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CHANGES IN CARBON AND NITROGEN STOCKS FOLLOWING CONVERSION OF PLANTATION FOREST TO DAIRY PASTURE ON PUMICE SOILS, IN THE CENTRAL NORTH ISLAND.

A thesis

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Abstract

Since 1990 approximately 36,000 ha of land in the Waikato has been converted from pine plantation to dairy farms. By changing land use from plantation forest to pasture there is potential to change soil properties. The property of interest, due to international discussion (Kyoto Protocol), is the potential for soils to store carbon.

My main objective was to determine the rate and magnitude of change in soil carbon, soil nitrogen, and C:N ratio following land conversion from pine plantation to pasture. My study examined three areas (Atiamuri, Tokoroa and Wairakei) in the Central North Island of New Zealand. At each study area sites ranging from pine plantation, through 2, 3, 4, 5 and 11 years since conversion, to long-term (>40 years) dairy or sheep/beef pasture, were identified. Three transects were established at each site and 7 soil core samples each to a depth of 60 cm, were taken at random intervals along each transect. Soil cores were split into horizons with samples from each horizon bulked together for each transect. At the midpoint of each transect a pit was dug and soil dry bulk density samples were taken from each horizon. At one pit from each site a sample of each soil horizon was taken.

In the laboratory all soil samples were passed through a 2 mm sieve and air dried. Air dried samples were crushed and analysed for total carbon and total nitrogen with a TruSpec CN Carbon/Nitrogen Determinator.
Soil dry bulk density was lower ($P<0.05$) in the pine sites Ap horizons (0.47 to 0.54 g cm^{-3}) than the Ap horizon for all other sites (0.59 to 0.76 g cm^{-3}) at the Atiamuri, Tokoroa and Wairakei areas. There was no significant difference in Ap horizon depths between pine forest, recent conversion and long-term pasture sites at any of the study areas. Carbon concentration in the Ap horizon (5.5 to 9 %) showed few significant differences between land-use sites. The total soil carbon at Atiamuri and Wairakei was higher ($P<0.05$) in the long-term pastures (88 to 100 t/ha) than in the pine (42 to 54 t/ha), however there was no significant difference between pine and long-term pasture at Tokoroa and data from recently converted sites were variable with no apparent significant differences. Total soil nitrogen at all three study areas was higher ($P<0.05$) in the long-term pasture sites (5 to 8 t/ha) than in the pine sites (9 to 12 t/ha). The C:N ratio in the Ap horizon was higher ($P<0.05$) in pine sites (mean of 16) than in the long-term pasture sites (mean of 10). The variability in the recently converted sites meant that generally no short-term changes in carbon, nitrogen or C:N ratio, following conversion from pine forest to dairy pasture were discernable.

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Chapter 1.

Introduction

1.1 Background

Over the past decade New Zealand plantation forests have been harvested and the land use converted to dairy farming. The focus of conversion is from pine plantation (*pinus radiata*) forest to dairy farms in New Zealand is in the Central North Island between Lake Taupo and Tokoroa (Figure 1.1). In the Waikato Region 36,000 ha of plantation forest have been converted to dairy farms since 1990 (Tikkisetty 2010 pers. comm.). The Central North Island was planted in pine forest during the late 1920's to early 1930's as soils in this area were deficient in Co and other trace elements. Deficiency of soils in Co caused a disease called 'bush sickness', which was rectified during the mid-1930's with regular addition of Co fertilisers making pastoral farming a viable activity for the Central North Island.

Figure 1.1: North Island, New Zeland with Hamilton, Tokoroa and Taupo as refernce points. Box represents the area in the Central North Island where most of the conversion from plantation forest to pasture has happened.

Establishment of pasture after forest harvesting may cause a change in soil properties, as well as the build up of nutrients within the soil profile. Pasture cover can lead to a build up of carbon in the soil profile (Dejardins et al., 1994). Carbon build up within the soil profile can have positive effects on soil physical and chemical properties. Physical effects include better soil structure, increased resistance to compaction, greater plant rooting depth of flora, and increased soil water holding capacity (soils less prone to drought) (McLaren & Cameron, 1996).

Effects on chemical properties with increasing soil carbon content include increased cation exchange capacity, which allows soils to hold more nutrients (Dejardins et al., 1994). Nitrogen may also accumulate after conversion of forest to pasture with addition of nitrogen fertilizer common practise in pastoral agriculture (Vitousek et al., 1997b). Accumulation of nitrogen in the soil profile will be, in part due to changes in management practices that come with pastoral farming such as the addition of nitrogen based fertilizers, but will also be due to greater storage of nitrogen with increased carbon (Compton & Boone, 2000). The varying rates of carbon and nitrogen accumulation in soil cause changes in the C:N ratio, and as greater amounts of N are added there is often a reduction in the C:N ratio.

New Zealand lacks data on changes in carbon and nitrogen pools following land use change. Few New Zealand studies have looked at carbon and nitrogen after conversion from forest to pasture. There is uncertainty in what happens to the carbon and nitrogen pools after land use change. A recent study by Hedley *et al.* (2009) examined soils in the Central North Island near Lake Taupo. Their study sampled the soil surface (15 cm sampling depth). What happens to the carbon and nitrogen pools below 15 cm in the soil profile is not well known in New Zealand and an area of interest as soils with low concentrations of carbon such as forests have potential to accumulate carbon following a change in land use.

Currently international interest in carbon and nitrogen is high as both are potential green house gasses (GHG). Countries participating in the Kyoto protocol (New Zealand is a signatory) must reduce their GHG emissions or face large fines.

Carbon and nitrogen accumulation in soils can potentially off-set GHG emissions as carbon and nitrogen pools in soil are regarded as storage.

My study will focus on three farm groups in the Central North Island of New Zealand (Figure 1.2). The first farm group situated approximately 30 km south west of Rotorua in Atiamuri (Mathis Farm), one approximately 25 km north east of Lake Taupo in Wairakei (Wairakei Pastoral) and one approximately 11 km west of Tokoroa (Maxwell Farms). All three farms have been (or have had a part of the farm) converted to dairy pasture from plantation forest (*Pinus radiata*). Soils at Atiamuri, Tokoroa and Wairakei are derived from Taupo pumice deposits emplaced during the 232 ± 4 AD (about 1780 years ago) eruption (Hogg *et al.*, 2009). The soil profile contains clasts of pumice ranging from 1 mm to 250 mm in size with larger clasts being found at Wairakei than at Atiamuri and Tokoroa as Wairakei is closer to the eruption source.

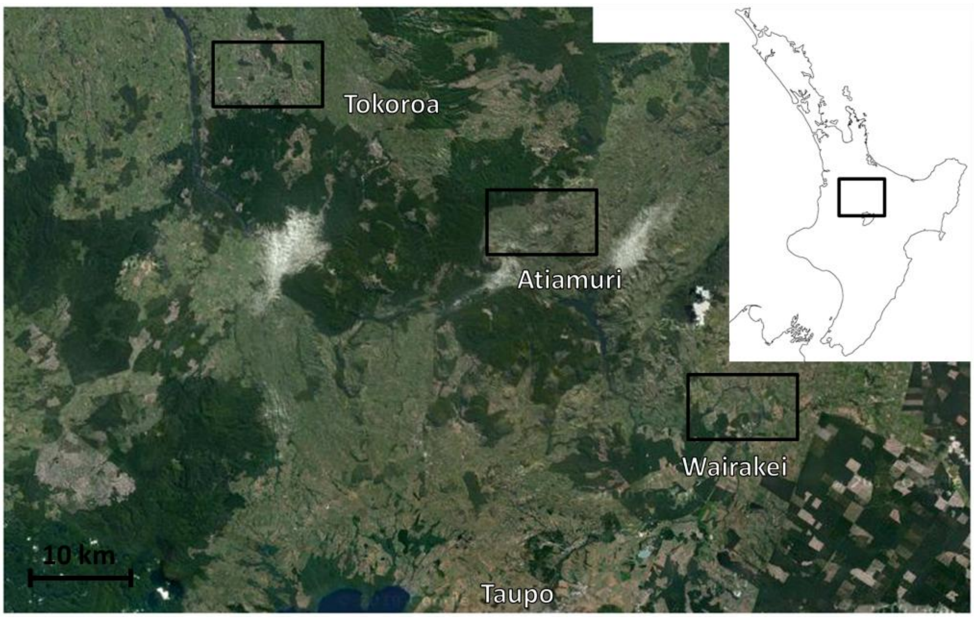

Figure 1.2: Atiamuri, Tokoroa and Wairakei study areas, Taupo City is bottom middle as point of reference.

1.2 Objectives

The overall objective of this thesis is to improve our understanding of soil organic matter following land use change. The land use change considered here is conversion of plantation forest to dairy pasture. Soil, to a depth of 60 cm, will be sampled in order to observe organic matter changes throughout the soil profile. Specific objective are to:

- Determine the accumulation rates for carbon and nitrogen following conversion from plantation forest to pasture at three sites in the Central North Island: Atiamuri, Tokoroa and Wairakei.
- Determine the C: N ratio in soils from the Atiamuri, Tokoroa and Wairakei sites to a depth of 60 cm.

Chapter 2.
Literature Review: Soil Organic Matter Following a Change in Land-use from Plantation Forest to Pasture

2.1 Introduction

Land use change around the world can cause changes in soil physical and chemical properties (Dejardins et al., 1994). Altering above ground vegetation causes changes in soil mineral nutrient inputs and uptakes. Carbon inputs to soil may change when if forest is cleared to make way for pasture. Currently much of the world's research into land use change from forest to pasture and the change in soil carbon and nitrogen pools following conversion of forest to pasture is focused on the Amazon. Some Amazonian rainforest is currently being removed to make way for pasture. According to Fearnside & Barbosa (1998), as of 1994 an area of 470 x 10^3 km^2 of Brazilian Amazon has been cleared, of that an estimated 47% was converted to pasture. With such large areas of forest being converted to pasture changes in localised carbon cycling will occur, influencing carbon concentrations in both soils and the local atmosphere (Neill *et al.*, 1997).

New Zealand has, in the past, undergone land use change firstly removal of forest during Polynesian settlement mainly through the use of fire. Further removal of forest was commenced when Europeans arrived (McWethy *et al.*, 2009). Until recently land use change of forest to pasture had almost ceased with many plantation forest being established during the late 1920’s to early 1930’s, and little to no native forest being removed since the 1930’s (Ewers *et al.*, 2006). With high prices being obtained for dairy products on the international market some plantation forests have been converted to pasture between 2000 and 2010. While studies in New Zealand have examined forests and the forestry industry few studies, to date, have looked at soil organic matter changes with a change of land use (Vajda *et al*., 2001; Ewers *et al.*, 2006; McWethy *et al*., 2009; MAF, 2009). The lack of information on changes in the soil organic matter pools following conversion of forest to pasture is concerning as the carbon and nitrogen content of the soil will impact on farm productivity.

Soil carbon is an important reservoir of world carbon as it is a large pool of carbon and changes in it can have an effect on the worlds carbon balance (Davidson & Janssens, 2006). Losses of carbon from soil lead to reductions in productivity as well as contributing to green house gas emissions (Schimel, 1992). Changes in soil carbon concentration can cause a change in the carbon to nitrogen ratio (C:N). Plant growth and microbial activity may change due to a change in the C:N ratio (McLaren & Cameron, 1996). Soil carbon can impact on plant and microbial activity, as well as being a possible source of GHG, thus it is important to determine what happens to soil carbon when land use change occurs.

With a change in land use comes a change in management practices. Most forest soils receive natural inputs of nitrogen through processes such as N fixation atmospheric deposition and break down of dead plant and animal biomass. Once land has been converted from forest to pasture management practices change and fertiliser addition is common with pastoral agriculture and cropping (McLaren & Cameron, 1996). Along with a potential change in soil carbon with land use change, we may also see a change in soil nitrogen due to increase N inputs through fertiliser.

2.2 Land-use Change

2.2.1 Overview: Land-use Change

Approximately one-third to one-quarter of the Earth's surface has been modified by human activity (Vitousek *et al.*, 1997a). Modification of the Earth's surface includes extensive land use change (deforestation, removal of scrubland) to make way for infrastructure, pasture and crop land. Land use change has been occurring throughout the world, throughout history (Skole & Tucker, 1993). Until the development of satellite imagery predictions on total areas and rates of different land use changes were rough at best. With satellite images scientists have been able to determine rates and the extent of land use changes around the world (Skole & Tucker, 1993; Mayaux *et al.*, 1998). Approximately 30% of the total land area on Earth is currently forest, with around 130 000 km^2 being modified every year (Schmitt *et al.*, 2009). Tropical areas are undergoing a greater extent of land use change as tropical rainforest areas are still large in comparison with temperate forests.

2.2.2 Land-use change in New Zealand

Before human settlement approximately 82% of New Zealand's total area was indigenous forest, at present 23% of New Zealand remains in native forest (Ewers *et al.*, 2006). Instead of further removal of native forest, plantation forests were established, consisting of mainly conifers (*pinus radiata*) and some eucalypts (MAF, 2009). Plantation forests provide for New Zealand's need for timber as a building material, paper manufacture and as a source of export income. New Zealand's plantation forestry was established in the late 1920's as the demand for wood was increasing and there was a wish to keep the remaining native forests rather than logging them further (FAO, 1996). Approximately 6.6% of New Zealand's total area is in plantation forestry (MAF, 2009). With the current high prices obtained for dairy products on the international market some plantation forests are being converted to dairy pasture (New Zealand Dairy Exporter, 2009). The majority of land use change from plantation forests to pasture in New Zealand is occurring in the central North Island (Smith & Horgan, 2006).

2.2.3 Soil Issues

Soils in the central North Island of New Zealand are mostly Pumice Soil, originally planted in forest due to their low potential for pasture production. Pumice soils in the Central North Island were originally considered to have low potential for pasture production due to the lack of soils nutrients (particularly trace elements such as calcium, cobalt and iron), topography being unfavourable, and the tendency for the soils to become drought stricken during summer (Askew & Rigg, 1932; Grange & Taylor, 1932). One problem was animals contracting a disease called bush sickness, caused by cobalt deficiency in soil. Bush sickness was rectified during the mid 1920's to early 1930's through the introduction of cobalt to fertiliser (Chapman, 1983). All the aforementioned factors lead to the establishment of pine plantation as *pinus radiata* could cope with the conditions in the Central North Island and still maintain healthy growth. However due to the high dairy prices and advances in technology dairy pasture has become economically viable in the Central North Island. High demand and good prices for dairy products has driven the conversion of plantation forest to pasture.

2.3 Carbon

2.3.1 Overview: Soil Carbon

A drop in carbon or alternately rise in carbon in soil could see a drop or increase in plant productivity (Drake *et al.*, 1997). Land use change can alter the concentration of carbon in soils altering their physical and chemical properties (Six *et al.*, 2002). Changes in the soil carbon concentration can influence life within soil.

Carbon stocks in soil can vary greatly depending on land use. With deforestation and conversion of land to pasture recent studies have been looking at carbon pool changes with change of land use (Fearnside & Barbosa, 1998; García-Oliva *et al.*, 2006). With the advent of the Kyoto protocol many countries which have been undertaking deforestation/land use change are trying to determine the carbon levels in soils as there may be an opportunity in some circumstances to accumulate carbon within the soil profile under pasture (García-Oliva *et al.*, 2006). Results from studies of carbon (usually with nitrogen also) changes after deforestation have obtained conflicting results. Some studies show that when land use is changed from forest to pasture there is a decrease in the soil carbon content (Murty *et al.*, 2002; Lo Seen *et al*., 2010); however other studies have found increases in soil carbon under pasture (de Moraes *et al*., 1996; Fearnside & Barbosa, 1998; Sparling & Schipper, 2004; Battle-Bayer *et al*., 2010).

2.3.2 Carbon Cycle

Soil carbon is part of the bigger global carbon cycle; the global carbon balance is affected by factors including solar radiation, anthropogenic activities (burning of fuels for energy, environmental management practices), and natural processes (erosion, transportation) (Figure 2.1) (Mclaren & Cameron, 1996). When any one part of the global carbon cycle is altered changes may occur in different carbon sinks which may cause a change in that pool (Davidsons & Janssens, 2006). A good example of the cause of carbon balance shift is when land use is changed. Often when an area of land is changed from one use to another the soil carbon pool is altered due to changes in vegetation, animal species and management practices. With changes in vegetation and animal species possible changes in the rate at which biomass (carbon rich plant and animal waste) is added to soil can occur (Davidson & Janssens, 2006). Management practices may also influence the carbon budget, for example fertilisation may influence carbon cycling in two ways; fertilisation may stimulate vegetation growth, with more growth comes more death which means more carbon rich biomass added to soil. The second way management of land may influence the soil carbon cycle is if fertiliser high in carbon is added to land, which may lead to an increase in carbon content in the soil (Murty *et al.*, 2002).

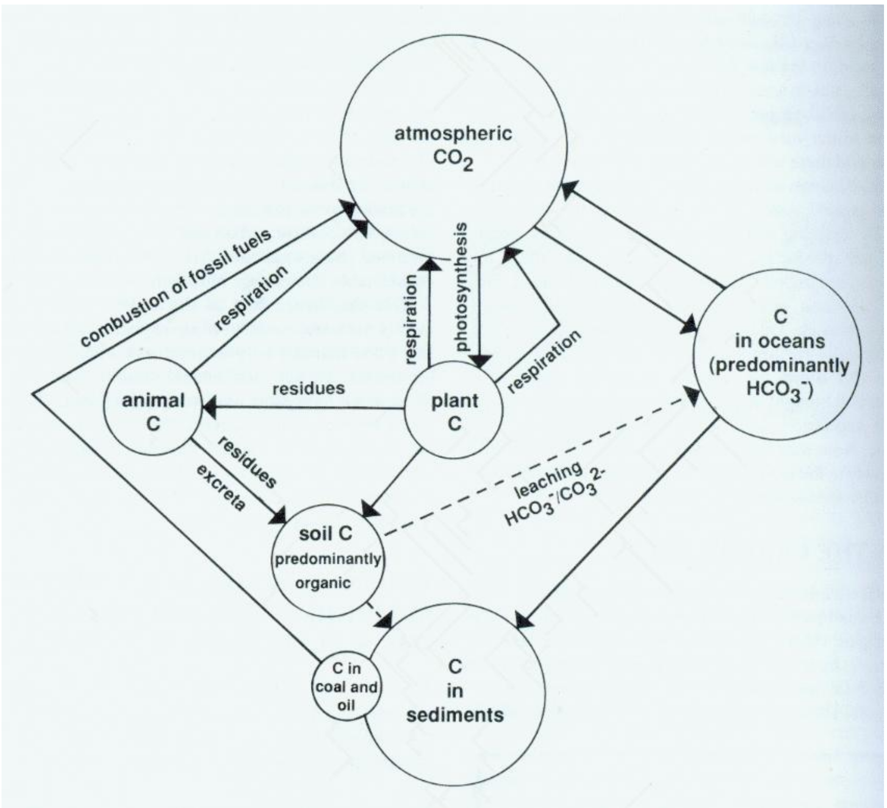

Figure 2.1: Simplified global carbon cycle, displaying the processes which affect the balance of each carbon pool (Mclaren & Cameron, 1996).

2.3.3 Soil Carbon Changes

Studies have yielded conflicting results for carbon pools after deforestation. A review paper by Murty *et al*. (2002) found roughly half of the literature they reviewed showed an increase in the soil carbon pool after land use change from forest to pasture and half a decrease after the same land use change. Although there were conflicting results overall there appeared to be a decrease in soil carbon upon conversion of forest to pasture. Murty *et al*. (2002) considered the results from all the papers they had studied (Figure 2.2).

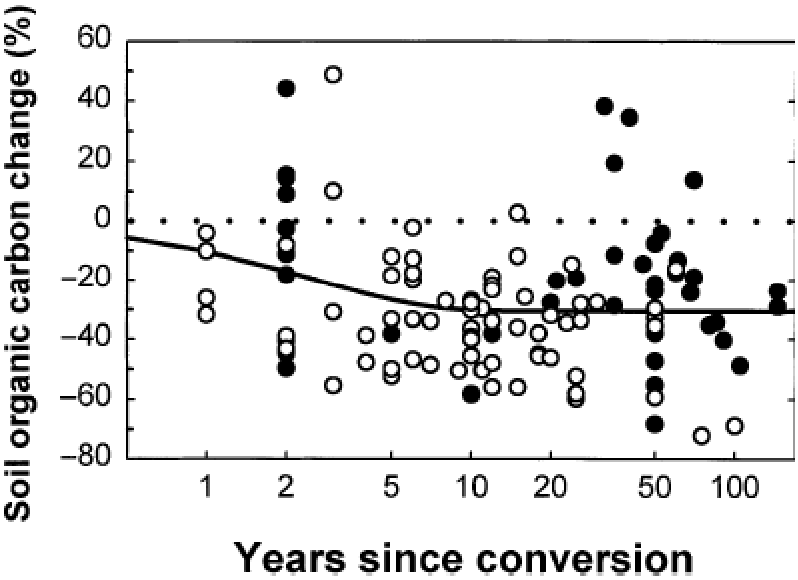

Figure 2.2: Soil organic carbon change after conversion of tropical forest to pasture. Data points are measured carbon results. Open circles have not had bulk density taken into account closed circles have had bulk density taken into account. Black line represents the line of best fit which has been fitted to all data (Murty *et al*., 2002).

Results from Figure 2.2 shows how variable the soil carbon values can be, some increases in soil carbon being as high as 50% after land use change, which is a promising result for people looking at increasing soil carbon to improve soil fertility. However other results showed losses of almost 70% of the soil organic carbon after conversion of forest to pasture. Overall a trend of decreasing organic matter upon conversion of forest to pasture was reported (Murty *et al.*, 2002).

A study from Brazil on soil carbon stocks in pastures which had been converted from forest found that soil carbon stocks decreased after conversion from forest to pasture, depending on farm management practices (Fearnside & Barbosa, 1998). Pastures under typical (standard in Brazil) management (minimal investment in management, leading to inappropriate management and miss-use of fertilisers) lost more carbon from soil when compared to pastures under ideal management (investment in correct management practices, being more careful with fertilisers and tillage) (Table 2.1.).

Table 2.1: Soil from various sites in Brazil under poor and ideal management practices and their total carbon pools and changes since converted from forest to pasture. Pasture age is the time since conversion from forest to pasture. All values were calculated for a soil depth of 0 – 20cm (table modified from Fearnside & Barbosa, 1998).

Location	Soil Type	Pasture age (yr)	Carbon stock (t C / ha)		
			Pre-conversion	Post-conversion	Change in C stock
Sites under poor management					
Capitao Poco	Ultisol	10	31.4	28.6	-2.8
Paragominas	Ultisol	10	15.1	12.0	-3.1
Suia Missu	Oxisol	11	25.1	12.9	-12.2
Ilha de Maraca	Ultisol	12	25.7	22.4	-3.3
Paragominas	Ultisol	23	40.3	37.2	-3.1
Sites under ideal management					
Nova Vida	Ultisol	81	25.1	39.7	14.6
Manaus	Oxisol	8	90.0	92.6	2.6
Niva Vida	Ultisol	20	26.0	26.4	0.9
Nova Vida	Ultisol	20	35.0	41.1	6.1
Paragominas	Oxisol	23	40.3	52.1	11.8

Change in carbon content of a soil following conversion from forest to pasture varies between sites (Table 2.1), with one site showing a loss of 12.2 t C / ha. Sites that had been in pasture for the longest period showed the largest accumulations of carbon, showing that under “better” farm management practices carbon can accumulate in soil when land has been converted from forest to pasture. Fearnside & Barbosa (1998) suggested that when land-use change takes place carbon is more easily lost than gained, and that accumulation of carbon after deforestation can occur if careful pasture management practices are adopted.

2.3.4 Changes in Soil Carbon after Land-use Change in New Zealand

Conversion of plantation forest to pasture has been going on for some time few studies have been conducted in New Zealand to determine what happens to the soil carbon pool following change. There has been research into the effects of land use change in New Zealand by both Polynesian and European settlers. Land use change research was aimed at determining when land use change began in order to determine when Polynesians colonised New Zealand, as well as to determine the extent and rate of deforestation that New Zealand underwent in the past (Vajda *et al.*, 2001; Ewers *et al.*, 2006; McWethy *et al.*, 2009). Afforestation (pasture to pine forest) studies have been conducted in New Zealand. A study of afforestation on degraded pasture in the Mackenzie Basin, South Island, New Zealand which has undergone afforestation using *pinus nigra* showed that for most depths up to a maximum of 30 cm an increase in total carbon was observed after 5 and 10 years in forest (Table 2.2). Overall an increase in total carbon was observed for the profile (Davis *et al.*, 2007). In New Zealand soil accumulates carbon upon afforestation of pasture to grassland, will the opposite occur, loss upon land use change from forest to pasture. There is the possibility that New Zealand will lose carbon from soils during land use change from forest to pasture, however there are some lessons to be learnt from the international studies. If farmers manage converted pastures (land which has undergone a forest to pasture conversion) carefully they do have the opportunity to build up carbon under pasture rather than experiencing loss.

Table 2.2: Total carbon % and content of soil in the Mackenzie Basin following land use change (pasture to forest) at 5 year and 10 year into forest. Values are an average of 4 stocking treatments, numbers in brackets are standard errors associated with those averages (modified from Davis *et al.*, 2007).

Soil depth	Carbon (%)		Carbon (Mg ha^{-1})	
(cm)	Year 5	Year 10	Year 5	Year 10
0 – 10	4.4 (0.10)	4.6 (0.07)	34.6 (1.01)	37.2 (0.69)
10 – 20	3.2 (0.07)	3.4 (0.03)	31.3 (0.99)	32.0 (0.28)
20 – 30	2.9 (0.07)	2.9 (0.03)	28.7 (1.20)	28.6 (0.39)
Total	-	-	94.6 (2.34)	97.9 (1.01)

Hedley et al. (2009) investigated carbon and nitrogen pools after plantation forest has been converted to dairy pasture on pumice soils in the Central North Island of New Zealand in Atiamuri and near Tokoroa. Hedley *et al*. (2009) sampled paddocks which had been in pasture 1, 3 and 5 years since conversion from plantation forest to dairy pasture as well as long term dairy pasture sites. Each age was sampled at 5 locations along a transect of an individual paddock. A corer was used to sample to 7.5 and 15 cm depths with the all the 7.5 cm samples bulked and all the 15 cm samples bulked for an individual transect. Hedley *et al*. (2009) show that soil carbon content increased with time since conversion from plantation forest to pasture, with long term pastures having higher carbon content than the 1 and 3 years since conversion pasture (Table 2.3). Variability in the results obtained by Headly *et al.* (2009) coupled with the Atiamuri 5 years since conversion site having higher carbon content than the long term dairy pasture mean their results do not display a clear pattern as to the rate of carbon accumulation in the soils that they sampled.

Table 2.3: Total carbon content of soil at Atiamuri, Tokoroa and Manawahe for 1, 3, 5 years since conversion and long term dairy pasture, for two depths of 0 – 7.5 cm and 0 – 15 cm. All values are the mean of 15 results, the number in brackets is the standard error (modified from Hedley *et al.*, 2009).

Farm	Site	Total Carbon (t/ha) Depth 0 – 7.5 cm	Total Carbon (t/ha) Depth 0 – 15 cm
Atiamuri	1 year conversion	36.5	16.9
	5 year conversion	72.9	29.6
	Long term dairy pasture	70.4	26.4
Tokoroa	3 year conversion	69.5	32.1
	Long term dairy pasture	82.8	33.8
Manawahe	1 year conversion	17.3	8.1
	5 year conversion	71.5	31.5
	Long term dairy pasture	96.0	33.1

Sparling & Schipper (2004) found carbon in long-term dairy pastures 66.9 t/ha carbon was significantly higher than carbon in plantation forest soils with 46.4 t/ha carbon (Table 2.4). However Sparling & Schipper (2004) followed the methods of Sparling & Schipper (2002) which did not necessarily sample dairy pasture and plantation forest on the same soil type, which may account for the difference in carbon between sites. Regardless of the possible difference in soil types found at sampling site the study by Sparling & Schipper (2004) suggests that soil carbon increases under long-term dairy pasture when compared to pine plantation.

Table 2.4: Total carbon to a depth of 10 cm for pine plantation and long-term dairy pasture (modified from Sparling & Schipper, 2004).

Site	Total carbon (t/ha)	Standard error
Pine plantation (n = 67)	46.4	2.2
Long-term dairy pasture (n = 127)	66.9	1.8

The New Zealand Soil Bureau (1968) reported carbon concentrations for the Taupo Soil of 10.1 % in the Ap horizon, 1.4 % in the B horizon and 0.6 % in the C horizon. The site the New Zealand soil Bureau sampled was off of the Rotorua-Taupo Highway 8 km south of Waiotapu. The site sampled was in tussock, bracken fern and mingi mingi meaning the land was likely to have been unaltered due to farming activities.

2.4 Nitrogen

2.4.1 Overview: Nitrogen

Nitrogen is an essential plant nutrient which is involved in plant metabolic processes such as photosynthesis (Reich *et al.*, 1992). In order for plants to utilise carbon, nitrogen must be present in sufficient concentrations in order for healthy growth and normal plant metabolic processes to take place (Reich *et al.*, 1997). When land use is altered the soil nitrogen pool size has the potential to change with the land use (Vitousek *et al.*, 1997a). The plant and animal species present in, or on, soils can alter the rate at which nitrogen is added or taken from soils and in turn affects the size of the soil nitrogen pool.

2.4.2 Nitrogen Cycle

Nitrogen is added to the soil profile in several ways. Dead plant and animal material (including animal excrement) can add nitrogen to soil through organic matter input. Organic nitrogen is not necessarily in a plant available form and may need to be decomposed by micro-organisms in order to become available to plants (Six et al., 2002).

Nitrogen may be added to soil through fixation by plants. Fixation of nitrogen by plants occurs due to a symbiotic relationship of a plant with a micro-organism. Symbiotic *rhizobium* (micro-organism) usually takes residence in legume roots; these micro-organisms are able to use atmospheric nitrogen (N_2) for metabolic processes (Vitousek et al., 1997b). After metabolism of atmospheric nitrogen (N_2) by *rhizobium* molecules of nitrogen (in aqueous forms) which are a waste product are used by the plant which the *rhizobium* is in symbiosis with. Atmospheric nitrogen which has been fixed by legumes becomes part of the soil profile once the plant dies and is incorporated into soil through decomposition (Six *et al.*, 2002).

Nitrogen fertilisers are added to soil to improve plant growth and productivity (Foley *et al.*, 2005). In pastoral systems the anthropogenic addition of nitrogen allows for intensive farming practices and gives an increase in production per hectare in many pastoral systems (Vitousek *et al.*, 1997a).

Dead plant and animal material, nitrogen fixation by legumes and fertilisers all affect the nitrogen balance and size of the nitrogen pool in soil (Vitousek *et al*., 1997a; 1997b; Six *et al.*, 2002). Under different land uses addition and removal of nitrogen will vary. Management of plantation forests see additions of nitrogen to soil mainly through plant and animal biomass, and nitrogen fixation from legumes. Much of the removal of nitrogen from a plantation forest system is through removal of woody biomass when trees are harvested (Johnson & Curtis, 2001).

Pastoral systems have additions of nitrogen through plant and animal biomass, nitrogen fixation by legumes, and in many pastoral systems, nitrogen fertiliser addition. Removal of nitrogen from pastoral soils includes animal and plant uptake, gaseous loss through volatilization and leaching (McLaren & Cameron, 1996; Vitousek *et al.*, 1997) (Figure 2.3). A large portion of the nitrogen used by plants and animals is lost from the pastoral soil system through removal of either plant biomass or animal biomass (meat, milk and wool). In order for plants to maintain production, and in turn animals to maintain production, pastoral farmers may add nitrogen to their land to replace that which is lost through removal of plant and animal biomass (McLaren & Cameron, 1996). Anthropogenic additions of nitrogen to soil through fertilisers cause changes in nitrogen cycling in soils. With more mineral nitrogen in soils it is possible to get increased leaching though nitrification of ammonium as well as losses through immobilisation and volatilisation (Vitousek *et al.*, 1997b).

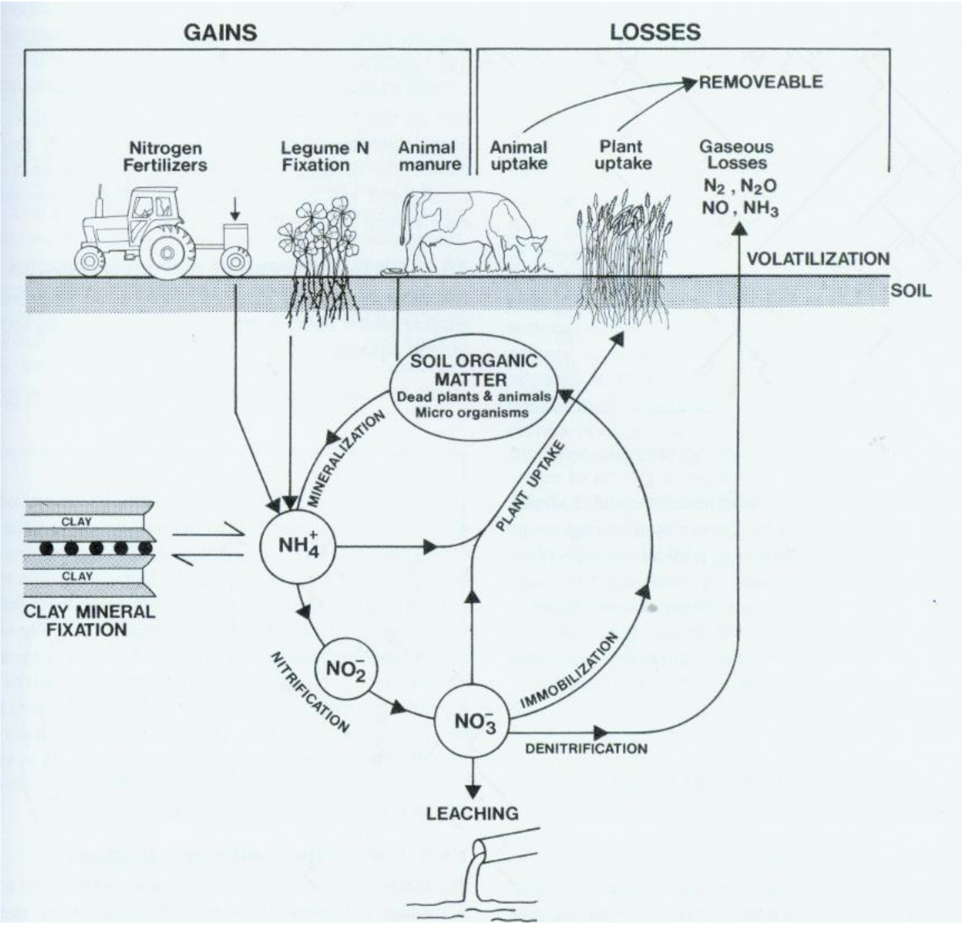

Figure 2.3: Typical nitrogen cycle under pasture management (from McLaren & Cameron, 1996).

2.4.3 Changes in Soil Nitrogen Following Conversion of Plantation Forest to Pasture

With a change in land use many studies have observed a change in the soil nitrogen pool (Neill *et al.*, 1997; Vitousek *et al*., 1997b; Murty *et al.*, 2002; Hedley *et al.*, 2009). In many cases nitrogen accumulation in the soil profile after conversion of land from forest to pasture is attributed to the anthropogenic input of nitrogen to encourage maximum yields from grass crops.

2.4.4 New Zealand and Nitrogen Following Land-use Change from Plantation Forest to Pasture

New Zealand Soil Bureau (1968) reported nitrogen values in Taupo Soil of 0.52 % in the A horizon, 0.10 % in the B horizon and 0.05 % in the C horizon. The Nitrogen results reported by the New Zealand Soil Bureau are from the site as the carbon results which were taken from a site off of the Rotorua-Taupo Highway 8 km south of Waiotapu.

Hedley *et al.* (2009) reported that nitrogen in soils increased after conversion of plantation forest (*pinus radiata*) to pasture. The study was conducted in the Waikato, three farms that had Taupo Pumice Soil were chosen as study areas. After initial conversion of plantation forest to dairy pasture nitrogen in soils increases (increase seen on both dairy farms), with long term dairy sites having the highest soil nitrogen values (Table 2.5). Increases in soil nitrogen can be attributed to differences in management between plantation forest and dairy pasture. Some of the increase in nitrogen seen in pastures after the plantation forest to dairy pasture land use change is due to the use of nitrogen fertilisers; however Hedley *et al.* (2009) believe more leguminous plant species present, specifically more clover present is the main cause for increase in soil nitrogen.

Table 2.5: Total nitrogen content of soil at Atiamuri and Tokoroa for 1, 3, 5 years since conversion and long term dairy pasture, for two depths of 0 – 7.5 cm and 0 – 15 cm. All values are the mean of 15 results, the number in brackets is the standard error (modified from Hedley *et al.*, 2009).

Farm	Site	Total Nitrogen (t/ha)	
		Depth 0 – 7.5 cm	Depth 0 – 15 cm
Atiamuri	1 year conversion	2.1	1.0
	5 year conversion	4.8	1.9
	Long term dairy pasture	6.6	2.4
Tokoroa	3 year conversion	4.5	2.0
	Long term dairy pasture	7.5	2.9
Manawahe	1 year conversion	1.2	0.5
	5 year conversion	5.2	2.2
	Long term dairy pasture	8.8	2.8

Chapter 3.
Description of Study Areas & Site Selection

3.1 Introduction

Three dairy farms which were recently converted from plantation forest to pasture were chosen as study areas. The three study areas are located in the Central North Island of New Zealand at Atiamuri, Tokoroa and Wairakei (Figure 3.1). For the Atiamuri, Tokoroa and Wairakei study areas sites were chosen which were flat and had varying times since conversion from plantation forest (*pinus radiata*) to dairy pasture. Atiamuri, Tokoroa and Wairakei share the same soil type; the Taupo Pumice Soil. Each of the tree study areas, have sites which represent plantation forest (*pinus radiata*), a range of times since conversion to pasture and long-term pasture (Table 3.1). The sites are described in this chapter (3) and field and laboratory methods are described in chapter 4.

The soil parent material at all the study areas is Pumice Soil formed from Taupo Pumice (rhyolitic composition) deposited during the 232 ± 5 AD eruption (Hogg *et al.*, 2009). Eruptive material was deposited as part of a pyroclastic flow. The pyroclastic flow deposit is the result of the eruption plume collapsing and creating a surge of hot ash and rock which travels over the topography filling gullies and thinning on hills (Healy, 1992).

Table 3.1: Study area and age of sites sampled during field work.

Study Area	Time Since Conversion (years)						Long Term Pasture	
	Pine	2	3	4	5	11	Dairy	Sheep/Beef
Tokoroa	x	x	x		x		x	x
Wairakei	x	x	x	x	x		xx	
Artiamuri	x	x			x	x	x	

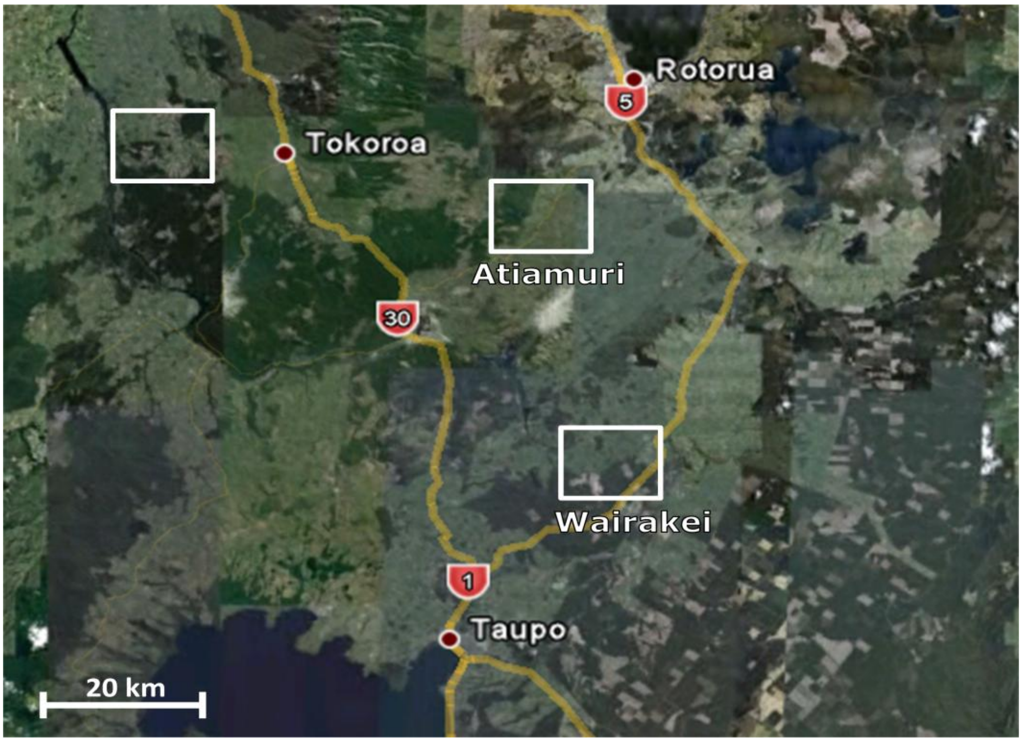

Figure 3.1: Atiamuri, Tokoroa and Wairakei study areas represented y white boxes, with Taupo City, Rotorua City and Tokoroa Town as reference points (modified from google maps, 2010).

3.2 Tokoroa

3.2.1 History of Maxwell Farms

The Maxwell Farms properties investigated in this study are located approximately 10 km west of Tokoroa (Figure 3.2; Table 3.2). Plantation forestry had been the dominant land use on Maxwell Farms land since the 1920's. Before plantation forest was established the dominant vegetation was scrub and native bush (Ewers *et al.*, 2006). Near the end of 2004 land use on Maxwell Farms began to change with 2nd or 3rd rotation forest (Figure 3.3) being harvested and land converted to dairy pasture (Figure 3.4; 3.5; 3.6). Currently Maxwell Farms, Tokoroa, is split into 6 farm units. Each farm unit is a stand-alone farm with each unit having its own milking shed and houses for workers. The individual farm units each have about 1000 dairy cows. All farm units follow a standardised fertiliser regime and get around 200 kg N/ ha annually, phosphorus and potassium are added as required as soils are regularly tested and the levels of all major soil nutrients monitored. Nitrogen application usually occurs in spring and autumn (Tuck, 2010 pers, comm.).

Table 3.2: Tokoroa site numbers and treatment.

Tokoroa Site No.	Treatment
1	Pine
2	2 years since conversion
3	3 years since conversion
4	5 years since conversion
5	Long-term dairy pasture
6	Long-term sheep/beef pasture

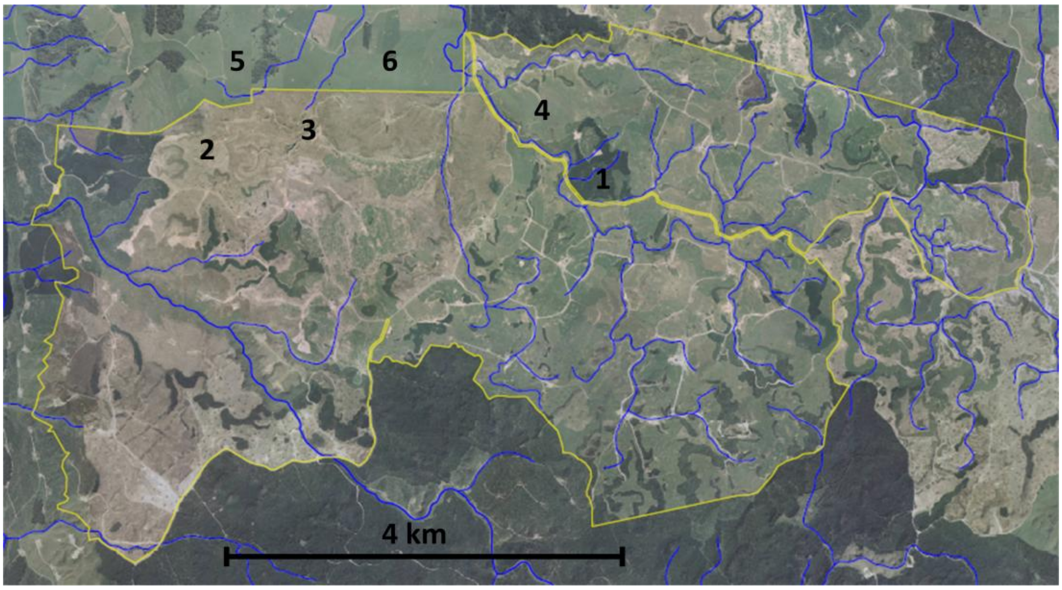

Figure 3.2: Tokoroa study area with numbers representing sample sites, yellow line represents Maxwell Farms property boundary. 1 = pine; 2 = 2 years since conversion; 3 = 3 years since conversion; 4 = 5 years since conversion; 5 = long-term dairy pasture; 6 = long-term sheep/beef pasture (modified from Environment Waikato 2010).

Figure 3.3: Pine forest, Tokoroa Study area.

Figure 3.4: 2 years since conversion, Tokoroa study area.

Figure 3.5: 3 years since conversion, Tokoroa study area.

Figure 3.6: 5 years since conversion, Tokoroa study area.

3.2.2 Conversion of Maxwell Farms land

Due to the size of the area involved removal of plantation forest was carried out in stages, with infrastructure such as roads, dwellings for farm workers, and dairy shed areas being developed first. Contractors then moved out from the areas that were initially converted from forest to pasture. Areas with the longest period since conversion from forest to pasture on Maxwell Farms are usually closest to milking sheds and progressively become younger away from milking sheds. Converting forestry land to dairy pasture involved harvesting mature trees while, smaller, non-mature trees were removed by bulldozers. Much of the Maxwell Farms land underwent some re-contouring. Bulldozers were used during conversion to flatten out small undulations and fill small hollows (Tuck, 2010 pers, comm.). A pattern of thin Ap horizons was observed on the small rises, with over-thickened Ap horizons in small hollows in the landscape. The process of converting plantation forestry to producing dairy pasture took, on average, 8 to 10 weeks (Tuck, 2010 pers, comm.).

3.2.3 Long-term Pasture Tokoroa

All Maxwell Farms land at Tokoroa was converted from forest in the last 2 to 6 years (between 2004 and 2010). To find long-term dairy and long-term sheep/beef pastoral sites for comparison we had to identify nearby farms. To the north of Maxwell Farms (next properties across northern boundary) are two farms, the Hunt dairy farm (owned by Mervin Hunt, managed by Wayne Watson) (Figure 3.7) and the Ranger sheep/beef farm (owned and operated by Andrew Ranger and family) (Figure 3.8). The Hunt and Ranger properties have both been in pasture for at least 50 years (Ranger, 2010 pers, comm.). The Hunt dairy farm was originally converted from native scrub and bush to a sheep farm and from sheep was converted to a dairy farm and has been so for at least 40 years (Hunt, 2010 pers, comm.). The Ranger property has been a sheep/beef farm since it was converted from scrub and bush.

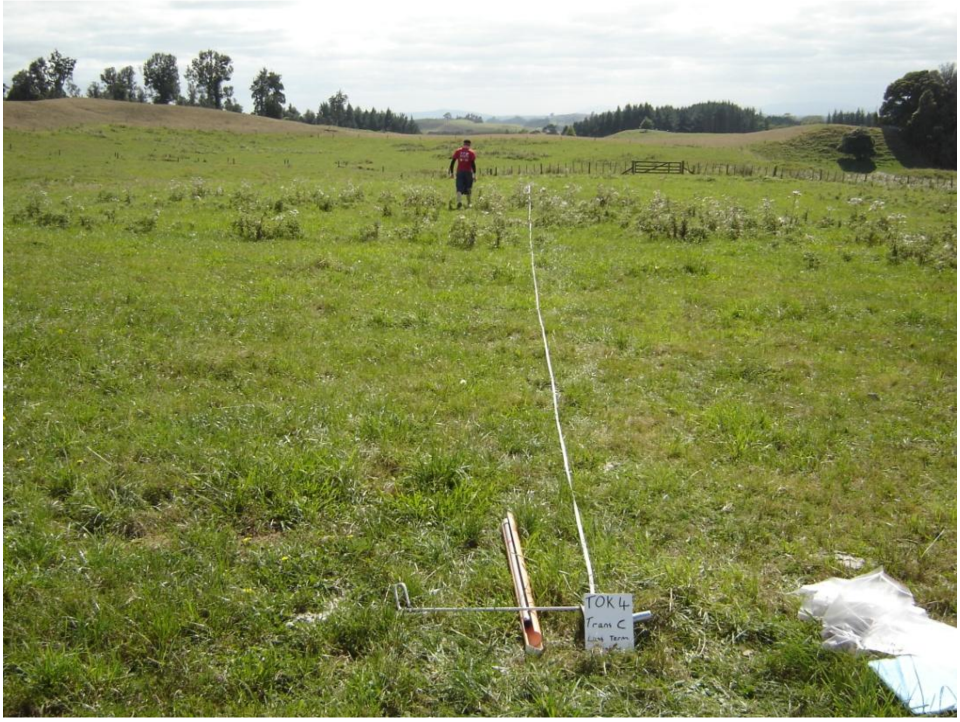

Figure 3.7: Long-term dairy pasture, Tokoroa study area.

Figure 3.8: Long-term sheep/beef, Tokoroa study area.

3.2.4 Topography at Tokoroa

Land in the Tokoroa area is very broken. The landscape consists of undulating hills some of which are reasonably steep with slopes of up to 40^{o}. Many steep ignimbrite outcrops scatter the area and are visible on the steeper parts of the Maxwell Farms. A remnant terrace persists throughout the area; most of the flat land in the field area is located on this terrace (Figure 3.9). Even on the flat terrace micro-topographic features include many small humps and hollows. Slash (the waste tree material from pine harvesting) has been heaped in the paddocks. Many of the slash heaps were still visible at the time of sampling as they have been left to decompose (Figure 3.9). For uniformity all our sites were selected to fall on the terrace areas.

Figure 3.9: Example of topography at Tokoroa study area. Picutre taken from remnant terrace looking out to another remnant terrace.

3.2.5 Soil and Parent Material at Tokoroa

Soils in the Tokoroa area are Typic Orthic Pumice Soils with a loamy sand or sandy loam texture in the top soil. The Cu horizon shows little evidence of weathering and from field observation appears to be the original unaltered Taupo pumice parent material. Below the Taupo pumice deposit was chocolate brown coloured clay denoted by bB. The buried B horizon (bB) horizon was not observed within 60 cm of the soil surface at all sites, but was common throughout the Tokoroa area. The bB horizon represents the previous soil before the deposition of the Taupo pumice.

3.3 Atiamuri

3.3.1 History of Mathis Farm

The Mathis Farm is owned by Brian Mathis and located along State Highway 30 approximately 21 km south east of Tokoroa (Figure 3.10; Table 3.3). The Mathis Farm was originally in native scrub and bush before land use was changed to dairy pasture in the 1930's. Some land on the Mathis property was used for plantation (*Pinus radiata*) forestry, however during autumn of 1999 land use change began and some of the plantation forest was converted to dairy pasture (Figure 3.11; 3.12; 3.13; 3.14). The newest conversion from plantation forest to dairy pasture was carried out 2 years ago. Fertiliser management on the Mathis property varies with the long term dairy pasture (Figure 3.15) requiring less N than the more recently converted pastures. Areas that were recently converted usually require fertilisation after grazing receiving approximately 200 kg N/ ha annually. The long term pasture usually receives around 130 kg N/ ha annually (personal communication, Mathis, 2010).

Table 3.3: Atiamuri site numbers and treatment.

Atiamuri Site No.	Treatment
1	Pine
2	2 years since conversion
3	5 years since conversion
4	11 years since conversion
5	Long-term dairy pasture

Figure 3.10: Atiamuri study area and site numbers. 1 = pine; 2 = 2 years since conversion; 3 = 5 years since conversion; 4 = 11 years since conversion; 5 = long-term dairy pasture (modified from google maps 2010).

Figure 3.11: Pine forest, Atiamuri study area.

Figure 3.12: 2 years since conversion, Atiamuri study area.

Figure 3.13: 5 years since conversion, Atiamuri study area.

Figure 3.14: 11 years since conversion, Atiamuri study area.

Figure 3.15: Long-term dairy pasture, Atiamuri study area.

3.3.2 Conversion of the Mathis Property

Forest to pasture conversion at the Mathis property involved harvesting trees and re-contouring to smooth out small undulations. Debris left following tree felling was pushed into long slash heaps known as wind-rows. Wind-rows were left for a few years then buried in place after a period of decomposition. Following pasture establishment fertiliser was applied at 2 to 3 T/ ha of lime and 800 kg/ ha of diammonium phosphate. Diammonium phosphate was added for 2 years after conversion within that time the converted sites Olsen P levels rose to the same as those found in the long term dairy pastures (personal communication, Mathis, 2010).

3.3.3 Topography at Atiamuri

Land at Atiamuri on the Mathis property is flat with only a few small undulations on the recently converted parts of the farm. There is a gully down the eastern edge of the farm however the gully was not sampled.

3.3.4 Soil and Parent material Atiamuri

Soil parent material is the same Taupo pumice that is found at Tokoroa. Soil profile descriptions were similar to Tokoroa with many of the soil profiles found to have a loamy sand or sandy loam texture. Horizonation of soil was similar to Tokoroa with Ap, Bw and Cu horizons present. At the Atiamuri study area there was little variation in horizon depths between sites.

3.4 Wairakei

3.4.1 History of Wairakei Pastoral Ltd

Wairakei Pastoral Ltd is a part of Landcorp a state owned enterprise. Wairakei Pastoral Ltd controls approximately 25 000 ha of land in the Central North Island approximately 25 km north east of Taupo on State Highway 5 (Figure 3.16; Table 3.4) (Bullick, pers, comm. 2010). Land at the Wairakei site is owned by a third party and is leased to Wairakei Pastoral Ltd. Plantation forest was established in the 1920's at Wairakei and much of the land in Warakei is still currently in plantation forest (Figure 3.17). During 2004 Wairakei Pastoral Ltd began to receive control of land at Wairakei and during spring 2005 began to convert from plantation forest to pasture. Wairakei Pastoral Ltd chose to create 6 standalone dairy farms, however all farms follow a standard operating procedure regardless of size. Physical size of farms varies and so too does the number of dairy cattle ranging from 1000 to 2000 grazing on an individual farm.

Table 3.4: Wairakei site numbers and treatment.

Wairakei Site No.	Treatment
1	Pine
2	2 years since conversion
3	3 years since conversion
4	4 years since conversion
5	5 years since conversion
6	Long-term dairy pasture (A) (Broderson)
7	Long-term dairy pasture (B) (Feather)

Figure 3.16: Wairakei study area with numbers representing sampled sites, dashed line is the Waikato River. 1 = pine; 2 = 2 years since conversion; 3 = 3 years since conversion; 4 = 4years since conversion; 5 = 5 years since conversion; 6 = long-term dairy pasture (A) (Broderson); 7 = long-term dairy pasture (B) (Feather) (modified from google maps 2010).

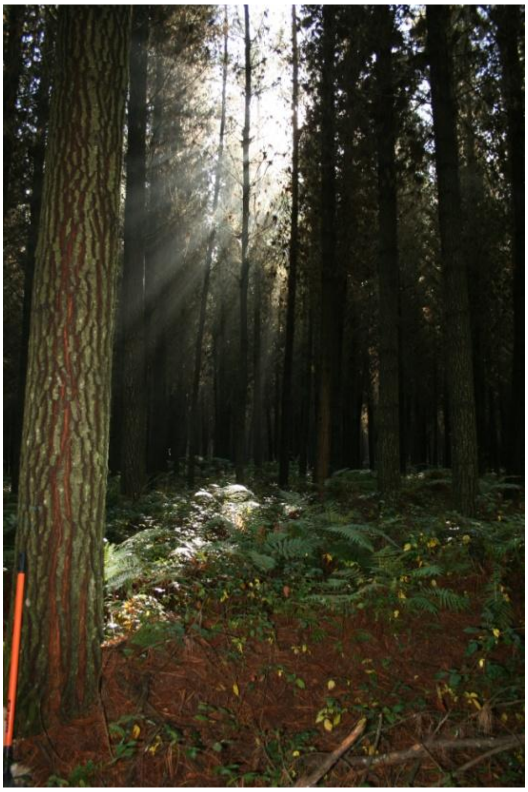

Figure 3.17: Pine forest, Wairakei study area.

3.4.2 Wairakei Pastoral Conversion from Plantation Forest to Pasture

Conversion from plantation forest to pasture of Wairakei Pastoral Ltd land was undertaken in stages with the flattest areas of land converted from forest to pasture first (4 and 5 years since conversion, Figure 3.20; 3.21). Less desirable hilly areas were converted following establishment of dairy pasture on the flat land (2 and 3 years since conversion, Figure 3.18; 3.19). During conversion from forestry to dairy pasture larger mature trees were harvested while smaller juvenile trees were plucked from the ground using diggers. Any debris left was collected into slash heaps or wind-rows, many of which were burnt and buried in place following burning. Initial fertiliser addition following conversion to dairy pasture included 3.5 T/ ha lime, and 1.7 T/ ha superphosphate put on in the first year in split doses, and 260 to 270 kg N/ ha in the first two years. After 2 years fertiliser applications of approximately 650 kg/ ha of superphosphate and 200 kg N/ ha are applied in split doses on, this fertiliser application was standard for all Wairakei Pastoral Ltd dairy farms (personal communication Bullick, 2010).

Figure 3.18: 2 years since conversion, Wairakei study area.

Figure 3.19: 3 years since conversion, Wairakei study area.

Figure 3.20: 4 years since conversion, Wairakei study area

Figure 3.21: 5 years since conversion, Wairakei study area.

3.4.3 Long-term Dairy Pasture at Wairakei

Long-term dairy pasture (A) is a dairy farm owned by Robin Brodison and is located about 4 km north west of Wairakei Pastoral Ltd. Before being a dairy farm Nui Frisian was a sheep farm owned by Landcorp, however during the 1950's Nui Frisian was converted to dairy and has been a dairy farm since (Figure 3.22). Fertiliser has been applied at 150 kg N/ ha and 600 kg/ ha of superphosphate annually for the past 10 years. Most of Nui Friesian has had whey on it however no part of the farm in the last 5 years has had whey applied to it (Broderson, 2010 pers, comm.).

Figure 3.22: Long-term dairy (A) (Broderson Farm), Wairakei study area.

The Feather Dairy farm is located on the eastern boundary of the 5 years since conversion site in the Wairakei study area. The Feather Dairy farm has been a dairy pasture for approximately 40 years and was converted to dairy from plantation forest (Feather, 2010 pers. comm.) (Figure 3.23). Nitrogen fertiliser is applied 3 times a year at a rate of approximately 120 kg N / ha and 500 kg / ha of superphosphate annually. The paddocks used for sampling have had whey applied in the past, however for the last 10 years no whey has been applied to the farm.

Figure 3.23: Long-term dairy (B) (Feather Farm), Wairakei study area.

3.4.4 Topography at Wairakei

Most of the Wairakei Pastoral Ltd land is flat, with some small hills and some gullies on some farms. Most paddocks were flat with some small humps and hollows in paddocks.

Nui Friesian has a small hill in the north western part of the farm. Most paddocks are flat with some very small humps and hollows, as well as the occasional small ridge through a paddock.

The Feather dairy farm is flat with some small undulations through paddocks, and a ridge running through one of the paddocks used in sampling.

3.4.5 Soil and Parent Material at Wairakei

Like Tokoroa and Atiamuri, Wairakei has Taupo pumice parent material. Being closer to the eruption source (Lake Taupo) coarser pumice clasts can be seen in all soil profiles. Soil profile descriptions yield a texture of either loamy sand or a sandy loam, and have an Ap, Bw and Cu horizon. Pumice is abundant throughout the soil profile at all of the recently converted Wairakei Pastoral Ltd sites. Nui Friesian did not appear to have much pumice in the Ap horizon, though the Bw and Cu horizons had obvious pumice clasts. The Feather Dairy farm did not have obvious pumice clasts in the Ap horizon, but through the Bw and Cu horizons pumice was obvious.

Chapter 4.
Field & Laboratory Methods

4.1 Introduction

The field and laboratory methods used in this thesis are described here. All equations used to calculate results are included.

4.2 Field Methods

4.2.1 Site Selection

In order to obtain comparable samples from my three study areas, landscape position had to be taken into account at each sampling site. Flat sites which are remnant tephra covered terraces were chosen at all three study areas as flat land was more likely to have uniform soil profiles. At the Tokoroa study area a remnant terrace landform was identified and all samples were taken from the terrace landform. The Atiamuri and Wairakei study areas were both reasonably flat and all sampling was done on flat land making an effort to avoid small ridges in paddocks. All three study areas either had, or still have, wind rows and slash heaps. On all study areas where wind rows and slash heaps still exist, or were present in the past, an effort was made to keep soil pits and the transect clear as near wind rows and slash heaps soil was more likely to have greater disturbance and was also more likely have an abundance of woody plant material. Time since conversion of plantation forest to pasture was established at Atiamuri, Tokoroa and Wairakei, and sites on each of the study areas were selected according to time since conversion and suitable landscape position. Each study area had varying time since conversion of plantation forest to pasture. Artiamuri, Tokoroa and Wairakei while having varying time since conversion of land all had a forest sampling site and at least one long-term dairy pasture sampling site.

4.2.2 Sampling

On each sampling site three transects were established. Each transect had a letter assigned to it (A, B, C), a GPS co-ordinate recorded for its start point and an orientation taken using a compass. Each transect was 50 m in length and samples were taken at seven random intervals along the transect. Samples for carbon and nitrogen analysis were taken using a 60 cm hand driven corer (Figure 4.1). For each transect core samples were split into individual soil horizons, depths were recorded for each soil horizon, and samples from the 7 cores along each transect were bulked according to horizon.

Pits were dug at 25 m intervals along each transect. From each pit bulk density samples were taken using cores 6 cm in diameter and 5 cm deep. In each pit 3 bulk density cores were taken per soil horizon. One pit on each site was designated as the master pit. The master pit had a soil profile description undertaken following Milne *et al*. (1995) method for soil description in New Zealand. A soil sample for carbon and nitrogen analysis was taken from the master pit. A scrape of soil was taken from the pit wall using a spade to cut the bottom of a soil horizon and a knife to cut a vertical slice of soil from the pit. Scrape samples were taken for all horizons present in each “master” pits.

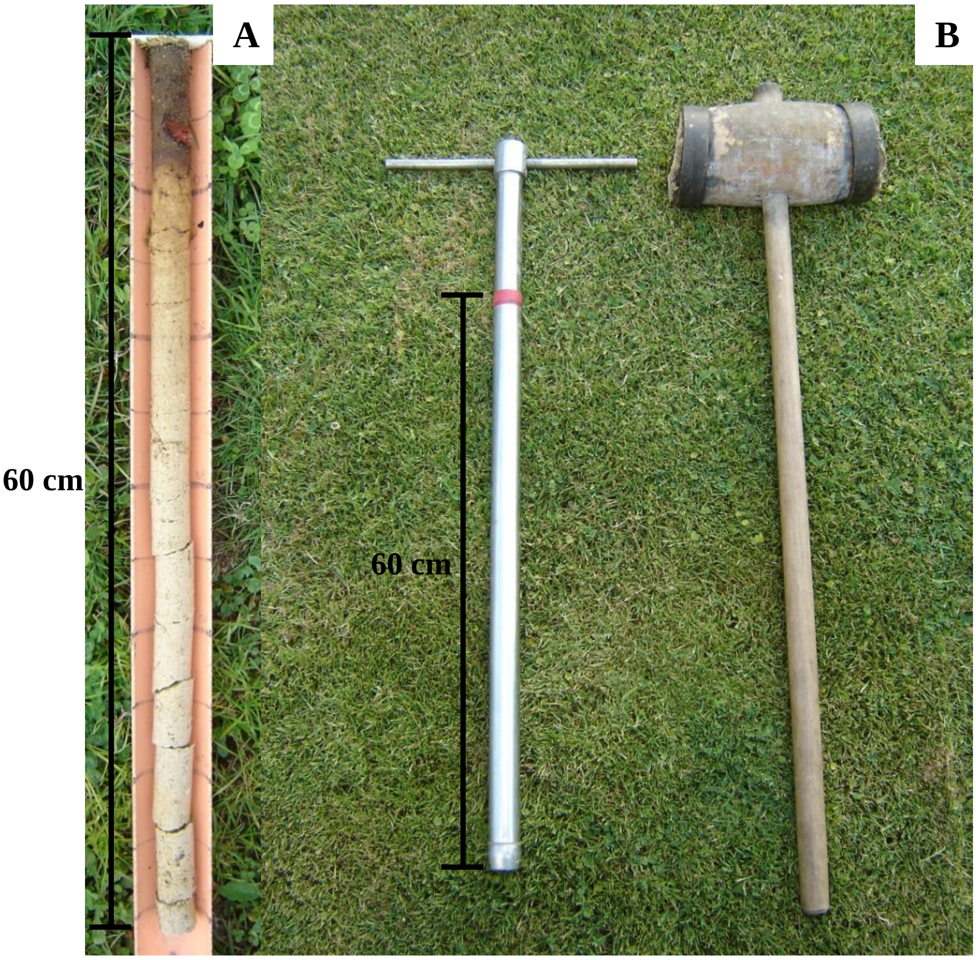

Figure 4.1: Soil core sampling. (A) Soil core from Wairakei long-term dairy (Broderson). (B) Mallet and corer used for sampling.

4.3. Laboratory Methods

4.3.1 Carbon and Nitrogen Analysis Using a TruSpec CN Carbon/Nitrogen Determinator

A TruSpec CN Carbon/Nitrogen Determinator produced by the Laboratory Equipment Corporation (LECO furnace) is a fast way of obtaining accurate total soil carbon and nitrogen. A LECO furnace combusts a 0.25 g sample of soil (up to 1 g sample), combusting it using an electrical flux in a conducting matrix mixed with the soil sample. The high frequency electrical flux produces a maximum temperature of 1050 ºC to provide complete combustion of the organic matter in soil sample. A LECO high frequency combustion furnace can detect carbon from 0.005% to 50% and nitrogen from 0.008% to 100% of sample.

Analysis using a LECO furnace has three phases, purge, combustion and analysis. During the purge phase sample is placed in a chamber which is sealed and purged of atmospheric gases using oxygen gas (O_2).

The sample is combusted in a furnace at 950 ºC. In order to ensure complete combustion takes place oxygen is pumped into the furnace during combustion of the sample. Combusted material is passed through a secondary furnace (850 ºC) to further ensure complete combustion of sample.

Gases produced through combustion are passed through an infrared carbon dioxide (CO_2) detector and the carbon dioxide gas concentration is measured. The gas analysed for carbon dioxide is passed through a hot copper loop to remove oxygen and to ensure nitrous oxide gases (NO_x) are converted to nitrogen gas (N_2), at this stage of analysis helium gas is used as a carrier gas. Carbon dioxide and water are removed from the nitrogen gas sample using Lecosorb and Anhydrone. Nitrogen gas is analysed using a thermal conductivity cell to determine percent of nitrogen in the remaining gas (LECO Corporation, 2006) (Figure 4.2).

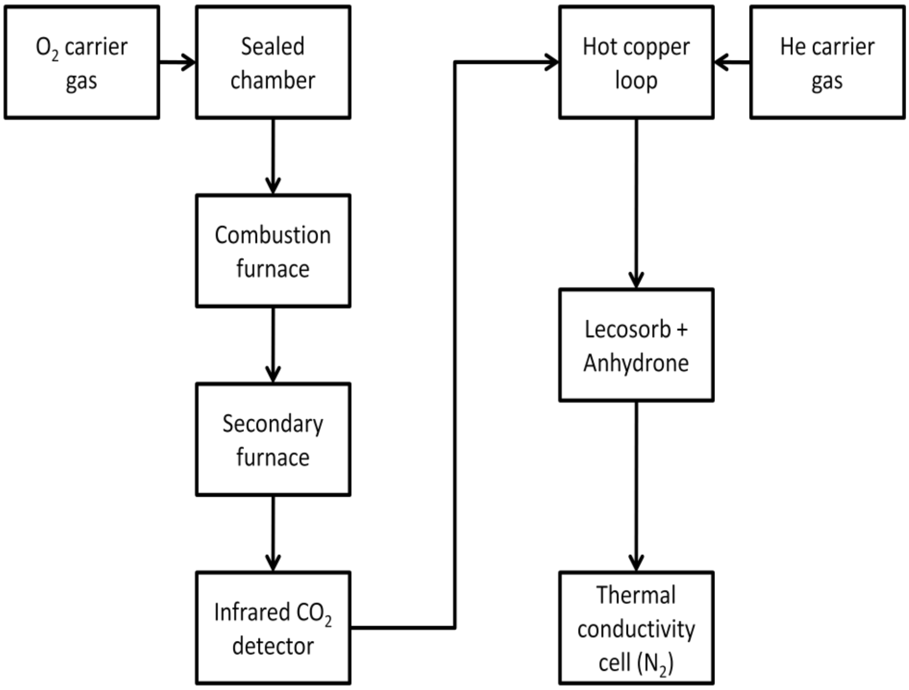

Figure 4.2: Simplified flow path for analysis of carbon and nitrogen using a TruSpec CN Carbon/Nitrogen Determinator.

4.3.2 Sample Preparation for Carbon and Nitrogen Analysis

Core samples were air dried and sieved through a 2 mm sieve in order to obtain the fine earth fraction of soil. During sieving any visible charcoal present was removed and discarded. Any of the constituents of the soil (pumice, wood, green plant material) that would not pass through the 2 mm sieve were discarded. Sieved and dried samples were sub-sampled using a riffle to split the sample in half. Samples were split in half until approximately 10 g of sample remained in the catch tray. The smaller sub-sample was crashed to a fine powder using an agate mortar and pestle and sent to a LECO furnace (Figure 4.3) for total carbon and nitrogen determination (Blakemore *et al.*, 1987). The moisture factor for air dried and crushed samples were determined as carbon and nitrogen results need to be corrected for moisture. Aluminium oven trays were weighed, air dried and crushed sample was added to the oven trays and on oven tray containing air dried and crushed sample was re-weighed. The moisture factor samples were dried in an oven at 105 ºC for 24 hours. Oven dried moisture factor samples were cooled in a desiccator and weighed in order to obtain a dry mass. Moisture Factor was calculated using Equation 4.1 (McLaren & Cameron, 1996).

Figure 4.3: TruSpec CN Carbon/Nitrogen Determinator (LECO furnace). With two reaction columns used to purify gas from combusted sample.

Equation 4.1

Moisture Factor

$$M_f = \frac{(M_d - M_t)}{(M_w - M_t)}$$

M_f – Moisture factor

M_t – Mass of tin (g)

M_d – Mass of dry soil and tin (g)

M_w – Mass of wet soil and tin (g)

4.3.3 Bulk Density

Aluminium oven trays were weighed, bulk density samples were added to the oven trays and oven dried at 105 ºC for 24 hours. Oven dried bulk density samples were cooled in a desiccator and weighed to obtain a dry mass. Bulk density was calculated using a standard bulk density equation (Equation 4.2) (McLaren & Cameron, 1996).

Equation 4.2

Dry bulk density equation

$$\rho_b = \frac{M_s}{V_t}$$

ρ_b – Dry bulk density (g cm^{-3})

M_s – Mass of dry soil (g) (M_s = mass of dry sample and tin – mass of tin)

V_t – Total volume of soil (cm^3) (volume of soil = volume of core used in soil bulk density sampling)

$$V_t = \pi r^2 \times h$$

r – Radius of core used in bulk density sampling (cm)

h – Height of core used in sampling (cm)

4.3.4 Fine Earth Fraction

Only the fine earth fraction of the soil was analysed for carbon and nitrogen, so in order to correctly estimate the amount of carbon or nitrogen in a soil profile a soil fine earth fraction density (g cm^{-3}) was calculated. Once bulk density had been measured samples used for bulk density were sieved through a 2 mm sieve. Aluminium oven trays were weighed and the fine earth fraction of the bulk density sample (all of the bulk density sample that had passed through the 2 mm sieve) was added to the oven tray. The fine earth fraction of bulk density was oven dried at 105 ºC for 24 hours. The oven dried fine earth fraction samples were cooled in a dessicator and weighed. Fine earth fraction density was calculated using Equation 4.3.

Equation 4.3

Fine earth fraction density equation

$$\rho_{FEF} = \frac{M_{FEF}}{V_t}$$

ρ_{FEF} – Fine earth fraction density (g cm^{-3})

M_{FEF} – Mass of dry fine earth fraction (g) (M_{FEF} = mass of dry fine earth fraction sample and tin – mass of tin)

V_t – Total volume of soil (cm^3) (volume of soil = volume of core used in soil bulk density sampling).

$$V_t = \pi r^2 \times h$$

r – Radius of core used in bulk density sampling (cm)

h – Height of core used in sampling (cm)

4.4. Calculation of Results

4.4.1 Calculation of Carbon in Soil Profile

In order to obtain the volume of carbon in the soil profile soil horizon depth, bulk density and soil carbon had to be combined. For each horizon carbon mass was calculated according to depth (equation 4.4) (Shipper *et al.*, 2007). All final soil carbon masses were corrected for moisture using the moisture factor determined for the ground carbon and nitrogen samples.

Equation 4.4

Soil carbon mass for each soil horizon

$$M_c = \left[\frac{(T_h \times P_C \times \rho_b)}{10}\right] \times M_f$$

M_c – Carbon mass in an average horizon (kg m^{-2})

T_h – Horizon thickness (cm)

P_C – Carbon percentage (%)

ρ_b – Bulk density of the soil horizon (g cm^{-3})

10 – Multiplication factor for converting g to kg

M_f – Moisture factor

4.4.2 Calculation of Nitrogen in Soil Profile

Nitrogen in the soil profile was calculated using the same equation as was used to calculate the mass of carbon in the soil profile. Mass of nitrogen was calculated by replacing the soil carbon percentage (P_C) with the soil nitrogen percentage (P_N) (equation 4.5)

Equation 4.5

Soil nitrogen mass in each soil horizon

$$M_N = \left[\frac{(T_h \times P_N \times \rho_b)}{10}\right] \times M_f$$

M_N – Nitrogen mass in each horizon (kg m^{-2})

T_h – Horizon thickness (cm)

P_N – Carbon percentage (%)

ρ_b – Bulk density of the soil horizon (g cm^{-3})

10 – Multiplication factor for converting g to kg

M_f – Moisture factor

4.5 Statistical Analysis

Statistical analysis of results was carried out using Microsoft® Excel® 2007 version 12.0.6524.5003. Further statistical analysis was carried out using StatSoft. Inc. Statistica version 9.1.

Chapter 5.
Results: Soil Profile, Carbon & Nitrogen

5.1 Introduction

Soil description and carbon and nitrogen results for the three study areas; Atiamuri, Tokoroa and Wairakei, are presented in this chapter.

5.2 Soil Description

5.2.1 Atiamuri Soil

Soil at the Atiamuri study site had a texture of loamy sand or sandy loam (full soil profile descriptions in appendices). Pumice was found in all soil profiles. The long-term dairy pasture had less visible pumice fragments in the Ap horizon than other sites (Figure 5.1).

Soil horizon thickness varied throughout the Atiamuri study area, with no trend in horizon depths relative to the time since conversion from forest (Table 5.1). All cores and profile pit samples were taken to a maximum depth of 60 cm. Where the underlying bB horizon was encountered in the top 60 cm of the profile the total thickness of the Cu horizon was recorded and the underlying bB horizon material was discarded. Soil Ap horizons in the Atiamuri area ranged from black (10YR 2/1) to brownish black (7.5YR 2/2).

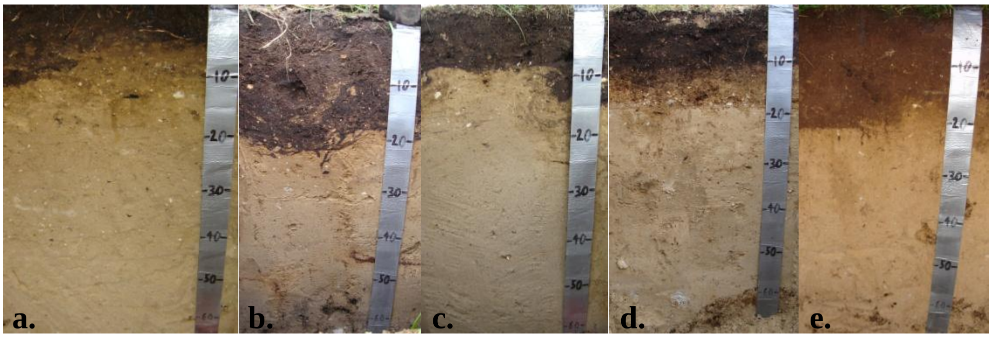

Figure 5.1: Soil profiles at Atiamuri. a. pine plantation, b. 2 years since conversion, c. 5 years since conversion, d. 11 years since conversion and e. long-term dairy pasture.

Table 5.1: Mean soil horizon thicknesss at Atiamuri study area. Mean horizon thickness was a combination of all soil core and pit horizon thickness. SD is the standard deviation (N = 22).

Site	Horizon thickness					
	Ap horizon		Bw horizon		Cu horizon*	
	(cm)	SD	(cm)	SD	(cm)	SD
Pine Plantation	13.1	5.3	18.2	6.0	28.0	8.0
2 years since conversion	13.3	5.1	14.9	6.6	28.6	8.5
5 years since conversion	13.0	6.0	12.9	3.2	33.2	7.5
11 years since conversion	11.5	4.2	15.2	4.9	27.8	9.6
Long-term dairy pasture	16.9	3.0	11.4	3.9	31.5	4.7

* Cu soil horizon thickness recorded was limited to the thickness down to the sampling depth of 60 cm.

The pine plantation Ap horizon had the lowest fine earth fraction value in part due to the low bulk density of the pine forest Ap horizon. Pine forest soil Ap horizon had a bulk density of 0.47 g cm^{-3} which was lower ($P<0.05$) than all other sites in the Atiamuri area (Table 5.2). A pattern of increasing fine earth fraction (g cm^{-3}) with depth was observed at the pine plantation, and 2 and 5 years since conversion sites, in the Atiamuri study area (Table 5.3).

Table 5.2: Soil dry bulk density results for the Atiamuri study area. Bulk density results are the mean value of all bulk density values that were calculated for Atiamuri. SD is the standard deviation (N = 22).

Site	Soil dry bulk density					
	Ap horizon		Bw horizon		Cu horizon	
	(g cm^{-3})	SD	(g cm^{-3})	SD	(g cm^{-3})	SD
Pine Plantation	0.47	0.09	0.74	0.07	0.76	0.04
2 years since conversion	0.72	0.03	0.77	0.03	0.81	0.06
5 years since conversion	0.67	0.04	0.75	0.08	0.83	0.09
11 years since conversion	0.71	0.02	0.74	0.06	0.76	0.10
Long-term dairy pasture	0.72	0.04	0.74	0.05	0.73	0.04

Table 5.3: Fine earth fraction results for the Atiamuri study area. Fine earth fraction results are the mean value of all fine earth fraction values that were calculated for Atiamuri. SD is the standard deviation (N = 22).

Site	Fine earth fraction					
	Ap horizon		Bw horizon		Cu horizon	
	(g cm^{-3})	SD	(g cm^{-3})	SD	(g cm^{-3})	SD
Pine Plantation	0.43	0.09	0.70	0.07	0.73	0.04
2 years since conversion	0.67	0.04	0.71	0.05	0.76	0.05
5 years since conversion	0.62	0.04	0.69	0.12	0.79	0.11
11 years since conversion	0.68	0.03	0.65	0.04	0.72	0.04
Long-term dairy pasture	0.66	0.04	0.67	0.05	0.69	0.05

5.2.2 Tokoroa Soil

The soil in Tokoroa study area had soil textures of either sandy loam or loamy sand. In the top-soil of the recently converted pasture sites there was a lot of wood present. The long-term dairy and long-term sheep/beef sites had a sharper Ap-Bw horizon boundary than the other sites sampled (Figure 5.2). The pine forest, 3 years since conversion and 5 years since conversion sites at Tokoroa had the darkest coloured Ap horizons with a black (10YR 1.7/1) colour (Figure 5.2). In some of the pits and many of the cores taken at the Tokoroa study area a clay rich bB horizon was observed beneath the Taupo pumice within the top 60 cm of the soil profile. Ap horizon thickness did not vary much between land use sites at Tokoroa with no significant differences between land use sites (Table 5.4).

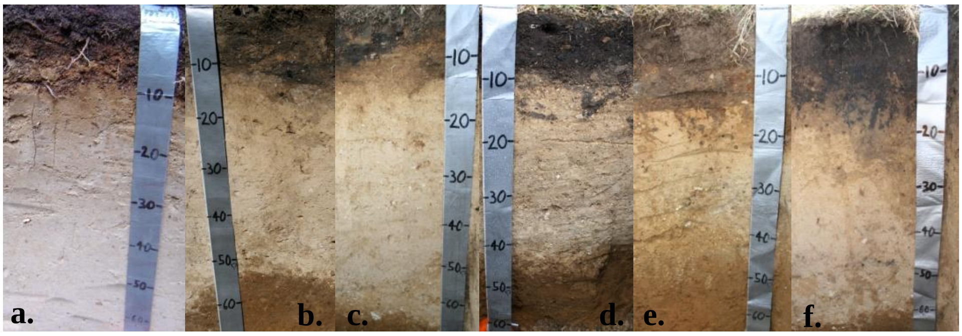

Figure 5.2: Soil profiles at Tokoroa. a. pine plantation, b. 2 years since conversion, c. 3 years since conversion, d. 5 years since conversion, e. long-term dairy pasture and f. long term sheep/beef pasture.

Table 5.4: Mean soil horizon thicknesss at the Tokoroa study area. Mean horizon thickness was a combination of all soil core and pit horizon thickness. SD is the standard deviation (N = 19 for 2, 3 and 5 years since conversion; N = 21 for pine plantation; N = 22 for long-term dairy pasture and long-term sheep/beef).

Site	Horizon thickness					
	Ap horizon		Bw horizon		Cu horizon*	
	(cm)	SD	(cm)	SD	(cm)	SD
Pine Plantation	11.8	2.1	16.6	4.3	29.0	7.0
2 years since conversion	11.1	3.8	12.4	5.1	22.2	6.3
3 years since conversion	10.8	3.7	13.8	5.9	28.9	9.4
5 years since conversion	10.1	3.3	12.1	4.2	28.3	6.7
Long-term dairy pasture	12.3	4.2	12.1	4.4	20.4	7.9
Long-term sheep/beef	12.3	1.9	17.2	4.0	28.3	4.5

* Cu soil horizon thickness recorded was limited to the thickness down to the sampling depth of 60 cm.

At the Tokoroa sites the fine earth fraction was lower in the Ap horizon than in the Bw horizon for all sites (Table 5.6). The pine plantation Ap horizon had the lowest fine earth fraction value with 0.49 g cm^{-3} which is due to the pine also having the lowest bulk density with 0.54 g cm^{-3} (Table 5.5).

Table 5.5: Soil dry bulk density for Tokoroa study area. Bulk density results are the mean of all fine earth fraction values that were calculated for Tokoroa. SD is the standard deviation (N = 19 for 2, 3 and 5 years since conversion; N = 21 for pine plantation; N = 22 for long-term dairy pasture and long-term sheep/beef).

Site	Soil dry bulk density Ap horizon		Bw horizon		Cu horizon	
	($g\ cm^{-3}$)	SD	($g\ cm^{-3}$)	SD	($g\ cm^{-3}$)	SD
Pine Plantation	0.54	0.11	0.77	0.06	0.79	0.10
2 years since conversion	0.59	0.21	0.69	0.06	0.76	0.03
3 years since conversion	0.69	0.06	0.72	0.03	0.73	0.06
5 years since conversion	0.64	0.04	0.71	0.01	0.73	0.04
Long-term dairy pasture	0.67	0.08	0.71	0.04	0.69	0.05
Long-term sheep/beef	0.61	0.05	0.70	0.03	0.77	0.08

Table 5.6: Mean fine earth fraction for Tokoroa study area. Fine earth fraction results are the mean of all fine earth fraction values that were calculated for Tokoroa. SD is the standard deviation (N = 19 for 2, 3 and 5 years since conversion; N = 21 for pine plantation; N = 22 for long-term dairy pasture and long-term sheep/beef).

Site	Fine earth fraction Ap horizon		Bw horizon		Cu horizon	
	($g\ cm^{-3}$)	SD	($g\ cm^{-3}$)	SD	($g\ cm^{-3}$)	SD
Pine Plantation	0.49	0.06	0.75	0.06	0.76	0.08
2 years since conversion	0.62	0.05	0.74	0.05	0.72	0.05
3 years since conversion	0.67	0.06	0.68	0.05	0.68	0.06
5 years since conversion	0.61	0.05	0.67	0.08	0.69	0.06
Long-term dairy pasture	0.65	0.07	0.69	0.05	0.65	0.04
Long-term sheep/beef	0.59	0.04	0.68	0.03	0.72	0.07

5.2.3 Wairakei Soil

The Wairakei study area had a coarser soil texture for all sites when compared with the soils at the Atiamuri and Tokoroa study areas. Large pumice clasts (up to 10 cm wide) were found in many of the pits in the Wairakei study area. Both of the long-term dairy pasture sites at Wairakei had well developed top soils with distinct boundaries (Figure 5.3). Wairakei Ap soil horizons were darker in colour at the two long-term pasture (both long-term dairy A and B having 7.5YR 2/1 Ap horizons) sites and at the forest site (7.5YR 2/1) when compared with the 3 (5YR 3/2), 4 and 5 years since conversion sites at Wairakei (Figure 5.3). Soil horizon thickness at the Wairakei study area was variable throughout all sites (Table 5.7).

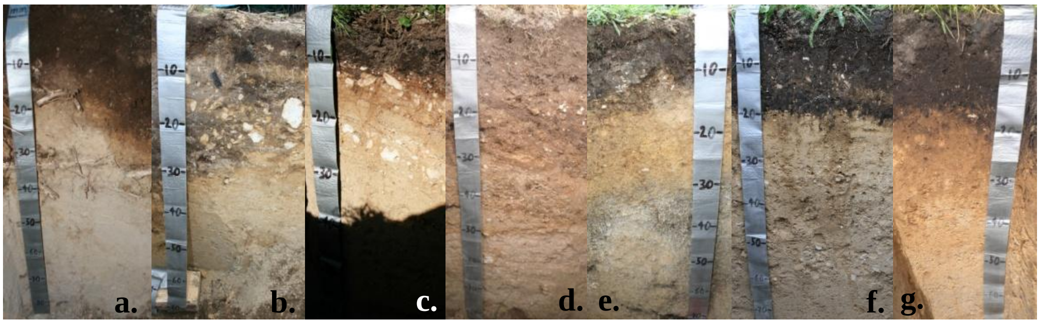

Figure 5.3: Soil profiles at Wairakei. a. pine plantation, b. 2 years since conversion, c. 3 years since conversion, d. 4 years since conversion, e. 5 years since conversion, f. long-term dairy pasture (Broderson Farm), g. long term dairy pasture (Feather Farm).

Table 5.7: Mean soil horizon thickness at the Wairakei study area. Mean horizon thickness was a combination of all soil core and pit horizon thickness. SD is the standard deviation (N = 22).

Site	Horizon thickness: Ap horizon (cm)	SD	Bw horizon (cm)	SD	Cu horizon* (cm)	SD
Pine Plantation	14.5	9.4	15.8	8.1	28.6	7.5
2 years since conversion	13.7	7.2	16.4	6.1	27.6	6.7
3 years since conversion	13.5	7.3	17.5	6.1	27.2	9.6
4 years since conversion	18.3	5.0	19.3	4.8	20.9	7.0
5 years since conversion	15.2	3.9	22.6	8.9	20.4	8.6
Long-term dairy pasture (A) (Broderson)	16.1	3.6	24.0	8.7	19.8	8.4
Long-term dairy pasture (B) (Feather)	17.0	3.5	25.8	8.8	17.5	8.0

* Cu soil horizon thickness recorded was limited to the thickness down to the sampling depth of 60 cm.

The pine site at Wairakei had a dry bulk density of 0.48 g cm-3 in the Ap horizon which was significantly lower ($P<0.05$) than any other treatment (Table 5.8). Pine plantation had a fine earth fraction value in the Ap horizon of 0.40 g cm^{-3} which was lower ($P<0.05$) than all other sites at Wairakei (Table 5.9). The Wairakei pine site having the lowest dry bulk density and lowest fine earth fraction is consistent with the results from Atiamuri and Tokoroa. All sites other than the long-term dairy pasture (Broderson) sampled at Wairakei showed an increase in fine earth fraction values with depth.

Table 5.8: Soil dry bulk density values for the Wairakei study area. Mean bulk density was a combination of all fine earth fractions calculated for Wairakei. SD is the standard deviation (N = 22).

Site	Soil dry bulk density					
	Ap horizon		Bw horizon		Cu horizon	
	(g cm^{-3})	SD	(g cm^{-3})	SD	(g cm^{-3})	SD
Pine Plantation	0.48	0.13	0.61	0.08	0.80	0.10
2 years since conversion	0.72	0.07	0.81	0.08	0.96	0.08
3 years since conversion	0.63	0.05	0.73	0.06	0.92	0.09
4 years since conversion	0.68	0.06	0.76	0.09	0.80	0.06
5 years since conversion	0.67	0.08	0.80	0.04	0.82	0.05
Long-term dairy pasture (A) (Broderson)	0.72	0.11	0.73	0.20	0.67	0.09
Long-term dairy pasture (B) (Feather)	0.76	0.02	0.79	0.03	0.91	0.17

Table 5.9: Mean fine earth fraction values for the Wairakei study area. Mean fine earth fraction was a combination of all fine earth fractions calculated for Wairakei. SD is the standard deviation (N = 22).

Site	Fine earth fraction					
	Ap horizon		Bw horizon		Cu horizon	
	(g cm^{-3})	SD	(g cm^{-3})	SD	(g cm^{-3})	SD
Pine Plantation	0.40	0.12	0.48	0.13	0.71	0.13
2 years since conversion	0.66	0.08	0.70	0.11	0.81	0.04
3 years since conversion	0.54	0.06	0.63	0.09	0.82	0.10
4 years since conversion	0.50	0.05	0.57	0.10	0.60	0.09
5 years since conversion	0.60	0.08	0.72	0.06	0.72	0.08
Long-term dairy pasture (A) (Broderson)	0.64	0.14	0.60	0.25	0.55	0.14
Long-term dairy pasture (B) (Feather)	0.68	0.04	0.71	0.07	0.80	0.17

5.3 Carbon

5.3.1 Atiamuri Carbon

Carbon percentage values in the Atiamuri study area ranged from 5.67 to 6.77 % in the Ap horizon (Figure 5.4). There were no significant differences in carbon % values between sites in the Ap horizon. The Bw and Cu horizons were generally consistent.

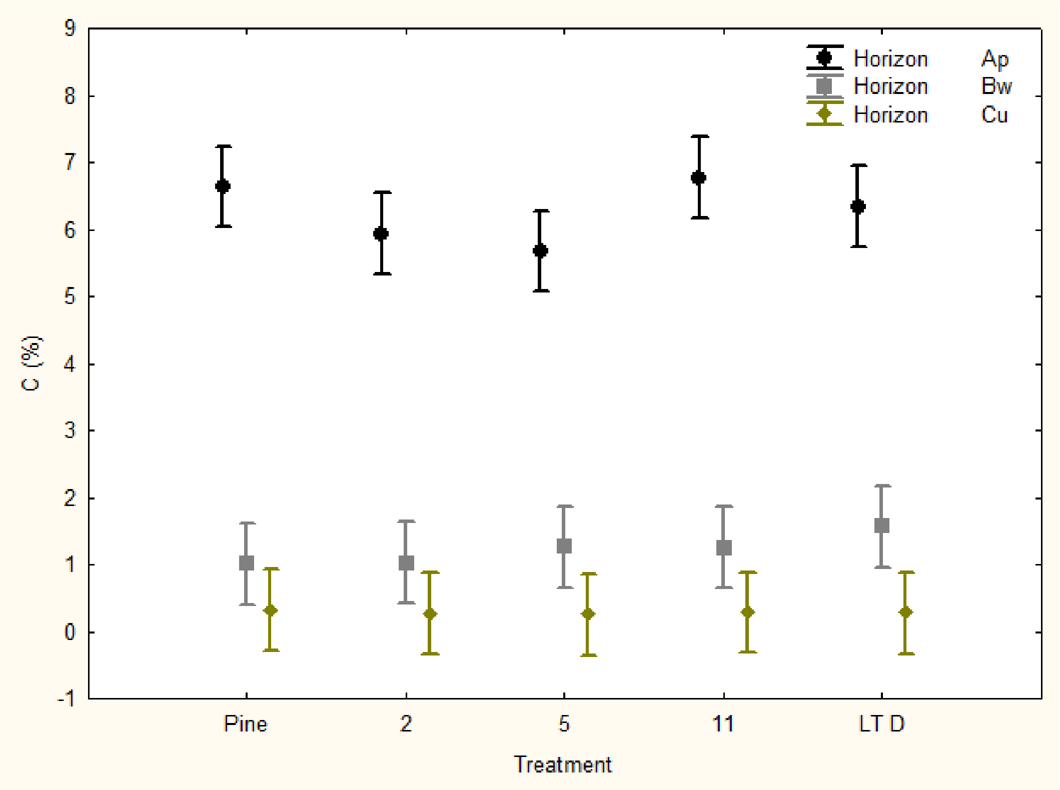

Figure 5.4: Soil carbon percent for the Atiamuri study area. Pine is pine plantation. 2 is 2 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long-term dairy. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

When considering the total carbon in each horizon the 11 years since conversion and long-term dairy sites Ap horizons were higher ($P<0.05$) in carbon content than the pine forest Ap horizon (Figure 5.5). Long-term dairy had a higher ($P<0.05$) carbon content in the Ap horizon than the 5 years since conversion site.

Carbon in the Ap horizon at the Atiamuri study site was variable. The Ap horizon at most sites in the Atiamuri study area was higher ($P<0.05$) than the Bw and Cu horizons, however the pine forest Ap horizon carbon content was not significantly different from its Bw horizon. Carbon in the Bw horizon at the Atiamuri study area remained stable, and did not change much over time. None of the Bw horizons carbon values were significantly different from one another. Cu horizon carbon values were consistent at all sites. There are no significant differences between the carbon content of the Bw and Cu horizons at any of the sites in the Atiamuri study area.

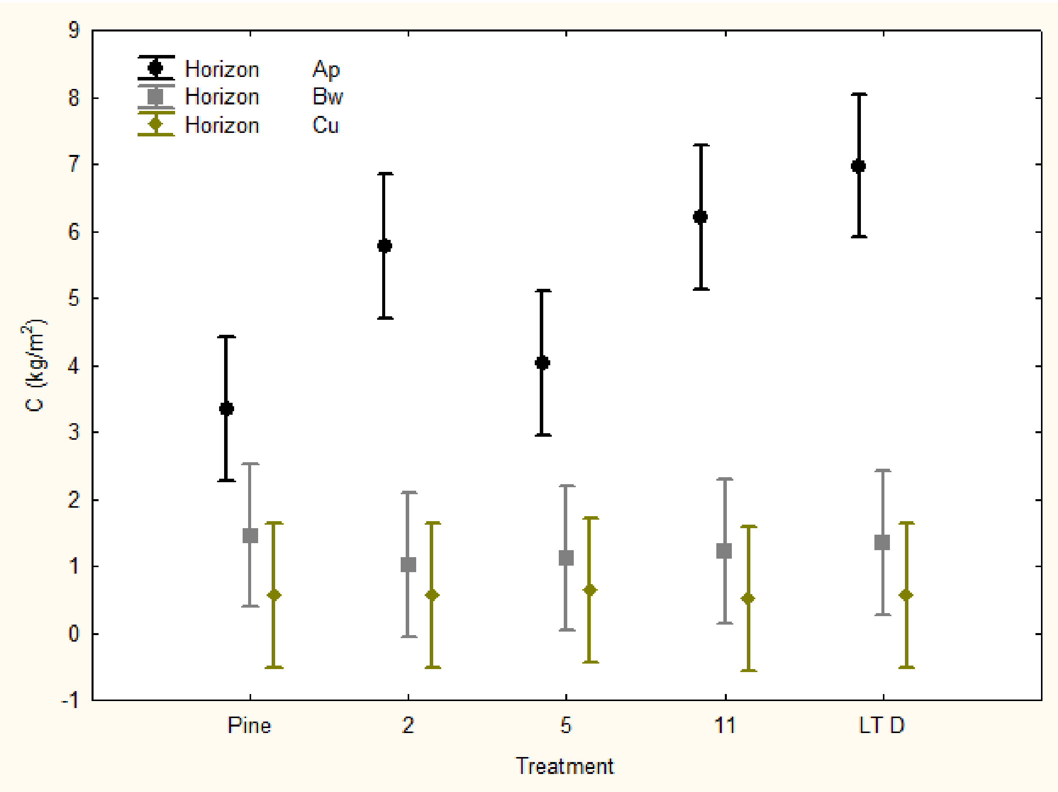

Figure 5.5: Total soil carbon for the Atiamuri study area. Pine is pine plantation. 2 is 2 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long-term dairy. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.3.2 Tokoroa Carbon

The 3 years since conversion site had the lowest carbon % in the Ap horizon in the Tokoroa area which was approximately 6 % and was lower (P<0.05) than all other sites in the area (Figure 5.6). The long-term sheep/beef site had the highest carbon % in the Ap horizon at approximately 9 % and was higher (P<0.05) than the 2 years since conversion and long-term dairy sites. Carbon % in the Bw and Cu horizons did not vary much with time since conversion.

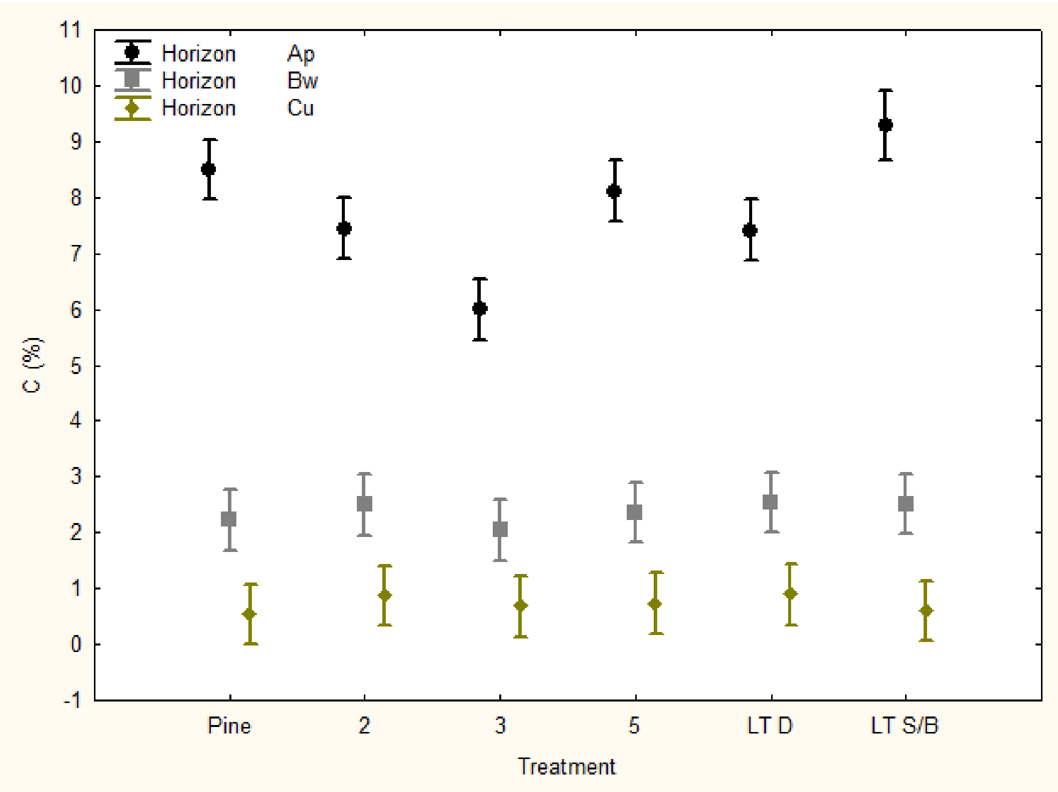

Figure 5.6: Soil carbon percent for the Tokoroa study area. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion. 5 is 5 years since conversion LT Dairy is long-term dairy, LT S/B is long-term sheep/beef. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results (P<0.05).

At Tokoroa the long-term dairy and long-term sheep/beef (C approx. 6 kg/m^2) sites had higher ($P<0.05$) carbon contents in the Ap horizon than the 3 years since conversion (C approx. 4 kg/m^2) site but were not significantly different from pine or other conversion sites (Figure 5.7). The Tokoroa study area had a higher ($P<0.05$) carbon content in its Ap horizon than the Bw and Cu horizons. There were no statistically significant differences between sites in the Bw horizon carbon results. There was a little fluctuation in the Cu horizon carbon content and none of the Cu carbon values were shown to be significantly different from one another. Most of the sites in the Tokoroa area did not show a significant difference in carbon content between the Bw and Cu horizon. The long-term sheep/beef site was the only site with a difference in carbon content between its Bw and Cu horizons.

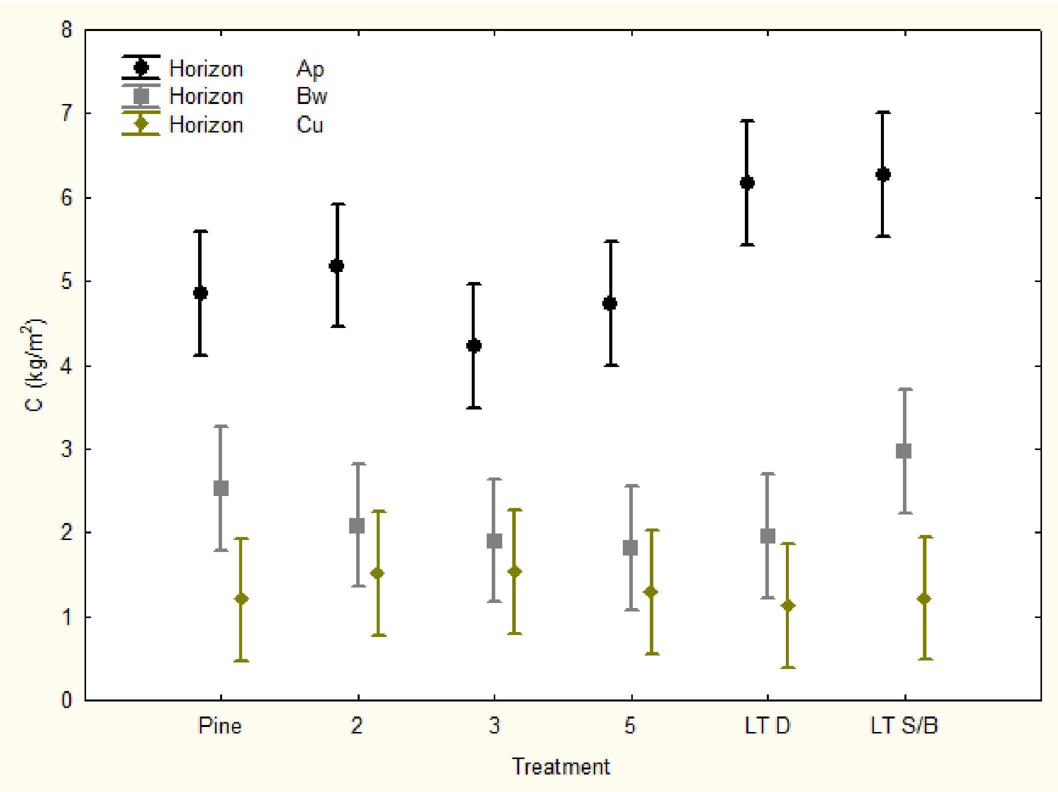

Figure 5.7: Total soil carbon for the Tokoroa study area. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion. 5 is 5 years since conversion LT Dairy is long-term dairy, LT S/B is long-term sheep/beef. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.3.3 Wairakei Carbon

The pine site had the lowest mean Ap horizon carbon % at the Wairakei study area with 5.56 % carbon, while the pine site did have a lower mean carbon % than both the long-term sites which had 6.53 and 7.14 % carbon in the Ap horizon these results were not significantly different from each other (Figure 5.8). The Bw and Cu horizon did not change much with time the Bw horizon ranging from 1.05 to 1.56 % carbon and the Cu ranged from 0.21 to 0.39 % carbon.

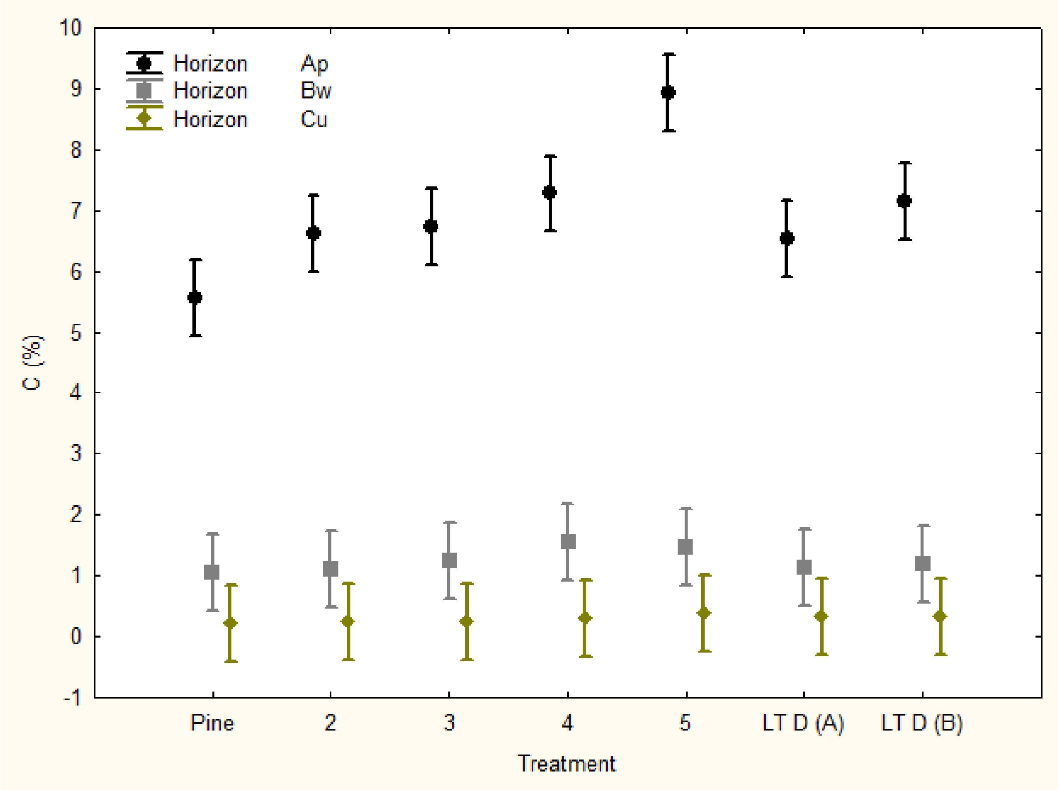

Figure 5.8: Soil carbon percent for the Wairakei study area. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. LT D (A) is long-term dairy (Broderson Farm), LT D (B) is long-term dairy (Feather Farm). Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

Soil carbon in the Ap horizon at the Wairakei study area has increased with treatment from pine through 2, 3, 4, 5 years since conversion to long-term pasture. The pine site had a carbon value of approximately 2.9 kg/m^2 (Figure 5.9). The Ap horizon carbon content of the pine site was lower ($P<0.05$) than the 2, 4 and 5 year since conversion sites, and both the long-term dairy sites (Figure 5.9). Carbon content in the Ap horizon at long-term dairy (A) was approximately 7.0 kg/m^2 which is higher ($P<0.05$) than the 3 years since conversion site. Long-term dairy (B) had the highest carbon content in its Ap horizon with 7.6 kg/m^2. Long-term dairy (B) had a higher ($P<0.05$) Ap horizon carbon content than the pine, 2, 3 and 4 years since conversion. For most of the sites in the Wairakei area Ap horizons have higher carbon contents than the Bw and Cu horizons. The pine forest site Ap horizon is not statistically different from the 5 years since conversion Bw horizon carbon content. Carbon in the Bw horizon did not change much with treatment. There were no significant differences between any of the Bw carbon values. Carbon content in the Cu horizon at Wairakei were consistent with time since conversion.

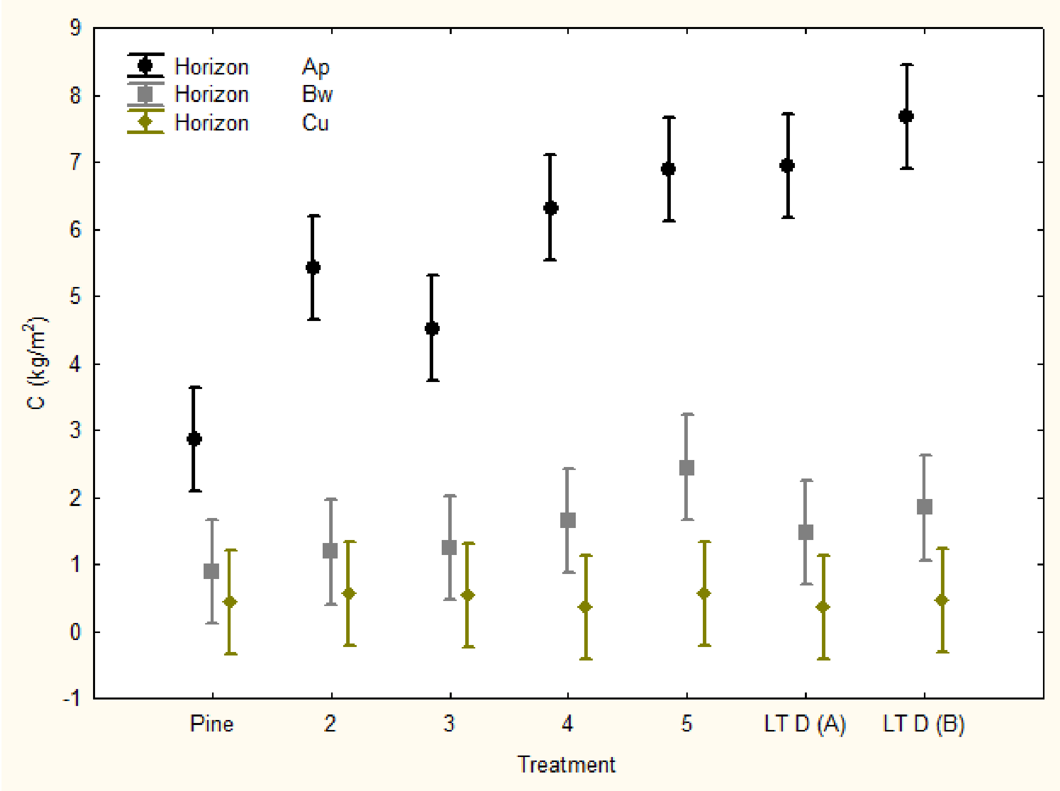

Figure 5.9: Total soil carbon for the Wairakei Study area. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. LT D (A) is long-term dairy (Broderson Farm), LT D (B) is long-term dairy (Feather Farm). Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.4 Nitrogen

5.4.1 Atiamuri Nitrogen

In the Atiamuri area the long-term dairy site had the highest nitrogen % in the Ap horizon with approximately 0.7 %. The long-term dairy Ap horizon nitrogen content was higher (P<0.05) than all other sites in the Atiamuri area (Figure 5.10). The 11 years since conversion had approximately 0.55 % nitrogen in the Ap horizon which was higher (P<0.05) than the pine site. The Bw and Cu horizons nitrogen content was generally consistent between land use sites.

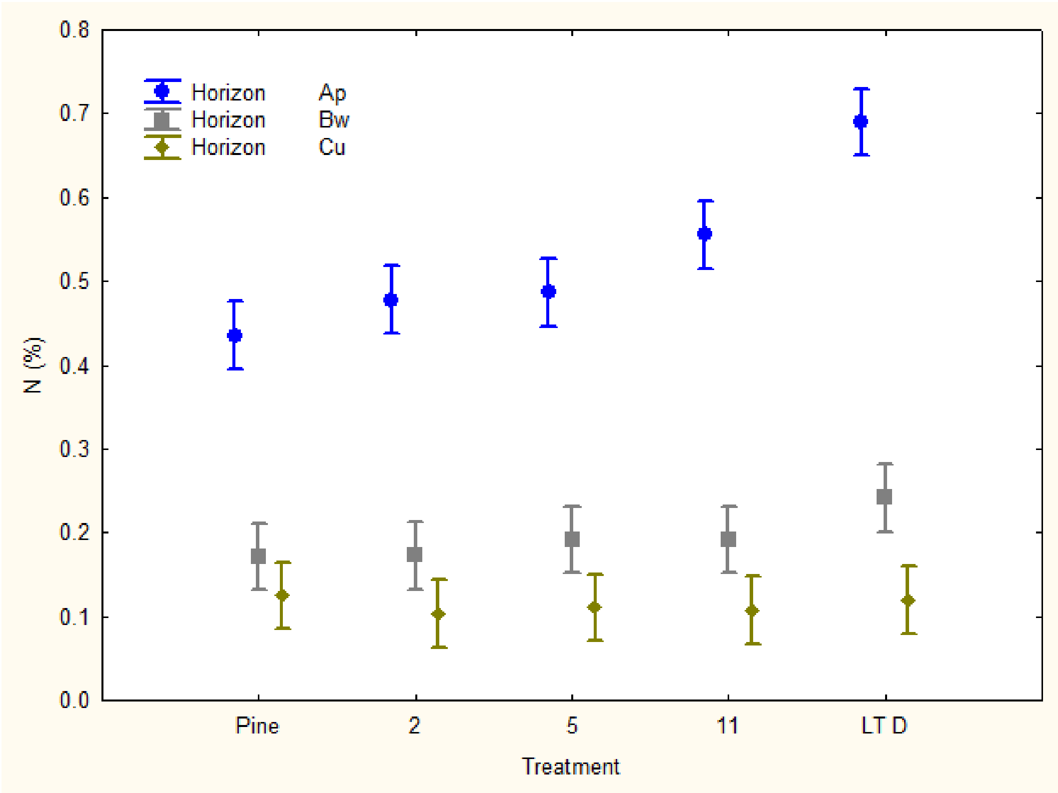

Figure 5.10: Soil nitrogen percent for the Atiamuri study area. Pine is pine plantation. 2 is 2 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long-term dairy. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results (P<0.05).

The 2 and 11 years since conversion sites at Atiamuri had a nitrogen content of approximately 0.45 kg/m^2 in the Ap horizon. The long-term dairy had a nitrogen content of 0.75 kg/m2 in the Ap horizon which was higher ($P<0.05$) than all other sites in the Atiamuri area. The pine site had an Ap horizon nitrogen content of 0.22 kg/m^2 which was lower ($P<0.05$) than the 2 and 5 years since conversion and the long-term dairy sites. The 2, 11 years since conversion and long-term dairy pasture had higher ($P<0.05$) nitrogen content in the Ap than the Bw horizon. There was no difference in nitrogen content between Ap and Bw horizons at the pine and 5 years since conversion sites. Nitrogen in the Bw horizon fluctuated but there was no significant differences between Bw horizon nitrogen values between land use sites. There were no significant differences between Cu horizon nitrogen content between land use sites. Nitrogen in the Bw and Cu horizons at Atiamuri were not statistically different from one another at any of the sites.

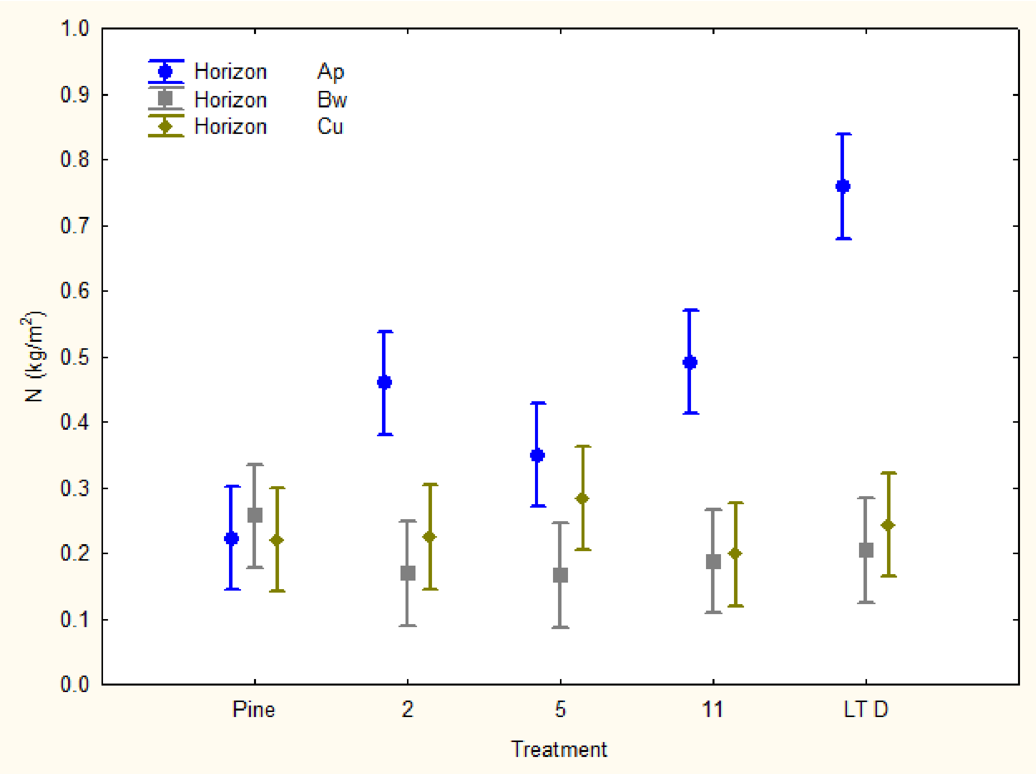

Figure 5.11: Total soil nitrogen for Atiamuri study area. Pine is pine plantation. 2 is 2 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long-term dairy. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.4.2 Tokoroa Nitrogen

In the Tokoroa study area the long-term sheep/beef site had the highest nitrogen % value in the Ap horizon with approximately 0.9 % nitrogen (Figure 5.12). The long-term sheep/beef Ap horizon had a higher nitrogen content than all other sites in the Tokoroa area. The long-term dairy site had the next highest nitrogen % value in the Tokoroa area with approximately 0.7 % nitrogen. The long-term dairy Ap horizon had a higher ($P<0.05$) nitrogen content than the pine and recently converted sites. The lowest nitrogen % value in the Ap horizon was the 3 years since conversion site with approximately 0.4 % nitrogen which was lower ($P<0.05$) than all sites except the 2 years since conversion sites. Nitrogen % values in the Bw and Cu horizons were generally consistent between land use sites.

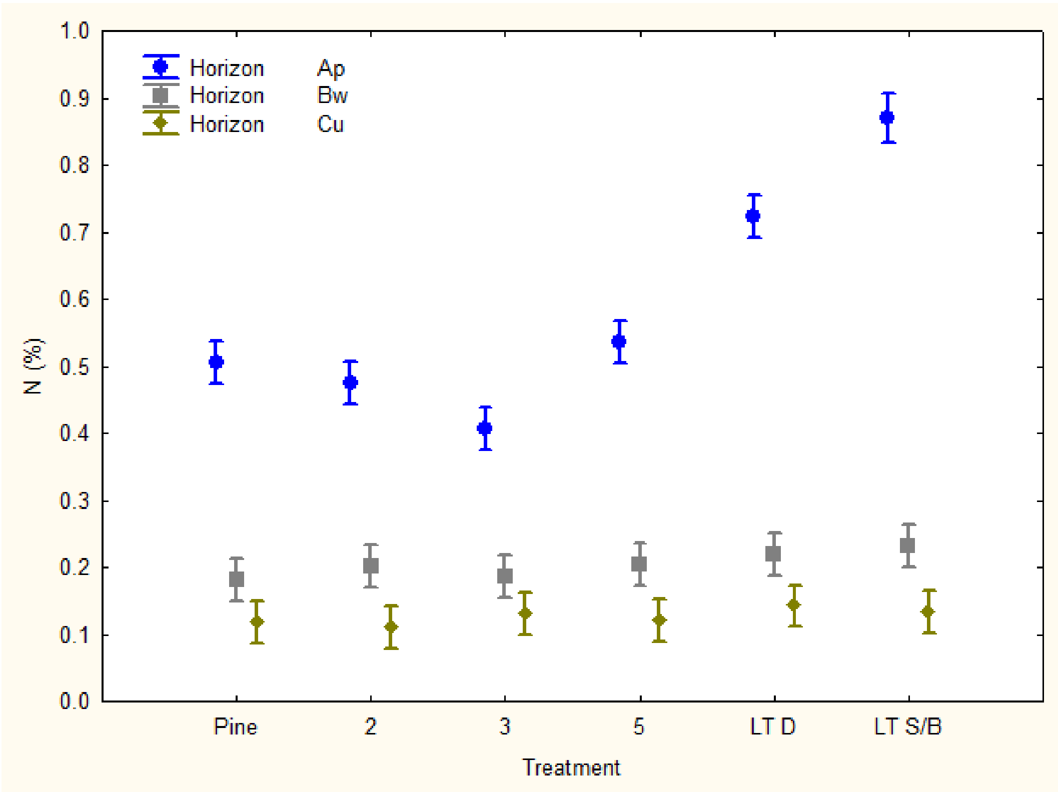

Figure 5.12: Soil nitrogen percent for the Tokoroa study area. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion. 5 is 5 years since conversion LT Dairy is long-term dairy, LT S/B is long-term sheep/beef. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

The long-term dairy and long-term sheep/beef sites had approximately 0.6 kg/m^2 nitrogen in their Ap horizons (Figure 5.13). The long-term dairy and long-term sheep/beef sites had higher (P<0.05) nitrogen content in the Ap horizon than all other sites in the Tokoroa area. There was little difference in nitrogen between the pine and 2 and 3 and 5 years since conversion sites. The long-term dairy and long-term sheep/beef sites had higher (P<0.05) nitrogen content in their Ap horizon than Bw horizon. The Bw and Cu horizons had no significant differences between each other or land use sites.

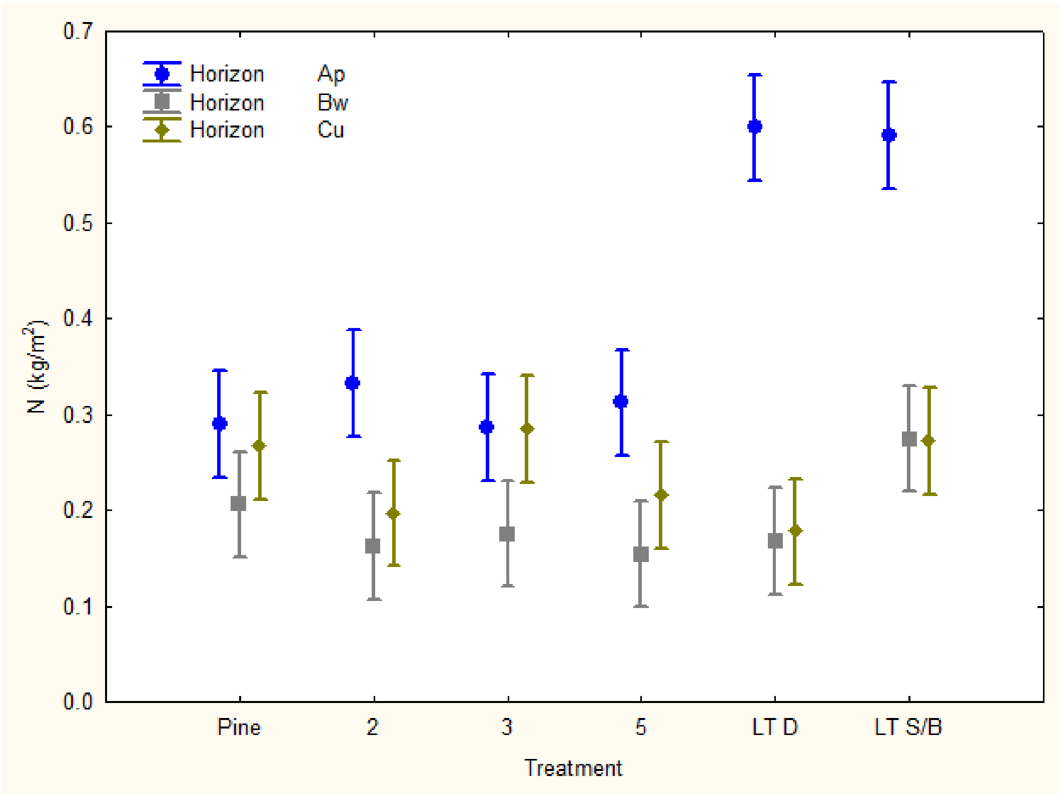

Figure 5.13: Total soil nitrogen for Tokoroa study area. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion. 5 is 5 years since conversion LT Dairy is long-term dairy, LT S/B is long-term sheep/beef. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results (P<0.05).

5.4.3 Wairakei Nitrogen

The long-term dairy (A) and (B) sites had the highest ($P<0.05$) nitrogen % value in the Ap horizon in the Wairakei area with approximately 0.7 % nitrogen. The 4 and 5 years since conversion shared a similar nitrogen % value for the Ap horizon with approximately 0.5 % nitrogen. The 4 and 5 years since conversion sites had higher ($P<0.05$) Ap horizon nitrogen contents than the pine site and 2 and 5 years since conversion sites (Figure 5.14). The Bw and Cu horizons were generally consistent with between land use sites.

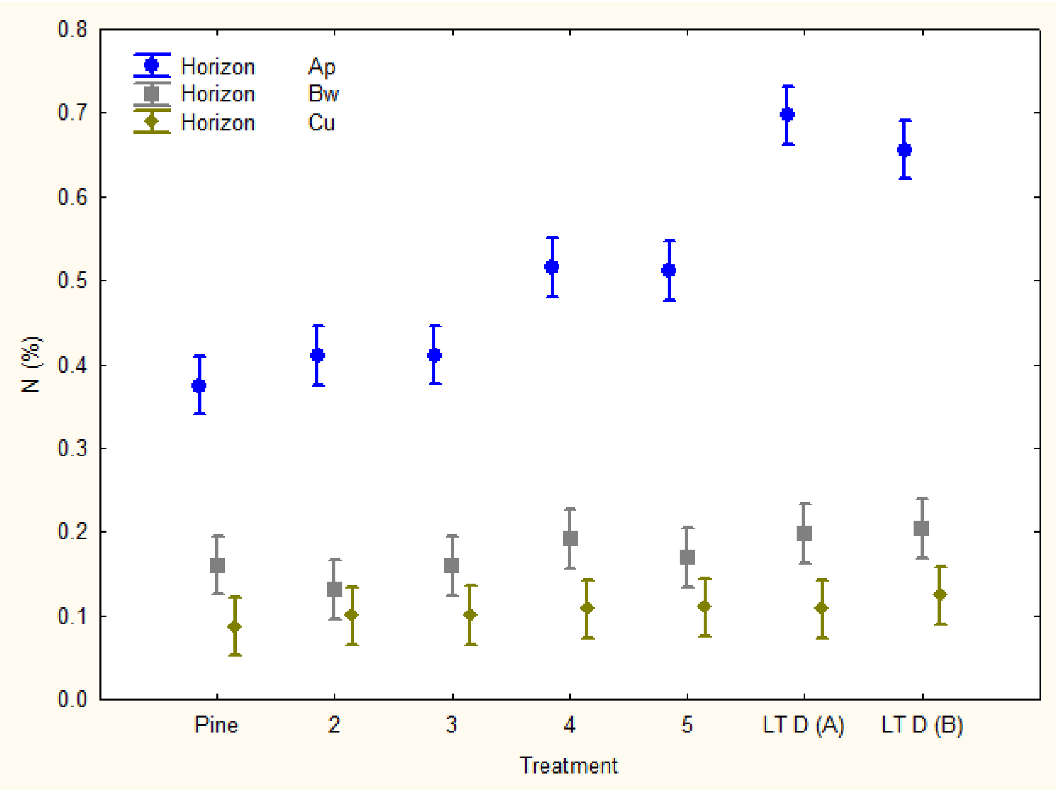

Figure 5.14: Soil nitrogen percent for the Wairakei study area. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. LT D (A) is long-term dairy (Broderson Farm), LT D (B) is long-term dairy (Feather Farm). Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

The pine site at had the lowest (P<0.05) nitrogen content in its Ap horizon with 0.2 % nitrogen (Figure 5.15). The pine site Ap horizon nitrogen content was lower (P<0.05) than the 4 and 5 years since conversion and both long-term dairy sites. The long-term dairy sites had the highest (P<0.05) Ap horizon nitrogen values in the Wairakei study area with long-term dairy (A) having 0.74 g cm^{-2} nitrogen and long-term dairy (B) having 0.71 g cm^{-2} nitrogen. Generally there were no significant differences in Ap horizon nitrogen content in the recently converted sites. The Bw and Cu horizons were generally consistent between land use sites.

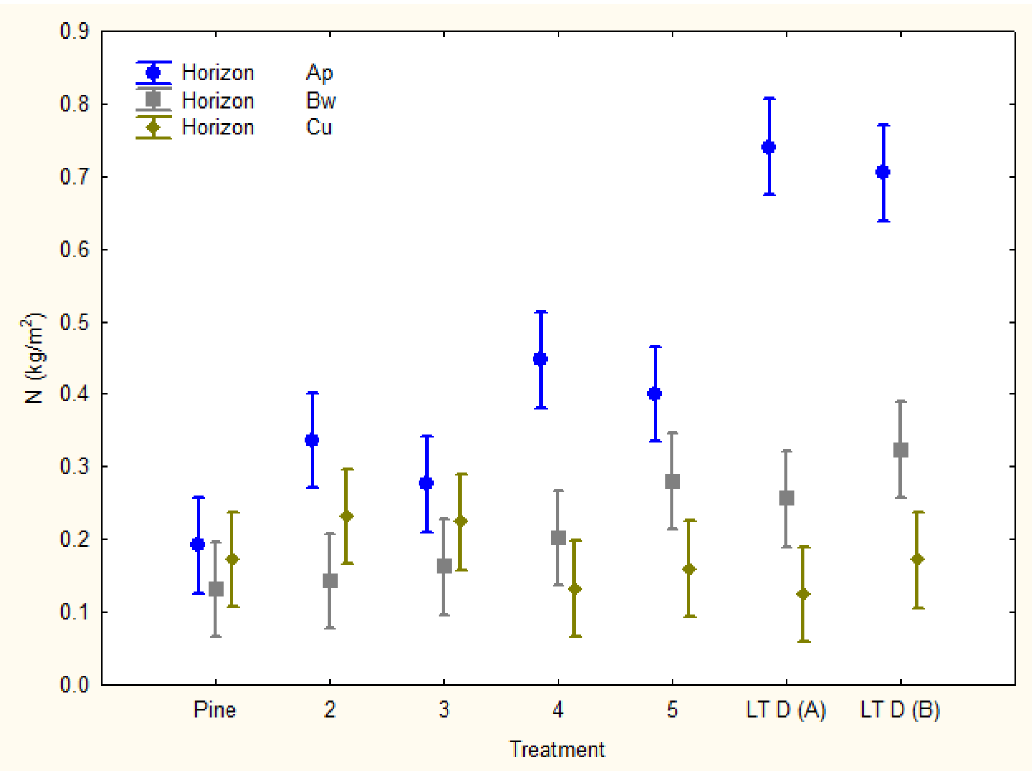

Figure 5.15: Total soil nitrogen for Wairakei study area. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. LT D (A) is long-term dairy (Broderson Farm), LT D (B) is long-term dairy (Feather Farm). Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results (P<0.05).

5.5 C:N

5.5.1 Atiamuri C:N

The C:N ratio at the Atiamuri study area generally decreased with time since conversion (Figure 5.16). Pine had the highest ($P<0.05$) C:N ratio in the Ap horizon with a value of 15. Long-term dairy had the lowest C:N ratio in the Ap horizon with a value of 9 (Figure 5.16). The 2 and 5 and 11 years since conversion sites had no significant differences in the Ap horizon. The long-term dairy site had a lower ($P<0.05$) C:N ratio in the Ap horizon than all other sites in the Atiamuri area. C:N ratio in the Bw horizon did not display much change and there was no significant differences between any of the sites. The Cu horizon C:N did not show much change with time since conversion. The C:N decreased down the soil profile with the highest values in the Ap horizon and lowest in the Cu. The Ap, Bw and Cu horizons were significantly different from one another.

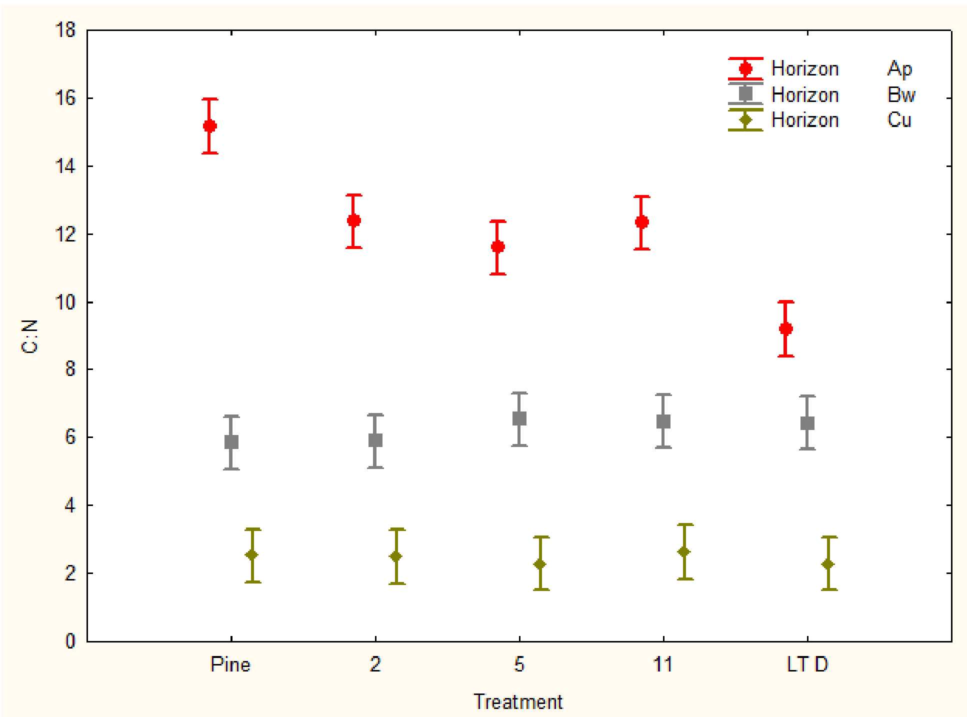

Figure 5.16: C:N ratio for Atiamuri study area. Pine is pine plantation. 2 is 2 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long-term dairy. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.5.2 Tokoroa C:N

Pine had the highest C:N ratio in the Ap horizon with a value of 17 (Figure 5.17). Pine had a higher ($P<0.05$) C:N in the Ap horizon than the long-term dairy and long-term sheep/beef sites. In the Ap horizon pine, and the recently converted sites displayed no significant differences in C:N values between each other. C:N values in the Ap horizon for the long-term dairy and long-term sheep/beef showed no significant difference from one another. Both the long-term dairy and long-term sheep/beef sites had lower ($P<0.05$) C:N values in the Ap horizon than all the other sites in the Tokoroa area. The Bw horizon C:N values were generally consistent between land use sites. The long-term dairy and long-term sheep/beef Ap horizon values were not significantly different from any of the Bw horizon results from any of the sites in the Tokoroa area. The Cu horizon C:N values fluctuated with the highest C:N value being 8 at the 2 years since conversion site. The 2 years since conversion had a higher ($P<0.05$) C:N value in the Cu horizon than the pine site. Other than the pine and 2 years since conversion there were no other significant differences in Cu horizon C:N results.

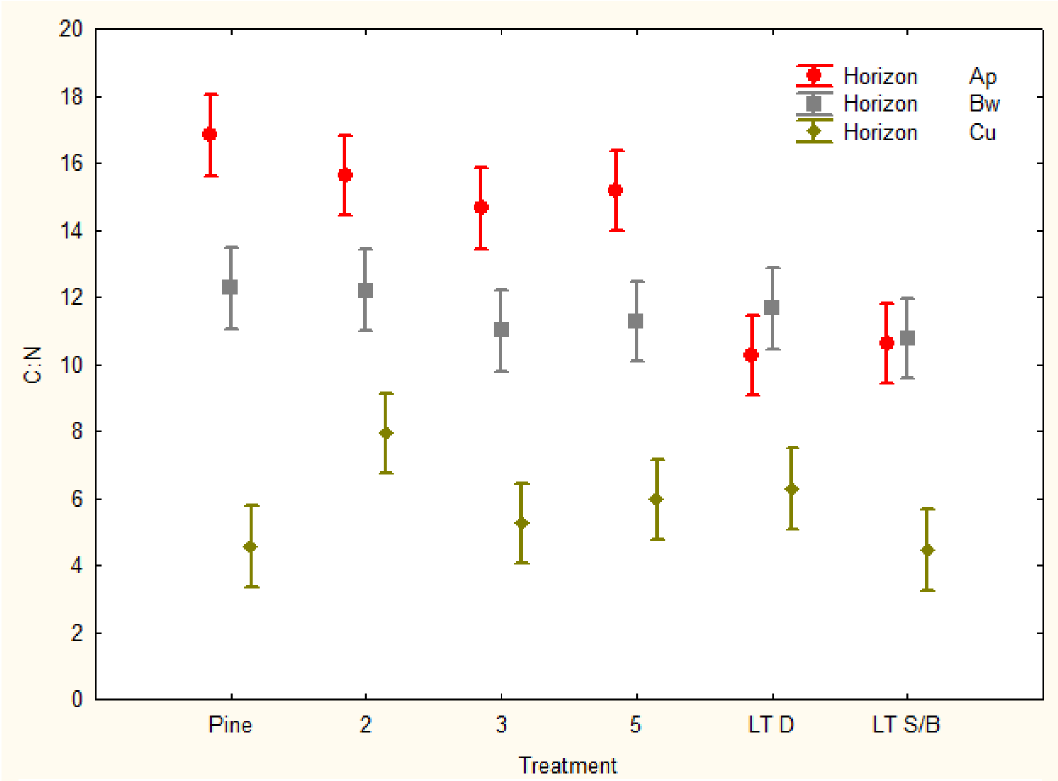

Figure 5.17: C:N ratio for the Tokoroa study area. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion. 5 is 5 years since conversion LT Dairy is long-term dairy, LT S/B is long-term sheep/beef. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results (P<0.05).

5.5.3 Wairakei C:N

Long-term dairy (A) had C:N value of 9.7 in the Ap horizon and long-term dairy (B) had a C:N value of 10.4 for the Ap horizon (Figure 5.18). Long-term dairy (A) and long-term dairy (B) C:N values for the Ap horizon were not significantly different. Long-term dairy (A) and long-term dairy (B) had lower (P<0.05) C:N values in the Ap horizon than all other sites in the Wairakei area. The 5 years since conversion had a C:N value of 17 which was the highest in the Wairakei area. The 5 years since conversion had a higher (P<0.05) C:N value in the Ap horizon than the 4 years since conversion site. In the Ap horizon there was no significant (P<0.05) difference between the pine and 2 and 3 and 4 years since conversion sites (Figure 5.18). There is no significant differences between the C:N values in the Bw horizon in the Wairakei study area. The Cu horizon C:N values were generally consistent between land use sites.

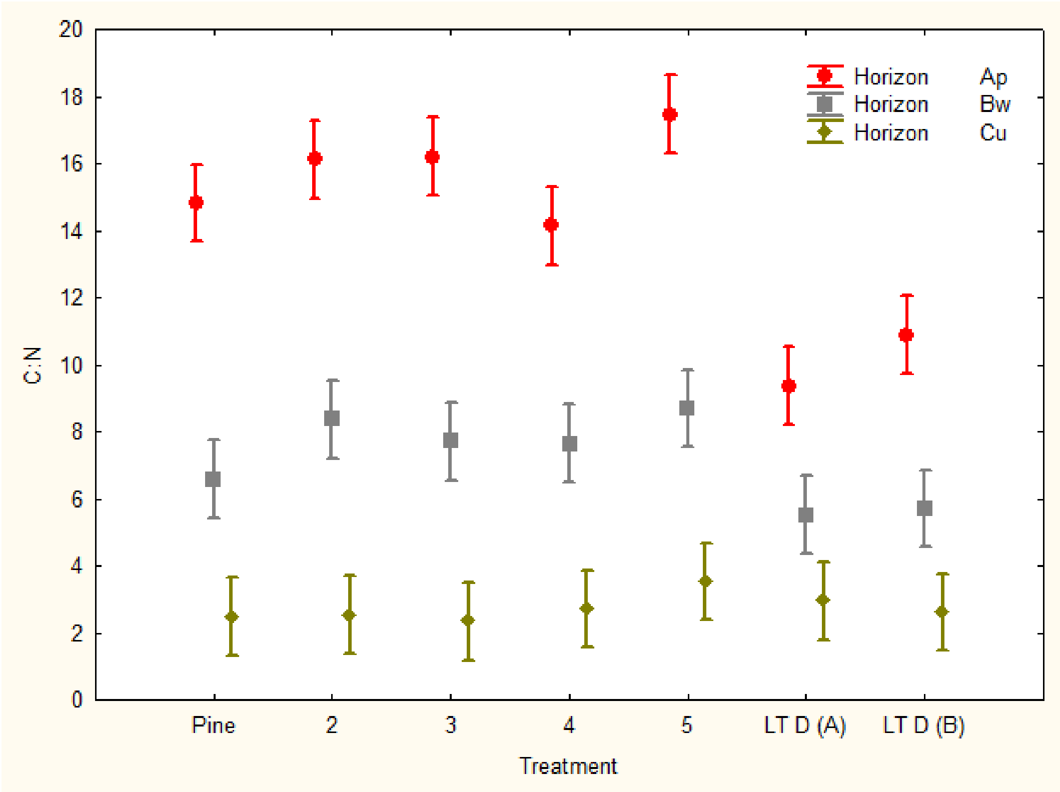

Figure 5.18: C:N ratio for Wairakei study area. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. LT D (A) is long-term dairy (Broderson Farm), LT D (B) is long-term dairy (Feather Farm). Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.6 Total Soil Carbon & Nitrogen

5.6.1 Total Soil Carbon

Total soil carbon was highest in the long-term sheep/beef site at Tokoroa with approximately 105 t/ha carbon. The Tokoroa pine site had the highest ($P<0.05$) soil carbon for pine with approximately 85 t/ha carbon. Atiamuri and Wairakei had similar total carbon results for the 2 years since conversion site with approximately 73 t/ha carbon with Tokoroa 2 years since conversion showing no significant difference with 88 t/ha carbon (Figure 5.19). All of the long-term sites total carbon results at around 90 t/ha carbon (Figure 5.19). All long term sites hd higher ($P<0.05$) total carbon than the Atiamuri and Wairakei pine sites. The Tokoroa pine site had a total carbon value of approximately 85 t/ha which was not significantly different from the long term sites. Wairakei 5 years since conversion had a higher ($P<0.05$) carbon content at 100 t/ha carbon than Atiamuri 5 years since conversion with 55 t/ha carbon. The Wairakei area recently converted sites all had approximately 70 t/ha carbon or higher. Most of the recently converted sites along with the long-term sites at Wairakei had a higher ($P<0.05$) total carbon value than the pine site. The Atiamuri long-term dairy site had a total carbon value of 88 t/ha. The Atiamuri pine site had a total carbon value of 54 t/ha. Atiamuri long-term dairy site had higher ($P<0.05$) total carbon than the Atiamuri pine site. None of the sites at Tokoroa were significantly different from one another.

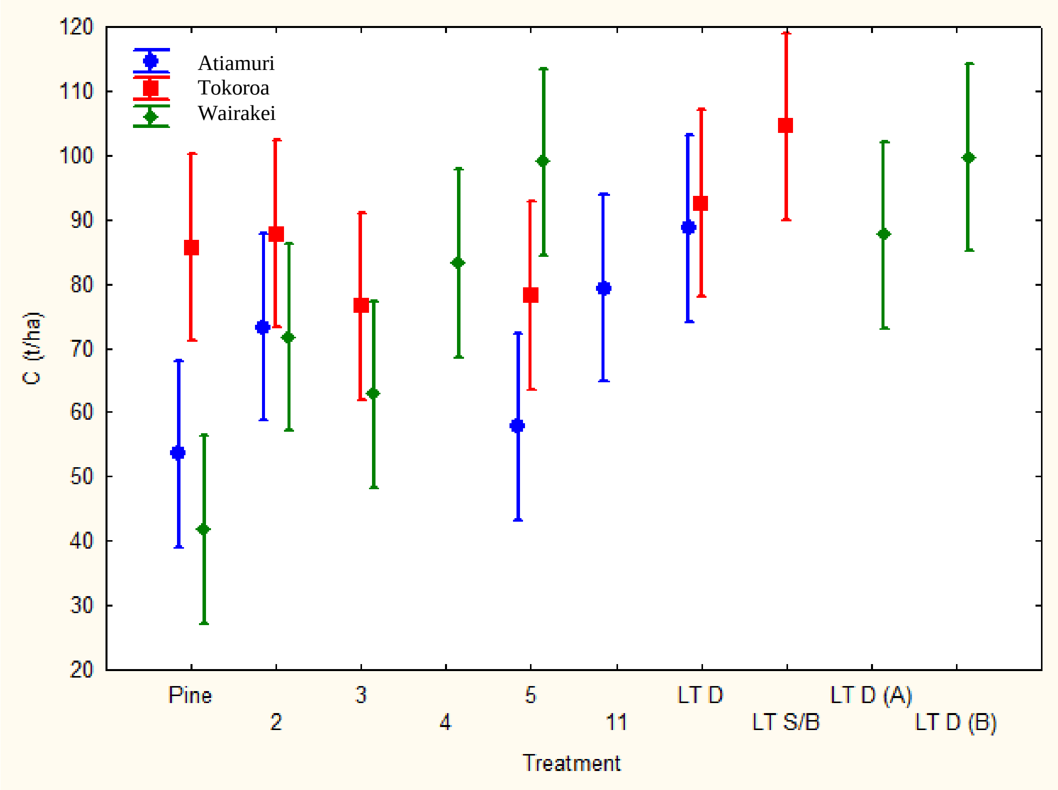

Figure 5.19: Total soil carbon to a depth of 60 cm for Atiamuri, Tokoroa and Wairakei. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long term dairy for the Atiamuri and Tokoroa study areas. LT S/B is long-term sheep/beef at Tokoroa. LT D (A) is the long-term dairy (Broderson Farm) at Wairakei. LT D (B) is the long-term dairy (Feather Farm) at Wairakei. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results ($P<0.05$).

5.6.2 Total Soil Nitrogen

The long-term dairy site at Atiamuri, the long-term sheep/beef at Tokoroa and both of the long-term dairy sites at Wairakei all have higher ($P<0.05$) total soil nitrogen at approximately 12 t/ha nitrogen than the three pine sites which ranged from approximately 5 to 7.5 t/ha nitrogen (Figure 5.20). The Wairakei pine site had the lowest total nitrogen with 5 t/ha nitrogen which was lower ($P<0.05$) than many of the recently converted site as well as the Tokoroa pine site which had approximately 7.5 t/ha nitrogen. The long-term dairy site in the Atiamuri area had the highest nitrogen content with approximately 12 t/ha which was higher (P<0.05) all of the recently converted sites, all pine sites and the Tokoroa long-term dairy site which had approximately 9.5 t/ha nitrogen. Soil total nitrogen in the recently converted sites did not vary much ranging between approximately 6.5 to 8.5 t/ha nitrogen.

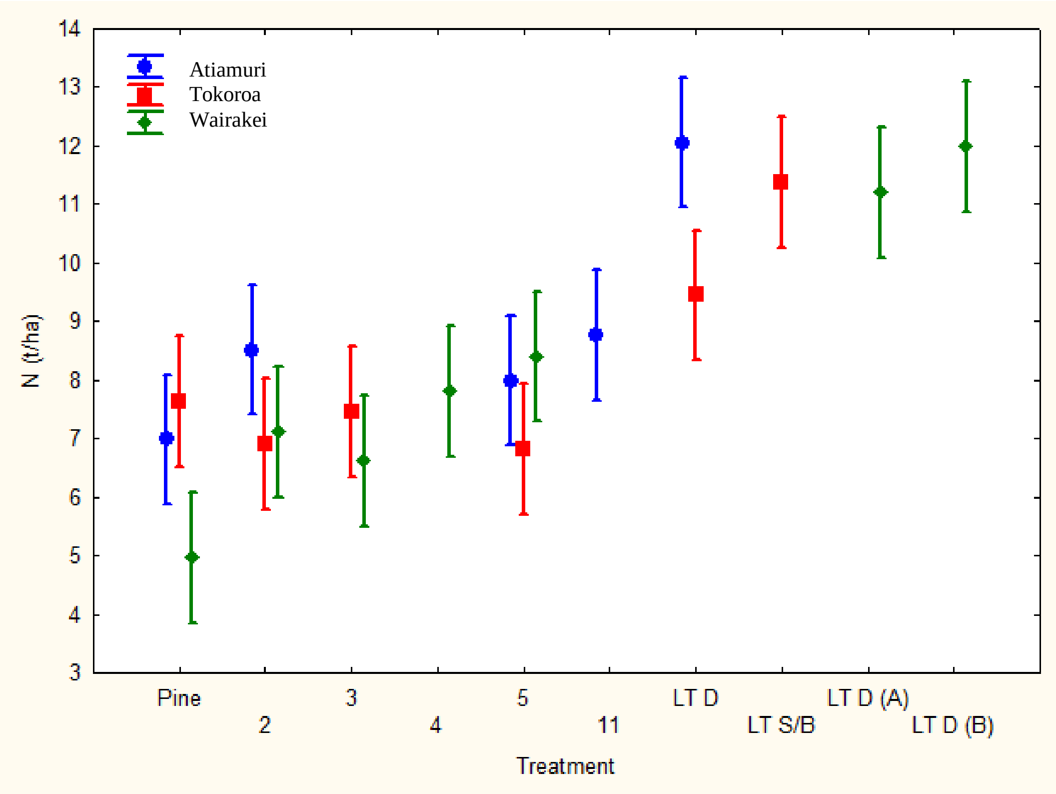

Figure 5.20: Total soil nitrogen to a depth of 60 cm for Atiamuri, Tokoroa and Wairakei. Pine is pine plantation. 2 is 2 years since conversion site. 3 is 3 years since conversion site. 4 is 4 years since conversion site. 5 is 5 years since conversion site. 11 is 11 years since conversion site. LT D is long term dairy for the Atiamuri and Tokoroa study areas. LT S/B is long-term sheep/beef at Tokoroa. LT D (A) is the long-term dairy (Broderson Farm) at Wairakei. LT D (B) is the long-term dairy (Feather Farm) at Wairakei. Error bars are 95% simultaneous confidence intervals. If error bars overlap there is no significant difference between results (P<0.05).

Chapter 6.
Discussion, Conclusion & Recommendations

6.1 Introduction & Summary of Key Points

The purpose of my study was to determine whether there is a change in the carbon and nitrogen pools in soils in the Central North Island with land use change of plantation forest to dairy pasture. In this chapter I discuss the findings and implications.

Three study sites (Atiamuri, Tokoroa and Wairakei) were chosen in the central North Island. Sites ranging from pine plantations through dairy pastures 2, 3, 4, 5 and 11 years since conversion and long-term (>40 years) dairy or sheep/beef pastures were identified in the three study areas. At each site soil samples were taken, along with bulk density samples. Soil samples were analysed for total carbon and nitrogen using a TruSpec CN Carbon/Nitrogen Determinator (LECO furnace).

6.2 Discussion of Soil Profile Results

6.2.1 Soil Horizon Depths

Soil horizon depths at all three study areas did not vary significantly between treatments. Soil profiles for the pine and recently converted sites in all three study areas had been previously disturbed, during pine harvest, forest planting and on conversion to pasture. Despite how much disturbance the sites have had the Ap horizon depth for the pine and recently converted sites did not differ significantly from the long-term pastures.

6.3 Findings and Discussion of Soil Carbon Results

6.3.1 Trends in Soil Carbon

At the Atiamuri and Wairakei study areas the carbon content in the Ap horizon was significantly ($P<0.05$) lower in the pine than the long-term pasture sites, however there were no significant differences in carbon content between the pine and the long-term pasture sites at the Tokoroa area. Higher soil carbon content in long-term pasture than in pine suggest that carbon can accumulate with time once land is converted to pasture. In some cases there is too much variability in the measurements to determine any differences.

Many studies of change in soil carbon following land use change report an increase in soil carbon with a change from forest to pasture (de Moraes *et al*., 1996; Fearnside & Barbosa, 1998; Battle-Bayer *et al*., 2010). My results show that in some cases long term pastures have higher carbon content than pine plantations meaning there is a possibility of accumulation of carbon in soils. However the recently converted sites were variable with no short-term pattern of accumulation evident.

Hedley *et al.* (2009) reported that carbon accumulated under pastures which have been converted from pine to dairy pasture in the Atiamuri and Tokoroa study areas. Not all of the long-term sites (>25 years since conversion) in Hedley *et al*. (2009) had higher carbon content than the 5 years since conversion sites. Hedley *et al.* (2009) reported higher ($P<0.05$) carbon content in the long-term pasture (26.4 t/ha carbon to a depth of 15 cm) than 1 year since conversion (16.9 t/ha carbon to a depth of 15 cm).

My study did not include any 1 year since conversion sites however my pine site at Atiamuri had a carbon content of 55 t/ha which was to a depth of 13.1 cm. My long-term pasture site at Atiamuri had approximately 90 t/ha carbon to 16.9 cm depth. For the 5 years since conversion sites Hedley *et al.* (2009) reported 72.9 t/ha carbon at Atiamuri to 7.5 cm depth. For the 15 cm sampling depth Hedley *et al*. (2009) reported carbon values of 29.6 t/ha at Atiamuri 5 years since conversion site. My results for the 5 years since conversion sites showed that to a depth of 14.8 cm Atiamuri had approximately 57.7 t/ha carbon, Tokoroa 47 t/ha carbon to 10.1 cm depth and Wairakei 69 t/ha carbon to 13.7 cm depth. My results have higher carbon content than Hedley *et al*. (2009) probably due to my sampling being by horizon depth, I used the fine earth fraction instead of bulk density when calculating results and I took my bulk density/fine earth fraction and carbon/nitrogen samples from each of the soil horizons I encountered during sampling. My study used an average of soil horizon depths, where as Hedley used two set depths of 0 – 7.5 cm and 0 – 15 cm. By using a set depth there is potential to get mixing of soil horizons with different carbon content. My A horizon depth measurements showed a mean of 14 cm. Hedley *et al*. (2009) depth was more or less comparable with my A horizon samples. While neither Hedley *et al*. (2009) nor my study show an obvious pattern of accumulation of carbon over time we do both show than long-term pastures have significantly higher carbon content that recently converted sites.

Results from Sparling & Schipper (2004) suggested that soil under long-term pasture had higher carbon content than soils under pine plantation. Sparling & Schipper (2004) found that soil under pine plantation had an average carbon content of 46.4 t/ ha to 10 cm depth, my results ranged from approximately 42 t/ha at Wairakei and 86 t/ha carbon at Tokoroa under pine forest to a depth of 60 cm. Differences in carbon between study areas can be attributed to a combination of factors. Soil horizon depths were different between study areas due to land management practices and natural variability. Soil dry bulk density was often different between study areas. The amount of coarse pumice material in each horizon differed between sites.

In the pine forest sites and recently converted pasture sites there was often wood and charcoal present in the Ap horizon. The wood and charcoal in the Ap horizon could have potentially influenced the total carbon percent and total nitrogen percent given by analysis of soil samples. The sometimes subtle differences in the soil horizon depth, dry bulk density, course fragments present, and carbon content of soil lead to the differences between study areas once total soil carbon was calculated. Long-term dairy pastures in the Sparling & Schipper (2004) study had an average of 66.9 t/ha carbon to a depth of 10 cm. The long-term dairy pastures results my study produced were all around 90 t/ha carbon over a 60 cm depth. Although the carbon values in my study were higher and more variable than those of Sparling & Schipper (2004), we do see the same increase in carbon with significantly more carbon in the long-term pastures than in pine plantations at two of my three study areas.

The New Zealand Soil Bureau (1968) reported a percent carbon value in the A horizon of the Taupo Soil of 10.1 % which was much higher than any of the sites I sampled. My highest percent carbon result was the long-term sheep/beef at Tokoroa with 9 % carbon in the Ap horizon. The B horizon result for the Taupo Soil the New Zealand Soil Bureau (1968) reported is 1.4 % carbon. My results range between 1 to 2 % carbon at all my sites which is a similar result to that of the New Zealand Soil Bureau. The New Zealand Soil Bureau (1968) reported 0.6 % carbon in the C horizon of the Taupo Soil they sampled. My Cu horizon results are between 0.2 and 0.6 % carbon which is a similar result to the New Zealand Soil Bureau (1968) report. The difference between my results for A horizon and the New Zealand Soil Bureau (1968) is most likely due to the land use differences. The New Zealand Soil Bureau (1968) took samples from land which was still under native vegetation (tussock, bracken fern, mingi mingi) and was likely to have been almost unaltered due to human activity. The sites I sampled where either currently used as pine plantation (pine trees, blackberry) or were pastures (mostly rye grass, clover).

6.3.2 Variability in Carbon Data

The variability in soil carbon values was mainly in the recently converted sites. The recently converted sites were highly disturbed through the process of removing pine trees and preparing land for conversion. Variability in the carbon content of the soils could be due to the natural variation in the soils. The pine sites have had soil disturbed during the preparation and planting of pine trees on bulldozed rows that were about 0.5 m higher than intervening hollows. Harvesting which has the potential to create scalped areas with shallow Ap horizons, as well as potential of over-thickening of Ap horizons in other areas. Similar scalping and over thickening could occur in the recently converted pasture sites through the methods used to prepare land for pasture. All of the recent pasture conversions had soil disturbance when land was prepared for pasture through the removal of pine trees and landscaping. Many of the recently converted pastures had logs and branches bulldozed into windrows and slash heaps, which can potentially scalp the soil surface horizons. Bulk density and fine earth fraction results would have likely been affected by the disturbance of the soil during the pasture establishment process. The main variability in the bulk densities and fine earth fractions can be seen in the Ap horizon which would have had the greatest disturbance. The Bw and Cu horizons do not show much evidence for disturbance during conversion from pine to pasture. The Bw and Cu horizons had few significant differences between sites or study areas.

6.4 Nitrogen

6.4.1 Trends in Soil Nitrogen

The long-term pastures had higher ($P<0.05$) soil nitrogen content than the pine sites. Soil nitrogen was less variable than carbon at all the study areas. Not all of the recently converted sites showed a significant difference in soil nitrogen from pine. The Atiamuri 2 and 11 years since conversion sites had higher ($P<0.05$) soil nitrogen in the Ap horizon than pine, however there was no significant difference in soil nitrogen to a depth of 60 cm. Nitrogen content in the pine site at Wairakei was lower ($P<0.05$) than the 2, 4 and 5 years since conversion sites at Wairakei. Changes in land use of pine forest to pasture means a change in plant species and land management practices. Pasture management usually encourages the growth of legume species such as clover, while forest management may not (Vitousek *et al*., 1997b). All of the pastoral sites sampled during this investigation have had nitrogen fertilisers applied regularly as part of farm management. Most pine plantations do not receive regular nitrogen fertilisation. Nitrogen fertilisation coupled with the increase in nitrogen fixation by plants is probably the reason for an increase in soil nitrogen content under pasture when compared with pine forest.

Hedley *et al*. (2009) found a significant increase in soil nitrogen from the 1 year since conversion (2.1 t/ha nitrogen to 7.5 cm depth) to the 5 years since conversion site (4.8 t/h nitrogen to 7.5 cm depth) and an increase from the 5 years since conversion to the long-term pasture site (6.6 t/ha nitrogen to 7.5 cm depth) they sampled at Atiamuri. I found the pine site at Atiamuri had lower ($P<0.05$) nitrogen content with approximately 0.22 kg/m^2 in the Ap horizon while the 2 and 11 years since conversions both had approximately 0.48 kg/m^2 in the Ap horizon.

Between the 2 and 11 years since conversion sites there was no significant difference in nitrogen in the Ap horizon. Nitrogen in the Ap horizon at Atiamuri was significantly higher for the long-term dairy site than the other sites in the Atiamuri study area. The long-term dairy site has higher ($P<0.05$) total soil nitrogen than any other site in the Atiamuri area with approximately 12 t/ha nitrogen. The Tokoroa long-term sheep/beef and the Wairakei long-term dairy (A) both have approximately 11.4 t/ha total nitrogen and are not significantly different from the Atimuri long-term dairy site. The long-term dairy (B) site at Wairakei has approximately 11.8 t/ha total nitrogen and is not significantly different from Atiamuri long-term dairy, Tokoroa long-term sheep/beef or Wairakei long-term dairy (A). There were no significant differences between pine and any of the recently converted sites. At Tokoroa Hedley *et al.* (2009) reported an increase in nitrogen for the 7.5 cm sample depth 4.5 t/ha nitrogen at the 3 years since conversion site compared to 7.5 t/ha at the long-term pasture site. My results for Tokoroa did not show a significant difference between the 3 years since conversion and the long-term dairy for total soil nitrogen, however I did find a significant increase in nitrogen from 7.5 t/ha at the 3 years since conversion site to 11.3 t/ha at the long-term sheep and beef site. I had higher total nitrogen at my sites than Hedley *et al.* (2009) found for comparable sites at Tokoroa.

The New Zealand Soil Bureau (1968) reported nitrogen in the A horizon of 0.52 %. My results for the Ap horizon for the pine sites ranged from 0.39 to 0.5 % nitrogen which is a similar result to the New Zealand Soil Bureau (1968). Most of my other treatments had higher percent nitrogen results in the A horizon than the New Zealand Soil Bureau (1968) results. The pasture sites I sampled probably have higher percent nitrogen values due to higher nitrogen inputs through leguminous plant species (clover) and through the use of nitrogen fertilisers by farmers. Sites sampled by the New Zealand Soil Bureau (1968) had little or no nitrogen input through leguminous plant species, and most likely had no nitrogen fertiliser applied to the land.

6.5 C:N ratio

The C:N ratios at Atiamuri, Tokoroa and Wairakei decreased with time since conversion, pine had the highest C:N ratio in the Ap horizon with 15 for both Atiamuri and Wairakei and 17 at Tokoroa. The long-term sites had the lowest C:N ratio in the Ap horizon with 9 at Atiamuri long-term dairy, approximately 10.5 for the Tokoroa long-term dairy and long-term sheep/beef and 9.5 for Wairakei long-term dairy (A) and 11 for Wairakei long-term sheep/beef. The C:N ratio differences reflect the higher nitrogen contents at the long-term pasture sites. Hedley *et al.* (2009) found that the C:N ratio declined with time since conversion. For the 7.5 cm sampling depth at Atiamuri Hedley *et al.* (2009) found C:N of 17.9 at their 1 year since conversion site declining to 14.8 at the 5 years since conversion site with a further decline to 10.6 in their long-term pasture site. Hedley *et al.* (2009) found a similar decrease in C:N ratio at Tokoroa with a C:N value of 15.2 for the 7.5 cm sampling depth in the 3 years since conversion site declining to 11.1 for the 7.5 cm sampling depth in the long-term pasture. Sparling & Schipper (2004) found significantly higher C:N ratio in pine plantation with a C:N value of 15.5 than in long-term pasture with C:N of 11.3. My results show a similar pattern of a decrease in C:N ratio with time since conversion in the Ap horizon.

6.6 Experimental Limitations

Random sampling was not appropriate as a part of my experiment. Sites and sampling transects were selected to ensure that all sites sampled were on the same landscape unit. Sites near roads, gates, troughs and debris piles were avoided. Selecting “ideal” sites may have added some bias to my experiment; however due to time limitations random sampling was not an effective sampling design.

The soil sample taken for carbon/nitrogen analysis was small in comparison to the overall soil sample size taken from the field. Approximately 10 g of sub-sample was taken from each of the pit scrape and soil core samples. The sub-sample taken by splitting the sample with a riffle to ensure a random sub-sample of soil was taken. Although the soil samples were homogenised through sieving and a random sample taken through splitting, there is still a high chance that sub-samples were not representative of the average carbon/nitrogen value. Taking replicate sub-samples of a soil sample would have given information about how consistent or representative the sub-samples were. The analytical cost precluded use of replicate sub-samples.

Many carbon and nitrogen studies sample by depth rather than horizon (de Moraes *et al*., 1996; Fearnside & Barbosa, 1998; Sparling & Schipper, 2004; Hedley *et al*., 2009; Battle-Bayer *et al*., 2010). Sampling by depth ensures that no matter the site samples are taken at the same depth. Sampling by depth can cause complication when an overlying horizon is mixed with an underlying horizon, which could potentially alter carbon concentration for a sample. I sampled by soil horizon in order to obtain a carbon and nitrogen content that was not biased due to mixing of soil horizons. In order to sample by horizon depth of every horizon in each core taken was recorded. For soil horizons with similar properties the person dividing a core into its constituent horizons had to be careful to ensure consistent determination of horizon boundaries. In order to remove some of the bias caused by the division of soil horizons the same person chose the division for all soil cores for a site.

6.7 Conclusions

- There were no significant differences in Ap horizon depths between pine forest, recently converted or long-term pasture sites at any of the study areas
- Soil dry bulk density in Ap horizons was lower ($P<0.05$) in pine plantation sites (0.47 to 0.54 g cm^{-3}) than the other sites (0.59 to 0.76 g cm^{-3}) at each study area.
- Carbon concentration in the Ap horizon (5.5 to 9 %) showed few significant differences between land-use sites and no clear trend with time since conversion of forest to pasture.
- Total carbon in the profile to a depth of 60 cm at the Atiamuri and Wairakei study areas was lower ($P<0.05$) in the pine (42 to 54 t/ha) than in long-term pastures (88 to 100 t/ha) which reflects the lower bulk density in the pine sites. There were no important significant differences in soil

carbon to a depth of 60 cm between the pine plantation sites at the Tokoroa study area.

- There were no significant differences in total carbon in the Bw (mean of 1.7 kg/m^2) or Cu horizons (mean of 0.78 kg/m^2) between sites or study areas.
- Total nitrogen to a depth of 60 cm was lower ($P<0.05$) in pine sites (5 to 8 t/ha) than the long-term dairy or sheep/beef sites (9 to 12 t/ha).
- Nitrogen concentration in the Ap horizon was lower ($P<0.05$) in pine (mean of 0.44 %) than in long-term pasture sites (mean of 0.73 %).
- There were no important significant differences in nitrogen in the Bw (mean of 1.2 kg/m^2) or Cu (mean of 0.68 kg/m^2) horizons between sites or study areas.
- The C:N ratio in the Ap horizon at all study areas was higher ($P<0.05$) in the pine (mean = 16) than in the long-term pasture sites (mean = 10) reflecting the higher nitrogen in the long-pasture sites.
- A limitation of this study was that at all of the pine plantation and recently converted pasture sites charcoal and wood was present, causing highly variable results for carbon, nitrogen and soil dry bulk density.

6.8 Recommendations

In order to better understand the rate of accumulation of carbon and nitrogen in soil with change in land use from pine plantation to pasture going back to the same sites I sampled in 2 to 5 years and re-sampling: Re-sampling and testing of the sites I used would help to build up a carbon and nitrogen time series for each site. The time series data may allow for determination of the rate of accumulation of carbon and nitrogen over time with land use change of pine forest to pasture.

Finding and sampling some 0 to 2 years since conversion sites is desirable as I believe that major changes happen to the soil Ap horizon during the first 2 years since conversion. Finding and sampling a site which is still under pine plantation and take further samples just after conversion to pasture. Ideally continue the study with 6 month sampling intervals for the first 2 years after conversion on the same site. After the first 2 years samplings at 6 monthly intervals, decrease the sampling interval to once a year. Sampling the same site and following its development from pine plantation to pasture would allow for a true chronosequence of soil carbon and nitrogen to be constructed and would potentially lead to carbon and nitrogen soil accumulation curves.

Sampling by depth rather than soil horizon would make field work easier and quicker. Sampling by depth would allow for more samples to be taken in the same time period as I had. More soil samples would give a better average soil carbon and nitrogen values. Sampling by depth would also allow for easier comparisons with published soil carbon and nitrogen results, as most published information and was produced from soil samples taken according to arbitrary depth sampling.

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Appendix A.

Soil Profile Descriptions

This appendix contains the soil profile descriptions for Atiamuri, Tokoroa and Wairakei Study areas. Soil profile description based on Milne *et al.* (1995), soil classification after Hewitt (1998).

Table A.1: Soil profile description of the Atiamuri pine plantation site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 2.4 km north of State Highway 30, and 130 m from forestry road in pine plantation forest at the northern boundary of Mathis farm, upper Atiamuri, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 19' 33.3"
Easting:		176˚ 02' 18.4"
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		315 m asl
Geomorphic position:		Profile on flat area in plantation forest, many small undulation in the area around the pit
Vegetation:		Pine (*Pinus radiata*), blackberry, fern
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Plantation forest
Soil data		
Horizon	Depth (cm)	
Ap	0 – 13	Black (10YR 2/1) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, abundant very fine to coarse roots, moderate NaF reaction, distinct smooth boundary.
Bw	13 – 47	Brown (10YR 4/4) loamy sand, non sticky, non plastic, weak soil strength, friable, moderate pedality, many very fine to medium polyhedral peds breaking to apedal earthy, many very fine to fine roots, light grey (10YR 8/2) common very fine to fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	47 – 81	Dull yellowish brown (10YR 5/4) loamy sand, non sticky, non plastic, weak soil strength, friable, weak pedality, common fine polyhedral peds breaking to apedal earthy, light grey (10YR 8/1) few very fine pumice lapilli, moderate NaF reaction.

Table A.2: Soil profile description of the Atiamuri 2 years since conversion site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 600 m north west of State Highway 30, in paddock 40 Mathis farm, upper Atiamuri, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 19’ 49.4”
Easting:		176˚ 03’ 03.7”
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		299 m asl
Geomorphic position:		Profile on flat part of paddock, paddock slopes off very steeply on the north eastern boundary to a lower terrace
Vegetation:		Rye grass, white clover, coxfoot, doc, dandelion
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Dairy pasture
Soil data		
Horizon	Depth (cm)	
Ap	0 – 20	Brownish black (10YR 3/2) sandy loam, non sticky, non plastic, weak soil strength, brittle failure, moderate pedality, many fine to coarse polyhedral peds breaking to apedal earthy, abundant very fine to fine roots, light grey (10YR 8/1) common very fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	20 – 32	Yellowish brown (10YR 5/6) sandy loam, non sticky, non plastic, weak soil strength, brittle failure, moderate pedality, many fine to course polyhedral peds breaking to apedal earthy, many very fine to fine roots, light grey (10YR 8/2) many fine pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	32 – 70	Dull yellow orange (10YR 7/3) sandy loam, non sticky, non plastic, weak soil strength, brittle failure, moderate pedality, many fine to course polyhedral peds breaking to apedal earthy, few very fine roots, light grey (10YR 8/1) many fine pumice lapilli, moderate NaF reaction.

Table A.3: Soil profile description of the Atiamuri 5 years since conversion site

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo sandy loam
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit approximately 1.3km north west of State Highway 30, in paddock 40 Mathis farm, upper Atiamuri, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 19’ 40.3”	
Easting:	176˚ 02’ 30.0”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	293 m asl	
Geomorphic position:	Profile on flat paddock, with some small undulation in paddock	
Vegetation:	Rye grass and white clover, with coxfoot, brown top, doc, plantane dandelion	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 10	Brownish black (7.5YR 2/2) sandy loam, non sticky, non plastic, weak soil strength, brittle failure, weakly pedal, many fine polyhedral peds breaking to apedal earthy, abundant very fine to fine roots, moderate NaF reaction, distinct smooth boundary.
Bw	10 – 27	Brown (7.5YR 4/6) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weakly pedal, common fine to course polyhedral peds breaking to apedal earthy, many very fine to fine roots, light grey (7.5YR 8/2) common fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	27 – 76	Dull yellow orange (10YR 7/3) loamy sand, non sticky, non plastic, weak soil strength, friable failure, weakly pedal, common fine polyhedral peds breaking to apedal earthy, few very fine roots, light grey (7.5YR 8/2) few fine to course pumice lapilli, moderate NaF reaction.

Table A.4: Soil profile description of the Atiamuri 11 years since conversion site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo sandy loam
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit approximately 300 m north of State Highway 30, in paddock 53 Mathis farm, upper Atiamuri, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 19’ 59.6”	
Easting:	176˚ 03’ 13.3”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	301 m asl	
Geomorphic position:	Profile on flat part of paddock near the base of a small ridge	
Vegetation:	Rye grass and clover, with coxfoot, yarrow, twin cress, nodding thistle, poa, dock, mellow	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 23	Brownish black (7.5YR 2/2) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weakly pedal, common fine polyhedral peds breaking to apedal earthy, abundant very fine to fine roots, light grey (7.5YR 8/1) few very fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	23 – 40	Brown (7.5YR 4/6) sandy loam, non sticky, non plastic, weak soil strength, brittle failure, moderately pedal, many fine to course polyhedral peds breaking to apedal earthy, many very fine to fine roots, light grey (7.5YR 8/2) common fine pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	40 – 80	Dull yellowish brown (10YR 4/3) sandy loam, non sticky, non plastic, weak soil strength, brittle failure, weakly pedal, common fine polyhedral peds breaking to apedal earthy, few very fine to fine roots, light grey (7.5YR 8/2) many fine to medium pumice lapilli, moderate NaF reaction.

Table A.5: Soil profile description of the Atiamuri long-term dairy pasture site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 150 m north west of State Highway 30, in paddock 12 Mathis farm, upper Atiamuri, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 20’ 04.9”
Easting:		176˚ 03’ 03.9”
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		303 m asl
Geomorphic position:		Profile on flat part of paddock, paddock flat with some small undulations
Vegetation:		Rye grass, white clover, coxfoot, yarrow, doc, dandelion, fogg
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Dairy pasture
Soil data		
Horizon	Depth (cm)	
Ap	0 – 19	Brownish black (10YR 2/2) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weak pedality, common fine to medium polyhedral peds breaking to apedal earthy, abundant very fine to fine roots, light grey (10YR 8/1) few very fine pumice lapilli, weak NaF reaction, distinct smooth boundary.
Bw	19 – 33	Yellowish brown (10YR 5/6) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weak pedality, common very fine to medium polyhedral peds breaking to apedal earthy, many very fine to fine roots, light grey (10YR 8/1) common very fine to fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	33 – 72	Dull yellow orange (10YR 7/4) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weak pedality, common fine to medium polyhedral peds breaking to apedal earthy, common very fine roots, light grey (10YR 8/1) common very fine to fine pumice lapilli, moderate NaF reaction.

Table A.6: Soil profile description of the Tokoroa pine plantation site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 4 km west north west of the intersection between Jack Henry Road and the entrance to Maxwell Farms, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 12’ 56.3”
Easting:		175˚ 44’ 34.9”
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		300 m asl
Geomorphic position:		Profile on flat area in plantation forest, some small undulation in the area around the pit
Vegetation:		Pine (*Pinus radiata*), blackberry, fern
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Plantation forest
Soil data		
Horizon	Depth (cm)	
Ap	0 – 13	Black (10YR 1.7/1) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, abundant very fine to coarse roots, moderate NaF reaction, distinct smooth boundary.
Bw	13 – 28	Dark brown (10YR 3/3) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, many very fine to fine roots, light grey (10YR 8/2) common very fine to fine pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	28 – 68	Dull yellow orange (10YR 6/4) loamy sand, non sticky, non plastic, weak soil strength, friable, weak pedality, common fine polyhedral peds breaking to apedal earthy, light grey (10YR 8/1) few very fine pumice lapilli, moderate NaF reaction.
bB	68 – 84	Brown (7.5YR 4/6) silt loam, moderately sticky, moderately plastic, weak soil strength, apedal massive, strong NaF recation.

Table A.7: Soil profile description of the Tokoroa 2 years since conversion site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo sandy loam
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit located on Maxwell Farms Tokoroa Unit 6 paddock 49, approximately 7 km west north west of the intersection between Jack Henry Road and the entrance to Maxwell Farms Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 12’ 36.6”	
Easting:	176˚ 42’ 38.5”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	324 m asl	
Geomorphic position:	Pit on shoulder of low hill approximately 100 m south of sheep farm boundary, 50 m south east of gully edge	
Vegetation:	Rye grass, white clove, nodding thistle, scotch thistle, ink weed, doc	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 12	Brownish black (7.5YR 2/2) sandy loam; few fine to coarse prominent bright brown (7.5YR 5/6) mottles; slightly sticky, slightly plastic, firm soil strength, brittle, moderate pedality, many fine to coarse platy peds, many very fine to fine roots, strong NaF reaction, abrupt convolute boundary.
Bw	12 – 18	Brown (10YR 4/4) loamy sand, slightly sticky, non plastic, weak soil strength, brittle failure, weak pedality, common fine to course blocky peds breaking to apedal earthy, light grey (10YR 8/2) common fine pumice lapilli, strong NaF reaction, distinct wavy boundary.
Cu	18 – 52	Light yellow (2.5Y 7/3) sandy loam, non sticky, non plastic, weak soil strength, friable, apedal earthy, light grey (7.5YR 8/1) few very fine to medium pumice lapilli, strong NaF reaction, distinct wavy boundary.
bB	52 – 70	Brown (7.5YR 4/6) silt loam, moderately sticky, moderately plastic, weak soil strength, apedal massive, strong NaF recation.

Table A.8: Soil profile description of the Tokoroa 3 years since conversion site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo loamy sand
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit located on Maxwell Farms Tokoroa Unit 6 paddock 15, approximately 7.2 km west north west of the intersection between Jack Henry Road and the entrance to Maxwell Farms, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 13' 02.7"	
Easting:	176˚ 43' 15.5"	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	327 m asl	
Geomorphic position:	Pit on terrace landform, top of terrace is a small flat area with some small undulations, paddock is steep with a lower terrace in the eastern part of paddock	
Vegetation:	Rye grass, white clover, Yorkshire fog, ink weed, fox glove, scotch thistle, nodding thistle	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 10	Black (10YR 1.7/1) loamy sand, non sticky, non plastic, slightly firm soil strength, brittle failure, moderate pedality, abundant fine to coarse blocky peds breaking to apedal earthy, many very fine to fine roots, weak NaF reaction, distinct smooth boundary.
Bw	10 – 23	Dark brown (10YR 3/4) loamy sand, non sticky, non plastic, slightly firm soil strength, brittle failure, moderate pedality, common fine to course blocky peds breaking to apedal earthy, many very fine roots, light grey (10YR 8/2) few very fine to medium pumice lapilli, weak NaF reaction, distinct smooth boundary.
Cu	23 – 61	Dull yellowish brown (10YR 5/4) loamy sand, non sticky, non plastic, slightly firm soil strength, brittle failure, weak pedality, common very fine to course blocky peds breaking to apedal earthy, few very fine roots, light grey (10YR 8/2) few very fine to medium pumice lapilli, weak NaF reaction, distinct smooth boundary.
bB	61 – 85	Brown (7.5YR 4/6) silt loam, moderately sticky, moderately plastic, weak soil strength, apedal massive breaking to apedal earthy, moderate NaF reaction.

Table A.9: Soil profile description of the Tokoroa 5 years since conversion site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo loamy sand
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit located on Maxwell Farms Tokoroa Unit 6 paddock 49, approximately 4.5 km west north west of the intersection between Jack Henry Road and the entrance to Maxwell Farms, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 12’ 37.4”
Easting:		176˚ 44’ 06.4”
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		312 m asl
Geomorphic position:		Pit on terrace landform, top of terrace is flat with some small undulation
Vegetation:		Rye grass, white clover, nodding thistle, scotch thistle, Yorkshire fog, ragwort, fox glove
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Dairy pasture
Soil data		
Horizon	Depth (cm)	
Ap	0 – 10	Black (10YR 1.7/1) loamy sand; few fine prominent brown (7.5YR 5/6) mottles; non sticky, non plastic, slightly firm soil strength, brittle, moderate pedality, many fine to coarse blocky peds breaking to apedal earthy, many very fine to fine roots, light grey (10YR 8/2) very few very fine pumice lapilli, weak NaF reaction, distinct occluded boundary.
Bw	10 – 20	Brown (10YR 4/4) loamy sand, non sticky, non plastic, slightly firm soil strength, brittle failure, weak pedality, common fine to course blocky peds breaking to apedal earthy, common very fine roots, light grey (10YR 8/2) few fine to medium pumice lapilli, weak NaF reaction, indistinct smooth boundary.
Cu	20 – 44	Light yellow (10YR 5/6) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weak pedality, common fine to course blocky peds breaking to apedal earthy, few very fine roots, light grey (10YR 8/1) few very fine to fine pumice lapilli, weak NaF reaction, distinct smooth boundary.
bB	44 – 80	Brown (7.5YR 4/6) silt loam, moderately sticky, moderately plastic, weak soil strength, apedal massive breaking to apedal earthy, moderate NaF reaction.

Table A.10: Soil profile description of the Tokoroa long-term dairy pasture site.

Soil name:	Series: Taupo Pumice Soil Type: Taupo sandy loam	
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit located on Hunt farm approximately 7.5 km west north west of the intersection between Jack Henry Road and the entrance to Maxwell Farms Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 12’ 32.6”	
Easting:	175˚ 42’ 17.9”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	333 m asl	
Geomorphic position:	Profile on flat part of paddock, paddock flat with some small undulations, gully directly south of paddock	
Vegetation:	Plantain, pasbalum, yarrow, ragwort	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 15	Very dark brown (7.5YR 2/3) sandy loam, slightly sticky, slightly plastic, weak soil strength, brittle failure, moderate pedality, abundant very fine to fine polyhedral peds breaking to apedal earthy, abundant very fine to fine roots, light grey (10YR 8/1) few very fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	15 – 24	Yellowish brown (10YR 5/6) loamy sand, slightly sticky, non plastic, weak soil strength, brittle failure, weak pedality, common very fine to fine polyhedral peds breaking to apedal earthy, few microfine roots, light grey (10YR 8/1) few very fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	24 – 43	Yellowish Brown (10YR 5/8) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, weak pedality, common fine to medium polyhedral peds breaking to apedal earthy, common microfine roots, light grey (10YR 8/1) fine very fine to medium pumice lapilli, moderate NaF reaction.
bB	43 – 70	Brown (7.5YR 4/6) silt loam, moderately sticky, moderately plastic, weak soil strength, apedal massive, strong NaF recation.

Table A.11: Soil profile description of the Tokoroa long-term sheep/beef site.

Soil name:	Series: Taupo Pumice Soil Type: Taupo sandy loam	
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit located on Ranger sheep and beef farm approximately 6 km west north west of the intersection between Jack Henry Road and the entrance to Maxwell Farms Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 12' 31.2"	
Easting:	175˚ 43' 19.4"	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	314 m asl	
Geomorphic position:	Profile on flat part of paddock, paddock flat with some small undulations, small hill to the south west of paddock	
Vegetation:	Rye grass, brown top, fogg, yarrow	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Sheep and beef grazing	

Soil data

Horizon	Depth (cm)	
Ap	0 – 12	Black (7.5YR 2/1) sandy loam, slightly sticky, slightly plastic, weak soil strength, brittle failure, moderate pedality, abundant very fine to fine polyhedral peds breaking to apedal earthy, abundant microfine to fine roots, light grey (10YR 8/1) very few very fine to medium pumice lapilli, moderate NaF reaction, distinct occluded boundary.
Bw	12 – 31	Brown (10YR 4/6) loamy sand, slightly sticky, slightly plastic, weak soil strength, friable, weak pedality, common very fine to coarse polyhedral peds breaking to apedal earthy, many microfine roots, light grey (10YR 8/1) common extremely fine to fine pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	31 – 63	Yellowish Brown (10YR 5/6) loamy sand; few very fine prominent orange (5YR 6/8) mottle; slightly sticky, non plastic, weak soil strength, friable, weak pedality, common fine to medium polyhedral peds breaking to apedal earthy, common microfine roots, light grey (10YR 8/1) very fine to medium pumice lapilli, moderate NaF reaction.
bB	63 – 76	Brown (7.5YR 4/6) silt loam, moderately sticky, moderately plastic, weak soil strength, apedal massive, light grey (10YR 8/1) few fine pumice lapilli, strong NaF recation.

Table A.12: Soil profile description of the Wairakei pine plantation site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 300 m north west of State Highway 5, 25 km north north east of Taupo City, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 32' 06.3"
Easting:		176˚ 15' 44.0"
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		386 m asl
Geomorphic position:		Profile on flat area in plantation forest, many small ridges and undulation in the area around the pit
Vegetation:		Pine (*Pinus radiata*), blackberry
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Plantation forest
Soil data		
Horizon	Depth (cm)	
Ap	0 – 19	Black (7.5YR 2/1) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, abundant very fine to fine roots, light grey (10YR 8/2) common very fine to coarse pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	19 – 37	Orange (7.5YR 6/6) loamy sand, non sticky, non plastic, weak soil strength, brittle, cloddy, many very fine to medium roots, light grey (10YR 8/2) many very fine to coarse pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	37 – 95	Light brownish grey (7.5YR 7/1) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, many fine to medium roots, light grey (10YR 8/1) abundant very fine to coarse pumice lapilli, moderate NaF reaction.

Table A.13: Soil profile description of the Wairakei 2 years since conversion site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo sandy loam
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit approximately 150m south east of State Highway 5 in paddock 413 Pinta farm Wairakei Pastoral LTD, 25 km north north east of Taupo City, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 32’ 10.0”	
Easting:	176˚ 15’ 51.4”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	362 m asl	
Geomorphic position:	Pit on flat part of paddock, flat part of paddock is a small terrace	
Vegetation:	Rye grass, white clove, chicory, plantain, yarrow, Californian thisle	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 11	Brownish black (10YR 2/3) loamy sand, slightly sticky, non plastic, weak soil strength, brittle, apedal earthy, abundant very fine to fine roots, light grey (10YR 8/2) many fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	11 – 26	Yellowish brown (10YR 5/8) loamy sand, non sticky, non plastic, weak soil strength, brittle failure, cloddy, abundant microfine roots, light grey (10YR 8/1) abundant fine to very coarse pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	26 – 70	Orange (10YR 6/3) loamy sand, non sticky, non plastic, weak soil strength, brittle, apedal earthy, light grey (710YR 8/1) abundant very fine to very coarse pumice lapilli, moderate NaF reaction.

Table A.14: Soil profile description of the Wairakei 3 years since conversion site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 150m south east of State Highway 5 in paddock 521 Pinta farm Wairakei Pastoral LTD, 25 km north north east of Taupo City, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 31’ 59.6”
Easting:		176˚ 16’ 03.3”
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		364 m asl
Geomorphic position:		Pit on flat part of paddock, flat part of paddock is a small terrace
Vegetation:		Rye grass, white clove, Californian thistle, blackberry
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Dairy pasture
Soil data		
Horizon	Depth (cm)	
Ap	0 – 13	Dark reddish brown (5YR 3/2) sandy loam, non sticky, non plastic, weak soil strength, friable, apedal earthy, abundant very fine to fine roots, light grey (10YR 8/2) common fine pumice lapilli, weak NaF reaction, distinct smooth boundary.
Bw	13 – 31	Brown (7.5YR 4/6) loamy sand, non sticky, non plastic, moderate soil strength, brittle failure, moderate pedality, abundant fine to course blocky peds breaking to apedal earthy, abundant microfine roots, light grey (10YR 8/2) many fine to coarse pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	31 – 76	Orange (7.5YR 7/6) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, light grey (7.5YR 8/2) many very fine to medium pumice lapilli, weak NaF reaction.

Table A.15: Soil profile description of the Wairakei 4 years since conversion site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo loamy sand
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit approximately 300 m north west of State Highway 5 on Renown farm Wairakei Pastoral LTD, 25 km north north east of Taupo City, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 30’ 49.7”	
Easting:	176˚ 17’ 00.9”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	354 m asl	
Geomorphic position:	Pit on flat part of paddock, paddock has some small undulation through the paddock	
Vegetation:	Rye grass, white clove, doc	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 16	Brownish black (7.5YR 2/2) loamy sand, slightly sticky, non plastic, weak soil strength, friable, apedal earthy, abundant very fine to fine roots, light grey (10YR 8/2) common very fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	16 – 36	Brown (7.5YR 4/4) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, common microfine roots, light grey (10YR 8/1) abundant fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Cu	36 – 90	Light brownish grey (7.5YR 7/2) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earthy, light grey (10YR 8/1) abundant very fine to very coarse pumice lapilli, moderate NaF reaction.

Table A.16: Soil profile description of the Wairakei 5 years since conversion site.

Soil name:		Series: Taupo Pumice Soil Type: Taupo sandy loam
Soil classification		
NZ Soil Classification:		Immature Orthic Pumice Soil
Site Data		
Location		
Word descriptor:		Pit approximately 100 m west of State Highway 5 paddock 308 Renown farm Wairakei Pastoral LTD, 25 km north north east of Taupo City, Central North Island, New Zealand
GPS Co-ordinates (WGS84)		
Southing:		38˚ 29’ 53.0”
Easting:		176˚ 17’ 20.1”
Annual Rainfall:		*c*. 1300 mm
Mean Air Temperature:		12 ˚C
Elevation:		356 m asl
Geomorphic position:		Pit on flat part of paddock, many small undulations, paddock on a small ridge, western paddock boundary is a steep cliff
Vegetation:		Rye grass, white clove, chicory, plantain
Parent material:		Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)
Drainage class:		Well drained
Land use:		Dairy pasture
Soil data		
Horizon	Depth (cm)	
Ap	0 – 8	Brownish black (7.5YR 2/2) sandy loam, non sticky, non plastic, weak soil strength, brittle, moderate pedality, abundant fine to medium polyhedral peds, abundant very fine to fine roots, light grey (7.5YR 8/1) few very fine pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Bw	8 – 36	Bright black (7.5YR 5/8) sandy loam, non sticky, non plastic, weak soil strength, friable, apedal earthy, common microfine roots, light grey (7.5YR 8/1) abundant fine to medium pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	36 – 70	Orange (7.5YR 6/6) sandy loam, non sticky, non plastic, weak soil strength, friable, apedal earthy, light grey (10YR 8/1) abundant fine to medium pumice lapilli, moderate NaF reaction.

Table A.17: Soil profile description of the Wairakei long-term dairy (A) (Broderson) site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo loamy sand
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit approximately 600 m north of Tutukau Road paddock 31 Nui Friesian, 27 km north north east of Taupo City, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 29’ 13.7”	
Easting:	176˚ 15’ 01.4”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	376 m asl	
Geomorphic position:	Pit in very flat paddock with small undulations throughout paddock	
Vegetation:	Rye grass, white clove, yarrow, coxfoot, scotch thistle, nodding thistle	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 20	Black (7.5YR 2/1) loamy sand, slightly sticky, non plastic, weak soil strength, very friable, apedal earth, abundant very fine to fine roots, light grey (7.5YR 8/2) common fine pumice lapilli, moderate NaF reaction, distinct smooth boundary.
Bw	20 – 36	Bright brown (7.5YR 5/6) loamy sand, non sticky, non plastic, weak soil strength, very friable, apedal earthy, many fine roots, light grey (7.5YR 8/1) many fine to medium pumice lapilli, moderate NaF reaction, indistinct smooth boundary.
Cu	36 – 81	Bright yellowish brown (10YR 6/6) loamy sand, non sticky, non plastic, weak soil strength, very friable, apedal earthy, common fine roots, light grey (10YR 8/1) abundant fine to coarse pumice lapilli, moderate NaF reaction.

Table A.18: Soil profile description of the Wairakei long-term dairy (B) (Feather) site.

Soil name:	Series:	Taupo Pumice Soil
	Type:	Taupo loamy sand
Soil classification		
NZ Soil Classification:	Immature Orthic Pumice Soil	
Site Data		
Location		
Word descriptor:	Pit approximately 500 m west of State Highway 5 paddock 27 Feather farm, 25 km north north east of Taupo City, Central North Island, New Zealand	
GPS Co-ordinates (WGS84)		
Southing:	38˚ 29’ 55.8”	
Easting:	176˚ 17’ 24.5”	
Annual Rainfall:	*c*. 1300 mm	
Mean Air Temperature:	12 ˚C	
Elevation:	356 m asl	
Geomorphic position:	Pit in very flat paddock with small undulations throughout paddock	
Vegetation:	Rye grass, white clove, yarrow, brown top	
Parent material:	Unconsolidated, pumiceous ignimbrite (Taupo Ignimbrite *c*. 232 AD)	
Drainage class:	Well drained	
Land use:	Dairy pasture	

Soil data

Horizon	Depth (cm)	
Ap	0 – 16	Black (7.5YR 2/1) loamy sand, non sticky, non plastic, weak soil strength, friable, apedal earth, abundant fine roots, strong NaF reaction, distinct smooth boundary.
Bw	16 – 36	Yellowish brown (10YR 5/6) loamy sand, non sticky, non plastic, weak soil strength, very friable, apedal earthy, many very fine roots, light grey (7.5YR 8/1) many fine pumice lapilli, strong NaF reaction, indistinct smooth boundary.
Cu	36 – 75	Light yellowish brown (7.5YR 8/3) loamy sand, non sticky, non plastic, weak soil strength, very friable, apedal earthy, common very fine roots, light grey (7.5YR 8/1) abundant fine to coarse pumice lapilli, moderate NaF reaction.

Appendix B.

Transect & Pit Locations

This appendix contains GPS co-ordinates and orientation to magnetic north for transects and GPS co-ordinates for pits.

Table B.1: Atiamuri study area transects and master pit locations. GPS co-ordinates are WGS84 format. Orientation is to magnetic north.

Site	Transect/Pit	Orientation	GPS Co-ordinates (WGS84)	
			Southing	Easting
Pine Plantation	Transect A	020˚	38˚ 19’ 33.4”	176˚ 02’ 18.0”
	Transect B	024˚	38˚ 19’ 33.2”	176˚ 02’ 16.3”
	Transect C	292˚	38˚ 19’ 33.1”	176˚ 02’ 16.3”
	Pit A	-	38˚ 19’ 33.3”	176˚ 02’ 18.4”
2 years since conversion	Transect A	352	38˚ 19’ 49.7”	176˚ 03’ 03.6”
	Transect B	110˚	38˚ 19’ 48.1”	176˚ 03’ 03.2”
	Transect C	004˚	38˚ 19’ 51.3”	176˚ 03’ 04.3”
	Pit A	-	38˚ 19’ 49.4”	176˚ 03’ 03.7”
5 years since conversion	Transect A	270˚	38˚ 19’ 40.8”	176˚ 02’ 31.3”
	Transect B	222˚	38˚ 19’ 38.2”	176˚ 02’ 29.8”
	Transect C	228˚	38˚ 19’ 41.2”	176˚ 02’ 30.9”
	Pit A	-	38˚ 19’ 40.3”	176˚ 02’ 30.0”
11 years since conversion	Transect A	039˚	38˚ 20’ 05.7”	176˚ 03’ 12.9”
	Transect B	006˚	38˚ 20’ 02.6”	176˚ 03’ 12.5”
	Transect C	005˚	38˚ 20’ 00.2”	176˚ 03’ 12.4”
	Pit A	-	38˚ 19’ 59.6”	176˚ 03’ 13.3”
Long-term dairy pasture	Transect A	254˚	38˚ 20’ 04.9”	176˚ 03’ 05.0”
	Transect B	250˚	38˚ 20’ 03.8”	176˚ 03’ 04.3”
	Transect C	268˚	38˚ 20’ 02.0”	176˚ 03’ 05.1”
	Pit A	-	38˚ 20’ 04.9”	176˚ 03’ 03.9”

Table B.2: Tokoroa study area transects and master pit locations. GPS co-ordinates are WGS84 format. Orientation is to magnetic north.

Site	Transect/Pit	Orientation	GPS Co-ordinates (WGS84)	
			Southing	Easting
Pine Plantation	Transect A	190˚	38˚ 12’ 54.9”	175˚ 44’ 36.2”
	Transect B	198˚	38˚ 12’ 57.6”	175˚ 44’ 39.7”
	Transect C	128˚	38˚ 12 59.2	175˚ 44’ 37.3”
	Pit A	-	38˚ 12’ 56.3”	175˚ 44’ 34.9”
2 years since conversion	Transect A	042˚	38˚ 12’ 37.1”	175˚ 42’ 37.6”
	Transect B	180˚	38˚ 12’ 36.0”	175˚ 42’ 40.0”
	Transect C	012˚	38˚ 12’ 36.6”	176˚ 42’ 38.5”
	Pit A	-	38˚ 12’ 36.6”	176˚ 42’ 38.5”
3 years since conversion	Transect A	150˚	38˚ 13’ 01.9”	175˚ 43’ 15.2”
	Transect B	282˚	38˚ 13’ 03.6”	175˚ 43’ 15.4”
	Transect C	004˚	38˚ 13’ 02.6”	175˚ 43’ 13.2”
	Pit A	-	38˚ 13’ 02.7”	176˚ 43’ 15.5”
5 years since conversion	Transect A	228˚	38˚ 12’ 37.4”	175˚ 44’ 06.4”
	Transect B	204˚	38˚ 12’ 37.9”	175˚ 44’ 08.0”
	Transect C	104˚	38˚ 12’ 40.0”	175˚ 44’ 07.1”
	Pit A	-	38˚ 12’ 37.4”	176˚ 44’ 06.4”
Long-term dairy pasture	Transect A	127˚	38˚ 12’ 31.7”	175˚ 42’ 20.2”
	Transect B	127˚	38˚ 12’ 32.6”	175˚ 42’ 19.2”
	Transect C	340˚	38˚ 12’ 25.7”	175˚ 42’ 17.9”
	Pit A	-	38˚ 12’ 32.6”	175˚ 42’ 17.9”
Long-term sheep/beef	Transect A	348˚	38˚ 12’ 32.1”	175˚ 42’ 19.4”
	Transect B	348˚	38˚ 12’ 30.4”	175˚ 43’ 20.2”
	Transect C	348˚	38˚ 12’ 28.5”	175˚ 43’ 20.4”
	Pit A	-	38˚ 12’ 31.2”	175˚ 43’ 19.4”

Table B.3: Wairakei study area transects and master pit locations. GPS co-ordinates are WGS84 format. Orientation is to magnetic north.

Site	Transect/Pit	Orientation (degrees)	GPS Co-ordinates (WGS84)	
			Southing	Easting
Pine Plantation	Transect A	332˚	38˚ 32’ 07.3”	176˚ 15’ 44.3”
	Transect B	344˚	38˚ 32’ 00.5”	176˚ 15’ 50.8”
	Transect C	239˚	38˚ 31’ 57.4”	176˚ 15’ 54.3”
	Pit A	-	38˚ 32’ 06.3”	176˚ 15’ 44.0”
2 years since conversion	Transect A	145˚	38˚ 32’ 09.4”	176˚ 15’ 51.0”
	Transect B	050˚	38˚ 32’ 17.1”	176˚ 15’ 44.7”
	Transect C	154˚	38˚ 32’ 19.1”	176˚ 15’ 43.6”
	Pit A	-	38˚ 32’ 10.0”	176˚ 15’ 51.4”
3 years since conversion	Transect A	056˚	38˚ 31’ 59.7”	176˚ 16’ 02.6”
	Transect B	053˚	38˚ 31’ 56.2”	176˚ 16’ 06.3”
	Transect C	164˚	38˚ 32’ 03.2”	176˚ 16’ 01.4”
	Pit A	-	38˚ 31’ 59.6”	176˚ 16’ 03.3”
4 years since conversion	Transect A	146˚	38˚ 30’ 48.8”	176˚ 17’ 00.7”
	Transect B	146˚	38˚ 30’ 48.8”	176˚ 16’ 59.9”
	Transect C	267˚	38˚ 30’ 39.7”	176˚ 16’ 54.9”
	Pit A	-	38˚ 30’ 49.7”	176˚ 17’ 00.9”
5 years since conversion	Transect A	228˚	38˚ 29’ 51.9”	176˚ 17’ 20.8”
	Transect B	095˚	38˚ 29’ 52.7”	176˚ 17’ 19.2”
	Transect C	198˚	38˚ 29’ 54.4”	176˚ 17’ 20.5”
	Pit A	-	38˚ 29’ 53.0”	176˚ 17’ 20.1”
Long-term dairy pasture (A) (Broderson)	Transect A	045˚	38˚ 29’ 14.1”	176˚ 15’ 00.5”
	Transect B	032˚	38˚ 29’ 18.4”	176˚ 14’ 59.4”
	Transect C	034˚	38˚ 29’ 20.6”	176˚ 15’ 10.5”
	Pit A	-	38˚ 29’ 13.7”	176˚ 15’ 01.4”
Long-term dairy pasture (B) (Feather)	Transect A	082˚	38˚ 29’ 50.4”	176˚ 17’ 23.4”
	Transect B	034˚	38˚ 29’ 56.2”	176˚ 17’ 23.8”
	Transect C	026˚	38˚ 30’ 10.1”	176˚ 17’ 25.7”
	Pit A	-	38˚ 29’ 55.8”	176˚ 17’ 24.5”

Appendix C.

Carbon & Nitrogen Data

This appendix contains the data which was used for construction of graphs and statistical analysis found in the results section of the thesis. For Atiamuri, Tokoroa and Wairakei study areas is presented in Tables C.1, C.2 and C.3.

Table C.1: Raw data for carbon and nitrogen calculations for the Atiamuri study area. Treatments are pine is pine plantation, numbers represent years since conversion to pasture and LT D is long-term dairy. C % and N % are the carbon and nitrogen % values produced through analysis of soil by LECO furnace. FEF is fine earth fraction results. MF is moisture factor. C is soil carbon content. N is soil nitrogen content.

Treatment	Transect	Horizon	Thickness (cm)	C %	N %	C:N	FEF (g cm^{-3})	MF	C (kg/m^2)	N (kg/m^2)
Pine	A	Ap	13.4	6.15	0.41	14.85	0.351	0.96	2.78	0.19
Pine	B	Ap	13.3	5.56	0.39	14.11	0.527	0.96	3.73	0.26
Pine	C	Ap	12.6	6.58	0.45	14.62	0.424	0.96	3.38	0.23
Pine	Pit A	Ap	13.0	8.25	0.48	17.05	0.351	0.94	3.53	0.21
2	A	Ap	15.3	5.56	0.48	11.53	0.656	0.96	5.35	0.46
2	B	Ap	12.8	5.36	0.42	12.67	0.711	0.96	4.66	0.37
2	C	Ap	11.0	5.16	0.44	11.69	0.633	0.96	3.45	0.29
2	Pit A	Ap	20.0	7.66	0.56	13.56	0.656	0.96	9.61	0.71
5	A	Ap	8.4	6.45	0.54	11.93	0.656	0.96	3.41	0.29
5	B	Ap	14.2	5.50	0.46	11.89	0.593	0.96	4.45	0.37
5	C	Ap	16.8	3.97	0.38	10.57	0.623	0.97	4.02	0.38
5	Pit A	Ap	10.0	6.78	0.57	11.93	0.656	0.96	4.26	0.36
11	A	Ap	11.4	6.22	0.57	11.01	0.720	0.96	4.89	0.44
11	B	Ap	11.9	6.56	0.57	11.49	0.661	0.95	4.92	0.43
11	C	Ap	9.5	7.71	0.63	12.21	0.660	0.95	4.60	0.38
11	Pit A	Ap	23.0	6.58	0.45	14.52	0.720	0.95	10.39	0.72
LT D	A	Ap	16.1	6.98	0.74	9.48	0.663	0.95	7.14	0.75
LT D	B	Ap	15.6	5.69	0.64	8.96	0.683	0.96	5.81	0.65
LT D	C	Ap	18.6	5.93	0.66	8.98	0.646	0.95	6.79	0.76
LT D	Pit A	Ap	19.0	6.77	0.73	9.33	0.663	0.96	8.17	0.88
Pine	A	Bw	16.9	1.10	0.18	6.17	0.774	0.97	1.40	0.23
Pine	B	Bw	18.3	1.06	0.17	6.25	0.680	0.97	1.28	0.20
Pine	C	Bw	17.2	1.11	0.19	5.99	0.644	0.97	1.20	0.20
Pine	Pit A	Bw	34.0	0.76	0.15	4.97	0.774	0.97	1.95	0.39
2	A	Bw	17.0	0.95	0.16	6.06	0.685	0.97	1.08	0.18
2	B	Bw	15.2	1.18	0.20	6.04	0.691	0.98	1.21	0.20
2	C	Bw	12.9	1.21	0.18	6.81	0.749	0.97	1.14	0.17
2	Pit A	Bw	12.0	0.74	0.16	4.65	0.685	0.98	0.60	0.13
5	A	Bw	13.4	1.34	0.22	6.07	0.579	0.97	1.01	0.17
5	B	Bw	12.3	1.10	0.17	6.45	0.784	0.97	1.04	0.16
5	C	Bw	12.4	0.90	0.16	5.53	0.706	0.98	0.77	0.14
5	Pit A	Bw	17.0	1.70	0.21	8.08	0.579	0.96	1.61	0.20
11	A	Bw	15.1	1.06	0.18	5.73	0.628	0.97	0.97	0.17
11	B	Bw	14.1	1.11	0.17	6.60	0.680	0.97	1.03	0.16
11	C	Bw	16.1	1.16	0.19	5.98	0.638	0.97	1.16	0.19
11	Pit A	Bw	17.0	1.65	0.22	7.56	0.628	0.97	1.72	0.23
LT D	A	Bw	13.9	1.86	0.27	6.99	0.749	0.97	1.87	0.27
LT D	B	Bw	9.3	1.32	0.22	6.03	0.687	0.97	0.82	0.14
LT D	C	Bw	10.7	1.31	0.22	5.85	0.653	0.97	0.89	0.15
LT D	Pit A	Bw	14.0	1.76	0.26	6.83	0.749	0.97	1.79	0.26

Pine	A	Cu	29.6	0.31	0.13	2.44	0.731	0.99	0.66	0.27
Pine	B	Cu	26.4	0.30	0.12	2.49	0.716	0.99	0.56	0.22
Pine	C	Cu	30.1	0.31	0.12	2.59	0.740	0.99	0.68	0.26
Pine	Pit A	Cu	13.0	0.34	0.13	2.55	0.731	0.99	0.32	0.12
2	A	Cu	25.1	0.25	0.10	2.43	0.815	0.98	0.50	0.21
2	B	Cu	32.0	0.28	0.11	2.57	0.721	0.99	0.64	0.25
2	C	Cu	28.9	0.26	0.11	2.39	0.747	0.99	0.56	0.24
2	Pit A	Cu	28.0	0.24	0.09	2.57	0.815	0.99	0.53	0.21
5	A	Cu	38.2	0.27	0.12	2.32	0.750	0.99	0.76	0.33
5	B	Cu	30.6	0.26	0.12	2.23	0.915	0.99	0.71	0.32
5	C	Cu	30.9	0.21	0.09	2.17	0.706	0.99	0.44	0.20
5	Pit A	Cu	33.0	0.27	0.12	2.36	0.750	0.98	0.66	0.28
11	A	Cu	30.9	0.26	0.10	2.63	0.713	0.99	0.57	0.22
11	B	Cu	27.6	0.27	0.12	2.29	0.705	0.99	0.52	0.23
11	C	Cu	26.0	0.31	0.11	2.79	0.732	0.99	0.59	0.21
11	Pit A	Cu	20.0	0.27	0.10	2.78	0.713	0.99	0.38	0.14
LT D	A	Cu	30.0	0.31	0.13	2.48	0.676	0.94	0.59	0.24
LT D	B	Cu	34.4	0.24	0.10	2.44	0.725	0.99	0.60	0.25
LT D	C	Cu	30.7	0.26	0.12	2.13	0.675	0.99	0.53	0.25
LT D	Pit A	Cu	27.0	0.27	0.13	2.02	0.676	0.99	0.48	0.24

Table C.2: Raw data for carbon and nitrogen calculations for the Tokoroa study area. Treatments are pine is pine plantation, numbers represent years since conversion to pasture, LT D is long-term dairy and LT S/B is long-term sheep/beef. C % and N % are the carbon and nitrogen % values produced through analysis of soil by LECO furnace. FEF is fine earth fraction results. MF is moisture factor. C is soil carbon content. N is soil nitrogen content.

Treatment	Transect	Horizon	Thickness (cm)	C %	N %	C:N	FEF (g cm^{-3})	MF	C (kg/m^2)	N (kg/m^2)
Pine	A	Ap	13.3	8.23	0.51	16.06	0.469	0.95	4.88	0.30
Pine	B	Ap	10.6	8.57	0.49	17.56	0.459	0.95	3.97	0.23
Pine	C	Ap	12.5	8.34	0.53	15.79	0.554	0.95	5.50	0.35
Pine	Pit A	Ap	13.0	8.86	0.50	17.85	0.469	0.93	5.05	0.28
2	A	Ap	8.3	8.00	0.49	16.17	0.576	0.95	3.64	0.22
2	B	Ap	13.2	6.33	0.43	14.80	0.657	0.95	5.22	0.35
2	C	Ap	14.7	8.38	0.52	15.99	0.618	0.95	7.23	0.45
2	Pit A	Ap	12.0	7.07	0.46	15.53	0.576	0.95	4.65	0.30
3	A	Ap	11.6	5.61	0.39	14.51	0.728	0.95	4.51	0.31
3	B	Ap	8.9	6.01	0.44	13.72	0.697	0.96	3.57	0.26
3	C	Ap	11.9	7.52	0.47	16.03	0.652	0.95	5.55	0.35
3	Pit A	Ap	10.0	4.82	0.34	14.34	0.728	0.93	3.27	0.23
5	A	Ap	10.3	8.88	0.58	15.23	0.605	0.95	5.26	0.35
5	B	Ap	10.8	6.82	0.48	14.15	0.620	0.95	4.35	0.31
5	C	Ap	9.2	7.83	0.49	15.99	0.615	0.95	4.22	0.26
5	Pit A	Ap	10.0	8.94	0.58	15.30	0.605	0.94	5.07	0.33
LT D	A	Ap	14.4	7.46	0.72	10.41	0.690	0.96	7.08	0.68
LT D	B	Ap	11.7	7.65	0.74	10.34	0.562	0.96	4.82	0.47
LT D	C	Ap	11.6	7.18	0.76	9.51	0.688	0.96	5.48	0.58
LT D	Pit A	Ap	15.0	7.35	0.68	10.78	0.690	0.96	7.27	0.67
LT S/B	A	Ap	11.1	8.86	0.85	10.39	0.631	0.94	5.86	0.56
LT S/B	B	Ap	12.1	9.51	0.91	10.50	0.598	0.94	6.48	0.62
LT S/B	C	Ap	13.1	9.25	0.86	10.75	0.549	0.94	6.27	0.58
LT S/B	Pit A	Ap	12.0	9.07	0.84	10.78	0.631	0.94	6.47	0.60
Pine	A	Bw	17.1	2.32	0.19	12.44	0.691	0.96	2.65	0.21
Pine	B	Bw	17.4	2.08	0.17	12.42	0.745	0.97	2.60	0.21
Pine	C	Bw	14.8	2.10	0.19	11.14	0.798	0.97	2.40	0.22
Pine	Pit A	Bw	15.0	2.40	0.18	13.06	0.691	0.97	2.43	0.19
2	A	Bw	14.6	3.23	0.21	15.63	0.683	0.96	3.11	0.20
2	B	Bw	9.2	1.71	0.18	9.46	0.780	0.97	1.19	0.13
2	C	Bw	14.7	3.11	0.24	13.10	0.747	0.96	3.28	0.25
2	Pit A	Bw	6.0	1.94	0.18	10.56	0.683	0.97	0.77	0.07
3	A	Bw	17.8	1.58	0.17	9.28	0.732	0.97	1.99	0.21
3	B	Bw	12.8	2.20	0.19	11.35	0.731	0.97	1.99	0.18
3	C	Bw	11.1	2.32	0.19	12.10	0.683	0.96	1.69	0.14
3	Pit A	Bw	13.0	2.10	0.19	11.27	0.732	0.97	1.93	0.17
5	A	Bw	9.0	2.21	0.20	10.80	0.612	0.97	1.18	0.11
5	B	Bw	10.7	1.33	0.15	8.85	0.699	0.97	0.97	0.11

5	C	Bw	16.8	2.91	0.22	12.96	0.707	0.96	3.33	0.26
5	Pit A	Bw	10	2.97	0.24	12.47	0.612	0.97	1.76	0.14
LT D	A	Bw	14.9	2.60	0.20	13.04	0.689	0.96	2.57	0.20
LT D	B	Bw	11.2	2.43	0.22	10.98	0.655	0.97	1.73	0.16
LT D	C	Bw	10.9	2.99	0.27	10.92	0.728	0.96	2.28	0.21
LT D	Pit A	Bw	9.0	2.12	0.18	11.70	0.689	0.96	1.26	0.11
LT S/B	A	Bw	18.1	2.61	0.22	11.65	0.705	0.96	3.20	0.27
LT S/B	B	Bw	18.0	2.79	0.25	11.23	0.663	0.97	3.22	0.29
LT S/B	C	Bw	16.4	2.78	0.26	10.51	0.686	0.96	3.01	0.29
LT S/B	Pit A	Bw	19.0	1.85	0.19	9.66	0.705	0.98	2.42	0.25
Pine	A	Cu	25.6	0.56	0.12	4.56	0.814	0.99	1.16	0.25
Pine	B	Cu	29.0	0.51	0.10	5.27	0.671	0.98	0.97	0.19
Pine	C	Cu	32.7	0.65	0.13	4.92	0.780	0.98	1.62	0.33
Pine	Pit A	Cu	32.0	0.40	0.12	3.48	0.814	0.99	1.04	0.30
2	A	Cu	23.8	0.97	0.10	10.10	0.727	0.98	1.65	0.16
2	B	Cu	18.1	0.64	0.09	7.53	0.732	0.98	0.84	0.11
2	C	Cu	22.8	1.10	0.14	7.75	0.710	0.98	1.74	0.22
2	Pit A	Cu	34.0	0.74	0.12	6.29	0.727	0.98	1.81	0.29
3	A	Cu	22.4	0.52	0.13	4.00	0.730	0.98	0.84	0.21
3	B	Cu	31.7	0.72	0.13	5.63	0.679	0.98	1.53	0.27
3	C	Cu	31.3	0.66	0.13	5.15	0.774	0.98	1.57	0.30
3	Pit A	Cu	37.0	0.82	0.13	6.21	0.730	0.98	2.18	0.35
5	A	Cu	26.9	0.71	0.12	6.08	0.680	0.98	1.27	0.21
5	B	Cu	35.8	0.44	0.09	4.95	0.674	0.99	1.03	0.21
5	C	Cu	22.9	0.86	0.13	6.63	0.704	0.99	1.36	0.21
5	Pit A	Cu	24.0	0.92	0.15	6.17	0.680	0.98	1.47	0.24
LT D	A	Cu	23.9	0.89	0.12	7.33	0.619	0.98	1.29	0.18
LT D	B	Cu	17.1	1.06	0.16	6.78	0.652	0.98	1.15	0.17
LT D	C	Cu	20.5	1.07	0.15	7.18	0.676	0.98	1.45	0.20
LT D	Pit A	Cu	19.0	0.53	0.14	3.78	0.619	0.97	0.61	0.16
LT S/B	A	Cu	28.5	0.53	0.13	4.13	0.791	0.98	1.17	0.28
LT S/B	B	Cu	27.1	0.71	0.14	5.00	0.733	0.98	1.37	0.27
LT S/B	C	Cu	29.6	0.74	0.15	5.12	0.645	0.98	1.39	0.27
LT S/B	Pit A	Cu	29.0	0.41	0.12	3.59	0.791	0.97	0.92	0.26

Table C.3: Raw data for carbon and nitrogen calculations for the Wairakei study area. Treatments are pine is pine plantation, numbers represent years since conversion to pasture, LT D (A) is long-term dairy (Broderson) and LT D (B) is long-term dairy (Feather). C % and N % are the carbon and nitrogen % values produced through analysis of soil by LECO furnace. FEF is fine earth fraction results. MF is moisture factor. C is soil carbon content. N is soil nitrogen content.

Treatment	Transect	Horizon	Thickness (cm)	C %	N %	C:N	FEF (g cm^{-3})	MF	C (kg/m^2)	N (kg/m^2)
Pine	A	Ap	16.6	7.03	0.44	15.88	0.258	0.96	2.88	0.18
Pine	B	Ap	12.1	5.26	0.31	16.91	0.466	0.96	2.86	0.17
Pine	C	Ap	14.1	5.99	0.39	15.28	0.475	0.96	3.86	0.25
Pine	Pit A	Ap	19	3.95	0.35	11.20	0.258	0.96	1.86	0.17
2	A	Ap	11.9	6.07	0.39	15.57	0.621	0.97	4.33	0.28
2	B	Ap	16.5	6.21	0.41	15.23	0.652	0.97	6.46	0.42
2	C	Ap	13.1	7.49	0.41	18.08	0.691	0.96	6.51	0.36
2	Pit A	Ap	11	6.68	0.43	15.54	0.621	0.96	4.38	0.28
3	A	Ap	14.1	9.00	0.49	18.48	0.508	0.96	6.18	0.33
3	B	Ap	10.2	6.40	0.42	15.28	0.533	0.96	3.36	0.22
3	C	Ap	16.4	4.68	0.32	14.61	0.562	0.97	4.17	0.29
3	Pit A	Ap	13	6.87	0.42	16.42	0.508	0.96	4.37	0.27
4	A	Ap	17.4	7.06	0.53	13.24	0.540	0.96	6.40	0.48
4	B	Ap	16.6	7.80	0.53	14.66	0.501	0.96	6.24	0.43
4	C	Ap	21.1	7.49	0.49	15.40	0.461	0.96	6.97	0.45
4	Pit A	Ap	16	6.74	0.51	13.24	0.540	0.97	5.66	0.43
5	A	Ap	14.1	9.19	0.53	17.25	0.563	0.96	6.98	0.40
5	B	Ap	16.2	8.27	0.50	16.48	0.700	0.96	8.99	0.55
5	C	Ap	16.1	8.94	0.51	17.38	0.532	0.96	7.34	0.42
5	Pit A	Ap	8.5	9.27	0.50	18.71	0.563	0.96	4.27	0.23
LT D (A)	A	Ap	16.2	6.35	0.66	9.60	0.712	0.96	7.01	0.73

LT D (A)	B	Ap	15.4	6.03	0.66	9.20	0.757	0.96	6.75	0.73
LT D (A)	C	Ap	16.1	7.41	0.79	9.38	0.462	0.96	5.28	0.56
LT D (A)	Pit A	Ap	20	6.34	0.68	9.30	0.712	0.96	8.67	0.93
LT D (B)	A	Ap	16.7	6.82	0.62	11.00	0.652	0.96	7.15	0.65
LT D (B)	B	Ap	15.4	7.13	0.66	10.83	0.712	0.96	7.50	0.69
LT D (B)	C	Ap	18.5	6.58	0.61	10.70	0.682	0.96	7.99	0.75
LT D (B)	Pit A	Ap	16	8.03	0.73	10.98	0.652	0.96	8.01	0.73
Pine	A	Bw	13.5	1.22	0.17	7.04	0.604	0.98	0.97	0.14
Pine	B	Bw	19.3	1.03	0.15	6.86	0.493	0.98	0.95	0.14
Pine	C	Bw	14	0.82	0.15	5.32	0.343	0.98	0.38	0.07
Pine	Pit A	Bw	18.5	1.15	0.16	7.09	0.604	0.98	1.25	0.18
2	A	Bw	18.9	1.04	0.14	7.65	0.684	0.98	1.32	0.17
2	B	Bw	15.3	0.91	0.12	7.45	0.792	0.98	1.09	0.15
2	C	Bw	15.1	1.46	0.14	10.51	0.618	0.98	1.33	0.13
2	Pit A	Bw	15	0.99	0.13	7.84	0.684	0.98	0.99	0.13
3	A	Bw	15.4	1.34	0.16	8.55	0.518	0.98	1.04	0.12
3	B	Bw	20.3	0.82	0.13	6.09	0.672	0.98	1.10	0.18
3	C	Bw	16.9	1.15	0.15	7.74	0.687	0.98	1.30	0.17
3	Pit A	Bw	18	1.67	0.20	8.42	0.518	0.96	1.50	0.18
4	A	Bw	20.1	0.94	0.14	6.64	0.531	0.98	0.98	0.15
4	B	Bw	20.9	1.03	0.17	6.02	0.480	0.98	1.01	0.17
4	C	Bw	16.9	1.20	0.16	7.31	0.697	0.98	1.39	0.19
4	Pit A	Bw	20	3.07	0.29	10.60	0.531	0.98	3.19	0.30
5	A	Bw	20.8	1.79	0.18	10.12	0.710	0.98	2.58	0.25
5	B	Bw	19.2	1.22	0.16	7.44	0.725	0.98	1.66	0.22
5	C	Bw	27.1	1.29	0.16	7.83	0.711	0.98	2.43	0.31
5	Pit A	Bw	27.5	1.62	0.17	9.34	0.710	0.98	3.11	0.33
LT D (A)	A	Bw	19.1	1.08	0.18	5.89	0.762	0.98	1.54	0.26
LT D (A)	B	Bw	23	1.55	0.23	6.60	0.755	0.97	2.61	0.39
LT D (A)	C	Bw	31.2	1.32	0.22	6.08	0.272	0.98	1.09	0.18
LT D (A)	Pit A	Bw	16	0.54	0.16	3.49	0.762	0.99	0.65	0.19
LT D (B)	A	Bw	25.2	0.83	0.17	5.05	0.627	0.98	1.30	0.26
LT D (B)	B	Bw	22.2	1.02	0.19	5.29	0.716	0.98	1.58	0.30
LT D (B)	C	Bw	28.2	1.01	0.20	5.19	0.773	0.98	2.16	0.42
LT D (B)	Pit A	Bw	20	1.90	0.26	7.23	0.627	0.97	2.32	0.32
Pine	A	Cu	28	0.27	0.10	2.72	0.798	0.99	0.59	0.22
Pine	B	Cu	28.6	0.21	0.10	2.14	0.781	0.99	0.47	0.22
Pine	C	Cu	30	0.21	0.08	2.61	0.545	0.99	0.35	0.13
Pine	Pit A	Cu	22.5	0.16	0.07	2.41	0.798	0.99	0.29	0.12
2	A	Cu	25.4	0.29	0.10	3.00	0.817	0.99	0.59	0.20
2	B	Cu	24.8	0.30	0.10	2.98	0.786	0.99	0.57	0.19
2	C	Cu	31.8	0.21	0.10	1.98	0.828	0.99	0.54	0.27
2	Pit A	Cu	34	0.21	0.10	2.14	0.817	0.99	0.58	0.27
3	A	Cu	27	0.26	0.10	2.51	0.810	0.99	0.57	0.23
3	B	Cu	27.6	0.20	0.10	2.04	0.740	0.99	0.41	0.20
3	C	Cu	26.8	0.24	0.09	2.51	0.918	0.98	0.58	0.23
3	Pit A	Cu	29	0.24	0.10	2.29	0.810	0.99	0.55	0.24
4	A	Cu	22.5	0.23	0.10	2.41	0.511	0.99	0.26	0.11
4	B	Cu	21.6	0.26	0.11	2.45	0.603	0.99	0.33	0.14
4	C	Cu	18.1	0.35	0.11	3.23	0.695	0.99	0.43	0.13
4	Pit A	Cu	24	0.34	0.12	2.75	0.511	0.99	0.41	0.15
5	A	Cu	19.4	0.52	0.11	4.89	0.620	0.99	0.62	0.13
5	B	Cu	24.6	0.42	0.12	3.43	0.760	0.99	0.77	0.23
5	C	Cu	16.7	0.39	0.12	3.14	0.779	0.98	0.50	0.16
5	Pit A	Cu	24	0.22	0.09	2.58	0.620	0.99	0.33	0.13
LT D (A)	A	Cu	24.7	0.30	0.09	3.38	0.545	0.99	0.40	0.12
LT D (A)	B	Cu	21.6	0.39	0.12	3.20	0.701	0.99	0.58	0.18
LT D (A)	C	Cu	12.6	0.37	0.11	3.33	0.398	0.99	0.18	0.05
LT D (A)	Pit A	Cu	24	0.21	0.11	1.89	0.545	0.99	0.27	0.14
LT D (B)	A	Cu	14.6	0.29	0.11	2.54	0.715	0.99	0.30	0.12
LT D (B)	B	Cu	22.4	0.23	0.11	2.17	0.669	0.99	0.35	0.16
LT D (B)	C	Cu	12.3	0.30	0.12	2.57	1.001	0.99	0.36	0.14
LT D (B)	Pit A	Cu	24	0.51	0.16	3.18	0.715	0.99	0.86	0.27

Appendix D.

Statistical Analysis Data

This appendix contains the statistical analysis of the data used to produces the graphs found in the results, chapter 5. All statistics were carried out using StatSoft. Inc. Statistica version 9.1.

Table D.1: Univariate test of significance for carbon (kg/m^2) for the Atiamuri study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	331.9824	1	331.9824	290.9834	0.000000
Treatment	11.4918	4	2.8729	2.5181	0.054337
Horizon	259.0663	2	129.5331	113.5361	0.000000
Treatment* Horizon	25.9457	8	3.2432	2.827	0.012088
Error	51.3404	45	1.1409		

Table D.2: Univariate test of significance for nitrogen (kg/m^2) for the Atiamuri study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	5.234192	1	5.234192	848.5842	0.000000
Treatment	0.194926	4	0.048732	7.9005	0.000065
Horizon	0.787904	2	0.393952	63.8688	0.000000
Treatment* Horizon	0.477536	8	0.059692	9.6775	0.000000
Error	0.277567	45	0.006168		

Table D.3: Univariate test of significance for C:N for the Atiamuri study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	2879.496	1	2879.496	4796.076	0.000000
Treatment	21.938	4	5.485	9.135	0.000017
Horizon	952.607	2	476.303	793.329	0.000000
Treatment* Horizon	53.121	8	6.640	11.060	0.000000
Error	27.017	45	0.600		

Table D.4: Univariate test of significance for carbon % for the Atiamuri study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	401.8926	1	401.8926	1110.832	0.000000
Treatment	1.4950	4	0.3738	1.033	0.400672
Horizon	415.7146	2	207.8573	574.518	0.000000
Treatment* Horizon	2.7466	8	0.3433	0.949	0.487006
Error	16.2807	45	0.3618		

Table D.5: Univariate test of significance for nitrogen % for the Atiamuri study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	4.654905	1	4.654905	2936.916	0.000000
Treatment	0.088419	4	0.022105	13.947	0.000000
Horizon	1.946076	2	0.973038	613.918	0.000000
Treatment* Horizon	0.084260	8	0.010533	6.645	0.000010
Error	0.071323	45	0.001585		

Table D.6: Bonferroni test of variable C (kg/m^2) for the Atiamuri area. Test errors between MS = 1.1409, df = 45. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - 3.3525	{2} - 1.4566	{3} - .55268	{4} - 5.7650	{5} - 1.0072	{6} - .55828	{7} - 4.0355	{8} - 1.1059	{9} - .64486	{10} - 6.2006	{11} - 1.2212	{12} - .51446	{13} - 6.9757	{14} - 1.3423	{15} - .55075
1	Pine	Ap		1.000000	0.060130	0.268997	0.345000	0.061490	1.000000	0.493924	0.086676	0.049554	0.743526	0.051592	0.001892	1.000000	0.059669
2	Pine	Bw	1.000000		1.000000	0.000090	1.000000	1.000000	0.143137	1.000000	1.000000	0.000013	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.060130	1.000000		0.000001	1.000000	1.000000	0.003481	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
4	2	Ap	0.268997	0.000090	0.000001		0.000012	0.000002	1.000000	0.000018	0.000002	1.000000	0.000031	0.000001	1.000000	0.000054	0.000001
5	2	Bw	0.345000	1.000000	1.000000	0.000012		1.000000	0.023784	1.000000	1.000000	0.000002	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	0.061490	1.000000	1.000000	0.000002	1.000000		0.003566	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
7	5	Ap	1.000000	0.143137	0.003481	1.000000	0.023784	0.003566		0.035631	0.005175	0.660286	0.056756	0.002950	0.034128	0.091765	0.003452
8	5	Bw	0.493924	1.000000	1.000000	0.000018	1.000000	1.000000	0.035631		1.000000	0.000003	1.000000	1.000000	0.000000	1.000000	1.000000
9	5	Cu	0.086676	1.000000	1.000000	0.000002	1.000000	1.000000	0.005175	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
10	11	Ap	0.049554	0.000013	0.000000	1.000000	0.000002	0.000000	0.660286	0.000003	0.000000		0.000004	0.000000	1.000000	0.000007	0.000000
11	11	Bw	0.743526	1.000000	1.000000	0.000031	1.000000	1.000000	0.056756	1.000000	1.000000	0.000004		1.000000	0.000000	1.000000	1.000000
12	11	Cu	0.051592	1.000000	1.000000	0.000001	1.000000	1.000000	0.002950	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000
13	LT D	Ap	0.001892	0.000000	0.000000	1.000000	0.000000	0.000000	0.034128	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
14	LT D	Bw	1.000000	1.000000	1.000000	0.000054	1.000000	1.000000	0.091765	1.000000	1.000000	0.000007	1.000000	1.000000	0.000000		1.000000
15	LT D	Cu	0.059669	1.000000	1.000000	0.000001	1.000000	1.000000	0.003452	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	

Table D.7: Bonferroni test of variable N (kg/m^2) for the Atiamuri area. Test errors between MS = 0.00617, df = 45. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - .22232	{2} - .25594	{3} - .22004	{4} - .45868	{5} - .16875	{6} - .22416	{7} - .34938	{8} - .16634	{9} - .28327	{10} - .49122	{11} - .18688	{12} - .19785	{13} - .75836	{14} - .20446	{15} - .24272
1	Pine	Ap		1.000000	1.000000	0.010936	1.000000	1.000000	1.000000	1.000000	1.000000	0.001631	1.000000	1.000000	0.000000	1.000000	1.000000
2	Pine	Bw	1.000000		1.000000	0.071222	1.000000	1.000000	1.000000	1.000000	1.000000	0.011635	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	1.000000	1.000000		0.009594	1.000000	1.000000	1.000000	1.000000	1.000000	0.001424	1.000000	1.000000	0.000000	1.000000	1.000000
4	2	Ap	0.010936	0.071222	0.009594		0.000461	0.012152	1.000000	0.000399	0.297280	1.000000	0.001372	0.002632	0.000256	0.003882	0.034556
5	2	Bw	1.000000	1.000000	1.000000	0.000461		1.000000	0.227961	1.000000	1.000000	0.000063	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	1.000000	1.000000	1.000000	0.012152	1.000000		1.000000	1.000000	1.000000	0.001820	1.000000	1.000000	0.000000	1.000000	1.000000
7	5	Ap	1.000000	1.000000	1.000000	1.000000	0.227961	1.000000		0.201418	1.000000	1.000000	0.563027	0.949340	0.000000	1.000000	1.000000
8	5	Bw	1.000000	1.000000	1.000000	0.000399	1.000000	1.000000	0.201418		1.000000	0.000055	1.000000	1.000000	0.000000	1.000000	1.000000
9	5	Cu	1.000000	1.000000	1.000000	0.297280	1.000000	1.000000	1.000000	1.000000		0.053693	1.000000	1.000000	0.000000	1.000000	1.000000
10	11	Ap	0.001631	0.011635	0.001424	1.000000	0.000063	0.001820	1.000000	0.000055	0.053693		0.000192	0.000375	0.001811	0.000559	0.005425
11	11	Bw	1.000000	1.000000	1.000000	0.001372	1.000000	1.000000	0.563027	1.000000	1.000000	0.000192		1.000000	0.000000	1.000000	1.000000
12	11	Cu	1.000000	1.000000	1.000000	0.002632	1.000000	1.000000	0.949340	1.000000	1.000000	0.000375	1.000000		0.000000	1.000000	1.000000
13	LT D	Ap	0.000000	0.000000	0.000000	0.000256	0.000000	0.000000	0.000000	0.000000	0.000000	0.001811	0.000000	0.000000		0.000000	0.000000
14	LT D	Bw	1.000000	1.000000	1.000000	0.003882	1.000000	1.000000	1.000000	1.000000	1.000000	0.000559	1.000000	1.000000	0.000000		1.000000
15	LT D	Cu	1.000000	1.000000	1.000000	0.034556	1.000000	1.000000	1.000000	1.000000	1.000000	0.005425	1.000000	1.000000	0.000000	1.000000	

Table D.8: Bonferroni test of variable C:N ratio for the Atiamuri area. Test errors between MS = 0.60039, df = 45. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	**Horizon**	**{1} - 15.156**	**{2} - 5.8440**	**{3} - 2.5162**	**{4} - 12.363**	**{5} - 5.8884**	**{6} - 2.4902**	**{7} - 11.581**	**{8} - 6.5321**	**{9} - 2.2689**	**{10} - 12.308**	**{11} - 6.4693**	**{12} - 2.6209**	**{13} - 9.1849**	**{14} - 6.4234**	**{15} - 2.2686**
1	Pine	Ap		0.000000	0.000000	0.000698	0.000000	0.000000	0.000005	0.000000	0.000000	0.000499	0.000000	0.000000	0.000000	0.000000	0.000000
2	Pine	Bw	0.000000		0.000025	0.000000	1.000000	0.000022	0.000000	1.000000	0.000005	0.000000	1.000000	0.000049	0.000023	1.000000	0.000005
3	Pine	Cu	0.000000	0.000025		0.000000	0.000019	1.000000	0.000000	0.000000	1.000000	0.000000	0.000001	1.000000	0.000000	0.000001	1.000000
4	2	Ap	0.000698	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000065	0.000000	0.000000
5	2	Bw	0.000000	1.000000	0.000019	0.000000		0.000016	0.000000	1.000000	0.000004	0.000000	1.000000	0.000037	0.000031	1.000000	0.000004
6	2	Cu	0.000000	0.000022	1.000000	0.000000	0.000016		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000001	1.000000
7	5	Ap	0.000005	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	0.007516	0.000000	0.000000
8	5	Bw	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000001	0.001633	1.000000	0.000000
9	5	Cu	0.000000	0.000005	1.000000	0.000000	0.000004	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000
10	11	Ap	0.000499	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.000091	0.000000	0.000000
11	11	Bw	0.000000	1.000000	0.000001	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000001	0.001117	1.000000	0.000000
12	11	Cu	0.000000	0.000049	1.000000	0.000000	0.000037	1.000000	0.000000	0.000001	1.000000	0.000000	0.000001		0.000000	0.000001	1.000000
13	LT D	Ap	0.000000	0.000023	0.000000	0.000065	0.000031	0.000000	0.007516	0.001633	0.000000	0.000091	0.001117	0.000000		0.000845	0.000000
14	LT D	Bw	0.000000	1.000000	0.000001	0.000000	1.000000	0.000001	0.000000	1.000000	0.000000	0.000000	1.000000	0.000001	0.000845		0.000000
15	LT D	Cu	0.000000	0.000005	1.000000	0.000000	0.000004	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	

Table D.9: Bonferroni test of variable carbon % for the Atiamuri area. Test errors between MS = 0.36179, df = 45. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	**Horizon**	**{1} - 6.6335**	**{2} - 1.0067**	**{3} - .31365**	**{4} - 5.9348**	**{5} - 1.0216**	**{6} - .25718**	**{7} - 5.6733**	**{8} - 1.2623**	**{9} - .25085**	**{10} - 6.7677**	**{11} - 1.2465**	**{12} - .27900**	**{13} - 6.3425**	**{14} - 1.5620**	**{15} - .26987**
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
2	Pine	Bw	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.549668	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
5	2	Bw	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.382577	1.000000
7	5	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
8	5	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	5	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	0.367172	1.000000
10	11	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000
11	11	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000
12	11	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	0.440521	1.000000
13	LT D	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
14	LT D	Bw	0.000000	1.000000	0.549668	0.000000	1.000000	0.382577	0.000000	1.000000	0.367172	0.000000	1.000000	0.440521	0.000000		0.415359
15	LT D	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.415359	

Table D.10: Bonferroni test of variable nitrogen % for the Atiamuri area. Test errors between MS = 0.00158, df = 45. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	**Horizon**	**{1} - .43550**	**{2} - .17142**	**{3} - .12468**	**{4} - .47787**	**{5} - .17258**	**{6} - .10340**	**{7} - .48660**	**{8} - .19148**	**{9} - .11032**	**{10} - .55512**	**{11} - .19150**	**{12} - .10685**	**{13} - .68952**	**{14} - .24162**	**{15} - .11955**
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.011174	0.000000	0.000000	0.000000	0.000002	0.000000
2	Pine	Bw	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.015099	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	0.911792	0.000000	0.000000	0.000000	0.000000	0.000000
5	2	Bw	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	0.323206	1.000000	0.000000	0.322407	1.000000	0.000000	0.001302	1.000000
7	5	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	0.000001	0.000000	0.000000
8	5	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	0.323206	0.000000		0.632736	0.000000	1.000000	0.453286	0.000000	1.000000	1.000000
9	5	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.632736		0.000000	0.631237	1.000000	0.000000	0.002929	1.000000
10	11	Ap	0.011174	0.000000	0.000000	0.911792	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.002040	0.000000	0.000000
11	11	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	0.322407	0.000000	1.000000	0.631237	0.000000		0.452187	0.000000	1.000000	1.000000
12	11	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.453286	1.000000	0.000000	0.452187		0.000000	0.001953	1.000000
13	LT D	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000000	0.000000	0.002040	0.000000	0.000000		0.000000	0.000000
14	LT D	Bw	0.000002	1.000000	0.015099	0.000000	1.000000	0.001302	0.000000	1.000000	0.002929	0.000000	1.000000	0.001953	0.000000		0.008465
15	LT D	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.008465	

Table D.11: Univariate test of significance for carbon (kg/m^2) for the Tokoroa study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	612.8942	1	612.8942	1138.413	0.000000
Treatment	6.9757	5	1.3951	2.591	0.035802
Horizon	203.1098	2	101.5549	188.632	0.000000
Treatment* Horizon	11.0595	10	1.1059	2.054	0.045062
Error	29.0723	54	0.5384		

Table D.12: Univariate test of significance for nitrogen (kg/m^2) for the Tokoroa study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	5.474919	1	5.474919	1792.923	0.000000
Treatment	0.214395	5	0.042879	14.042	0.000000
Horizon	0.597632	2	0.298816	97.856	0.000000
Treatment* Horizon	0.320896	10	0.032090	10.509	0.000000
Error	0.164896	54	0.003054		

Table D.13: Univariate test of significance for C:N ratio for the Tokoroa study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	5.474919	1	5.474919	1792.923	0.000000
Treatment	0.214395	5	0.042879	14.042	0.000000
Horizon	0.597632	2	0.298816	97.856	0.000000
Treatment* Horizon	0.320896	10	0.032090	10.509	0.000000
Error	0.164896	54	0.003054		

Table D.14: Univariate test of significance for carbon % for the Tokoroa study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	927.2991	1	927.2991	3175.473	0.000000
Treatment	9.2625	5	1.8525	6.344	0.000110
Horizon	635.0589	2	317.5294	1087.358	0.000000
Treatment* Horizon	15.7700	10	1.5770	5.400	0.000018
Error	15.4770	53	0.2920		

Table D.15: Univariate test of significance for nitrogen % for the Tokoroa study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	6.583071	1	6.583071	6669.563	0.00
Treatment	0.251365	5	0.050273	50.933	0.00
Horizon	2.811021	2	1.405510	1423.977	0.00
Treatment* Horizon	0.318181	10	0.031818	32.236	0.00
Error	0.052313	53	0.000987		

Table D.16: Bonferroni test of variable carbon (kg/m^2) for the Tokoroa area. Test errors between MS = 0.53838, df = 54. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treat ment	Horizon	{1} - 4.8490	{2} - 2.5182	{3} - 1.1989	{4} - 5.1833	{5} - 2.0853	{6} - 1.5076	{7} - 4.2237	{8} - 1.9017	{9} - 1.5308	{10} - 4.7245	{11} - 1.8086	{12} - 1.2855	{13} - 6.1645	{14} - 1.9608	{15} - 1.1270	{16} - 6.2709	{17} - 2.9615	{18} - 1.2150
1	Pine	Ap		0.005742	0.000001	1.000000	0.000305	0.000005	1.000000	0.000084	0.000006	1.000000	0.000044	0.000001	1.000000	0.000128	0.000000	1.000000	0.094080	0.000001
2	Pine	Bw	0.005742		1.000000	0.000603	1.000000	1.000000	0.272893	1.000000	1.000000	0.012920	1.000000	1.000000	0.000001	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.000001	1.000000		0.000000	1.000000	1.000000	0.000049	1.000000	1.000000	0.000001	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.196570	1.000000
4	2	Ap	1.000000	0.000603	0.000000		0.000029	0.000000	1.000000	0.000008	0.000001	1.000000	0.000004	0.000000	1.000000	0.000012	0.000000	1.000000	0.011684	0.000000
5	2	Bw	0.000305	1.000000	1.000000	0.000029		1.000000	0.019940	1.000000	1.000000	0.000721	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	0.000005	1.000000	1.000000	0.000000	1.000000		0.000424	1.000000	1.000000	0.000012	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
7	3	Ap	1.000000	0.272893	0.000049	1.000000	0.019940	0.000424		0.006083	0.000498	1.000000	0.003285	0.000090	0.068190	0.008955	0.000029	0.035408	1.000000	0.000055
8	3	Bw	0.000084	1.000000	1.000000	0.000008	1.000000	1.000000	0.006083		1.000000	0.000202	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	3	Cu	0.000006	1.000000	1.000000	0.000001	1.000000	1.000000	0.000498	1.000000		0.000015	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
10	5	Ap	1.000000	0.012920	0.000001	1.000000	0.000721	0.000012	1.000000	0.000202	0.000015		0.000105	0.000003	1.000000	0.000305	0.000001	0.658985	0.196072	0.000002
11	5	Bw	0.000044	1.000000	1.000000	0.000004	1.000000	1.000000	0.003285	1.000000	1.000000	0.000105		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
12	5	Cu	0.000001	1.000000	1.000000	0.000000	1.000000	1.000000	0.000090	1.000000	1.000000	0.000003	1.000000		0.000000	1.000000	1.000000	0.000000	0.322523	1.000000
13	LT D	Ap	1.000000	0.000001	0.000000	1.000000	0.000000	0.000000	0.068190	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000014	0.000000
14	LT D	Bw	0.000128	1.000000	1.000000	0.000012	1.000000	1.000000	0.008955	1.000000	1.000000	0.000305	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000
15	LT D	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000029	1.000000	1.000000	0.000001	1.000000	1.000000	0.000000	1.000000		0.000000	0.129060	1.000000
16	LT S/B	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.035408	0.000000	0.000000	0.658985	0.000000	0.000000	1.000000	0.000000	0.000000		0.000006	0.000000
17	LT S/B	Bw	0.094080	1.000000	0.196570	0.011684	1.000000	1.000000	1.000000	1.000000	1.000000	0.196072	1.000000	0.322523	0.000014	1.000000	0.129060	0.000006		0.215735
18	LT S/B	Cu	0.000001	1.000000	1.000000	0.000000	1.000000	1.000000	0.000055	1.000000	1.000000	0.000002	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.215735	

Table D.17: Bonferroni test of variable nitrogen (kg/m^2) for the Tokoroa area. Test errors between MS = 0.00305, df = 54. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treat ment	Horizon	{1} - .29020	{2} - .20586	{3} - .26690	{4} - .33222	{5} - .16181	{6} - .19647	{7} - .28622	{8} - .17531	{9} - .28444	{10} - .31203	{11} - .15406	{12} - .21558	{13} - .59947	{14} - .16786	{15} - .17754	{16} - .59117	{17} - .27451	{18} - .27194
1	Pine	Ap		1.000000	1.000000	1.000000	0.274085	1.000000	1.000000	0.737600	1.000000	1.000000	0.151151	1.000000	0.000000	0.430283	0.863521	0.000000	1.000000	1.000000
2	Pine	Bw	1.000000		1.000000	0.319182	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.852444	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
4	2	Ap	1.000000	0.319182	1.000000		0.008969	0.155756	1.000000	0.028233	1.000000	1.000000	0.004563	0.650916	0.000001	0.015065	0.033990	0.000003	1.000000	1.000000
5	2	Bw	0.274085	1.000000	1.000000	0.008969		1.000000	0.369256	1.000000	0.421024	0.049063	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.860989	1.000000
6	2	Cu	1.000000	1.000000	1.000000	0.155756	1.000000		1.000000	1.000000	1.000000	0.702743	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
7	3	Ap	1.000000	1.000000	1.000000	1.000000	0.369256	1.000000		0.975722	1.000000	1.000000	0.205597	1.000000	0.000000	0.575106	1.000000	0.000000	1.000000	1.000000
8	3	Bw	0.737600	1.000000	1.000000	0.028233	1.000000	1.000000	0.975722		1.000000	0.144433	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	3	Cu	1.000000	1.000000	1.000000	1.000000	0.421024	1.000000	1.000000	1.000000		1.000000	0.235451	1.000000	0.000000	0.653359	1.000000	0.000000	1.000000	1.000000
10	5	Ap	1.000000	1.000000	1.000000	1.000000	0.049063	0.702743	1.000000	0.144433	1.000000		0.025827	1.000000	0.000000	0.080073	0.171800	0.000000	1.000000	1.000000
11	5	Bw	0.151151	1.000000	0.852444	0.004563	1.000000	1.000000	0.205597	1.000000	0.235451	0.025827		1.000000	0.000000	1.000000	1.000000	0.000000	0.494091	0.595425
12	5	Cu	1.000000	1.000000	1.000000	0.650916	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
13	LT D	Ap	0.000000	0.000000	0.000000	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000
14	LT D	Bw	0.430283	1.000000	1.000000	0.015065	1.000000	1.000000	0.575106	1.000000	0.653359	0.080073	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000
15	LT D	Cu	0.863521	1.000000	1.000000	0.033990	1.000000	1.000000	1.000000	1.000000	1.000000	0.171800	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000
16	LT S/B	Ap	0.000000	0.000000	0.000000	0.000003	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
17	LT S/B	Bw	1.000000	1.000000	1.000000	1.000000	0.860989	1.000000	1.000000	1.000000	1.000000	1.000000	0.494091	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000
18	LT S/B	Cu	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.595425	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	

Table D.18: Bonferroni test of variable C:N ratio for the Tokoroa area. Test errors between MS = 1.4488, df = 54. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treat ment	**Horizon**	**{1} - 16.816**	**{2} - 12.263**	**{3} - 4.5570**	**{4} - 15.624**	**{5} - 12.189**	**{6} - 7.9177**	**{7} - 14.651**	**{8} - 11.001**	**{9} - 5.2485**	**{10} - 15.166**	**{11} - 11.272**	**{12} - 5.9589**	**{13} - 10.259**	**{14} - 11.660**	**{15} - 6.2661**	**{16} - 10.606**	**{17} - 10.762**	**{18} - 4.4588**
1	Pine	Ap		0.000281	0.000000	1.000000	0.000205	0.000000	1.000000	0.000001	0.000000	1.000000	0.000004	0.000000	0.000000	0.000021	0.000000	0.000000	0.000000	0.000000
2	Pine	Bw	0.000281		0.000000	0.035126	1.000000	0.000674	1.000000	1.000000	0.000000	0.188865	1.000000	0.000000	1.000000	1.000000	0.000001	1.000000	1.000000	0.000000
3	Pine	Cu	0.000000	0.000000		0.000000	0.000000	0.035097	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000002	0.000000	1.000000	0.000000	0.000000	1.000000
4	2	Ap	1.000000	0.035126	0.000000		0.026469	0.000000	1.000000	0.000209	0.000000	1.000000	0.000658	0.000000	0.000008	0.003260	0.000000	0.000038	0.000075	0.000000
5	2	Bw	0.000205	1.000000	0.000000	0.026469		0.000919	0.841782	1.000000	0.000000	0.145075	1.000000	0.000000	1.000000	1.000000	0.000001	1.000000	1.000000	0.000000
6	2	Cu	0.000000	0.000674	0.035097	0.000000	0.000919		0.000000	0.098650	0.423772	0.000000	0.035902	1.000000	1.000000	0.007949	1.000000	0.397132	0.232106	0.024099
7	3	Ap	1.000000	1.000000	0.000000	1.000000	0.841782	0.000000		0.011466	0.000000	1.000000	0.032827	0.000000	0.000555	0.137926	0.000000	0.002343	0.004414	0.000000
8	3	Bw	0.000001	1.000000	0.000000	0.000209	1.000000	0.098650	0.011466		0.000002	0.001430	1.000000	0.000035	1.000000	1.000000	0.000130	1.000000	1.000000	0.000000
9	3	Cu	0.000000	0.000000	1.000000	0.000000	0.000000	0.423772	0.000000	0.000002		0.000000	0.000000	1.000000	0.000040	0.000000	1.000000	0.000009	0.000004	1.000000
10	5	Ap	1.000000	0.188865	0.000000	1.000000	0.145075	0.000000	1.000000	0.001430	0.000000		0.004335	0.000000	0.000062	0.020099	0.000000	0.000273	0.000527	0.000000
11	5	Bw	0.000004	1.000000	0.000000	0.000658	1.000000	0.035902	0.032827	1.000000	0.000000	0.004335		0.000011	1.000000	1.000000	0.000040	1.000000	1.000000	0.000000
12	5	Cu	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000035	1.000000	0.000000	0.000011		0.000815	0.000002	1.000000	0.000188	0.000097	1.000000
13	LT D	Ap	0.000000	1.000000	0.000002	0.000008	1.000000	1.000000	0.000555	1.000000	0.000040	0.000062	1.000000	0.000815		1.000000	0.002894	1.000000	1.000000	0.000001
14	LT D	Bw	0.000021	1.000000	0.000000	0.003260	1.000000	0.007949	0.137926	1.000000	0.000000	0.020099	1.000000	0.000002	1.000000		0.000007	1.000000	1.000000	0.000000
15	LT D	Cu	0.000000	0.000001	1.000000	0.000000	0.000001	1.000000	0.000000	0.000130	1.000000	0.000000	0.000040	1.000000	0.002894	0.000007		0.000690	0.000358	1.000000
16	LT S/B	Ap	0.000000	1.000000	0.000000	0.000038	1.000000	0.397132	0.002343	1.000000	0.000009	0.000273	1.000000	0.000188	1.000000	1.000000	0.000690		1.000000	0.000000
17	LT S/B	Bw	0.000000	1.000000	0.000000	0.000075	1.000000	0.232106	0.004414	1.000000	0.000004	0.000527	1.000000	0.000097	1.000000	1.000000	0.000358	1.000000		0.000000
18	LT S/B	Cu	0.000000	0.000000	1.000000	0.000000	0.000000	0.024099	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000001	0.000000	1.000000	0.000000	0.000000	

Table D.19: Bonferroni test of variable carbon % for the Tokoroa area. Test errors between MS = 0.29202, df = 53. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - 8.4973	{2} - 2.2263	{3} - .53103	{4} - 7.4425	{5} - 2.4965	{6} - .86550	{7} - 5.9900	{8} - 2.0460	{9} - .68180	{10} - 8.1155	{11} - 2.3540	{12} - .73077	{13} - 7.4088	{14} - 2.5368	{15} - .88828	{16} - 9.2750	{17} - 2.5077	{18} - .59933
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	0.000004	0.000000	0.000000	1.000000	0.000000	0.000000	0.954321	0.000000	0.000000	1.000000	0.000000	0.000000
2	Pine	Bw	0.000000		0.007119	0.000000	1.000000	0.120835	0.000000	1.000000	0.026388	0.000000	1.000000	0.039933	0.000000	1.000000	0.144969	0.000000	1.000000	0.012966
3	Pine	Cu	0.000000	0.007119		0.000000	0.000611	1.000000	0.000000	0.033884	1.000000	0.000000	0.002264	1.000000	0.000000	0.000420	1.000000	0.000000	0.000551	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	0.057154	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.007035	0.000000	0.000000
5	2	Bw	0.000000	1.000000	0.000611	0.000000		0.012514	0.000000	1.000000	0.002440	0.000000	1.000000	0.003797	0.000000	1.000000	0.015253	0.000000	1.000000	0.001149
6	2	Cu	0.000000	0.120835	1.000000	0.000000	0.012514		0.000000	0.488260	1.000000	0.000000	0.042340	1.000000	0.000000	0.008796	1.000000	0.000000	0.011343	1.000000
7	3	Ap	0.000004	0.000000	0.000000	0.057154	0.000000	0.000000		0.000000	0.000000	0.000136	0.000000	0.000000	0.075482	0.000000	0.000000	0.000000	0.000000	0.000000
8	3	Bw	0.000000	1.000000	0.033884	0.000000	1.000000	0.488260	0.000000		0.117532	0.000000	1.000000	0.173616	0.000000	1.000000	0.578007	0.000000	1.000000	0.059978
9	3	Cu	0.000000	0.026388	1.000000	0.000000	0.002440	1.000000	0.000000	0.117532		0.000000	0.008723	1.000000	0.000000	0.001692	1.000000	0.000000	0.002204	1.000000
10	5	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000136	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
11	5	Bw	0.000000	1.000000	0.002264	0.000000	1.000000	0.042340	0.000000	1.000000	0.008723	0.000000		0.013391	0.000000	1.000000	0.051210	0.000000	1.000000	0.004192
12	5	Cu	0.000000	0.039933	1.000000	0.000000	0.003797	1.000000	0.000000	0.173616	1.000000	0.000000	0.013391		0.000000	0.002641	1.000000	0.000000	0.003431	1.000000
13	LT D	Ap	0.954321	0.000000	0.000000	1.000000	0.000000	0.000000	0.075482	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.005330	0.000000	0.000000
14	LT D	Bw	0.000000	1.000000	0.000420	0.000000	1.000000	0.008796	0.000000	1.000000	0.001692	0.000000	1.000000	0.002641	0.000000		0.010742	0.000000	1.000000	0.000793
15	LT D	Cu	0.000000	0.144969	1.000000	0.000000	0.015253	1.000000	0.000000	0.578007	1.000000	0.000000	0.051210	1.000000	0.000000	0.010742		0.000000	0.013834	1.000000
16	LT S/B	Ap	1.000000	0.000000	0.000000	0.007035	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.005330	0.000000	0.000000		0.000000	0.000000
17	LT S/B	Bw	0.000000	1.000000	0.000551	0.000000	1.000000	0.011343	0.000000	1.000000	0.002204	0.000000	1.000000	0.003431	0.000000	1.000000	0.013834	0.000000		0.001036
18	LT S/B	Cu	0.000000	0.012966	1.000000	0.000000	0.001149	1.000000	0.000000	0.059978	1.000000	0.000000	0.004192	1.000000	0.000000	0.000793	1.000000	0.000000	0.001036	

Table D.20: Bonferroni test of variable nitrogen % for the Tokoroa area. Test errors between MS = 0.00099, df = 53. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - .50605	{2} - .18170	{3} - .11698	{4} - .47525	{5} - .20203	{6} - .11055	{7} - .40745	{8} - .18515	{9} - .12983	{10} - .53470	{11} - .20428	{12} - .12078	{13} - .72328	{14} - .21910	{15} - .14195	{16} - .86897	{17} - .23217	{18} - .13275
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	0.007072	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	Pine	Bw	0.000000		0.799022	0.000000	1.000000	0.352475	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.000000	0.799022		0.000000	0.052428	1.000000	0.000000	0.517638	1.000000	0.000000	0.037929	1.000000	0.000000	0.004121	1.000000	0.000000	0.000527	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	0.542980	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	2	Bw	0.000000	1.000000	0.052428	0.000000		0.020597	0.000000	1.000000	0.307116	0.000000	1.000000	0.089756	0.000000	1.000000	1.000000	0.000000	1.000000	0.449544
6	2	Cu	0.000000	0.352475	1.000000	0.000000	0.020597		0.000000	0.223260	1.000000	0.000000	0.014748	1.000000	0.000000	0.001514	1.000000	0.000000	0.000187	1.000000
7	3	Ap	0.007072	0.000000	0.000000	0.542980	0.000000	0.000000		0.000000	0.000000	0.000075	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	3	Bw	0.000000	1.000000	0.517638	0.000000	1.000000	0.223260	0.000000		1.000000	0.000000	1.000000	0.834400	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	3	Cu	0.000000	1.000000	1.000000	0.000000	0.307116	1.000000	0.000000	1.000000		0.000000	0.227791	1.000000	0.000000	0.028458	1.000000	0.000000	0.003980	1.000000
10	5	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000075	0.000000	0.000000		0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
11	5	Bw	0.000000	1.000000	0.037929	0.000000	1.000000	0.014748	0.000000	1.000000	0.227791	0.000000		0.065376	0.000000	1.000000	1.000000	0.000000	1.000000	0.335595
12	5	Cu	0.000000	1.000000	1.000000	0.000000	0.089756	1.000000	0.000000	0.834400	1.000000	0.000000	0.065376		0.000000	0.007374	1.000000	0.000000	0.000965	1.000000
13	LT D	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000		0.000000	0.000000	0.000021	0.000000	0.000000
14	LT D	Bw	0.000000	1.000000	0.004121	0.000000	1.000000	0.001514	0.000000	1.000000	0.028458	0.000000	1.000000	0.007374	0.000000		0.158156	0.000000	1.000000	0.043505
15	LT D	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.158156		0.000000	0.024761	1.000000
16	LT S/B	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000021	0.000000	0.000000		0.000000	0.000000
17	LT S/B	Bw	0.000000	1.000000	0.000527	0.000000	1.000000	0.000187	0.000000	1.000000	0.003980	0.000000	1.000000	0.000965	0.000000	1.000000	0.024761	0.000000		0.006236
18	LT S/B	Cu	0.000000	1.000000	1.000000	0.000000	0.449544	1.000000	0.000000	1.000000	1.000000	0.000000	0.335595	1.000000	0.000000	0.043505	1.000000	0.000000	0.006236	

Table D.21: Univariate test of significance for carbon (kg/m^2) for the Wairakei study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	567.0782	1	567.0782	945.2242	0.000000
Treatment	34.8108	6	5.8018	9.6706	0.000000
Horizon	446.7839	2	223.3920	372.3570	0.000000
Treatment* Horizon	38.0963	12	3.1747	5.2917	0.000004
Error	37.7962	63	0.5999		

Table D.22: Univariate test of significance for nitrogen (kg/m^2) for the Wairakei study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	6.425035	1	6.425035	1483.801	0.000000
Treatment	0.503350	6	0.083892	19.374	0.000000
Horizon	1.178053	2	0.589027	136.030	0.000000
Treatment* Horizon	0.711409	12	0.059284	13.691	0.000000
Error	0.272798	63	0.004330		

Table D.23: Univariate test of significance for C:N ratio for the Wairakei study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	5392.171	1	5392.171	4049.743	0.000000
Treatment	143.147	6	23.858	17.918	0.000000
Horizon	1851.211	2	925.605	695.168	0.000000
Treatment* Horizon	110.439	12	9.203	6.912	0.000000
Error	83.884	63	1.331		

Table D.24: Univariate test of significance for carbon % ratio for the Wairakei study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	675.1320	1	675.1320	1723.619	0.000000
Treatment	12.1317	6	2.0220	5.162	0.000227
Horizon	729.8469	2	364.9235	931.653	0.000000
Treatment* Horizon	14.0367	12	1.1697	2.986	0.002347
Error	24.6767	63	0.3917		

Table D.25: Univariate test of significance for nitrogen % ratio for the Wairakei study area. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept	5.808460	1	5.808460	4776.136	0.000000
Treatment	0.197833	6	0.032972	27.112	0.000000
Horizon	2.644186	2	1.322093	1087.121	0.000000
Treatment* Horizon	0.199345	12	0.016612	13.660	0.000000
Error	0.076617	63	0.001216		

Table D.26: Bonferroni test of variable carbon (kg/m^2) for the Wairakei area. Test errors between MS = 0.59994, df = 63. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - 2.8639	{2} - .88968	{3} - .42350	{4} - 5.4215	{5} - 1.1790	{6} - .56585	{7} - 4.5204	{8} - 1.2339	{9} - .52456	{10} - 6.3166	{11} - 1.6438	{12} - .35925	{13} - 6.8937	{14} - 2.4442	{15} - .55465	{16} - 6.9307	{17} - 1.4734	{18} - .35855	{19} - 7.6630	{20} - 1.8380	{21} - .46525
1	Pine	Ap		0.129749	0.007348	0.003420	0.650809	0.018217	0.756266	0.868771	0.014036	0.000007	1.000000	0.004839	0.000000	1.000000	0.016977	0.000000	1.000000	0.004816	0.000000	1.000000	0.009614
2	Pine	Bw	0.129749		1.000000	0.000000	1.000000	1.000000	0.000002	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.007348	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.098878	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
4	2	Ap	0.003420	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000001	0.000000	1.000000	0.000198	0.000000	1.000000	0.000000	0.000000	0.025943	0.000003	0.000000
5	2	Bw	0.650809	1.000000	1.000000	0.000000		1.000000	0.000015	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	0.018217	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.225055	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
7	3	Ap	0.756266	0.000002	0.000000	1.000000	0.000015	0.000000		0.000022	0.000000	0.356212	0.000397	0.000000	0.011314	0.071074	0.000000	0.008927	0.000121	0.000000	0.000062	0.001489	0.000000
8	3	Bw	0.868771	1.000000	1.000000	0.000000	1.000000	1.000000	0.000022		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	3	Cu	0.014036	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	0.177899	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
10	4	Ap	0.000007	0.000000	0.000000	1.000000	0.000000	0.000000	0.356212	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
11	4	Bw	1.000000	1.000000	1.000000	0.000001	1.000000	1.000000	0.000397	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
12	4	Cu	0.004839	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	0.067497	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
13	5	Ap	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.011314	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
14	5	Bw	1.000000	1.000000	0.098878	0.000198	1.000000	0.225055	0.071074	1.000000	0.177899	0.000000	1.000000	0.067497	0.000000		0.211215	0.000000	1.000000	0.067213	0.000000	1.000000	0.126279
15	5	Cu	0.016977	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.211215		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
16	LT D (A)	Ap	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.008927	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000
17	LT D (A)	Bw	1.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000121	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000
18	LT D (A)	Cu	0.004816	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.067213	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000
19	LT D (B)	Ap	0.000000	0.000000	0.000000	0.025943	0.000000	0.000000	0.000062	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
20	LT D (B)	Bw	1.000000	1.000000	1.000000	0.000003	1.000000	1.000000	0.001489	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000
21	LT D (B)	Cu	0.009614	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.126279	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	

Table D.27: Bonferroni test of variable nitrogen (kg/m^2) for the Wairakei area. Test errors between MS = 0.00433, df = 63. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - .19222	{2} - .13132	{3} - .17209	{4} - .33613	{5} - .14251	{6} - .23134	{7} - .27652	{8} - .16197	{9} - .22371	{10} - .44719	{11} - .20179	{12} - .13188	{13} - .40004	{14} - .28013	{15} - .15946	{16} - .74025	{17} - .25591	{18} - .12431	{19} - .70459	{20} - .32292	{21} - .17163
1	Pine	Ap		1.000000	1.000000	0.619996	1.000000	1.000000	1.000000	1.000000	1.000000	0.000167	1.000000	1.000000	0.007077	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
2	Pine	Bw	1.000000		1.000000	0.008893	1.000000	1.000000	0.571928	1.000000	1.000000	0.000001	1.000000	1.000000	0.000054	0.454566	1.000000	0.000000	1.000000	1.000000	0.000000	0.023821	1.000000
3	Pine	Cu	1.000000	1.000000		0.166659	1.000000	1.000000	1.000000	1.000000	1.000000	0.000031	1.000000	1.000000	0.001481	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.399318	1.000000
4	2	Ap	0.619996	0.008893	0.166659		0.020518	1.000000	1.000000	0.083081	1.000000	1.000000	1.000000	0.009276	1.000000	1.000000	0.069708	0.000000	1.000000	0.005212	0.000000	1.000000	0.161617
5	2	Bw	1.000000	1.000000	1.000000	0.020518		1.000000	1.000000	1.000000	1.000000	0.000003	1.000000	1.000000	0.000135	0.915373	1.000000	0.000000	1.000000	1.000000	0.000000	0.053486	1.000000
6	2	Cu	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	0.003818	1.000000	1.000000	0.121329	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
7	3	Ap	1.000000	0.571928	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	0.105896	1.000000	0.592399	1.000000	1.000000	1.000000	0.000000	1.000000	0.365286	0.000000	1.000000	1.000000
8	3	Bw	1.000000	1.000000	1.000000	0.083081	1.000000	1.000000	1.000000		1.000000	0.000013	1.000000	1.000000	0.000661	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.205302	1.000000
9	3	Cu	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.002106	1.000000	1.000000	0.071369	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
10	4	Ap	0.000167	0.000001	0.000031	1.000000	0.000003	0.003818	0.105896	0.000013	0.002106		0.000365	0.000001	1.000000	0.135764	0.000011	0.000007	0.024367	0.000001	0.000137	1.000000	0.000030
11	4	Bw	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000365		1.000000	0.014563	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
12	4	Cu	1.000000	1.000000	1.000000	0.009276	1.000000	1.000000	0.592399	1.000000	1.000000	0.000001	1.000000		0.000056	0.471079	1.000000	0.000000	1.000000	1.000000	0.000000	0.024816	1.000000
13	5	Ap	0.007077	0.000054	0.001481	1.000000	0.000135	0.121329	1.000000	0.000661	0.071369	1.000000	0.014563	0.000056		1.000000	0.000540	0.000000	0.611627	0.000030	0.000003	1.000000	0.001429
14	5	Bw	1.000000	0.454566	1.000000	1.000000	0.915373	1.000000	1.000000	1.000000	1.000000	0.135764	1.000000	0.471079	1.000000		1.000000	0.000000	1.000000	0.288501	0.000000	1.000000	1.000000
15	5	Cu	1.000000	1.000000	1.000000	0.069708	1.000000	1.000000	1.000000	1.000000	1.000000	0.000011	1.000000	1.000000	0.000540	1.000000		0.000000	1.000000	1.000000	0.000000	0.173521	1.000000
16	LT D (A)	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000007	0.000000	0.000000	0.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000
17	LT D (A)	Bw	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.024367	1.000000	1.000000	0.611627	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000
18	LT D (A)	Cu	1.000000	1.000000	1.000000	0.005212	1.000000	1.000000	0.365286	1.000000	1.000000	0.000001	1.000000	1.000000	0.000030	0.288501	1.000000	0.000000	1.000000		0.000000	0.014182	1.000000
19	LT D (B)	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000137	0.000000	0.000000	0.000003	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
20	LT D (B)	Bw	1.000000	0.023821	0.399318	1.000000	0.053486	1.000000	1.000000	0.205302	1.000000	1.000000	1.000000	0.024816	1.000000	1.000000	0.173521	0.000000	1.000000	0.014182	0.000000		0.387791
21	LT D (B)	Cu	1.000000	1.000000	1.000000	0.161617	1.000000	1.000000	1.000000	1.000000	1.000000	0.000030	1.000000	1.000000	0.001429	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.387791	

Table D.28: Bonferroni test of variable C:N ratio for the Wairakei area. Test errors between MS = 1.3315, df = 63. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - 14.817	{2} - 6.5784	{3} - 2.4701	{4} - 16.105	{5} - 8.3633	{6} - 2.5243	{7} - 16.197	{8} - 7.6998	{9} - 2.3369	{10} - 14.136	{11} - 7.6423	{12} - 2.7115	{13} - 17.458	{14} - 8.6849	{15} - 3.5107	{16} - 9.3680	{17} - 5.5149	{18} - 2.9507	{19} - 10.880	{20} - 5.6899	{21} - 2.6153
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.405669	0.000000	0.000000	0.000002	0.000000	0.000000	0.001940	0.000000	0.000000
2	Pine	Bw	0.000000		0.000895	0.000000	1.000000	0.001145	0.000000	1.000000	0.000486	0.000000	1.000000	0.002658	0.000000	1.000000	0.078677	0.232569	1.000000	0.007606	0.000369	1.000000	0.001727
3	Pine	Cu	0.000000	0.000895		0.000000	0.000000	1.000000	0.000000	0.000004	1.000000	0.000000	0.000006	1.000000	0.000000	0.000000	1.000000	0.000000	0.086211	1.000000	0.000000	0.042527	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000005	0.000000	0.000000
5	2	Bw	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000001	0.000000	1.000000	0.000027	1.000000	0.185821	0.000002	0.636355	0.359418	0.000000
6	2	Cu	0.000000	0.001145	1.000000	0.000000	0.000000		0.000000	0.000006	1.000000	0.000000	0.000008	1.000000	0.000000	0.000000	1.000000	0.000000	0.106852	1.000000	0.000000	0.053049	1.000000
7	3	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000003	0.000000	0.000000
8	3	Bw	0.000000	1.000000	0.000004	0.000000	1.000000	0.000006	0.000000		0.000002	0.000000	1.000000	0.000014	0.000000	1.000000	0.000619	1.000000	1.000000	0.000045	0.050052	1.000000	0.000009
9	3	Cu	0.000000	0.000486	1.000000	0.000000	0.000000	1.000000	0.000000	0.000002		0.000000	0.000003	1.000000	0.000000	0.000000	1.000000	0.000000	0.050435	1.000000	0.000000	0.024505	1.000000
10	4	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.027892	0.000002	0.000000	0.000041	0.000000	0.000000	0.036657	0.000000	0.000000
11	4	Bw	0.000000	1.000000	0.000006	0.000000	1.000000	0.000008	0.000000	1.000000	0.000003	0.000000		0.000019	0.000000	1.000000	0.000805	1.000000	1.000000	0.000059	0.039565	1.000000	0.000012
12	4	Cu	0.000000	0.002658	1.000000	0.000000	0.000001	1.000000	0.000000	0.000014	1.000000	0.000000	0.000019		0.000000	0.000000	1.000000	0.000000	0.220693	1.000000	0.000000	0.112152	1.000000
13	5	Ap	0.405669	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.027892	0.000000	0.000000		0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
14	5	Bw	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000002	1.000000	0.000000	0.000000		0.000006	1.000000	0.052106	0.000000	1.000000	0.105008	0.000000
15	5	Cu	0.000000	0.078677	1.000000	0.000000	0.000027	1.000000	0.000000	0.000619	1.000000	0.000000	0.000805	1.000000	0.000000	0.000006		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
16	LT D (A)	Ap	0.000002	0.232569	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000041	1.000000	0.000000	0.000000	1.000000	0.000000		0.002826	0.000000	1.000000	0.006108	0.000000
17	LT D (A)	Bw	0.000000	1.000000	0.086211	0.000000	0.185821	0.106852	0.000000	1.000000	0.050435	0.000000	1.000000	0.220693	0.000000	0.052106	1.000000	0.002826		0.535941	0.000002	1.000000	0.152498
18	LT D (A)	Cu	0.000000	0.007606	1.000000	0.000000	0.000002	1.000000	0.000000	0.000045	1.000000	0.000000	0.000059	1.000000	0.000000	0.000000	1.000000	0.000000	0.535941		0.000000	0.281308	1.000000
19	LT D (B)	Ap	0.001940	0.000369	0.000000	0.000005	0.636355	0.000000	0.000003	0.050052	0.000000	0.036657	0.039565	0.000000	0.000000	1.000000	0.000000	1.000000	0.000002	0.000000		0.000005	0.000000
20	LT D (B)	Bw	0.000000	1.000000	0.042527	0.000000	0.359418	0.053049	0.000000	1.000000	0.024505	0.000000	1.000000	0.112152	0.000000	0.105008	1.000000	0.006108	1.000000	0.281308	0.000005		0.076556
21	LT D (B)	Cu	0.000000	0.001727	1.000000	0.000000	0.000000	1.000000	0.000000	0.000009	1.000000	0.000000	0.000012	1.000000	0.000000	0.000000	1.000000	0.000000	0.152498	1.000000	0.000000	0.076556	

Table D.29: Bonferroni test of variable carbon % for the Wairakei area. Test errors between MS = 0.39169, df = 63. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	Horizon	{1} - 5.5557	{2} - 1.0524	{3} - .21413	{4} - 6.6117	{5} - 1.0981	{6} - .25003	{7} - 6.7372	{8} - 1.2422	{9} - .23440	{10} - 7.2728	{11} - 1.5607	{12} - .29315	{13} - 8.9177	{14} - 1.4775	{15} - .38725	{16} - 6.5313	{17} - 1.1217	{18} - .31607	{19} - 7.1400	{20} - 1.1904	{21} - .33085
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.053034	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.140399	0.000000	0.000000
2	Pine	Bw	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.717347	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000464	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
5	2	Bw	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
6	2	Cu	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	0.905286	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
7	3	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	0.001335	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
8	3	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	3	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	0.818473	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
10	4	Ap	0.053034	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.090390	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000
11	4	Bw	0.000000	1.000000	0.717347	0.000000	1.000000	0.905286	0.000000	1.000000	0.818473	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
12	4	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
13	5	Ap	0.000000	0.000000	0.000000	0.000464	0.000000	0.000000	0.001335	0.000000	0.000000	0.090390	0.000000	0.000000		0.000000	0.000000	0.000233	0.000000	0.000000	0.033514	0.000000	0.000000
14	5	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
15	5	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
16	LT D (A)	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000233	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000
17	LT D (A)	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000
18	LT D (A)	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000
19	LT D (B)	Ap	0.140399	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.033514	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
20	LT D (B)	Bw	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000
21	LT D (B)	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	

Table D.30: Bonferroni test of variable nitrogen % for the Wairakei area. Test errors between MS = 0.00122, df = 63. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treat ment	Horiz on	{1} - .37448	{2} - .15950	{3} - .08675	{4} - .41037	{5} - .13060	{6} - .09940	{7} - .41115	{8} - .15925	{9} - .10033	{10} - .51517	{11} - .19165	{12} - .10775	{13} - .51105	{14} - .16940	{15} - .10953	{16} - .69717	{17} - .19753	{18} - .10755	{19} - .65602	{20} - .20372	{21} - .12380
1	Pine	Ap		0.000000	0.000000	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000070	0.000000	0.000000	0.000133	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000000
2	Pine	Bw	0.000000		0.935194	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
3	Pine	Cu	0.000000	0.935194		0.000000	1.000000	1.000000	0.000000	0.962468	1.000000	0.000000	0.014904	1.000000	0.000000	0.285973	1.000000	0.000000	0.006457	1.000000	0.000000	0.002615	1.000000
4	2	Ap	1.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	0.015115	0.000000	0.000000	0.026841	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
5	2	Bw	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.895626	1.000000
6	2	Cu	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	1.000000	1.000000	0.000000	0.083646	1.000000	0.000000	1.000000	1.000000	0.000000	0.038064	1.000000	0.000000	0.016157	1.000000
7	3	Ap	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.016851	0.000000	0.000000	0.029861	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
8	3	Bw	0.000000	1.000000	0.962468	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
9	3	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000		0.000000	0.094465	1.000000	0.000000	1.000000	1.000000	0.000000	0.043158	1.000000	0.000000	0.018390	1.000000
10	4	Ap	0.000070	0.000000	0.000000	0.015115	0.000000	0.000000	0.016851	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000068	0.000000	0.000000
11	4	Bw	0.000000	1.000000	0.014904	0.000000	1.000000	0.083646	0.000000	1.000000	0.094465	0.000000		0.244719	0.000000	1.000000	0.305188	0.000000	1.000000	0.238666	0.000000	1.000000	1.000000
12	4	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.244719		0.000000	1.000000	1.000000	0.000000	0.115651	1.000000	0.000000	0.050922	1.000000
13	5	Ap	0.000133	0.000000	0.000000	0.026841	0.000000	0.000000	0.029861	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000	0.000000	0.000000	0.000000	0.000036	0.000000	0.000000
14	5	Bw	0.000000	1.000000	0.285973	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000		1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000
15	5	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.305188	1.000000	0.000000	1.000000		0.000000	0.145471	1.000000	0.000000	0.064590	1.000000
16	LT D (A)	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000		0.000000	0.000000	1.000000	0.000000	0.000000
17	LT D (A)	Bw	0.000000	1.000000	0.006457	0.000000	1.000000	0.038064	0.000000	1.000000	0.043158	0.000000	1.000000	0.115651	0.000000	1.000000	0.145471	0.000000		0.112682	0.000000	1.000000	0.835536
18	LT D (A)	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.238666	1.000000	0.000000	1.000000	1.000000	0.000000	0.112682		0.000000	0.049569	1.000000
19	LT D (B)	Ap	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000068	0.000000	0.000000	0.000036	0.000000	0.000000	1.000000	0.000000	0.000000		0.000000	0.000000
20	LT D (B)	Bw	0.000001	1.000000	0.002615	0.000000	0.895626	0.016157	0.000000	1.000000	0.018390	0.000000	1.000000	0.050922	0.000000	1.000000	0.064590	0.000000	1.000000	0.049569	0.000000		0.399749
21	LT D (B)	Cu	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.835536	1.000000	0.000000	0.399749	

Table D.31: Univariate test of significance for carbon (t/ha) for all three study areas. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept		0			
Treatment	2481.56	2	1240.781	5.914513	0.004757
Horizon		0			
Treatment* Horizon	5641.20	6	940.200	4.481715	0.000945
Error	11328.43	54	209.786		

Table D.32: Univariate test of significance for nitrogen (t/ha) for all three study areas. Tests are sigma-restricted parameterization. SS is the sum of squares. MS is the mean of squares. F is the distribution. P is the probability.

	SS	Degr. of Freedom	MS	F	P
Intercept		0			
Treatment	9.95019	2	4.975093	4.050006	0.022970
Horizon		0			
Treatment* Horizon	26.93972	6	4.489953	3.655075	0.004065
Error	66.33448	54	1.228416		

Table D.33: Bonferroni test of variable carbon (t/ha) for all three study areas. Test errors between MS = 209.79, df = 54. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	**Area**	**{1} - 53.618**	**{2} - 85.662**	**{3} - 41.771**	**{4} - 73.305**	**{5} - 87.762**	**{6} - 71.663**	**{8} - 76.562**	**{9} - 62.789**	**{12} - 83.196**	**{13} - 57.862**	**{14} - 78.186**	**{15} - 98.925**	**{16} - 79.363**	**{19} - 88.687**	**{20} - 92.523**	**{23} - 104.47**	**{27} - 87.626**	**{30} - 99.663**
1	Pine	Ati		0.432890	1.000000	1.000000	0.237580	1.000000	1.000000	1.000000	0.851858	1.000000	1.000000	0.007252	1.000000	0.181223	0.056753	0.001108	0.247116	0.005675
2	Pine	Tok	0.432890		0.011563	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
3	Pine	Wai	1.000000	0.011563		0.499092	0.005777	0.782759	0.196700	1.000000	0.025668	1.000000	0.121416	0.000122	0.085028	0.004239	0.001148	0.000017	0.006044	0.000094
4	2	Ati	1.000000	1.000000	0.499092		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.552369	1.000000	1.000000
5	2	Tok	0.237580	1.000000	0.005777	1.000000		1.000000	1.000000	1.000000	1.000000	0.781219	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
6	2	Wai	1.000000	1.000000	0.782759	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.348555	1.000000	1.000000
7	3	Ati																		
8	3	Tok	1.000000	1.000000	0.196700	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
9	3	Wai	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	0.132031	1.000000	1.000000	0.816837	0.023620	1.000000	0.105758
10	4	Ati																		
11	4	Tok																		
12	4	Wai	0.851858	1.000000	0.025668	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
13	5	Ati	1.000000	1.000000	1.000000	1.000000	0.781219	1.000000	1.000000	1.000000	1.000000		1.000000	0.028810	1.000000	0.607202	0.204321	0.004695	0.810304	0.022762
14	5	Tok	1.000000	1.000000	0.121416	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
15	5	Wai	0.007252	1.000000	0.000122	1.000000	1.000000	1.000000	1.000000	0.132031	1.000000	0.028810	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
16	11	Ati	1.000000	1.000000	0.085028	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000
17	11	Tok																		
18	11	Wai																		
19	LT D	Ati	0.181223	1.000000	0.004239	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.607202	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000
20	LT D	Tok	0.056753	1.000000	0.001148	1.000000	1.000000	1.000000	1.000000	0.816837	1.000000	0.204321	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000
21	LT D	Wai																		

22	LT S/B	Ati																		
23	LT S/B	Tok	0.001108	1.000000	0.000017	0.552369	1.000000	0.348555	1.000000	0.023620	1.000000	0.004695	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000
24	LT S/B	Wai																		
25	LT D (A)	Ati																		
26	LT D (A)	Tok																		
27	LT D (A)	Wai	0.247116	1.000000	0.006044	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.810304	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000
28	LT D (B)	Ati																		
29	LT D (B)	Tok																		
30	LT D (B)	Wai	0.005675	1.000000	0.000094	1.000000	1.000000	1.000000	1.000000	0.105758	1.000000	0.022762	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	

Table D.34: Bonferroni test of variable nitrogen (t/ha) for all three study areas. Test errors between MS = 1.2284, df = 54. Numbers in brackets along the top row correspond to the numbers down the first column. Each number represents the treatment and horizon following it.

	Treatment	**Area**	**{1} - 6.9830**	**{2} - 7.6295**	**{3} - 4.9562**	**{4} - 8.5159**	**{5} - 6.9050**	**{6} - 7.0998**	**{8} - 7.4597**	**{9} - 6.6219**	**{12} - 7.8086**	**{13} - 7.9899**	**{14} - 6.8167**	**{15} - 8.3964**	**{16} - 8.7595**	**{19} - 12.055**	**{20} - 9.4487**	**{23} - 11.376**	**{27} - 11.205**	**{30} - 11.991**
1	Pine	Ati		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000005	0.411610	0.000111	0.000246	0.000006
2	Pine	Tok	1.000000		0.188507	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000095	1.000000	0.002121	0.004527	0.000128
3	Pine	Wai	1.000000	0.188507		0.004842	1.000000	1.000000	0.357967	1.000000	0.093617	0.045062	1.000000	0.008143	0.001647	0.000000	0.000070	0.000000	0.000000	0.000000
4	2	Ati	1.000000	1.000000	0.004842		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.005290	1.000000	0.090746	0.177675	0.006990
5	2	Tok	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000003	0.308162	0.000077	0.000171	0.000004
6	2	Wai	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000008	0.628953	0.000191	0.000420	0.000011
7	3	Ati																		
8	3	Tok	1.000000	1.000000	0.357967	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.000043	1.000000	0.000990	0.002138	0.000058

9	3	Wai	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	1.000000	0.000001	0.103604	0.000020	0.000046	0.000001
10	4	Ati																		
11	4	Tok																		
12	4	Wai	1.000000	1.000000	0.093617	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	1.000000	0.000219	1.000000	0.004679	0.009848	0.000294
13	5	Ati	1.000000	1.000000	0.045062	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	0.000503	1.000000	0.010271	0.021278	0.000674
14	5	Tok	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	1.000000	0.000002	0.220799	0.000051	0.000114	0.000003
15	5	Wai	1.000000	1.000000	0.008143	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	0.003129	1.000000	0.056132	0.111483	0.004149
16	11	Ati	1.000000	1.000000	0.001647	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000		0.015103	1.000000	0.234091	0.444025	0.019799
17	11	Tok																		
18	11	Wai																		
19	LT D	Ati	0.000005	0.000095	0.000000	0.005290	0.000003	0.000008	0.000043	0.000001	0.000219	0.000503	0.000002	0.003129	0.015103		0.243087	1.000000	1.000000	1.000000
20	LT D	Tok	0.411610	1.000000	0.000070	1.000000	0.308162	0.628953	1.000000	0.103604	1.000000	1.000000	0.220799	1.000000	1.000000	0.243087		1.000000	1.000000	0.309430
21	LT D	Wai																		
22	LT S/B	Ati																		
23	LT S/B	Tok	0.000111	0.002121	0.000000	0.090746	0.000077	0.000191	0.000990	0.000020	0.004679	0.010271	0.000051	0.056132	0.234091	1.000000	1.000000		1.000000	1.000000
24	LT S/B	Wai																		
25	LT D (A)	Ati																		
26	LT D (A)	Tok																		
27	LT D (A)	Wai	0.000246	0.004527	0.000000	0.177675	0.000171	0.000420	0.002138	0.000046	0.009848	0.021278	0.000114	0.111483	0.444025	1.000000	1.000000	1.000000		1.000000
28	LT D (B)	Ati																		
29	LT D (B)	Tok																		
30	LT D (B)	Wai	0.000006	0.000128	0.000000	0.006990	0.000004	0.000011	0.000058	0.000001	0.000294	0.000674	0.000003	0.004149	0.019799	1.000000	0.309430	1.000000	1.000000	