soil is compared across dairy and drystock farms (Whitehead *et al.*, 2010).

Now that two different approaches have indicated that dairy farms on flat land had less soil C than drystock farms, it is important to identify any implications of the difference. Are soils under dairying on flat land continuing to lose C and what are the implications for the farming sector if they are? For farmers, it is important that their soil has the highest soil quality possible to support their yields. Soil C is an important component of many fundamental soil properties, if soil C is lost how would this influence production and environmental performance? As regulations move towards carbon schemes in an effort to address the issue of climate change, there may be an opportunity for C sequestration under dairy farms, however further research is required to investigate the possibilities.

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Appendix A. Questionnaire templates

Site ID:

Master of Science

Thesis Project 2011-2012

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Questionnaire – Dairy farm

Students: Alice Barnett Amy Taylor
Phone:
Mobile:
Email:

Please fill in this questionnaire to the best of your ability. If you have any queries please contact Alice or Amy, or note these on the form and they will get back to you.

Once completed, please return to:

Contact person(s)

Name:			
Address: (residential / postal)			
Phone:		Mobile:	
Email:			
Relationship to farm:	*e.g. owner, manager, sharemilker, worker etc*		
How long have you been on this farm?			

Landowner, if different from contact person(s)

Name:			
Address: (residential / postal)			
Phone:		Mobile:	
Email:			

Dairy Farm 1

Site ID:

General details for the whole farm

Total farm size (ha):		Effective area (ha):	
Milking area (ha), if this differs from effective area: (i.e. if support block included in total farm size)			
Topography:			
Annual rainfall (mm):			

Land use history

Sequence of land uses with approximate or best guess dates (e.g. forest cleared around 1900, sheep and beef farm till 1970, then converted to dairy): ______

If possible, describe general management during the last 30 years, or since the farm became a dairy farm. In particular were there any major changes in management (e.g. 5 years ago started importing lots of maize silage, or changed to organic farming 10 years ago): ______

When did use of N fertiliser commence on the farm? ______

Site ID:

Animal Information

For most of the questions below we are interested in average or "typical values" for the last 5 years.

Breed:	☐ Friesian ☐F x J ☐ Jersey ☐ Ayrshire ☐ Other: ______________				
Stocking rate, including R2 heifers milked;	________________cows/ha; or peak cow number: ________________				
Milk solids yield (kg/ha/yr):		or Total MS yield (kg /yr):			
Calving date (day/month):		Dry off date:		Lactation length (days):	
Milking once a day:	☐ Yes ☐ No If yes, start date: Dry off date:				
Mature cow weight (kg):		Number R1 heifer replacements:			
Replacements grazed off farm:	☐ Weaners # off: _______	☐ 9-21 months # off: _______	☐ Always on farm		
Effluent disposal system:	☐ Spray from sumps ☐ Holding ponds	☐ Oxidation ponds ☐ Other ______________________			

If possible, could you estimate stocking rate and MS production for the last 10 years?

Stocking rate: ________________________cows/ha and MS production: ____________________

Other stock

Are there any other stock on farm (not included in above table): Y / N

Do they graze the milking area? Y / N

Please detail other stock on farm in the table below:

Animal type	Date on	Number	LW on (kg)	Date off	LW off (kg)

Describe the management of other stock: ____

____

____

Dairy Farm 3

Site ID:

Farm Management Information

Winter management

Cows grazed off farm?	Y / N	How many animals?		Dates off farm:	
Feed pad used?	Y / N	How many animals on pad?		When used?	
Standoff pad used?	Y / N	How many animals on pad?		When used?	
Sacrifice paddock used?	Y / N	How many animals on paddock?		When used?	

Supplementary feed

A. Supplements brought onto farm & not grown on farm.

Supplement type	Dry weight (t)	Or; wet weight (t)	Or; number of bales	Where fed (i.e. in shed or paddock)

B. Supplements made on farm and used on farm

Type:____

Quantity:____________________ Where fed:____________________

C. Supplements made on farm and exported

Type:____

Quantity taken off farm:________________________________

Dairy Farm 4

Site ID:

Fertiliser

Please detail the typical annual fertiliser applications in the table below:

Fertiliser type:	Application rate (kg/ha/yr)	OR; total applied (t/yr)	Area applied to (ha/yr)	Month(s) applied

How frequently is lime applied? ____________ Application rate per ha: ____________

What are the approximate values for: Olsen P: ____________ pH: ____________

Cropping

If crops are used, please detail in the table below:

Type of crop:	Area covered/planted per year:

Water irrigation

If the farm has water irrigation please detail in the table below:

Area irrigated:		Number of days irrigation is used:		Quantity of water used:	

Past management

Is the management described above typical of management for the last 20 or 30 years?

Y / N / don't know

If no, please explain the major differences________________________

____

____

Dairy Farm 5

Site ID:

Information specific to the paddock to be sampled

Is management of this paddock typical of management on the rest of the farm?: Y / N

If no, explain any differences:____

____

____

Estimate relative productivity of the paddock compared to the farm "average" (e.g. a poor paddock that probably grows 25% less grass compared to farm average):________________________

____

____

Effluent

Does the paddock receive dairy effluent?: Y / N

If yes, what method is used (e.g. spray from sump, pond sludge, solids from feed pad):__________

____

Frequency and quantity of application:____________________________________

Cropping history

Has the paddock been cropped in the last 10 years?: Y / N

If yes, detail crops used with approximate dates:______________________________

____

____

Describe the last cropping sequence (e.g. spray, plough, roll, sow turnips, graze turnips, and then direct drill permanent pasture):____

____

____

____

Site ID:

Pasture renewal

Have pastures been renewed other than through a cropping rotation?: Y / N

How were pastures renewed: ☐Cultivation ☐Spray/direct drill ☐Direct drill ☐Other:__________

How frequently & when was this last done?:__________

If cultivation was used recently (last 5 years) describe the cultivation sequence:__________

Pasture species

What pasture species were sown in this paddock?:__________

Is this similar to what had been sown previously?: Y / N

If no, detail previous species used:__________

Other

Does this paddock have artificial drainage?: Y / N

Drainage type (e.g. hump & hollow, mole & tile etc):__________

When was it installed?:__________

Have any organic based fertilisers ever been applied (e.g. whey, chicken manure)?: Y / N

If yes, when:__________ How much applied?:__________

Dairy Farm 7

Site ID:

Do animals other than dairy cows graze this paddock? Please detail type of animal, when and how long grazed for?: ______________________

____

If we have already sampled, when was the paddock last grazed prior to our sampling?: ______

____

Is there any other info specific to this paddock which might be relevant (e.g. grass grub infestation or heavily pugged 2 years ago)?: ______________________

____

____

____

Any other comments:

____

____

____

____

____

____

Thank you very much for completing our questionnaire!
The quality of the information written will directly impact our research and we appreciate you taking the time to answer all our questions.
Cheers, Alice & Amy

Dairy Farm 8

Site ID:

Master of Science

Thesis Project 2011-2012

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Questionnaire – Drystock farm

Students: Alice Barnett Amy Taylor
Phone:
Mobile:
Email:

Please fill in this questionnaire to the best of your ability. If you have any queries please contact Alice or Amy, or note these on the form and they will get back to you.

Once completed, please return to:

Contact person(s)

Name:			
Address: (residential / postal)			
Phone:		Mobile:	
Email:			
Relationship to farm:	*e.g. owner, manager, worker etc*		
How long have you been on this farm?			

Landowner, if different from contact person(s)

Name:			
Address: (residential / postal)			
Phone:		Mobile:	
Email:			

Drystock Farm 1

Site ID:

General details for the whole farm

Total farm size (ha):		Effective area (ha):	
Topography:			
Annual rainfall (mm):			

Is the paddock we will be sampling in a distinct block compared to other parts of the farm? Y / N

<u>If yes, please answer the rest of the questions in relation to the block the paddock to be sampled is in.</u>

Block effective area (ha):__________ Block topography:__________

Land use history

Sequence of land uses with approximate or best guess dates (e.g. forest cleared around 1900, dairy farm till 1970, then converted to sheep and beef): __________

If possible, please describe general management during the last 30 years, or since the farm became a drystock farm. In particular were there any major changes in management (e.g. 10 years ago sold all breeding cows and brought in and finished heifers): __________

When did use of N fertiliser commence?__________

Drystock Farm 2

Site ID:

Animal Information

Livestock

If you calculate stocking rates on a stock unit basis, what have been typical winter stocking rate for the last 10 years?

Cattle SU:		Deer SU:	
Sheep SU:		Other SU:	
Total SU:			

For the questions below we are interested in "average" or "typical values" for the last five years.

Sheep

Please write down the general stock policy for sheep (e.g. run 500 Romney ewes and finish all lambs by March at 17 kg carcase weight. Also buy in about 500 store lambs in December and finish by April):

____

____

____

____

____

If possible, please fill in the following tables.

A. Breeding stock Breed: ____________________________

Stock class	Number wintered	Live weight (kg)
Ewes		
Ewe hogget replacements		
Rams		

Site ID:

Hogget's lambed: Y / N

Lambing date:		Weaning date:	
Number of lambs:		Weaning weight (kg):	

Enter all non-replacement lambs in the trading table below (ie. if weaned in December, month on will be December):

B. Trading sheep

Note: For animals staying on farm for more than one year (i.e. past the end of June), record "Month off" as June with LW off, and then enter in "Month on" July in the next year class.

Stock class	Month on	Number	LW on (kg)	Month(s*) off	LW off (kg)	Or; CW (kg)

*Indicate approximately how many went off in each month____________________

Annual wool yield, if known (total, kg/ha or kg per head):____________________

Cattle

Please write down the general stock policy for cattle (e.g. buy in, 100 kg bull calves in December, kill 50% at 18 months in May/June (@550 kg LW) and the remainder as 2yr olds in Dec/Jan (@650 kg LW)).

Site ID:

If possible, please fill in the following tables.

A. Breeding stock Breed: ______________________________

Stock class	Number wintered	Live weight (kg)
Cows		
R1 replacement heifers		
R2 replacement heifers		
Breeding bulls		

R2 heifers calved?: Y / N

Calving date:		Weaning date:	
Number of calves:		Weaning weight (kg):	

Enter all non-replacement calves in the trading table below (i.e. if weaned in March, month on will be March):

B. Trading cattle or dairy grazers.

Note: For animals staying on farm for more than one year (i.e. past the end of June), record "Month off" as June with LW off, and then enter in "Month on" July in the next year class.

Site ID:

Stock class	Month on	Number	LW on (kg)	Month(s*) off	LW off (kg)	Or; CW (kg)

*Indicate approx. how many went off in each month:______________________________

Deer

Please write down the general stock policy for deer: ______________________________

If possible please fill in the following tables.

A. Breeding stock Breed: ______________________________

Stock class	Number wintered	Live weight (kg)
Mixed age breeding hinds		
R1 Breeding hinds		
R2 Breeding hinds		
Breeding stags		
Velvet stags		

Drystock Farm 6

Site ID:

Fawning date:		Weaning date:	
Number of fawns:		Weaning weight (kg):	

Enter all non-replacement fawns in the trading table below (i.e. if weaned in March, month on will be March):

B. Trading deer

Note: For animals staying on farm for more than one year (i.e. past the end of June), record "Month off" as June with LW off and then enter in "Month on" July in the next year class.

Stock class	**Month on**	**Number**	**LW on (kg)**	**Month(s*) off**	**LW off (kg)**	**Or; CW (kg)**

*Indicate approx. how many went off in each month______________________________

____

Annual velvet yield, if known (total, kg/ha or kg per head):____________________________

Other stock

Are there any other stock on farm (not included in above categories): Y / N

Please detail other stock on farm in the table below:

Animal type	Date on	Number	LW on (kg)	Date off	LW off (kg)

Describe the management of other stock: ____

____

Drystock Farm 7

Site ID:

Farm Management Information

Winter management

Cows grazed off farm?	Y / N	How many animals?		Dates off farm:	
Feed pad used?	Y / N	How many animals on pad?		When used?	
Standoff pad used?	Y / N	How many animals on pad?		When used?	
Sacrifice paddock used?	Y / N	How many animals on paddock?		When used?	

Supplementary feed

A. Supplements brought onto farm & not grown on farm.

Supplement type	Dry weight (t)	Or; wet weight (t)	Or; number of bales	Where fed (i.e. in shed or paddock)

B. Supplements made on farm and used on farm

Type:____

Quantity:____________________ Where fed:____________________

C. Supplements made on farm and exported

Type:____

Quantity taken off farm:________________________________

Site ID:

Fertiliser

Please detail the typical annual fertiliser applications in the table below:

Fertiliser type:	Application rate (kg/ha/yr)	OR; total applied (t/yr)	Area applied to (ha/yr)	Month(s) applied

How frequently is lime applied? ______________ Application rate per ha: ____________________

What are the approximate values for: Olsen P: ________________ pH: ______________

Cropping

If crops are used, please detail in the table below:

Type of crop:	Area covered/planted per year:

Water irrigation

If the farm has water irrigation please detail in the table below:

Area irrigated:		Number of days irrigation is used:		Quantity of water used:	

Past management

Is the management described above typical of management for the last 20 or 30 years?

Y / N / don't know

If no, please explain the major differences____

____

____

Drystock Farm 9

Site ID:

Information specific to the paddock to be sampled

Is management of this paddock typical of management on the rest of the farm or block?: Y / N

If no, explain any differences:____

____

____

Estimate relative productivity of the paddock compared to the farm "average" (e.g. a poor paddock that probably grows 25% less grass compared to farm average):________________________

____

____

Effluent

Does the paddock receive effluent?: Y / N

If yes, what method is used (e.g. spray from sump, pond sludge, solids from feed pad):__________

____

Frequency and quantity of application:________________________________

Cropping history

Has the paddock been cropped in the last 10 years?: Y / N

If yes, detail crops used with approximate dates:________________________________

____

____

Describe the last cropping sequence (e.g. spray, plough, roll, sow turnips, graze turnips, and then direct drill permanent pasture):________________________________

____

____

____

Drystock Farm 10

Site ID:

Pasture renewal

Have pastures been renewed other than through a cropping rotation?: Y / N

How were pastures renewed: ☐Cultivation ☐Spray/direct drill ☐Direct drill ☐Other:__________

How frequently & when was this last done?:__________

If cultivation was used recently (last 5 years) describe the cultivation sequence:__________

Pasture species

What pasture species were sown in this paddock?:__________

Is this similar to what had been sown previously?: Y / N

If no, detail previous species used:__________

Other

Does this paddock have artificial drainage?: Y / N

Drainage type (e.g. hump & hollow, mole & tile etc):__________

When was it installed?:__________

Have any organic based fertilisers ever been applied (e.g. whey, chicken manure)?: Y / N

If yes, when:__________ How much applied?:__________

Does the type and number of animals grazing this paddock differ from the rest of the block or farm? If yes, please detail type and number of animal grazed: __________

Drystock Farm 11

Site ID:

If we have already sampled, when was the paddock last grazed prior to our sampling?: ____________

Is there any other info specific to this paddock which might be relevant (e.g. grass grub infestation or heavily pugged 2 years ago)?: ____________

Any other comments:

Thank you very much for completing our questionnaire!
The quality of the information written will directly impact our research and we appreciate you taking the time to answer all our questions.
Cheers, Alice & Amy

Drystock Farm 12

Appendix B. Stocking rate information

Table B.1. Ewe equivalent stock unit (SU) system recommended by Coop (1965) (taken from Woodford and Nicol, 2004).

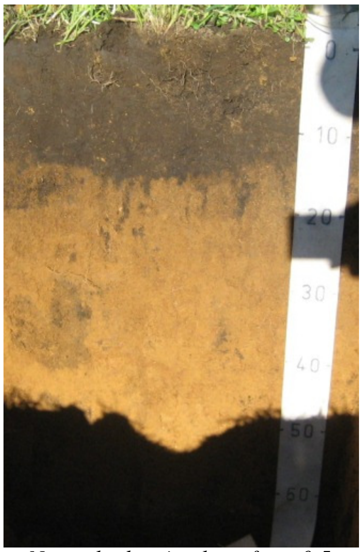
Stock Class	Live weight (kg)	Ewe equivalent (SU)
Ewe	54	1.0
Hogget	23-41	0.6
Ram	73	0.8
Jersey cow	360	6.5
Friesian cow (town supply)	550	8.5
Beef breeding cow	450	6
Weaner cattle	135-270	3.5
Yearling cattle	270-360	4
Two-year-old cattle	360-450	4.5
Weaner cattle	160-340	4
Yearling cattle	340-500	5

Table B.2. Estimated stocking rates based on information provided in a farm management questionnaire and converted to Coop (1965) stock unit (SU) system.

Site	Land use	SU ha^{-1}	Site	Land use	SU ha^{-1}
01	Dairy	26	12	Dairy	25
02	Dairy	26	12	Drystock	14
02	Drystock	19	13	Dairy	27
03	Dairy	27	14	Drystock	9
03	Drystock	30	16	Dairy	26
04	Dairy	14	17	Drystock	8
04	Drystock	10	18	Dairy	25
06	Dairy	23	18	Drystock	18
06	Drystock	28	19	Drystock	13
07	Dairy	25	20	Dairy	25
08	Dairy	27	21	Drystock	8
08	Drystock	7	22	Drystock	6
09	Dairy	21	23	Dairy	24
09	Drystock	7	23	Drystock	21
10	Dairy	23	24	Drystock	21
11	Drystock	11	26	Dairy	21

Appendix C. Soil profile descriptions

Site: 01D
Date observed: 12/10/2012



Note, shadow in photo from 0.5 m to 0.7 m

Reference data

Soil name: Te Kuiti silt loam (LOT)
NZSC: Typic Orthic Allophanic

Site data

Location: Pit located in the second paddock to the east of Innes Road. Pit approximately 25 m from property boundary fence and 50 m from the paddocks western fence.
GPS reference: 175 07' 07.7"E, 38 09' 10.7"S
Annual rainfall: 1550 mm at Otewa
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 109 m asl
Geomorphic position: Profile on a 5-8° slope with a west aspect, on the mid-slope of a low hill surrounded by hilly topography.
Erosion/deposition: Negligible
Vegetation: Pasture - mainly ryegrass not much clover
Parent material: Volcanic
Drainage class: Well drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-18	10 YR 2/3, silt loam, non-sticky, non-plastic, weak, many microfine roots, strong NaF reaction, distinct boundary.
Bw1	18-43	10 YR 4/6, silt loam, non-sticky, non-plastic, weak, few microfine roots, strong NaF reaction, indistinct boundary.
Bw2	43-100+	10 YR 5/6, silty clay, moderately sticky, slightly plastic, slightly firm, very few extremely fine roots, strong NaF reaction.

Site: 01S
Date observed: 12/10/2012

Note, shadow in photo from 0.6 m

Reference data

Soil name: Te Kuiti silt loam (LOT)
NZSC: Typic Orthic Allophanic

Site data

Location: Pit located in
GPS reference: 175 07' 07.4"E, 38 09' 12.4"S
Annual rainfall: 1550 mm at Otewa
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 111 m asl
Geomorphic position: Profile on a 7° slope with a northwest aspect, on the mid-slope of a low hill surrounded by hilly topography.
Erosion/deposition: Negligible
Vegetation: Pasture - ryegrass, flat weeds, clover
Parent material: Volcanic
Drainage class: Well drained
Land use: Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 2/3, silt loam, non-sticky, non-plastic, weak, strongly developed pedality with polyhedral peds, abundant microfine and extremely fine and few large roots, strong NaF reaction, distinct boundary.
Bw1	17-40	10 YR 4/6, silt loam, non-sticky, non-plastic, weak, moderately developed pedality with polyhedral peds, many microfine and few large roots, strong NaF reaction, wavy boundary.
Bw2	40-100+	10 YR 5/6, silty clay, moderately sticky, slightly plastic, slightly firm, moderately developed roots with polyhedral peds, common mircofine roots, strong NaF reaction.

Site: 02D
Date observed: 24/3/2011

Reference data

Soil name:	Waihou
NZSC:	Typic Orthic Allophanic

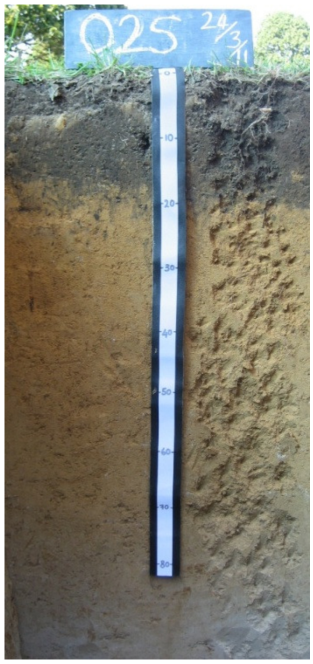
Site data

Location:	Pit approximately 50 m west of Strange Road and 50 m south of dwelling
GPS reference:	NZTM 1836523E, 5844746N
Annual rainfall:	1211 mm at Te Aroha
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	13 m asl
Geomorphic position:	Profile on 0° slope on a levee on flat to gently undulating topography of the lowlands
Erosion/deposition:	Nil
Vegetation:	Pasture - plantain, buttercup, chicory, less clover than 02S, penny royal, ryegrass, 15 % bare ground.
Parent material:	Volcanic fall deposits and alluvium
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-9	10 YR 2/2, silt loam, moderately sticky, very plastic, firm, brittle, strongly developed pedality with fine to very coarse polyhedral breaking to apedal earthy, weak NaF reaction, distinct smooth boundary.
AB	9-23	10 YR 2/2 and 10YR 5/6, silt loam, slightly sticky, very plastic, firm, brittle, strongly developed pedality with fine to very coarse blocky breaking to apedal earthy, strong NaF reaction, distinct smooth boundary.
Bw1	23-51	10 YR 5/8, silt loam, slightly sticky, moderately plastic, slightly firm, brittle, moderately pedal with medium to very coarse blocky breaking to apedal earthy, strong NaF reaction, diffuse smooth boundary.
Bw2	51-88	10 YR 5/6, sandy loam, slightly sticky, slightly plastic, firm, brittle, weakly developed pedality with medium to very coarse blocky breaking to apedal earthy, strong NaF reaction, diffuse smooth boundary.
Cu	88-100+	10 YR 7/2, sand, non-sticky, non-plastic, loose, brittle, apedal single grained.

Site: 02S
Date observed: 24/3/2011



Reference data

Soil name:	Waihou
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit approximately 50 m west of Strange Road and 20 m south of hedge.
GPS reference:	NZTM 1836578E, 5844661N
Annual rainfall:	1211 mm at Te Aroha
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	23 m asl
Geomorphic position:	Profile on 0° slope on a levee on flat to gently undulating topography of the lowlands
Erosion/deposition:	Nil
Vegetation:	Pasture - clover approx 30%, dandelion, California thistle, bare ground 15%, narrow leaf plantain, Indian dash, buttercup, mellow.
Parent material:	Volcanic fall deposits and alluvium
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-16	10 YR 2/2, silt loam, slightly sticky, moderately plastic, slightly firm, brittle, moderately pedal with coarse polyhedral breaking to apedal earthy, abundant very fine and few medium roots, strong NaF reaction, indistinct occluded boundary.
Bw1	16-38	10 YR 5/8, sandy clay loam, moderately sticky, moderately plastic, slightly firm, brittle, weakly developed pedality with coarse to extremely course blocky breaking to apedal earthy, many very fine and few medium roots, strong NaF reaction, diffuse smooth boundary.
Bw2	38-70	10 YR 6/4, sandy clay loam, moderately sticky, very plastic, weak, brittle, weakly developed pedality with medium to extremely coarse blocky breaking to apedal earthy, common very fine and few medium roots, moderate NaF reaction, diffuse smooth boundary.
BC	70-90	10 YR 7/3, many mottles (10YR 7/4), sandy loam, slightly sticky, moderately plastic, weak, brittle, weakly developed pedality with medium to extremely coarse breaking to apedal earthy, few fine and few medium roots, weak NaF reaction, diffuse smooth boundary.
Cu	90-100+	10 YR 7/2, common mottles (7.5 YR 7/6), loamy sand, slightly sticky, non-plastic, very weak, brittle, very weakly developed pedality with medium to extremely coarse block and platy breaking to apedal earthy, few very fine roots.

Site: 03D
Date observed: 30/3/2011

Reference data

Soil name:	Waihou
NZSC:	Typic Orthic Allophanic

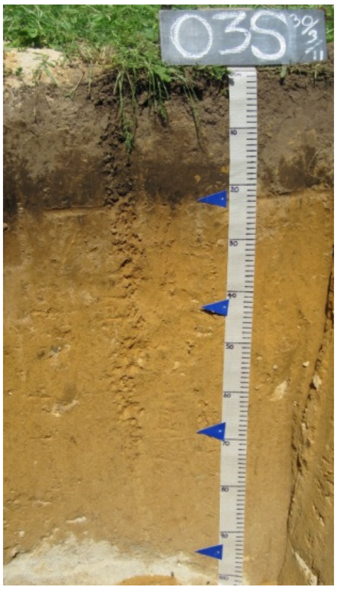
Site data

Location:	Pit approximately 75 m west of Strange Road and 50 m west of house.
GPS reference:	NZTM 1836519E, 5844187N
Annual rainfall:	1211 mm at Te Aroha
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	24 m asl
Geomorphic position:	Profile on 0° slope on a levee on flat to gently undulating topography of the lowlands
Erosion/deposition:	Nil
Vegetation:	Pasture - rye grass and white clover dominant, narrow leaf plantain, doc, California thistles, dandelion, penny royal, buttercup, yarrow, red clover.
Parent material:	Volcanic fall deposits and alluvium
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-18	10 YR 2/2, silt loam, slightly sticky, slightly plastic, weak, brittle, strongly developed pedality with very fine to coarse polyhedral breaking to medium polyhedral peds, abundant fine and very fine roots, moderate NaF reaction, distinct occluded boundary.
Bw1	18-34	7.5 YR 4/6, clay loam, moderately sticky, slightly plastic, slightly firm, brittle, moderately developed pedality with fine to coarse blocky breaking to fine to medium polyhedral peds, abundant fine roots, very strong NaF reaction, indistinct smooth boundary.
Bw2	34-56	10 YR 6/6, clay loam, moderately sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with fine to coarse blocky breaking to medium polyhedral peds, many fine roots, very strong NaF reaction, diffuse smooth boundary.
BC	56-85	10 YR 7/4, clay loam, moderately sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with medium to coarse polyhedral breaking to fine polyhedral peds, common very fine roots, strong NaF reaction, diffuse smooth boundary.
Cu	85-100+	2.5 YR 8/3, sandy loam, non-sticky, non-plastic, weak, brittle, moderately developed pedality with fine to coarse polyhedral and granular breaking to medium blocky peds, moderate NaF reaction.

Site: 03S
Date observed: 30/3/2011



Reference data

Soil name:	Waihou
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit approximately 50 m west of Strange Road and 30 m north of paddock trough, in line with the paddock gate from Strange Road.
GPS reference:	NZTM 1836519E, 5844187N
Annual rainfall:	1211 mm at Te Aroha
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	13 m asl
Geomorphic position:	Profile on 0° slope on a levee on flat to gently undulating topography of the lowlands
Erosion/deposition:	Nil
Vegetation:	Pasture - yarrow, 2% bare ground, ryegrass, doc, California thistles, narrow leaf plantain, dandelion, butter cup, white clover, mellow, mostly rye grass dominant.
Parent material:	Volcanic fall deposits and alluvium
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-23	10 YR 2/2, silt loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with fine to coarse polyhedral breaking to very fine to medium polyhedral peds, abundant fine and very fine roots, strong NaF reaction, distinct occluded boundary.
Bw1	23-43	7.5 YR 4/4, silt loam, non-sticky, slightly plastic, very weak, brittle, moderately developed pedality with fine to coarse polyhedral breaking to fine to medium polyhedral peds, abundant very fine to fine roots, strong NaF reaction, indistinct smooth boundary.
Bw2	43-68	10 YR 4/6, clay loam, slightly sticky, moderately plastic, weak, brittle, moderately developed pedality with fine to coarse polyhedral breaking to medium to coarse blocky peds, abundant very fine roots, strong NaF reaction, diffuse smooth boundary.
BC	68-95	10 YR 5/6, sandy clay loam, slightly sticky, moderately plastic, weak, brittle, moderately developed pedality with fine to coarse blocky breaking to fine to medium blocky peds, many very fine roots, strong NaF reaction, abrupt wavy boundary.
Cu	95-100+	2.5 YR 6/3, sand, loose, apedal single grained, common very fine roots.

Site: 04D
Date observed: 7/4/2011

Reference data

Soil name:	Naike clay loam
NZSC:	Mottled Orthic Granular

Site data

Location:	Pit approximately 70 m from the northern boundary fence and 50 m from the escarpment to the east.
GPS reference:	NZTM 1773028E, 5842374N
Annual rainfall:	1190 mm in Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	48 m asl
Geomorphic position:	Profile on 4° concave slope with northwest aspect on a foot slope of a hill in rolling land.
Erosion/deposition:	Negligible
Vegetation:	Pasture - predominantly ryegrass and white clover, plus ragwort, broad leaf plantain, dock, California thistles, daisy.
Parent material:	Volcanic fall deposits overlying rock
Drainage class:	Moderately well drained
Land use:	Dairy grazing

Soil data

Horizon	Depth (cm)	
Ap	0-14	10YR 2/2, silt loam, slightly sticky, moderately plastic, slightly firm, semi deformable, strongly developed pedality with very fine to course polyhedral peds, abundant very fine to medium roots, distinct wavy boundary.
Ap/Bw	14-26	10 YR 4/6, silty clay, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with fine to coarse polyhedral breaking to fine polyhedral peds, many very fine to fine roots, indistinct wavy boundary.
Bw1	26-54	10 YR 5/6, common fine mottles (7.5 YR 4/6), silty clay, sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with fine to coarse blocky breaking to fine polyhedral peds, many very fine to fine roots, diffuse smooth boundary.
Bw2	54-68	10 YR 5/4, many medium mottles and few distinct Fe/Mn coatings (7.5 YR 4/4), silty clay, sticky, very plastic, slightly firm, brittle, moderately developed pedality with fine to coarse blocky breaking to fine blocky peds, common very fine roots, distinct smooth boundary.
Cu	68-81+	10 YR 5/6, many medium mottles and few distinct Fe/Mn coatings (7.5 YR 5/8), silty clay, very sticky, very plastic, very firm, brittle, strongly developed pedality with medium to very coarse platy breaking to medium platy and blocky peds, few very fine roots.

Site: 04S
Date observed: 7/4/2011

Reference data

Soil name:	Naike clay loam
NZSC:	Mottled Orthic Granular

Site data

Location:	Pit approximately 20 m north of boundary fence and 150 m from pine tree block to the north and 25 m from fence to the east.
GPS reference:	NZTM 1772992E, 5842494N
Annual rainfall:	1190 mm in Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	44 m asl
Geomorphic position:	Profile on 2° concave slope with southeast aspect on a foot slope of a hill in rolling land.
Erosion/deposition:	Negligible
Vegetation:	Pasture - ryegrass and clover dominant, broad leaf plantain, thistles, dandelion, penny royal.
Parent material:	Volcanic fall deposits overlying rock
Drainage class:	Moderately well drained
Land use:	Drystock grazing

Soil data

Horizon	Depth (cm)	
Ap	0-15	10 YR 3/2, silt loam, slightly sticky, moderately plastic, weak, semi deformable, strongly developed pedality with medium polyhedral breaking to fine polyhedral peds, abundant fine roots, distinct boundary.
Ap/Bw	15-37	10 YR 5/4, silty clay, sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse polyhedral breaking to fine to medium polyhedral peds, many fine roots, indistinct boundary.
Bw1	37-45	10 YR 6/6 common fine (7.5YR 6/6 and 2.5 YR 7/3) and many medium (10 YR 6/8) mottles, silty clay, sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse polyhedral breaking to very fine to fine polyhedral peds, many very fine roots, indistinct smooth boundary.
Bw2	45-62	10 YR 6/6, common fine mottles (7.5 YR 6/6), silty clay, sticky, very plastic, slightly firm, brittle, moderately developed pedality with coarse polyhedral breaking to very fine to fine polyhedral peds, many very fine roots, indistinct smooth boundary.
Cu	62+	2.5 YR 7/2, common fine mottles (7.5 YR 5/8), silty clay, very sticky, very plastic, very firm, brittle, massive with coarse blocky breaking to coarse blocky peds, common fine roots.

Site: 06D
Date observed: 13/4/2011

Reference data

Soil name:	Horotiu-Te Kowhai complex
NZSC:	Typic Orthic Gley

Site data

Location:	Pit in second paddock down race from Aspin Road on right side, approximately 65 m from drain and boundary fence.
GPS reference:	NZMG 2730482E, 6368857N
Annual rainfall:	1190 mm in Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	72 m asl
Geomorphic position:	Profile on flat depression of a flood plain of a flat plain
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap(g)	0-16	10 YR 3/2 with common fine mottles (7.5 YR 4/4), silty clay, very sticky, very plastic, weak, brittle, strongly developed pedality with coarse polyhedral breaking to fine polyhedral peds, many very fine and fine roots, no NaF reaction, distinct wavy and occluded boundary.
Apg/Bg	16-23	2.5 YR 7/3 with common fine mottles (7.5 YR 4/6), silty clay, very sticky, very plastic, weak, brittle, strongly developed pedality with fine to medium polyhedral peds, many very fine and fine roots, no NaF reaction, distinct smooth boundary.
Bg1	23-39	2.5 YR 7/2 with common fine mottles (7.5 YR 5/6), silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with coarse blocky breaking to medium columnar peds, many fine roots, no NaF reaction, indistinct smooth boundary.
Bg2	39-65	2.5 YR 7/2 with many medium mottles (7.5 YR 6/6), silty clay, moderately sticky, very plastic, slightly firm, brittle, strongly developed pedality with very coarse blocky breaking to coarse blocky peds, many fine roots, no NaF reaction, distinct smooth boundary.
BCg	65-79+	10 YR 7/2 with many medium mottles (7.5 YR 5/6 and 7.5 YR 6/4) and few faint clay coatings (10 YR 2/3) and few Fe/Mn concretions, silty clay, moderately plastic, very plastic, very firm, semi-deformable, strongly developed pedality with very coarse blocky breaking to medium blocky peds, no NaF reaction.

Site: 06S
Date observed: 13/4/2011

Reference data

Soil name:	Horotiu-Te Kowhai complex
NZSC:	Typic Orthic Gley

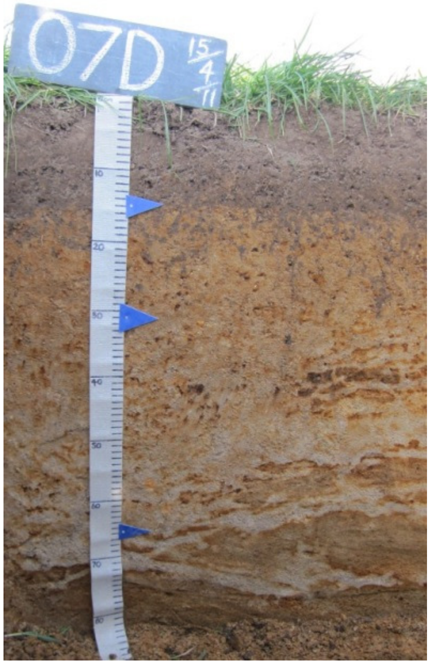
Site data

Location:	Pit in second paddock 50 m from Aspin Road and approximately 40 m from large main drain between this property and 06D property.
GPS reference:	NZMG 2730334E, 63688067N
Annual rainfall:	1190 mm in Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	74 m asl
Geomorphic position:	Profile on flat depression of a flood plain of a flat plain
Erosion/deposition:	Nil
Vegetation:	Pasture - ryegrass and white clover, narrow leaf and broad leaf plantain, dock, dandelion, paspalum.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap(g)	0-17	10 YR 3/2 with common fine mottles (7.5 YR 4/4), silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with coarse polyhedral breaking to fine polyhedral peds, abundant very fine to medium roots, no NaF reaction, distinct smooth and occluded boundary.
Apg/Bg	17-28	10 YR 7/3 with many medium mottles (7.5 YR 5/6) and few distinct Fe/Mn concretions, (7.5 YR 17/1), silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with coarse polyhedral breaking to fine polyhedral peds, abundant very fine to fine roots, no NaF reaction, indistinct smooth boundary.
Bg1	28-63	2.5 YR 7/3 and 7.5 YR 6/4 with many medium mottles (7.5 YR 6/6), common clay coatings (2.5 YR 7/3) and few distinct Fe/Mn concretions, (7.5 YR 17/1), silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with very coarse blocky breaking to coarse blocky peds, many fine roots, no NaF reaction, indistinct wavy boundary.
BCg	63-72+	10 YR 7/2 and 7.5 YR 6/6 with many coarse mottles (7.5 YR 5/8) and common faint clay coatings (10 YR 7/2), very sticky, very plastic, slightly firm, semi-deformable, strongly developed pedality with coarse blocky breaking to medium columnar and blocky peds, few fine roots no NaF reaction.

Site: 07D
Date observed: 15/4/2011



Reference data

Soil name:	Horotiu sandy loam
NZSC:	Typic Orthic Gley

Site data

Location:	Pit in the second paddock back from Hooker Road, and adjacent to Pencarrow Road, approximately 43 m from Pencarrow road and 30 m from a fence line to the west.
GPS reference:	NZMG 2719373E, 6368543N
Annual rainfall:	1190 mm in Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	57 m asl
Geomorphic position:	Profile on a planar slope of a terracette of flat to gently undulating lowland area.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass plus, dandelion, paspalum, plantain, white clover.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-15	10 YR 2/2, silt loam, slightly sticky, moderately plastic, firm, friable, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant microfine and extremely fine and common very fine roots, no NaF reaction, abrupt occluded boundary.
Ap/Bw(g)	15-31	10 YR 5/4 with common very fine distinct (7.5 YR 4/6), silty clay, moderately sticky, moderately plastic, slightly firm, friable, strongly developed pedality with very fine and fine polyhedral and medium polyhedral peds, very fine distinct Fe/Mn concretions (5 YR 1-7/1), many microfine and extremely fine roots, no NaF reaction, distinct smooth boundary
Bg	31-59	10 YR 7/3 with many fine to coarse prominent (7.5 YR 6/8) and common medium prominent (5 YR 3/6) mottles, silty clay loam, slightly firm, brittle, strongly developed pedality with very coarse and extremely coarse blocky breaking to coarse blocky peds, common extremely fine roots, no NaF reaction, distinct wavy boundary.
Cu	59-80+	10 YR 7/2 with many coarse prominent (10 YR 5/8) and common medium distinct (2.5 YR 7/2) mottles, sandy loam, slightly sticky, slightly plastic, weak, apedal single grained, no NaF reaction.

Site: 07S
Date observed: 15/4/2011

Reference data

Soil name:	Horotiu sandy loam
NZSC:	Typic Orthic Gley

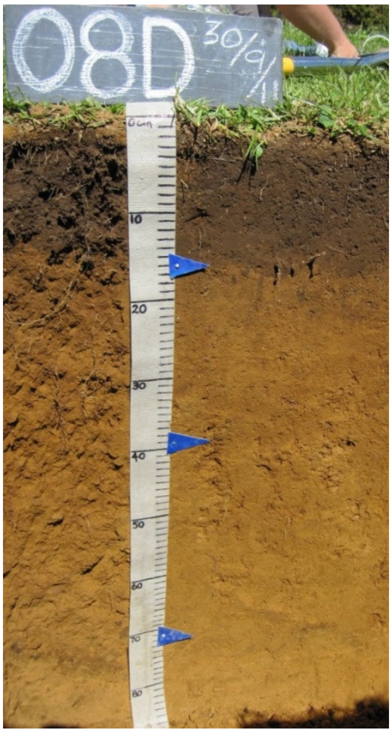
Site data

Location:	Pit is approximately 47 m from Pencarrow Road and 30 m from hedge boundary.
GPS reference:	NZMG 2719275E, 6368569N
Annual rainfall:	1190 mm in Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	59 m asl
Geomorphic position:	Profile on a planar slope of a terracette of flat to gently undulating lowland area.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dandelion, narrow leaf plantain, California thistles
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 3/2, silt loam, moderately sticky, moderately plastic, weak, friable, strongly developed pedality with medium polyhedral and very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, no NaF reaction, abrupt occluded boundary.
Ap/Bw(g)	17-30	10 YR 6/4 with common very fine faint mottles (7.5 YR 5/6) and extremely fine distinct Fe/Mn concretions (5 YR 2/2), clay loam, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse blocky breaking to very fine and fine polyhedral peds, many extremely fine roots, no NaF reaction, distinct smooth boundary.
Bg	30-49	10 YR 7/3 with many coarse prominent (7.5 YR 4/6) and common coarse prominent (10 YR 6/6) mottles, sandy clay loam, moderately sticky, slightly plastic, slightly firm, brittle, moderately developed pedality with coarse blocky and medium polyhedral peds, common extremely fine roots, no NaF reaction, indistinct wavy boundary.
Cu	49-80+	10 YR 8/2 with many medium prominent (10 YR 5/8) and common medium prominent (5 YR 4/6) mottles, sandy loam, slightly plastic, non-plastic, apedal single grained, no NaF reaction.

Site: 08D
Date observed: 30/9/2011



Reference data

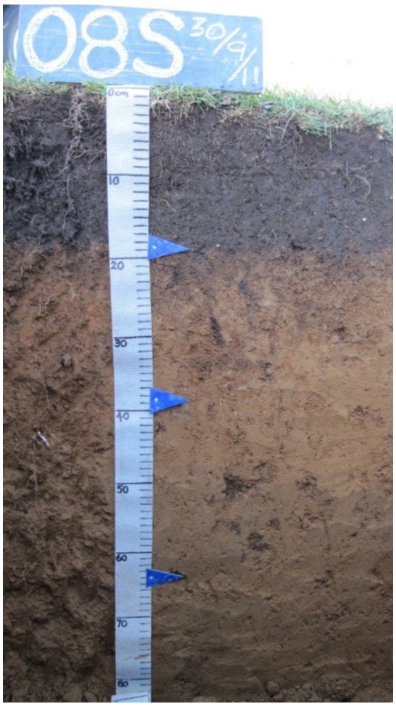
Soil name:	Otorohanga Silt Loam
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit was in the second paddock northwest of the entrance to the milk tanker track and approximately 30 m from the boundary fence and hedge and 15 m from the fence and gate to the south east that adjoins the first paddock that is northwest of the tanker track.
GPS reference:	NZMG 2719298E, 6330931N
Annual rainfall:	1550 mm at Otewa
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	112 m asl
Geomorphic position:	Profile on a flat plain of a summit area of a hill surrounded by easy rolling land.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup, dock.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-16	10 YR 2/3, silt loam, non-sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and common very fine roots, very strong NaF reaction, sharp smooth and occluded boundary.
Bw1	16-39	10 YR 4/4, clay loam, slightly sticky, moderately plastic, weak, brittle, moderately developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and common very fine roots, very strong NaF reaction, distinct smooth boundary.
Bw2	39-71	10 YR 4/6, clay loam, slightly sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with coarse blocky breaking to medium blocky peds, many extremely fine and few very fine roots, very strong NaF reaction, distinct wavy boundary.
Bw3	71-86+	10 YR 6/6, clay loam, slightly sticky, moderately plastic, firm, brittle, weakly developed pedality with coarse platy breaking to medium blocky peds, many extremely fine roots, very strong NaF reaction.



Site: 08S
Date observed: 30/9/2011

Reference data

Soil name:	Otorohanga Silt Loam
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit was in a paddock adjoining Swainson Road at the eastern boundary of the farm, adjacent to the dairy block. This paddock also often has a silage stack. The pit was approximately 50 m perpendicular from Swainson Road and 30 m from the boundary hedge with the dairy block.
GPS reference:	NZMG 2719282E, 6330870N
Annual rainfall:	1550 mm at Otewa
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	116 m asl
Geomorphic position:	Profile on a flat plain of a summit area of a hill surrounded by rolling and undulating topography.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominant ryegrass and white clover plus, dock, California thistles, dandelion.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-18	10 YR 2/3, silt loam, non-sticky, moderately plastic, slightly weak, friable, moderately developed pedality with very fine, fine polyhedral peds, abundant extremely fine and few very fine and fine roots, very strong NaF reaction, abrupt smooth and occluded boundary.
Bw1	18-38	10 YR 4/4, clay loam, non-sticky, moderately plastic, weak, brittle, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, very strong NaF reaction, indistinct smooth boundary.
Bw2	38-63	10 YR 4/6, clay loam, non-sticky, moderately plastic, slightly very weak, brittle, moderately developed pedality with coarse blocky and medium polyhedral peds, abundant extremely fine and few very fine roots, very strong NaF reaction, distinct wavy boundary.
Bw3	63-84+	10 YR 4/6, clay loam, non-sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with coarse blocky breaking to medium blocky peds, many extremely fine roots, very strong NaF reaction.

Site: 09D
Date observed: 21/4/2012

Reference data

Soil name: Horotiu sandy loam
NZSC: Typic Orthic Allophanic

Site data

Location:	Pit located down race (Banks Road) past large stables on the southern side of race, at the first race intersection in the paddock at the southwest corner of the intersection. Approximately 30 m south of the hedge and fence to the northern side and 50 m from the fence to the southeastern side of th paddock.
GPS reference:	NZMG 2721790E, 6366420N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	63 m asl
Geomorphic position:	Profile on planar slope of a terrace in flat to gently undulating topography.
Erosion/deposition:	Nil
Vegetation:	Pasture - ryegrass and white clover plus, dock.
Parent material:	Alluvium
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-16	10 YR 3/1, silt loam, slightly sticky, slightly plastic, weak, brittle, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant microfine and extremely fine roots, abrupt smooth and occluded boundary.
Bw1	16-34	10 YR 5/4, clay loam and sandy loam, non-sticky, non-plastic, weak, brittle, strongly developed pedality with medium and coarse blocky peds, many extremely fine and common very fine roots, indistinct smooth boundary.
Bw2	34-68	10 YR 5/6, sandy loam, non-sticky, non-plastic, weak, brittle, moderately developed pedality with coarse blocky breaking to medium polyhedral peds, many microfine and extremely fine and few very fine roots, distinct wavy boundary.
BC	68-80+	10YR 5/6 to 5/3, sand, non-sticky, non-plastic, apedal single grained, common extremely fine roots.

Site: 09S
Date observed: 21/4/2012

Reference data

Soil name: Horotiu sandy loam
NZSC: Typic Orthic Allophanic

Site data

Location:	Pit located down race (Banks Road) past large stables on the southern side of race, at the first race intersection in the paddock at the northwest corner of the intersection. Approximately 20 m north of the fence to the southern side of the paddock and 70 m from the fence on the southeastern side of the paddock.
GPS reference:	NZMG 2721800E, 6366485N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	68 m asl
Geomorphic position:	Profile on planar slope of a terrace in flat to gently undulating topography.
Erosion/deposition:	Nil
Vegetation:	Pasture - ryegrass and white clover plus, dock, dandelion and mellow.
Parent material:	Alluvium
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 3/1, silt loam, slightly sticky, slightly plastic, weak, friable, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and few very fine roots, abrupt smooth boundary.
Bw1	17-37	10 YR 5/4, clay loam and sandy loam, slightly sticky, slightly plastic, weak, brittle, strongly developed pedality with coarse blocky breaking to fine and very fine polyhedral peds, many extremely fine and few very fine roots, distinct smooth boundary.
Bw2	37-61	10 YR 5/6, sandy loam, non-sticky, non-plastic, slightly firm, brittle, moderately developed pedality with coarse blocky breaking to medium blocky peds, common microfine and extremely fine, indistinct smooth boundary.
BC	61-71+	10YR 5/6 to 5/3, loamy sand, non-sticky, non-plastic, very weak, friable, massive, common microfine fine roots.

Site: 10D
Date observed: 4/5/2011

Reference data

Soil name: Topehahae (GRT)
NZSC: Typic Sandy Gley

Site data

Location:	Pit in paddock adjacent to Aspin Road and boundary with another property, at the southeastern end of farm. Approximately 110 m from Aspin Road, 63 m from race and 35 m from boundary with poplar trees.
GPS reference:	NZMG 2731108E, 6370576N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	81 m asl
Geomorphic position:	Profile on a 1-2° slope of a depression in a flood plain of flat to gently undulating land.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dock, mellow and dandelion.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap(g)	0-17	10 YR 3/2 with common extremely fine distinct mottles (7.5 YR 2/3), silty loam, slightly sticky, slightly plastic, weak, brittle, strongly developed pedality with medium and very fine and fine polyhedral peds, abundant extremely fine and many very fine roots, abrupt smooth and occluded boundary.
Bg1	17-45	2.5 YR 7/2 with common very fine prominent (7.5 YR 6/8) and few extremely fine prominent (7.5 YR 4/6) mottles, sandy loam, non-sticky, non-plastic, weak, semi-deformable, moderately developed pedality with coarse blocky breaking to medium blocky peds, many extremely fine roots, indistinct smooth boundary.
Bg2	45-70+	2.5 YR 8/2 with common fine prominent (10 YR 6/8) and common very fine prominent (7.5 YR 5/6) mottles, 7.5 YR 2/1 clay coatings around mottles and root channels, sandy loam, non-sticky, non-plastic, weak, semi-deformable, massive, common extremely fine and few very fine roots.

Site: 10S
Date observed: 4/5/2011

Reference data

Soil name: Tauwhare (ROM)
NZSC: Typic Sandy Gley

Site data

Location:	Pit in paddock adjacent to Aspin Road and boundary with another property, at the north-eastern side of farm. Approximately 20 m from Aspin Road, 40 m from the boundary with poplar trees to the west.
GPS reference:	NZMG 2731185E, 6370537N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	84 m asl
Geomorphic position:	Profile on a 2-3° slope of a depression in a flood plain of flat to gently undulating land.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass and white clover plus, paspalum.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap(g)	0-16	10 YR 3/2 with common extremely fine distinct mottles (7.5 YR 2/3), silty loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with medium and very fine and fine polyhedral peds, abundant microfine and extremely fine and common very fine roots, distinct smooth and occluded boundary.
Bg1	16-34	2.5 YR 7/2 with many very fine prominent (7.5 YR 6/6) and few extremely fine distinct (5 YR 4/4) mottles and extremely fine common prominent sesquioxide coatings (7.5 YR 1.7/1), sand, non-sticky, non-plastic, weak, brittle, strongly developed pedality with coarse blocky breaking to medium blocky peds, many extremely fine and few very fine roots, indistinct smooth boundary.
Bg2	34-67	2.5 YR 7/1 with common very fine distinct (10 YR 6/6) and few extremely fine distinct (7.5 YR 6/6) mottles, sand, non-sticky, non-plastic, very weak, brittle, moderately developed pedality with very coarse and extremely coarse blocky breaking to coarse blocky peds, common extremely fine roots, indistinct and wavy boundary.
BCg	67-75+	2.5 YR 8/2 with few extremely fine prominent (7.5 YR 5/8) and common very fine and fine prominent (10 YR 5/8) mottles, sandy clay loam, non-sticky, non-plastic, slightly firm, brittle, massive, few extremely fine roots.

Site: 11D
Date observed: 29/9/2011

Reference data

Soil name: Hamilton clay loam (NOT)
NZSC: Typic Orthic Granular

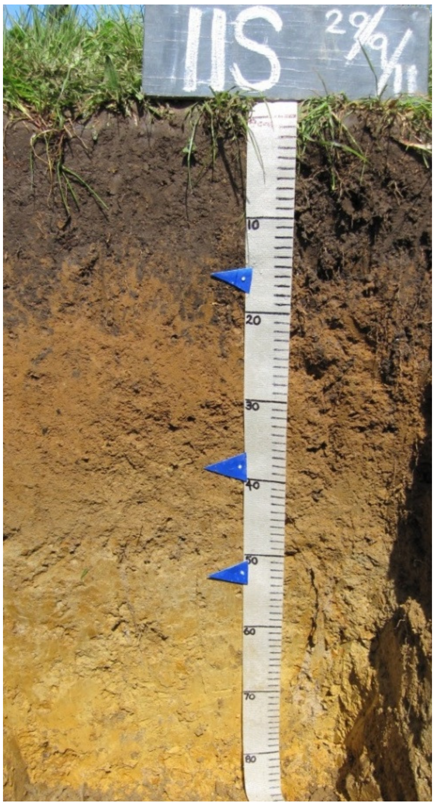
Site data

Location:	Pit in paddock at eastern end of farm, approximately 270m from Tahuroa Road in the paddock with a small stream running through it, that is south of a separate property with dwelling along Tahuroa road.
GPS reference:	NZMG 2727537E, 6379739N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	69 m asl
Geomorphic position:	Profile on 3-4° shoulder slope with western aspect of a low hill of rolling land in hilly topography.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass and white clover plus, narrow leaf plantain, dandelion, dock.
Parent material:	Volcanic over rock
Drainage class:	Moderately well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 3/2, silt loam, moderately sticky, moderately plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine, no NaF reaction, sharp smooth and occluded boundary.
Bw	17-34	10 YR 4/4, silty clay, moderately sticky, very plastic, weak, brittle, strongly developed pedality with coarse polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, no NaF reaction, distinct smooth boundary.
Bw(g)	34-60	10 YR 6/4 with common fine faint (10 YR 6/3) and common very fine distinct (7.5 YR 5/6) mottles and extremely fine common distinct Mn coatings (10 YR 1.7/1), silty clay, moderately sticky, very plastic, slightly firm, brittle, moderately developed pedality with coarse blocky breaking to medium polyhedral peds, many extremely fine and few very fine roots, no NaF reaction, abrupt wavy boundary.
BCg	60-83+	10 YR 7/2 with abundant medium prominent (7.5 YR 5/6) and few very fine distinct (7.5 YR4/6) mottles, silty clay, moderately sticky, very plastic, slightly firm, brittle, weakly developed pedality with coarse platy peds, many extremely fine roots, no NaF reaction.

Site: 11S
Date observed: 29/9/2011



Reference data

Soil name: Hamilton clay loam (NOT)
NZSC: Typic Orthic Granular

Site data

Location: Pit is in a paddock on the western boundary of the farm near Tahuroa road, on the southern side of the pond and stream that runs through this paddock. The paddock is opposite the intersection of Tahuroa and Nicholls Road.
GPS reference: NZMG 2727614E, 6379725N
Annual rainfall: 1190 mm at Hamilton
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 68 m asl
Geomorphic position: Profile on 3-4° shoulder slope near the upper slope with southwest aspect on a low hill of rolling land and hilly topography.
Erosion/deposition: Nil
Vegetation: Pasture - dominantly ryegrass and white clover plus, buttercup, dandelion, dock.
Parent material: Volcanic over rock
Drainage class: Moderately well drained
Land use: Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-16	10 YR 2/2, silt loam, slightly sticky, slightly plastic, weak, friable, moderately developed pedality with very fine and fine polyhedral peds, abundant extremely fine and common very fine, no NaF reaction, indistinct wavy and occluded boundary.
Bw	16-38	10 YR 5/6, silty clay, very sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse and medium polyhedral peds, abundant extremely fine and common very fine roots, no NaF reaction, distinct smooth boundary.
Bw(g)	38-53	10 YR 6/4 with many medium distinct (10 YR 6/2) and common very fine distinct (7.5 YR 4/4) mottles, silty clay, very sticky, very plastic, slightly firm, brittle, moderately developed pedality with coarse blocky breaking to medium polyhedral peds, many extremely fine and few very fine roots, no NaF reaction, indistinct wavy boundary.
BCg	53-85+	10 YR 7/2 with many medium prominent (7.5 YR 5/6) and common fine distinct (7.5 YR4/6) mottles, silty clay, very sticky, firm, brittle, weakly developed pedality with coarse platy peds, many microfine and extremely fine roots, no NaF reaction.

Site: 12D
Date observed: 2/6/2011

Reference data

Soil name:	Te Kuiti silt loam (LOT)
NZSC:	Typic Orthic Allophanic

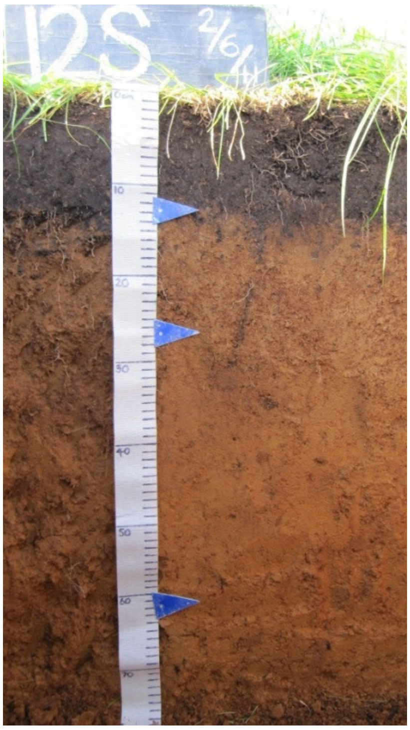
Site data

Location:	Pit located in a paddock at the south western area of the farm, at the bottom of a slope in a paddock with a line of pine trees on the western fence line. Pit was approximately 30 m from the boundary fence.
GPS reference:	NZMG 2697323E, 6347111N
Annual rainfall:	1127 mm at Te Awamutu
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	140 m
Geomorphic position:	Profile on a 6-8° slope on the foot slope of a hill in strongly rolling, hilly topography.
Erosion/deposition:	Unknown
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dandelion, dock.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-14	10 YR 1.7/1, silt loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, abrupt smooth, wavy and occluded boundary.
Ap/Bw	14-29	10 YR 4/3, silt loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many microfine roots, strong NaF reaction, distinct wavy boundary.
Bw	29-59	10 YR 4/4 with very fine few distinct clay coatings (7.5 YR 4/3) down root channels, clay loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with very fine and fine polyhedral breaking to very fine and fine polyhedral peds, many microfine and few very fine roots and indistinct smooth boundary.
BC	59-72+	7.5 YR 4/6 with very fine few distinct clay coatings (7.5 YR 4/3) down root channels, clay loam, slightly sticky, moderately plastic, slightly firm, brittle, medium polyhedral and very fine and fine polyhedral peds, common microfine roots, strong NaF reaction.

Site: **12S**
Date observed: **2/6/2011**



Reference data

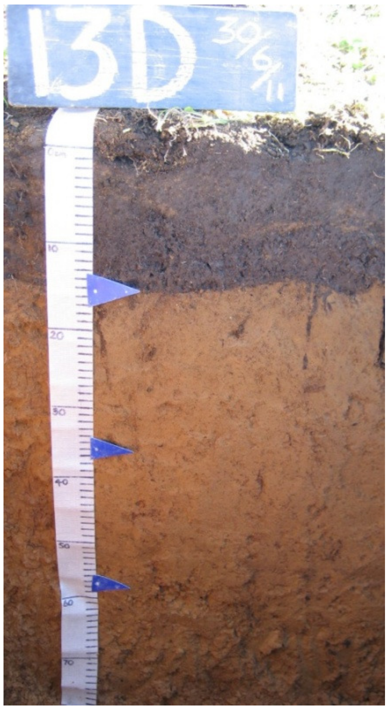
Soil name:	Te Kuiti silt loam (LOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit located in a paddock at the northern area of the farm, at the top of a slope in a paddock above a gully area. The pit was approximately 30 m south from the boundary fence.
GPS reference:	NZMG 2697254E, 6347050N
Annual rainfall:	1127 mm at Te Awamutu
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	134 m asl
Geomorphic position:	Profile on a 5° slope on a planar slope of the upper slope area of a hill in strongly rolling, hilly topography.
Erosion/deposition:	Unknown
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dandelion, buttercup, dock.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-13	10 YR 1.7/1, silt loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and many very fine roots, strong NaF reaction, abrupt smooth and occluded boundary.
Ap/Bw	13-27	10 YR 4/3, silt loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with very fine and fine polyhedral peds, many extremely fine and common very fine roots, strong NaF reaction, distinct smooth boundary.
Bw	27-62	10 YR 4/4 with few extremely fine faint clay coatings (5 YR 4/6) down root channels, clay loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, many extremely fine and common very fine roots, strong NaF reaction, distinct wavy boundary.
BC	62-76+	7.5 YR 4/6 with common very fine faint clay coatings (5 YR 4/6) down root channels, clay loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse blocky breaking to medium blocky peds, common microfine and extremely fine roots, strong NaF reaction.



Site: 13D
Date observed: 30/6/2011

Reference data

Soil name: Ohaupo silt loam (LOT)
NZSC: Typic Orthic Allophanic

Site data

Location: Pit was in paddock south of O'Shea Road, at the north-eastern boundary of the farm. The paddock was to the east of the paddock with the two water tanks in it and opposite a dwelling on the other side of O'Shea Road. Approximately 20 m south from O'Shea Road and 160 m east of the two water tanks.
GPS reference: NZMG 2701081E, 6355982N
Annual rainfall: 1127 mm at Te Awamutu
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 83 m asl
Geomorphic position: Profile on a 1-2° slope on a midslope of a hill in rolling to hilly land.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, buttercup.
Parent material: Volcanic
Drainage class: Well drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-16	10 YR 3/1, silt loam, slightly sticky, slightly plastic, weak, friable, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine roots, medium NaF reaction, sharp smooth boundary.
Bw1	16-36	10 YR 4/6 to 7.5 YR 4/6, clay loam, non-sticky, slightly plastic, weak, friable, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine roots, strong NaF reaction, distinct smooth boundary.
Bw2	36-58	7.5 YR 4/4, clay loam, slightly sticky, slightly plastic, weak, brittle, strongly developed pedality with medium polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, distinct wavy boundary.
Bw3	58-78+	7.5 YR 5/4 with few fine distinct clay coatings between peds and down root channels (7.5 YR 4/4), clay loam, non-sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with coarse blocky breaking to medium polyhedral peds, common extremely fine and few very fine roots, strong NaF reaction.

Site: 13S
Date observed: 30/6/2011

Reference data

Soil name: Ohaupo silt loam (LOT)
NZSC: Typic Orthic Allophanic

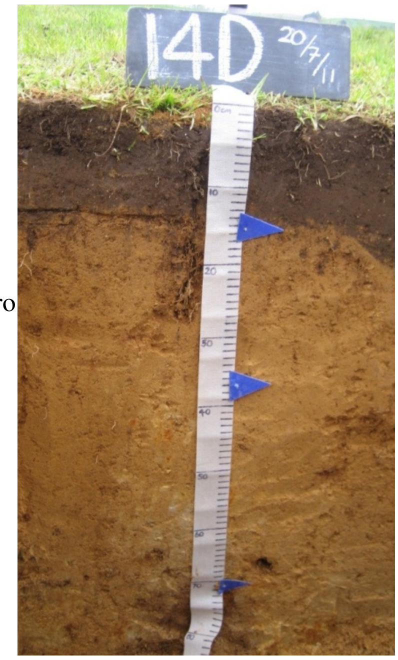
Site data

Location:	Pit was in paddock south of O'Shea Road, at the north-western boundary of the farm. The paddock was the first paddock to the west of the two water tanks in it. Approximately 30 m from O'Shea Road and 25 m from the two water tanks.
GPS reference:	NZMG 2700983E, 6355815N
Annual rainfall:	1127 mm at Te Awamutu
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	95 m asl
Geomorphic position:	Profile on a 1-2° slope with northwest facing aspect, on a planar slope of a hill in rolling to hilly land.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, narrow leaf plantain, dandelion, dock, prickles.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-16	10 YR 2/1, silt loam, slightly sticky, moderately plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine and many very fine roots, strong NaF reaction, abrupt, smooth and occluded boundary.
Bw1	16-43	10 YR 4/6, clay loam, non-sticky, non-plastic, weak, friable, moderately developed pedality with medium blocky breaking to very fine and fine polyhedral peds, many extremely fine and common very fine roots, strong NaF reaction, indistinct smooth boundary.
Bw2	43-66	7.5 YR 5/6, clay loam/ sandy loam, non-sticky, non-plastic, weak, friable, moderately developed pedality with coarse blocky and medium polyhedral peds, many extremely fine and common very fine roots, strong NaF reaction, distinct smooth boundary.
Bw3	66-75+	7.5 YR 5/4 with few very fine faint clay coatings between peds and down root channels (7.5 YR 5/6), clay loam, non-sticky, slightly plastic, weak, friable, moderately developed pedality with medium and coarse blocky peds, common microfine roots, strong NaF reaction.

Site: 14D
Date observed: 20/4/2012



Reference data

Soil name: Otorohanga silt loam (LOT)
NZSC: Typic Orthic Allophanic

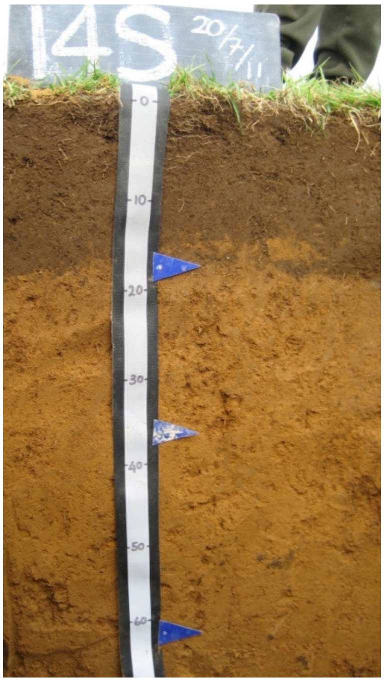
Site data

Location: Pit in a paddock that borders Te Miro Road, approximately 64 m in a straight line from the paddock gate from the road.
GPS reference: NZMG 2736837E, 6373398N
Annual rainfall: 1190 mm at Hamilton
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 193 m asl
Geomorphic position: Profile on a planar slope of a terracette with pugged ground, on flat to gently undulating land in a valley plateau surrounded by mountains
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, buttercup, flat weeds , mellow.
Parent material: Volcanic
Drainage class: Moderately well drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-15	10 YR 2/3, slightly sticky, slightly plastic, slightly firm, friable, strongly developed pedality with very fine, fine and medium polyhedral peds, strong NaF reaction, many extremely fine, few fine and many very fine roots, abrupt wavy boundary.
Bw1	15-37	10 YR 5/6, non-sticky, non-plastic, slightly firm, brittle, moderately developed pedality with very fine, fine and medium polyhedral breaking to very fine and fine polyhedral peds, strong NaF reaction, common microfine roots, indistinct occluded boundary.
Bw2	37-71	10 YR 6/6 with very few very fine distinct (2.5 Y 7/4) and very few very fine to fine prominent (7.5 YR 5/6) mottles, non-sticky, non-plastic, weak, brittle, weakly developed pedality with coarse blocky breaking to very fine, fine and medium polyhedral peds, strong NaF reaction, few microfine roots, indistinct occluded boundary.
Bw(g)	71-90+	2.5 YR 7/6 with very few very fine to fine prominent (7.5 YR 5/6) mottles, non-sticky, non-plastic, weak, brittle, weakly developed pedality with coarse to extremely coarse blocky breaking to medium blocky peds, moderate NaF reaction.

Site: 14S
Date observed: 20/4/2012



Reference data

Soil name:	Otorohanga silt loam (LOT)
NZSC:	Typic Orthic Allophanic

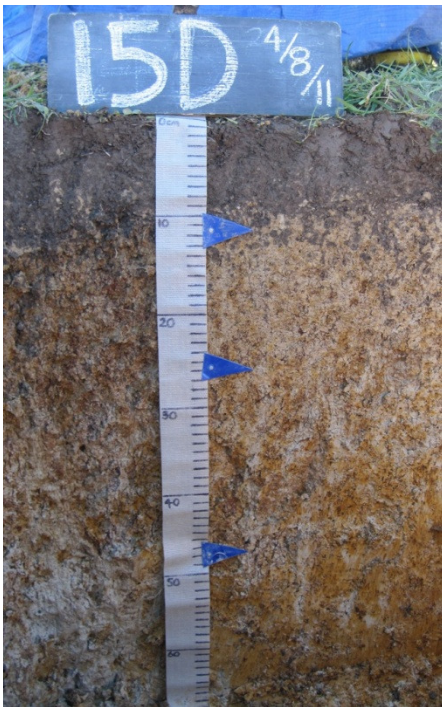
Site data

Location:	Pit in a paddock that borders Te Miro Road, approximately 40 m in a straight line perpendicular from the road side fence. The paddock has telephone poles through it.
GPS reference:	NZMG 2736955E, 6373403N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	196 m asl
Geomorphic position:	Profile on a planar slope on a slight mound/ terracette with pugged ground, on flat to gently undulating land in a valley plateau surrounded by mountains
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, flat weeds.
Parent material:	Volcanic
Drainage class:	Moderately well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 3/3, loamy sand, slightly sticky, slightly plastic, weak, friable, moderately developed pedality with very fine, fine and medium polyhedral breaking to very fine and fine polyhedral peds, strong NaF reaction, many extremely fine and microfine roots, abrupt smooth boundary.
Bw1	17-36	10 YR 5/8, non-sticky, non-plastic, weak, friable, moderately developed pedality with very fine and fine blocky and polyhedral breaking to very fine and fine polyhedral peds, strong NaF reaction, common microfine and many extremely fine roots, indistinct occluded boundary.
Bw2	36-62	10 YR 6/6, non-sticky, non-plastic, weak, friable, weakly developed pedality with very fine and fine blocky breaking to very fine and fine blocky and polyhedral peds, strong NaF reaction, common extremely fine and many microfine roots, indistinct occluded boundary.
Bw(g)	62-78+	2.5 YR 7/4 with common extremely fine prominent (7.5 YR 4/6) mottles, non-sticky, non-plastic, firm, brittle, weakly developed pedality with coarse blocky breaking to medium blocky peds, moderate NaF reaction.

Site: 15D
Date observed: 4/8/2011



Reference data

Soil name: Otorohanga silt loam (LOT)
NZSC: Typic Orthic Gley

Site data

Location: Pit in a paddock on the corner of Taihia and Shanks Roads. Approximately 60 m from Taihia Road and 45 m from Shanks Road.
GPS reference: NZMG 2710715E, 6326157N
Annual rainfall: 1550 mm at Otewa
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 75 m asl
Geomorphic position: Profile on a slight depression in pugged ground of a hollow on flat to gently undulating land on a terrace.
Erosion/deposition: Nil
Vegetation: Pasture - dominantly ryegrass and white clover plus, buttercup, dock.
Parent material: Alluvium
Drainage class: Poorly drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-12	10 YR 4/2, clay loam, moderately sticky, moderately plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, many extremely fine and few very fine roots, no NaF reaction, distinct smooth and occluded boundary.
Bg1	12-26	10 YR 6/4 with common very fine distinct (7.5 YR 6/6) and common extremely fine distinct (7.5 YR 5/6) mottles, clay loam, moderately sticky, moderately plastic, weak, brittle, strongly developed pedality with medium polyhedral breaking to fine and very fine polyhedral peds, many extremely fine roots, no NaF reaction, distinct smooth boundary.
Bg2	26-48	2.5 YR 7/2 with many medium prominent (7.5 YR 6/8) and few extremely fine prominent (7.5 YR 5/6) mottles, silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with coarse blocky peds, many micro fine and extremely fine roots, no NaF reaction, indistinct smooth boundary.
Bg3	48-68+	2.5 YR 8/1 with common fine prominent (7.5 YR 6/8) and few extremely fine (7.5 YR 5/6) mottles, silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with coarse columnar peds, many microfine and extremely fine roots, no NaF reaction.

Site: 15S
Date observed: 4/8/2011

Reference data

Soil name: Otorohanga silt loam (LOT)
NZSC: Typic Orthic Gley

Site data

Location:	Pit in a paddock on the corner of Taihia and Shanks Roads. Approximately 80 m from Taihia Road and 20 m from Shanks Road.
GPS reference:	NZMG 2710724E, 6326083N
Annual rainfall:	1550 mm at Otewa
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	68 m asl
Geomorphic position:	Profile on a foot slope in pugged ground of a hollow on flat to gently undulating land on a terrace.
Erosion/deposition:	Nil
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup, dock.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-15	10 YR 3/1, silt loam, slightly sticky, slightly plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine and few very fine roots, slight NaF reaction, distinct smooth and occluded boundary.
Bg1	15-29	10 YR 7/4 with common very fine distinct (7.5 YR 5/6) mottles, clay loam, moderately sticky, moderately plastic, weak, brittle, medium polyhedral and medium spheroidal peds, many extremely fine roots, no NaF reaction, indistinct boundary.
Bg2	29-49	2.5 YR 7/3 with many fine prominent (7.5 YR 5/8) and few extremely fine prominent (7.5 YR 5/8) mottles, silty clay, moderately sticky, moderately plastic, weak, brittle, medium blocky peds, many extremely fine roots, no NaF reaction, distinct boundary.
Bg3	49-66+	2.5 YR 7/4 with abundant fine distinct (7.5 YR 5/8) mottles, silty clay, moderately sticky, very plastic, weak, brittle, medium block breaking to very fine and fine polyhedral peds, many extremely fine roots, no NaF reaction.

Site: 16D
Date observed: 9/8/2011

Reference data

Soil name:	Otorohanga silt loam (LOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit in a paddock that borders the drystock farm main race to the east of Earle Road. Pit approximately 20 m from the fence bordering the race.
GPS reference:	NZMG 2731986E, 6342706N
Annual rainfall:	1550 mm at Otewa
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	229 m asl
Geomorphic position:	Profile on a 10-12° slope with a northeast aspect at the midslope of an easy rolling hill in hilly topography.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, mellow, ragwort, thistles.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-19	10 YR 3/3,silt loam, non-sticky, slightly plastic, weak, brittle, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, abrupt smooth boundary.
Ap/Bw	19-29	10 YR 3/4, clay loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, many extremely fine and common very fine roots, strong NaF reaction, distinct smooth and occluded boundary.
Bw1	29-64	10 YR 4/6, clay loam, non-sticky, slightly plastic, weak, brittle, moderately developed pedality with medium blocky breaking to medium polyhedral peds, many extremely fine roots, strong NaF reaction, distinct wavy boundary.
Bw2	64-79+	10 YR 5/6, silt loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with coarse prismatic and medium blocky peds, common microfine roots, strong NaF reaction.

Site: 16S
Date observed: 9/8/2011

Reference data

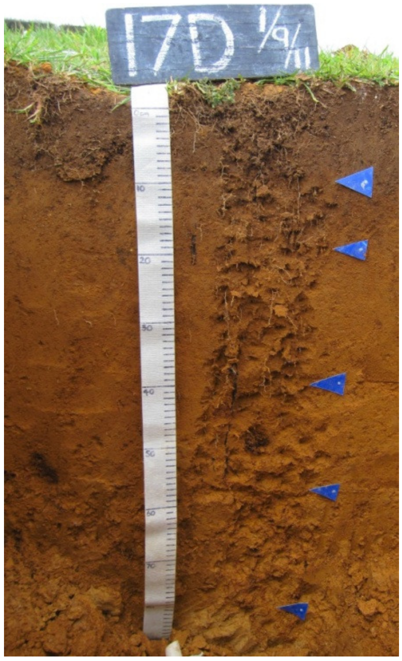
Soil name:	Otorohanga silt loam (LOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit in a paddock that on the outside of a 90° bend in the main race to the east of the dwelling.
GPS reference:	NZMG 2731371E, 6342616N
Annual rainfall:	1550 mm at Otewa
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	231 m asl
Geomorphic position:	Profile on a 6° slope with southwest aspect at the midslope of an easy rolling hill in hilly topography.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dock, dandelion.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-23	10 YR 3/3, silt loam, non-sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with very fine and fine polyhedral breaking to very fine and fine polyhedral peds, many extremely fine and many very fine roots, strong NaF reaction, distinct smooth boundary.
Ap/Bw	23-34	10 YR 4/4, clay loam, non-sticky, slightly plastic, slightly firm, brittle, moderately developed pedality with medium blocky breaking to very fine and fine polyhedral peds, many extremely fine and common very fine roots, strong NaF reaction, distinct smooth and occluded boundary.
Bw1	34-58	10 YR 5/6, silt loam, non-sticky, slightly plastic, weak, brittle, moderately developed pedality with coarse blocky breaking to very fine and fine polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, abrupt smooth boundary.
Bw2	58-79+	10 YR 6/6, clay loam, non-sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with coarse prismatic breaking to medium and coarse blocky peds, common extremely fine roots, strong NaF reaction.



Site: 17D
Date observed: 1/9/2011

Reference data

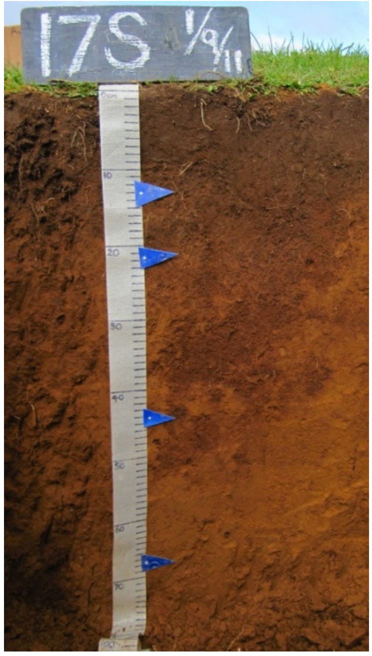
Soil name: Te Kuiti sandy loam (LOT)
NZSC: Typic Orthic Allophanic

Site data

Location: Pit located in a paddock on the north-eastern area of the farm, south of a patch of pine trees that are in the neighbouring property. Approximately 60 m north of the end of the race at the southern boundary of the paddock and 35 m from the property boundary.
GPS reference: NZMG 2711281E, 6316278N
Annual rainfall: 1550 mm at Otewa
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 379 m asl
Geomorphic position: Profile on a 5° slope with a north aspect on the midslope of a low hill in easy rolling land surrounded by hilly topography.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, daisy, dandelion.
Parent material: Volcanic
Drainage class: Well drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-11	10 YR 2/3, silt loam, slightly sticky, moderately plastic, weak, friable, moderately developed pedality with very fine and fine polyhedral peds, abundant microfine and common fine roots, strong NaF reaction, distinct irregular boundary.
AB	11-20	7.5 YR 4/4, sandy loam, slightly sticky, moderately plastic, very weak, friable, weakly developed pedality with coarse and extremely coarse polyhedral breaking to very fine to coarse polyhedral peds, many microfine and few very fine roots, strong NaF reaction, distinct smooth boundary.
Bw1	20-40	7.5 YR 4/6, sandy loam, non-sticky, slightly plastic, weak, friable, moderately developed pedality with very coarse and extremely coarse blocky breaking to very fine to coarse polyhedral and blocky peds, many microfine roots, strong NaF reaction, diffuse smooth boundary.
Bw2	40-62	7.5 YR 4/6, sandy loam, non-sticky, slightly plastic, weak, friable, moderately developed pedality with very coarse and extremely coarse blocky breaking to very fine and fine polyhedral and blocky peds, many micro fine roots, strong NaF reaction, diffuse smooth boundary.
Bw3	62-80	7.5 YR 5/6, sandy loam, slightly sticky, moderately plastic, weak, friable, moderately developed pedality with blocky breaking to medium and coarse blocky peds, few micro fine roots, strong NaF reaction.



Site: 17S
Date observed: 1/9/2011

Reference data

Soil name: Te Kuiti sandy loam (LOT)
NZSC: Typic Orthic Allophanic

Site data

Location: Pit located in a paddock in the eastern area of the farm near Pururu East Road, adjacent to a patch of pine trees to the north. Approximately 40-50 m west from the property boundary.
GPS reference: NZMG 2711360E, 6316263N
Annual rainfall: 1550 mm at Otewa
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 387 m asl
Geomorphic position: Profile on a 5-7° slope with a northeast aspect on the midslope of a low hill in easy rolling land surrounded by hilly topography.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, dock, daisy.
Parent material: Volcanic
Drainage class: Well drained
Land use: Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-13	10 YR 3/3, silt loam, slightly sticky, very plastic, weak, friable, strongly developed pedality with very fine and fine and medium polyhedral peds, many microfine and extremely fine and few very fine roots, strong NaF reaction, abrupt smooth boundary.
Ap/Bw	13-22	7.5 YR 4/4, sandy loam, slightly sticky, moderately plastic, weak, brittle, moderately developed pedality with very fine and fine and medium polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, distinct smooth and occluded boundary.
Bw1	22-44	7.5 YR 4/6, sandy loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, many microfine and extremely fine roots, strong NaF reaction, indistinct wavy boundary.
Bw2	44-68	7.5 YR 5/6, sandy loam, slightly sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with very medium blocky breaking to polyhedral peds, many extremely fine and microfine roots, strong NaF reaction, abrupt wavy boundary.
Bw3	68-76+	7.5 YR 5/6, sandy loam, slightly sticky, slightly plastic, very firm, brittle, moderately developed pedality with coarse blocking breaking to medium polyhedral peds, strong NaF reaction.

Site: 18D
Date observed: 28/9/2011

Reference data

Soil name:	Ohaupo silt loam (LOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit located in a paddock that borders Norwegian Road to the east and another property to the north. Approximately 60 m south east of Norwegian Road and 25 m south of the hedge along the property boundary.
GPS reference:	NZMG 2728729E, 6356830N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	112 m asl
Geomorphic position:	Profile on a 4-5° planar slope with a north-north-west aspect at the lower slope of a low easy rolling hill surrounded by hilly topography.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dock.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-13	10 YR 2/2, silt loam, slightly sticky, moderately plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, abrupt smooth and occluded boundary.
Bw1	13-28	10 YR 5/6, clay loam, slightly sticky, slightly plastic, weak, brittle, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and few very fine roots, strong NaF reaction, indistinct smooth boundary.
Bw2	28-67	10 YR 5.5/6, clay loam, moderately sticky, moderately plastic, weak, brittle, strongly developed pedality with medium polyhedral and very fine and fine polyhedral peds, many extremely fine roots, strong NaF reaction, instinct wavy boundary.
BC	67-83+	10 YR 5/4, clay loam, moderately sticky, moderately plastic, weak, friable, moderately developed pedality with coarse blocky and medium blocky peds, common extremely fine roots, strong NaF reaction.

Site: 18S
Date observed: 28/9/2011

Reference data

Soil name: Ohaupo silt loam (LOT)
NZSC: Typic Orthic Allophanic

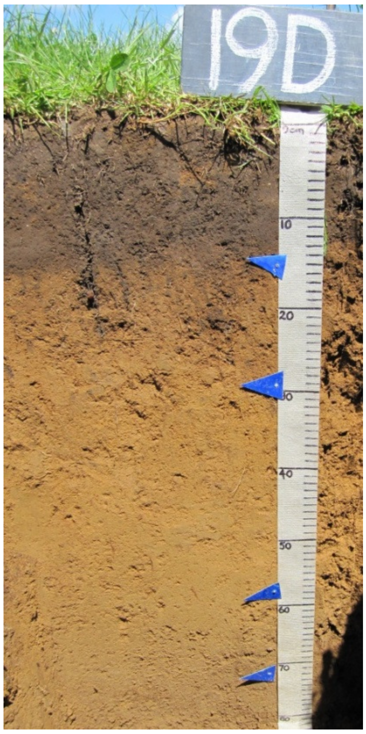
Site data

Location:	Pit located in a paddock at the southern end of the farm, that is the second paddock back from Norwegian Road and has a hedge along the property boundary fence. Approximately 20-30 m north of the hedge along the property boundary.
GPS reference:	NZMG 2728777E, 6356883N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	127 m asl
Geomorphic position:	Profile on a 6-8° planar slope with a north east aspect at the midslope of a low rolling hill surrounded by hilly topography.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup, California thistles, dandelion.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-21	10 YR 2/2, silt loam, slightly sticky, moderately plastic, weal. Friable, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, sharp smooth boundary.
Bw1	21-38	7.5 YR 4/4, silt loam, slightly sticky, slightly plastic, weak, brittle, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, distinct smooth boundary.
Bw2	38-62	10 YR 5/6, clay loam, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse blocky and medium polyhedral peds, common extremely fine and few very fine roots, strong NaF reaction, indistinct smooth boundary.
Bw3	62-82	10 YR 5/6, clay loam, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse blocky and very fine and fine polyhedral peds, common extremely fine roots, strong NaF reaction, abrupt smooth boundary.
BC	82-86+	10 YR 5/4, clay loam, moderately sticky, moderately plastic, firm, brittle, moderately developed pedality with medium columnar and very fine and fine polyhedral peds, few micro fine roots, strong NaF reaction.

Site: 19D
Date observed: 3/11/2011



Reference data

Soil name:	Hamilton clay loam (NOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit located in a paddock that borders Tahuroa Road and the tanker track, near some sheds and barns. Approximately 65 m east of Tahuroa Road and 20 m south of a dwelling.
GPS reference:	NZMG 2727884E, 6380146N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	73 m asl
Geomorphic position:	Profile on 2° slope with a northwest aspect, on a planar slope of a lower slope of a terrace in undulating land in a lowland.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-15	10 YR 2/2, silt loam, slightly sticky, slightly plastic, slightly firm, friable, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and many very fine roots, very strong NaF reaction, distinct smooth and occluded boundary.
Bw1	15-29	10 YR 4/6, silt loam/ clay loam, slightly sticky, slightly plastic, weak, friable, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, indistinct smooth boundary.
Bw2	29-58	10 YR 5/6, clay loam, slightly sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, indistinct smooth boundary.
Bw3	58-71	10 YR 5/6, silty clay, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine and fine polyhedral peds, many extremely fine roots, strong NaF reaction, distinct smooth boundary.
Bw4	71-81+	10 YR 5/4, silty clay, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine and fine polyhedral peds, common extremely fine roots, medium NaF reaction.

Site: **19S**
Date observed: **3/11/2011**

Reference data
Soil name: Hamilton clay loam (NOT)
NZSC: Typic Orthic Allophanic

Site data

Location:	Pit located in a paddock that borders Tahuroa Road and farms main house. Approximately 50-60 m west of Tahuroa Road and 100 m north-northeast of the main house.
GPS reference:	NZMG 2727745E, 6380255N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	76 m asl
Geomorphic position:	Profile on 2-3° slope with a northeast aspect, on a planar slope of a foot slope of a terrace in undulating land in a lowland.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, narrow leaf plantain, California thistles, broad leaf plantain.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-15	10 YR 2/2, silt loam, slightly sticky, moderately plastic, slightly firm, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, medium NaF reaction, distinct smooth and occluded boundary.
Bw1	15-32	10 YR 4/4, clay loam, non-sticky, non-plastic, weak, very friable, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, distinct smooth boundary.
Bw2	32-56	10 YR 4/6, clay loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, indistinct diffuse boundary.
Bw3	56-76	10 YR 5/6, clay loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine roots, strong NaF reaction, indistinct smooth boundary.
Bw4	76-83+	10 YR 5/4, silty clay, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, common microfine and extremely fine roots, very faint NaF reaction.

Site: 20D
Date observed: 4/11/2011

Reference data

Soil name: Horotiu-Te Kowhai complex
NZSC: Typic Orthic Gley

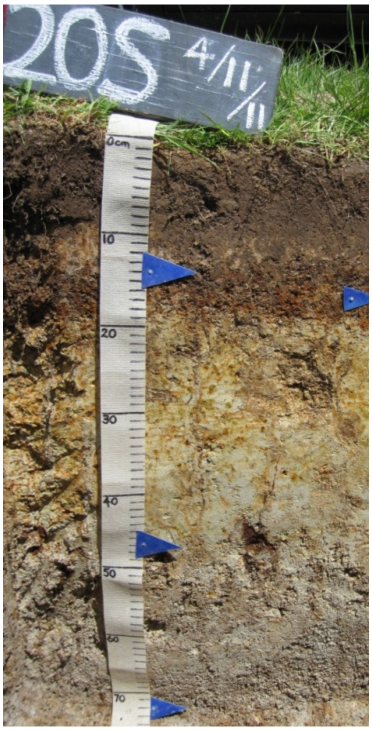
Site data

Location: Pit located in a paddock that borders Tauwhare Road and the adjacent property. Paddock has poplar trees along the property boundary with deer fencing. Pit located in the low flood plain part of the paddock, approximately 35-45 m from the farm boundary.
GPS reference: NZMG 2726025E, 6379826N
Annual rainfall: 1190 mm at Hamilton
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 54 m asl
Geomorphic position: Profile on planar slope in a hollow of a flood plain of flat to gently undulating land in a plain.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, buttercup, dock.
Parent material: Alluvium
Drainage class: Poorly drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Apg	0-12	10 YR 3/2 with common extremely fine faint (7.5 YR 4/4) mottles, silt loam, slightly sticky, moderately plastic, firm, brittle, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, no NaF reaction, indistinct wavy and occluded boundary.
Bg	12-36	2.5 YR 7/2 with common very fine prominent (7.5 YR 3/3) and few very fine distinct (7.5 YR 5/6) mottles, clay loam, non-sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with medium and coarse blocky and very fine and fine polyhedral peds, many extremely fine and common very fine roots, no NaF reaction, indistinct wavy boundary.
BCg	36-63	2.5 YR 7/1 with many fine and medium prominent (7.5 YR 5/6) and few fine prominent (7.5 YR 6/6) mottles and few extremely fine prominent Mn around roots, sandy, non-sticky, non-plastic, weak, brittle, partly massive and partly apedal single grained, many extremely fine and dew very fine roots, no NaF reaction, abrupt smooth boundary.
Cg	63-65+	2.5 YR 7/1 with common, medium prominent (7.5 YR 4/5) and common fine prominent (7.5 YR 6/6) mottles and few extremely fine prominent Mn pan with gravels, sand, non-sticky, non-plastic, massive, few extremely fine roots, no NaF reaction.

Site: 20S
Date observed: 4/11/2011



Reference data

Soil name: Horotiu-Te Kowhai complex
NZSC: Typic Orthic Gley

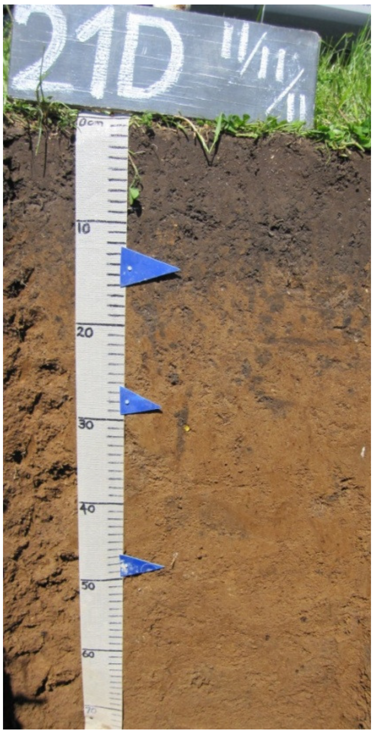
Site data

Location:	Pit located in a paddock that borders Tauwhare Road and the adjacent property to the north. Paddock has poplar trees along the property boundary with deer fencing. Pit located in the low flood plain part of the paddock, approximately 30 m from the farm boundary and 15 m from the western fence.
GPS reference:	NZMG 2726041E, 6379750N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	55 m asl
Geomorphic position:	Profile on planar slope in a hollow of a flood plain of flat to gently undulating land in a plain.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup, narrow leaf plantain.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Apg	0-14	10 YR 3/2 with few extremely fine distinct (7.5 YR 4/4) mottles, silt loam, moderately stick, moderately plastic, slightly firm, semi-deformable, strongly developed pedality with coarse polyhedral breaking to very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, no NaF reaction, distinct smooth boundary.
Bg	14-47	2.5 YR 7/2 with common fine prominent (10 YR 6/6) and common very fine prominent (5 YR 4/6) mottles and few very fine prominent (5 YR 2/1) Mn around root channels, clay loam, slightly sticky, slightly plastic, firm, brittle, moderately developed pedality with coarse blocky breaking to medium blocky peds, common extremely fine roots, no NaF reaction, distinct wavy boundary.
BCg	47-70	10 YR 6/2 with few very fine prominent (7.5 YR 4/6) and few fine prominent (10 YR 6/6) mottles, sand, non-sticky, no plastic, weak, apedal single grained, few extremely fine roots, no NaF reaction, indistinct wavy boundary.
Cg	70-71+	10 YR 6/1 with common very fine prominent (5 YR 2/1) Mn on gravel, sand, firm, massive, few extremely fine roots, no NaF reaction.

Site: **21D**
Date observed: **11/11/2011**



Reference data

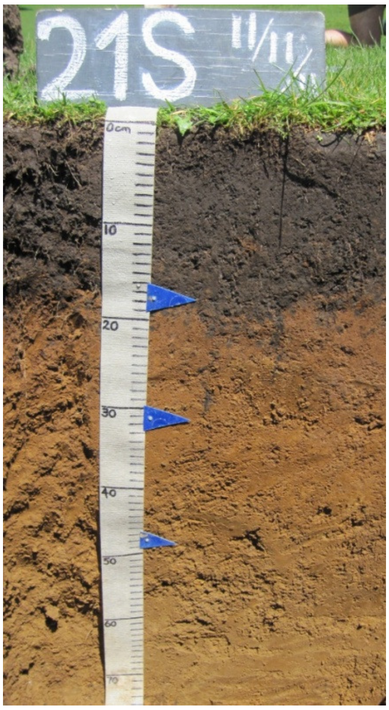
Soil name: Hamilton clay loam (NOT)
NZSC: Typic Orthic Granular

Site data

Location: Pit located in a paddock that borders the end of Lang Road and the farm house driveway. Pit approximately 46 m from Land Road and 20 m from the driveway.
GPS reference: NZMG 2729384E, 6375791N
Annual rainfall: 1190 mm at Hamilton
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 107 m asl
Geomorphic position: Profile on a 5-6° slope with a northern aspect on pugged ground, on a midslope of a hill in easy rolling land surrounded by hilly land.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, California thistles, dandelion, lots of other weeds, a very poor pasture.
Parent material: Volcanic over rock
Drainage class: Moderately well drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-14	10 YR 2/1, silt loam, non-sticky, moderately plastic, weak, brittle, strongly developed pedality with very fine and fine polyhedral peds, many extremely fine and few fine roots, no NaF reaction, distinct smooth boundary.
Ap/Bw	14-28	7.5 YR 3/4, silt loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with medium to very fine polyhedral breaking to very fine and fine polyhedral peds, many extremely fine and few fine roots, no NaF reaction, indistinct occluded boundary.
Bw(f)	28-48	7.5 YR 4/4 with few extremely fine faint (7.5 4/6) mottles and very few extremely fine faint Mn, silty clay, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with medium, very fine and fine blocky peds, many extremely fine roots, no NaF reaction, indistinct smooth boundary.
BC	48-76+	7.5 YR 4/4, silty clay, moderately sticky, very plastic, slightly firm, brittle, moderately developed pedality with coarse prismatic breaking to coarse blocky peds, many extremely fine and few very fine roots, no NaF reaction.



Site: 21S
Date observed: 11/11/2011

Reference data
Soil name: Hamilton clay loam (NOT)
NZSC: Typic Orthic Granular

Site data
Location: Pit located in a paddock with the driveway to the main house, at the end of Lang Road. Pit between 2 races, 10 m from the eastern race and 20 m from the western race.
GPS reference: NZMG 2729457E, 6375803N
Annual rainfall: 1190 mm at Hamilton
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 96 m asl
Geomorphic position: Profile on a 3-4° slope with a northwest aspect on a midslope of a hill in easy rolling land surrounded by hilly land.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus other weeds.
Parent material: Volcanic over rock
Drainage class: Moderately well drained
Land use: Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-18	10 YR 2/1 with few very fine faint Mn coatings, silt loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine roots, no NaF reaction, distinct smooth boundary.
Ap/Bw	18-31	7.5 YR 4/3 with few very fine distinct Mn coatings, silt loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, many extremely fine roots, no NaF reaction, distinct smooth and occluded boundary.
Bw	31-49	7.5 YR 4/4, silty clay, slightly firm, brittle, strongly developed pedality with medium blocky breaking to medium polyhedral peds, many extremely fine roots, no NaF reaction, indistinct smooth boundary.
BC	49-73+	7.5 YR 4/4 with few extremely fine faint (7.5 YR 5/6) mottles, silty clay, slightly firm, brittle, strongly developed pedality with coarse prismatic breaking to medium blocky peds, many extremely fine roots, no NaF reaction.

Site: 22D
Date observed: 18/11/2011

Reference data

Soil name: Topehahae (GRT)
NZSC: Typic Orthic Gley

Site data

Location:	Pit located in a paddock that borders Flume Rd and the tanker track. Pit approximately 35 m from Flume Rd and 35 m from the track.
GPS reference:	NZMG 2730140E, 6371796N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	75 m asl
Geomorphic position:	Profile on pugged ground in a hollow of a flood plain of flat to gently undulating land, of a plain.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, broad leaf plantain, dock, very patchy.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 3/2, silt loam/ silty clay, moderately sticky, moderately plastic, hard, brittle, strongly developed pedality with medium, fine and very fine polyhedral peds, many extremely fine and common fine roots, no NaF reaction, abrupt smooth and occluded boundary.
Bg1	17-48	2.5 YR with common very fine prominent (7.5 YR 6/6) and few extremely fine prominent (7.5 YR 4/4) mottles, silty clay, moderately sticky, moderately plastic, hard, brittle, strongly developed pedality with coarse and medium blocky peds, many extremely fine and few very fine roots, no NaF reaction, indistinct smooth boundary.
Bg2	48-75+	10 YR 7/2 with common fine prominent (5 YR 4/6) and common medium distinct (2.5 YR 6/4) mottles, silty clay, moderately sticky, very plastic, hard, brittle, strongly developed pedality with coarse prismatic breaking to medium blocky peds, many extremely fine roots, no NaF reaction.

Site: 22S
Date observed: 18/11/2011

Reference data

Soil name: Topehahae (GRT)
NZSC: Typic Orthic Gley

Site data

Location:	Pit located in a paddock that borders Flume Rd and the main farm entrance. Pit approximately 35 m from Flume Rd and 50 m from the track.
GPS reference:	NZMG 2730131E, 6371901N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	72 m asl
Geomorphic position:	Profile on pugged ground in a hollow of a flood plain of flat to gently undulating land, of a plain.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup, dandelion, plantain, paspalum.
Parent material:	Alluvium
Drainage class:	Poorly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-14	10 YR 3/2 with common extremely fine distinct (7.5 YR 3/4) mottles, silt loam, moderately sticky, moderately plastic, weak, brittle, moderately developed pedality with medium polyhedral breaking to very fine and fine polyhedral peds, many extremely fine and few very fine roots, no NaF reaction, abrupt smooth and occluded boundary.
Bg1	14-33	2.5 YR 7/1 with common extremely fine prominent (7.5 YR 3/4) and common very fine prominent (7.5 YR 5/6) mottles, silty clay, moderately stick, very plastic, slightly firm, brittle, strongly developed pedality with medium and coarse blocky breaking to medium blocky peds, many extremely fine and few very fine roots, no NaF reaction, distinct smooth boundary.
Bg2	33-70	5 GY with many fine prominent (7.5 YR 6/6) and common very fine prominent (7.5 YR 5/8) mottles, silty clay, moderately sticky, very plastic, firm, brittle, strongly developed pedality with coarse prismatic peds, many microfine roots, no NaF reaction, indistinct smooth boundary.
BCg	70-75+	5 YG 5/1 with common fine prominent (7.5 YR 6/6) and common very fine prominent (7.5 YR 5/8) mottles, silty clay, moderately sticky, very plastic, firm, brittle, strongly developed pedality with coarse prismatic breaking to medium blocky peds, many microfine roots, no NaF reaction.

Site: **23D**
Date observed: **25/11/2011**

Reference data

Soil name: Horotiu
NZSC: Typic Orthic Allophanic

Site data

Location: Pit located in a paddock that borders Grey Road and the tanker track. The pit was located approximately 35 m from Grey Road.
GPS reference: NZMG 2700574E, 6358717N
Annual rainfall: 1190 mm at Hamilton
Mean air temperature: 13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS): 58 m asl
Geomorphic position: Profile on a 1-2° slope with a northeast aspect, on a levee of a low terrace in an undulating lowland.
Erosion/deposition: Negligible
Vegetation: Pasture - dominantly ryegrass and white clover plus, broad leaf plantain, dock, buttercup, patchy compared to sheep site.
Parent material: Alluvium
Drainage class: Well drained
Land use: Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-18	10 YR 2/2, silt loam, slightly sticky, moderately plastic, weak, friable, strongly developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and many very fine roots, moderate NaF reaction, distinct wavy and occluded boundary.
Bw1	18-33	7.5 YR 4/4, clay loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with medium blocking breaking to very fine and fine polyhedral peds, many extremely fine and common very fine roots, moderate NaF reaction indistinct smooth boundary.
Bw2	33-59	7.5 YR 4/6, clay loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with coarse prismatic breaking to medium polyhedral peds, many extremely fine roots, moderate NaF reaction, indistinct smooth boundary.
Bw3	59-75+	7.5 YR 4/4, silty clay, moderately sticky, moderately plastic, weak, brittle, moderately developed pedality with coarse blocky breaking to very fine and fine blocky peds, many microfine roots, moderate NaF reaction.

Site: 23S
Date observed: 25/11/2011

Reference data

Soil name: Horotiu
NZSC: Typic Orthic Allophanic

Site data

Location:	Pit located in a paddock that borders Grey and opposite the neighbouring dairy farm shed. Paddock has power poles though it. Pit approximately 20 m to the edge of the terrace, 15 m to the bottom of the hill and 23 m from a power pole.
GPS reference:	NZMG 2700751E, 6358726N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	49 m asl
Geomorphic position:	Profile on a 0° slope on a levee of a low terrace in an undulating lowland.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, broad leaf plantain, buttercup, thistles and other weeds.
Parent material:	Alluvium
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 2/2, silt loam, slightly sticky, moderately plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine and common very fine roots, moderate NaF reaction, abrupt smooth and occluded boundary.
Bw1	17-36	10 YR 5/4, clay loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with medium blocking breaking to very fine and fine polyhedral peds, many extremely fine roots, moderate NaF reaction distinct smooth boundary.
Bw2	36-68	10 YR 5/6 with few extremely fine distinct (7.5 YR 5/6) clay coatings down root channels, clay loam, moderately sticky, moderately plastic, weak, brittle, strongly developed pedality with coarse blocky breaking to medium blocky peds, many extremely fine roots, moderate NaF reaction, indistinct smooth boundary.
Bw3	68-81+	7.5 YR 5/6, clay loam, slightly sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with medium blocky breaking to very fine and fine blocky peds, many microfine roots, moderate NaF reaction.

Site: 24D
Date observed: 28/11/2011

Reference data

Soil name: Okete clay loam (NOT)
NZSC: Typic Orthic Allophanic

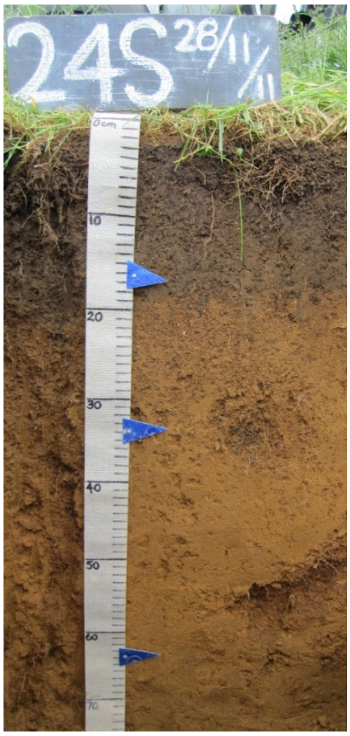
Site data

Location:	Pit located in a paddock on the western side of the junction of Hodgson, Grey and Rosborough Roads. Approximately 40 m from Grey Rd and 30 m from Rosborough Rd.
GPS reference:	NZMG 2700674E, 6359106N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	75 m asl
Geomorphic position:	Profile on a 2-3° slope with a western aspect on the upper slope of a hill in strongly rolling hill country.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup, dock, California thistles, ragwort.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-14	10 YR 3/2, silt loam, slightly sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and few very fine roots, strong NaF reaction, abrupt smooth and occluded boundary.
Bw1	14-38	10 YR 5/4, clay loam, non-sticky, non-plastic, slightly firm, brittle, moderately developed pedality with medium blocky breaking to very fine and fine polyhedral peds, many extremely fine and few very fine roots, strong NaF reaction, distinct wavy boundary.
Bw2	38-57	10 YR 5/6, with few very fine distinct (10 YR 4/4) organic coatings down root channels, clay loam, slightly sticky, moderately plastic, weak, brittle, strongly developed pedality with medium and coarse blocky breaking to medium polyhedral peds, many extremely fine roots, strong NaF reaction, indistinct wavy boundary.
BC	57-72+	10 YR 5/4, clay loam, slightly sticky, moderately plastic, slightly firm, brittle strongly developed pedality with medium and coarse prismatic breaking to very fine and fine blocky peds, common extremely fine roots, strong NaF reaction.

Site: 24S
Date observed: 28/11/2011



Reference data

Soil name:	Okete clay loam (NOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit located in a paddock on the eastern side of the junction of Hodgson, Grey and Rosborough Roads. Approximately 50 m from Hodgson Rd and to the east of the power poles running through the paddock.
GPS reference:	NZMG 2700892E, 6359029N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	68 m asl
Geomorphic position:	Profile on a 0° slope on the midslope of a hill in strongly rolling hill country.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass, white clover, narrow leaf plantain, dock, buttercups, paspalum, dandelion.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-17	10 YR 3/1, silt loam, slightly sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and common very fine roots, strong NaF reaction, abrupt smooth and occluded boundary.
Bw1	17-34	10 YR 5/6, clay loam, slightly sticky, slightly plastic, weak, friable, strongly developed pedality with very fine and fine polyhedral peds, abundant extremely fine roots, strong NaF reaction, distinct smooth boundary.
Bw2	34-64	10 YR 6/6, with few extremely fine distinct organic coatings down root channels, clay loam, slightly sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine roots, strong NaF reaction, indistinct smooth boundary.
BC	64-76+	10 YR 6/6 with few extremely fine faint organic coatings down root channels, clay loam, slightly sticky, moderately plastic, weak, friable, moderately developed pedality with medium columnar breaking to very fine and fine blocky peds, many extremely fine roots, strong NaF reaction.

Site: 25D
Date observed: 1/12/2011

Reference data

Soil name: Kaniwhaniwha silt loam (RFW)
NZSC: Mottled Orthic Brown

Site data

Location:	Pit located in a paddock in the southwest area of the farm, near a stream. Pit approximately 40 m from the property boundary.
GPS reference:	NZMG 2698521E, 6369055N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	22 m asl
Geomorphic position:	Profile on a terracette of a levee on a terrace in undulating land surrounded by lowlands.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dock, California thistles and other weeds.
Parent material:	Alluvium
Drainage class:	Imperfectly drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-19	10 YR 4/2, silt loam/ silty clay, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with very fine and fine polyhedral peds, many extremely fine roots, no NaF reaction, distinct wavy and occluded boundary.
Bw(g)	19-40	10 YR 5/4 with common very fine faint (7.5 YR 5/6) and few fine faint (10 YR 6/3) mottles, silty clay, moderately sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with medium blocky peds, many extremely fine roots, no NaF reaction, distinct smooth boundary.
Bwg	40-67	2.5 YR 7/3 with many fine prominent (7.5 YR 5/6) mottles, silty clay, very sticky, moderately plastic, firm, brittle, moderately developed pedality with coarse columnar breaking to medium blocky peds, common extremely fine roots, no NaF reaction, distinct smooth boundary.
BCg	67-75+	2.5 YR 7/2 with many medium prominent (7.5 YR 5/8) mottles, silty clay, very sticky, very plastic, slightly firm, brittle, moderately developed pedality with coarse and medium blocky breaking to very fine and fine blocky peds, common microfine roots, no NaF reaction.

Site: 25S
Date observed: 1/12/2011

Reference data

Soil name: Kaniwhaniwha silt loam (RFW)
NZSC: Mottled Orthic Brown

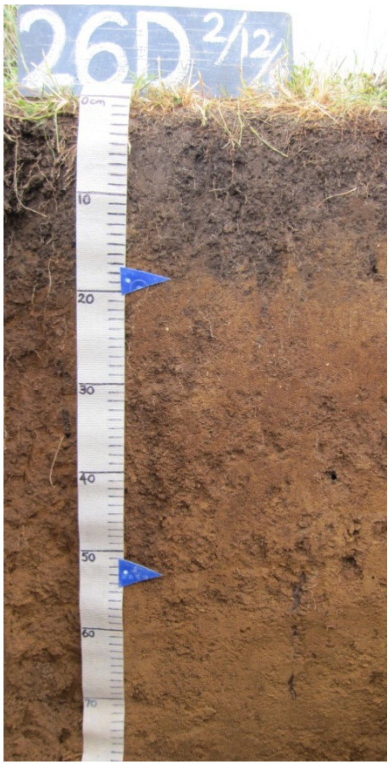
Site data

Location:	Pit located in a paddock in the northeast area of the farm, near a stream and in a paddock with a pond. Pit approximately 50 m from the property boundary.
GPS reference:	NZMG 2698488E, 6368968N
Annual rainfall:	1190 mm at Hamilton
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	25 m asl
Geomorphic position:	Profile on a terracette of a levee on a terrace in undulating land surrounded by lowlands.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, dandelion, paspalum.
Parent material:	Alluvium
Drainage class:	Imperfectly drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-24	10 YR 4/2, silt loam, moderately sticky, moderately plastic, slightly firm, brittle, moderately developed pedality with very fine, fine and medium polyhedral peds, abundant extremely fine and common very fine roots, no NaF reaction, distinct wavy and occluded boundary.
Bw(g)	24-41	10 YR 5/4 with few very fine distinct (7.5 YR 5/6) mottles and few extremely fine prominent (10 YR 2/1) Mn coatings, silty clay, very sticky, moderately plastic, slightly firm, brittle, strongly developed pedality with medium blocky breaking to fine and very fine polyhedral peds, many extremely fine roots, no NaF reaction, distinct smooth boundary.
Bg1	41-68	2.5 YR 7/2 with many fine prominent (7.5 YR 4/6) and common very fine distinct (10 YR 7/4) mottles, silty clay, very sticky, very plastic, slightly firm, brittle, strongly developed pedality with medium prismatic breaking to medium blocky peds, many extremely fine roots, no NaF reaction, distinct smooth boundary.
Bg2	68-77+	2.5 YR 7/1 with many medium prominent (7.5 YR 5/6) and common extremely fine prominent (7.5 YR 4/6) mottles, silty clay, very sticky, very plastic, firm, brittle, moderately developed pedality with medium columnar breaking to very fine and fine blocky peds, common microfine roots, no NaF reaction.

Site: 26D
Date observed: 2/12/2011



Reference data

Soil name:	Kiwitahi silt loam (LOT)
NZSC:	Typic Orthic Allophanic

Site data

Location:	Pit in a paddock that borders Starky Rd, a farm workers house and the neighbouring property, with a hedge along the boundary. Approximately 25m east from the boundary and 20 m south of the paddocks trough.
GPS reference:	NZMG 2733052E, 6382197N
Annual rainfall:	1124 mm at Matamata
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	61 m asl
Geomorphic position:	Profile on a 6-8° slope with a west aspect, on the midslope of a rolling hill, surrounded by hilly land.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, buttercup.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Dairy farming

Soil data

Horizon	Depth (cm)	
Ap	0-19	10 YR 2/1, silt loam, non-sticky, slightly plastic, weak, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine and common very fine roots, moderate NaF reaction, abrupt smooth and occluded boundary.
Bw1	19-53	7.5 YR 5/4, silty clay, moderately sticky, moderately plastic, very firm, brittle, moderately developed pedality with medium blocky peds, many extremely fine roots, weak NaF reaction, distinct smooth boundary.
Bw2	53-79+	7.5 YR 5/4, silty clay, moderately sticky, moderately plastic, weak, brittle, weakly developed pedality with coarse prismatic breaking to very fine and fine blocky, common microfine roots, weak NaF reaction.

Site: 26S
Date observed: 2/12/2011

Reference data

Soil name: Kiwitahi silt loam (LOT)
NZSC: Typic Orthic Allophanic

Site data

Location:	Pit in a paddock that borders Starky Rd, a dwelling and the neighbouring property, with a hedge along the boundary. Approximately 40 m west from the boundary and 70 m north of Starky Road.
GPS reference:	NZMG 2733053E, 6382112N
Annual rainfall:	1124 mm at Matamata
Mean air temperature:	13.7 °C (estimated from Ruakura, Hamilton)
Elevation (GPS):	65 m asl
Geomorphic position:	Profile on a 5-8° slope with a west aspect, on the midslope of a rolling hill, surrounded by hilly land.
Erosion/deposition:	Negligible
Vegetation:	Pasture - dominantly ryegrass and white clover plus, narrow leaf plantain, California thistles, dandelion.
Parent material:	Volcanic
Drainage class:	Well drained
Land use:	Drystock farming

Soil data

Horizon	Depth (cm)	
Ap	0-20	10 YR 2/1, clay loam, non-sticky, slightly plastic, slightly firm, brittle, strongly developed pedality with very fine, fine and medium polyhedral peds, many extremely fine and common very fine roots, moderate NaF reaction, distinct smooth and occluded boundary.
Bw1	20-50	7.5 YR 5/4, clay loam, slightly sticky, slightly plastic, slightly firm, brittle, moderately developed pedality with coarse blocky breaking to medium polyhedral peds, many extremely fine and few very fine roots, moderate NaF reaction, indistinct smooth boundary.
Bw2	50-78+	7.5 YR 5/6, clay loam, moderately sticky, moderately plastic, weak, brittle, weakly developed pedality with coarse prismatic breaking to very fine and fine blocky, common microfine roots, moderate NaF reaction.

Appendix D. Raw data

Table D.1. Raw data for total C and N calculations. Abbreviations are: UD is upper depth, LD is lower depth, TD is total depth, AD is air dried soil, OD is oven dried soil, MF is moisture factor, BD1 is soil dry bulk density sample 1, BD2 is soil dry bulk density sample 2, Avg BD is the mean soil dry bulk density, TC is total C and TN is total N.

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	%C_{AD}	%N_{AD}	MF (%)	%C_{OD}	%N_{OD}	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
01	Dairy	Ap	0.00	0.18	0.18	12.1	0.98	1.14	13.82	1.12	0.66	0.66	0.66	165	13.4	12.3
01	Dairy	Bw1	0.18	0.43	0.25	6.7	0.50	1.18	7.84	0.59	0.57	0.55	0.56	110	8.3	13.3
01	Dairy	Bw2	0.43	0.60	0.17	3.1	0.27	1.15	3.60	0.31	0.60	0.63	0.62	38	3.3	11.4
01	Drystock	Ap	0.00	0.17	0.17	13.1	1.09	1.16	15.21	1.27	0.61	0.69	0.65	168	14.0	12.0
01	Drystock	Bw1	0.17	0.40	0.23	6.3	0.51	1.16	7.29	0.59	0.58	0.57	0.58	96	7.8	12.3
01	Drystock	Bw2	0.40	0.60	0.20	3.5	0.30	1.17	4.15	0.35	0.66	0.66	0.66	55	4.6	11.9
02	Dairy	Ap	0.00	0.09	0.09	5.8	0.66	1.09	6.35	0.72	0.83	0.88	0.86	49	5.6	8.8
02	Dairy	AB	0.09	0.23	0.14	2.6	0.30	1.08	2.78	0.33	0.83	0.78	0.81	31	3.7	8.6
02	Dairy	Bw1	0.23	0.51	0.28	1.1	0.17	1.10	1.24	0.18	0.81	0.81	0.81	28	4.1	6.9
02	Dairy	Bw2	0.51	0.60	0.09	0.3	0.08	1.06	0.33	0.08	0.76	0.81	0.78	2	0.6	4.0

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	%C_{AD}	%N_{AD}	MF (%)	%C_{OD}	%N_{OD}	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
02	Drystock	Ap	0.00	0.16	0.16	6.0	0.67	1.11	6.63	0.74	0.73	0.88	0.81	85	9.6	8.9
02	Drystock	Bw1	0.16	0.38	0.22	1.4	0.20	1.08	1.48	0.22	0.87	0.95	0.91	30	4.3	6.9
02	Drystock	Bw2	0.38	0.60	0.22	0.4	0.09	1.11	0.43	0.10	1.05	1.13	1.09	10	2.5	4.1
03	Dairy	Ap	0.00	0.18	0.18	6.9	0.75	1.09	7.50	0.81	0.85	0.83	0.84	113	12.3	9.2
03	Dairy	Bw1	0.18	0.34	0.16	2.1	0.27	1.10	2.29	0.30	0.75	0.76	0.75	28	3.6	7.7
03	Dairy	Bw2	0.34	0.60	0.26	0.8	0.15	1.09	0.92	0.17	0.85	0.89	0.87	21	3.8	5.5
03	Drystock	Ap	0.00	0.23	0.23	5.9	0.63	1.09	6.44	0.69	0.97	0.83	0.90	133	14.3	9.3
03	Drystock	Bw1	0.23	0.43	0.20	2.3	0.32	1.09	2.53	0.35	0.73	0.79	0.76	39	5.3	7.3
03	Drystock	Bw2	0.43	0.60	0.17	0.8	0.14	1.08	0.83	0.15	0.92	0.94	0.93	13	2.4	5.4
04	Dairy	Ap	0.00	0.14	0.14	4.4	0.44	1.07	4.74	0.47	1.10	0.93	1.02	68	6.7	10.1
04	Dairy	Ap/Bw	0.14	0.26	0.12	2.6	0.28	1.07	2.78	0.30	0.99	1.10	1.05	35	3.8	9.2
04	Dairy	Bw1	0.26	0.60	0.34	1.2	0.16	1.07	1.24	0.17	1.11	1.06	1.08	46	6.4	7.2
04	Drystock	Ap	0.00	0.15	0.15	6.5	0.61	1.07	6.90	0.65	0.92	1.01	0.96	100	9.4	10.6
04	Drystock	Ap/Bw	0.15	0.37	0.22	2.6	0.26	1.05	2.71	0.27	1.12	1.14	1.13	67	6.7	10.0
04	Drystock	Bw1	0.37	0.45	0.08	1.0	0.14	1.06	1.03	0.15	1.19	1.17	1.18	10	1.4	6.8

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	$\%C_{AD}$	$\%N_{AD}$	MF (%)	$\%C_{OD}$	$\%N_{OD}$	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
04	Drystock	Bw2	0.45	0.60	0.15	0.7	0.12	1.06	0.75	0.13	1.16	1.13	1.14	13	2.3	5.7
06	Dairy	Ap(g)	0.00	0.16	0.16	4.0	0.49	1.07	4.31	0.52	1.05	1.10	1.08	74	9.0	8.2
06	Dairy	Apg/Bg	0.16	0.23	0.07	1.6	0.23	1.05	1.67	0.24	1.23	1.17	1.20	14	2.0	6.9
06	Dairy	Bg1	0.23	0.39	0.16	0.7	0.14	1.04	0.68	0.14	1.20	1.35	1.27	14	2.9	4.8
06	Dairy	Bg2	0.39	0.60	0.21	0.4	0.12	1.05	0.46	0.12	1.35	1.17	1.26	12	3.2	3.8
06	Drystock	Ap(g)	0.00	0.17	0.17	6.1	0.67	1.07	6.51	0.72	1.01	1.10	1.05	116	12.9	9.1
06	Drystock	Apg/Bg	0.17	0.28	0.11	1.9	0.27	1.05	1.97	0.28	1.11	1.13	1.12	24	3.4	7.1
06	Drystock	Bg	0.28	0.60	0.32	0.6	0.14	1.06	0.60	0.14	1.09	1.00	1.04	20	4.8	4.2
07	Dairy	Ap	0.00	0.17	0.17	2.8	0.31	1.09	3.05	0.34	1.09	1.21	1.15	60	6.6	9.1
07	Dairy	Ap/Bw(g)	0.17	0.33	0.16	0.9	0.13	1.04	0.91	0.13	1.33	1.20	1.27	18	2.7	6.8
07	Dairy	Bg	0.33	0.60	0.27	0.3	0.08	1.07	0.32	0.08	1.10	1.08	1.09	9	2.5	3.8
07	Drystock	Ap	0.00	0.17	0.17	3.4	0.35	1.06	3.56	0.37	1.12	1.24	1.18	72	7.4	9.7
07	Drystock	Ap/Bw(g)	0.17	0.33	0.16	1.1	0.13	1.04	1.17	0.13	1.23	1.27	1.25	24	2.6	9.0
07	Drystock	Bg	0.33	0.60	0.27	0.3	0.04	1.04	0.28	0.04	1.17	1.12	1.14	9	1.4	6.3
08	Dairy	Ap	0.00	0.16	0.16	8.7	0.95	1.28	11.15	1.22	0.69	0.71	0.70	124	13.6	9.2

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	$\%C_{AD}$	$\%N_{AD}$	MF (%)	$\%C_{OD}$	$\%N_{OD}$	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
08	Dairy	Bw1	0.16	0.39	0.23	3.5	0.38	1.33	4.64	0.50	0.59	0.59	0.59	63	6.9	9.2
08	Dairy	Bw2	0.39	0.60	0.21	1.6	0.18	1.38	2.21	0.25	0.57	0.56	0.57	26	3.0	8.9
08	Drystock	Ap	0.00	0.18	0.18	8.5	0.9	1.22	10.40	1.10	0.67	0.70	0.69	128	13.6	9.4
08	Drystock	Bw1	0.18	0.38	0.20	3.4	0.38	1.24	4.21	0.47	0.65	0.61	0.63	53	5.9	8.9
08	Drystock	Bw2	0.38	0.60	0.22	2.7	0.26	1.39	3.75	0.36	0.61	0.64	0.63	52	5.0	10.4
09	Dairy	Ap	0.00	0.17	0.17	6.1	0.69	1.12	6.81	0.77	0.80	0.85	0.83	96	10.8	8.8
09	Dairy	Bw1	0.17	0.34	0.17	1.8	0.21	1.32	2.37	0.28	0.74	0.77	0.76	31	3.6	8.6
09	Dairy	Bw2	0.34	0.60	0.26	1.1	0.14	1.31	1.44	0.18	0.80	0.87	0.83	31	4.0	7.9
09	Drystock	Ap	0.00	0.17	0.17	5.0	0.57	1.11	5.54	0.63	0.77	0.87	0.82	78	8.8	8.8
09	Drystock	Bw1	0.17	0.34	0.17	1.5	0.18	1.32	1.98	0.24	0.86	0.88	0.87	29	3.5	8.3
09	Drystock	Bw2	0.34	0.60	0.26	0.9	0.12	1.26	1.14	0.15	0.97	1.11	1.04	31	4.1	7.5
10	Dairy	Ap(g)	0.00	0.22	0.22	2.6	0.26	1.08	2.86	0.28	0.94	1.14	1.04	66	6.5	10.1
10	Dairy	Bg1	0.22	0.47	0.25	0.5	0.10	1.03	0.55	0.10	1.19	1.20	1.19	17	3.0	5.5
10	Dairy	Bg2	0.47	0.60	0.13	0.1	0.04	1.01	0.13	0.04	1.18	1.33	1.25	2	0.7	3.1
10	Drystock	Ap(g)	0.00	0.17	0.17	2.4	0.25	1.14	2.70	0.29	0.96	1.21	1.09	50	5.4	9.3

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	%C_{AD}	%N_{AD}	MF (%)	%C_{OD}	%N_{OD}	BD1 (t m^{-3})	BD2 (t m^{-3})	Avg BD (t m^{-3})	TC (t ha^{-1})	TN (t ha^{-1})	C:N
10	Drystock	Bg1	0.17	0.36	0.19	0.4	0.07	1.06	0.42	0.07	1.27	1.30	1.29	10	1.8	5.9
10	Drystock	Bg2	0.36	0.60	0.24	0.2	0.06	1.03	0.16	0.06	1.46	1.28	1.37	5	1.9	2.7
11	Dairy	Ap	0.00	0.17	0.17	4.8	0.48	1.07	5.07	0.51	1.02	1.12	1.07	92	9.3	9.9
11	Dairy	Bw	0.17	0.34	0.17	1.5	0.16	1.07	1.64	0.17	1.09	1.15	1.12	31	3.2	9.8
11	Dairy	Bw(g)	0.34	0.60	0.26	0.5	0.09	1.05	0.57	0.10	1.21	1.31	1.26	19	3.2	5.8
11	Drystock	Ap	0.00	0.16	0.16	3.5	0.33	1.05	3.65	0.35	0.99	1.18	1.08	63	6.1	10.5
11	Drystock	Bw	0.16	0.38	0.22	0.9	0.12	1.06	0.97	0.13	1.19	1.19	1.19	25	3.4	7.6
11	Drystock	Bw(g)	0.38	0.60	0.22	0.5	0.08	1.04	0.55	0.09	1.24	1.34	1.29	16	2.5	6.3
12	Dairy	Ap	0.00	0.14	0.14	12.2	1.01	1.13	13.77	1.14	0.60	0.60	0.60	115	9.5	12.1
12	Dairy	Ap/Bw	0.14	0.29	0.15	8.2	0.59	1.13	9.25	0.66	0.57	0.49	0.53	73	5.3	14.0
12	Dairy	Bw	0.29	0.60	0.31	4.5	0.33	1.15	5.18	0.38	0.48	0.53	0.51	82	6.0	13.6
12	Drystock	Ap1	0.00	0.13	0.13	15.5	1.35	1.12	17.40	1.52	0.57	-	0.57	128	11.2	11.5
12	Drystock	Ap/Bw	0.13	0.27	0.14	8.3	0.65	1.12	9.28	0.73	0.58	-	0.58	75	5.9	12.7
12	Drystock	Bw	0.27	0.60	0.33	5.1	0.39	1.14	5.81	0.44	0.49	-	0.49	95	7.2	13.2
13	Dairy	Ap	0.00	0.16	0.16	11.6	1.15	1.12	12.94	1.29	0.69	0.69	0.69	143	14.2	10.0

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	%C_{AD}	%N_{AD}	MF (%)	%C_{OD}	%N_{OD}	BD1 (t m^{-3})	BD2 (t m^{-3})	Avg BD (t m^{-3})	TC (t ha^{-1})	TN (t ha^{-1})	C:N
13	Dairy	Bw1	0.16	0.36	0.20	4.2	0.37	1.13	4.79	0.42	0.62	0.52	0.57	55	4.8	11.5
13	Dairy	Bw2	0.36	0.60	0.24	2.9	0.25	1.14	3.26	0.29	0.54	0.62	0.58	45	4.0	11.3
13	Drystock	Ap	0.00	0.16	0.16	10.5	0.93	1.13	11.90	1.05	0.67	0.69	0.68	129	11.4	11.3
13	Drystock	Bw1	0.16	0.43	0.27	4.1	0.36	1.14	4.65	0.42	0.55	0.45	0.50	63	5.6	11.2
13	Drystock	Bw2	0.43	0.60	0.17	3.3	0.29	1.13	3.72	0.33	0.40	0.47	0.44	28	2.4	11.4
14	Dairy	Ap	0.00	0.15	0.15	10.7	1.04	1.26	13.46	1.31	0.58	0.66	0.62	126	12.2	10.3
14	Dairy	Bw1	0.15	0.37	0.22	4.1	0.41	1.14	4.69	0.47	0.64	0.57	0.60	62	6.2	10.0
14	Dairy	Bw2	0.37	0.60	0.23	1.6	0.18	1.14	1.83	0.21	0.57	0.61	0.59	25	2.8	8.9
14	Drystock	Ap	0.00	0.17	0.17	8.4	0.82	1.16	9.74	0.95	0.63	0.68	0.65	108	10.6	10.2
14	Drystock	Bw1	0.17	0.36	0.19	2.8	0.28	1.17	3.27	0.33	0.59	0.55	0.57	36	3.6	10.0
14	Drystock	Bw2	0.36	0.60	0.24	2.2	0.23	1.11	2.45	0.26	0.56	0.61	0.58	34	3.6	9.6
15	Dairy	Ap	0.00	0.12	0.12	4.5	0.44	1.05	4.70	0.46	0.96	1.09	1.03	58	5.7	10.1
15	Dairy	Bg1	0.12	0.26	0.14	1.2	0.13	1.04	1.24	0.13	1.12	1.14	1.13	20	2.1	9.3
15	Dairy	Bg2	0.26	0.48	0.22	0.1	0.00	1.04	0.09	0.00	1.17	1.16	1.17	2	0.0	0.0
15	Dairy	Bg3	0.48	0.60	0.12	1.2	0.16	1.05	1.25	0.17	1.17	1.14	1.15	17	2.4	7.3

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	$\%C_{AD}$	$\%N_{AD}$	MF (%)	$\%C_{OD}$	$\%N_{OD}$	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
15	Drystock	Ap	0.00	0.15	0.15	5.1	0.52	1.06	5.39	0.55	0.86	0.99	0.93	75	7.7	9.7
15	Drystock	Bg1	0.15	0.29	0.14	1.7	0.17	1.03	1.78	0.17	1.04	1.30	1.17	29	2.9	10.2
15	Drystock	Bg2	0.29	0.49	0.20	0.7	0.08	1.03	0.75	0.08	1.30	1.27	1.29	19	2.2	8.9
15	Drystock	Bg3	0.49	0.60	0.11	0.6	0.07	1.03	0.60	0.07	1.29	1.18	1.24	8	0.9	8.8
16	Dairy	Ap	0.00	0.19	0.19	8.0	0.92	1.19	9.55	1.10	0.66	0.60	0.63	114	13.1	8.7
16	Dairy	Ap/Bw	0.19	0.29	0.10	3.3	0.41	1.46	4.80	0.60	0.64	0.61	0.62	30	3.7	8.0
16	Dairy	Bw1	0.29	0.60	0.31	2.1	0.26	1.61	3.38	0.42	0.60	0.57	0.59	61	7.6	8.1
16	Drystock	Ap	0.00	0.23	0.23	6.8	0.78	1.27	8.66	0.99	0.72	0.75	0.74	147	16.8	8.7
16	Drystock	Ap/Bw	0.23	0.34	0.11	4.6	0.55	1.33	6.11	0.73	0.63	0.66	0.64	43	5.2	8.4
16	Drystock	Bw1	0.34	0.60	0.26	2.8	0.31	1.52	4.25	0.47	0.68	0.74	0.71	78	8.7	9.0
17	Dairy	Ap	0.00	0.11	0.11	13.9	1.4	1.28	17.80	1.79	0.56	0.54	0.55	108	10.9	9.9
17	Dairy	AB	0.11	0.20	0.09	9.2	0.83	1.22	11.20	1.01	0.55	0.55	0.55	55	5.0	11.1
17	Dairy	Bw1	0.20	0.40	0.20	5.4	0.49	1.53	8.28	0.75	0.53	0.47	0.50	83	7.5	11.0
17	Dairy	Bw2	0.40	0.60	0.20	3.3	0.3	1.59	5.23	0.48	0.43	0.47	0.45	47	4.3	11.0
17	Drystock	Ap	0.00	0.13	0.13	11.5	1.13	1.41	16.20	1.59	0.57	0.61	0.59	124	12.2	10.2

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	$\%C_{AD}$	$\%N_{AD}$	MF (%)	$\%C_{OD}$	$\%N_{OD}$	BD1 (t m^{-3})	BD2 (t m^{-3})	Avg BD (t m^{-3})	TC (t ha^{-1})	TN (t ha^{-1})	C:N
17	Drystock	Ap/Bw	0.13	0.22	0.09	10.0	0.75	1.24	12.41	0.93	0.54	0.52	0.53	59	4.4	13.3
17	Drystock	Bw1	0.22	0.44	0.22	6.2	0.45	1.53	9.47	0.69	0.46	0.45	0.45	94	6.8	13.8
17	Drystock	Bw2	0.44	0.60	0.16	2.5	0.23	1.54	3.86	0.36	0.50	0.49	0.49	31	2.8	10.9
18	Dairy	Ap	0.00	0.13	0.13	9.4	1.06	1.13	10.66	1.20	0.71	0.70	0.70	98	11.0	8.9
18	Dairy	Bw1	0.13	0.28	0.15	4.2	0.48	1.14	4.79	0.55	0.66	0.70	0.68	49	5.6	8.8
18	Dairy	Bw2	0.28	0.60	0.32	1.6	0.19	1.20	1.92	0.23	0.74	0.74	0.74	46	5.4	8.4
18	Drystock	Ap	0.00	0.21	0.21	6.4	0.72	1.14	7.27	0.82	0.72	0.74	0.73	111	12.5	8.9
18	Drystock	Bw1	0.21	0.38	0.17	1.6	0.2	1.13	1.82	0.23	0.77	0.75	0.76	23	2.9	8.0
18	Drystock	Bw2	0.38	0.60	0.22	1.3	0.15	1.16	1.50	0.17	0.74	0.81	0.78	26	3.0	8.7
19	Dairy	Ap	0.00	0.15	0.15	7.9	0.85	1.10	8.70	0.94	0.74	0.75	0.75	97	10.5	9.3
19	Dairy	Bw1	0.15	0.29	0.14	2.6	0.3	1.10	2.87	0.33	0.72	0.73	0.73	29	3.4	8.7
19	Dairy	Bw2	0.29	0.60	0.31	1.3	0.17	1.11	1.45	0.19	0.76	0.80	0.78	35	4.6	7.6
19	Drystock	Ap	0.00	0.15	0.15	8.3	0.9	1.11	9.24	1.00	0.69	0.71	0.70	97	10.5	9.2
19	Drystock	Bw1	0.15	0.32	0.17	2.8	0.34	1.12	3.13	0.38	0.65	0.64	0.65	34	4.2	8.2
19	Drystock	Bw2	0.32	0.60	0.28	1.3	0.16	1.12	1.45	0.18	0.73	0.75	0.74	30	3.7	8.1

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	%C_{AD}	%N_{AD}	MF (%)	%C_{OD}	%N_{OD}	BD1 (t m^{-3})	BD2 (t m^{-3})	Avg BD (t m^{-3})	TC (t ha^{-1})	TN (t ha^{-1})	C:N
20	Dairy	Apg	0.00	0.12	0.12	4.3	0.44	1.05	4.51	0.46	1.10	1.19	1.15	62	6.3	9.8
20	Dairy	Bg	0.12	0.36	0.24	1.0	0.13	1.04	1.04	0.13	1.15	1.19	1.17	29	3.8	7.7
20	Dairy	BCg	0.36	0.60	0.24	0.3	0.06	1.03	0.31	0.06	1.13	1.12	1.13	8	1.7	5.0
20	Drystock	Apg	0.00	0.14	0.14	4.4	0.44	1.05	4.64	0.46	0.83	0.99	0.91	59	5.9	10.0
20	Drystock	Bg	0.14	0.47	0.33	0.6	0.09	1.04	0.63	0.09	1.35	1.36	1.35	28	4.2	6.7
20	Drystock	BCg	0.47	0.60	0.13	0.5	0.08	1.03	0.52	0.08	1.15	1.14	1.14	8	1.2	6.3
21	Dairy	Ap	0.00	0.14	0.14	4.4	0.46	1.06	4.64	0.49	1.07	1.09	1.08	70	7.3	9.6
21	Dairy	Ap/Bw	0.14	0.28	0.14	2.1	0.23	1.05	2.21	0.24	1.10	1.11	1.11	34	3.8	9.1
21	Dairy	Bw(f)	0.28	0.48	0.20	1.2	0.15	1.06	1.27	0.16	1.18	1.14	1.16	30	3.7	8.0
21	Dairy	BC	0.48	0.60	0.12	0.8	0.1	1.07	0.85	0.11	1.04	0.98	1.01	10	1.3	8.0
21	Drystock	Ap	0.00	0.18	0.18	4.6	0.47	1.06	4.87	0.50	0.95	1.07	1.01	88	9.0	9.8
21	Drystock	Ap/Bw	0.18	0.31	0.13	1.3	0.15	1.08	1.40	0.16	1.07	1.07	1.07	20	2.3	8.7
21	Drystock	Bw	0.31	0.48	0.17	0.9	0.11	1.09	0.98	0.12	1.01	-	1.01	17	2.1	8.2
21	Drystock	BC	0.48	0.60	0.12	0.9	0.11	1.08	0.97	0.12	0.97	-	0.97	11	1.4	8.2
22	Dairy	Ap	0.00	0.17	0.17	4.7	0.5	1.06	4.98	0.53	1.10	1.09	1.10	93	9.9	9.4

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	%C_{AD}	%N_{AD}	MF (%)	%C_{OD}	%N_{OD}	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
22	Dairy	Bg1	0.17	0.48	0.31	1.9	0.23	1.05	2.00	0.24	1.22	1.21	1.22	75	9.1	8.3
22	Dairy	Bg2	0.48	0.60	0.12	0.9	0.11	1.07	0.96	0.12	1.26	1.15	1.21	14	1.7	8.2
22	Drystock	Apg	0.00	0.14	0.14	5.5	0.58	1.07	5.91	0.62	0.73	0.88	0.80	67	7.0	9.5
22	Drystock	Bg1	0.14	0.33	0.19	1.1	0.14	1.05	1.16	0.15	1.17	1.29	1.23	27	3.4	7.9
22	Drystock	Bg2	0.33	0.60	0.27	0.6	0.09	1.07	0.64	0.10	1.30	1.29	1.30	23	3.4	6.7
23	Dairy	Ap	0.00	0.18	0.18	6.0	0.6	1.12	6.74	0.67	0.94	0.94	0.94	114	11.4	10.0
23	Dairy	Bw1	0.18	0.38	0.20	3.0	0.28	1.15	3.46	0.32	0.90	0.84	0.87	60	5.6	10.7
23	Dairy	Bw2	0.38	0.60	0.22	1.4	0.16	1.19	1.67	0.19	0.88	0.94	0.91	33	3.8	8.8
23	Drystock	Ap	0.00	0.17	0.17	8.2	0.79	1.13	9.28	0.89	0.66	0.81	0.74	116	11.2	10.4
23	Drystock	Bw1	0.17	0.36	0.19	3.7	0.36	1.15	4.26	0.41	0.76	0.73	0.74	60	5.9	10.3
23	Drystock	Bw2	0.36	0.60	0.24	2.7	0.29	1.18	3.18	0.34	0.69	0.69	0.69	53	5.7	9.3
24	Dairy	Ap	0.00	0.14	0.14	8.6	0.89	1.16	9.96	1.03	0.75	0.70	0.73	101	10.5	9.7
24	Dairy	Bw1	0.14	0.38	0.24	3.4	0.35	1.32	4.49	0.46	0.59	0.54	0.57	61	6.3	9.7
24	Dairy	Bw2	0.38	0.60	0.22	1.9	0.2	1.30	2.46	0.26	0.58	0.60	0.59	32	3.4	9.5
24	Drystock	Ap	0.00	0.17	0.17	10.7	1.04	1.15	12.29	1.19	0.66	0.72	0.69	144	14.0	10.3

Site	Land use	Horizon	UD (m)	LD (m)	TD (m)	$\%C_{AD}$	$\%N_{AD}$	MF (%)	$\%C_{OD}$	$\%N_{OD}$	BD1 ($t\ m^{-3}$)	BD2 ($t\ m^{-3}$)	Avg BD ($t\ m^{-3}$)	TC ($t\ ha^{-1}$)	TN ($t\ ha^{-1}$)	C:N
24	Drystock	Bw1	0.17	0.34	0.17	7.6	0.62	1.25	9.47	0.77	0.68	0.65	0.67	107	8.7	12.3
24	Drystock	Bw2	0.34	0.60	0.26	3.6	0.29	1.33	4.80	0.39	0.59	0.67	0.63	78	6.3	12.4
25	Dairy	Ap	0.00	0.19	0.19	3.3	0.37	1.07	3.53	0.40	1.17	1.01	1.09	73	8.2	8.9
25	Dairy	Bw(g)	0.19	0.40	0.21	2.0	0.24	1.08	2.17	0.26	1.07	1.06	1.07	48	5.8	8.3
25	Dairy	Bwg	0.40	0.60	0.20	0.9	0.12	1.11	1.00	0.13	1.10	1.03	1.07	21	2.8	7.5
25	Drystock	Ap	0.00	0.24	0.24	3.4	0.41	1.09	3.71	0.45	1.03	0.98	1.00	89	10.8	8.3
25	Drystock	Bw(g)	0.24	0.41	0.17	1.5	0.19	1.09	1.63	0.21	1.12	1.11	1.12	31	3.9	7.9
25	Drystock	Bg1	0.41	0.60	0.19	1.3	0.17	1.10	1.43	0.19	1.11	1.06	1.09	30	3.9	7.6
26	Dairy	Ap	0.00	0.19	0.19	4.7	0.5	1.11	5.21	0.55	0.93	0.89	0.91	90	9.6	9.4
26	Dairy	Bw1	0.19	0.53	0.34	1.5	0.19	1.12	1.68	0.21	0.90	0.94	0.92	53	6.7	7.9
26	Dairy	Bw2	0.53	0.60	0.07	1.0	0.12	1.11	1.11	0.13	1.00	1.03	1.02	8	0.9	8.3
26	Drystock	Ap	0.00	0.20	0.20	5.9	0.62	1.11	6.57	0.69	0.79	0.79	0.79	104	10.9	9.5
26	Drystock	Bw1	0.20	0.50	0.30	1.9	0.23	1.08	2.05	0.25	0.78	0.90	0.84	52	6.3	8.3
26	Drystock	Bw2	0.50	0.60	0.10	0.7	0.09	1.10	0.77	0.10	0.99	0.83	0.91	7	0.9	7.8