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Nutrient Accumulation in Soils Under Long-Term Farm Dairy Effluent Application

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Abstract

Land-based application of farm dairy effluent (FDE) has been encouraged by regional councils since the introduction of the resource management act (RMA) in 1991. The problems associated with FDE irrigation are high levels of nitrate in ground and surface waters which can lead to human health issues where the groundwater is used as drinking-water and environmental degradation of streams, rivers and lakes. Regional councils impose nitrogen loading limits to reduce the likelihood of environmental problems from nitrate leaching. Long-term data investigating FDE application and the associated soil changes over time is currently unavailable and the nutrient budgeting tool OVERSEER[®] Nutrient Budgets 2 is validated against only short-term trials. Therefore, assumptions made in the model for long-term FDE application areas may not be correct.

The project investigated the soil chemical characteristics of six long-term (>6 years) farm dairy effluent paddocks and matched non-effluent paddocks in the Waikato and Bay of Plenty. Fieldwork involved the removal of five core samples from each paddock, with each core yielding six sub-samples of 75 mm depth. Soil analyses included bulk density calculations, cation exchange capacity, total carbon, nitrogen and phosphorus determination and Olsen P.

It was found that two sites had the same total cation exchange capacity in the effluent and non-effluent paddocks, but the proportions of the individual cations were different. A significant ($\alpha = 0.05$) difference in the exchangeable potassium concentration existed between the pairs of paddocks with much greater potassium found in the areas irrigated with FDE. No discernable difference in the concentrations of carbon and nitrogen was found between the topsoil of the effluent and non-effluent paddocks. This was due to the highly variable nature of the effluent and the soils themselves, and the large pool of nutrients in the soil, requiring a large change before a noticeable difference occurred. The total

nitrogen and phosphorus levels found in the soil profiles (0-450 mm) of the effluent and non-effluent paddocks were very similar, and reflects the large additions of fertilisers to non-effluent paddocks.

The OVERSEER[®] Nutrient Budgets model was used to produce nutrient budgets for farms from the Waikato and Bay of Plenty and predictions of accumulation of nutrients over time. Comparisons made between the OVERSEER[®] results and soil chemical analyses revealed that with the exception of potassium, it was not possible to accurately predict the nutrient concentration in the soil by extrapolation of OVERSEER[®] data. This was due to changes in management practices over time and the inherent variability of soils. If the model is to be used as a regulatory tool, accurate fertiliser records must be kept, along with frequent pasture and soil analysis. It is also advisable that a soil map of the farm area is completed in order to most accurately use the model.

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CHAPTER 1: Introduction

The intensification of dairying in NZ caused by increased herd numbers (LIC 2004) has led to a greater volume of farm dairy effluent (FDE) being produced each year. Previous management of FDE allowed its disposal to surface waters, which causes nutrient enrichment and degradation of the streams, rivers and lakes, called eutrophication.

With the introduction of the resource management act (RMA) in 1991, regional councils became more aware and accountable of the environmental effects of land management decisions and started to encourage the treatment of the FDE through the soil-plant system via land application.

The only constraint on the farmers with this new legislation is an annual maximum nitrogen loading. In the Waikato, this limit is set at $150 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, while in the Bay of Plenty; it is now at $200 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (Cameron & Trenouth 1999). These limits are designed to minimise the nitrate-nitrogen (NO_3^-) that is leached out of the system as high concentrations of NO_3^- in groundwater that is used as a drinking-water source have been linked with human health problems and to reduce the eutrophication potential in nearby streams and rivers.

Improper management of FDE systems can lead to these environmental problems and several computer programmes are available which enable farmers and consultants to estimate their annual nitrogen inputs, outputs and losses. This gives them the knowledge of the environmental consequences of some of their decisions such as timing of fertiliser application. One such computer model is OVERSEER[®] Nutrient Budgets 2 (v. 5.0.14.0), developed by AgResearch and available for free off the internet. The assumptions and calculations made in the model have been validated against the numerous short-term fertiliser and effluent trials conducted in New

Zealand (Ledgard *et al.* 1999). The model is not, however, validated against any long-term FDE investigations. The issues involved with FDE application are not as straight-forward as fertilisers as FDE contains varying concentrations of nutrients, in a liquid form, and with a carbon source. FDE is also often applied at inappropriate times such as when the soil is saturated and when pasture growth is slow.

The general purpose of the research was to investigate the validity of using OVERSEER[®] to give nutrient budgets for long-term FDE paddocks as actual leaching losses and storage in the soil may be different to those predicted by OVERSEER[®]. This was achieved by the following objectives:

1. investigate soil chemical properties under long-term (>6 years) irrigation of FDE and compare with non-irrigated areas.
2. use data derived from the soil chemical analyses and farmer interviews to produce nutrient budgets for sites using OVERSEER[®] Nutrient Budgets 2 (v.5.0.14.0).
3. attempt to use phosphorus as an indicator of the quantity of nutrients applied over time and predict soil accumulation rates.
4. use OVERSEER[®] data to extrapolate accumulation rates and compare with the results from soil chemical analysis.
5. evaluate the performance of OVERSEER[®] in prediction of nutrient movement in long-term organic nutrient application situations.

Previous research into the issue and sustainability of FDE irrigation onto land has focussed on the form and concentrations of nutrients, particularly nitrogen, phosphorus and sulfur, lost from the soil profile as drainage and overland flow (Cameron *et al.* 1999; Di & Cameron 2002). Few studies have investigated the changes that occur in the soil with FDE application.

The outline of this thesis follows the standard format, with chapter 1 being a short introduction to the subject, chapter 2 containing a review of the literature pertaining to FDE and irrigation of FDE onto land and chapter 3 describing the fieldwork and soil chemical analyses undertaken. Chapters 4, 5 and 6 involve the results and discussion part of the three aspects of the project: soil chemistry, the use of OVERSEER[®], and the comparison and evaluation of OVERSEER[®] and the soil results. Chapter 7 concludes the research with a summary and recommendations for future work.

CHAPTER 2: **A Review on the Composition, Influence and Effect of Farm Dairy Effluent on Soil and Issues Relating to its Application**

2.1 Introduction

The introduction of the resource management act (RMA) in 1991 saw changes occur in the disposal methods of farm dairy effluent (FDE). Traditionally, a two-pond system was used to reduce the biological oxygen demand (BOD) of the raw FDE before discharge into the nearest water body. While effective at removing the solids and BOD, these ponds did not achieve success in reducing the nitrogen and phosphorus content of the effluent (Warburton 1977). As a consequence, nuisance aquatic weed growth occurred in many streams and rivers and the eutrophication of these water bodies led to a decline in fish and other aquatic organisms (Hickey *et al.* 1989). The RMA required the land managers to become more environmentally accountable and this resulted in regional councils implementing policy changes towards land disposal of effluent. Returning nutrients to the soil makes environmental and economic sense but the manner in which it is done, and the concentrations involved, requires forethought, research and planning.

Poorly planned FDE disposal schemes can result in groundwater contamination with potentially harmful compounds, particularly nitrate; surface water contamination, which promotes aquatic weed growth and destroys habitat, and soil compaction and degradation (Hickey *et al.* 1989; Longhurst *et al.* 2000a). These problems occur because the operators are not aware of the limitations of the scheme, or of the consequences of their actions (Houlbrooke *et al.* 2004c; Smith & Monaghan 2003). Issues such as appropriate rates of application, stock management practices and the longevity of effluent schemes are still

being researched and debated and this review presents the current information.

2.2 Composition of Farm Dairy Effluent

Farm dairy effluent (FDE) is generated when the herd is being milked. Dung and urine is dropped onto the concrete pad and washed into a storage pond or sump. Teat washings also contribute to the wastewater generated so that the average effluent comprises 10% excreta, 4% teat washings and 86% wash-water (Longhurst *et al.* 2000a). With the intensification of dairy farming that has occurred in the past 10 years, and the consequent increase in dairy cow numbers (up 44%) (Houlbrooke *et al.* 2004c) cattle are spending more time in the milking area, and the volume of waste generated has increased. The increasingly common use of feed pads has also increased the amount of waste that requires disposal.

The chemical and physical composition of FDE reported in the literature varies considerably and Table 2.1 shows some of the values found.

Table 2.1: Composition of farm dairy effluent from literature sources for selected nutrients

N (mg L ⁻¹)	P (mg L ⁻¹)	K (mg L ⁻¹)	FDE	Source
182	18	-	Raw	Cooke <i>et al.</i> (1979)
190	21	-	Raw	Macgregor <i>et al.</i> (1979)
164-222	53-93	290-528	Raw	Goold (1980)
208	35	160		Vanderholm (1984)
120-350	-	-	Raw	Silva <i>et al.</i> (1999)
400	70	370	Raw	Roach <i>et al.</i> (2001)
214	26	242	Anaerobic pond	Roach <i>et al.</i> (2001)
150-340	22-123	-	Raw	Di & Cameron (2002)
138-423	-	-	Raw	Di <i>et al.</i> (2002)
80	15	53	Raw	Hawke & Summers (2003)
135	22	231	Aerobic pond	Bolan <i>et al.</i> (2004)

Differences may be due to a number of factors such as herd size, breed and farm management, but may be related to sample collection method as there is no standardised method for sampling the FDE (Longhurst *et al.* 2000a). The time of year sampling occurs can have an effect on the composition and the stage of lactation can affect the concentration of cations like calcium (Ca) in the excreta. The type and quality of feed also contribute to the variation as does the use of an oxidation or holding pond (Longhurst *et al.* 2000a; Houlbrooke *et al.* 2004c). The amount of solids in the effluent is also highly variable with Longhurst *et al.* (2000a) reporting a range of 0.04% to 5.3% and an average of 0.9%. An earlier review by Vanderholm (1984) found a lower average solids content of 0.72% but this has been attributed to a decrease in the amount of wash-water used per cow (Longhurst *et al.*, 2000a).

Table 2.1 shows that the most often measured component of FDE is nitrogen (N) and is often the only measured (or reported) parameter of FDE irrigation experiments. This is due to environmental concerns and regulatory requirements with respect to land application rates. Research has shown that high rates of nitrogen being applied to land can result in high concentrations of nitrate in groundwater and surface waters, leading to eutrophication of streams, rivers and lakes (Di & Cameron 2002; Bruere & Pickles 2003). Table 2.1 shows the total nitrogen content of the effluent and for raw effluent, around 80% of this is in the organic form, as urea and protein (Longhurst *et al.* 2000a). Table 2.2 shows the partitioning of raw dairy shed effluent used in an experiment by Silva *et al.* (1999) in Canterbury, NZ. It is apparent from this table that the remaining 20% of the total nitrogen is in the ammonium form (NH_4^+ -N) with only traces of nitrate (NO_3^- -N) and nitrite (NO_2^- -N).

Table 2.2: Nitrogen (N) forms found in raw farm dairy effluent from May 1996 to February 1997*.

Time of application	pH	Total N (mg L ⁻¹)	NH ₄ ⁺ (mg L ⁻¹)	NO ₃ ⁻ (mg L ⁻¹)	NO ₂ ⁻ (mg L ⁻¹)
May 1996	8.1	350	10	0.00	0.00
August 1996	7.1	120	30	0.50	0.08
November 1996	8.2	240	60	0.16	0.22
February 1997	7.9	250	53	0.08	0.12

* Source: Silva *et al.* 1999.

The concentrations of phosphorus (P) found in Table 2.1 are of less concern environmentally as the amount of P applied from the effluent, when it is applied at recommended N loading rates of 150-200 kg N ha⁻¹ yr⁻¹, is generally less than is required for maintenance of optimal growth of pasture. Sometimes additional P in the form of superphosphate or other fertiliser is applied to blocks receiving FDE to maximise growth and utilise the 'free' nitrogen (Longhurst *et al.* 2000a). Phosphorus does not leach in the same way that nitrogen compounds do as it is strongly adsorbed by the soil, so the major loss pathway for P is via overland flow. This can be a problem if the effluent is applied during the wet season, or when the soil is at field capacity and the additional water from the effluent cannot infiltrate, and runs off (Cameron *et al.* 1997).

The other major elemental component of effluent is potassium (K). Many studies have shown that the concentration of K can range from around 80% of the N content in the effluent to double the N content (Goold 1980; Longhurst *et al.* 2000a; Bolan *et al.* 2004), and at recommended N loading rates, is always in excess of the maintenance requirements of the soil/plant system. This leads to high concentrations of K in the soil and consequently in the herbage as plants take up more potassium than they need. This can cause a decrease in the concentrations of other cations in the herbage, and can lead to animal health problems (Mason and Young 1999; Longhurst *et al.* 2000a; Bolan *et al.* 2004).

2.3 Influence of Farm Dairy Effluent on Soil Nutrient Concentrations

Little research has been carried out on the long-term impact on the soil of FDE applications although it is generally recognised that soil fertility is increased after effluent application (Cameron *et al.* 1997). Concentrations of nitrogen (N), phosphorus (P) and potassium (K) have been found to be higher after irrigation with effluent (Cameron *et al.* 1997; Hawke & Summers 2003). Roach *et al.* (2001) found concentrations of K in the soil significantly higher in the effluent-irrigated sites than non-irrigated sites and Bolan *et al.* (2004) detected an increase in exchangeable K corresponding to an increase in effluent loading. They also determined a link between effluent irrigation and calcium and magnesium concentrations in the soil. These cations decreased in concentration with increasing effluent application and this was related to competition with the high concentration of K that caused leaching of the other basic cations.

Hawke & Summers (2003) found significantly higher pH values in the 0-5 cm depth of the effluent-treated sites than the non-treated sites; however, the difference was not significant at other depths. An increase in the organic matter content of the soil through the addition of effluent results in a higher cation exchange capacity (CEC), and an increase in nutrient status (Cameron *et al.* 1997).

2.4 Influence of Farm Dairy Effluent on Herbage

Table 2.3 gives the values reported in the literature on the increase in pasture production achieved with FDE application. The range of values cited is a reflection on the different amounts of effluent applied in the various experiments.

Table 2.3: Increase in pasture production (%) due to application of FDE.

Increase	FDE	Comments	Source
27%	Raw	Low rate	Goold (1980)
43%	Raw	High rate	Goold (1980)
24%	Raw		Longhurst <i>et al.</i> (1999)
7-24%	Raw	Waikato trial	Roach <i>et al.</i> (2001)
2-17%	Anaerobic pond	Taranaki trial	Roach <i>et al.</i> (2001)
44%	Raw		Di <i>et al.</i> (2002)

Roach *et al.* (2001) applied varying concentrations of effluent; from 75 kg N ha⁻¹ to 375 kg N ha⁻¹ in the Waikato trial in 17 applications over 18 months, and from 100 kg N ha⁻¹ to 400 kg N ha⁻¹ spread over 8 applications from September to April in the Taranaki trial. They found the response both immediate and long lasting and this was attributed to the inorganic (readily available) and organic components of the effluent. Around 80% of the N applied as FDE is in the organic form and this is a slow-release source of N for the plants as it requires microbial breakdown to become available.

The values reported by Goold (1980) are higher than some of the more recent findings and are based on an average application of 156 kg N ha⁻¹ for the low rate and 312 kg N ha⁻¹ for the high rate. These levels are high, considering regional councils recommend a maximum N loading of 150-200 kg ha⁻¹ yr⁻¹ be applied to the soil (Cameron and Trenouth 1999). This experiment, however, was one of the first to investigate FDE disposal and these legal parameters were not in place. The percentage increases in pasture production equate to an increase of 16 and 12.6 kg dry matter (DM) per kg N applied for the low and high treatments respectively. These values are similar to those reported by Steele (1976) who gave a range of 7.8-12.7 kg DM per kg N applied using urea as the N source at 100 kg N ha⁻¹ yr⁻¹, and Bolan *et al.* (2004) who found a response of 4.1 to 7.2 kg DM per kg N applied using FDE at 200 kg N ha⁻¹ yr⁻¹.

The botanical composition of the pasture under FDE-irrigation may change with the commencement of application. Roach *et al.* (2001) found that ryegrass dominated over clover with an increasing concentration of N applied and they found that clover N fixation decreased as a readily available source in the soil was utilised over atmospheric N. This is in contrast to earlier findings by Goold (1980) who stated that the application of FDE had little effect on the botanical composition in spring.

Other findings include herbage elemental analyses conducted to determine the concentration of potassium by Roach *et al.* (2001) and Bolan *et al.* (2004). Both studies found higher levels of K in the pasture and soil but Bolan *et al.* found levels of calcium (Ca) and magnesium (Mg) decreasing with an increasing amount of FDE applied while Roach *et al.* found no indication of this depletory effect of K on Ca and Mg levels. If some change is measured then this is likely to be as a result of the luxury uptake of K by the plants and this causes a decreased uptake of other cations, in order to remain uncharged. This can lead to nutrient imbalance and animal health problems like hypocalcaemia (milk fever) and hypomagnesaemia (grass tetany) (Bolan *et al.* 2004).

The measurement of the effects FDE application has on the pasture and quality of drainage water is confounded by the dung and urine deposition that occurs during grazing events. Silva *et al.* (1999) found that when cattle urine was applied to lysimeters that also received dairy shed effluent, the nitrate in leachate exceeded the World Health Organisation (WHO) limit for drinking water while the lysimeters under the effluent-only treatment did not give significant NO_3^- concentrations in drainage waters.

2.5 Dung and Urine Effects

The fate of N deposited as dung or urine has been more extensively studied than the fate of N applied as FDE. Information on the influence

of dung and urine patches on the pasture quality and overall N loss from pastures is of value in understanding the fate of N applied as FDE (a mixture of dung, urine and shed washings). Paddocks receiving FDE are usually in the normal grazing rotation and calculations of nutrient loss on a farm-scale are complicated by dung and urine deposition during grazing (Houlbrooke *et al.* 2004a; Sharpley *et al.* 1976). These depositions of highly concentrated nutrients over a small area of the paddock can lead to leaching, increased pasture production and change the chemical properties of the soil, increasing its heterogeneity. Ledgard *et al.* (1982) calculated that cattle urine was deposited around nine times per day per animal and that this creates an affected area of 0.45 m². Silva *et al.* (1999) estimated that around 25% of a paddock receives urine each year, assuming a stocking rate of 3 cows ha⁻¹. These calculations indicate that a large proportion of the farm may be affected by N-enriched urine patches and this can greatly increase the amount of N lost from nutrient balances by volatilisation, denitrification and leaching. Dung has less of an effect than urine due to a large amount of the N in undigested herbage having a high C:N ratio. This stimulates more immobilisation of N during its decomposition by soil microbes.

The most frequently measured component of the urine is the N content. This value changes depending on season and can range from a total N content of 0.67% in spring to 0.88% in winter (Ledgard *et al.* 1982). The partitioning of N in the urine also changes, with Ledgard *et al.* (1982) reporting urea concentrations of 80% in winter and 54% in spring.

Longhurst *et al.* (2000b) states that the N content of a cow dung patch is 852 kg ha⁻¹ while a cow urine patch has a concentration of 448 kg N ha⁻¹. This is in contrast to Di *et al.* (2002) who used 1000 kg N ha⁻¹ to simulate urine patches and Houlbrooke *et al.* (2004a) who state that the concentration of N in urine is around 8000-15000 mg L⁻¹, which equates to 1000 kg N ha⁻¹. Silva *et al.* (1999) found the total N concentration in

urine to be 7300 mg L⁻¹ which is close to the values reviewed by Houlbrooke *et al.* (2004a).

The deposition of urine onto the soil has immediate and long lasting effects (Ledgard *et al.* 1982). The pH rises due to an increase in hydroxyl (OH⁻) ions from the hydrolysis of urea, which also increases the ammonium (NH₄⁺) concentration. Silva *et al.* (1999) found an initial pH of 7.6 under urine spots and Condon *et al.* (2004) investigated the acidifying power of urine by measuring pH initially and at regular intervals after application of urine. They found that on day 0, the pH increased by 1.3 units and this was attributed to the rapid hydrolysis of urea between application and sampling. Day 1 had the greatest pH change of +3 units and this corresponds to the highest NH₄⁺ concentration measured. These high pH levels encouraged ammonia (NH₃) volatilisation and during the first 8 days, 27% of the applied N was lost as NH₃. This compares well with Ball and Ryden (1984) who showed up to 66% NH₃ loss during warm, dry conditions and an overall average loss of 28%. By day 8, nitrification became the dominant process and the pH correspondingly decreased. By the end of the experiment, the subsoil layers were acidic (around pH 4). This effect can have environmental consequences, as well as a drop in productivity.

The cycling of cations in urine was investigated by Early *et al.* (1998) who found that high concentrations of K in urine resulted in high concentrations of K in the soil (Templeton silt loam) and pasture. Very little of the K applied (1.8%) was leached out of the profile (1200 mm) over the 12 months of the experiment and this was attributed to strong adsorption onto cation exchange sites so that little K is left in the soil solution, available for leaching. Calcium and Mg were leached from the profile even though no Ca or Mg was applied in the synthetic urine. Thus the leached cations were displaced from the exchange sites by K and moved with nitrate as a companion ion.

Carran (1988) found that urine had a large effect on K uptake by plants under different moisture regimes on a silt loam in Gore. Under a wet soil regime, around 85 kg K ha⁻¹ of urine K was taken up, while under dry conditions, this value was only 36 kg K ha⁻¹. This was due to the counter-ion effect in balancing high rates of NO₃⁻ uptake in the wet treatment. Moist aerobic conditions favour the production and plant availability of NO₃⁻ while a fluctuating dry/moist regime that does not support much plant growth favours its accumulation.

Holland & During (1977) found that very dry conditions in a Horotiu sandy loam in the Waikato inhibit nitrification and immobilisation which means that if a wet autumn follows a dry summer, extensive amounts of nitrate can be leached from urine spots. Di & Cameron (2002) concluded that lower leaching losses of NO₃⁻ in spring, compared with autumn, were due to greater pasture N uptake, greater immobilisation and greater losses via other processes like denitrification, volatilisation and the large amount of drainage that occurs over winter on a Lismore stony silt loam in Mid-Canterbury.

2.6 FDE Irrigation

The efficiency of nutrient removal and long term sustainability of any effluent irrigation scheme primarily depends upon the soil structure, texture, mineralogy and moisture status. The first three are inherent characteristics of the soil and cannot be changed while the last factor is subject to variations in climate and management strategies.

2.6.1 Preferential flow and artificial drainage

Irrigation when the soil is near or at field capacity will lead to preferential flow in soils that demonstrate bypass flow. When this occurs, the nutrients bypass the soil system and exit as drainage water or into groundwater (Houlbrooke *et al.* 2004b) with little nutrient removal achieved. Houlbrooke *et al.* (2004b) demonstrated that when the soil moisture deficit was at 6 mm, a FDE irrigation event of 25 mm gave 10

mm of drainage and 8 mm of surface runoff. This is equivalent to 70% of the applied effluent leaving the soil system essentially unfiltered and would result in contamination of nearby surface waters or groundwater. The levels of N and P measured in the drainage waters of this experiment were many times greater than the levels reported to significantly promote aquatic weed growth and shows that ill-timed effluent applications can have a serious effect on the sustainability of the scheme.

Macropore flow is an important characteristic determining the path and residence time of the effluent in the soil system. Silva *et al.* (2000) used tension infiltrometers to control the pressure in lysimeters filled with free-draining Templeton fine sandy loam so that the macropores were excluded from the solute pathway. They found that at 0 kPa, 12.2% of the total N applied was in the leachate, while at 0.5 kPa (macropores excluded), only 0.25% of total N was in the leachate. This means that 98% of the N leached was via macropore flow. Analysis of the leachate found that under 0.5 kPa, the urine had sufficient time to hydrolyse, nitrify, denitrify and immobilise so that very little mineral N was detected in the leachate. Under no suction, urea and NH_4^+ were detected in the leachate, and no NO_3^- was found. This is because the drainage rate of the 0.5 kPa lysimeter was 5 times slower than the 0 kPa sites and there was no time for nitrification or immobilisation in the zero suction samples.

These findings have consequences for situations where effluent is applied to mole and tile drained pastures. When these soils are at field capacity, any effluent applied will be rapidly transported to the drainage system and then into streams and rivers with little nutrient removal occurring. According to Silva *et al.* (2000) and Monaghan and Smith (2004), if macropore flow occurs, the major forms of N contaminating the waterways will be organic and ammonical, not nitrate.

Houlbrooke *et al.* (2003), however, irrigated aerobic pond FDE onto pasture on a mole-pipe drained Tokomaru silt loam and 88% of the total-N in the resulting drainage water was nitrate-N and at concentrations greater than the WHO limit of 11.3 mg L^{-1} .

Little research has been done to estimate losses in this type of situation, where effluent is sprayed onto grazed pasture with mole and tile drainage, but Houlbrooke *et al.* (2004a) has documented the outcomes of two drainage events coinciding with grazing, on mole and tile drained Tokomaru silt loam under pasture during the 2003 winter drainage season. In one experiment, 36 mm of natural rainfall gave 13.5 mm of drainage. The area had been grazed only 2 hours previously and no surface runoff occurred, primarily due to the soil moisture status: the event occurred in early June, at the beginning of the drainage season. Concentrations of N in the drainage were about 2 times greater in the recently grazed plots than the plots grazed 7 days previously, with NO_3^- being the dominant form of N. This was found to be consistent with other studies (Holland & During 1977; Di *et al.* 1998) which showed high levels of NO_3^- in drainage waters in the early part of the leaching season. This is due to the build-up of mineralisable N from microbial activity over the dry summer period when pasture growth is limited by water availability and evapotranspiration generally exceeds precipitation.

Silva *et al.* (1999) showed in studies on a free-draining Templeton fine sandy loam, that during winter, around 80% of water inputs in the form of natural and simulated rainfall, and flood irrigation of FDE were collected as leachate. Smith & Monaghan (2003) also found that most losses occurred in late winter and early spring and this was attributed to soil treading by cattle in the moist soil conditions. This experiment investigated overland flow in drained and undrained plots of fragic perch-gley Pallic and Pallic firm Brown soils with silt loam textures and found that an increase in stocking density on the undrained plots resulted in an increase in overland flow. The artificial drainage was

found to considerably reduce the losses of N and P via overland flow due to reduced soil moisture levels. The amount of P lost via overland flow was estimated to be a maximum of 0.23 kg ha^{-1} , and when this is compared to the 43 kg of P per hectare applied in the effluent, it is small. However, even this small amount of P can accelerate aquatic weed growth.

Toor *et al.* (2004) estimated on a free-draining Lismore stony silt loam that annual P losses via surface pathways could be up to 2 kg ha^{-1} in grassland systems. They also found that dissolved unreactive P formed the major constituent of the total P lost and this would not be available for aquatic plant uptake.

Research shows that application of FDE to soils with drainage systems and moisture contents at field capacity may lead to preferential and macropore flow and result in little remediation of the effluent. Daily water balances can be used to assess the soil moisture status and decide whether application of FDE is appropriate or not.

2.6.2 Soil moisture budgets

Irrigation of FDE onto already wet soils can generate nutrient enriched runoff and macropore flow (Houlbrooke *et al* 2004b; Monaghan & Smith 2004) For best practice, FDE irrigation should be scheduled onto soils that have sufficient water deficit to prevent runoff and direct drainage of partially treated effluent. Surprisingly few suggestions have been put forward to solve the problem of estimating the soil moisture deficit on a practical farm-scale despite the fact that this knowledge would greatly improve the efficiency and environmental viability of land FDE irrigation schemes.

Scheduling can be achieved by running a daily water balance using a model generated by Scotter *et al.* (1979) and refined by Moir *et al.*

(2000). Although these models do not accurately reflect actual soil water deficit, they are good enough to improve irrigation scheduling.

Houlbrooke *et al* (2004a) tested the daily water balance model for a Tokomaru soil by comparing rainfall and irrigation with drainage volumes and estimation of the soil moisture deficit.

To demonstrate the effect of irrigation regardless of soil moisture conditions, Houlbrooke *et al.* (2004b) applied an average depth of 30 mm of FDE to soils in the Manawatu. They found that 16% of the total annual volume applied reached surface water either via drainage or runoff. The largest losses occurred in late winter and early spring when lactation first begins and soil moisture is at a maximum. They also showed the impact of applying 25 mm of FDE to a soil with a moisture deficit of 6 mm, and this resulted in 10 mm of drainage and 8 mm of surface runoff which is the equivalent of 70% of the applied volume. The concentrations of N and P measured in the drainage waters were less than half the applied concentration, so some nutrient removal had occurred. However, the 12 kg N ha⁻¹ and 2 kg P ha⁻¹ that was lost to drainage is significant when compared with the estimated annual loss from mole and pipe drains of 27 kg N ha⁻¹. This means that a single ill-timed FDE irrigation event can contribute to nearly half the expected annual N loss from a grazed dairy pasture, and shows that if the irrigation was deferred to a period of soil water deficit then bypass flow of untreated effluent could be reduced (Houlbrooke *et al.* 2004b).

2.6.3 Deferred irrigation

Deferred irrigation is a concept put forward by Houlbrooke *et al.* (2004b) where farmer does not irrigate FDE until the soil moisture conditions are acceptable in order to reduce drainage and leaching problems and avoid soil degradation. A pond is used to store the effluent during times when the conditions are unsuitable (mostly during late winter and early spring), and daily weather records and computer simulation models

used to estimate soil moisture deficits, and schedule irrigation. This programme gives 4-6 irrigation events per year with depths ranging from 10 to 25 mm per event and compensates for the early lactation period when soil moisture levels are high. Houlbrooke *et al.* (2004b) used deferred irrigation over three lactation periods and found that it generated an average drainage volume of 1.1% of total volume applied, which indicates its success in minimising drainage and reducing the risk of environmental problems. They also recommend that if there is insufficient storage capacity, the effluent is applied at the lowest rate possible to minimise the drainage.

2.6.4 Irrigator effects

In another paper, Houlbrooke *et al.* (2004d) demonstrate that the rotating irrigators commonly used, do not give a uniform application of effluent. In particular, they showed that areas of the spray pattern parallel to the line of travel received greater amounts of FDE. This means that if the rate applied is close to matching the soil water deficit, these areas at the edge of the irrigator's path, will receive a depth of FDE which exceeds the deficit and will saturate the soil, leading to drainage or runoff. An average application depth of 25 mm gave a peak application depth along the edges of 55 mm. Thus, the application depth chosen should take into account the uneven distribution and the peak depth used to schedule irrigation. The authors also mention that a further consideration to take into account when scheduling irrigation, was the wind, as this can slow down the irrigator giving a greater depth applied than planned, and can throw a greater quantity of FDE downwind, giving a more uneven distribution.

An alternative type of irrigator is the oscillating irrigator which gives a more uniform coverage, especially in calm conditions. Houlbrooke *et al.* (2004d) carried out drainage simulations, comparing the two types of irrigators under different soil moisture deficit conditions. They found that when the deficit was 25 mm and the FDE application depth also 25 mm,

the rotating irrigator gave 14% of the applied volume as drainage while the oscillating irrigator gave 7%. When the moisture deficit is 32 mm, with the same application depth applied, the rotating irrigator had 6% of the applied FDE as drainage and the oscillating irrigator gave no drainage. In order for the rotating irrigator to achieve zero drainage, the soil moisture deficit would have to be 45 mm, with an application depth of 25 mm.

This knowledge is important in situations where groundwater contamination and nutrient enrichment of surface waters is of concern.

2.6.5 Regional council requirements

Currently there is no national legislation that controls the application of FDE to land. Individual regional councils have the authority to set limits that best suit their situations. Although land application and the traditional two-pond treatment systems both carry environmental risks, most councils encourage the irrigation of FDE onto land. The approach taken by each council differs, such as Environment Waikato (EW) making it a permitted activity while Environment Bay of Plenty (EBOP) have ruled it is a discretionary activity requiring a resource consent. The technical limitations placed on the application also vary from region to region. The requirements in the Waikato are that the application of FDE shall not cause ponding for more than 5 hours following irrigation and not cause effluent to enter surface waters, with a maximum loading rate of 25 mm depth per application (Cameron & Trenouth 1999). In the Bay of Plenty it is required that any area where FDE will be sprayed must be more than 20 m from any watercourse or farm drain, and that effluent shall not reach waters by overland flow or percolate rapidly to surface or ground waters (Cameron & Trenouth 1999). While EBOP stipulates that the rate of application should not exceed the capacity of a particular soil and topography, it allows an application depth of up to 50 mm per day. This is in contrast to the Dairying and the Environment Committee manual which recommends a maximum application depth in order to

avoid surface ponding and runoff of 15-24 mm, depending on soil type (Cameron & Trenouth 1999).

The legislation in place to limit the quantity of FDE that is applied to land is concerned with the nitrogen loading on the soil. The annual loading limits have been set to ensure that the nitrogen applied remains in the soil and is utilised by the pasture. In the Waikato, the maximum N loading is $150 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (Cameron & Trenouth 1999) while the Bay of Plenty council allows up to $200 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (Larson 2004). As the concentration of nutrients in FDE fluctuate greatly, it is difficult for farmers to know the exact quantity of nutrients being applied. Two methods are commonly used by farmers to gauge the rate of application:

- 1) Visual assessment of ponding and runoff
- 2) Knowing the volume to be applied and estimates of concentrations of nutrients in FDE, allowing the irrigator to be set to an appropriate speed.

Other methods to comply with regional council requirements are simple rules of thumb. They include estimation of the effluent area required as 10-15% of the total useable land area, or in the BOP, at least 2.4 ha per 100 cows for application of raw FDE (Larson 2004).

In order to reduce the environmental impact of FDE application to land, councils have encouraged the adherence to Best Management Practices. These guidelines give farmers a list of ways to improve the efficiency of their land application of FDE and avoid environmental problems. They include the application of FDE to short pasture, at the lowest possible rate, and to withhold animals from the treated pasture for at least 10 days after application. Farmers are encouraged to record which paddocks are sprayed and ensure that adequate rotation occurs. Regular soil testing of the whole farm, including separate tests for the effluent paddocks is recommended, as is regular maintenance of the irrigation system to ensure effective delivery of the FDE (Environment Waikato 2004).

If farmers want to check the allocation of nutrients to the soil, to ensure they do not exceed their regional council N limit, or for fertiliser supplementation purposes, they can use the decision-support model OVERSEER[®] Nutrient Budgets 2. A review of this model is covered in Chapter 5. The computer model allocates nutrients based on production levels and for FDE spray application scenarios, fractional time is calculated for collecting yards and milking sheds. While the model has been validated against numerous NZ studies relationships between soil test result, nutrient availability and losses from the system, the allocation of nutrients in FDE to effluent blocks has not been validated.

Apart from a brief study by Hawke & Summers (2003), there has been no in-depth study of the influence of long-term FDE application on soil properties. Also, the role that OVERSEER[®] is expected to play in auditing rates of nutrient application has not been evaluated in terms of nutrients accumulating in soil.

Therefore, this thesis aims to find sites where there are good farm records of FDE and fertiliser application such that nutrient accumulation in soil of effluent and non-effluent paddocks can be compared.

2.7 Summary

The most widely promoted method of FDE treatment is renovation through the soil profile. When applied to the soil, effluent can provide a large proportion of the nutrients required by pasture and improve productivity.

A large range of FDE composition exists in the literature and the variation is due to many factors including season, breed of cattle, fertiliser and supplements used on-farm, and even the time of day sampling occurs.

Nitrogen, phosphorus and potassium are the major nutrients in FDE and are required for plant growth, but N and P can cause ecological problems such as eutrophication of waterways, if allowed to enter the environment in high concentrations.

The rate and timing of effluent application should be considered to avoid drainage of N to groundwater and overland flow of P to surface waters and ensure effective treatment of the effluent. High levels of K in pasture can lead to metabolic disorders in cattle, and thus the amount of FDE applied should minimise these risks while maximising production.

Improved techniques and technologies like deferred irrigation and oscillating irrigators need to be adopted to minimise the impact of effluent application on the environment.

Regional councils are responsible for ensuring FDE application does not cause environmental problems and yet few constraints are in place to limit the quantity of nutrients applied to the soil.

Little research has been conducted into the effects long-term FDE application has on the accumulation of nutrients in the soil while no studies have validated the OVERSEER[®] Nutrient Budgets 2 model for FDE paddocks. This thesis aims to address this gap in knowledge.

CHAPTER 3: Materials and Methods

3.1 Site Descriptions

The Six dairy farms sampled were in the Waikato and Bay of Plenty where land application of farm dairy effluent (FDE) has been encouraged. A summary of some farm characteristics is given in Table 3.1 and shows a wide range in herd sizes and number of years of FDE application.

Paired non-effluent paddocks at each site were chosen on the basis of proximity to the effluent paddock, slope, aspect and soil types, with the aim of reducing variation in soil type between the effluent and non-effluent paddocks as much as possible. Farmers were interviewed to obtain information on the longevity of FDE application, other nutrient inputs into the site (fertiliser and supplements) and general farm statistics. This data was then used in the nutrient budgeting model OVERSEER[®] Nutrient Budgets 2 (ver.5.0.14) to give nutrient balances for each farm's effluent and non-effluent blocks and obtain predictions regarding the fate of nutrients applied to the soil.

Table 3.1: Summary of site characteristics

Farm	Location	Rainfall (mm)	Soil type	Soil order	Herd size	Years of FDE application
A	Waikato	1200	Horotiu silt loam	Allophanic	170	20
B	Waikato	1500	Te Kowhai silt loam	Granular	760	6
C	BOP*	2000	Mangorewa sandy loam	Podzol	310	6
D	BOP	1500	Te Ngae loamy sand	Recent	820	16
D	BOP	1500	Rotomahana shallow sandy loam	Allophanic	820	16
E	BOP	2000	Mangorewa sandy loam	Podzol	510	10
F	Waikato	1200	Kereone silt loam	Allophanic	121	7

* BOP = Bay of Plenty region

3.1.1 Site A

The site was located on the eastern edge of Hamilton City (37.778°S, 175.313°E) with an annual rainfall of 1200 mm. The soil sampled was Horotiu silt loam, an Allophanic Soil which is derived from alluvium and is well drained with high phosphorus (P) retention due to the presence of allophane (Singleton 1991). The farm has a herd size of 170 cows, and an area of 50 ha, 10 of which is taken up by the effluent block. Effluent has been applied at this site for more than 20 years.



Plate 3.1: The effluent paddocks at Site A (left) and B (right).

3.1.2 Site B

Samples were taken from a site near Ohaupo (37.920°S, 175.225°E). The soil was classified as a Granular Soil and the soil type as Te Kowhai silt loam which has formed from a combination of coarse alluvium deposited by the Waikato river and fine silts and clays deposited when the river changed course. This layering gives rise to compacted subsoil horizons which restrict the downward movement of water and produce poorly drained conditions. P retention is low and the presence of halloysite causes the soil to be sticky when wet, and to shrink and crack when dry (Grange *et al.* 1939; Singleton 1991). The site, located on flat land, has an effluent application history of 6 years and the area irrigated is 30 ha. The total farm area is 180 ha and the herd size is 760 cows.

3.1.3 Sites C and E

These sites were neighbouring farms in the Mamaku plateau (38.041°S, 176.116°E and 38.040°S, 176.102°E). The soil type was Mangorewa sandy loam, which is classified as a Podzol, and is formed from ash, pumice and ignimbrite. Pumice gravel at depth ensures good drainage in a high rainfall area (2000 mm per annum). The topography of the landscape is gently rolling to rolling hills. The soil has a low nutrient status and low P retention (Rijkse 1979).

Site C has a herd size of 310 cows, an effluent area of 20 ha and total farm area of 120 ha. Effluent has been applied for the past 6 years.

Site E has a herd size of 510 cows, a farm area of 190 ha and has been irrigating effluent for 10 years. For 8 of those years, the effluent area was 10 ha and this was increased to 25 ha 2 years ago.



Plate 3.2: Effluent paddocks at sites C (left) and E (right).

3.1.4 Site D

The area was located near the shore of Lake Rotorua (38.122°S, 176.317°E) which receives 1500 mm rainfall annually. A Recent Soil (Te Ngae loamy sand) and an Allophanic Soil (Rotomahana shallow sandy loam) were sampled as both had received effluent. The Te Ngae loamy sand has formed from pumice colluvium and alluvium over Rotomahana mud and is well drained but with a weakly developed texture. It occurs on the flat areas of the farm, nearer the lake. The Rotomahana shallow sandy loam has formed from Rotomahana mud over ash and pumice. It is also well drained but is limited by the mud

layer which is difficult to work in wet conditions. It is found on the rolling hills rising from the shoreline. Both soils have a moderate P retention (Rijkse 1979). The farm has a herd size of 820 cows, an area of 280 ha and effluent application to the land has occurred for the past 16 years.



Plate 3.3: Effluent paddocks at sites D (left) and F (right).

3.1.5 Site F

Site F was located south-east of Morrinsville (37.705°S , 175.627°E) on flat and gently undulating topography. The soil type was Kereone silt loam, an Allophanic Soil that has formed from fine-textured rhyolitic and andesitic volcanic ash. The annual rainfall at the site is 1200 mm and the soil is well-drained with good structure and physical properties. It had a very high P retention due to the presence of allophane (Wilson 1980). The farm has a herd size of 121 cows and an area of 40 ha. The site has an effluent application history of 7 years to an area of 6 ha.

3.2 Soil Sampling

To avoid the high field variability that exists in soil properties, the strategy for soil sampling was to sample patches of soil occurring in effluent and non-effluent paddocks that were on contiguous sections of soil type and similar micro-relief. Soil samples (5 cores 49 mm internal diameter and 450 mm deep, from each paddock) were taken in autumn 2005. For practical and analytical reasons, the number of cores was limited to 5, as each core was divided into six 75 mm depths (6 segment samples), generating 30 samples per paddock and 60 samples per farm. The location of each core was taken using GPS and

to minimise variation, similar sward and micro-topography were chosen. Extreme care was taken when cutting and transferring the 75 mm segments of cores to sample bags to ensure no loss of soil, as each section was weighed when dry and the bulk density calculated. Photographs of each core were taken (Plates 3.4 – 3.11) and visual criteria such as depth of A horizon, extent of mottling and colour of soil were used to select the most similar cores for each pair of effluent and non-effluent paddocks. Initially 3 cores from each paddock were selected for analyses. For some sites additional cores (up to a total of 5) were analysed if the coefficient of variation for the analysis remained high.

Site A – Effluent



Site A – Non-Effluent

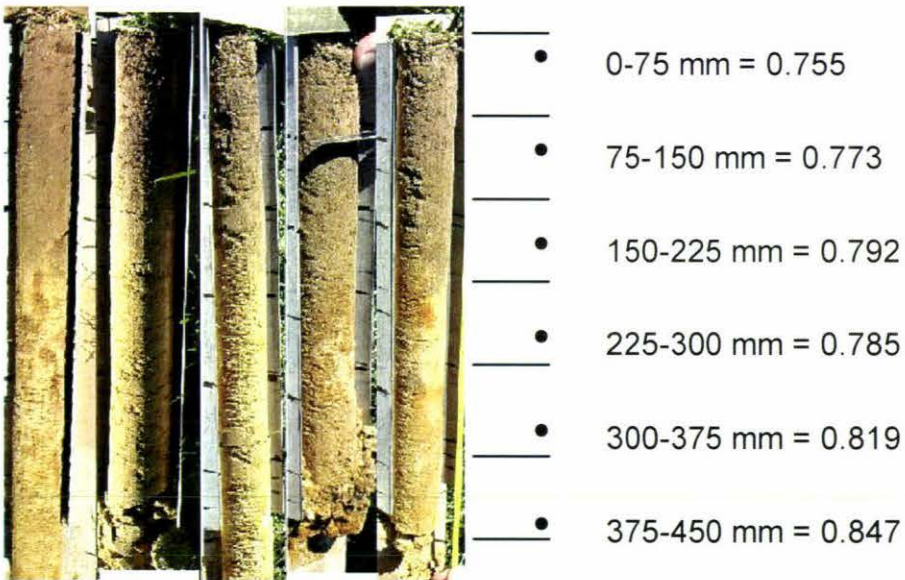
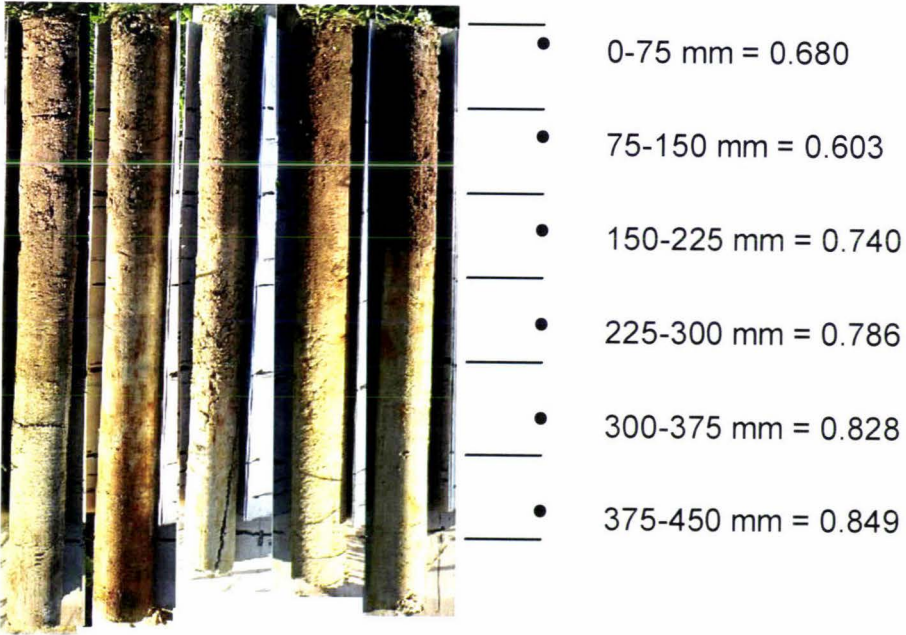


Plate 3.4: Photos of each core taken at site A. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

Site B – Effluent



Site B – Non-Effluent

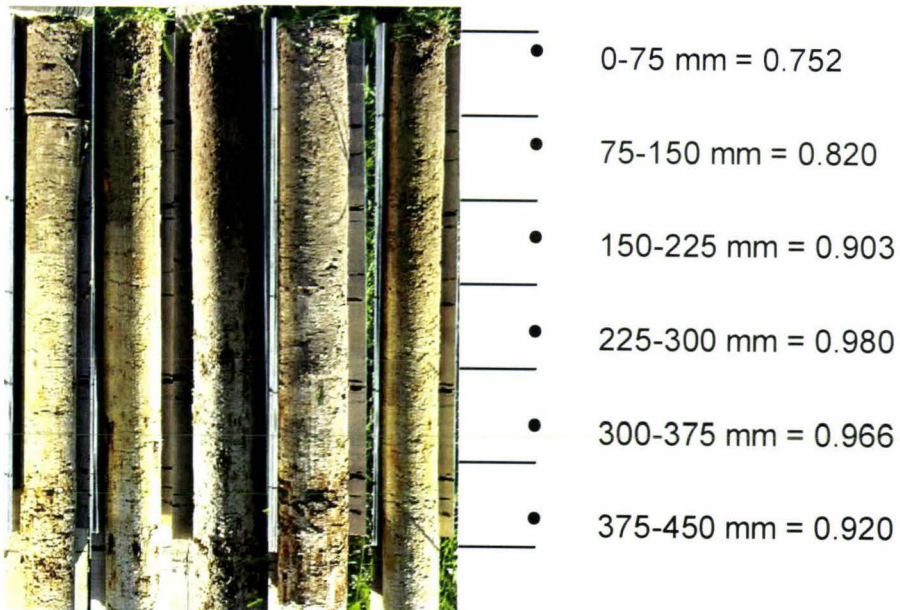
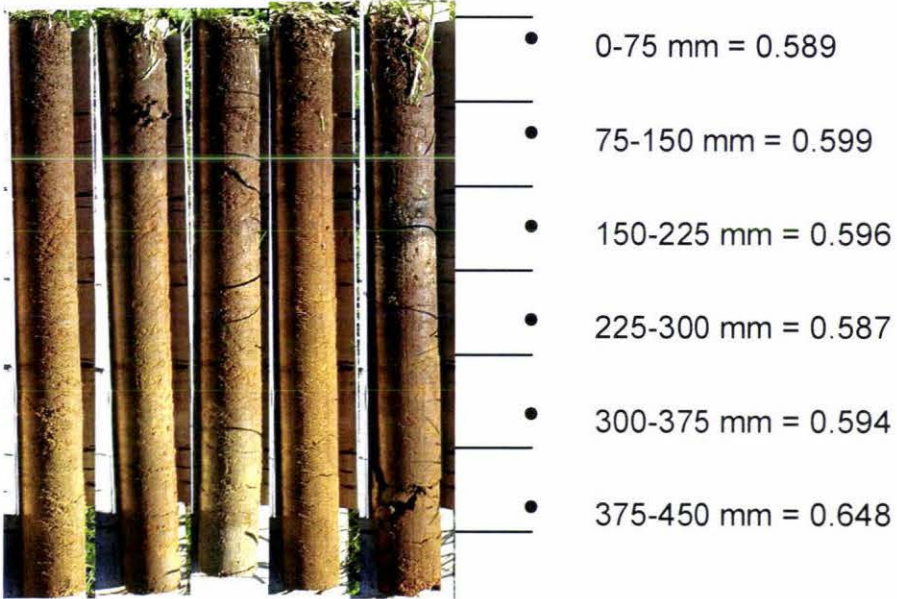


Plate 3.5: Photos of each core taken at site B. Each core was divided into 75 mm increments, the bulk density calculated (g cm⁻³) and reported next to the corresponding depth.

Site C – Effluent



Site C – Non-Effluent

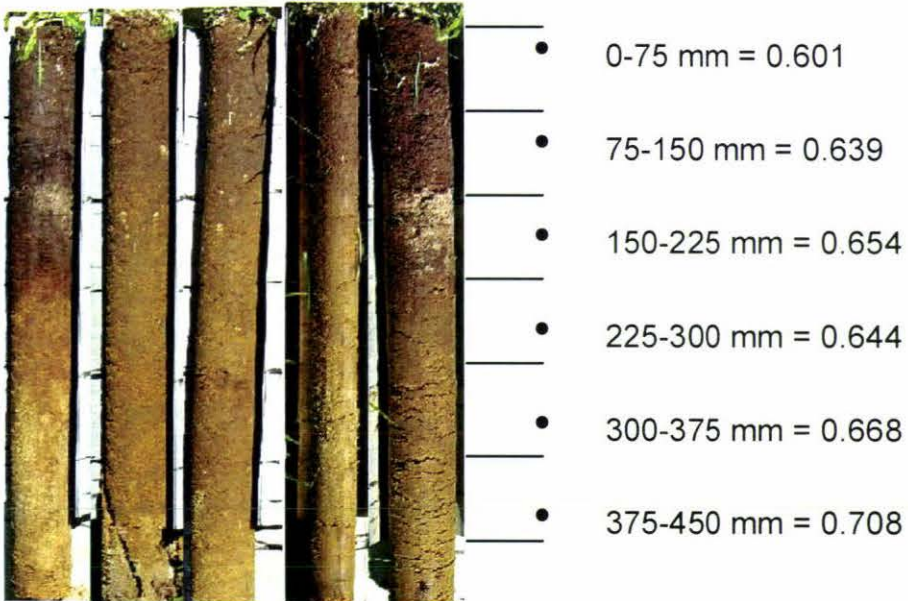
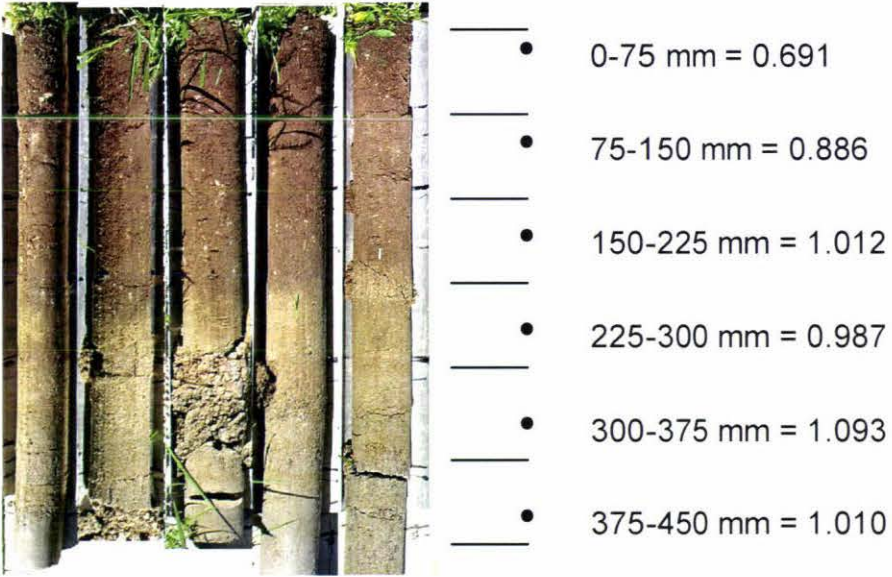


Plate 3.6: Photos of each core taken at site C. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

Site D (sand) – Effluent



Site D (sand) – Non-Effluent

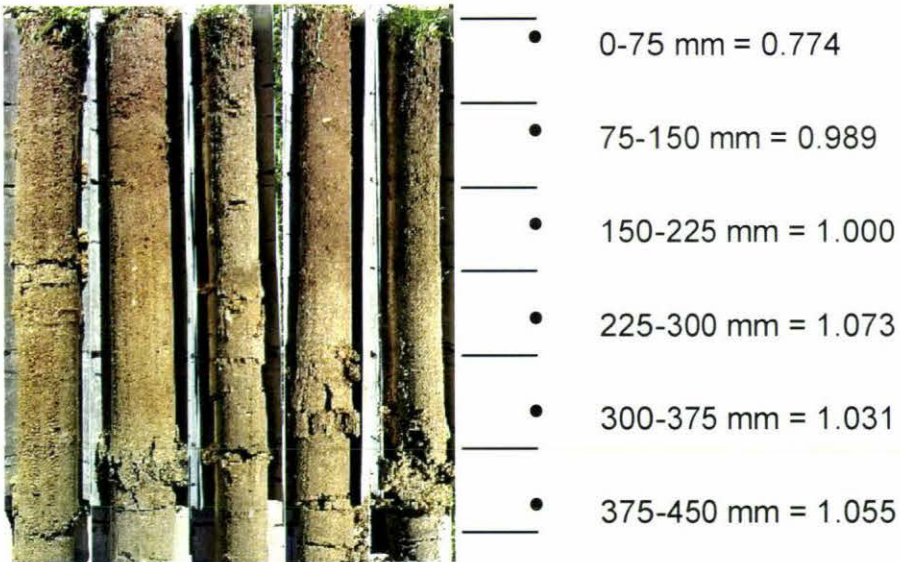


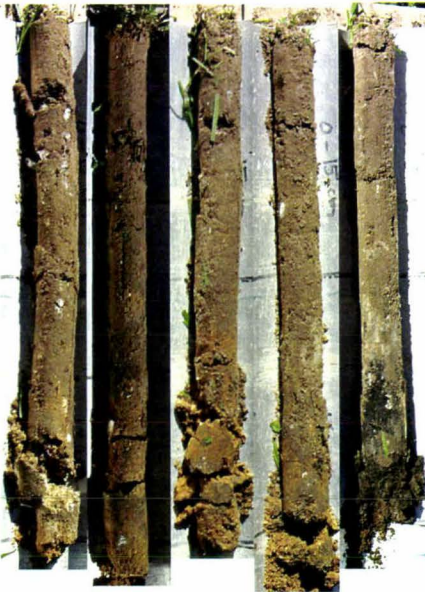
Plate 3.7: Photos of each core taken at the sandy part of site D. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

Site D (mud) – Effluent



- 0-75 mm = 1.021
- 75-150 mm = 1.069
- 150-225 mm = 1.019
- 225-300 mm = 0.729

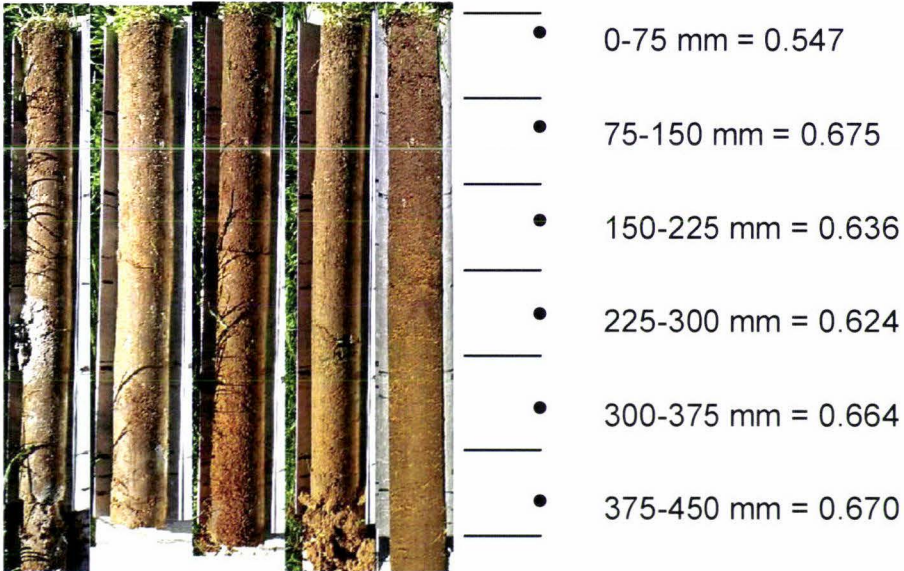
Site D (mud) – Non-Effluent



- 0-75 mm = 0.962
- 75-150 mm = 1.094
- 150-225 mm = 1.094
- 225-300 mm = 1.017

Plate 3.8: Photos of each core taken at the more rolling parts of site D. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

Site E – Long-Term Effluent



Site E – Short-Term Effluent

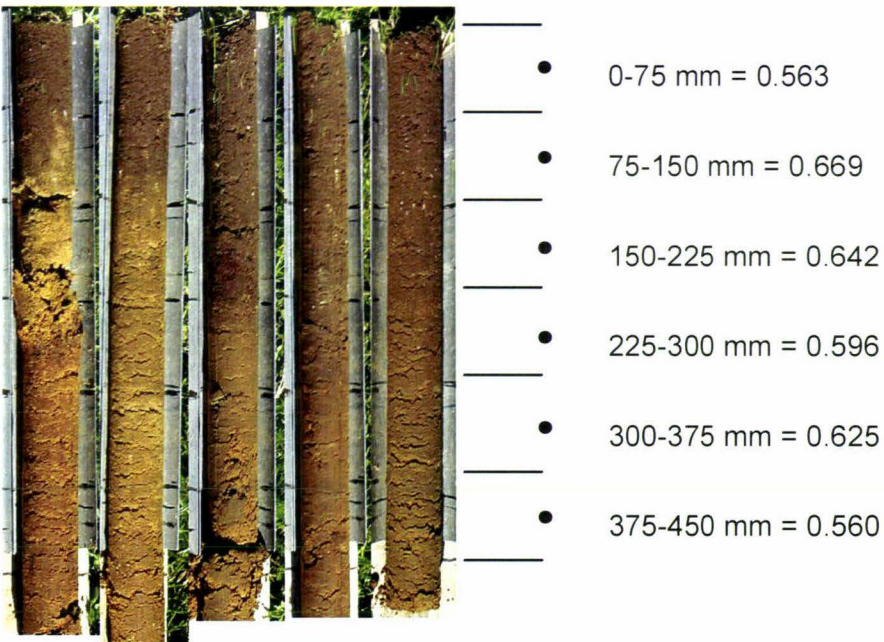


Plate 3.9: Photos of each core taken of the effluent paddocks at site E. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

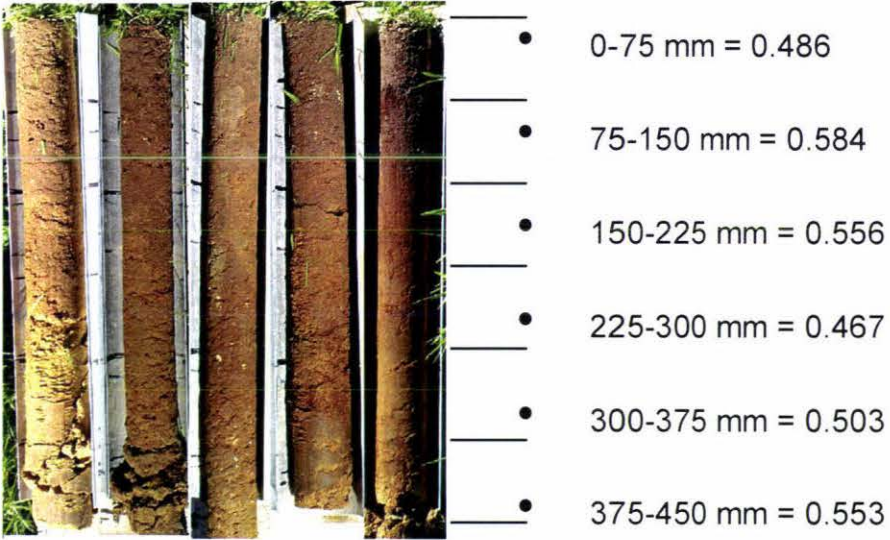
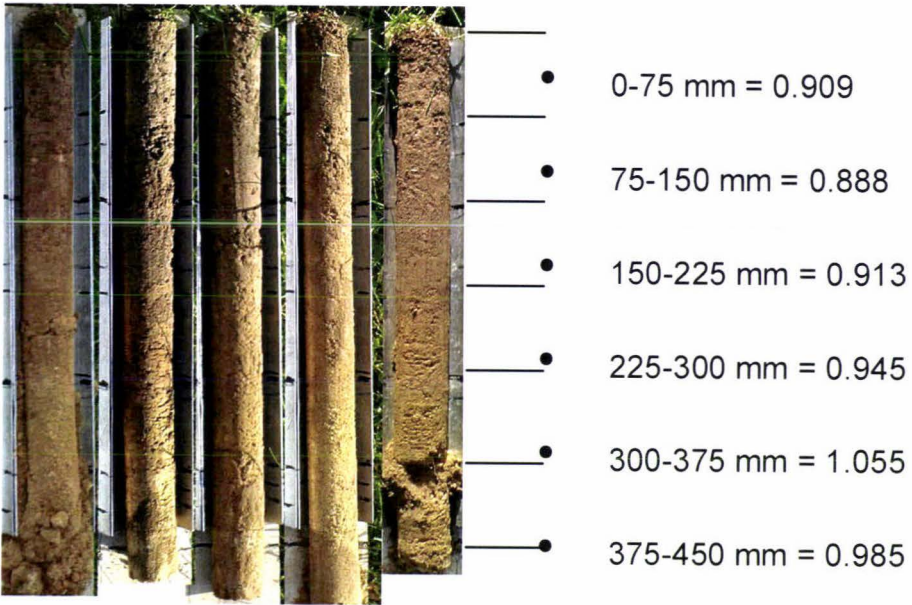
Site E – Non-Effluent

Plate 3.10: Photos of each core taken of the non-effluent paddock at site E. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

Site F – Effluent



Site F – Non-Effluent

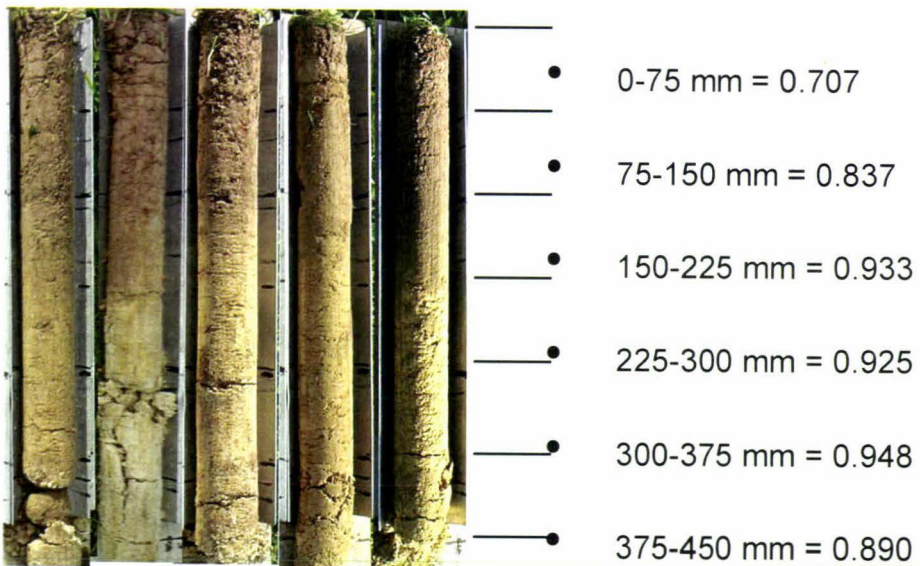


Plate 3.11: Photos of each core taken at site F. Each core was divided into 75 mm increments, the bulk density calculated (g cm^{-3}) and reported next to the corresponding depth.

3.3 Chemical Analysis

After air-drying and sieving (<2 mm), samples from 6 segments of three cores from each paddock were analysed for exchangeable cations using a modified version of the semi-micro leaching method described by Blakemore *et al.* (1987).

One gram of soil and three grams of acid washed silica sand was leached with 50 mL of 1 molL⁻¹ ammonium acetate at pH 7 and the cations (Ca²⁺, Mg²⁺, K⁺, Na⁺) were determined using a GBC Avanta sigma atomic absorption spectrometer.

After initial analysis, more cores from some sites were analysed to reduce the variation found, although the coefficient of variation for potassium results remained high for all sites (see Appendix).

Representative sub-samples were finely ground and analysed for total nitrogen (N) and total phosphorus (P) using a Kjeldahl-type digestion. Analysis was performed by Auto Analyser using the indo-phenol Prussian blue method for N and vanadomolybdate method for P (Blakemore *et al.* 1987).

Total carbon and nitrogen were determined by combustion on finely ground samples from the 0-75 mm depth using a Leco FP 2000 analyser (www.leco.com).

Samples from the 0-75 mm and 75-150 mm depths were analysed for Olsen-soluble phosphorus using the method described by Blakemore *et al.* (1987).

Statistical analysis between effluent and non-effluent paddocks was made using one-way analysis of variance procedure by SAS Institute Inc. (SAS 1989).

CHAPTER 4: Soil Chemical Characteristics

4.1 Introduction

The chemical characteristics of the soils sampled were determined using the methods described in Chapter 3. The exchangeable cations (calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+) and hydrogen (H^+)) were extracted using leaching columns and then analysed using atomic absorption spectroscopy (Ca^{2+} , Mg^{2+} , K^+ , Na^+) and a pH meter to calculate exchangeable acidity (H^+)

Cations exist in the soil in three forms:

1. In soil solution
2. In exchangeable form held on soil colloids by permanent or variable charge
3. In non-exchangeable form found as components of the soil particles and released by weathering (Hesse 1971; Doll & Lucas 1973)

The proportion of each cation in the soil that is in an available form for plant uptake (in solution or on exchange sites) is much smaller than the amount held in the non-exchangeable form (Doll & Lucas 1973). The concentration of cations in the soil solution is in equilibrium with the cations on the soil colloid surfaces and exchange reactions occur when the equilibrium is upset (McLaren & Cameron 1996).

It is recognised now that there are two mechanisms by which positively charged ions are attracted to particles in the soil and remain available for plant uptake. These two mechanisms are known as permanent and variable charge.

Permanent charge is a result of the structural cations within the clay mineral being replaced with cations of smaller charge, giving a net negative charge to the mineral. This charge imbalance results in cations

being attracted to the outside of the mineral (McLaren & Cameron 1996). In some clay minerals such as vermiculite, these cations are not held strongly by the mineral and are in equilibrium with the soil solution. Thus they can be exchanged with, as the need requires (McLaren & Cameron 1996).

Variable charge is due to the dissociation of H^+ from organic matter functional groups and the addition or removal of H^+ from hydroxyl (OH^-) groups on various types of mineral surfaces (McLaren & Cameron 1996). The types of minerals which lead to variable charge are iron and aluminium oxides and hydrous oxides, and the short range order aluminosilicates. Their amount of charge varies with pH. A more acid soil (more H^+ in solution) has less available exchange sites for cations than an alkaline soil (high pH, low H^+ concentration) (McLaren & Cameron 1996).

Cations are essential for plant growth and development and also affect the physical properties of a soil. In terms of plant requirements, the most important cations are calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+).

The cation exchange capacity (CEC) of a soil is generally defined as the sum of exchangeable cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+ and H^+) in a soil, however, this value can vary, depending on the conditions under which it is measured (Chapman 1965; Sumner & Miller 1996). In very acidic soils, aluminium (Al^{3+}) is also measured. CEC is usually used as an indicator of soil fertility and fertiliser recommendations can be based upon the results.

If there is an excess of cations in solution and all exchange sites are filled, the remaining cations are leached. Due to its size/charge ratio, K^+ tends to knock larger cations such as Ca^{2+} and Mg^{2+} off the exchange sites and these cations are then leached from the rootzone. In situations where an excessive amount of K^+ is applied to the soil (i.e.

FDE irrigation), the proportion of K^+ on the exchange sites will increase causing a concomitant decrease in Ca^{2+} and Mg^{2+} . This can then affect the quality of the pasture as less Ca^{2+} and Mg^{2+} is available for plant uptake and pasture concentrations drop, leading to animal health problems such as hypocalcaemia and hypomagnesaemia (low blood serum levels of Ca^{2+} and Mg^{2+} respectively) (Mason & Young 1999; Wilson 2002). Increases in CEC are generally caused by an increase in organic matter content and this can be due to the application of a carbon (C) source such as effluent, manure, and leaf litter.

4.2 Comparison of Cation Content with Depth

The concentrations of cations found in each soil profile are shown in Figures 4.1 - 4.5. The plots given for site A show that at the 0-75 mm depth, the sum of the cations is the same ($\alpha=0.05$) in both paddocks, but the proportions of each cation are different. Potassium (K^+) concentrations are higher in the effluent paddock and there is an overall significant difference ($\alpha=0.05$) between the two paddocks, with the effluent paddock containing 1200 kg K per hectare more than the non-effluent area (Table 4.1). This is consistent with the effluent paddock receiving 20 times more K on an annual basis (219 vs. 19 kg K ha⁻¹ yr⁻¹) compared to the non-effluent paddock (Table 5.6, Chapter 5; Appendix 4.1).

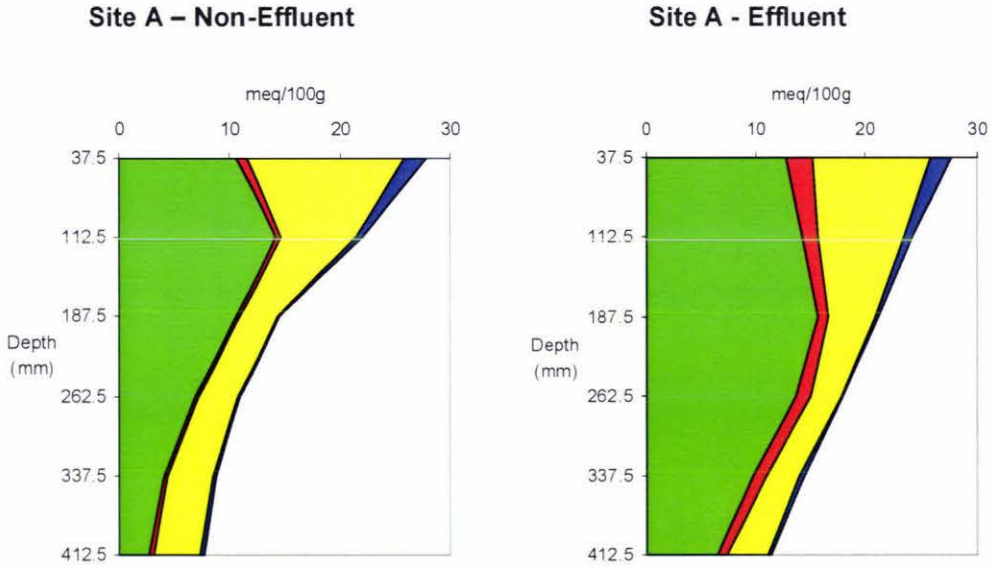


Figure 4.1: Exchangeable cation concentrations (meq 100 g⁻¹ soil) in the soil profiles of effluent and non-effluent paddocks at site A.

(Mg²⁺ ■, Ca²⁺ ■, K⁺ ■, H⁺ ■)

Table 4.1: Total difference[±] (kg ha⁻¹) between effluent and non-effluent paddock profiles (0-450 mm) for potassium (K⁺), calcium (Ca²⁺) and magnesium (Mg²⁺) at all sites.

Site	Total K difference (kg ha ⁻¹)	Total Ca difference (kg ha ⁻¹)	Total Mg difference (kg ha ⁻¹)
A	1204*	-461	27
B	496*	975*	294*
C	194*	451	57
D (sand)	414*	833*	215*
D (mud)	402*	279	32
E [^]	360*	-979	31
F	504*	375	247*

[±] Difference = sum of soil profile cation (kg ha⁻¹) (Effluent – Non-effluent)

* Significant difference at 5 % level

[^] Site E difference between long-term effluent and non-effluent paddock

The soil profile cation distribution pattern was markedly different between the effluent and non-effluent paddocks at site B (Figure 4.2). The effluent paddock had higher cation exchange capacity (the sum of all exchangeable cations in Figure 4.2 and significantly higher concentrations of all three nutrient cations (K^+ , Ca^{2+} , Mg^{2+}) in the 0-75 mm depth of profile, however, only the concentration of Mg^{2+} in the effluent paddock at 75-150 mm is significantly different to the non-effluent samples. When the results are summed over the whole profile, the difference per hectare between the effluent and non-effluent paddocks is found to be significant for these three cations. Table 4.1 shows that the effluent paddock has greater total amounts in the 0-450 mm depth than the non-effluent paddock for all nutrient cations. Greater amounts of exchangeable K^+ , Ca^{2+} and Mg^{2+} in the soil profile of the effluent paddock are consistent with inputs for all these cations being greater in the effluent paddock (Table 5.6, Chapter 5; Appendix 4.1) The total cation exchange capacity (CEC) has increased as a result of effluent application in the 0-150 mm depth but has decreased in the rest of the profile. Higher CEC values are associated with the higher organic C values in the 0-75 mm depth of the effluent paddock (Figure 4.6, Appendix 1.1).

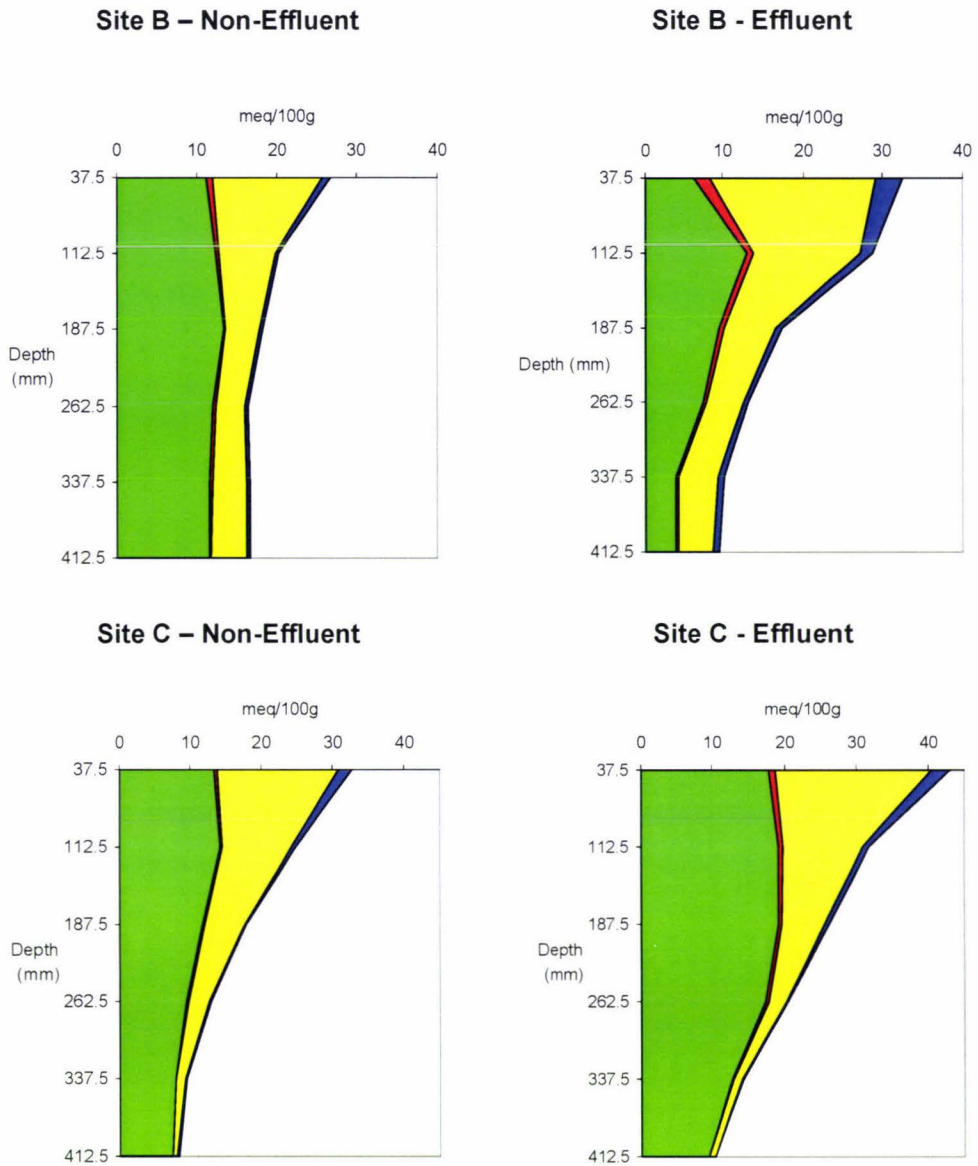


Figure 4.2: Exchangeable cation concentrations (meq 100 g⁻¹ soil) in the soil profiles of effluent and non-effluent paddocks at sites B and C.

(Mg²⁺ ■, Ca²⁺ ■, K⁺ ■, H⁺ ■)

At site C the cation exchange capacity in the effluent paddock was found to be greater than the non-effluent paddock at all depths (Figure 4.2). Again, this was consistent with high organic C concentrations in the 0-75 mm depth of the effluent paddock compared to the non-effluent paddock (Figure 4.6). The largest increase occurred in the exchangeable acidity (H⁺) concentration, suggesting a potential

decrease in pH. However, this pH difference is not predicted by OVERSEER[®] (Appendix 4.3). Compared to sites A and B, the difference between the inputs of K into the effluent and non-effluent paddocks is smaller resulting in a smaller K⁺ gain in the soil profile (Table 5.6, Chapter 5; Appendix 4.3). Despite the non-effluent block having higher Ca²⁺ and Mg²⁺ inputs from fertiliser (than effluent), amounts of exchangeable Ca²⁺ and Mg²⁺ are greater in the profile of the effluent area (Table 4.1).

Application of effluent at site D on the sandy soil has resulted in a significant ($\alpha=0.05$) increase in the K⁺ and Mg²⁺ concentrations in the 0-75 mm depth (Figure 4.3).

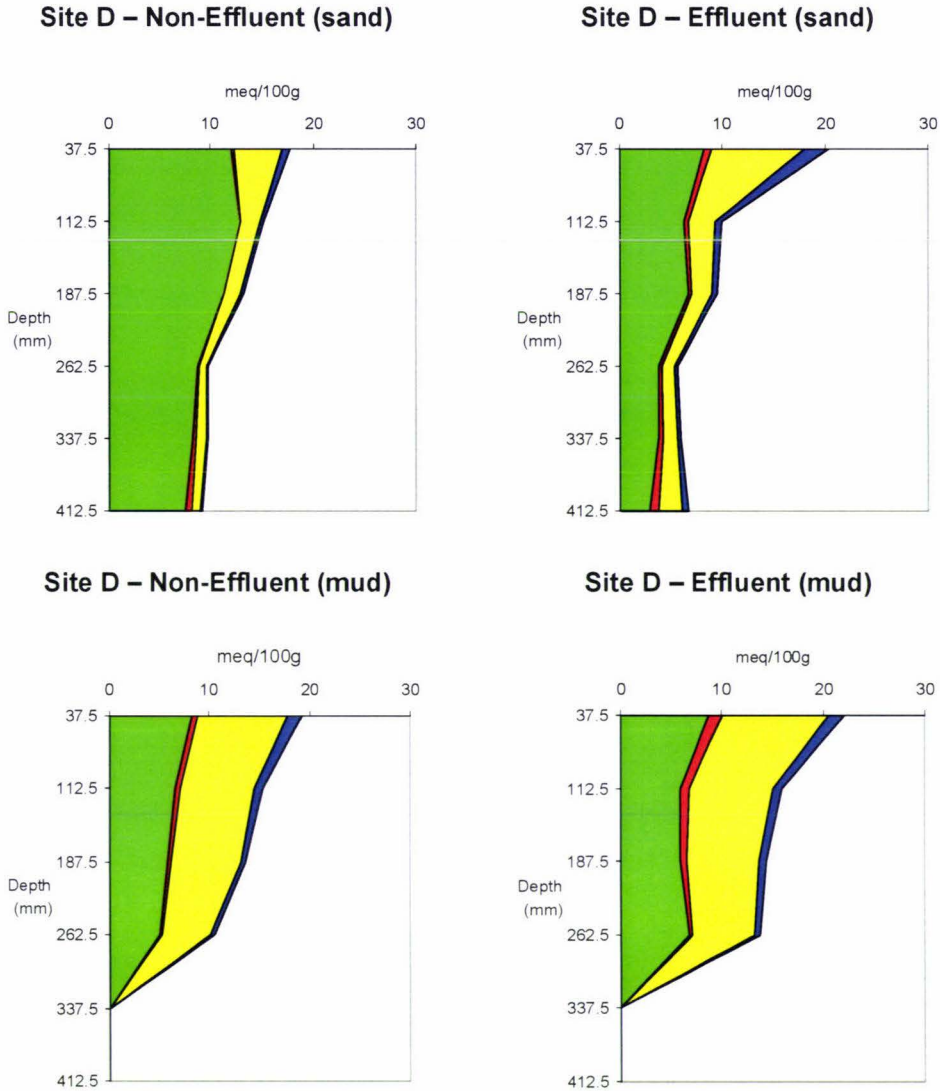


Figure 4.3: Exchangeable cation concentrations (meq 100 g⁻¹ soil) in the soil profiles of effluent and non-effluent paddocks at site D.

(Mg²⁺ ■, Ca²⁺ ■, K⁺ ■, H⁺ ■)

The CEC found in the topsoils is similar at both the sandy and mud parts of site D. This is consistent with the little difference found in the organic C values in both areas (Figure 4.6). At the sandy site D, the total amounts of K⁺, Ca²⁺ and Mg²⁺ over the whole effluent paddock profile are also significantly greater than the non-effluent samples, and the effluent paddock has over 800 kg ha⁻¹ more calcium in the whole profile than the non-effluent paddock (Table 4.1). This result is not consistent with differences in Ca inputs via effluent and fertiliser, which

are small (Appendix 4.4). It could, however, be due to the greater H^+ concentration found in the non-effluent paddock, as high levels of H^+ and Al^{3+} can lead to greater Ca^{2+} leaching.

On the areas covered with Rotomahana mud, little difference occurs between the effluent and non-effluent paddocks (Figure 4.3).

Site E has a long-term effluent area (10 years of application) and a short-term block (2 years) and the cation distributions for these two paddocks are quite different to, and substantially smaller than, the non-effluent paddock.

These paddocks do not appear to 'pair' well as the organic C concentrations in the 0-75 mm depth are significantly higher in the non-effluent paddock (Figure 4.6). This is consistent with higher CEC in this area. While lower CEC may explain the low Ca^{2+} concentrations in the effluent treated area, Ca^{2+} inputs are higher in the fertiliser applied to the non-effluent area than in effluent applied to FDE paddocks (Appendix 4.5). Despite lower accumulations of Ca^{2+} and Mg^{2+} , K^+ has accumulated in the profiles of the effluent paddocks (Table 4.1; Figure 4.4).

The concentration of Mg^{2+} in the 0-75 mm depth of the short-term effluent paddock is significantly smaller than the concentrations found in the other two paddocks. Table 4.1 shows that the total amounts of Ca^{2+} in the whole profile in the non-effluent paddock is larger than in the long-term effluent paddock by more than 900 kg ha^{-1} . A major assumption made in this project is that the soil chemical characteristics in each pair of paddocks were similar before effluent irrigation began so that any difference is due to the application of FDE. The changes in CEC and soil carbon suggests that either the paddocks had different soil chemistry initially or different fertiliser application rates to give these greater concentrations of Ca^{2+} . The method of choosing sampling sites and cores for analysis should have removed some soil type variation.

Thus the most probable explanation is different fertiliser histories. The difference in Ca^{2+} partly results from the non-effluent block receiving fertiliser inputs of $78 \text{ kg ha}^{-1} \text{ yr}^{-1}$ and the effluent paddock receiving only $32 \text{ kg Ca ha}^{-1} \text{ yr}^{-1}$.

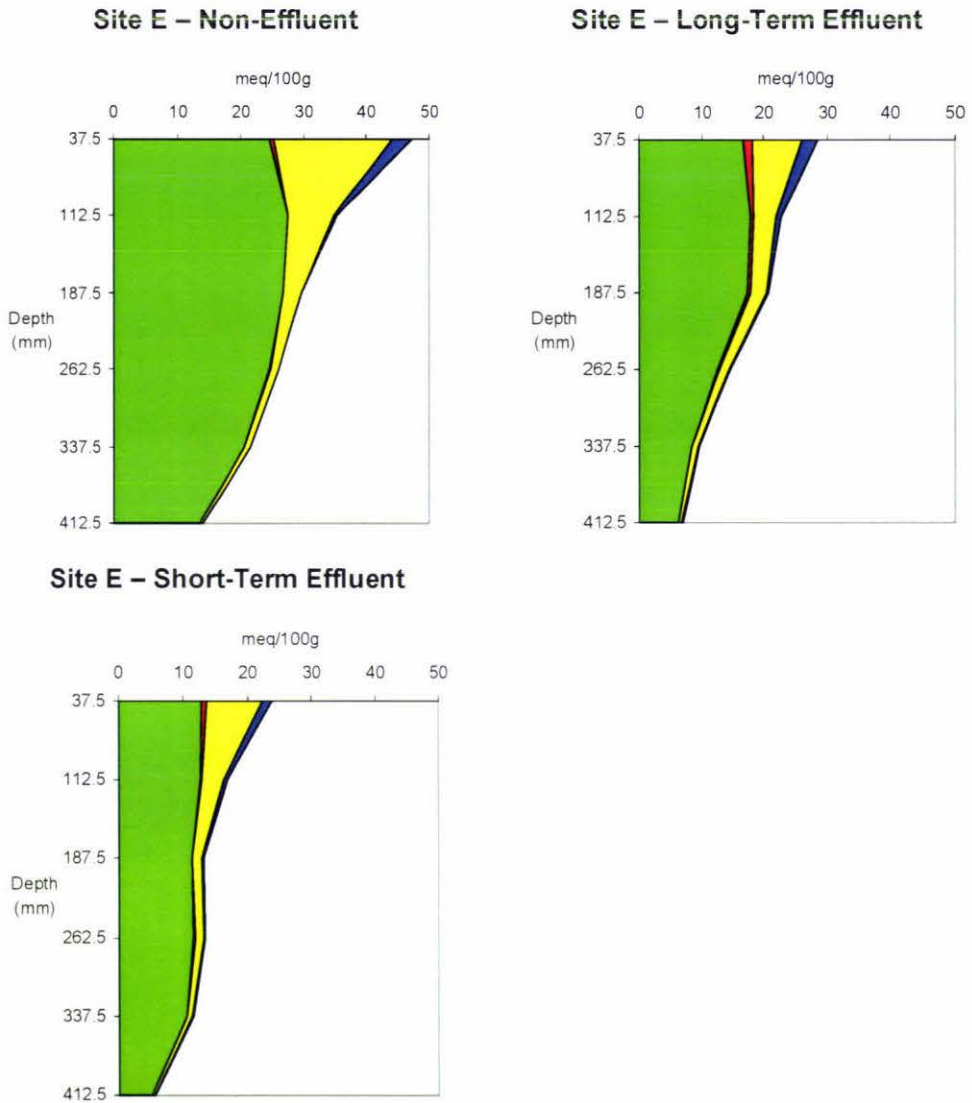


Figure 4.4: Exchangeable cation concentrations ($\text{meq } 100 \text{ g}^{-1} \text{ soil}$) in the soil profiles of effluent and non-effluent paddocks at site E.

(Mg^{2+} ■, Ca^{2+} ■, K^+ ■, H^+ ■)

A significant increase in the concentration of K^+ in the 0-75 mm depth has occurred due to effluent application at site F (Figure 4.5). This is in agreement with the higher estimated annual input of $184 \text{ kg K ha}^{-1} \text{ yr}^{-1}$ (Appendix 4.6). The total CEC in the effluent paddock is lower in this upper layer and this is consistent with lower organic C in the 0-75 mm depth of the effluent paddock. Lower CEC has probably resulted in more Ca^{2+} leaching and despite Ca^{2+} inputs being greater at the effluent site, the topsoil exchangeable Ca^{2+} concentration is lower than at the non-effluent area. This is consistent with concentrations of exchangeable Ca^{2+} increasing down the profile of the effluent area (Figure 4.5). The total amount of Ca^{2+} in the profile, however, is larger in the effluent paddock than the non-effluent paddock (Table 4.1).

The average concentration of Mg^{2+} is significantly greater in the effluent paddock than the non-effluent area, with higher Mg concentrations in the effluent paddock occurring at all depths. This site has greater nutrient inputs in the effluent paddock, as it receives the same amount of fertiliser as the rest of the farm, and also receives effluent, so the difference between the paddocks was not unexpected.

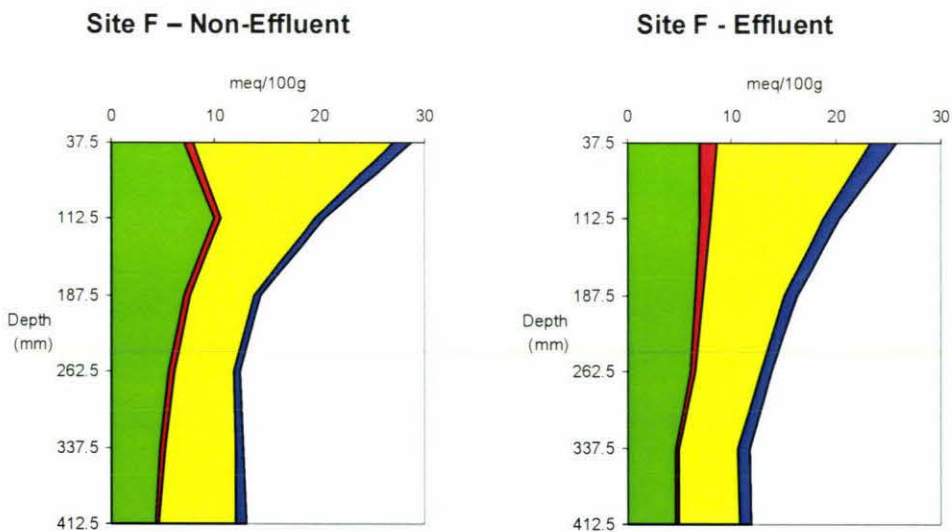


Figure 4.5: Exchangeable cation concentrations ($\text{meq } 100 \text{ g}^{-1} \text{ soil}$) in the soil profiles of effluent and non-effluent paddocks at site F.

(Mg^{2+} ■, Ca^{2+} ■, K^+ ■, H^+ ■)

4.2.1 Implications of exchangeable cation results

All of the effluent paddocks in the study had potassium levels that were at or above the optimum 8-10 MAF QT units recommended for dairying (Ledgard *et al.* 1991). The non-effluent paddocks at sites A, B, D (mud), and F were also above this recommended level with the remaining farms (C and E) below, although these sites were in the Bay of Plenty which traditionally has low levels of K due to the pumiceous nature of the soils (Ledgard *et al.* 1991). The problem of high concentrations of K^+ in the soil is an animal health issue with luxury consumption of potassium by the plants which gives a high K^+ content to the pasture. This in turn causes a reduced intake by the dairy cows, of Ca^{2+} and Mg^{2+} and can lead to early lactation metabolic problems like hypocalcaemia and hypomagnesaemia. Application of effluent has been found to decrease the Ca^{2+} and Mg^{2+} content in pasture (Bolan *et al.* 2000), but only to levels below the lactation and pregnancy Ca^{2+} requirements. Others have found that the luxury uptake of K^+ and consequent lowering of Ca^{2+} and Mg^{2+} concentrations is exacerbated by the concurrent application of nitrogen and phosphorus, as occurs in effluent irrigation (Carran 1988; Wilson 1996).

In order to reduce calcium and magnesium deficiencies in soils that receive effluent, many farmers add these nutrients to the soil as fertiliser or pasture dusting, or to the animal directly via drenches. A more sustainable but potentially more costly approach would be to reduce the effluent loading to levels which would supply the optimum potassium concentrations (Bolan *et al.* 2000), instead of the current emphasis on nitrogen limits. The difficulty would be in trying to estimate the annual K loading based on a single effluent sample as the concentration of K in effluent can vary widely, and few authors have reported full effluent cation composition values to compare potential ranges.

4.3 Carbon and Nitrogen Analysis

It is important to know the carbon (C) content of a soil in order to calculate the capacity of the soil to store nitrogen (N). The amount of N stored is dependent on the amount of organic C available for bonding, and the consequences of exceeding the N storage capacity include greater nitrate (NO_3^-) leaching (Schipper *et al.* 2004). Under pastoral agriculture, the C:N ratio tends to decrease as the soil stores more N from legume-fixation, fertiliser and FDE application, however, the C:N ratio of topsoils rarely falls below 10 as simpler organic compounds (ratios less than 10) are hydrolysed by soil enzymes or mineralised by soil microbes to inorganic forms (Schipper *et al.* 2004).

There is no consistent effect of FDE application on soil C and N values and a wide range of carbon and nitrogen contents at the 0-75 mm depth are shown in Figure 4.6. At sites B, C and D, soil C concentrations in the 0-75 mm depth are higher in effluent paddocks but this trend is reversed at sites A, E and F (Figure 4.6). However, only two sites, B and D, had greater N topsoil values in the effluent areas.

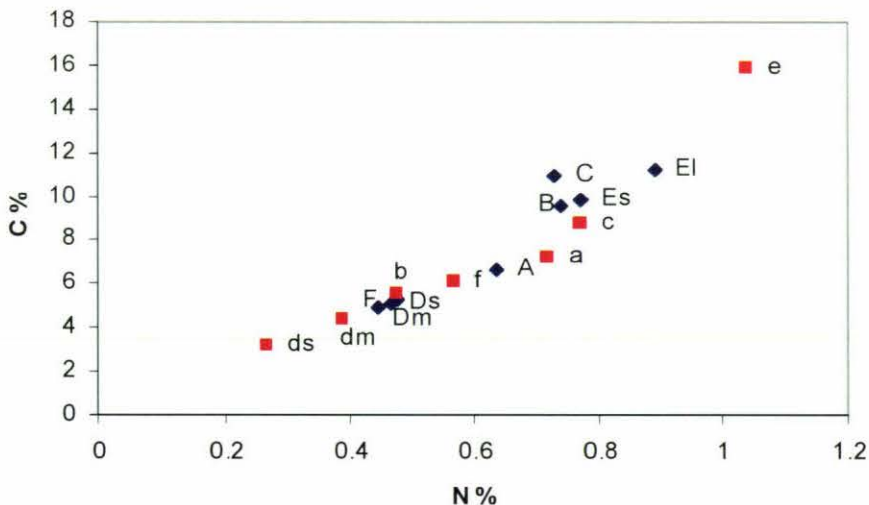


Figure 4.6: Carbon (C %) and nitrogen (N %) content of topsoils (0-75 mm) measured by Leco combustion method. Effluent samples (A, B, C, Ds, Dm, Elong, Eshort, F) ◆ and non-effluent samples (a, b, c, ds, dm, e, f) ■.

Table 4.2 shows the C:N ratios determined for the 0-75 mm depth. The C:N ratio (Table 4.2) for these topsoil samples are all either low or medium, as classified by Blakemore *et al.* (1987), and no significant difference between the effluent and non-effluent paddocks is obvious, reflecting the variability of the C:N ratio in effluent (2.9-18.7), as reported in literature (Silva *et al.* 1999; Di *et al.* 2002). These findings confirm the supposition by Cameron *et al.* (1997) that the organic matter content in effluent is too low to significantly affect the organic carbon content of the soil, and contrasts with the results of Barkle *et al.* (2000) who found a significant difference in organic matter content after very high carbon and nitrogen application rates.

Table 4.2: Carbon: Nitrogen ratio for all sites in the 0-75 mm depth

Site	Effluent	Non-Effluent
A	10	10
B	13	12
C	15	11
D (sand)	11	12
D (mud)	11	11
E (long)	13	15
E (short)	13	
F	11	11

4.4 Comparison of Total Nitrogen Determination Techniques

Total C and total P analysis enabled N to be determined by two methods: Leco combustion and Kjeldahl digest. A strong correlation ($R^2=0.97$) between the two methods used to determine total nitrogen is shown in Figure 4.7. There is no consistent bias of one method over the other as Leco gives slightly higher results for sites A, B, C and E but lower N content for sites D and F. On average, however, the error in using Leco N to predict Kjeldahl N is -0.0118% of the N value. The 'goodness of fit' of the data (as it follows a 1:1 line) enables the assumption that either method is suitable for relative assessment of soil N content but care must be taken in comparing values that are determined by different methods.

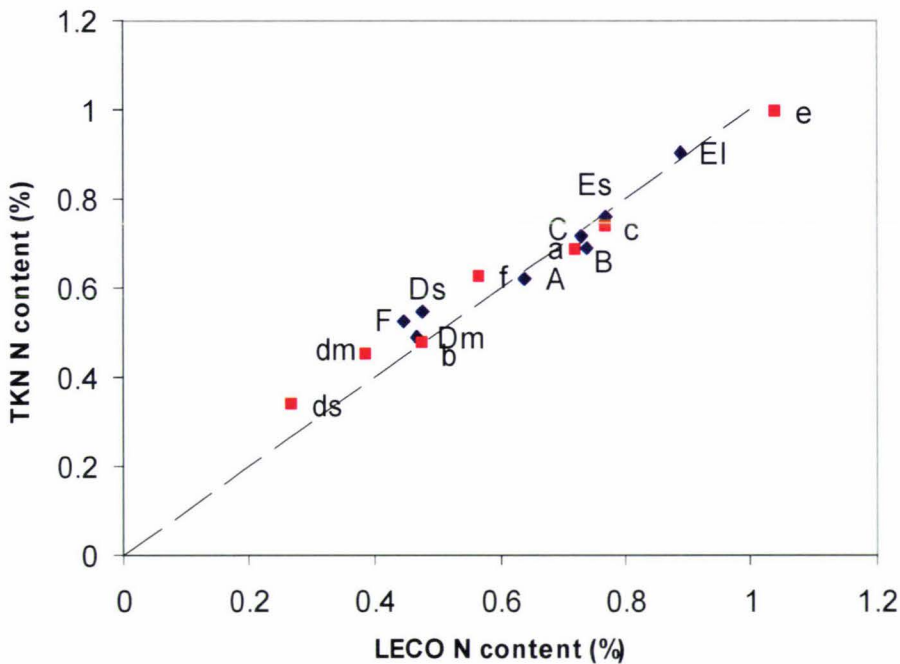


Figure 4.7: Nitrogen content (%) in the 0-75 mm depth, determined by two methods: total Kjeldahl nitrogen digest (TKN) and combustion (Leco). A 1:1 line is shown in black. Effluent samples (A, B, C, Ds, Dm, Elong, Eshort, F) ◆ and non-effluent samples (a, b, c, ds, dm, e, f) ■.

4.5 Comparison of Total Nitrogen and Total Phosphorus Contents with Soil Depth

There is a general trend of decreasing nutrient content with depth, and of nutrient levels in paddocks becoming more similar as depth increases.

Many sites show little differentiation between the effluent and non-effluent paddocks in total nitrogen and phosphorus content. This is a reflection of the size of the pool of nutrients relative to the amount applied. For significant differences to occur, large amounts must be applied, or a long period of application, or very different nutrient strategies applied to two paddocks. Sites B (Figure 4.8) and F (Figure 4.9) have a large difference in total nitrogen contents when the whole profile is summed, with over $1700 \text{ kg N ha}^{-1}$ more in the effluent

paddocks (Table 4.2). At site F, this is partly due to the large quantity of N (190 kg N ha^{-1}) (Appendix 4.6) that is applied annually as urea to the farm, including the effluent area which receives effluent-N also. Site B is a high-producing farm which brings a large amount of supplements onto the farm, and has relatively low urea application rates (30 kg N ha^{-1}) (Appendix 4.2). It also has a large difference in the amount of total phosphorus in the profile, with $1000 \text{ kg P ha}^{-1}$ more in the effluent paddock than the non-effluent area, so it is likely that the two paddocks were not as well paired as expected prior to effluent application.

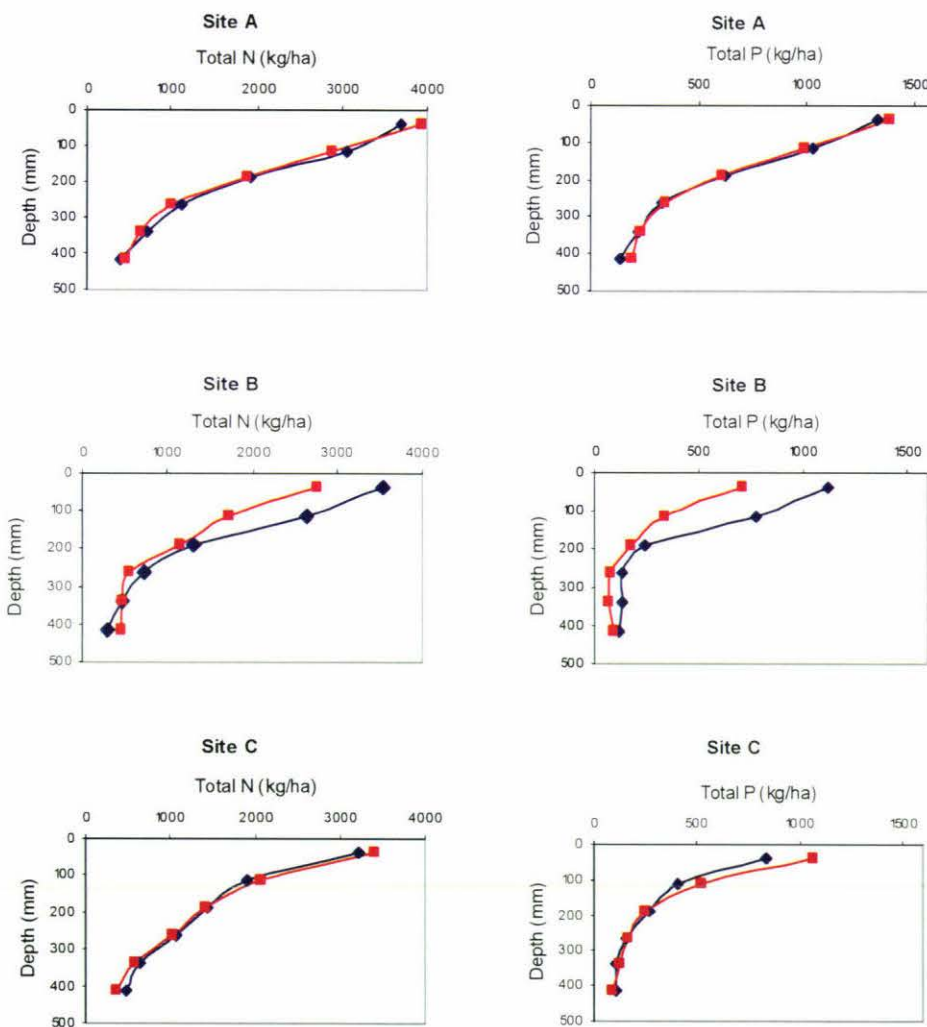


Figure 4.8: Total nitrogen (N) and total phosphorus (P) (kg ha^{-1}) determined in the soil profile of the effluent (◆) and non-effluent (■) paddocks at sites A-C.

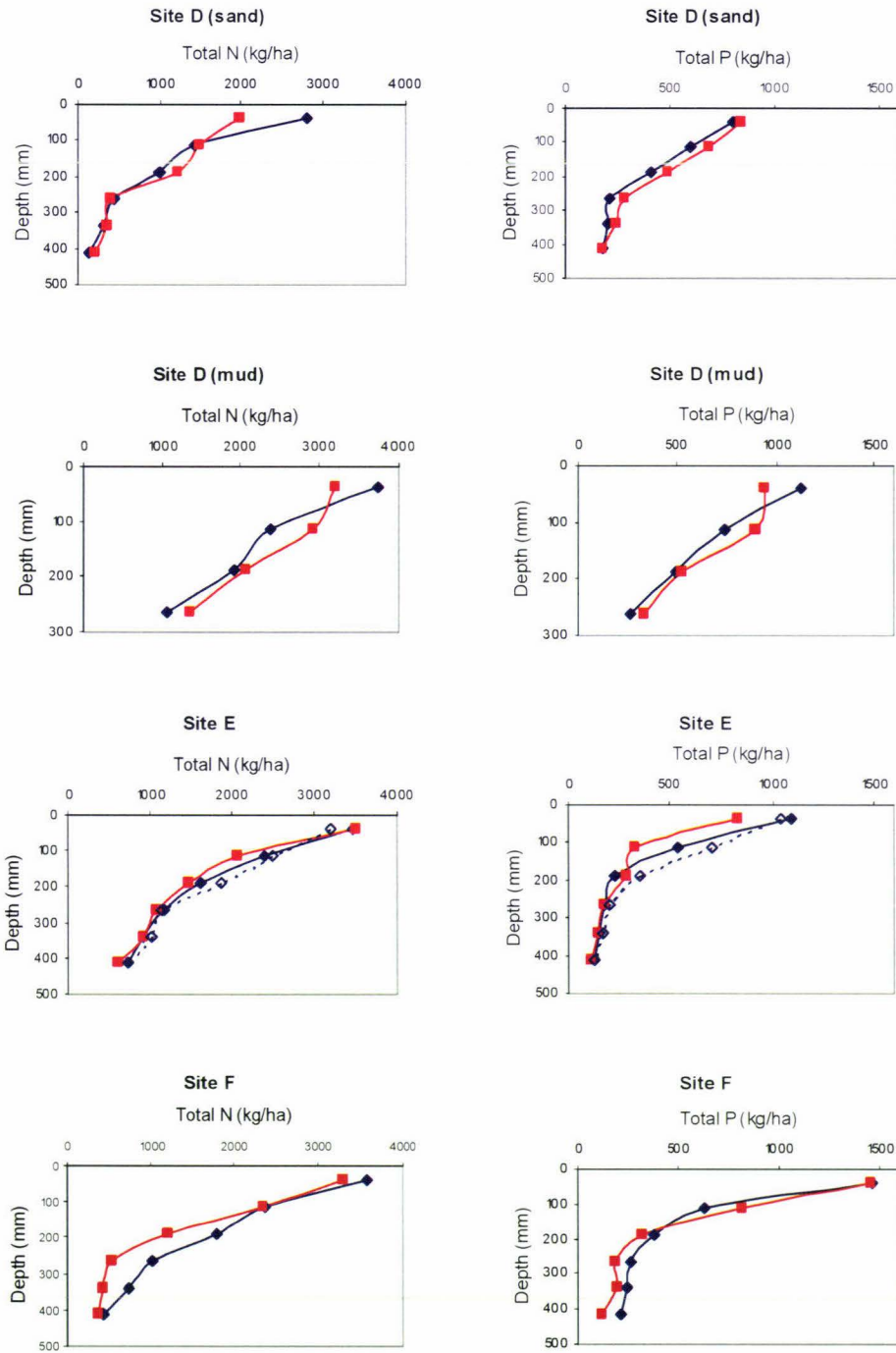


Figure 4.9: Total nitrogen (N) and total phosphorus (P) (kg ha^{-1}) determined in the soil profile of the effluent (◆) and non-effluent (■) paddocks at sites D-F. At site E, the short-term effluent paddock is represented by ◇ .

Table 4.3: Difference[±] between effluent and non-effluent paddock soil profile results (0-450 mm) for total nitrogen (N) and total phosphorus (P).

Site	Total N difference (kg ha ⁻¹)	Total P difference (kg ha ⁻¹)
A	145	-75
B	1871	1063
C	-134	-343
D (sand)	474	-323
D (mud)	-421	-75
E*	643	448
F	1712	96

[±] Difference = sum of soil profile cation (kg ha⁻¹) (Effluent – Non-effluent)

Significant differences in the total nitrogen contents occur at site B, in the 75-150 mm depth, site D (sand) (Figure 4.9) at the 0-75 mm depth and at site E, between the short-term effluent and non-effluent paddocks at the 0-75 mm depth. The only statistically significant difference between paddocks for total phosphorus content was found at site C in the 0-75 mm depth (Figure 4.8). Some of the sites (A, C and D) show a larger phosphorus pool in the non-effluent paddocks than the effluent paddocks (Table 4.3) and this is in contrast to the findings of Hawke and Summers (2003) who found an increase of P in the FDE irrigated samples. At sites C and D, this is due to management operating on a no-fertiliser policy on the effluent blocks (Appendix 3.2), with the result that the amount of effluent-sourced P is less than the amount of fertiliser-P applied to the rest of the farm (Appendices 4.3 and 4.4). The result of higher P in the non-effluent block at site A is unexpected as the whole farm receives the same fertiliser application rate (Appendix 2.4.1) and the effluent block Olsen P value is greater than the non-effluent paddock (Table 4.4). Therefore it is possible that the paddocks are not well matched.

One of the original concepts of the project was to use phosphorus as an accumulation marker to calculate how much nutrient had been applied in the effluent over time, using a simplified mass balance model like that developed by Saggart *et al.* (1990). Inputs such as herbage

accumulation, animal intake, nutrients in excreta, topography and the removal of nutrients from the system via product were used to predict at least 79% of the variation in P found in soil samples, from a 12 year experimental period (Saggar *et al.* 1990). Due to the limited and incomplete information on past nutrient inputs and outputs and the possibility of poorly matched pairs of paddocks, a mass balance approach did not work with the current data. This approach can only be used if farmers and farm managers keep continuous, accurate records of fertiliser history and farm management practices, and these are passed on when management changes. In Chapters 5 and 6, an alternative approach is evaluated using OVERSEER[®] Nutrient Budgets 2 software to estimate historic changes in soil nutrient content.

4.6 Olsen P

Olsen P was determined on the 0-75 mm depth samples and was found to be either high (30-50) or very high (>50), as classified by Blakemore *et al.* (1987) for both effluent and non-effluent paddocks (Table 4.4). High Olsen P usually indicates excessive use of phosphorus fertiliser, especially in allophanic soils, like site A and F, although current fertiliser application rates (Appendix three) do not agree with this.

Table 4.4: Olsen P soil test values ($\mu\text{g g}^{-1}$) for effluent and non-effluent paddocks.

Site	Effluent	Non-effluent
A	34	30
B	36	40
C	31	60
D (sand)	90	104
D (mud)	70	38
E (long-term)	72	42
E (short-term)	58	-
F	67	75

4.7 Summary

The chemical composition of the soils in effluent paddocks was different from non-effluent paddocks. Greater potassium and magnesium concentrations were found in the soil samples taken from effluent paddocks and this was consistent with K^+ inputs to effluent areas being larger than non-effluent areas, however, calcium results showed no clear trend. Contrasting differences in potassium and calcium concentrations were likely to be due to differences in the application of lime and/or superphosphate, and changes in management practices. The high concentrations of exchangeable potassium found could be a source of animal health problems as plants take up K in abundance which leads to a high-K content in the pasture and consequently low calcium and magnesium levels in the animal. Many farmers mitigate this problem by applying supplements or dusting to pasture, although reducing the potassium concentration applied in the effluent would be a more sustainable option. Some sites showed an increase in cation exchange capacity or a change in the relative abundance of each cation and generally reflect an 'improvement' to the soil.

The carbon, nitrogen and phosphorus results do not show overwhelming evidence that effluent application has increased the concentration of these nutrients in the soil. Investigation into these nutrients is confounded by the general application of fertilisers, especially urea and superphosphate to the rest of the farm, and by the size of the nutrient pool where a much larger increase is required to be significant, compared with the smaller pool of exchangeable cations.

These results are discussed further in Chapter 6, where they are compared with outputs from the OVERSEER[®] model that predict changes in soil content.

CHAPTER 5: OVERSEER[®] Nutrient Budgets

5.1 Introduction

OVERSEER[®] Nutrient Budgets is decision support software initially developed by AgResearch in the 1990s, and allows for a quantitative estimation of the fate of nutrients in a farm system. It accounts for the input of nutrients from the environment, fertilisers, supplementary feedstuff and animal remedies and simulates the farm production system and farm management practices to model the fate of those nutrients as products, atmospheric, leaching and runoff losses and storage in the soil. The algorithms in the model utilise databases formulated from New Zealand fertiliser materials, supplementary feeds and farm production and environmental research (Ledgard *et al.* 1999). The model is designed to create a nutrient budget for a farm or particular management block to assist with integrated nutrient management, maximise nutrient use efficiency and minimise adverse impacts of excess nutrients on the environment.

It allows farmers to evaluate the effectiveness of fertiliser policies i.e. whether too much or too little is being applied to maintain or improve production, and gives them the opportunity to investigate the likely outcome of changes in management such as the use of different supplements, fertilisers and altered stocking rates. It has also been proposed as the tool that farms in the Lake Taupo catchment will be assessed with in order to limit their nitrate losses to the environment (Ledgard *et al.* 2001; Dragten & Thorrold 2005).

Nutrient budgets were created in OVERSEER[®] using information derived from site visits, interviews with farmers and soil chemical analyses. The outputs (immobilisation/absorption and change in the inorganic pool) of these budgets were then used to predict the amount of nutrients accumulated in the soil over time. In Chapter 6, these

values are then compared with the results from the soil chemical analyses.

5.2 Site Information

Examples of the general site information required by OVERSEER® is shown in Table 5.1. In this part of the model, the level of production and the amount of nutrient inputs from supplements and animal remedies are calculated.

Table 5.1: Site specific parameters required by the OVERSEER® Nutrient Budget 2 model and information from sites C and F*.

	Parameter	Site C	Site F
	Region	Bay of Plenty	Waikato
Area	Effluent (ha)	20	6
	Non-effluent (ha)	100	34
Stock	Number of cows	310	121
	Breed	Friesian	FxJ cross
	Total milk solids (kg)	102000	48391
	Yearlings grazed	Off farm	Off farm
	Effluent disposal method	Spray	Spray
	Animal health supplements	Drenching: 30g MgO cow ⁻¹ day ⁻¹ for 16 weeks	Pasture dusting: 25kg MgO ha ⁻¹ yr ⁻¹ 7kg lime flour ha ⁻¹ yr ⁻¹
	Supplements added	Average pasture silage 40T	None

* Data for the other sites can be found in Appendix three

5.3 Block Information

Tables 5.2 and 5.3 show the input variables using data from sites C and F for the effluent and non-effluent areas respectively. The general block and fertiliser information was gathered in a series of interviews with the farmers while the soil test data is based on soil samples taken from each site in autumn 2005.

In the final nutrient budget, the denitrification and leaching losses for nitrogen are based on three major aspects –the surplus and source of N in the system, the amount of drainage and the soil order chosen. The drainage rate is determined by the rainfall and the surplus N from nitrogen input (urine, dung, fertiliser), so the soil order chosen can have a major influence on the final nutrient budget (Ledgard *et al.* 1999). Therefore it is important for farmers to have a reasonable knowledge of the soils in their situation. The use of the most recent soil test results is also important as the model apportions some of the output factors (immobilisation, leaching and change in inorganic pool) based on the amount in the soil (test value).

Table 5.2: Input variables for the effluent areas of sites C and F.

Effluent Area		Site C	Site F
Block general	Topography	Rolling	Flat
	Distance from coast (km)	50	50
	Rainfall (mm)	2000	1200
	Drainage (mm)	1340	444
	Effluent application rate	Medium	Medium
	Development status	Developed	Developed
	Pasture type	Ryegrass/ white clover	Ryegrass/ white clover
	Soil	Podzol	Allophanic
	Type	Mangorewa sandy loam	Kereone silt loam
	Olsen P	32	67
	QT K	10	31
	Organic S	22.6	11.3
	QT Ca	23	24
	QT Mg	41	59
	QT Na	3	5
Fertiliser (kg ha ⁻¹)	N	0	190
	P	0	64
	S	0	78
	K	0	64
	Ca	0	121
	Mg	0	20
	Na	0	0
	N added May-June	0	59
Soluble P added May-Oct	0	39	
Supplements removed	None	14T silage	

Table 5.3: Input variables for the non-effluent areas of sites C and F.

Non-Effluent Area		Site C	Site F	
Block general	Topography	Rolling	Rolling	
	Distance from coast (km)	50	50	
	Rainfall (mm)	2000	1200	
	Drainage (mm)	1340	444	
	Development status	Developed	Developed	
	Pasture type	Ryegrass/ white clover	Ryegrass/ white clover	
Soil	Order	Podzol	Allophanic	
	Type	Mangorewa sandy loam	Kereone silt loam	
	Olsen P	35	75	
	QT K	7	13	
	Organic S	22.6	23.8	
	QT Ca	19	24	
	QT Mg	29	35	
	QT Na	3	7	
	Fertiliser (kg ha ⁻¹)	N	180	190
		P	50	64
S		40	78	
K		30	74	
Ca		110	151	
Mg		30	20	
Na		0	0	
N added May-June		25	59	
Soluble P added May-Oct	15	39		
Supplements removed	18T silage	7T silage		

5.4 Nutrient Budgets

The equations used to calculate the separate output factors are based on New Zealand research results and one of the key assumptions made in the nitrogen (N) system is that the change in inorganic pool is always zero because winter leaching, plant uptake and denitrification always returns this pool to 2% of total soil N (Russell 1988). This means that the sum of inputs must equal the sum of the rest of the outputs. After the N has been partitioned into product, transfer, supplements removed, atmospheric losses and immobilised N, the remainder is assumed to be leached. Other nutrients (P, K, Ca, Mg) are modelled so that the

inorganic pool (adsorbed P and exchangeable cations) is proportional to the soil test values and losses are proportional to the stocking rate (Carey & Metherell 2002).

The product and transfer losses are dependent on the pasture intake (which is estimated from the animal production or stocking rate), the pasture nutrient concentration (derived from the soil test results and the fertiliser input data), and the proportion of excreta transfer that occurs on a yearly basis (herd and farm size) (Ledgard *et al.* 1999).

The amount of N that is fixed from the atmosphere as inputs into the system is based on the pasture production (estimated from the animal production figures) and the % of legume in the pasture (the default is medium and rarely requires alteration). The rate of fixation is automatically adjusted for the effects of fertiliser or effluent application (Ledgard *et al.* 1999).

Figures 5.1 and 5.2 show the nutrient budget outputs from OVERSEER® for the effluent and non-effluent paddocks of sites C and F. The concentrations of nutrients applied to the pasture from effluent vary with the level of production, supplements used and fertiliser policy and are not based on an average value.

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	0	0	0	0	0	0	0	0.0
Effluent Added	137	17	133	15	31	16	1	-3.0
Atmospheric / clover N	114	0	2	5	4	8	28	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	8	0	1	0	3	0.0
Supplements	12	2	10	1	3	6	1	-0.2
Outputs								
Product	70	13	15	4	18	1	4	-0.6
Transfer	31	4	33	3	7	4	0	-0.6
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	38	0	0	0	0	0	0	-0.2
Leaching/runoff	36	7	85	37	144	19	87	-2.7
Immobilisation/absorption	89	47	0	-24	0	0	0	-0.6
Change in inorganic soil pool	0	-49	20	0	-131	6	-59	1.5

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	180	50	30	40	110	30	0	-0.3
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	94	0	2	5	4	8	28	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	15	0	1	0	3	0.0
Supplements	12	2	10	1	3	6	1	-0.2
Outputs								
Product	70	13	15	4	18	1	4	-0.6
Transfer	31	4	28	3	7	3	0	-0.7
Supplements removed	5	1	4	1	1	0	0	0.0
Atmospheric	59	0	0	0	0	0	0	0.0
Leaching/runoff	58	8	40	59	130	20	86	-4.1
Immobilisation/absorption	63	52	0	-21	0	0	0	-0.1
Change in inorganic soil pool	0	-23	-29	0	-38	19	-59	4.8

Figure 5.1: Nutrient budgets from OVERSEER® for the effluent (shaded) and non-effluent areas of site C.

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	190	64	74	78	151	20	0	0.0
Effluent Added	170	23	190	22	39	22	3	-3.7
Atmospheric / clover N	81	0	2	4	2	5	17	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	10	0	2	2	8	0.0
Supplements	16	2	14	1	6	16	0	0.1
Outputs								
Product	96	17	21	6	24	2	6	-0.7
Transfer	34	4	36	3	7	4	0	-0.6
Supplements removed	72	11	65	5	17	7	2	0.3
Atmospheric	93	0	0	0	0	0	0	-0.4
Leaching/runoff	65	0	197	82	233	30	60	-4.9
Immobilisation/absorption	97	52	0	10	0	0	0	-0.5
Change in inorganic soil pool	0	8	-29	0	-79	23	-39	3.2

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	190	64	74	78	151	20	0	0.0
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	131	0	2	4	2	5	17	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	16	0	2	2	8	0.0
Supplements	16	2	14	1	6	16	0	0.1
Outputs								
Product	96	17	21	6	24	2	6	-0.7
Transfer	36	5	38	5	8	4	1	-0.7
Supplements removed	6	1	5	1	1	1	0	0.0
Atmospheric	75	0	0	0	0	0	0	0.0
Leaching/runoff	57	1	54	88	216	31	49	-4.0
Immobilisation/absorption	66	55	0	-16	0	0	0	-0.1
Change in inorganic soil pool	0	-9	-12	0	-88	5	-30	5.6

Figure 5.2: Nutrient budgets from OVERSEER® for the effluent (shaded) and non-effluent areas of site F.

5.4.1 Summaries of selected nutrients (N, P, K)

The nutrient budget information from each site for nitrogen (N), phosphorus (P) and potassium (K) was extracted from the individual OVERSEER® budgets like Figures 5.1 and 5.2 and can be found in Tables 5.4-5.6. This procedure allows for comparison between different management strategies and site characteristics for the nutrients of interest.

A wide variation in N inputs from fertiliser, effluent and atmospheric sources is shown in Table 5.4. The calculation by OVERSEER® for the concentration of N in effluent can vary, and is based on the level of production on the farm, and the supplements brought in. In some situations, application rates greater than the regional council limits of 150 kg N ha⁻¹ yr⁻¹ (Waikato) and 200 kg N ha⁻¹ yr⁻¹ (Bay of Plenty) is being applied to the effluent paddocks and this can lead to a greater chance of nitrate leaching to groundwater. Many councils have based their N loading limits on the amount of N produced per cow, the volume of effluent produced and the lactation period. These variables can fluctuate yearly, within a season and even between daily milkings, and do not give a reliable estimate of the amount of N produced. They also assume that no fertiliser N is applied to the effluent paddocks (Cameron & Trenouth 1999), which is an invalid assumption in a number of cases, as seen in Table 5.4.

The N budgets show that the final nitrate concentration is affected by the N surplus, but also by the rainfall, and amount of drainage that occurs on site. An example of this is the N surplus from the non-effluent paddock at site B of 168 kg ha⁻¹, and from the effluent paddock at site C of 193 kg ha⁻¹. Due to the greater rainfall (2000 mm vs. 1500 mm) at site C, the estimated nitrate concentration in drainage water is only 3 ppm, compared to 6 ppm at site B. Another factor in OVERSEER® that can influence the amount of N leaching is whether any N-fertiliser is applied during the high-risk months of May, June and July. These

months have high rainfall and little plant growth, allowing excess N to drain from the available root zone.

Many of the paddocks sampled had an above-optimum Olsen P level which indicates a surplus of P inputs, and are currently correcting for this oversupply through application of sub-maintenance levels of P. This is why many of the sites in Table 5.5 have a negative change in the inorganic pool; the soil store of P is decreasing as inputs are insufficient to maintain the current level of P and still have P lost through product, transfer, and absorption into the soil matrix (unavailable to plants).

Unlike nitrogen, phosphorus movement is affected by the soil order selected as some soils contain allophane, a clay mineral which strongly adsorbs P, effectively removing it from the plant available pool. Allophanic and Granular soils (sites A, B, D (mud) and F) have high P retention capabilities while Podzols and Recent soils (sites C, D (sand) and E) have low P retention (McLaren & Cameron 1996). High rates of P leaching/runoff from a system can lead to environmental problems like the eutrophication of surface waters, and this has become a public issue as streams and lakes become unusable due to algal and aquatic plant growth (Cameron & Trenouth 1999).

The topography and rainfall are also important variables affecting the amount of P that is lost from the system, as shown by Table 5.5, where the sites with high P leaching/runoff have rolling topography and/or relatively high rainfall. This is due to overland flow (runoff) being the predominant pathway for P loss from dairy farms (Sharpley & Syers 1976; Toor *et al.* 2004).

Table 5.4: Nitrogen data (kg ha⁻¹) from OVERSEER® Nutrient Budgets for all sites based on 2004 management practices.

	Site A		Site B		Site C		Site D			Site E		Site F	
	Effluent	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent	Effluent (sand)	Effluent (mud)	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent
Inputs													
Fertiliser	41	40	30	31	0	180	0	0	160	80	200	190	190
Effluent	199	-	274	-	137	-	225	225	-	161	-	170	-
Atmosphere	93	155	161	245	114	94	101	101	114	89	97	81	131
Supplements	23	23	28	28	12	12	24	24	24	0	0	16	16
Outputs													
Product	85	85	136	136	70	70	79	79	79	74	74	96	96
Transfer	52	51	65	59	31	31	46	44	41	29	30	34	36
Supplements removed	0	0	0	0	0	5	0	0	12	0	0	72	6
Atmosphere	62	36	87	49	38	59	67	61	62	56	63	93	75
Leaching	41	28	63	40	36	58	38	42	44	49	64	65	57
Immobilised	45	18	142	20	89	63	121	126	60	120	66	97	66
N status													
Drainage water (ppm)	9	6	9	6	3	4	8	9	10	4	5	15	13
Surplus	271	133	357	168	193	216	272	272	219	255	223	361	241

Table 5.5: Phosphorus data (kg ha⁻¹) from OVERSEER[®] Nutrient Budgets for all sites based on 2004 management practices.

	Site A		Site B		Site C		Site D			Site E		Site F	
	Effluent	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent	Effluent (sand)	Effluent (mud)	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent
Inputs													
Fertiliser	19	19	59	59	0	50	0	0	62	26	72	64	64
Effluent	23	-	36	-	17	-	29	29	-	21	-	23	-
Slow release	3	3	3	3	3	3	3	3	3	3	3	3	3
Supplements	4	4	6	6	2	2	4	4	4	0	0	2	2
Outputs													
Product	15	15	24	24	13	13	14	14	14	13	13	17	17
Transfer	6	6	8	7	4	4	5	5	5	4	4	4	5
Supplements removed	0	0	0	0	0	1	0	0	2	0	0	11	1
Leaching	0	0	0	1	7	8	1	1	1	14	9	0	1
Absorption	29	25	33	22	47	52	34	31	32	88	62	52	55
Change in inorganic pool	-1	-20	39	14	-49	-23	-19	-16	15	-69	-13	8	-9
P status													
P lost	0.2	0.1	0.4	1.0	7.0	8.3	1.2	1.4	1.5	14.0	9.3	0.4	1.0

Table 5.6: Potassium data (kg ha⁻¹) from OVERSEER® Nutrient Budgets for all sites based on 2004 management practices.

	Site A		Site B		Site C		Site D			Site E		Site F	
	Effluent	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent	Effluent (sand)	Effluent (mud)	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent
Inputs													
Fertiliser	0	19	0	95	0	30	0	0	40	0	87	74	74
Effluent	219	-	320	-	133	-	245	245	-	161	-	190	-
Atmosphere	2	2	2	2	2	2	2	2	2	2	2	2	2
Slow release	10	17	4	19	8	15	4	7	38	12	12	10	16
Supplements	18	18	14	14	10	10	20	20	20	0	0	14	14
Outputs													
Product	19	19	31	31	15	15	17	17	17	16	16	21	21
Transfer	56	52	69	65	33	28	47	47	42	33	27	36	38
Supplements removed	0	0	0	0	0	4	0	0	10	0	0	65	5
Leaching	259	45	180	48	85	50	50	201	42	168	46	197	54
Change in inorganic pool	-84	-60	60	-14	20	-29	158	9	-11	-42	12	-29	-12

Table 5.6 shows the very large quantities of K that are applied to effluent paddocks when the effluent application rate is based on the maximum nitrogen loading rate. The application and leaching of excessive amounts of potassium is not an environmental issue in that it does not lead to poor water quality, but it does represent a loss in soil quality, is a farm management issue and can lead to animal health problems.

High concentrations of K were measured in most of the effluent paddocks studied (Table 4.1, Chapter 4) and this is due to the large quantity applied in effluent. Potassium leaching, while high, is generally not the problem, as the majority is readily retained by the soil and taken up preferentially by plants. It is the loss of Ca and Mg through leaching and the preferential uptake of K (McNaught *et al.* 1973) that leads to animal health problems like hypocalcaemia and hypomagnesaemia, as the cattle do not receive enough of these nutrients in the pasture at critical times of the year (calving and early lactation) (Wilson 2002). This is especially a problem when large concentrations of nitrate are also in the soil, as a companion ion for plant uptake (with K) or for leaching (with Ca and Mg) (Mason & Young 1999; Bolan *et al.* 2000).

Some of the sites in Table 5.6 show a negative change in the inorganic pool and this is due to high K test results in the input variables, and reduced K inputs compared with previous years. The quantity of K leached each year is calculated by OVERSEER®, using an algorithm on the soil result data supplied for K. Based on this number, an amount of K loss is determined and this is independent of the amount of potassium entering the system through inputs. When the inputs are less than the quantity leached, the model makes up the balance from the inorganic pool and as a consequence, the soil test result is predicted to drop. A full nutrient history for the past 15 years was available for site A and the annual nutrient budgets show application of K fertiliser to the whole farm in previous years, enabling the soil pool of K to accumulate (Appendix two).

5.4.2 Partitioning Nutrients

The only nutrient which the OVERSEER[®] model treats differently, depending on its origin, is N. Organic sources such as effluent are immobilised more strongly than fertiliser sources such as urea (Figure 5.3a). In turn, this has an impact on the predicted amount of N leached (Figure 5.3b).

The other nutrients of interest (P, K, Ca and Mg) do not display this source partitioning.

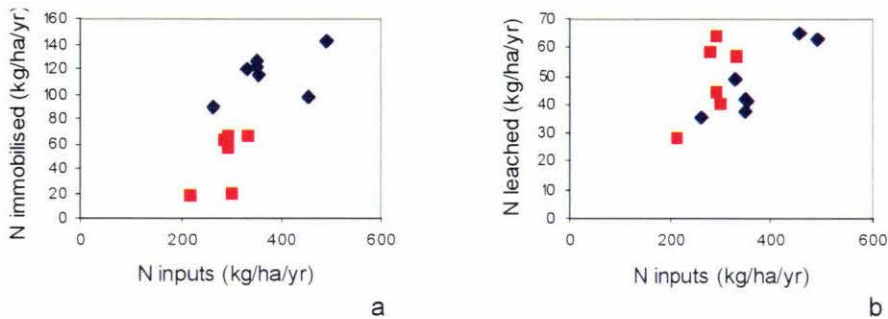


Figure 5.3: OVERSEER[®] partitioning of nitrogen (N) based on nutrient source of input (effluent and fertiliser) for immobilisation (a) and leaching losses (b) across all study sites (A-F) (Effluent paddock ◆, non-effluent paddock ■).

Figure 5.4 shows a general trend of increasing inputs yielding a greater change in the inorganic pool of K and greater leaching losses with K removal and release from the inorganic pool being a function of soil type. While it appears that there are two populations, separated by source, it is only due to the smaller inputs and consequential smaller losses and changes in the non-effluent paddock. If large quantities of fertiliser K were added to the model, a large proportion would be leached and the rest would contribute to the soil pool.

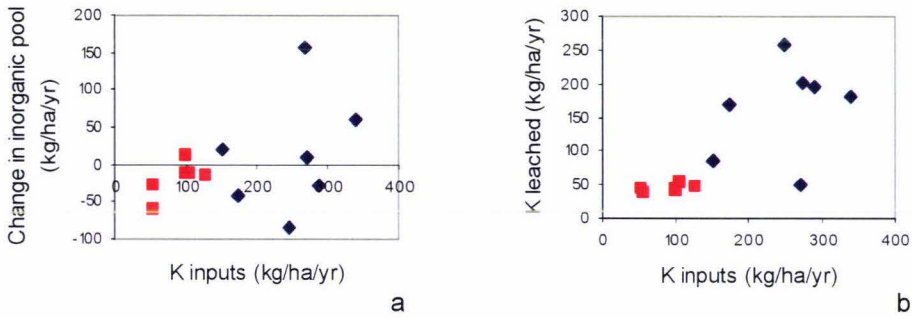


Figure 5.4: OVERSEER[®] predictions for the change in the inorganic pool of potassium (K) (a), and K leaching (b), based on nutrient source of input (effluent and fertiliser) (Effluent paddock \blacklozenge , non-effluent paddock \blacksquare) across all study sites (A-F).

The amount of P absorbed does not appear to be related to the amount of P in the system, as shown in Figure 5.5. This is partly a function of different soil types having different P retention characteristics. However, when the annual net gain or loss of P in the soil is calculated (by adding the P absorbed to the change in inorganic pool), a strong trend is exposed. This shows that according to OVERSEER[®], at small additions of phosphorus, only small gains or losses in the soil will occur, while larger inputs will give greater amounts of P available to plants.

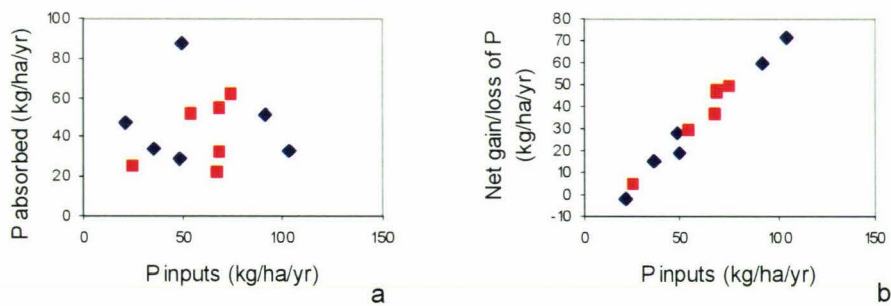


Figure 5.5: OVERSEER[®] predictions for phosphorus (P) for annual absorption (a) and the net gain or loss of P to the soil (absorption + change in inorganic pool) (b) across all study sites (A-F) (Effluent paddock \blacklozenge , non-effluent paddock \blacksquare).

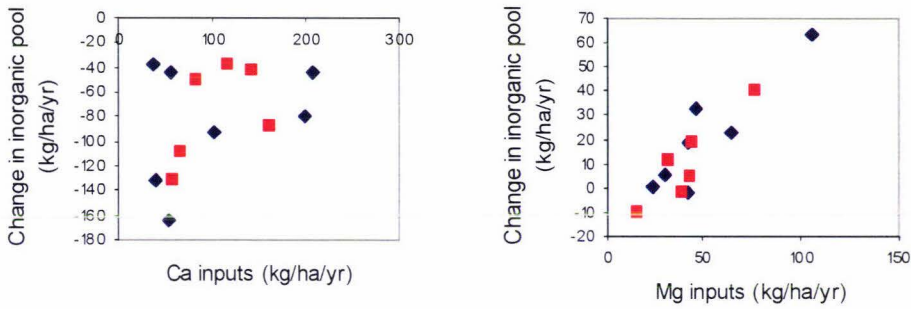


Figure 5.6: Calculated annual change in inorganic calcium (Ca) and magnesium (Mg) pools at different levels of inputs across all study sites (A-F). (Data from OVERSEER[®] nutrient budgets) (Effluent paddock ◆ , non-effluent paddock ■)

While the Mg inputs and change in inorganic pool are correlated, there does not appear to be such a relationship for calcium (Figure 5.6). Based on the current Ca inputs, the soil pool is decreasing at all sites. This may be mitigated by applications of lime every three or four years, which is considered in the OVERSEER[®] programme but lime has not been applied on the study sites in the last 2-3 years.

5.5 Using OVERSEER[®] to predict soil nutrient status

An attempt was made to estimate how much potassium had accumulated in the inorganic pool, and how much had leached from the topsoil over the course of effluent application. This was done by using the soil test result from the non-effluent paddock as a baseline, assuming it was in equilibrium and that any difference in soil test values between the two paddocks was created by effluent application over time. It was also assumed that current management practices (fertiliser, supplement, rate of effluent application and production levels etc) had been in practice for the duration of the application period. The non-effluent K Quick Test result was used as the initial input variable in the effluent paddock, and the consequent nutrient budget calculated. OVERSEER[®] gives a prediction on the increase or decrease of the soil test results, and this was used to correct the soil test value for the subsequent year's input variable, and iteratively calculate a new nutrient

budget, leaching losses and new soil test changes. This process was iterated for the number of years of effluent application.

The results of this process are presented in Figure 5.7, except for site A, which was calculated using the actual fertiliser history and applicable soil test results found in Appendix two.

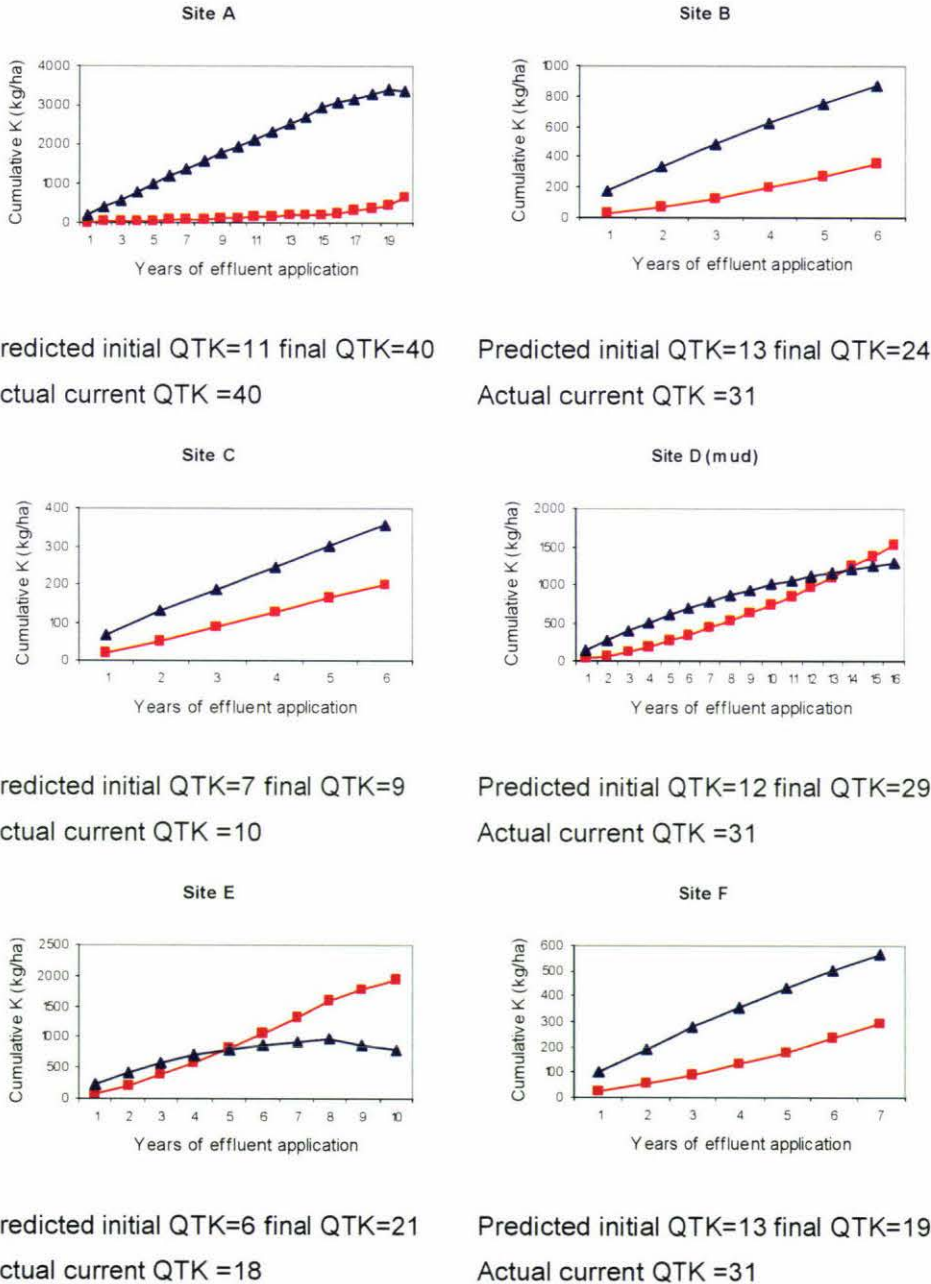


Figure 5.7: Accumulation of potassium (K) in the soil over the period of effluent application using OVERSEER® to predict leaching and the change in inorganic pool. (Leaching ▲ , accumulation in inorganic pool ■)

It is apparent from the site A graph shown in Figure 5.7, that leaching is being underestimated by OVERSEER[®]. When the exercise is completed in the same manner as the other sites i.e. using the non-effluent K test result as a starting point for the effluent paddock and creating successive nutrient budgets based on the predicted rise and fall of the QT value, a graph very similar to site D (mud) is produced (see Appendix two). In this scenario, however, the supplied fertiliser history for site A was used in the appropriate year to give a more accurate estimate instead of relying on current inputs which are zero for the effluent paddock. One of the reasons for the discrepancy between the two outputs could be the QT test result for K supplied by the farmer, as this appears to rise and fall with no apparent reason and may be due to poor sampling practice, or the inherent variability in soils (Morton *et al.* 2000).

The variable slopes of the curves in Figure 5.7 are a function of potassium inputs, the soil type, K test value and rainfall (which determines leaching losses). For some of the sites (B and F) the current potassium inputs were not enough to increase the QT value to recent levels. This means that either the past fertiliser or effluent application policy has changed over the years, with much greater historic-K inputs or that the partitioning of soil K by OVERSEER[®] does not accurately simulate actual processes. On sites other than A, current QTK values on non-effluent areas may not approximate initial values on effluent blocks, however, at site A, actual historic soil test values were used and OVERSEER[®] failed to predict current soil test values on the effluent area. The inorganic pool at site E shows a decline in recent years and this is due to the expansion of the effluent area from 10 ha to 25 ha. This significantly decreased the amount of K applied from effluent and resulted in a predicted loss of potassium from the inorganic pool.

The effect differing soil orders have on the amount of K leached and the change in the inorganic soil pool, at increasing soil QT values is shown in Figure 5.8. At each QT value, only the soil order was changed, to

incorporate the three soils found at site B, according to the soil map produced by Grange *et al.* (1939). A large variation in leaching and the soil pool occurs between soils, especially at high soil test values and this highlights the importance of having a correct soil map of the farm and recent soil test results when fertiliser and other management decisions are being made. This is particularly relevant for farms with multiple soil types, like site B.

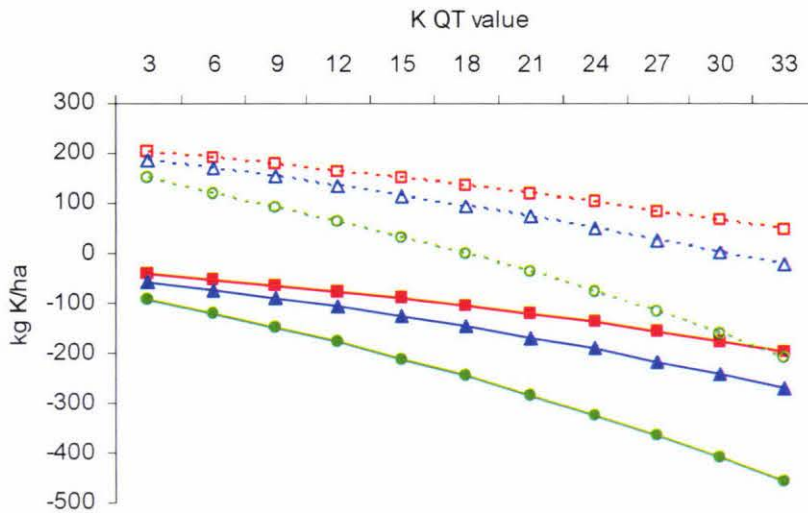


Figure 5.8: The effect of change in the potassium (K) quick test (QT) unit on the amount of K leached (—) ($\text{kg ha}^{-1} \text{yr}^{-1}$) and the change in the inorganic K pool (---) ($\text{kg ha}^{-1} \text{yr}^{-1}$) for Granular (\square), Allophanic (\triangle) and Podzol (\circ) soils found at site B. All other model input parameters were identical.

The amount of N accumulated that OVERSEER[®] has predicted is calculated from the immobilisation value given in each nutrient budget and multiplied by the number of years of effluent application (Table 5.7). A wide range of estimates exists due to the range of N input values, application rate (area) and length of time under effluent irrigation. In Chapter 6, these estimates will be compared to differences in measured amounts of soil N in the soil profiles of effluent and non-effluent areas.

The predicted accumulated P values in Table 5.7 are calculated from the addition of the absorbed and the change in inorganic pool values in each nutrient budget (based on current inputs), multiplied by the

number of years of effluent irrigation. Sites A and E are the exception to this, as a full nutrient history is known for site A and annual budgets have been calculated for the period of application (see Appendix two) and the effluent irrigation area at site E increased from 10 ha to 25 ha two years ago. In this situation, the nutrient budget for the 8 years of effluent application with a 10 ha area was calculated and the P absorbed + change in inorganic pool values multiplied by 8. A new budget was calculated for the last two years with the larger effluent area. Again, the absorbed and inorganic pool values were summed and then multiplied by 2. The 8-year and 2-year totals were then summed and used as the total amount of P accumulated. The difficulty with this simple extrapolation is that the current management practices (fertiliser applications, supplements used etc) are not constant from year to year and so the Olsen P result will vary, which in turn will affect the amount of phosphorus absorbed and the change in inorganic pool. At site C currently, no fertiliser is applied to the effluent block and this is why it appears that the effluent paddock has lost P. It actually has a high Olsen P value (31) and the farmer is trying to reduce it to a more desirable level.

Table 5.7: Prediction of nitrogen and phosphorus accumulated or lost from the soil (kg ha^{-1}) by extrapolation of current OVERSEER® data over the period of effluent application.

Site	Years of effluent application	Nitrogen		Phosphorus	
		Effluent	Non-effluent	Effluent	Non-effluent
A	20	900	360	960	466
B	6	852	120	432	216
C	6	534	378	-12	174
D (sand)	16	1936		240	
D (mud)	16	2016	360	240	752
E	10	2088	660	422	490
F	7	679	462	420	322

The predictions for the total amount of K, Ca and Mg accumulated or lost from the soil system over the effluent application period are shown in Table 5.8. These values are based on the change in inorganic pool

shown in each nutrient budget, and the number of years of effluent irrigation, again with the exception of site A, which was calculated from annual budgets (Appendix two).

It is interesting to contrast the fate of K at site F and the Rotomahana mud part of site D. Both these sites have a very high QT value of 31 and similar amounts of K inputs, but site D has a positive change in the inorganic pool while site F is losing K (Table 5.6). This is despite both soils being Allophanic and site F having a smaller rainfall and consequently smaller drainage volume. The only difference is that site F makes silage from the effluent paddock which is fed onto other blocks (selected in OVERSEER®) but also back onto the effluent paddock. However, there was no option in OVERSEER® (v.5.0.14.0) for this situation, and while some of the K is lost to other paddocks, some is retained, so the loss represented by the supplements removed value is incorrect. Although site F has a loss from the soil occurring, the QT test value does not change as the test itself and OVERSEER® require at least 40 kg ha⁻¹ of K to move the test value one unit on these types of soils.

The predicted accumulation of cations for site E is again based on the nutrient budget for a 10 ha application area for 8 years and the current 25 ha effluent application area budget for 2 years. This allows a positive value for K to be predicted, compared with the simple extrapolation from Table 5.6.

The majority of the sites in Table 5.8 show a significant decrease in Ca levels and this is probably an invalid prediction also. The effect of liming is difficult to simulate because many of the case study farms had not applied lime for at least 2-3 years and did not have historic QTCa and QTMg values for each paddock.

Table 5.8: Prediction of the accumulation or loss (kg ha^{-1}) of potassium, calcium and magnesium from the soil by extrapolation of current OVERSEER® data over the period of effluent application.

Site	Years of effluent application	Potassium		Calcium		Magnesium	
		Effluent	Non-effluent	Effluent	Non-effluent	Effluent	Non-effluent
A	20	2352	-1036	801	348	478	-32
B	6	360	-84	-258	-252	114	-60
C	6	120	-174	-786	-228	36	114
D (sand)	16	2528		-688		528	
D (mud)	16	144	-176	-2624	-1744	-32	-32
E	10	660	120	-85	-500	202	110
F	7	-203	-84	-553	-616	161	35

The concentrations of Mg in most of the soils sampled are at an average level (Blakemore *et al.* 1987) and only one site has a decline in the inorganic pool of magnesium. Many farmers use drenches and pasture dusting with magnesium oxide to prevent the occurrence of hypomagnesaemia and this can be a significant source of magnesium into the system. The differences found in the predicted total quantity of magnesium in the effluent and non-effluent paddocks are relatively small as the amount of magnesium cycling in the system is much smaller than the other cations. At most sites (C, D, E and F), however, the quantity of Mg that is leached is greater than the amount retained in the soil inorganic pool and this represents an economic waste (Appendix four).

5.6 Summary

The nutrient budgeting tool OVERSEER® can be used to estimate the annual nutrient loadings for differently managed areas of a farm. A comprehensive set of user-defined input variables are used to calculate the production and potential losses from the farm. The nutrient budget output indicates surplus or deficiency problems and can be used to trial different management scenarios to increase productivity, reduce

environmental losses or improve the economics of the farm operation. It is, however, limited as a tool to predict nutrient accumulation over time as the model is based on average annual inputs with no time factor involved. This means that the budget for a situation, given the same input variables, will be the same for years one and twenty. Whereas this may be an accurate prediction for some nutrients, it is possible that others will have a saturation point in the soil and the rate of accumulation may decline after that time. In order to test this theory, comparisons between the soil test results and OVERSEER® predictions need to be made, and are detailed in the next chapter.

CHAPTER 6: Evaluation of OVERSEER® predictions for nutrient accumulation in soil

6.1 Introduction

As mentioned in Chapter 5, Section 5.1, OVERSEER® Nutrient Budgets 2 is decision-support computer software designed to provide a long-term average input-output balance of nutrients for a farming system and provide an estimate of the accumulation of nutrients in the soil. In a grazed dairy farm context, the user is particularly interested in the environmental risk of NO_3^- leaching from grazed pasture, P enrichment of the soil and the loss and accumulation of exchangeable cations. Particular interest is focussed on the use of OVERSEER® to achieve integrated nutrient management between inputs of nutrients through fertiliser in combination with inputs from supplementary feed and FDE application.

The ability of the OVERSEER® Nutrient Budgets 2 model to provide accurate estimates of the fate of nutrients in dairy farming systems or even indicate the general trend in nutrient accumulation or leaching loss has not been widely tested except for validation against N leaching data, mostly from short-term fertiliser trials and drainage trials (Ledgard *et al.* 1999). No comparison has ever been published of measured nutrient accumulation under long-term farm dairy effluent (FDE) application situations and accumulation of nutrients in the soil as predicted by OVERSEER®. Ledgard *et al.* (1999) compared nitrogen movement data from a long-term N-fertiliser farmlet trial with the predictions made by OVERSEER® of atmospheric inputs, outputs, product, transfer and leaching losses and found that in general, the estimates were close to the measured values, but the model underestimated the loss of nitrogen to the atmosphere and via leaching from the soil profile. This comparison was, however, based on data

averaged over a three-year period and no accumulation over time was considered.

The following concepts are used:

1. It is assumed that prior to the beginning of effluent application, the nutrient input history of effluent and non-effluent paddocks were similar. It is assumed at this stage that the weight of each nutrient to 450 mm depth in each paddock was also similar.
2. For the period of effluent application, the effluent paddocks and non-effluent paddocks have different nutrient input regimes. This will result in differences in the weight of each nutrient to 450 mm soil depth in the effluent ($\text{Eff} \Sigma_{450} S \text{ kg ha}^{-1}$) and non-effluent paddocks ($\text{Non} \Sigma_{450} S \text{ kg ha}^{-1}$) at the time of sampling (S).
3. If all nutrient inputs and production statistics are entered into OVERSEER® Nutrient Budgets 2, the different nutrient input regimes will lead to OVERSEER® predicting different rates of nutrient accumulation in the soil of the effluent ($\text{Eff ONB} \text{ kg ha}^{-1} \text{ yr}^{-1}$) and non-effluent paddocks ($\text{Non ONB} \text{ kg ha}^{-1} \text{ yr}^{-1}$). The total amounts of nutrient accumulated in each paddock over the period of effluent application can be estimated by multiplying the annual accumulation rate by the number of years of effluent application.
4. The hypothesis is that the difference between the effluent and non-effluent paddocks in the weights of measured nutrient is correlated with the difference between paddocks in the nutrient immobilisation predicted by OVERSEER®.

$$(\text{Eff} - \text{Non}) \Sigma_{450} S \text{ kg ha}^{-1} \propto \text{years of application (yr)} \times (\text{Eff ONB} - \text{Non ONB})$$

This chapter tests this hypothesis by examining the effectiveness of OVERSEER® as a tool for accurate prediction of nutrient accumulation in dairy farm paddocks under FDE irrigation.

6.2 Methods

Calculation of nutrient accumulation using soil analysis data.

In this project, the amounts of soil nitrogen, phosphorus, potassium, calcium and magnesium used in the comparisons are calculated from the chemical analysis results detailed in Chapter 4 and Appendix 1. The concentrations are converted into kg ha^{-1} by multiplying the value by the weight of the soil in each 75 mm segment of core. The area of the core was converted from centimetres to hectares and each segment was then summed to give the total weight of each nutrient in the top 450 mm (300 mm for site D (mud)) of the soil profile per hectare (Appendix 5). Differences in the weights of nutrient to 450 mm in paired effluent and non-effluent paddocks were calculated

Calculation of nutrient accumulation using OVERSEER®.

The amount of nutrient (N, P, K, Ca, Mg) accumulated in the soil at both effluent and non-effluent paddocks, over the period of farm dairy effluent (FDE) application was calculated from the output given in the nutrient budgets prepared by OVERSEER®. Figure 6.1 shows the budget for the effluent paddock at site B where urea and superphosphate fertilisers are applied to the effluent block. The nutrient budgets for all the sites are found in Appendix 4. Since the fertiliser history for each site (except site A) was incomplete, the rates of accumulation were estimated using the current nutrient regime, extrapolated back in time.

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	30	59	0	100	137	0	0	0.0
Effluent Added	287	35	320	31	63	26	3	-6.0
Atmospheric / clover N	158	0	2	4	3	6	21	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	4	0	4	7	8	0.0
Supplements	28	6	14	5	1	3	1	-0.3
Outputs								
Product	136	24	31	8	33	3	9	-1.1
Transfer	65	7	69	5	14	7	1	-1.2
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	89	0	0	0	0	0	0	-0.6
Leaching/runoff	64	1	180	102	203	13	45	-4.9
Immobilisation/absorption	149	22	0	24	0	0	0	-1.0
Change in inorganic soil pool	0	49	60	0	-43	19	-21	2.5

Figure 6.1: Nutrient budget from OVERSEER® for the effluent paddock at site B

The estimated amount of N immobilised each year for each of the paddocks was taken and multiplied by the number of years of effluent application (equation 1). For P, the output variables from OVERSEER® used were the amount of P absorbed by the soil, and the change in the inorganic pool. These were summed and then multiplied by the number of years of application (equation 2).

$$\text{Yrs of application} \times \text{N immobilised (kg ha}^{-1} \text{ yr}^{-1}) = \text{N accumulated (kg ha}^{-1}) \quad (1)$$

$$\text{Yrs of application} \times (\text{P absorbed} + \text{inorganic pool}) \text{ (kg ha}^{-1} \text{ yr}^{-1}) = \text{P accumulated (kg ha}^{-1}) \quad (2)$$

The accumulation of phosphorus was calculated using the estimation of absorbed P and the change in the inorganic pool because, assuming P inputs remain the same over time, the sum of these two values should not change. This is due to the model balancing inputs and outputs. For example when the Olsen P level is reduced (as may have been in the past), the amount of P absorbed decreases, but the change in the inorganic pool increases to 'mop up' the remaining P. We have assumed that the Olsen P levels were not affecting production over the period of effluent application as the product loss is derived from the milk

solids and herd size values entered by the user, and this information from previous years was unavailable.

To calculate the accumulation of the cations (K^+ , Ca^{2+} , Mg^{2+}) in the soil, the estimated change in the inorganic pool was used, multiplied by the number of years of effluent irrigation (equation 3). For each of these nutrients, the difference between the effluent and non-effluent paddocks was also calculated (equation 4).

$$\text{Yrs of application} \times \text{change inorganic pool (kg ha}^{-1} \text{ yr}^{-1}) = \text{Accumulated cation} \quad (3)$$

$$\text{Effluent (kg ha}^{-1}) - \text{Non-Effluent (kg ha}^{-1}) = \text{Difference (kg ha}^{-1}) \quad (4)$$

The predictions by OVERSEER® for site A were calculated using nutrient budgets prepared for each year of effluent application as a nutrient history for this site was known (Appendix 2). The appropriate nutrient budget output (immobilisation/absorption, change in inorganic pool) from each year was summed together and then the difference between the effluent and non-effluent areas determined as in equation 4. It was not possible to separate the non-effluent area by soil type at site D as only a small portion of the non-effluent area is on the Recent sandy soil.

6.3 Results

Phosphorus

The relationship between the effluent and non-effluent paddocks for the difference in total soil total phosphorus to 450 mm ($TP_{(450\text{mm})}$) and the difference in P inputs (over time of effluent application) unfortunately shows little correlation at many sites (Figure 6.2). This lack of correlation indicates the assumption that the effluent and non-effluent paddocks were essentially the same prior to effluent application commencing, is false, or that the farm P input data is not an accurate record of what happened on the areas sampled.

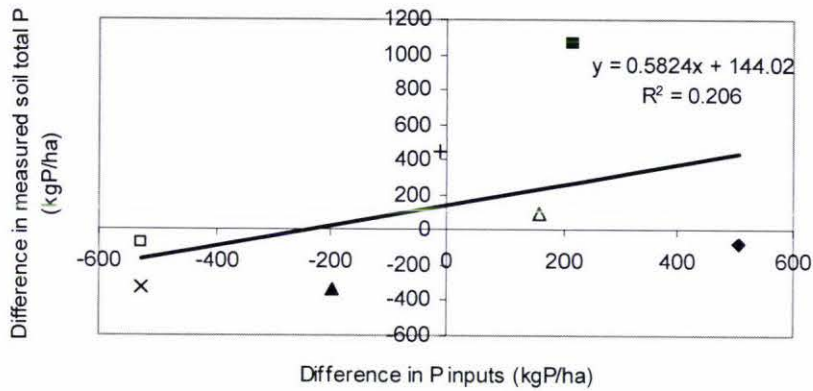


Figure 6.2: The difference (kg ha^{-1}) between the effluent and non-effluent paddocks for the P inputs estimated by OVERSEER® and the total soil P (to 450 mm) found by chemical analysis.

(Site A \blacklozenge , B \blacksquare , C \blacktriangle , Ds \times , Dm \square , E +, F \triangle)

At sites A, C and D, the effluent paddocks had smaller concentrations of P in the soil than the non-effluent paddocks (Table 6.1), and this is partly due to the reduced rates of fertiliser applied to the effluent paddock, compared with the rest of the farm. While effluent contains a wide range of nutrients (see Chapter 2), it does not supply them in the optimum concentrations for plant growth, especially when the effluent application rate is restricted by regional council limits of $150\text{--}200 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. The difference between the paddocks in the amount of P measured in the soil at site F and the prediction made by OVERSEER® match well. On this property, the whole farm receives the same fertiliser application rate (Table 5.5) and the same quantity each year. Over the 7 years of effluent application, 96 kg of extra P was retained in the soil of the effluent area (Table 6.1). This calculates out at a retention rate of $13\text{--}14 \text{ kg P ha}^{-1} \text{ yr}^{-1}$, which is similar to the rate ($14 \text{ kg P ha}^{-1} \text{ yr}^{-1}$) OVERSEER® predicted for the greater P accumulation rate in the effluent paddock compared to the non-effluent paddock (Table 6.1). At other sites, the two estimates of the difference in P accumulation between the effluent and non-effluent areas do not match well (Table 6.1, Figure 6.2).

Table 6.1: The calculated difference of phosphorus (P) concentrations found in the soil (effluent – non-effluent paddock) and the OVERSEER® prediction of the difference between paddocks in accumulation or loss of P.

Site	Soil difference (kg ha ⁻¹)	OVERSEER® difference (kg ha ⁻¹)
A	-75	494
B	1063	216
C	-340	-186
D (sand)	-328	-
D (mud)	-75	-512
E*	448	-68
F	96	98

* Site E effluent values pertain to long-term effluent paddock

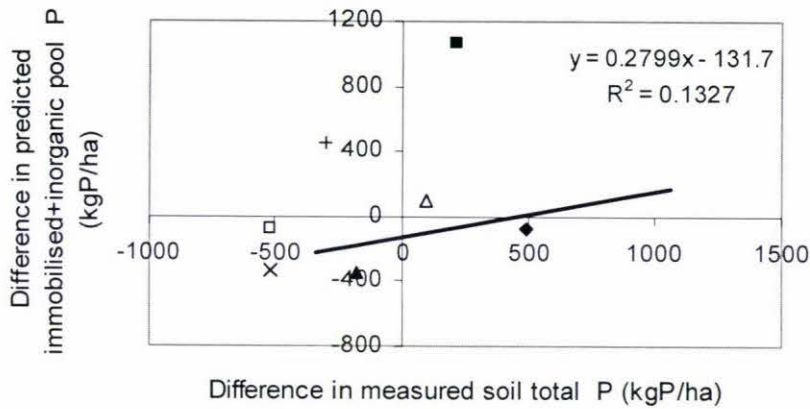


Figure 6.3: The difference (kg ha⁻¹) between the effluent and non-effluent paddocks for the OVERSEER® predictions of accumulation and the total of the actual values found in the soil (to 450 mm depth), for phosphorus (P).

(Site A \blacklozenge , B \blacksquare , C \blacktriangle , Ds \times , Dm \square , E $+$, F \triangle)

Saggar *et al.* (1990) demonstrated that approximately 70% of fertiliser applied P is generally conserved in the topsoil (0-150 mm) of grazed sheep pastures on Brown soils. The allocation made by OVERSEER® to the immobilised P pool and change in inorganic P pool is dependent on the soil type and slope. In Podzols, considerable P may be leached particularly at elevated Olsen P values (Metherell *et al.* 1995). Sites C and E in the Mamaku hills on Mangorewa sandy loam, a Podzol soil in an area of high rainfall (>2000 mm per annum) were chosen to evaluate P leaching loss differences. Up to 14 kg ha⁻¹ yr⁻¹ of P is predicted to be lost from each site through overland flow or leaching. Both sites have

high Olsen P values, contributing to the extreme P loss predicted by OVERSEER®. Unfortunately a comparison cannot be made because the relationship between the difference in P input and P measured in the soil (Figure 6.2) differ markedly for both sites, indicating that at site E, either the areas did not have similar P status prior to effluent application or the P input data is not an accurate summary of the last 10 years. Although current P inputs are moderate at these sites, the Olsen P values indicate much greater use of P fertiliser in the past. Thus the simple historic extrapolation made based on current nutrient information with moderate P inputs, high Olsen P and large P losses via overland flow could underestimate the actual amount of P applied over the effluent application period.

Nitrogen

The predicted differences between the amount of nitrogen immobilised by OVERSEER® (Effluent – Non-effluent) does not correlate well with the differences in total N found in the soil (Figure 6.4). The model tends to overestimate the immobilisation potential. There is, however, considerable uncertainty surrounding N inputs because unknown amounts are fixed each year, therefore, the estimates of N input from OVERSEER® are approximate only. At two sites (B and F), however, OVERSEER® underestimates the difference between the effluent and non-effluent paddocks. This is probably due to the large surplus of nitrogen from the high rates of fertiliser application (Site F) and large quantities of supplements brought in (Site B). In these two situations, it is possible that OVERSEER® overestimates the amount of nitrogen lost through leaching.

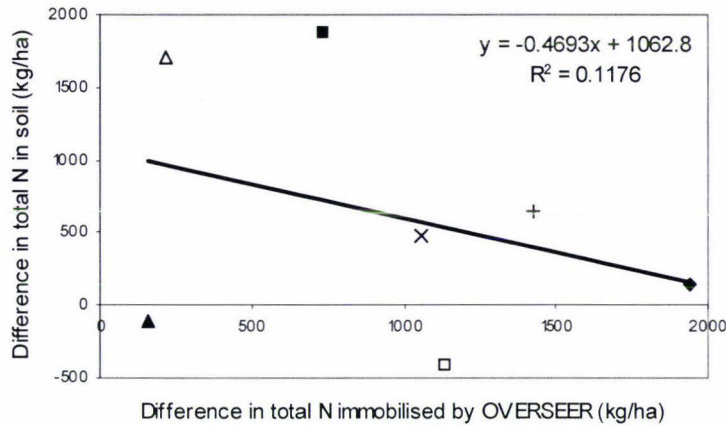


Figure 6.4: The difference (effluent – non-effluent) for the predicted amount of nitrogen (N) immobilised and the total N found in the soil.

(Site A ◆ , B ■ , C ▲ , Ds x , Dm □ , E + , F △)

Potassium

Unlike P, considerably more K (5-10 times) is added each year to effluent paddocks than non-effluent areas (Table 5.6). Such large differences mean the pre-effluent paddock history is less important than for P. This means that all sites have positive values for the differences in K inputs and measured soil K between effluent and non-effluent paddocks (Figure 6.5). There is also a reasonable correlation across all sites between increases in soil exchangeable K caused by increased K inputs. On average, 20% of the applied K remains in the soil as exchangeable K. Notably, OVERSEER® predicts that this varies between 12% and 51% on the Podzols and on the mud area of site D, these values are considerably lower (3-11%). This is due to the high soil test values combined with high rainfall, leading to predicted losses of excessive leaching.

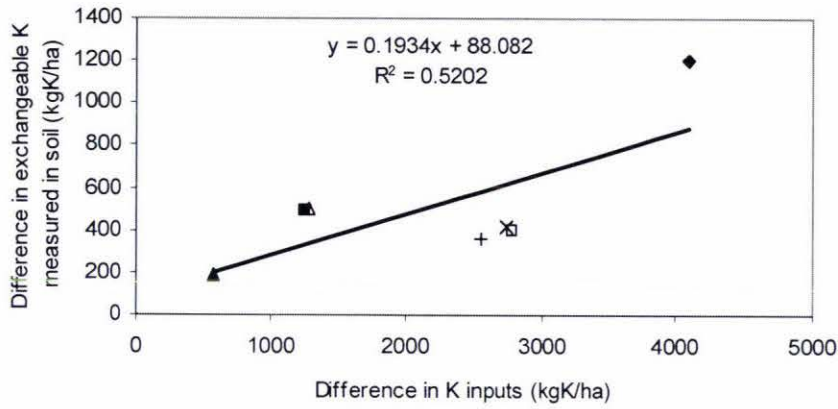


Figure 6.5: The difference (kg ha^{-1}) between the effluent and non-effluent paddocks for the K inputs estimated by OVERSEER® and the exchangeable soil K (0- 450 mm) found by chemical analysis.

(Site A \blacklozenge , B \blacksquare , C \blacktriangle , Ds \times , Dm \square , E $+$, F \triangle)

When the difference in soil exchangeable K is compared to the difference in the inorganic K in the soil predicted by OVERSEER®, there are major differences between soils (Figure 6.6). The 1:1 trend line indicated that more exchangeable K accumulated in the soil at sites E and F than OVERSEER® predicted whereas on the sandy part of site D, and site A, OVERSEER® predicts larger amounts of K accumulation in the inorganic pool than have been measured by soil analysis.

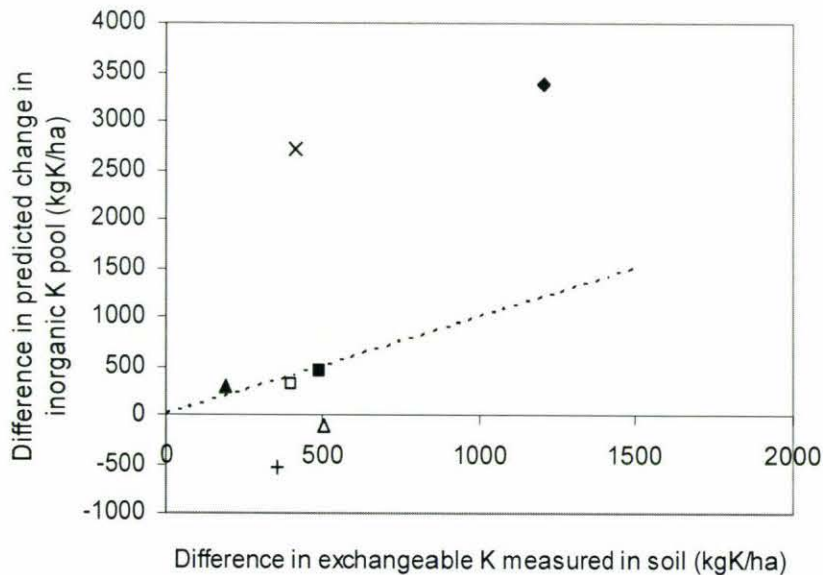


Figure 6.6: The difference (kg ha^{-1}) between the effluent and non-effluent paddocks for exchangeable soil K (0-450 mm) and the K change in inorganic pool predicted by OVERSEER®. A 1:1 line is shown.

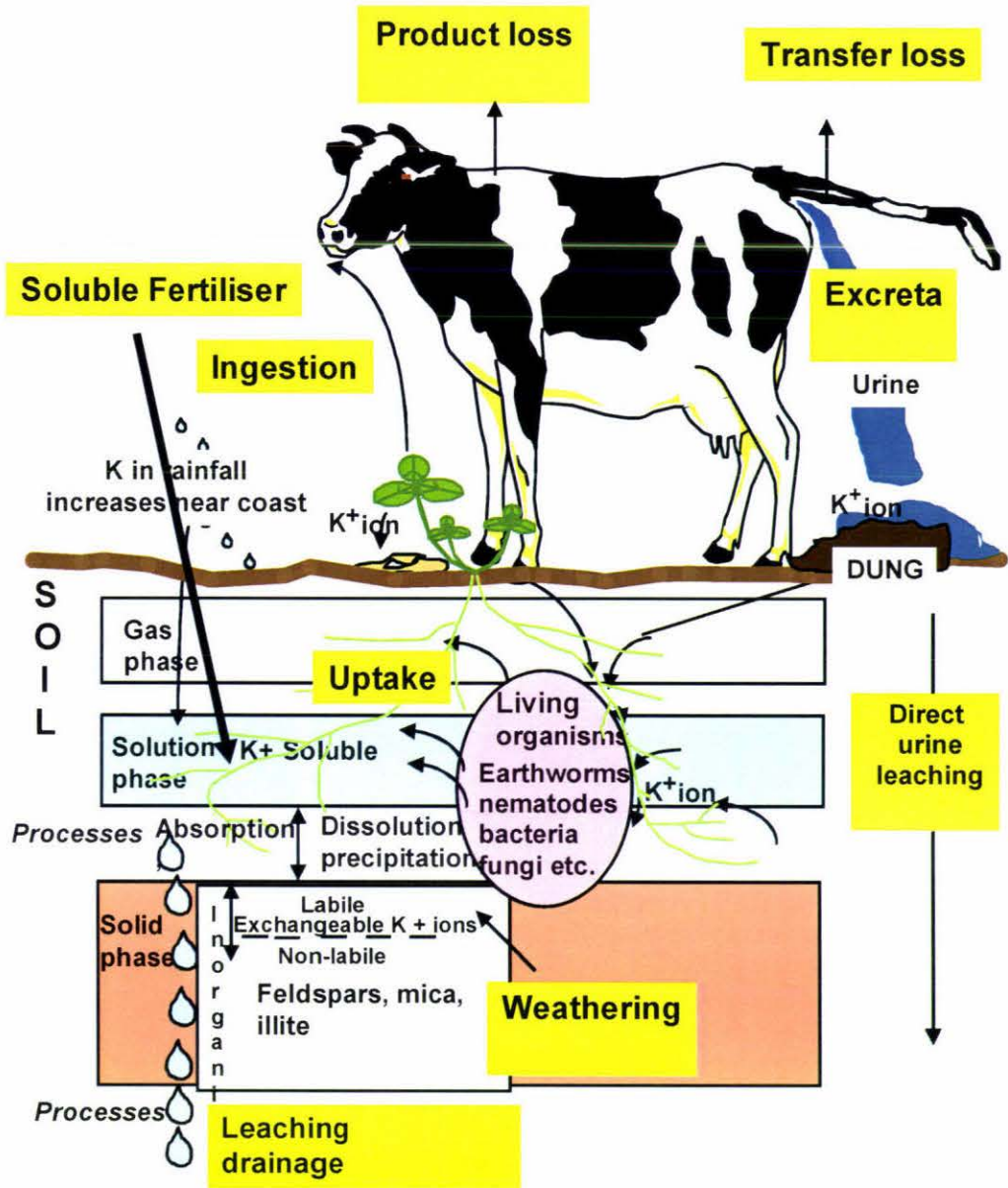


Figure 6.7: The potassium cycle on a dairy farm (source: FLRC 2005).

The main fate of K predicted by OVERSEER® is leaching (Table 5.6; Figure 6.7). Therefore, it is worthwhile examining the relationship between the difference in K inputs at each site and the sum of the difference in K leaching plus the difference in measured soil exchangeable K (Figure 6.8).

No values were calculated for the sandy part of site D as the non-effluent area is assumed to be only on the Rotomahana mud part of the

farm. Figure 6.8 shows that when the site A data is included in the population, there is a weak correlation with an R^2 of 0.49. When the data is removed, the relationship becomes stronger with an R^2 of 0.96, the linear relationship has a slope of 0.999 which suggests that the majority of the difference in K has been accounted for. This perhaps suggests that either there is little K transfer to fixed K in these soils or it occurs to a similar extent in the effluent and non-effluent paddocks.

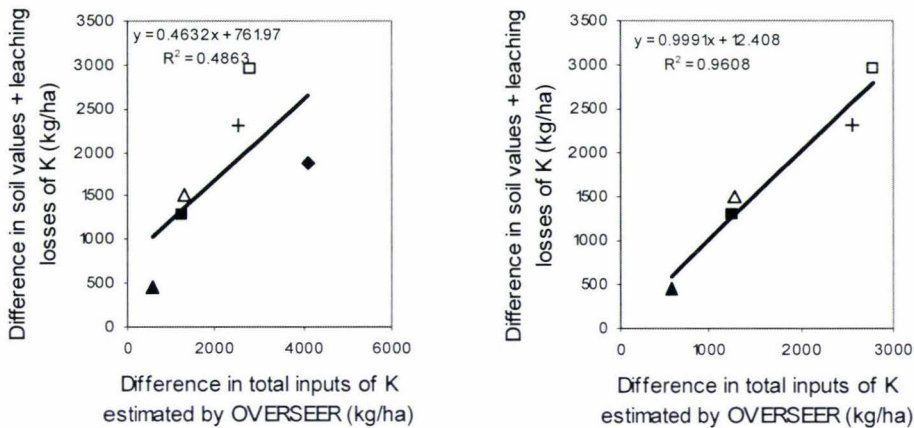


Figure 6.8: The difference (effluent – non-effluent) in potassium (K) inputs and the leaching losses estimated by OVERSEER® and the concentrations found in the soil profile (0-450 mm) (all values in kg ha^{-1}).

(Site A \blacklozenge , B \blacksquare , C \blacktriangle , Dm \square , E + , F \triangle)

At site A, effluent has been applied for more than 20 years and as a consequence, has the greatest concentration of K in the profile. Since the nutrient history for this site is known it is unlikely that OVERSEER® is overestimating the fertiliser input values. It is possible that the effluent-input into the system has been overestimated as the model calculates this by assuming the concentration of K in the feed ingested, and the predicted K loading is greater than the N loading (219 kg K ha^{-1} compared with 199 kg N ha^{-1}) which does not agree with the majority of effluent composition investigations (Vanderholm 1984; Roach *et al.* 2001; Hawke & Summers 2003). It is also possible that the amount of K being leached from the site is underestimated by the model, by around 2000 kgK ha^{-1} for the 20 year period. This is more probable as leaching

is difficult to predict and dependent on microclimate, structural and textural variations beneath the soil (layers of clay, sand, silt etc), variable rainfall and changing volumes of water used to apply the effluent.

Magnesium

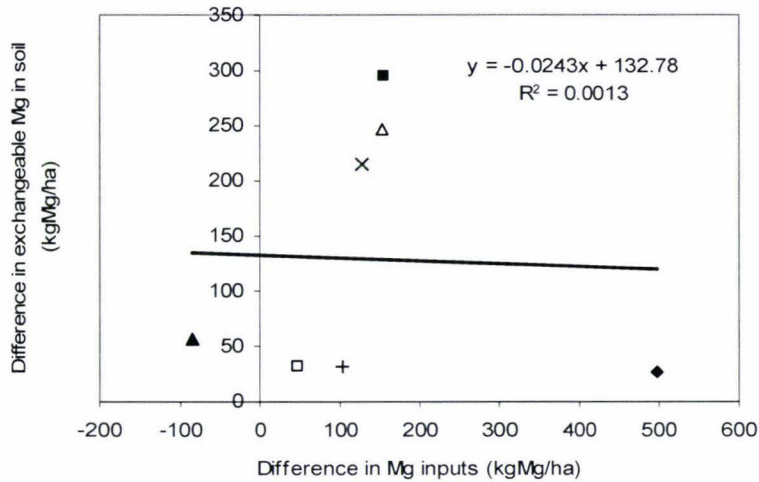


Figure 6.9: The difference (kg ha^{-1}) between the effluent and non-effluent paddocks for the Mg inputs estimated by OVERSEER® and the exchangeable soil Mg (to 450 mm) found by chemical analysis.

(Site A ◆ , B ■ , C ▲ , Ds x , Dm □ , E + , F △)

No correlation between the estimated Mg inputs and the concentrations of Mg measured in the soil, could be found. Similarly, when the predicted amounts of Mg leached over time were summed with the exchangeable Mg quantities, no relationships with predicted inputs was obtained. The Mg cycle in OVERSEER® is based on a similar framework to the K cycle, with inputs, outputs and soil concentrations defined by the user and inferred from production levels. Leaching losses are currently based on a number of factors including the quantity of drainage, a soil type constant, and the ratio of the Mg quicktest (QT) value to the sum of the Ca, Mg and K values (Carey & Metherell 2002). It has been suggested that an improvement of the leaching predictions could be made using soil cation affinity data, so that leaching losses were based on the selectivity of the soil for Mg (Carey & Metherell

2002). This would allow more accurate prediction of losses based on soil type, and could result in a more linear relationship between the losses predicted, soil concentrations and the estimated input values.

6.4 Discussion

6.4.1 Comparisons

The aim of this Chapter was to compare the measured and OVERSEER®-modelled differences in accumulation of N, P, K and Mg in paired paddocks (effluent and non-effluent) as a way of evaluating the partitioning of nutrients by the OVERSEER® model. Either because of different paddock P fertiliser histories prior to effluent application or to inaccurate P fertiliser application information, this comparison was not a fair test of OVERSEER®'s ability to allocate P to appropriate pools. Similar reasons and unknown N fixation values would invalidate the comparison of N. Another limitation of this study on commercial farms is that although efforts were taken to sample patches of soil that had similar profiles, the small area sampled may have seen highly variable FDE application rates.

For K, however, a comparison can be made because FDE carried much larger inputs of K to the effluent areas than fertiliser carried to the non-effluent areas. In Chapter 5 (Figure 5.4), it was concluded that OVERSEER® did not differentiate between K applied as FDE or KCl fertiliser. The amount of K OVERSEER® predicts is leached is dependent on soil type (Figure 5.8). There was good agreement across most sites between the difference in sum of measured exchangeable K and OVERSEER® leached K, and K inputs (Figure 6.8), which raise confidence in the 'conservation' of applied K within the measured and modelled pools. However, because K leached is such a large pool, it accounts for most of the variation explained in the linear relationship shown in Figure 6.8. OVERSEER®'s ability, based on the change in inorganic pool, to predict the change in soil test K, however, varied

considerably with soil type. Increases in soil test K due to effluent application could not be well predicted, particularly at sites E and F.

6.4.2 Allocation of nutrients to effluent stream

In conducting these comparisons, it was noticeable that OVERSEER® allocated high rates of N and K but not P to effluent areas compared to those indicated by other studies (Longhurst *et al.* 2000a; Hawke & Summers 2003). The OVERSEER® model calculations for the concentration of nutrients in FDE are based on assumptions about the amount of feed ingested, the nutrient content of that feed, and the amount of time spent on paddocks and in milking yards. Much of this data is derived from the input variables such as breed and size of herd, fertilisers used and the size of the farm. This method of calculation is not used by regional councils or many scientists when recommendations about effluent application are being made. Instead, the application rate for effluent irrigation is based on the herd size, number of days of lactation, the volume of wash-down water used in the milking yard and the average concentrations found in literature. While being subject to large errors of variation, this method of assessment is a simple tool that is commonly used to set maximum nitrogen loading limits (Cameron & Trenouth 1999). Comparisons between the values found in literature for nitrogen, phosphorus, potassium, calcium and magnesium and those predicted by OVERSEER® at each site are presented in Tables 6.2 and 6.3.

A large discrepancy exists between the N loading values calculated by OVERSEER® and those calculated from effluent concentrations found in the review by Longhurst *et al.* (2000a). This is probably due to the model factoring in the use of nitrogenous fertilisers (whereas the conventional method assumes no N fertiliser application) and the increased use of supplements on-farm. Using the estimated N loadings calculated by OVERSEER®, four of the six sites have exceeded the maximum annual N loading imposed by their respective regional

councils. These limits of 150 kg N ha⁻¹ yr⁻¹ for the Waikato and 200 kg N ha⁻¹ yr⁻¹ for the Bay of Plenty (BOP) have been specified in order to reduce the concentrations of nitrate leaving the farm through drainage. Nitrogen is the only nutrient that has such a restriction imposed by the regional councils as high concentrations of nitrate in drinking water can have an effect on human health, and the increased levels of nitrates in surface waters can lead to eutrophication of waterways, lakes and rivers. However, based on the N concentrations found by Longhurst *et al.* (2000a), with an average value of N in effluent of 269 g m⁻³, and a range of 181 – 506 g m⁻³, only one site exceeds their maximum permissible loading rate; site B could potentially apply 180 kg N ha⁻¹ yr⁻¹ instead of the 150 kg N ha⁻¹ yr⁻¹ allowed.

The wide range of concentrations reported in the literature causes difficulties when annual loading rates are calculated. This is due to the nutrient content in FDE fluctuating with many factors including season, supplements used, and even the time of day milking (and sampling) takes place. This variation ensures that any calculation or estimation of nutrient cycling via effluent irrigation must be regarded as flexible and subject to a degree of imprecision. The method in which OVERSEER® estimates the nutrient content of FDE may be more accurate, or tending to overestimate the concentration, as shown in Tables 6.2 and 6.3, but this in turn has consequences for the farmer where more land must be set aside for FDE irrigation and changes to farm operations made.

Table 6.2: Predicted effluent application rates (kg ha⁻¹) based on OVERSEER® nutrient budget values and the average and range of effluent concentrations reported in Longhurst *et al.* (2000a) for nitrogen and phosphorus

Site	Nitrogen			Phosphorus		
	Overseer	Average (269 g m ³)	Range (181-506 g m ³)	Overseer	Average (70 g m ³)	Range (40-80 g m ³)
A	199	64	43-120	24	17	10-19
B	274	95	64-180	36	25	14-28
C	137	58	39-110	17	15	9-17
D	225	77	52-145	30	20	12-23
E	161	77	52-145	21	20	11-23
F	170	76	51-143	23	20	11-23

It is clear, from Table 6.3, that OVERSEER® estimates the K concentration in the FDE at the sites sampled, to be much greater than the average found in the review by Longhurst *et al.* (2000a). This may be due to the differing methods of estimation, the use of K-fertilisers and the increased use of supplements. A high level of K in the soil is not an environmental issue, but it can lead to animal health problems as the cattle do not receive enough calcium and magnesium (Wilson 2002). Many farmers recognise this and supplement the animal with magnesium, either as a drench or dusted onto the pasture, and strategically place animals so that pregnant and early-lactating cows are not grazed on the effluent paddocks, where K concentrations are likely to be high.

There is little information regarding the concentrations of Ca and Mg in FDE, and the values given in Table 6.3 are based on those reported by Goold (1980). From this table, it appears that OVERSEER® is predicting reasonable numbers for the loading rates of these nutrients, with higher values reported by OVERSEER® due to increased rates of fertiliser application and the increased use of animal health supplements since Goold's data was published. The mechanisms for estimation of Ca and Mg cycling in the farm-system are similar to the other nutrients with an initial estimation of the pool based in the QT unit and adjusted for bulk density. A large amount of variation between soils exists in the

weathering input contribution part of the cycle (see Figure 6.6) as moisture, temperature and aerial deposition are the major influences in the amount of cations released (Carey & Metherell 2002) but the model uses averaged data for the soil group: volcanic, sedimentary, pumice and organic, not the individual soil type.

Table 6.3: Predicted rates (kg ha⁻¹) of potassium, calcium and magnesium applied annually in effluent based on OVERSEER® nutrient budget values and the average concentrations of potassium (Longhurst *et al.* (2000a)) and calcium and magnesium (Goold (1980)) found in effluent.

Site	Potassium			Calcium		Magnesium	
	Overseer	Average (370 g m ⁻³)	Range (164-705 g m ⁻³)	Overseer	Average (177 g m ⁻³)	Overseer	Average (39 g m ⁻³)
A	218	88	39-168	44	42	31	9
B	320	131	58-250	63	63	26	14
C	133	80	36-153	31	38	16	9
D	245	106	47-202	43	51	26	11
E	161	106	47-201	32	51	16	11
F	190	105	46-199	39	50	22	11

6.5 Conclusion

Limited success was made with the comparisons between the measured soil concentrations of N, P, K and Mg and the prediction made by OVERSEER® for the amount accumulated in the soil. The predictions of accumulation for N were not well correlated to the concentrations found in the soil and this can be attributed to the uncertainties of the actual amount of N fixed by legumes under varying conditions, and the possibility that N leaching losses could be underestimated by OVERSEER®.

Incomplete fertiliser histories, different soil P status prior to effluent irrigation and changing P application management strategies contributed to the inconsistencies found in the P data. As total P inputs were calculated using the most recent fertiliser application data, rather than historical records, we were unable to use P as a marker element to gauge the amount of effluent applied over time.

A general agreement was achieved between the K inputs estimated by OVERSEER® and the exchangeable K measured in the soil plus the predicted K leaching losses and the central assumption that the pairs of paddocks were essentially the same prior to effluent application was upheld in the case of K. This was attributed to the relatively small pool of K inherent in soils and the large amounts of K applied via effluent irrigation.

The estimation by OVERSEER® of the concentrations of nutrients applied to the effluent paddocks requires further study under controlled conditions, especially for K as this will allow better predictions of nutrient accumulation to be made.

CHAPTER 7: Conclusion

7.1 General conclusions

A general trend of a change in the cation composition was observed between the effluent and non-effluent paddocks. All sites showed an increase in the measured concentration of K found in the effluent paddocks and this is due to the very high loading of K the soil receives under farm dairy effluent (FDE) irrigation. For other nutrients (N, P, Ca, Mg) the difference in amounts of nutrients per hectare between the effluent and non-effluent paddocks were not significant, and this is due to the relative size of the individual nutrient pools requiring a very large increase or decrease to become apparent and statistically significant.

Due to the inherent variability in soils, it is advisable to collect as many samples as practical to ensure the chemical analysis results are representative of the paddock. A high coefficient of variation (see Appendix 1) was found in the cation analysis, particularly with the exchangeable potassium determination, and the precision could have been improved with more replicates.

OVERSEER[®] Nutrient Budgets 2 was used to prepare nutrient budgets for all the sites and based on the output; most sites exceed their regional council loading limit for N. Farmers were unaware of this as the algorithm used by OVERSEER[®] differs from the traditional method of estimating the N loss from the farm. OVERSEER[®] attempts to predict the annual nutrient loading via FDE application onto effluent blocks using such factors as the nutrient content of pasture, the supplements and fertilisers used, and the time spent in the milking area although the literature shows that effluent is a highly variable source of nutrients. The nutrient budgets also show that high concentrations of K are applied with the effluent, and this can have implications on the health of the

herd, with hypomagnesaemia and hypocalcaemia being associated with high K content in soil and pasture.

Of prime importance in the use of OVERSEER[®] is that the correct input variables are used. The most recent soil test results, milk solids production numbers and accurate fertiliser records are essential as well as knowledge about the soil type and the effect this has on the assumptions made by the model. Some sites were shown to be more prone to P loss by overland flow as this was determined by the soil type, rainfall and topography, while others, with more P inputs, had a low risk of P loss.

Since OVERSEER[®] is an annual model; it has a limited capacity in the prediction of nutrient accumulation when only current values and inputs are known. Some of the predictions made by OVERSEER[®] can be extrapolated by the number of years of FDE application to give an estimate of the quantity of nutrient in the soil. This method was applied successfully with potassium where the OVERSEER[®] estimate of the increase to the inorganic pool correlates with the summation of the quantity of exchangeable K found in the soil and the predicted amount of K lost via leaching. In order to obtain an accumulation due to the application of effluent, the non-effluent paddock results were subtracted from the effluent paddock as this was taken to be a baseline, or 'pre-effluent' value.

The extrapolation method did not work well for the other nutrients as in many cases, current inputs of fertiliser were below maintenance requirements. It was apparent from the soil test results, that previous applications of fertiliser had been much greater than was currently being applied and this meant that the predictions made by OVERSEER[®] for past inputs and outputs were incorrect.

In order to more accurately assess the power of OVERSEER[®] as an accumulation tool, a complete and accurate fertiliser and nutrient history

is required, as well as regular, long-term analysis of effluent, pasture, soil and drainage water, to give more information that can be compared with the model.

7.2 Recommendations for Future Study and Model Improvement

The OVERSEER[®] nutrient budget model is continually being improved and upgrades are available on a regular basis. With this in mind, it is suggested that more data from carefully controlled long-term trials is included in the validation of the nutrient cycles. Carefully controlled long-term trials are required because this study shows that fertiliser history information from commercial farms is often incomplete and FDE application could be highly variable.

One idea for research farms would be to use a marker element in their shed washdown water so that problems caused by variability of effluent application can be overcome. Such a marker could be rubidium (Rb), which behaves similarly to K.

In analysis of long-term trials, special note should be made of the changes in immobilisation rates and storage in organic and inorganic pools over time with increased organic-based nutrient additions (e.g. effluent).

The nutrient budgeting model OVERSEER[®] is a valuable tool that can aid in decision making, but it is limited to long-term annual average predictions that attempt to simulate the transfer of nutrients. It would be useful to the user if a version of the model could accommodate change caused by increased or decreased nutrient inputs and predict trends over time. For example, to be able to predict when net immobilisation of N on effluent blocks will plateau, and N inputs equal outputs. It would be useful if the slow increase in soil P loss as Olsen P increases could be predicted over time. The results given in the nutrient budget output for each block of land must be regarded as guides to nutrient redistribution

and loss and should not be used as simulating actual values. In a regulatory situation, the margins of variation should be broad so that a farmer is not penalised if leachate samples are taken and prove to be greater than those estimated by OVERSEER[®], due to the highly variable nature of soil and effluent.

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APPENDIX ONE: **Soil Chemical Analysis**

Appendix 1.1 Summary of Soil Analyses

The following tables provide the raw results of the soil chemical analyses described in chapter 3, and discussed in chapter 4, for each site. The bulk density calculations are based on the weight of soil in each segment of core (75 mm) and the volume that soil occupied in the soil core. Three of the five cores taken in each paddock were chosen as being the most similar on the basis of visual examination, and these were used in chemical analyses. For some sites, the coefficient of variation for the three results was very high, and a decision was made to reduce the variation by analysing more samples. Analysis of carbon and nitrogen by Leco was performed on the top 75 mm samples only, and the data correlated with the Kjeldahl total N results. Mineralisable nitrogen was determined using an anaerobic incubation method but the results proved inconclusive and were not included in the general discussion in chapter 4.

Appendix 1.1.1 Soil Chemical Results for Site A Effluent Paddock

Site A Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
A/1/1/0-7.5	114.40	0.81	3.58	8.29	1.16	0.18	28.20	6.55	2.96	22.75	1.02	1.76	18.8	0.15	0.64	6.56
A/1/2/0-7.5	117.21	0.83	0.92	9.82	1.29	0.19	25.96	5.10	1.75	35.07	1.34	1	21.6	0.05	0.53	5.37
A/1/3/0-7.5	122.62	0.87	0.57	13.52	1.95	0.29	27.57				1.97	1.3	30.7	0		
A/1/4/0-7.5	95.28	0.67	4.32	11.24	2.75	0.44	30.00	6.97	2.20	44.08	1.49	3.83	38.1	0	0.75	7.98
A/1/5/0-7.5	111.43	0.79									2.25	12.9	25	0		
A/1/1/7.5-15	102.67	0.73	1.94	10.09	0.55	0.19	25.27	5.45	1.63	12.32	0.56	0.51	11.2	0.07		
A/1/2/7.5-15	126.33	0.89	0.20	7.58	0.65	0.15	21.08	4.09	1.42	18.01	0.52	0.54	7.93	0.02		
A/1/3/7.5-15	109.49	0.77	0.35	10.14	1.17	0.15	25.56				1.3	1.26	13.9	0.16		
A/1/4/7.5-15	114.23	0.81	2.51	3.60	0.69	0.28	25.83	5.52	2.00	32.23	0.55	1.29	10.13	0.21		
A/1/5/7.5-15	111.51	0.79									0.88	11.1	8.39	0		
A/1/1/15-22.5	102.95	0.73	1.51	4.91	0.24	0.24	21.89	3.61	1.02		0.29	0.11	3.82	0.11		
A/1/2/15-22.5	101.85	0.72	0.55	3.90	0.28	0.18	19.91	2.61	0.73		0.3	0.22	1.63	0.27		
A/1/3/15-22.5	109.15	0.77	0.17	5.73	0.56	0.07	22.79				0.58	0.76	5.15	0.04		
A/1/4/15-22.5	108.10	0.76	1.93	1.96	0.24	0.14	20.53	3.95	1.71		0.37	0.56	3.5	0.11		
A/1/5/15-22.5	108.07	0.76									2.27	26	3.7	13.68		
A/1/1/22.5-30	99.23	0.70	1.52	2.13	0.14	0.14	16.42	2.00	0.62		0.19	0.04	1.59	0.24		
A/1/2/22.5-30	110.19	0.78	0.73	2.47	0.19	0.15	17.30	1.60	0.50		0.2	0.1	0.35	0.08		
A/1/3/22.5-30	114.83	0.81	0.21	3.58	0.31	0.07	17.92				4.22	1.14	6.1	0.08		
A/1/4/22.5-30	106.51	0.75	2.70	2.74	0.37	0.18	20.99	2.61	0.71		0.28	0.15	1.37	0.34		
A/1/5/22.5-30	99.76	0.71									0.41	24.8	1.02	14.21		
A/1/1/30-37.5	117.49	0.83	1.17	2.28	0.14	0.14	13.74	1.35	0.49		0.29	0.04	0.7	0.21		
A/1/2/30-37.5	114.61	0.81	0.25	4.07	0.34	0.31	14.97	1.08	0.35		0.1	0	0.27	0.08		
A/1/3/30-37.5	106.47	0.75	0.53	3.56	0.44	0.12	14.65				0.28	0.51	0.87	0.45		
A/1/4/30-37.5	117.14	0.83	2.87	2.83	0.42	0.15	15.03	1.27	0.34		0.15	0	0.69	0.03		
A/1/5/30-37.5	101.17	0.72									0.37	8.9	0.42	8.11		

Appendix 1.1.1 cont'd

Site A Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
A/1/1/37.5-45	112.48	0.80	0.43	2.77	0.22	0.18	11.09	0.70	0.33		0.84	0.17	0.85	0.33		
A/1/2/37.5-45	129.26	0.91	0.12	4.88	0.37	0.32	11.94	0.64	0.20		0.01	0	0.14	0.03		
A/1/3/37.5-45	104.55	0.74	0.81	4.06	0.53	0.06	12.96				0.28	0.28	0.36	0.35		
A/1/4/37.5-45	125.28	0.89	2.01	3.00	0.42	0.11	10.54	0.60	0.21		0.05	0	0.12	0.05		
A/1/5/37.5-45	110.24	0.78									0.29	1.08	0	0.85		

Appendix 1.1.2 Soil Chemical Results for Site A Non- Effluent Paddock

Site A Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
A/2/1/0-7.5	115.76	0.82	0.22	13.03	1.69	0.13	27.57				1.37	3.31				
A/2/2/0-7.5	114.78	0.81									1.84	2.01				
A/2/3/0-7.5	99.95	0.71	1.07	15.25	3.51	0.22	30.04	6.82	2.45	34.6	4.16	25.7	23.7	0.01	0.70	7.15
A/2/4/0-7.5	101.80	0.72	1.92	14.74	1.86	0.46	26.49	7.04	2.50	35.07	1.98	4.24	30	0.15	0.77	7.49
A/2/5/0-7.5	101.60	0.72	0.25	14.55	0.95	0.18	28.43	6.99	2.31	21.33	2.28	3.2	24.3	0	0.71	7.04
A/2/1/7.5-15	111.61	0.79	0.09	9.42	0.59	0.06	21.41				0.83	4.01				
A/2/2/7.5-15	116.99	0.83									0.6	1.22				
A/2/3/7.5-15	99.13	0.70	0.63	7.23	1.00	0.11	23.97	4.80	1.66	15.17	4.74	30	13.4	0.52		
A/2/4/7.5-15	105.98	0.75	1.30	5.14	0.50	0.31	21.00	5.10	1.70	19.91	2.28	3.2	9.72	0.07		
A/2/5/7.5-15	113.08	0.80	0.10	5.68	0.23	0.05	22.32	4.86	1.71	13.74	0.7	1.47	6.47	0		
A/2/1/15-22.5	109.20	0.77	0.06	4.37	0.29	0.06	14.78				0.41	1.27				
A/2/2/15-22.5	122.48	0.87									1.13	0.34				
A/2/3/15-22.5	117.82	0.83	0.09	3.47	0.28	0.09	13.93	3.03	1.11		0.54	3.77	1.98	2.89		
A/2/4/15-22.5	106.49	0.75	0.99	1.25	0.13	0.16	16.28	3.69	1.13		0.35	1.44	2.5	0.01		
A/2/5/15-22.5	104.02	0.74	0.06	3.88	0.12	0.04	12.85	2.75	0.80		0.35	0.4	1.34	0.4		

Appendix 1.1.2 cont'd

Site A Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
A/2/1/22.5-30	106.31	0.75	0.06	3.50	0.24	0.05	11.36				0.27	0.54				
A/2/2/22.5-30	130.60	0.92									0.44	0.13				
A/2/3/22.5-30	115.08	0.81	0.08	4.01	0.24	0.12	9.45	1.19	0.54		0.33	0.22	0.21	0.15		
A/2/4/22.5-30	100.03	0.71	1.17	1.73	0.14	0.13	13.17	2.31	0.70		0.28	0.51	0.58	0.79		
A/2/5/22.5-30	103.02	0.73	0.06	4.72	0.14	0.04	9.95	1.56	0.48		0.29	0.04	0.43	0.18		
A/2/1/30-37.5	115.60	0.82	0.07	4.05	0.26	0.06	10.69				0.56	1.73				
A/2/2/30-37.5	130.23	0.92									0.27	0.09				
A/2/3/30-37.5	115.00	0.81	0.06	5.57	0.61	0.09	8.83	0.74	0.29		0.25	0	0.04	0		
A/2/4/30-37.5	108.25	0.77	1.28	1.58	0.11	0.13	8.09	1.21	0.44		0.18	0.16	0	0.5		
A/2/5/30-37.5	110.26	0.78	0.08	4.81	0.13	0.08	7.60	1.14	0.37		0.17	0	0	0		
A/2/1/37.5-45	106.81	0.76	0.06	4.01	0.24	0.05	8.11				0.23	0.4				
A/2/2/37.5-45	149.98	1.06									0.34	0.17				
A/2/3/37.5-45	121.71	0.86	0.07	5.44	0.59	0.06	8.66	0.45	0.18		0.15	0	0	0		
A/2/4/37.5-45	115.05	0.81	1.17	2.44	0.14	0.11	6.36	0.89	0.42		0.18	0.11	0	0.03		
A/2/5/37.5-45	105.39	0.75	0.06	4.85	0.09	0.06	7.56	0.83	0.30		0.22	0	0.1	0.05		

Appendix 1.1.3 Soil Chemical Results for Site B Effluent Paddock

Site B Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
B/1/1/0-7.5	88.39	0.62														
B/1/2/0-7.5	85.44	0.60	4.66	24.62	6.22	0.57	42.32	10.14	2.68	42.65	2.05	8.79	29.9	0.34	1.03	12.93
B/1/3/0-7.5	106.93	0.76	0.99	18.26	1.90	0.21	27.61	6.22	1.49	32.70	1.2	3.13	20.2	0	0.64	8.55
B/1/4/0-7.5	97.11	0.69	0.69	19.08	2.50	0.28	28.79	5.86	2.36	124.17	2.59	6.27	21.6	0	0.55	7.30
B/1/5/0-7.5	103.03	0.73														
B/1/1/7.5-15	46.25	0.33														
B/1/2/7.5-15	87.19	0.62	1.97	8.44	1.92	0.49	30.32	5.47	1.29	16.11	0.69	9.35	9.6	0		
B/1/3/7.5-15	75.86	0.54	0.42	12.95	1.16	0.23	29.76	5.36	1.07	8.53	0.85	1.2	10.8	0		
B/1/4/7.5-15	110.30	0.78	0.26	18.63	1.74	0.15	27.03	5.62	2.15	101.42	1.78	2.1	26.8	0		
B/1/5/7.5-15	106.67	0.75														
B/1/1/15-22.5	95.15	0.67														
B/1/2/15-22.5	99.50	0.70	1.15	2.52	0.55	0.23	16.95	2.13	0.40		0.45	3.66	1.17	0.61		
B/1/3/15-22.5	91.16	0.64	0.23	5.89	0.52	0.26	20.66	2.61	0.36		0.44	0.23	1.83	0		
B/1/4/15-22.5	134.71	0.95	0.25	10.98	1.10	0.14	14.98	2.34	0.54		0.43	0.35	6.88	0		
B/1/5/15-22.5	102.53	0.72														
B/1/1/22.5-30	102.74	0.73														
B/1/2/22.5-30	102.62	0.73	0.86	2.35	0.59	0.26	12.81	1.62	0.32		0.38	0.87	0.67	0.3		
B/1/3/22.5-30	78.36	0.55	0.35	4.76	0.51	0.26	17.13	2.11	0.28		0.36	0.11	1.91	0		
B/1/4/22.5-30	139.36	0.99	0.22	6.47	0.82	0.15	10.16	0.79	0.24		0.31	0	0.76	0.02		
B/1/5/22.5-30	132.90	0.94														
B/1/1/30-37.5	98.55	0.70														
B/1/2/30-37.5	101.65	0.72	0.95	2.29	0.56	0.25	10.30	1.29	0.28		0.3	0.09	0.36	0.15		
B/1/3/30-37.5	126.62	0.90	0.63	6.26	0.99	0.23	10.62	0.80	0.10		0.27	0	0.5	0		

Appendix 1.1.3 cont'd

Site B Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
B/1/4/30-37.5	125.93	0.89	0.19	6.17	0.85	0.17	9.87	0.55	0.34		0.3	0	0.61	0.04		
B/1/5/30-37.5	132.88	0.94														
B/1/1/37.5-45	100.85	0.71														
B/1/2/37.5-45	85.63	0.61	0.87	1.86	0.42	0.20	8.36	0.71	0.24		0.21	0	0.19	0.08		
B/1/3/37.5-45	153.29	1.08	0.21	6.18	1.12	0.27	10.28	0.38	0.05		0.17	0	0.11	0		
B/1/4/37.5-45	120.92	0.85	0.18	5.62	0.97	0.20	10.72	0.49	0.62		0.3	0.01	0.26	0.12		
B/1/5/37.5-45	139.38	0.99														

Appendix 1.1.4 Soil Chemical Results for Site B Non- Effluent Paddock

Site B Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
B/2/1/0-7.5	113.03	0.80														
B/2/2/0-7.5	107.95	0.76	1.49	13.76	1.09	0.19	25.28	4.48	1.18	52.13	1.83	5.01	33.4	0.4	0.47	5.35
B/2/3/0-7.5	108.22	0.77	0.55	13.06	1.10	0.13	28.59	5.14	1.55	32.7	1.96	2.35	19.9	0	0.53	6.15
B/2/4/0-7.5	93.26	0.66														
B/2/5/0-7.5	109.14	0.77	0.38	14.40	0.97	0.15	27.15	5.29	1.36	35.07	1.14	1.14	22.9	0.26	0.43	5.09
B/2/1/7.5-15	98.07	0.69														
B/2/2/7.5-15	130.01	0.92	0.44	6.83	0.53	0.14	17.94	2.23	0.44	16.59	0.45	4.97	5.9	0		
B/2/3/7.5-15	112.22	0.79	0.31	6.43	0.37	0.07	20.93	3.40	0.63	15.17	0.4	0.61	6.09	0		
B/2/4/7.5-15	105.89	0.75														
B/2/5/7.5-15	133.75	0.95	0.10	7.53	0.55	0.08	22.01	2.21	0.43	9.48	0.52	0.46	8.4	0		
B/2/1/15-22.5	112.63	0.80														

Appendix 1.1.4 cont'd

Site B Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
B/2/2/15-22.5	134.93	0.95	0.23	4.96	0.38	0.08	16.91	1.72	0.27		0.33	3.34	4.93	0		
B/2/3/15-22.5	121.90	0.86	0.22	2.36	0.14	0.12	17.84	1.68	0.26		0.27	0.18	1.36	0		
B/2/4/15-22.5	122.51	0.87														
B/2/5/15-22.5	146.26	1.03	0.27	5.41	0.44	0.08	19.96	1.37	0.20		0.29	0.07	4.49	0		
B/2/1/22.5-30	104.69	0.74														
B/2/2/22.5-30	146.56	1.04	0.27	3.73	0.28	0.09	14.37	0.78	0.10		0.24	1.52	1.59	0.17		
B/2/3/22.5-30	136.13	0.96	0.22	1.69	0.14	0.15	15.95	0.74	0.10		0.22	0.04	0.72	0.01		
B/2/4/22.5-30	151.17	1.07														
B/2/5/22.5-30	154.77	1.09	0.47	5.47	0.44	0.09	18.96	0.66	0.08		0.17	0	1.05	0		
B/2/1/30-37.5	122.23	0.86														
B/2/2/30-37.5	137.46	0.97	0.26	4.46	0.33	0.12	15.17	0.74	0.12		0.21	0.71	1.36	0.03		
B/2/3/30-37.5	134.54	0.95	0.35	3.32	0.39	0.15	17.96	0.62	0.09		0.3	0.05	0.21	0		
B/2/4/30-37.5	139.86	0.99														
B/2/5/30-37.5	149.34	1.06	0.38	4.86	0.42	0.09	17.00	0.61	0.07		0.2	0	0.68	0		
B/2/1/37.5-45	125.99	0.89														
B/2/2/37.5-45	127.49	0.90	0.16	4.49	0.33	0.16	15.14	0.71	0.14		0.17	0.19	0.55	0.07		
B/2/3/37.5-45	128.90	0.91	0.27	3.94	0.52	0.14	17.37	0.65	0.10		0.15	0.03	0.84	0		
B/2/4/37.5-45	140.30	0.99														
B/2/5/37.5-45	127.55	0.90	0.17	4.45	0.45	0.12	17.69	0.73	0.15		0.22	0	1.26	0		

Appendix 1.1.5 Soil Chemical Results for Site C Effluent Paddock

Site C Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
C/1/1/0-7.5	82.25	0.58														
C/1/2/0-7.5	94.76	0.67	0.58	13.82	1.24	0.11	28.25	5.71	1.68	29.38	0.89	0.44	19.8	0	0.62	6.70
C/1/3/0-7.5	80.69	0.57														
C/1/4/0-7.5	86.36	0.61	1.14	16.91	1.71	0.17	32.43	7.16	1.82	30.81	2.02	0.96	31.6	0	0.68	8.39
C/1/5/0-7.5	72.34	0.51	0.58	34.17	4.88	0.21	68.59	8.68	2.14	66.35	1.54	0.46	36	0.06	0.90	17.72
C/1/1/7.5-15	78.61	0.56														
C/1/2/7.5-15	87.25	0.62	0.39	8.40	0.45	0.09	20.58	3.83	0.87	11.37	0.52	0.26	10.43	0		
C/1/3/7.5-15	85.27	0.60														
C/1/4/7.5-15	86.92	0.61	0.89	12.20	0.54	0.19	27.56	5.02	1.15	15.17	0.67	0.23	13.4	0		
C/1/5/7.5-15	85.83	0.61	0.55	12.55	1.51	0.14	47.26	3.59	0.64	67.3	0.63	0.11	10.92	0.19		
C/1/1/15-22.5	67.99	0.48														
C/1/2/15-22.5	86.92	0.61	0.65	6.33	0.38	0.12	21.23	4.08	0.67		0.61	0.16	10.69	0		
C/1/3/15-22.5	78.69	0.56														
C/1/4/15-22.5	96.93	0.69	0.30	5.81	0.30	0.15	16.56	2.15	0.30		0.36	0	3.93	0		
C/1/5/15-22.5	90.88	0.64	0.54	5.72	0.90	0.16	41.06	2.75	0.64		0.63	0.1	8.88	0.23		
C/1/1/22.5-30	73.87	0.52														
C/1/2/22.5-30	75.58	0.53	0.55	3.16	0.27	0.15	17.88	3.20	0.50		0.54	0.09	6.27	0		
C/1/3/22.5-30	76.93	0.54														
C/1/4/22.5-30	97.74	0.69	0.05	2.38	0.14	0.09	11.40	0.83	0.16		0.08	0	1.09	0.05		
C/1/5/22.5-30	90.69	0.64	0.45	1.58	0.30	0.14	32.46	2.91	0.35		0.57	0.1	3.77	0		
C/1/1/30-37.5	92.13	0.65														
C/1/2/30-37.5	69.74	0.49	0.22	1.53	0.17	0.10	13.26	2.37	0.38		0.32	0.09	2.9	0		
C/1/3/30-37.5	66.47	0.47														

Appendix 1.1.5 cont'd

Site C Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
C/1/4/30-37.5	106.32	0.75	0.03	1.00	0.06	0.04	7.38	0.38	0.10		0	0	0.23	0		
C/1/5/30-37.5	85.20	0.60	0.23	1.03	0.19	0.08	22.78	2.54	0.39		0.43	0	2.46	0		
C/1/1/37.5-45	92.84	0.66														
C/1/2/37.5-45	93.17	0.66	0.10	0.98	0.10	0.06	9.99	1.33	0.30		0.26	0.05	1.07	0		
C/1/3/37.5-45	77.54	0.55														
C/1/4/37.5-45	104.60	0.74	0.04	1.19	0.07	0.04	7.58	0.42	0.12		0	0	0.04	0		
C/1/5/37.5-45	90.06	0.64	0.07	0.33	0.08	0.04	14.28	1.62	0.30		0.18	0	0.84	0		

Appendix 1.1.6 Soil Chemical Results for Site C Non- Effluent Paddock

Site C Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
C/2/1/0-7.5	76.74	0.54														
C/2/2/0-7.5	81.10	0.57	0.74	9.28	1.97	0.19	30.93	7.53	2.55	47.87	1.29	0.93	33.8	0	0.81	9.08
C/2/3/0-7.5	97.58	0.69	0.37	29.70	1.53	0.09	32.94	7.04	2.75	80.57	1.71	0.55	23.9	0.51	0.70	8.16
C/2/4/0-7.5	83.63	0.59	0.53	12.34	1.76	0.11	33.49	8.09	3.04	66.35	1.28	0.64	37.5	0.03	0.81	9.04
C/2/5/0-7.5	85.90	0.61														
C/2/1/7.5-15	106.74	0.75														
C/2/2/7.5-15	84.77	0.60	0.51	5.10	0.70	0.21	22.78	4.63	1.08	8.53	0.92	0.29	11.5	0		
C/2/3/7.5-15	93.37	0.66	0.20	19.02	0.66	0.06	27.44	4.50	1.30	16.11	0.67	0.28	9.24	0		
C/2/4/7.5-15	80.46	0.57	0.27	5.20	0.63	0.08	24.93	4.56	1.03	13.27	0.91	0.27	11.7	0.2		
C/2/5/7.5-15	86.88	0.61														
C/2/1/15-22.5	98.57	0.70														

Appendix 1.1.6 cont'd

Site C Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
C/2/2/15-22.5	90.62	0.64	0.21	2.14	0.32	0.10	11.52	2.19	0.40		0.61	0.06	4.19	0		
C/2/3/15-22.5	92.52	0.65	0.37	12.13	0.50	0.05	25.55	3.46	0.66		0.67	0.15	7.3	0		
C/2/4/15-22.5	84.90	0.60	0.14	2.67	0.31	0.03	16.90	2.89	0.42		0.54	0.16	4.49	0.15		
C/2/5/15-22.5	96.15	0.68														
C/2/1/22.5-30	96.37	0.68														
C/2/2/22.5-30	88.27	0.62	0.13	1.02	0.19	0.06	7.66	0.86	0.20		0.34	0	1.15	0.05		
C/2/3/22.5-30	84.36	0.60	0.28	6.17	0.43	0.03	20.65	3.10	0.49		0.62	0.19	4.25	0		
C/2/4/22.5-30	88.41	0.63	0.06	1.45	0.15	0.01	10.43	1.54	0.25		0.33	0.08	1.95	0.06		
C/2/5/22.5-30	97.98	0.69														
C/2/1/30-37.5	79.35	0.56														
C/2/2/30-37.5	99.34	0.70	0.05	0.87	0.16	0.04	7.38	0.75	0.19		0.32	0	0.77	0		
C/2/3/30-37.5	91.67	0.65	0.10	2.17	0.23	0.01	12.51	1.83	0.36		0.35	0.03	2.07	0		
C/2/4/30-37.5	106.23	0.75	0.03	0.87	0.09	0.00	8.49	0.81	0.18		0.18	0	0.57	0		
C/2/5/30-37.5	95.90	0.68														
C/2/1/37.5-45	80.64	0.57														
C/2/2/37.5-45	104.54	0.74	0.04	0.69	0.10	0.05	7.13	0.59	0.16		0.2	0	0.55	0		
C/2/3/37.5-45	114.73	0.81	0.05	0.64	0.08	-0.01	8.26	0.63	0.16		0.11	0	0.2	0		
C/2/4/37.5-45	98.98	0.70	0.00	0.78	0.07	0.00	9.60	0.70	0.17		0.15	0	0.53	0		
C/2/5/37.5-45	101.63	0.72														

Appendix 1.1.7 Soil Chemical Results for Site D (sand) Effluent Paddock

Site D Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
D/4/1/0-7.5	97.44	0.69	0.92	7.57	1.98	0.09	19.32	5.97	1.63	90.05	1.08	0.5	24.7	0.09	0.54	5.93
D/4/2/0-7.5	97.63	0.69														
D/4/3/0-7.5	99.23	0.70														
D/4/4/0-7.5	95.63	0.68	0.53	11.46	3.03	0.23	22.75	5.59	1.67	90.05	1.26	1.39	21.3	0.08	0.49	5.44
D/4/5/0-7.5	98.99	0.70	0.79	7.60	2.09	0.13	19.35	4.93	1.42	95.26	2.37	1.21	23.8	0.04	0.42	4.48
D/4/1/7.5-15	123.08	0.87	0.48	3.47	0.56	0.08	10.85	2.31	1.08	86.73	0.27	0.1	2.92	0.59		
D/4/2/7.5-15	119.94	0.85														
D/4/3/7.5-15	134.62	0.95														
D/4/4/7.5-15	123.77	0.88	0.15	2.89	0.94	0.11	10.35	2.35	0.96	62.56	0.24	0.4	2.04	0.77		
D/4/5/7.5-15	124.96	0.88	0.30	1.81	0.43	0.07	8.86	1.95	0.74	48.82	0.42	0.23	1.7	1.14		
D/4/1/15-22.5	131.18	0.93	0.34	2.49	0.36	0.09	8.29	1.54	0.69		0.2	0.02	2.28	0.14		
D/4/2/15-22.5	142.50	1.01														
D/4/3/15-22.5	153.17	1.08														
D/4/4/15-22.5	143.20	1.01	0.18	1.75	0.63	0.12	11.44	1.25	0.44		0.15	0.58	0.64	2.04		
D/4/5/15-22.5	145.81	1.03	0.27	2.03	0.44	0.09	9.08	1.28	0.55		0.19	0.17	0.82	1.33		
D/4/1/22.5-30	142.95	1.01	0.24	1.35	0.18	0.07	5.59	0.76	0.33		0.14	0.01	0.73	0.58		
D/4/2/22.5-30	134.21	0.95														
D/4/3/22.5-30	128.89	0.91														
D/4/4/22.5-30	149.27	1.06	0.44	0.97	0.43	0.12	5.71	0.49	0.25		0.12	0.59	0.7	1.21		
D/4/5/22.5-30	142.67	1.01	0.38	1.24	0.26	0.16	5.78	0.50	0.25		0.19	0.1	0.62	0.26		
D/4/1/30-37.5	152.80	1.08	0.32	1.24	0.17	0.15	5.64	0.40	0.24		0.1	0.01	0.22	0		
D/4/2/30-37.5	138.71	0.98														
D/4/3/30-37.5	131.04	0.93														

Appendix 1.1.7 cont'd

Site D Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
D/4/4/30-37.5	187.48	1.33	0.98	1.39	0.48	0.14	6.74	0.33	0.23		0.11	0.56	0.2	0.99		
D/4/5/30-37.5	162.93	1.15	0.29	1.10	0.29	0.12	5.56	0.35	0.23		0.14	0.16	0.19	0.27		
D/4/1/37.5-45	166.71	1.18	0.28	2.34	0.46	0.29	7.11	0.16	0.20		0.08	0.03	0	0		
D/4/2/37.5-45	141.69	1.00														
D/4/3/37.5-45	124.99	0.88														
D/4/4/37.5-45	126.41	0.89	1.78	3.08	0.93	0.22	8.50	0.23	0.28		0.13	0.69	0	1.23		
D/4/5/37.5-45	154.60	1.09	0.43	1.46	0.48	0.14	5.01	0.18	0.21		0.09	0.54	0	1.1		

Appendix 1.1.8 Soil Chemical Results for Site D (sand) Non- Effluent Paddock

Site D Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
D/1/1/0-7.5	112.02	0.79														
D/1/2/0-7.5	103.04	0.73														
D/1/3/0-7.5	96.17	0.68	0.40	3.54	0.65	0.15	15.99	3.24	1.37	96.21	1.13	0.33	9.4	0	0.26	3.18
D/1/4/0-7.5	118.91	0.84	0.26	5.12	0.74	0.21	18.83	3.48	1.62	118.96	1	0.89	12.2	0	0.29	3.36
D/1/5/0-7.5	117.29	0.83	0.31	5.45	0.82	0.08	19.15	3.48	1.21	99.05	1.94	0.76	11.8	0.04	0.27	3.12
D/1/1/7.5-15	139.89	0.99														
D/1/2/7.5-15	139.34	0.99														
D/1/3/7.5-15	144.59	1.02	0.12	1.73	0.26	0.12	14.72	2.02	1.02	81.04	0.39	0.13	1.67	0.74		
D/1/4/7.5-15	129.08	0.91	0.10	2.24	0.27	0.16	16.52	2.65	1.24	88.15	0.35	0.51	3.66	0.15		
D/1/5/7.5-15	146.20	1.03	0.11	1.86	0.29	0.07	14.82	1.38	0.57	76.3	0.23	0.1	0.74	2.15		
D/1/1/15-22.5	139.45	0.99														

Appendix 1.1.8 cont'd

Site D Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
D/1/2/15-22.5	138.44	0.98														
D/1/3/15-22.5	150.25	1.06	0.10	1.67	0.21	0.08	13.31	1.54	0.73		0.25	0.06	1.1	1.04		
D/1/4/15-22.5	134.75	0.95	0.07	1.37	0.14	0.16	12.98	1.69	0.69		0.28	0.45	2.11	0.5		
D/1/5/15-22.5	144.07	1.02	0.09	1.91	0.36	0.09	13.69	1.66	0.54		0.4	0.24	3.71	0.7		
D/1/1/22.5-30	157.53	1.11														
D/1/2/22.5-30	168.12	1.19														
D/1/3/22.5-30	152.36	1.08	0.18	0.88	0.11	0.05	9.97	0.44	0.27		0.15	0.01	0.28	0		
D/1/4/22.5-30	134.82	0.95	0.11	0.65	0.07	0.14	9.72	0.51	0.29		0.12	0.09	0.32	0.14		
D/1/5/22.5-30	146.29	1.03	0.12	0.90	0.20	0.12	10.09	0.59	0.48		0.12	0.1	0.65	0.7		
D/1/1/30-37.5	147.54	1.04														
D/1/2/30-37.5	146.97	1.04														
D/1/3/30-37.5	136.31	0.96	0.35	0.88	0.13	0.06	8.92	0.41	0.27		0.16	0.01	0.24	0		
D/1/4/30-37.5	152.22	1.08	0.12	0.65	0.06	0.22	8.55	0.36	0.22		0.09	0.06	0.32	0.14		
D/1/5/30-37.5	146.18	1.03	0.40	1.49	0.37	0.23	12.49	0.69	0.48		0.14	0.11	0.8	0.48		
D/1/1/37.5-45	139.91	0.99														
D/1/2/37.5-45	163.33	1.15														
D/1/3/37.5-45	150.48	1.06	0.57	0.84	0.13	0.06	9.10	0.30	0.24		0.11	0.04	0.09	0		
D/1/4/37.5-45	152.27	1.08	0.62	1.05	0.19	0.13	8.25	0.17	0.19		0.21	0.09	0	0.07		
D/1/5/37.5-45	140.02	0.99	0.59	0.96	0.25	0.17	10.72	0.40	0.26		0.12	0.11	0.26	0.22		

Appendix 1.1.9 Soil Chemical Results for Site D (mud) Effluent Paddock

Site D Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
D/2/1/0-7.5	71.72	1.06	0.62	11.38	1.39	0.20	21.09	4.90	1.57	42.18	0.97	1.29	12.8	1.12	0.44	4.88
D/2/2/0-7.5	70.90	1.04									1.29	0.76	15.3	0		
D/2/3/0-7.5	62.44	0.92	2.22	11.20	1.61	0.30	24.09	5.20	1.40	36.02	1.39	12.72	22.7	0.01	0.52	5.67
D/2/4/0-7.5	73.43	1.08	1.34	8.59	1.56	0.16	21.64	4.69	1.45	43.13	0.69	2.01	10.5	0	0.45	4.76
D/2/5/0-7.5	67.91	1.00									1.98	3.24	16.6	0		
D/2/1/7.5-15	70.44	1.04	0.61	7.75	0.73	0.18	14.26	2.97	0.91	12.80	0.32	0.85	6.62	0.03		
D/2/2/7.5-15	74.98	1.10									0.46	0.26	4.07	0		
D/2/3/7.5-15	74.15	1.09	0.96	10.50	0.98	0.27	17.71	3.19	1.00	13.74	0.61	6	8.55	0.23		
D/2/4/7.5-15	71.09	1.05	0.96	6.73	1.05	0.17	16.41	2.95	0.89	16.59	0.36	1.21	6.68	0.19		
D/2/5/7.5-15	72.10	1.06									0.66	0.94	6.82	0		
D/2/1/15-22.5	72.94	1.07	0.40	7.57	0.66	0.37	15.26	2.37	0.61		0.27	0.76	3.85	0.03		
D/2/2/15-22.5	74.51	1.10									0.43	0.22	2.86	0		
D/2/3/15-22.5	63.96	0.94	0.54	9.20	0.70	0.25	15.69	2.72	0.71		0.83	1.78	5.92	0		
D/2/4/15-22.5	73.91	1.09	0.62	5.23	0.78	0.12	13.01	2.37	0.60		0.27	0.98	1.95	0.72		
D/2/5/15-22.5	60.26	0.89									0.98	1.63	4.38	0		
D/2/1/22.5-30	29.83	0.44	0.14	5.28	0.43	0.28	12.39	2.21	0.59		0.88	0.9	3.17	0		
D/2/2/22.5-30	NO SAMPLE															
D/2/3/22.5-30	38.37	0.57	0.42	7.85	0.59	0.24	17.85	2.51	0.64		0.39	1.85	1.81	0		
D/2/4/22.5-30	57.12	0.84	0.59	5.12	0.76	0.12	11.59	2.03	0.52		0.31	1.11	3.04	0.13		
D/2/5/22.5-30	52.90	0.78									0.61	1.49	1.98	0.09		

Appendix 1.1.10 Soil Chemical Results for Site D (mud) Non- Effluent Paddock

Site D Core ID	Core Weight (g)	Bulk Density (g/cm3)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
D/3/1/0-7.5	66.79	0.98									4.13	2.25	19.1	0		
D/3/2/0-7.5	75.43	1.11	0.44	7.16	0.80	0.31	17.46	4.10	1.28	40.76	0.75	0.25	11.8	0	0.35	3.89
D/3/3/0-7.5	61.44	0.91	0.96	7.64	1.52	0.25	20.36	4.68	1.32	44.55	1.79	1.69	16.2	0	0.41	4.65
D/3/4/0-7.5	56.59	0.83	0.40	11.81	1.92	0.40	20.77	4.78	1.35	28.91	0.93	0.45	16.7	0.16	0.42	4.67
D/3/5/0-7.5	66.00	0.97									6.37	4.56	31.3	0		
D/3/1/7.5-15	73.07	1.08									0.77	0.58	7.69	0		
D/3/2/7.5-15	74.90	1.10	0.42	7.16	0.61	0.25	14.69	3.33	1.17	27.49	0.41	0.56	7.58	0		
D/3/3/7.5-15	79.04	1.16	0.74	6.36	0.89	0.15	16.89	3.79	1.10	18.96	0.83	0.87	8.14	0.01		
D/3/4/7.5-15	70.70	1.04	0.27	8.77	1.11	0.29	15.45	3.53	1.00	9.95	0.69	0.3	11.4	0		
D/3/5/7.5-15	73.51	1.08									0.77	0.69	10.03	0		
D/3/1/15-22.5	78.29	1.15									0.86	0.3	8.12	0		
D/3/2/15-22.5	77.09	1.14	0.34	6.10	0.49	0.24	13.42	2.11	0.59		0.5	0.37	3.66	0		
D/3/3/15-22.5	60.93	0.90	0.54	5.11	0.58	0.14	13.87	2.75	0.66		0.39	1	3.91	0.29		
D/3/4/15-22.5	79.13	1.17	0.22	9.66	0.64	0.24	14.51	2.94	0.75		0.39	0.66	7.31	0		
D/3/5/15-22.5	75.89	1.12									0.46	0.76	6.03	0		
D/3/1/22.5-30	58.27	0.86									0.9	0.34	3.63	0.04		
D/3/2/22.5-30	76.57	1.13	0.16	4.71	0.40	0.19	10.46	1.86	0.47		0.27	0.5	2.21	0.49		
D/3/3/22.5-30	44.60	0.66	0.43	2.82	0.36	0.12	11.23	1.99	0.49		0.76	1.17	2.88	0.11		
D/3/4/22.5-30	78.54	1.16	0.11	7.30	0.33	0.15	10.39	1.72	0.44		0.31	0.43	2.12	0.45		
D/3/5/22.5-30	87.23	1.29									0.4	0.58	3.07	0.01		

Appendix 1.1.11 Soil Chemical Results for Site E Long-Term Effluent Paddock

Site E Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
E/1/1/0-7.5	86.81	0.61									3.15	0.57	26.6	0		
E/1/2/0-7.5	82.14	0.58									1.75	0.42	35.1	0		
E/1/3/0-7.5	78.38	0.55	2.45	6.44	1.67	0.21	27.03	8.22	2.43	62.09	1.99	9.31	33	0.02	0.81	10.21
E/1/4/0-7.5	69.09	0.49	0.71	7.66	2.88	0.25	27.75	9.00	2.87	65.88	1.69	0.76	49.7	0.04	0.87	10.83
E/1/5/0-7.5	70.57	0.50	1.66	9.34	2.95	0.21	31.65	9.90	3.25	89.10	1.66	0.47	38.1	0.08	0.99	12.62
E/1/1/7.5-15	112.98	0.80									0.41	0.11	3.25	0		
E/1/2/7.5-15	101.09	0.71									0.56	0.13	6.19	0		
E/1/3/7.5-15	82.84	0.59	0.64	2.46	0.34	0.13	19.82	3.70	0.55	8.06	0.76	10.58	8.01	0		
E/1/4/7.5-15	86.94	0.61	0.32	4.69	0.88	0.19	23.59	6.19	1.49	17.06	0.71	0.38	13.6	0		
E/1/5/7.5-15	93.40	0.66	0.64	3.30	0.81	0.13	24.88	5.72	1.48	26.07	0.65	0.41	9.48	0.18		
E/1/1/15-22.5	122.89	0.87									0.3	0.05	1.26	0		
E/1/2/15-22.5	87.33	0.62									0.6	0.1	4.17	0		
E/1/3/15-22.5	74.37	0.53	0.72	2.35	0.35	0.20	26.13	3.63	0.45		0.56	12.38	5.11	1.84		
E/1/4/15-22.5	83.80	0.59	0.27	2.97	0.46	0.23	18.93	4.39	0.61		0.69	0.07	5.88	0		
E/1/5/15-22.5	81.70	0.58	0.42	1.96	0.45	0.10	17.94	3.57	0.59		0.46	0.18	5.75	0.01		
E/1/1/22.5-30	103.99	0.74									0.41	0.06	1.32	0.01		
E/1/2/22.5-30	113.96	0.81									0.32	0	1.73	0		
E/1/3/22.5-30	66.26	0.47	0.49	1.83	0.35	0.24	20.41	3.33	0.45		0.58	10.71	3.79	3.71		
E/1/4/22.5-30	76.56	0.54	0.13	1.43	0.28	0.18	9.52	2.76	0.47		0.35	0	3.15	0		
E/1/5/22.5-30	80.20	0.57	0.24	1.26	0.34	0.09	14.42	2.82	0.46		0.4	0.11	3.92	0		
E/1/1/30-37.5	117.75	0.83									0.36	0.06	0.83	0.03		
E/1/2/30-37.5	114.94	0.81									0.34	0.01	1.22	0		
E/1/3/30-37.5	65.63	0.46	0.22	1.26	0.27	0.18	16.95	2.81	0.43		0.52	5.6	1.7	2.76		

Appendix 1.1.11 cont'd

Site E Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
E/1/4/30-37.5	75.51	0.53	0.03	0.85	0.18	0.08	4.89	2.06	0.39		0.3	0	0.85	0		
E/1/5/30-37.5	95.74	0.68	0.10	0.44	0.14	0.04	6.98	1.82	0.32		0.23	0	1.98	0		
E/1/1/37.5-45	117.54	0.83									0.55	0.06	0.91	0		
E/1/2/37.5-45	93.38	0.66									0.25	0	0.59	0.02		
E/1/3/37.5-45	66.80	0.47	0.12	0.77	0.13	0.08	11.09	1.67	0.29		0.5	1.64	1.53	1.3		
E/1/4/37.5-45	111.79	0.79	0.04	0.69	0.14	0.06	3.43	1.43	0.28		0.35	0	0.82	0.03		
E/1/5/37.5-45	84.50	0.60	0.09	0.36	0.15	0.03	6.87	1.63	0.28		0.2	0	1.43	0		

Appendix 1.1.12 Soil Chemical Results for Site E Short-Term Effluent Paddock

Site E Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
E/2/1/0-7.5	82.81	0.59	0.36	7.69	1.20	0.18	24.44	7.92	2.57	49.29	1.3	0.66	32.8	0	0.77	9.83
E/2/2/0-7.5	90.91	0.64	0.44	10.04	2.06	0.18	22.71	7.00	2.32	51.18	0.91	0.56	18.5	0	0.72	9.46
E/2/3/0-7.5	74.71	0.53	1.14	8.29	1.73	0.14	25.05	8.70	2.69	74.88	1.19	0.82	33.6	0	0.84	10.40
E/2/4/0-7.5	75.03	0.53									1.29	0.3	29.5	0		
E/2/5/0-7.5	74.67	0.53									1.27	0.19	31.2	0.08		
E/2/1/7.5-15	93.76	0.66	0.13	4.04	0.36	0.17	17.20	5.18	1.45	17.06	0.59	0.35	12.6	0		
E/2/2/7.5-15	89.32	0.63	0.15	3.98	0.76	0.16	17.54	4.74	1.38	25.12	0.55	0.25	8.33	0.11		
E/2/3/7.5-15	95.13	0.67	0.39	2.55	0.35	0.16	15.95	5.39	1.51	25.12	0.54	0.26	10.32	0.12		
E/2/4/7.5-15	92.32	0.65									0.46	0.12	6.71	0		
E/2/5/7.5-15	102.36	0.72									0.49	0.15	6.82	0		

Appendix 1.1.12 cont'd

Site E Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
E/2/1/15-22.5	88.41	0.63	0.09	1.89	0.19	0.16	13.58	4.15	1.00		0.4	0.11	6.58	0.02		
E/2/2/15-22.5	96.33	0.68	0.13	1.35	0.25	0.16	11.89	2.57	0.43		0.25	0.04	3.25	0		
E/2/3/15-22.5	83.33	0.59	0.17	1.41	0.20	0.22	14.49	4.95	0.79		0.43	0.11	7.2	0.02		
E/2/4/15-22.5	94.62	0.67									0.38	0	1.18	0		
E/2/5/15-22.5	91.32	0.65									0.27	0.04	0.47	0		
E/2/1/22.5-30	82.22	0.58	0.07	1.11	0.13	0.09	13.90	2.66	0.52		0.35	0.04	3.95	0		
E/2/2/22.5-30	93.45	0.66	0.12	1.44	0.28	0.21	12.04	2.19	0.40		0.3	0.05	3.39	0		
E/2/3/22.5-30	80.86	0.57	0.22	1.21	0.15	0.26	14.35	2.92	0.46		0.44	0.07	3.88	0		
E/2/4/22.5-30	80.21	0.57									0.37	0	1.62	0		
E/2/5/22.5-30	84.86	0.60									0.3	0.03	2.46	0		
E/2/1/30-37.5	95.56	0.68	0.04	0.60	0.03	0.02	11.90	1.88	0.35		0.26	0	2.47	0		
E/2/2/30-37.5	90.77	0.64	0.17	1.08	0.22	0.25	15.47	2.62	0.40		0.27	0.05	1.92	0		
E/2/3/30-37.5	77.35	0.55	0.08	0.68	0.09	0.09	7.19	2.11	0.38		0.31	0.03	1.69	0		
E/2/4/30-37.5	97.47	0.69									0.23	0	0.75	0		
E/2/5/30-37.5	81.04	0.57									0.29	0.02	0.44	0		
E/2/1/37.5-45	83.94	0.59	0.02	0.44	0.07	0.02	1.79	1.41	0.28		0.35	0	0.95	0		
E/2/2/37.5-45	84.51	0.60	0.12	0.65	0.12	0.26	9.90	2.12	0.34		0.27	0.03	1.4	0		
E/2/3/37.5-45	83.88	0.59	0.05	0.68	0.09	0.04	5.86	1.83	0.34		0.26	0.05	1.43	0		
E/2/4/37.5-45	73.54	0.52									0.26	0	1.31	0		
E/2/5/37.5-45	70.09	0.50									0.38	0.03	2.37	0		

Appendix 1.1.13 Soil Chemical Results for Site E Non- Effluent Paddock

Site E Core ID	Core Weight (g)	Bulk Density (g/cm3)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
E/3/1/0-7.5	80.10	0.57									1.75	0.65	44.5	0		
E/3/2/0-7.5	62.57	0.44									2.54	1.46	40	0		
E/3/3/0-7.5	75.96	0.54	0.72	11.09	2.08	0.15	34.04	9.20	2.26	38.86	3.56	0.92	36.3	0.07	0.93	12.66
E/3/4/0-7.5	67.67	0.48	0.57	15.38	3.27	0.22	36.94	9.89	3.02	102.84	3.51	1.48	47.7	0.01	1.02	12.46
E/3/5/0-7.5	57.06	0.40	0.47	30.65	3.57	0.10	71.03	10.75	1.77	45.5	2.5	0.1	49.3	0.18	1.16	22.64
E/3/1/7.5-15	92.68	0.66									0.66	0.25	10.4	0		
E/3/2/7.5-15	80.26	0.57									0.93	0.35	9.41	0		
E/3/3/7.5-15	74.27	0.53	0.12	4.51	0.62	0.11	29.11	4.94	0.78	4.74	0.61	0.2	6.67	0.05		
E/3/4/7.5-15	82.65	0.58	0.15	3.89	0.49	0.06	28.34	4.85	0.77	20.85	0.68	0.25	7.17	0.19		
E/3/5/7.5-15	82.93	0.59	0.07	13.05	0.85	0.14	49.10	0.00	0.00	56.87	0.89	0.11	7.75	0.33		
E/3/1/15-22.5	86.34	0.61									0.55	0.07	3.88	0		
E/3/2/15-22.5	84.61	0.60									0.73	0.14	4.22	0.04		
E/3/3/15-22.5	74.75	0.53	0.08	1.91	0.25	0.08	22.32	3.54	0.56		0.44	0.12	3.34	0		
E/3/4/15-22.5	68.30	0.48	0.12	1.33	0.17	0.03	26.64	4.15	0.61		0.57	0.11	4.13	0		
E/3/5/15-22.5	79.15	0.56	0.05	4.83	0.27	0.20	40.34	3.68	0.90		0.66	0.1	6.79	0.27		
E/3/1/22.5-30	71.95	0.51									0.38	0.03	2.75	0		
E/3/2/22.5-30	73.94	0.52									0.66	0.1	2.35	0.01		
E/3/3/22.5-30	63.67	0.45	0.09	1.31	0.16	0.07	26.62	3.09	0.49		0.37	0.13	3.32	0.01		
E/3/4/22.5-30	52.74	0.37	0.05	0.69	0.08	0.00	24.56	3.85	0.64		0.4	0.08	3.81	0		
E/3/5/22.5-30	67.79	0.48	0.06	2.05	0.10	0.01	27.23	3.12	0.56		0.46	0.09	3.76	0.02		
E/3/1/30-37.5	92.04	0.65									0.35	0.01	0.46	0		
E/3/2/30-37.5	76.80	0.54									0.51	0	0.98	0		
E/3/3/30-37.5	59.28	0.42	0.09	0.93	0.07	0.14	22.49	2.77	0.43		0.49	0.1	2.2	0		
E/3/4/30-37.5	56.07	0.40	0.03	0.70	0.06	-0.02	24.52	3.67	0.54		0.43	0.1	3.95	0		

Appendix 1.1.13 cont'd

Site E Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
E/3/5/30-37.5	71.74	0.51	0.04	1.11	0.03	-0.01	17.41	2.01	0.38		0.35	0.07	1.43	0.03		
E/3/1/37.5-45	96.58	0.68									0.26	0	0.28	0.01		
E/3/2/37.5-45	78.73	0.56									0.46	0	0.43	0.06		
E/3/3/37.5-45	61.65	0.44	0.11	0.65	0.02	0.25	18.53	2.39	0.42		0.29	0.04	1.26	0		
E/3/4/37.5-45	59.50	0.42	0.00	0.29	0.00	-0.04	12.76	1.53	0.28		0.2	0.02	0.97	0		
E/3/5/37.5-45	94.40	0.67	0.04	0.67	0.00	-0.03	10.67	0.98	0.21		0.24	0.05	0.44	0		

Appendix 1.1.14 Soil Chemical Results for Site F Effluent Paddock

Site F Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
F/2/1/0-7.5	118.74	0.84	1.40	14.96	3.26	0.21	26.09				1.09	0.23	20.3	0.02		
F/2/2/0-7.5	124.85	0.88	0.46	15.64	2.24	0.24	23.58	4.74	1.81	63.51	6.14	0.63	32.2	0.02	0.42	4.53
F/2/3/0-7.5	128.87	0.91	1.07	14.33	1.88	0.16	27.44	5.28	2.25	72.51	0.86	4.8	21.6	0	0.45	5.10
F/2/4/0-7.5	134.18	0.95	2.76	13.57	2.01	0.06	28.40	5.94	2.28	65.40	1.15	1.93	21.5	0	0.48	5.09
F/2/5/0-7.5	136.28	0.96	2.29	15.08	2.93	0.09	24.14				1.15	0.37	21.2	0		
F/2/1/7.5-15	119.75	0.85	0.67	11.58	1.83	0.22	19.29				0.48	0.18	9.76	0		
F/2/2/7.5-15	135.22	0.96	0.10	10.57	1.10	0.09	18.11	2.66	0.92	19.43	0.64	0.31	8.86	0.03		
F/2/3/7.5-15	123.26	0.87	0.39	11.18	1.48	0.13	21.93	3.31	0.98	23.70	0.85	6.86	8.43	0.08		
F/2/4/7.5-15	114.48	0.81	2.06	8.94	1.00	0.05	23.31	4.78	0.99	22.27	0.69	0.3	6.53	0.15		
F/2/5/7.5-15	135.56	0.96	2.17	11.24	2.11	0.09	19.36				0.44	0.17	8.25	0.02		
F/2/1/15-22.5	121.97	0.86	0.21	9.38	1.33	0.19	17.36				0.38	0.16	3.96	0.12		
F/2/2/15-22.5	141.62	1.00	0.09	8.90	0.75	0.14	16.14	1.86	0.58		0.42	0.16	4.31	0.03		
F/2/3/15-22.5	116.09	0.82	0.37	6.18	0.82	0.10	14.98	2.35	0.47		1	6.3	2.42	3.99		
F/2/4/15-22.5	125.23	0.89	1.59	5.17	0.72	0.05	17.53	3.68	0.64		0.53	0.25	3.21	0.34		
F/2/5/15-22.5	140.69	0.99	1.75	9.12	1.89	0.09	15.35				0.27	0.2	6.21	0.02		
F/2/1/22.5-30	131.90	0.93	0.09	7.39	1.24	0.14	13.87				0.22	0.07	1.63	0.29		
F/2/2/22.5-30	145.94	1.03	0.08	7.86	0.69	0.15	15.03	1.31	0.48		0.22	0.1	1.63	0.2		
F/2/3/22.5-30	137.39	0.97	0.27	4.78	0.62	0.16	13.32	1.20	0.28		0.17	1.39	0.82	1.02		
F/2/4/22.5-30	125.90	0.89	1.31	3.45	0.59	0.07	12.92	1.63	0.36		0.31	0.07	1.11	0.05		
F/2/5/22.5-30	127.21	0.90	1.18	7.36	1.73	0.10	14.12				0.24	0.24	2.77	0.17		
F/2/1/30-37.5	139.69	0.99	0.08	6.83	1.18	0.10	11.93				0.18	0.06	0.98	0.17		
F/2/2/30-37.5	147.44	1.04	0.06	7.35	0.74	0.05	11.95	0.73	0.34		0.18	0.06	0.54	0.07		
F/2/3/30-37.5	161.73	1.14	0.07	5.03	0.73	0.20	9.78	0.69	0.25		0.22	0.34	0.85	0.22		

Appendix 1.1.14 cont'd

Site F Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
F/2/4/30-37.5	145.45	1.03	0.97	3.62	0.66	0.07	12.82	1.42	0.38		0.22	0.04	0.7	0.14		
F/2/5/30-37.5	151.77	1.07	0.79	6.11	1.46	0.11	12.21				0.15	0.17	0.76	0.55		
F/2/1/37.5-45	110.43	0.78	0.14	7.37	1.31	0.10	12.66				0.72	0.14	1.9	0.11		
F/2/2/37.5-45	147.58	1.04	0.05	6.34	0.87	0.03	12.30	0.46	0.28		0.08	0.02	0.33	0.02		
F/2/3/37.5-45	148.57	1.05	0.04	5.15	0.68	0.16	9.79	0.46	0.22		0.14	0.14	0.39	0.13		
F/2/4/37.5-45	143.14	1.01	0.79	4.83	0.89	0.07	12.82	0.74	0.34		0.17	0.03	0.25	0.05		
F/2/5/37.5-45	153.65	1.09	0.60	5.94	1.31	0.10	11.70				0.14	0.09	0.4	0.27		

Appendix 1.1.15 Soil Chemical Results for Site F Non- Effluent Paddock

Site F Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
F/1/1/0-7.5	90.63	0.64	0.42	23.79	3.06	0.20	34.97			81.52	1.48	0.22	32.3	0.27		
F/1/2/0-7.5	93.14	0.66	0.34	18.13	1.46	0.14	28.82	7.14	2.71		1.42	0.25	28.1	0	0.66	7.01
F/1/3/0-7.5	105.28	0.74	0.65	19.07	1.60	0.11	28.93	5.88	2.47	51.18	1.25	0.29	27.4	0.11	0.54	5.79
F/1/4/0-7.5	114.06	0.81	1.39	16.68	1.01	0.10	24.18				2.17	0.29	19.6	0.15		
F/1/5/0-7.5	96.67	0.68	1.56	17.70	2.18	0.12	27.80	5.78	3.09	85.31	1.4	0.3	29.6	0	0.52	5.56
F/1/1/7.5-15	93.98	0.66	0.14	13.90	1.57	0.10	25.71			16.59	0.72	0.15	12.4	0		
F/1/2/7.5-15	110.91	0.78	0.15	6.71	0.61	0.07	20.04	5.59	1.50		0.63	0.18	7.06	0.05		
F/1/3/7.5-15	125.05	0.88	0.42	8.43	0.83	0.08	19.77	3.02	0.99	16.11	0.56	0.09	5.51	0.03		
F/1/4/7.5-15	130.14	0.92	0.65	7.50	0.53	0.07	17.50				0.45	0.03	7.96	0.04		
F/1/5/7.5-15	131.78	0.93	1.42	8.11	1.20	0.09	19.56	3.23	1.43	18.48	0.52	0.09	13.1	0.01		
F/1/1/15-22.5	104.17	0.74	0.07	10.14	0.66	0.09	20.96				0.44	0.11	4.47	0.06		
F/1/2/15-22.5	122.76	0.87	0.43	6.16	0.57	0.10	13.51	2.43	0.59		0.45	0.09	2.71	0.09		

Appendix 1.1.15 cont'd

Site F Core ID	Core Weight (g)	Bulk Density (g/cm ³)	CATIONS (meq/100g)					Total N & P (mg/g)		Olsen P	ANAEROBIC MINERALISABLE N (mg/L)				LECO	
			K	Mg	Ca	Na	CEC	TN	TP		NH4 D0	NO3 D0	NH4 D15	NO3 D15	N %	C %
F/1/3/15-22.5	149.87	1.06	0.46	5.21	0.50	0.08	12.51	1.07	0.35		0.17	0	1.11	0.01		
F/1/4/15-22.5	140.93	1.00	0.45	5.71	0.39	0.10	11.65				0.26	0	1.28	0.05		
F/1/5/15-22.5	141.70	1.00	1.30	4.31	0.56	0.09	13.75	1.72	0.47		0.24	0.03	2.54	0.08		
F/1/1/22.5-30	88.88	0.63	0.04	6.55	0.25	0.09	14.43				0.29	0.04	0.81	0.09		
F/1/2/22.5-30	128.23	0.91	0.32	6.71	0.76	0.23	13.03	0.92	0.32		0.34	0.06	0.6	0		
F/1/3/22.5-30	138.51	0.98	0.45	5.90	0.63	0.10	12.09	0.65	0.29		0.19	0	0.71	0.01		
F/1/4/22.5-30	157.21	1.11	0.46	6.24	0.47	0.08	13.50				0.18	0	0.57	0.05		
F/1/5/22.5-30	141.30	1.00	1.27	3.94	0.52	0.10	9.59	0.76	0.23		0.12	0	0.97	0.02		
F/1/1/30-37.5	97.02	0.69	0.05	7.74	0.29	0.11	13.18				0.21	0	0.47	0		
F/1/2/30-37.5	133.02	0.94	0.16	6.44	0.95	0.32	12.88	0.68	0.31		0.21	0.01	0.53	0		
F/1/3/30-37.5	163.05	1.15	0.35	6.66	0.88	0.15	11.79	0.61	0.29		0.21	0.01	0.49	0.06		
F/1/4/30-37.5	136.78	0.97	0.36	8.01	0.79	0.10	14.27				0.22	0	0.37	0.01		
F/1/5/30-37.5	140.24	0.99	1.17	5.04	0.72	0.12	12.05	0.63	0.25		0.19	0.01	0.9	0		
F/1/1/37.5-45	93.52	0.66	0.06	7.46	0.50	0.11	14.38				0.23	0.05	0.45	0		
F/1/2/37.5-45	126.80	0.90	0.13	6.80	1.16	0.34	13.42	0.58	0.28		0.19	0	0.3	0		
F/1/3/37.5-45	153.17	1.08	0.20	7.69	1.20	0.23	11.82	0.59	0.31		0.13	0.01	0.39	0.08		
F/1/4/37.5-45	120.64	0.85	0.18	8.38	1.51	0.19	15.25				0.18	0	0.41	0		
F/1/5/37.5-45	135.52	0.96	0.91	6.73	1.13	0.16	11.44	0.00	0.00		0.15	0.01	0.78	0.04		

Appendix 1.2 Exchangeable Cation Analysis

This data shows the raw results of the exchangeable cation analysis as described in Chapter 3, the mean, standard deviation and the coefficient of variation (COV) found in the results is also shown.

Appendix 1.2.1 Site A Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
A/1/1/0-7.5	15.00	3.58	8.29	1.16	0.18	28.20
A/1/2/0-7.5	13.75	0.92	9.82	1.29	0.19	25.96
A/1/3/0-7.5	11.25	0.57	13.52	1.95	0.29	27.57
A/1/4/0-7.5	11.25	4.32	11.24	2.75	0.44	30.00
mean	12.81	2.35	10.72	1.79	0.27	27.94
std dev	1.88	1.88	2.22	0.73	0.12	1.67
COV	15%	80%	21%	41%	45%	6%
A/1/1/7.5-15	12.50	1.94	10.09	0.55	0.19	25.27
A/1/2/7.5-15	12.50	0.20	7.58	0.65	0.15	21.08
A/1/3/7.5-15	13.75	0.35	10.14	1.17	0.15	25.56
A/1/4/7.5-15	18.75	2.51	3.60	0.69	0.28	25.83
mean	14.38	1.25	7.85	0.76	0.19	24.43
std dev	2.98	1.15	3.07	0.28	0.06	2.25
COV	21%	92%	39%	36%	31%	9%
A/1/1/15-22.5	15.00	1.51	4.91	0.24	0.24	21.89
A/1/2/15-22.5	15.00	0.55	3.90	0.28	0.18	19.91
A/1/3/15-22.5	16.25	0.17	5.73	0.56	0.07	22.79
A/1/4/15-22.5	16.25	1.93	1.96	0.24	0.14	20.53
mean	15.63	1.04	4.13	0.33	0.16	21.28
std dev	0.72	0.82	1.63	0.16	0.07	1.30
COV	5%	78%	39%	47%	45%	6%
A/1/1/22.5-30	12.50	1.52	2.13	0.14	0.14	16.42
A/1/2/22.5-30	13.75	0.73	2.47	0.19	0.15	17.30
A/1/3/22.5-30	13.75	0.21	3.58	0.31	0.07	17.92
A/1/4/22.5-30	15.00	2.70	2.74	0.37	0.18	20.99
mean	13.75	1.29	2.73	0.25	0.14	18.16
std dev	1.02	1.08	0.62	0.11	0.05	1.99
COV	7%	84%	23%	42%	35%	11%
A/1/1/30-37.5	10.00	1.17	2.28	0.14	0.14	13.74
A/1/2/30-37.5	10.00	0.25	4.07	0.34	0.31	14.97
A/1/3/30-37.5	10.00	0.53	3.56	0.44	0.12	14.65
A/1/4/30-37.5	8.75	2.87	2.83	0.42	0.15	15.03
mean	9.69	1.20	3.19	0.34	0.18	14.60
std dev	0.62	1.18	0.79	0.14	0.09	0.60
COV	6%	98%	25%	40%	49%	4%
A/1/1/37.5-45	7.50	0.43	2.77	0.22	0.18	11.09
A/1/2/37.5-45	6.25	0.12	4.88	0.37	0.32	11.94
A/1/3/37.5-45	7.50	0.81	4.06	0.53	0.06	12.96
A/1/4/37.5-45	5.00	2.01	3.00	0.42	0.11	10.54
mean	6.56	0.84	3.68	0.38	0.17	11.63
std dev	1.20	0.82	0.98	0.13	0.11	1.05
COV	18%	98%	27%	34%	65%	9%

Appendix 1.2.2 Site A Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
A/2/1/0-7.5	12.50	0.22	13.03	1.69	0.13	27.57
A/2/3/0-7.5	10.00	1.07	15.25	3.51	0.22	30.04
A/2/4/0-7.5	7.50	1.92	14.74	1.86	0.46	26.49
A/2/5/0-7.5	12.50	0.25	14.55	0.95	0.18	28.43
mean	10.63	0.87	14.39	2.00	0.25	28.13
std dev	2.39	0.81	0.95	1.08	0.15	1.50
COV	23%	93%	7%	54%	60%	5%
A/2/1/7.5-15	11.25	0.09	9.42	0.59	0.06	21.41
A/2/3/7.5-15	15.00	0.63	7.23	1.00	0.11	23.97
A/2/4/7.5-15	13.75	1.30	5.14	0.50	0.31	21.00
A/2/5/7.5-15	16.25	0.10	5.68	0.23	0.05	22.32
mean	14.06	0.53	6.87	0.58	0.13	22.17
std dev	2.13	0.57	1.92	0.32	0.12	1.32
COV	15%	108%	28%	55%	92%	6%
A/2/1/15-22.5	10.00	0.06	4.37	0.29	0.06	14.78
A/2/3/15-22.5	10.00	0.09	3.47	0.28	0.09	13.93
A/2/4/15-22.5	13.75	0.99	1.25	0.13	0.16	16.28
A/2/5/15-22.5	8.75	0.06	3.88	0.12	0.04	12.85
mean	10.63	0.30	3.25	0.20	0.09	14.46
std dev	2.17	0.46	1.38	0.09	0.05	1.45
COV	20%	155%	42%	44%	59%	10%
A/2/1/22.5-30	7.50	0.06	3.50	0.24	0.05	11.36
A/2/3/22.5-30	5.00	0.08	4.01	0.24	0.12	9.45
A/2/4/22.5-30	10.00	1.17	1.73	0.14	0.13	13.17
A/2/5/22.5-30	5.00	0.06	4.72	0.14	0.04	9.95
mean	6.88	0.34	3.49	0.19	0.08	10.98
std dev	2.39	0.55	1.28	0.06	0.04	1.66
COV	35%	161%	37%	31%	52%	15%
A/2/1/30-37.5	6.25	0.07	4.05	0.26	0.06	10.69
A/2/3/30-37.5	2.50	0.06	5.57	0.61	0.09	8.83
A/2/4/30-37.5	5.00	1.28	1.58	0.11	0.13	8.09
A/2/5/30-37.5	2.50	0.08	4.81	0.13	0.08	7.60
mean	4.06	0.37	4.00	0.28	0.09	8.80
std dev	1.87	0.60	1.73	0.23	0.03	1.36
COV	46%	162%	43%	83%	33%	15%
A/2/1/37.5-45	3.75	0.06	4.01	0.24	0.05	8.11
A/2/3/37.5-45	2.50	0.07	5.44	0.59	0.06	8.66
A/2/4/37.5-45	2.50	1.17	2.44	0.14	0.11	6.36
A/2/5/37.5-45	2.50	0.06	4.85	0.09	0.06	7.56
mean	2.81	0.34	4.18	0.27	0.07	7.67
std dev	0.62	0.55	1.30	0.23	0.03	0.99
COV	22%	163%	31%	85%	36%	13%

Appendix 1.2.3 Site B Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
B/1/2/0-7.5	6.25	4.66	24.62	6.22	0.57	42.32
B/1/3/0-7.5	6.25	0.99	18.26	1.90	0.21	27.61
B/1/4/0-7.5	6.25	0.69	19.08	2.50	0.28	28.79
mean	6.25	2.11	20.65	3.54	0.35	32.91
std dev	0.00	2.21	3.46	2.34	0.19	8.17
COV	0%	105%	17%	66%	54%	25%
B/1/2/7.5-15	17.50	1.97	8.44	1.92	0.49	30.32
B/1/3/7.5-15	15.00	0.42	12.95	1.16	0.23	29.76
B/1/4/7.5-15	6.25	0.26	18.63	1.74	0.15	27.03
mean	12.92	0.88	13.34	1.61	0.29	29.04
std dev	5.91	0.95	5.11	0.40	0.18	1.76
COV	46%	107%	38%	25%	63%	6%
B/1/2/15-22.5	12.50	1.15	2.52	0.55	0.23	16.95
B/1/3/15-22.5	13.75	0.23	5.89	0.52	0.26	20.66
B/1/4/15-22.5	2.50	0.25	10.98	1.10	0.14	14.98
mean	9.58	0.55	6.46	0.72	0.21	17.53
std dev	6.17	0.53	4.26	0.33	0.06	2.88
COV	64%	96%	66%	45%	30%	16%
B/1/2/22.5-30	8.75	0.86	2.35	0.59	0.26	12.81
B/1/3/22.5-30	11.25	0.35	4.76	0.51	0.26	17.13
B/1/4/22.5-30	2.50	0.22	6.47	0.82	0.15	10.16
mean	7.50	0.48	4.53	0.64	0.22	13.37
std dev	4.51	0.34	2.07	0.16	0.06	3.52
COV	60%	72%	46%	25%	28%	26%
B/1/2/30-37.5	6.25	0.95	2.29	0.56	0.25	10.30
B/1/3/30-37.5	2.50	0.63	6.26	0.99	0.23	10.62
B/1/4/30-37.5	2.50	0.19	6.17	0.85	0.17	9.87
mean	3.75	0.59	4.91	0.80	0.22	10.26
std dev	2.17	0.39	2.27	0.22	0.04	0.37
COV	58%	65%	46%	28%	19%	4%
B/1/2/37.5-45	5.00	0.87	1.86	0.42	0.20	8.36
B/1/3/37.5-45	2.50	0.21	6.18	1.12	0.27	10.28
B/1/4/37.5-45	3.75	0.18	5.62	0.97	0.20	10.72
mean	3.75	0.42	4.55	0.84	0.22	9.79
std dev	1.25	0.39	2.35	0.37	0.04	1.26
COV	33%	93%	52%	44%	17%	13%

Appendix 1.2.4 Site B Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
B/2/2/0-7.5	8.75	1.49	13.76	1.09	0.19	25.28
B/2/3/0-7.5	13.75	0.55	13.06	1.10	0.13	28.59
B/2/5/0-7.5	11.25	0.38	14.40	0.97	0.15	27.15
mean	11.25	0.81	13.74	1.05	0.16	27.00
std dev	2.50	0.60	0.67	0.07	0.03	1.66
COV	22%	74%	5%	7%	17%	6%
B/2/2/7.5-15	10.00	0.44	6.83	0.53	0.14	17.94
B/2/3/7.5-15	13.75	0.31	6.43	0.37	0.07	20.93
B/2/5/7.5-15	13.75	0.10	7.53	0.55	0.08	22.01
mean	12.50	0.28	6.93	0.48	0.10	20.29
std dev	2.17	0.17	0.56	0.10	0.04	2.11
COV	17%	61%	8%	21%	41%	10%
B/2/2/15-22.5	11.25	0.23	4.96	0.38	0.08	16.91
B/2/3/15-22.5	15.00	0.22	2.36	0.14	0.12	17.84
B/2/5/15-22.5	13.75	0.27	5.41	0.44	0.08	19.96
mean	13.33	0.24	4.25	0.32	0.10	18.24
std dev	1.91	0.03	1.65	0.16	0.02	1.56
COV	14%	11%	39%	51%	26%	9%
B/2/2/22.5-30	10.00	0.27	3.73	0.28	0.09	14.37
B/2/3/22.5-30	13.75	0.22	1.69	0.14	0.15	15.95
B/2/5/22.5-30	12.50	0.47	5.47	0.44	0.09	18.96
mean	12.08	0.32	3.63	0.28	0.11	16.43
std dev	1.91	0.13	1.89	0.15	0.03	2.33
COV	16%	40%	52%	53%	29%	14%
B/2/2/30-37.5	10.00	0.26	4.46	0.33	0.12	15.17
B/2/3/30-37.5	13.75	0.35	3.32	0.39	0.15	17.96
B/2/5/30-37.5	11.25	0.38	4.86	0.42	0.09	17.00
mean	11.67	0.33	4.21	0.38	0.12	16.71
std dev	1.91	0.06	0.80	0.05	0.03	1.42
COV	16%	18%	19%	13%	25%	8%
B/2/2/37.5-45	10.00	0.16	4.49	0.33	0.16	15.14
B/2/3/37.5-45	12.50	0.27	3.94	0.52	0.14	17.37
B/2/5/37.5-45	12.50	0.17	4.45	0.45	0.12	17.69
mean	11.67	0.20	4.29	0.43	0.14	16.74
std dev	1.44	0.06	0.30	0.09	0.02	1.39
COV	12%	29%	7%	22%	16%	8%

Appendix 1.2.5 Site C Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
C/1/2/0-7.5	12.50	0.58	13.82	1.24	0.11	28.25
C/1/4/0-7.5	12.50	1.14	16.91	1.71	0.17	32.43
C/1/5/0-7.5	28.75	0.58	34.17	4.88	0.21	68.59
mean	17.92	0.77	21.64	2.61	0.16	43.09
std dev	9.38	0.32	10.97	1.98	0.05	22.18
COV	52%	42%	51%	76%	30%	51%
C/1/2/7.5-15	11.25	0.39	8.40	0.45	0.09	20.58
C/1/4/7.5-15	13.75	0.89	12.20	0.54	0.19	27.56
C/1/5/7.5-15	32.50	0.55	12.55	1.51	0.14	47.26
mean	19.17	0.61	11.05	0.83	0.14	31.80
std dev	11.61	0.25	2.30	0.59	0.05	13.83
COV	61%	41%	21%	71%	35%	44%
C/1/2/15-22.5	13.75	0.65	6.33	0.38	0.12	21.23
C/1/4/15-22.5	10.00	0.30	5.81	0.30	0.15	16.56
C/1/5/15-22.5	33.75	0.54	5.72	0.90	0.16	41.06
mean	19.17	0.50	5.95	0.53	0.14	26.28
std dev	12.77	0.18	0.33	0.33	0.02	13.01
COV	67%	36%	6%	62%	13%	49%
C/1/2/22.5-30	13.75	0.55	3.16	0.27	0.15	17.88
C/1/4/22.5-30	8.75	0.05	2.38	0.14	0.09	11.40
C/1/5/22.5-30	30.00	0.45	1.58	0.30	0.14	32.46
mean	17.50	0.35	2.37	0.23	0.13	20.58
std dev	11.11	0.27	0.79	0.09	0.04	10.79
COV	63%	76%	33%	37%	28%	52%
C/1/2/30-37.5	11.25	0.22	1.53	0.17	0.10	13.26
C/1/4/30-37.5	6.25	0.03	1.00	0.06	0.04	7.38
C/1/5/30-37.5	21.25	0.23	1.03	0.19	0.08	22.78
mean	12.92	0.16	1.19	0.14	0.07	14.48
std dev	7.64	0.11	0.30	0.07	0.03	7.77
COV	59%	71%	25%	51%	37%	54%
C/1/2/37.5-45	8.75	0.10	0.98	0.10	0.06	9.99
C/1/4/37.5-45	6.25	0.04	1.19	0.07	0.04	7.58
C/1/5/37.5-45	13.75	0.07	0.33	0.08	0.04	14.28
mean	9.58	0.07	0.83	0.08	0.05	10.62
std dev	3.82	0.03	0.45	0.02	0.01	3.39
COV	40%	45%	54%	23%	28%	32%

Appendix 1.2.6 Site C Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
C/2/2/0-7.5	18.75	0.74	9.28	1.97	0.19	30.93
C/2/3/0-7.5	2.50	0.37	29.70	1.53	0.09	32.94
C/2/4/0-7.5	18.75	0.53	12.34	1.76	0.11	33.49
mean	13.33	0.55	17.10	1.75	0.13	32.45
std dev	9.38	0.18	11.02	0.22	0.06	1.35
COV	70%	34%	64%	13%	42%	4%
C/2/2/7.5-15	16.25	0.51	5.10	0.70	0.21	22.78
C/2/3/7.5-15	7.50	0.20	19.02	0.66	0.06	27.44
C/2/4/7.5-15	18.75	0.27	5.20	0.63	0.08	24.93
mean	14.17	0.33	9.77	0.66	0.12	25.05
std dev	5.91	0.16	8.01	0.04	0.08	2.33
COV	42%	50%	82%	6%	69%	9%
C/2/2/15-22.5	8.75	0.21	2.14	0.32	0.10	11.52
C/2/3/15-22.5	12.50	0.37	12.13	0.50	0.05	25.55
C/2/4/15-22.5	13.75	0.14	2.67	0.31	0.03	16.90
mean	11.67	0.24	5.65	0.38	0.06	17.99
std dev	2.60	0.12	5.62	0.11	0.04	7.08
COV	22%	50%	100%	29%	59%	39%
C/2/2/22.5-30	6.25	0.13	1.02	0.19	0.06	7.66
C/2/3/22.5-30	13.75	0.28	6.17	0.43	0.03	20.65
C/2/4/22.5-30	8.75	0.06	1.45	0.15	0.01	10.43
mean	9.58	0.16	2.88	0.26	0.03	12.91
std dev	3.82	0.11	2.85	0.15	0.02	6.84
COV	40%	70%	99%	57%	75%	53%
C/2/2/30-37.5	6.25	0.05	0.87	0.16	0.04	7.38
C/2/3/30-37.5	10.00	0.10	2.17	0.23	0.01	12.51
C/2/4/30-37.5	7.50	0.03	0.87	0.09	0.00	8.49
mean	7.92	0.06	1.30	0.16	0.02	9.46
std dev	1.91	0.03	0.75	0.07	0.02	2.70
COV	24%	56%	58%	46%	113%	29%
C/2/2/37.5-45	6.25	0.04	0.69	0.10	0.05	7.13
C/2/3/37.5-45	7.50	0.05	0.64	0.08	-0.01	8.26
C/2/4/37.5-45	8.75	0.00	0.78	0.07	0.00	9.60
mean	7.50	0.03	0.71	0.08	0.01	8.33
std dev	1.25	0.03	0.07	0.01	0.03	1.24
COV	17%	85%	10%	15%	259%	15%

Appendix 1.2.7 Site D (sand) Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
D/4/1/0-7.5	8.75	0.92	7.57	1.98	0.09	19.32
D/4/4/0-7.5	7.50	0.53	11.46	3.03	0.23	22.75
D/4/5/0-7.5	8.75	0.79	7.60	2.09	0.13	19.35
mean	8.33	0.75	8.88	2.37	0.15	20.47
std dev	0.72	0.20	2.24	0.58	0.07	1.97
COV	9%	27%	25%	24%	47%	10%
D/4/1/7.5-15	6.25	0.48	3.47	0.56	0.08	10.85
D/4/4/7.5-15	6.25	0.15	2.89	0.94	0.11	10.35
D/4/5/7.5-15	6.25	0.30	1.81	0.43	0.07	8.86
mean	6.25	0.31	2.73	0.65	0.08	10.02
std dev	0.00	0.16	0.84	0.27	0.02	1.03
COV	0%	53%	31%	41%	26%	10%
D/4/1/15-22.5	5.00	0.34	2.49	0.36	0.09	8.29
D/4/4/15-22.5	8.75	0.18	1.75	0.63	0.12	11.44
D/4/5/15-22.5	6.25	0.27	2.03	0.44	0.09	9.08
mean	6.67	0.26	2.09	0.48	0.10	9.60
std dev	1.91	0.08	0.37	0.14	0.02	1.64
COV	29%	30%	18%	29%	16%	17%
D/4/1/22.5-30	3.75	0.24	1.35	0.18	0.07	5.59
D/4/4/22.5-30	3.75	0.44	0.97	0.43	0.12	5.71
D/4/5/22.5-30	3.75	0.38	1.24	0.26	0.16	5.78
mean	3.75	0.35	1.19	0.29	0.12	5.69
std dev	0.00	0.11	0.20	0.13	0.04	0.10
COV	0%	30%	17%	45%	37%	2%
D/4/1/30-37.5	3.75	0.32	1.24	0.17	0.15	5.64
D/4/4/30-37.5	3.75	0.98	1.39	0.48	0.14	6.74
D/4/5/30-37.5	3.75	0.29	1.10	0.29	0.12	5.56
mean	3.75	0.53	1.24	0.32	0.14	5.98
std dev	0.00	0.39	0.14	0.16	0.01	0.66
COV	0%	74%	11%	49%	9%	11%
D/4/1/37.5-45	3.75	0.28	2.34	0.46	0.29	7.11
D/4/4/37.5-45	2.50	1.78	3.08	0.93	0.22	8.50
D/4/5/37.5-45	2.50	0.43	1.46	0.48	0.14	5.01
mean	2.92	0.83	2.29	0.62	0.21	6.87
std dev	0.72	0.83	0.81	0.26	0.07	1.76
COV	25%	100%	35%	42%	34%	26%

Appendix 1.2.8 Site D (sand) Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
D/1/3/0-7.5	11.25	0.40	3.54	0.65	0.15	15.99
D/1/4/0-7.5	12.50	0.26	5.12	0.74	0.21	18.83
D/1/5/0-7.5	12.50	0.31	5.45	0.82	0.08	19.15
mean	12.08	0.33	4.70	0.74	0.15	17.99
std dev	0.72	0.07	1.02	0.08	0.06	1.74
COV	6%	22%	22%	11%	43%	10%
D/1/3/7.5-15	12.50	0.12	1.73	0.26	0.12	14.72
D/1/4/7.5-15	13.75	0.10	2.24	0.27	0.16	16.52
D/1/5/7.5-15	12.50	0.11	1.86	0.29	0.07	14.82
mean	12.92	0.11	1.94	0.28	0.11	15.36
std dev	0.72	0.01	0.27	0.02	0.05	1.01
COV	6%	11%	14%	6%	42%	7%
D/1/3/15-22.5	11.25	0.10	1.67	0.21	0.08	13.31
D/1/4/15-22.5	11.25	0.07	1.37	0.14	0.16	12.98
D/1/5/15-22.5	11.25	0.09	1.91	0.36	0.09	13.69
mean	11.25	0.08	1.65	0.23	0.11	13.33
std dev	0.00	0.02	0.27	0.11	0.04	0.36
COV	0%	18%	16%	48%	36%	3%
D/1/3/22.5-30	8.75	0.18	0.88	0.11	0.05	9.97
D/1/4/22.5-30	8.75	0.11	0.65	0.07	0.14	9.72
D/1/5/22.5-30	8.75	0.12	0.90	0.20	0.12	10.09
mean	8.75	0.14	0.81	0.12	0.10	9.93
std dev	0.00	0.04	0.14	0.07	0.05	0.19
COV	0%	28%	17%	54%	49%	2%
D/1/3/30-37.5	7.50	0.35	0.88	0.13	0.06	8.92
D/1/4/30-37.5	7.50	0.12	0.65	0.06	0.22	8.55
D/1/5/30-37.5	10.00	0.40	1.49	0.37	0.23	12.49
mean	8.33	0.29	1.01	0.19	0.17	9.99
std dev	1.44	0.15	0.43	0.16	0.10	2.17
COV	17%	50%	43%	86%	57%	22%
D/1/3/37.5-45	7.50	0.57	0.84	0.13	0.06	9.10
D/1/4/37.5-45	6.25	0.62	1.05	0.19	0.13	8.25
D/1/5/37.5-45	8.75	0.59	0.96	0.25	0.17	10.72
mean	7.50	0.59	0.95	0.19	0.12	9.35
std dev	1.25	0.03	0.11	0.06	0.05	1.25
COV	17%	5%	11%	30%	44%	13%

Appendix 1.2.9 Site D (mud) Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
D/2/1/0-7.5	7.50	0.62	11.38	1.39	0.20	21.09
D/2/3/0-7.5	8.75	2.22	11.20	1.61	0.30	24.09
D/2/4/0-7.5	10.00	1.34	8.59	1.56	0.16	21.64
mean	8.75	1.39	10.39	1.52	0.22	22.27
std dev	1.25	0.80	1.56	0.12	0.07	1.60
COV	14%	58%	15%	8%	33%	7%
D/2/1/7.5-15	5.00	0.61	7.75	0.73	0.18	14.26
D/2/3/7.5-15	5.00	0.96	10.50	0.98	0.27	17.71
D/2/4/7.5-15	7.50	0.96	6.73	1.05	0.17	16.41
mean	5.83	0.84	8.33	0.92	0.21	16.13
std dev	1.44	0.20	1.95	0.17	0.05	1.74
COV	25%	24%	23%	19%	26%	11%
D/2/1/15-22.5	6.25	0.40	7.57	0.66	0.37	15.26
D/2/3/15-22.5	5.00	0.54	9.20	0.70	0.25	15.69
D/2/4/15-22.5	6.25	0.62	5.23	0.78	0.12	13.01
mean	5.83	0.52	7.34	0.71	0.25	14.65
std dev	0.72	0.11	1.99	0.06	0.12	1.44
COV	12%	21%	27%	9%	50%	10%
D/2/1/22.5-30	6.25	0.14	5.28	0.43	0.28	12.39
D/2/3/22.5-30	8.75	0.42	7.85	0.59	0.24	17.85
D/2/4/22.5-30	5.00	0.59	5.12	0.76	0.12	11.59
mean	6.67	0.39	6.08	0.59	0.21	13.94
std dev	1.91	0.23	1.53	0.17	0.09	3.41
COV	29%	59%	25%	28%	40%	24%

Appendix 1.2.10 Site D (mud) Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
D/3/2/0-7.5	8.75	0.44	7.16	0.80	0.31	17.46
D/3/3/0-7.5	10.00	0.96	7.64	1.52	0.25	20.36
D/3/4/0-7.5	6.25	0.40	11.81	1.92	0.40	20.77
mean	8.33	0.60	8.87	1.41	0.32	19.53
std dev	1.91	0.31	2.56	0.57	0.08	1.80
COV	23%	52%	29%	40%	24%	9%
D/3/2/7.5-15	6.25	0.42	7.16	0.61	0.25	14.69
D/3/3/7.5-15	8.75	0.74	6.36	0.89	0.15	16.89
D/3/4/7.5-15	5.00	0.27	8.77	1.11	0.29	15.45
mean	6.67	0.48	7.43	0.87	0.23	15.68
std dev	1.91	0.24	1.23	0.25	0.07	1.12
COV	29%	50%	17%	29%	31%	7%
D/3/2/15-22.5	6.25	0.34	6.10	0.49	0.24	13.42
D/3/3/15-22.5	7.50	0.54	5.11	0.58	0.14	13.87
D/3/4/15-22.5	3.75	0.22	9.66	0.64	0.24	14.51
mean	5.83	0.37	6.96	0.57	0.21	13.94
std dev	1.91	0.16	2.39	0.08	0.06	0.55
COV	33%	44%	34%	13%	28%	4%
D/3/2/22.5-30	5.00	0.16	4.71	0.40	0.19	10.46
D/3/3/22.5-30	7.50	0.43	2.82	0.36	0.12	11.23
D/3/4/22.5-30	2.50	0.11	7.30	0.33	0.15	10.39
mean	5.00	0.23	4.94	0.36	0.15	10.70
std dev	2.50	0.17	2.25	0.04	0.04	0.47
COV	50%	74%	45%	10%	25%	4%

Appendix 1.2.11 Site E Long-Term Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
E/1/3/0-7.5	16.25	2.45	6.44	1.67	0.21	27.03
E/1/4/0-7.5	16.25	0.71	7.66	2.88	0.25	27.75
E/1/5/0-7.5	17.50	1.66	9.34	2.95	0.21	31.65
mean	16.67	1.61	7.81	2.50	0.22	28.81
std dev	0.72	0.87	1.45	0.72	0.02	2.49
COV	4%	54%	19%	29%	10%	9%
E/1/3/7.5-15	16.25	0.64	2.46	0.34	0.13	19.82
E/1/4/7.5-15	17.50	0.32	4.69	0.88	0.19	23.59
E/1/5/7.5-15	20.00	0.64	3.30	0.81	0.13	24.88
mean	17.92	0.53	3.48	0.68	0.15	22.76
std dev	1.91	0.18	1.13	0.29	0.03	2.63
COV	11%	34%	32%	43%	23%	12%
E/1/3/15-22.5	22.50	0.72	2.35	0.35	0.20	26.13
E/1/4/15-22.5	15.00	0.27	2.97	0.46	0.23	18.93
E/1/5/15-22.5	15.00	0.42	1.96	0.45	0.10	17.94
mean	17.50	0.47	2.43	0.42	0.18	21.00
std dev	4.33	0.23	0.51	0.06	0.07	4.47
COV	25%	50%	21%	15%	37%	21%
E/1/3/22.5-30	17.50	0.49	1.83	0.35	0.24	20.41
E/1/4/22.5-30	7.50	0.13	1.43	0.28	0.18	9.52
E/1/5/22.5-30	12.50	0.24	1.26	0.34	0.09	14.42
mean	12.50	0.29	1.50	0.33	0.17	14.78
std dev	5.00	0.18	0.29	0.04	0.08	5.45
COV	40%	64%	19%	11%	45%	37%
E/1/3/30-37.5	15.00	0.22	1.26	0.27	0.18	16.95
E/1/4/30-37.5	3.75	0.03	0.85	0.18	0.08	4.89
E/1/5/30-37.5	6.25	0.10	0.44	0.14	0.04	6.98
mean	8.33	0.12	0.85	0.20	0.10	9.60
std dev	5.91	0.10	0.41	0.07	0.08	6.44
COV	71%	81%	48%	34%	76%	67%
E/1/3/37.5-45	10.00	0.12	0.77	0.13	0.08	11.09
E/1/4/37.5-45	2.50	0.04	0.69	0.14	0.06	3.43
E/1/5/37.5-45	6.25	0.09	0.36	0.15	0.03	6.87
mean	6.25	0.08	0.61	0.14	0.06	7.13
std dev	3.75	0.04	0.22	0.01	0.03	3.84
COV	60%	48%	36%	6%	45%	54%

Appendix 1.2.12 Site E Short-Term Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
E/2/1/0-7.5	15.00	0.36	7.69	1.20	0.18	24.44
E/2/2/0-7.5	10.00	0.44	10.04	2.06	0.18	22.71
E/2/3/0-7.5	13.75	1.14	8.29	1.73	0.14	25.05
mean	12.92	0.65	8.67	1.67	0.16	24.07
std dev	2.60	0.43	1.22	0.43	0.02	1.21
COV	20%	66%	14%	26%	13%	5%
E/2/1/7.5-15	12.50	0.13	4.04	0.36	0.17	17.20
E/2/2/7.5-15	12.50	0.15	3.98	0.76	0.16	17.54
E/2/3/7.5-15	12.50	0.39	2.55	0.35	0.16	15.95
mean	12.50	0.22	3.52	0.49	0.16	16.90
std dev	0.00	0.14	0.84	0.23	0.01	0.84
COV	0%	65%	24%	48%	4%	5%
E/2/1/15-22.5	11.25	0.09	1.89	0.19	0.16	13.58
E/2/2/15-22.5	10.00	0.13	1.35	0.25	0.16	11.89
E/2/3/15-22.5	12.50	0.17	1.41	0.20	0.22	14.49
mean	11.25	0.13	1.55	0.21	0.18	13.32
std dev	1.25	0.04	0.30	0.03	0.03	1.32
COV	11%	33%	19%	17%	18%	10%
E/2/1/22.5-30	12.50	0.07	1.11	0.13	0.09	13.90
E/2/2/22.5-30	10.00	0.12	1.44	0.28	0.21	12.04
E/2/3/22.5-30	12.50	0.22	1.21	0.15	0.26	14.35
mean	11.67	0.14	1.25	0.19	0.19	13.43
std dev	1.44	0.08	0.17	0.08	0.09	1.22
COV	12%	57%	13%	42%	47%	9%
E/2/1/30-37.5	11.25	0.04	0.60	0.03	0.02	11.90
E/2/2/30-37.5	13.75	0.17	1.08	0.22	0.25	15.47
E/2/3/30-37.5	6.25	0.08	0.68	0.09	0.09	7.19
mean	10.42	0.10	0.78	0.11	0.12	11.52
std dev	3.82	0.07	0.26	0.10	0.12	4.16
COV	37%	69%	33%	88%	98%	36%
E/2/1/37.5-45	1.25	0.02	0.44	0.07	0.02	1.79
E/2/2/37.5-45	8.75	0.12	0.65	0.12	0.26	9.90
E/2/3/37.5-45	5.00	0.05	0.68	0.09	0.04	5.86
mean	5.00	0.06	0.59	0.09	0.11	5.85
std dev	3.75	0.05	0.13	0.03	0.13	4.05
COV	75%	86%	22%	30%	121%	69%

Appendix 1.2.13 Site E Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
E/3/3/0-7.5	20.00	0.72	11.09	2.08	0.15	34.04
E/3/4/0-7.5	17.50	0.57	15.38	3.27	0.22	36.94
E/3/5/0-7.5	36.25	0.47	30.65	3.57	0.10	71.03
mean	24.58	0.59	19.04	2.97	0.15	47.33
std dev	10.18	0.13	10.28	0.79	0.06	20.57
COV	41%	21%	54%	27%	40%	43%
E/3/3/7.5-15	23.75	0.12	4.51	0.62	0.11	29.11
E/3/4/7.5-15	23.75	0.15	3.89	0.49	0.06	28.34
E/3/5/7.5-15	35.00	0.07	13.05	0.85	0.14	49.10
mean	27.50	0.11	7.15	0.65	0.10	35.52
std dev	6.50	0.04	5.12	0.18	0.04	11.77
COV	24%	39%	72%	28%	41%	33%
E/3/3/15-22.5	20.00	0.08	1.91	0.25	0.08	22.32
E/3/4/15-22.5	25.00	0.12	1.33	0.17	0.03	26.64
E/3/5/15-22.5	35.00	0.05	4.83	0.27	0.20	40.34
mean	26.67	0.08	2.69	0.23	0.10	29.77
std dev	7.64	0.04	1.88	0.05	0.09	9.41
COV	29%	45%	70%	24%	83%	32%
E/3/3/22.5-30	25.00	0.09	1.31	0.16	0.07	26.62
E/3/4/22.5-30	23.75	0.05	0.69	0.08	0.00	24.56
E/3/5/22.5-30	25.00	0.06	2.05	0.10	0.01	27.23
mean	24.58	0.06	1.35	0.11	0.03	26.14
std dev	0.72	0.02	0.68	0.04	0.04	1.40
COV	3%	30%	50%	35%	141%	5%
E/3/3/30-37.5	21.25	0.09	0.93	0.07	0.14	22.49
E/3/4/30-37.5	23.75	0.03	0.70	0.06	-0.02	24.52
E/3/5/30-37.5	16.25	0.04	1.11	0.03	-0.01	17.41
mean	20.42	0.05	0.91	0.05	0.04	21.47
std dev	3.82	0.03	0.20	0.02	0.09	3.66
COV	19%	62%	22%	44%	235%	17%
E/3/3/37.5-45	17.50	0.11	0.65	0.02	0.25	18.53
E/3/4/37.5-45	12.50	0.00	0.29	0.00	-0.04	12.76
E/3/5/37.5-45	10.00	0.04	0.67	0.00	-0.03	10.67
mean	13.33	0.05	0.53	0.01	0.06	13.98
std dev	3.82	0.06	0.21	0.01	0.16	4.07
COV	29%	115%	39%	173%	275%	29%

Appendix 1.2.14 Site F Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
F/2/1/0-7.5	6.25	1.40	14.96	3.26	0.21	26.09
F/2/2/0-7.5	5.00	0.46	15.64	2.24	0.24	23.58
F/2/3/0-7.5	10.00	1.07	14.33	1.88	0.16	27.44
F/2/4/0-7.5	10.00	2.76	13.57	2.01	0.06	28.40
F/2/5/0-7.5	3.75	2.29	15.08	2.93	0.09	24.14
mean	7.00	1.60	14.71	2.46	0.15	25.93
std dev	2.88	0.93	0.79	0.60	0.08	2.07
COV	41%	58%	5%	24%	50%	8%
F/2/1/7.5-15	5.00	0.67	11.58	1.83	0.22	19.29
F/2/2/7.5-15	6.25	0.10	10.57	1.10	0.09	18.11
F/2/3/7.5-15	8.75	0.39	11.18	1.48	0.13	21.93
F/2/4/7.5-15	11.25	2.06	8.94	1.00	0.05	23.31
F/2/5/7.5-15	3.75	2.17	11.24	2.11	0.09	19.36
mean	7.00	1.08	10.70	1.50	0.12	20.40
std dev	3.01	0.97	1.05	0.47	0.06	2.14
COV	43%	90%	10%	31%	54%	10%
F/2/1/15-22.5	6.25	0.21	9.38	1.33	0.19	17.36
F/2/2/15-22.5	6.25	0.09	8.90	0.75	0.14	16.14
F/2/3/15-22.5	7.50	0.37	6.18	0.82	0.10	14.98
F/2/4/15-22.5	10.00	1.59	5.17	0.72	0.05	17.53
F/2/5/15-22.5	2.50	1.75	9.12	1.89	0.09	15.35
mean	6.50	0.80	7.75	1.10	0.12	16.27
std dev	2.71	0.80	1.93	0.51	0.05	1.15
COV	42%	99%	25%	46%	45%	7%
F/2/1/22.5-30	5.00	0.09	7.39	1.24	0.14	13.87
F/2/2/22.5-30	6.25	0.08	7.86	0.69	0.15	15.03
F/2/3/22.5-30	7.50	0.27	4.78	0.62	0.16	13.32
F/2/4/22.5-30	7.50	1.31	3.45	0.59	0.07	12.92
F/2/5/22.5-30	3.75	1.18	7.36	1.73	0.10	14.12
mean	6.00	0.59	6.17	0.97	0.12	13.85
std dev	1.63	0.61	1.94	0.50	0.04	0.81
COV	27%	103%	32%	51%	30%	6%
F/2/1/30-37.5	3.75	0.08	6.83	1.18	0.10	11.93
F/2/2/30-37.5	3.75	0.06	7.35	0.74	0.05	11.95
F/2/3/30-37.5	3.75	0.07	5.03	0.73	0.20	9.78
F/2/4/30-37.5	7.50	0.97	3.62	0.66	0.07	12.82
F/2/5/30-37.5	3.75	0.79	6.11	1.46	0.11	12.21
mean	4.50	0.39	5.79	0.95	0.11	11.74
std dev	1.68	0.45	1.49	0.35	0.06	1.15
COV	37%	113%	26%	37%	54%	10%
F/2/1/37.5-45	3.75	0.14	7.37	1.31	0.10	12.66
F/2/2/37.5-45	5.00	0.05	6.34	0.87	0.03	12.30
F/2/3/37.5-45	3.75	0.04	5.15	0.68	0.16	9.79
F/2/4/37.5-45	6.25	0.79	4.83	0.89	0.07	12.82
F/2/5/37.5-45	3.75	0.60	5.94	1.31	0.10	11.70
mean	4.50	0.32	5.93	1.01	0.09	11.85
std dev	1.12	0.35	1.01	0.28	0.05	1.23
COV	25%	107%	17%	28%	51%	10%

Appendix 1.2.15 Site F Non-Effluent Paddock

Sample	meq H/100g	meq K/100g	meq Ca/100g	meq Mg/100g	meq Na/100g	meq CEC/100g
F/1/1/0-7.5	7.50	0.42	23.79	3.06	0.20	34.97
F/1/2/0-7.5	8.75	0.34	18.13	1.46	0.14	28.82
F/1/3/0-7.5	7.50	0.65	19.07	1.60	0.11	28.93
F/1/4/0-7.5	5.00	1.39	16.68	1.01	0.10	24.18
F/1/5/0-7.5	6.25	1.56	17.70	2.18	0.12	27.80
mean	7.00	0.87	19.08	1.86	0.13	28.94
std dev	1.43	0.56	2.77	0.79	0.04	3.88
COV	20%	65%	15%	42%	29%	13%
F/1/1/7.5-15	10.00	0.14	13.90	1.57	0.10	25.71
F/1/2/7.5-15	12.50	0.15	6.71	0.61	0.07	20.04
F/1/3/7.5-15	10.00	0.42	8.43	0.83	0.08	19.77
F/1/4/7.5-15	8.75	0.65	7.50	0.53	0.07	17.50
F/1/5/7.5-15	8.75	1.42	8.11	1.20	0.09	19.56
mean	10.00	0.56	8.93	0.95	0.08	20.52
std dev	1.53	0.53	2.86	0.43	0.01	3.07
COV	15%	95%	32%	46%	14%	15%
F/1/1/15-22.5	10.00	0.07	10.14	0.66	0.09	20.96
F/1/2/15-22.5	6.25	0.43	6.16	0.57	0.10	13.51
F/1/3/15-22.5	6.25	0.46	5.21	0.50	0.08	12.51
F/1/4/15-22.5	5.00	0.45	5.71	0.39	0.10	11.65
F/1/5/15-22.5	7.50	1.30	4.31	0.56	0.09	13.75
mean	7.00	0.54	6.30	0.54	0.09	14.48
std dev	1.90	0.45	2.25	0.10	0.01	3.72
COV	27%	84%	36%	19%	10%	26%
F/1/1/22.5-30	7.50	0.04	6.55	0.25	0.09	14.43
F/1/2/22.5-30	5.00	0.32	6.71	0.76	0.23	13.03
F/1/3/22.5-30	5.00	0.45	5.90	0.63	0.10	12.09
F/1/4/22.5-30	6.25	0.46	6.24	0.47	0.08	13.50
F/1/5/22.5-30	3.75	1.27	3.94	0.52	0.10	9.59
mean	5.50	0.51	5.87	0.53	0.12	12.53
std dev	1.43	0.46	1.12	0.19	0.06	1.85
COV	26%	90%	19%	36%	53%	15%
F/1/1/30-37.5	5.00	0.05	7.74	0.29	0.11	13.18
F/1/2/30-37.5	5.00	0.16	6.44	0.95	0.32	12.88
F/1/3/30-37.5	3.75	0.35	6.66	0.88	0.15	11.79
F/1/4/30-37.5	5.00	0.36	8.01	0.79	0.10	14.27
F/1/5/30-37.5	5.00	1.17	5.04	0.72	0.12	12.05
mean	4.75	0.42	6.78	0.73	0.16	12.83
std dev	0.56	0.44	1.18	0.26	0.09	0.99
COV	12%	105%	17%	36%	59%	8%
F/1/1/37.5-45	6.25	0.06	7.46	0.50	0.11	14.38
F/1/2/37.5-45	5.00	0.13	6.80	1.16	0.34	13.42
F/1/3/37.5-45	2.50	0.20	7.69	1.20	0.23	11.82
F/1/4/37.5-45	5.00	0.18	8.38	1.51	0.19	15.25
F/1/5/37.5-45	2.50	0.91	6.73	1.13	0.16	11.44
mean	4.25	0.29	7.41	1.10	0.21	13.26
std dev	1.68	0.35	0.68	0.37	0.09	1.63
COV	39%	119%	9%	33%	43%	12%

Appendix 1.3 Total Nitrogen and Phosphorus

This data shows the raw results of the total nitrogen (N) and phosphorus (P) analysis as described in Chapter 3, the mean, standard deviation and the coefficient of variation (CV) found is also shown.

Appendix 1.3.1 Site A Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
A/1/1	0-7.5	6.20	2.01
A/1/1	0-7.5	6.55	2.96
A/1/2	0-7.5	5.10	1.75
A/1/4	0-7.5	6.97	2.20
mean		6.21	2.23
std dev		0.80	0.52
CV		13%	23%
A/1/1	7.5-15	5.23	2.00
A/1/1	7.5-15	5.29	1.57
A/1/1	7.5-15	5.45	1.63
A/1/2	7.5-15	4.09	1.42
A/1/4	7.5-15	5.52	2.00
mean		5.12	1.72
std dev		0.59	0.27
CV		11%	15%
A/1/1	15-22.5	3.26	0.80
A/1/1	15-22.5	3.61	1.02
A/1/2	15-22.5	2.61	0.73
A/1/4	15-22.5	3.95	1.71
A/1/4	15-22.5	3.84	1.36
mean		3.45	1.12
std dev		0.54	0.41
CV		16%	36%
A/1/1	22.5-30	1.81	0.44
A/1/1	22.5-30	2.00	0.62
A/1/2	22.5-30	1.60	0.50
A/1/4	22.5-30	2.61	0.71
mean		2.01	0.57
std dev		0.44	0.12
CV		22%	22%
A/1/1	30-37.5	1.18	0.32
A/1/1	30-37.5	1.35	0.49
A/1/2	30-37.5	1.08	0.35
A/1/4	30-37.5	1.27	0.34
mean		1.22	0.37
std dev		0.12	0.08
CV		10%	21%
A/1/1	37.5-45	0.63	0.17
A/1/1	37.5-45	0.64	0.18
A/1/1	37.5-45	0.70	0.33
A/1/2	37.5-45	0.64	0.20
A/1/4	37.5-45	0.60	0.21
mean		0.64	0.22
std dev		0.03	0.06
CV		5%	29%

Appendix 1.3.2 Site A Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
A/2/3	0-7.5	6.69	2.43
A/2/3	0-7.5	6.82	2.45
A/2/4	0-7.5	7.04	2.50
A/2/5	0-7.5	6.99	2.31
mean		6.89	2.42
std dev		0.16	0.08
CV		2%	3%
A/2/3	7.5-15	4.80	1.66
A/2/4	7.5-15	5.10	1.70
A/2/5	7.5-15	4.86	1.71
mean		4.92	1.69
std dev		0.16	0.03
CV		3%	2%
A/2/3	15-22.5	3.03	1.11
A/2/4	15-22.5	3.69	1.13
A/2/5	15-22.5	2.75	0.80
mean		3.15	1.01
std dev		0.48	0.19
CV		15%	18%
A/2/3	22.5-30	1.19	0.54
A/2/4	22.5-30	2.31	0.70
A/2/5	22.5-30	1.56	0.48
mean		1.69	0.57
std dev		0.57	0.11
CV		34%	20%
A/2/3	30-37.5	0.74	0.29
A/2/4	30-37.5	1.21	0.44
A/2/5	30-37.5	1.14	0.37
mean		1.03	0.36
std dev		0.26	0.08
CV		25%	21%
A/2/3	37.5-45	0.45	0.18
A/2/4	37.5-45	0.89	0.42
A/2/5	37.5-45	0.83	0.30
mean		0.72	0.30
std dev		0.24	0.12
CV		33%	40%

Appendix 1.3.3 Site B Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
B/1/2	0-7.5	10.14	2.68
B/1/3	0-7.5	6.22	1.49
B/1/4	0-7.5	5.86	2.36
B/1/4	0-7.5	5.41	2.26
mean		6.91	2.20
std dev		2.18	0.50
CV		32%	23%
B/1/2	7.5-15	5.47	1.29
B/1/3	7.5-15	5.36	1.07
B/1/4	7.5-15	5.62	2.15
B/1/4	7.5-15	5.35	1.97
mean		5.45	1.62
std dev		0.13	0.52
CV		2%	32%
B/1/2	15-22.5	2.13	0.40
B/1/3	15-22.5	2.61	0.36
B/1/4	15-22.5	2.34	0.54
B/1/4	15-22.5	2.19	0.38
mean		2.32	0.42
std dev		0.21	0.08
CV		9%	20%
B/1/2	22.5-30	1.62	0.32
B/1/3	22.5-30	2.11	0.28
B/1/4	22.5-30	0.79	0.24
B/1/4	22.5-30	0.71	0.10
mean		1.31	0.23
std dev		0.68	0.10
CV		52%	41%
B/1/2	30-37.5	1.29	0.28
B/1/3	30-37.5	0.80	0.10
B/1/4	30-37.5	0.55	0.34
B/1/4	30-37.5	0.49	0.12
mean		0.78	0.21
std dev		0.36	0.12
CV		46%	55%
B/1/2	37.5-45	0.71	0.24
B/1/3	37.5-45	0.38	0.05
B/1/4	37.5-45	0.49	0.62
B/1/4	37.5-45	0.37	0.24
mean		0.49	0.29
std dev		0.16	0.24
CV		33%	82%

Appendix 1.3.4 Site B Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
B/2/2	0-7.5	4.48	1.18
B/2/3	0-7.5	5.14	1.55
B/2/3	0-7.5	5.29	1.36
B/2/5	0-7.5	4.28	0.91
mean		4.80	1.25
std dev		0.49	0.27
CV		10%	22%
B/2/2	7.5-15	2.23	0.44
B/2/3	7.5-15	3.40	0.63
B/2/5	7.5-15	2.21	0.43
mean		2.61	0.50
std dev		0.68	0.11
CV		26%	22%
B/2/2	15-22.5	1.75	0.28
B/2/2	15-22.5	1.72	0.27
B/2/3	15-22.5	1.68	0.26
B/2/5	15-22.5	1.37	0.20
mean		1.63	0.25
std dev		0.18	0.03
CV		11%	14%
B/2/2	22.5-30	0.76	0.10
B/2/2	22.5-30	0.78	0.10
B/2/3	22.5-30	0.74	0.10
B/2/5	22.5-30	0.66	0.08
mean		0.73	0.10
std dev		0.05	0.01
CV		7%	12%
B/2/2	30-37.5	0.74	0.12
B/2/3	30-37.5	0.62	0.09
B/2/5	30-37.5	0.61	0.07
mean		0.65	0.09
std dev		0.07	0.02
CV		11%	23%
B/2/2	37.5-45	0.71	0.14
B/2/3	37.5-45	0.65	0.10
B/2/5	37.5-45	0.73	0.15
B/2/5	37.5-45	0.63	0.15
mean		0.68	0.14
std dev		0.05	0.02
CV		7%	18%

Appendix 1.3.5 Site C Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
C/1/2	0-7.5	5.71	1.68
C/1/4	0-7.5	7.16	1.82
C/1/5	0-7.5	8.68	2.14
mean		7.18	1.88
std dev		1.48	0.23
CV		21%	12%
C/1/2	7.5-15	3.83	0.87
C/1/4	7.5-15	5.02	1.15
C/1/5	7.5-15	3.59	0.64
mean		4.15	0.89
std dev		0.77	0.26
CV		19%	29%
C/1/2	15-22.5	4.08	0.67
C/1/4	15-22.5	2.15	0.30
C/1/5	15-22.5	2.75	0.64
mean		2.99	0.54
std dev		0.99	0.20
CV		33%	38%
C/1/2	22.5-30	3.20	0.50
C/1/4	22.5-30	0.83	0.16
C/1/5	22.5-30	2.91	0.35
mean		2.32	0.34
std dev		1.30	0.17
CV		56%	50%
C/1/2	30-37.5	2.37	0.38
C/1/4	30-37.5	0.38	0.10
C/1/4	30-37.5	0.36	0.10
C/1/5	30-37.5	2.54	0.39
mean		1.41	0.24
std dev		1.21	0.17
CV		85%	69%
C/1/2	37.5-45	1.33	0.30
C/1/4	37.5-45	0.42	0.12
C/1/4	37.5-45	0.43	0.11
C/1/5	37.5-45	1.62	0.30
mean		0.95	0.21
std dev		0.61	0.11
CV		65%	52%

Appendix 1.3.6 Site C Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
C/2/2	0-7.5	7.53	2.55
C/2/3	0-7.5	6.56	2.73
C/2/3	0-7.5	7.04	2.75
C/2/4	0-7.5	8.09	3.04
C/2/4	0-7.5	7.62	0.49
mean		7.37	2.31
std dev		0.59	1.03
CV		8%	45%
C/2/2	7.5-15	4.63	1.08
C/2/3	7.5-15	4.18	1.33
C/2/3	7.5-15	4.50	1.30
C/2/4	7.5-15	4.56	1.03
C/2/4	7.5-15	4.60	1.02
mean		4.49	1.15
std dev		0.18	0.15
CV		4%	13%
C/2/2	15-22.5	2.19	0.40
C/2/3	15-22.5	3.46	0.66
C/2/3	15-22.5	3.77	0.72
C/2/4	15-22.5	2.89	0.42
C/2/4	15-22.5	2.82	0.41
mean		3.03	0.52
std dev		0.61	0.15
CV		20%	29%
C/2/2	22.5-30	0.86	0.20
C/2/3	22.5-30	2.69	0.36
C/2/3	22.5-30	3.16	0.49
C/2/3	22.5-30	3.10	0.49
C/2/4	22.5-30	1.54	0.25
mean		2.27	0.36
std dev		1.02	0.13
CV		45%	37%
C/2/2	30-37.5	0.75	0.19
C/2/3	30-37.5	1.83	0.36
C/2/4	30-37.5	0.81	0.18
mean		1.13	0.24
std dev		0.61	0.10
CV		54%	40%
C/2/2	37.5-45	0.59	0.16
C/2/3	37.5-45	0.63	0.16
C/2/4	37.5-45	0.70	0.17
mean		0.64	0.16
std dev		0.06	0.00
CV		9%	3%

Appendix 1.3.7 Site D (sand) Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
D/4/1	0-7.5	5.97	1.63
D/4/4	0-7.5	5.59	1.67
D/4/5	0-7.5	4.93	1.42
mean		5.49	1.57
std dev		0.53	0.13
CV		10%	8%
D/4/1	7.5-15	2.31	1.08
D/4/4	7.5-15	2.35	0.96
D/4/5	7.5-15	1.95	0.74
mean		2.20	0.93
std dev		0.22	0.17
CV		10%	18%
D/4/1	15-22.5	1.54	0.69
D/4/4	15-22.5	1.25	0.44
D/4/5	15-22.5	1.28	0.55
mean		1.36	0.56
std dev		0.16	0.13
CV		12%	22%
D/4/1	22.5-30	0.76	0.33
D/4/4	22.5-30	0.49	0.25
D/4/5	22.5-30	0.50	0.25
mean		0.59	0.28
std dev		0.15	0.04
CV		25%	16%
D/4/1	30-37.5	0.40	0.24
D/4/4	30-37.5	0.33	0.23
D/4/5	30-37.5	0.35	0.23
mean		0.36	0.23
std dev		0.04	0.01
CV		10%	3%
D/4/1	37.5-45	0.16	0.20
D/4/4	37.5-45	0.23	0.28
D/4/5	37.5-45	0.18	0.21
mean		0.19	0.23
std dev		0.04	0.05
CV		19%	20%

Appendix 1.3.8 Site D (sand) Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
D/1/3	0-7.5	3.24	1.37
D/1/4	0-7.5	3.45	1.59
D/1/4	0-7.5	3.48	1.62
D/1/5	0-7.5	3.48	1.21
mean		3.41	1.45
std dev		0.11	0.20
CV		3%	14%
D/1/3	7.5-15	2.02	1.02
D/1/4	7.5-15	2.65	1.24
D/1/5	7.5-15	1.38	0.57
mean		2.02	0.94
std dev		0.63	0.34
CV		31%	36%
D/1/3	15-22.5	1.54	0.73
D/1/4	15-22.5	1.69	0.69
D/1/5	15-22.5	1.66	0.54
mean		1.63	0.65
std dev		0.08	0.10
CV		5%	15%
D/1/3	22.5-30	0.44	0.27
D/1/4	22.5-30	0.51	0.29
D/1/5	22.5-30	0.59	0.48
D/1/5	22.5-30	0.57	0.46
mean		0.53	0.38
std dev		0.07	0.11
CV		12%	29%
D/1/3	30-37.5	0.41	0.27
D/1/4	30-37.5	0.36	0.22
D/1/5	30-37.5	0.69	0.48
mean		0.49	0.33
std dev		0.18	0.14
CV		36%	41%
D/1/3	37.5-45	0.30	0.24
D/1/3	37.5-45	0.30	0.24
D/1/4	37.5-45	0.17	0.19
D/1/5	37.5-45	0.40	0.26
mean		0.29	0.23
std dev		0.09	0.03
CV		33%	12%

Appendix 1.3.9 Site D (mud) Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
D/2/1	0-7.5	4.90	1.57
D/2/3	0-7.5	5.20	1.40
D/2/4	0-7.5	4.69	1.45
mean		4.93	1.48
std dev		0.26	0.09
CV		5%	6%
D/2/1	7.5-15	2.97	0.91
D/2/1	7.5-15	3.06	0.95
D/2/3	7.5-15	3.19	1.00
D/2/4	7.5-15	2.95	0.89
mean		3.04	0.94
std dev		0.11	0.05
CV		4%	5%
D/2/1	15-22.5	2.37	0.61
D/2/3	15-22.5	2.72	0.71
D/2/4	15-22.5	2.37	0.60
mean		2.49	0.64
std dev		0.20	0.06
CV		8%	9%
D/2/1	22.5-30	2.21	0.59
D/2/3	22.5-30	2.52	0.65
D/2/3	22.5-30	2.51	0.64
D/2/4	22.5-30	2.03	0.52
mean		2.32	0.60
std dev		0.24	0.06
CV		10%	10%

Appendix 1.3.10 Site D (mud) Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
D/3/2	0-7.5	4.10	1.28
D/3/3	0-7.5	4.68	1.32
D/3/4	0-7.5	4.78	1.35
mean		4.52	1.32
std dev		0.37	0.04
CV		8%	3%
D/3/2	7.5-15	3.33	1.17
D/3/3	7.5-15	3.79	1.10
D/3/4	7.5-15	3.53	1.00
mean		3.55	1.09
std dev		0.23	0.09
CV		7%	8%
D/3/2	15-22.5	2.11	0.59
D/3/3	15-22.5	2.75	0.66
D/3/4	15-22.5	2.94	0.75
mean		2.60	0.67
std dev		0.44	0.08
CV		17%	11%
D/3/2	22.5-30	1.86	0.47
D/3/3	22.5-30	1.99	0.49
D/3/4	22.5-30	1.72	0.44
mean		1.86	0.47
std dev		0.14	0.02
CV		7%	5%

Appendix 1.3.11 Site E Long-Term Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
E/1/3	0-7.5	8.22	2.43
E/1/4	0-7.5	9.00	2.87
E/1/5	0-7.5	9.90	3.25
mean		9.04	2.85
std dev		0.84	0.41
CV		9%	14%
E/1/3	7.5-15	3.70	0.55
E/1/4	7.5-15	6.19	1.49
E/1/5	7.5-15	5.72	1.48
mean		5.20	1.17
std dev		1.32	0.54
CV		25%	46%
E/1/3	15-22.5	3.63	0.45
E/1/4	15-22.5	4.39	0.61
E/1/5	15-22.5	3.57	0.59
mean		3.86	0.55
std dev		0.46	0.09
CV		12%	16%
E/1/3	22.5-30	3.33	0.45
E/1/4	22.5-30	2.76	0.47
E/1/5	22.5-30	2.82	0.46
mean		2.97	0.46
std dev		0.31	0.01
CV		10%	3%
E/1/3	30-37.5	2.81	0.43
E/1/4	30-37.5	2.06	0.39
E/1/5	30-37.5	1.82	0.32
mean		2.23	0.38
std dev		0.51	0.06
CV		23%	15%
E/1/3	37.5-45	1.67	0.29
E/1/4	37.5-45	1.43	0.28
E/1/5	37.5-45	1.63	0.28
mean		1.58	0.29
std dev		0.13	0.00
CV		8%	0%

Appendix 1.3.12 Site E Short-Term Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
E/2/1	0-7.5	7.92	2.57
E/2/2	0-7.5	6.90	2.34
E/2/2	0-7.5	7.00	2.32
E/2/3	0-7.5	8.70	2.69
mean		7.63	2.48
std dev		0.85	0.18
CV		11%	7%
E/2/1	7.5-15	5.18	1.45
E/2/2	7.5-15	4.74	1.38
E/2/2	7.5-15	4.78	1.37
E/2/3	7.5-15	5.39	1.51
mean		5.02	1.43
std dev		0.31	0.06
CV		6%	5%
E/2/1	15-22.5	4.15	1.00
E/2/2	15-22.5	2.57	0.43
E/2/3	15-22.5	4.95	0.79
mean		3.89	0.74
std dev		1.21	0.29
CV		31%	39%
E/2/1	22.5-30	2.66	0.52
E/2/2	22.5-30	2.19	0.40
E/2/3	22.5-30	2.92	0.46
mean		2.59	0.46
std dev		0.37	0.06
CV		14%	14%
E/2/1	30-37.5	1.88	0.35
E/2/2	30-37.5	2.62	0.40
E/2/3	30-37.5	2.11	0.38
E/2/3	30-37.5	2.14	0.38
mean		2.19	0.38
std dev		0.31	0.02
CV		14%	5%
E/2/1	37.5-45	1.41	0.28
E/2/2	37.5-45	2.12	0.34
E/2/3	37.5-45	1.83	0.34
mean		1.79	0.32
std dev		0.36	0.04
CV		20%	11%

Appendix 1.3.13 Site E Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
E/3/3	0-7.5	9.20	2.26
E/3/4	0-7.5	9.89	3.02
E/3/5	0-7.5	10.75	1.77
mean		9.95	2.35
std dev		0.77	0.63
CV		8%	27%
E/3/3	7.5-15	4.94	0.78
E/3/4	7.5-15	4.85	0.77
E/3/5	7.5-15	0.00	0.00
mean** only 2 samples		4.89	0.78
std dev		0.06	0.01
CV		1%	1%
E/3/3	15-22.5	3.54	0.56
E/3/4	15-22.5	4.15	0.61
E/3/5	15-22.5	3.68	0.90
E/3/5	15-22.5	3.79	0.91
mean		3.79	0.75
std dev		0.26	0.19
CV		7%	25%
E/3/3	22.5-30	3.09	0.49
E/3/4	22.5-30	3.85	0.64
E/3/5	22.5-30	3.12	0.56
mean		3.35	0.56
std dev		0.43	0.07
CV		13%	13%
E/3/3	30-37.5	2.77	0.43
E/3/4	30-37.5	3.67	0.54
E/3/5	30-37.5	2.01	0.38
mean		2.82	0.45
std dev		0.83	0.08
CV		29%	19%
E/3/3	37.5-45	2.39	0.42
E/3/4	37.5-45	1.53	0.28
E/3/5	37.5-45	0.98	0.21
mean		1.63	0.30
std dev		0.71	0.11
CV		43%	35%

Appendix 1.3.14 Site F Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
F/2/2	0-7.5	4.74	1.81
F/2/3	0-7.5	5.14	2.27
F/2/3	0-7.5	5.28	2.25
F/2/4	0-7.5	5.94	2.28
mean		5.28	2.15
std dev		0.50	0.23
CV		10%	11%
F/2/2	7.5-15	2.66	0.92
F/2/3	7.5-15	3.31	0.98
F/2/4	7.5-15	4.78	0.99
mean		3.58	0.96
std dev		1.09	0.04
CV		30%	4%
F/2/2	15-22.5	1.86	0.58
F/2/3	15-22.5	2.35	0.47
F/2/4	15-22.5	3.68	0.64
mean		2.63	0.56
std dev		0.94	0.08
CV		36%	15%
F/2/2	22.5-30	1.31	0.48
F/2/3	22.5-30	1.20	0.28
F/2/4	22.5-30	1.63	0.36
F/2/4	22.5-30	1.64	0.37
mean		1.45	0.37
std dev		0.23	0.09
CV		16%	23%
F/2/2	30-37.5	0.73	0.34
F/2/3	30-37.5	0.69	0.25
F/2/4	30-37.5	1.42	0.38
mean		0.95	0.32
std dev		0.41	0.07
CV		43%	21%
F/2/2	37.5-45	0.46	0.28
F/2/3	37.5-45	0.46	0.22
F/2/4	37.5-45	0.74	0.34
F/2/4	37.5-45	0.72	0.33
mean		0.60	0.30
std dev		0.16	0.06
CV		26%	19%

Appendix 1.3.15 Site F Non-Effluent Paddock

Sample	Depth (cm)	N in sample (mg/g)	P in sample (mg/g)
F/1/2	0-7.5	7.14	2.71
F/1/3	0-7.5	5.88	2.47
F/1/5	0-7.5	5.78	3.09
mean		6.27	2.76
std dev		0.76	0.31
CV		12%	11%
F/1/2	7.5-15	5.59	1.50
F/1/3	7.5-15	3.02	0.99
F/1/5	7.5-15	3.26	1.35
F/1/5	7.5-15	3.23	1.43
mean		3.77	1.31
std dev		1.22	0.23
CV		32%	17%
F/1/2	15-22.5	2.43	0.59
F/1/3	15-22.5	1.07	0.35
F/1/5	15-22.5	1.72	0.47
mean		1.74	0.47
std dev		0.68	0.12
CV		39%	26%
F/1/2	22.5-30	0.92	0.32
F/1/3	22.5-30	0.65	0.29
F/1/5	22.5-30	0.76	0.23
mean		0.78	0.28
std dev		0.13	0.05
CV		17%	16%
F/1/2	30-37.5	0.68	0.31
F/1/3	30-37.5	0.61	0.29
F/1/5	30-37.5	0.63	0.25
mean		0.64	0.28
std dev		0.04	0.03
CV		6%	11%
F/1/2	37.5-45	0.58	0.28
F/1/3	37.5-45	0.59	0.31
F/1/5	37.5-45	0.00	0.00
mean ** only 2 samples		0.59	0.29
std dev		0.01	0.02
CV		2%	8%

APPENDIX TWO: Site A Nutrient History

The fertiliser records and soil test results for the past 12 years was obtained for site A and entered into OVERSEER® Nutrient Budgets 2 to obtain annual nutrient budgets.

Appendix 2.1 Fertiliser Records from 1993 – 2003 for Site A

Year	Autumn Fertiliser	Rate (kg ha ⁻¹)	Spring Fertiliser	Rate (kg ha ⁻¹)	Lime (t ha ⁻¹)
1993	Super	300	KCl	100	3
1994	MagPhos	350	KCl	100	
1995	MagPhos	350	KCl	100	
1996	MagPhos	500	KCl	100	
1997	MagPhos	500	S-super	100	
1998	Super	500	KCl	50	
1999	Super	500	KCl	50	
2000	MagPhos	550	KCl	50	
2001	MagPhos	600	KCl	100	
2002	Super	625	MgO	50	
2003	Super	575	MgO	50	

Appendix 2.2 Site A Effluent Paddock Soil Test Results

Soil samples were collected from the same paddock in spring each year from 1990, excepting 2001 and 2003, where data was missing. The K, Ca and Mg results are measured in MAF QT units.

Year	pH	Olsen P	S	K	Ca	Mg
1990	5.8	26	14	17	8	23
1991	5.9	33	18	13	7	21
1992	5.8	38	20	11	7	17
1993	6.0	43	17	11	9	22
1994	6.3	41	8	14	11	23
1995	6.1	47	13	12	8	18
1996	6.1	33	6	12	10	19
1997	6.0	49	21	20	8	25
1998	5.7	58	13	21	8	25
1999	5.6	39	31	12	7	15
2000	5.7	37	42	16	6	10
2002	5.8	42	24	19	8	28
2004		34		40	15	38

Appendix 2.3 Site A Non-Effluent Paddock Soil Test Results

Year	pH	Olsen P	S	K	Ca	Mg
1990	5.8	40	10	20	8	25
1991	5.9	42	19	24	8	29
1992	5.8	56	11	16	6	17
1993	6.0	37	10	12	9	16
1994	6.3	38	12	15	10	21
1995	6.1	46	10	19	10	22
1996	6.1	45	9	15	10	20
1997	6.0	47	17	22	11	28
1998	5.7	46	29	29	7	17
1999	5.6	30	34	7	6	11
2000	5.7	30	25	8	6	11
2002	5.8	27	43	13	7	19
2004		30		14	19	40

Appendix 2.4 Annual Nutrient Budget Summaries

Annual nutrient budgets for site A were prepared using OVERSEER[®] Nutrient Budgets 2 and the fertiliser and soil test history detailed in Appendices 2.1-2.3. From the individual nutrient budgets, a summary of selected nutrients (phosphorus, potassium, calcium and magnesium) was made in order to track the accumulation of nutrients in the soil over time. Since the nutrient history provided by the farmer started at 1993 and irrigation of farm dairy effluent began in 1985, the nutrient budgets for intervening years were calculated using the 1993 data. These annual values were then summed together and are presented in the following table under 1985-1993.

Appendix 2.4.1 Summary of Phosphorus Data from OVERSEER® Nutrient Budgets 2

EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Olsen P result		38	43	41	47	33	49	58	39	37	37	42	34
INPUTS													
fertiliser	232	29	30	30	44	53	49	49	48	52	61	56	19
effluent	208	26	25	25	26	25	26	26	24	24	24	23	23
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	24	3	3	3	3	3	3	3	3	3	3	3	3
supplements	32	4	4	4	4	4	4	4	4	4	4	4	4
OUTPUTS													
product	120	15	15	15	15	15	15	15	15	15	15	15	15
transfer	48	6	6	6	6	6	6	6	6	6	6	6	6
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	0	0	0	0	0	0	0	0	0	0	0	0	0
immobilisation	256	32	36	34	39	30	40	46	34	33	33	36	29
change inorg pool	64	8	4	6	16	34	20	14	23	28	37	29	-1

Appendix 2.4.1 cont'd

NON-EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Olsen P results		56	37	38	46	45	47	46	30	30	30	27	30
INPUTS													
fertiliser	232	29	30	30	44	53	49	49	48	52	61	56	19
effluent	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	24	3	3	3	3	3	3	3	3	3	3	3	3
supplements	32	4	4	4	4	4	4	4	4	4	4	4	4
OUTPUTS													
product	120	15	15	15	15	15	15	15	15	15	15	15	15
transfer	48	6	6	6	6	6	6	6	6	6	6	6	6
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	0	0	0	0	0	0	0	0	0	0	0	0	0
immobilisation	344	43	31	31	37	37	38	37	27	27	27	25	25
change inorg pool	-224	-28	-15	-16	-8	1	-4	-3	7	11	19	17	-20

Appendix 2.4.2 Summary of Potassium Data from OVERSEER[®] Nutrient Budgets 2

EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Soil QT result		11	11	14	12	12	20	21	12	16	16	19	40
INPUTS													
fertiliser	400	50	50	50	50	0	25	25	25	50	0	0	0
effluent	1784	223	216	222	226	218	228	231	193	204	194	215	219
atmosphere	16	2	2	2	2	2	2	2	2	2	2	2	2
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	24	3	4	3	3	4	3	4	4	3	4	4	10
supplements	144	18	18	18	18	18	18	18	18	18	18	18	18
OUTPUTS													
product	152	19	19	19	19	19	19	19	19	19	19	19	19
transfer	440	55	55	55	55	54	56	56	55	56	55	56	56
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	560	70	69	85	75	66	115	122	66	92	82	102	259
immobilisation	0	0	0	0	0	0	0	0	0	0	0	0	0
change inorg pool	1232	154	148	137	151	104	87	83	103	111	63	63	-84

Appendix 2.4.2 cont'd

NON-EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Soil QT result		16	12	15	19	15	22	29	7	8	8	13	14
INPUTS													
fertiliser	400	50	50	50	50	0	25	25	25	50	0	0	19
effluent	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	16	2	2	2	2	2	2	2	2	2	2	2	2
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	120	15	18	16	14	17	13	11	24	22	24	18	17
supplements	144	18	18	18	18	18	18	18	18	18	18	18	18
OUTPUTS													
product	152	19	19	19	19	19	19	19	19	19	19	19	19
transfer	432	54	52	53	55	52	55	56	45	48	45	51	52
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	464	58	41	53	72	46	83	124	20	26	21	38	45
immobilisation	0	0	0	0	0	0	0	0	0	0	0	0	0
change inorg pool	-360	-45	-23	-40	-61	-81	-99	-142	-14	-1	-40	-70	-60

Appendix 2.4.3 Summary of Calcium Data from OVERSEER® Nutrient Budgets 2

EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Soil QT result		7	9	11	8	10	8	8	7	6	6	8	15
INPUTS													
fertiliser	528	734	70	70	100	120	110	110	110	120	138	127	44
effluent	232	29	33	35	34	35	35	31	29	29	29	31	43
atmosphere	16	2	2	2	2	2	2	2	2	2	2	2	2
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	16	2	2	2	2	2	2	2	2	2	2	2	2
supplements	88	11	11	11	11	11	11	11	11	11	11	11	11
OUTPUTS													
product	176	22	22	22	22	22	22	22	22	22	22	22	22
transfer	56	7	8	9	8	8	8	8	7	7	7	8	10
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	680	85	95	114	93	106	100	101	90	99	99	97	163
immobilisation	0	0	0	0	0	0	0	0	0	0	0	0	0
change inorg pool	-32	664	-6	-24	27	34	31	25	36	37	55	47	-93

Appendix 2.4.3 cont'd

NON-EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Soil QT result		6	9	10	10	10	11	7	6	6	6	7	19
INPUTS													
fertiliser	528	734	70	70	100	120	110	110	110	120	138	127	42
effluent	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	16	2	2	2	2	2	2	2	2	2	2	2	2
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	16	2	2	2	2	2	2	2	2	2	2	2	2
supplements	88	11	11	11	11	11	11	11	11	11	11	11	11
OUTPUTS													
product	176	22	22	22	22	22	22	22	22	22	22	22	22
transfer	56	7	8	8	8	8	9	7	7	7	7	7	10
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	624	78	92	100	105	101	111	102	65	68	68	77	156
immobilisation	0	0	0	0	0	0	0	0	0	0	0	0	0
change inorg pool	-208	642	-36	-45	-20	5	-17	-6	31	38	56	36	-131

Appendix 2.4.4 Summary of Magnesium Data from OVERSEER[®] Nutrient Budgets 2

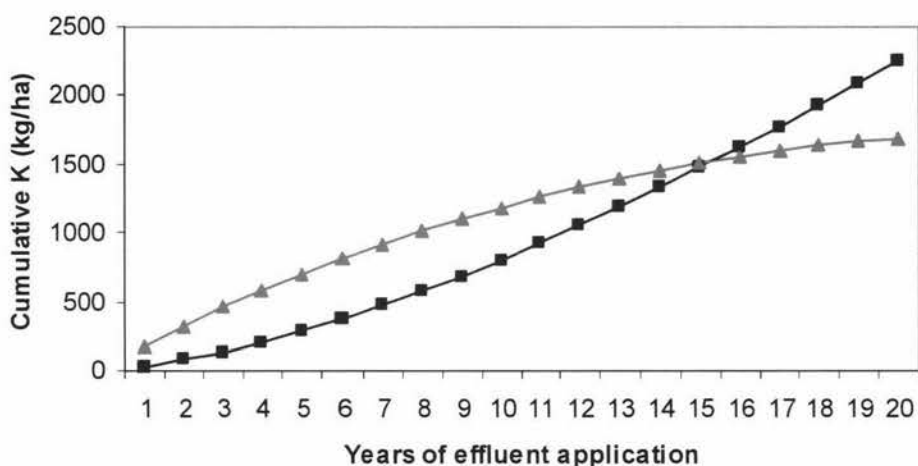
EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Soil QT result		17	22	23	18	19	25	25	15	10	10	28	38
INPUTS													
fertiliser	56	7	19	19	27	27	0	0	30	32	26	26	51
effluent	192	24	25	26	26	27	27	24	24	23	24	27	30
atmosphere	40	5	5	5	5	5	5	5	5	5	5	5	5
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	16	2	2	2	2	2	2	2	2	2	2	2	2
supplements	152	19	19	19	19	19	19	19	19	19	19	19	19
OUTPUTS													
product	16	2	2	2	2	2	2	2	2	2	2	2	2
transfer	48	6	6	7	6	7	7	7	6	6	6	7	7
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	248	31	29	31	31	32	32	32	33	38	38	30	34
immobilisation	0	0	0	0	0	0	0	0	0	0	0	0	0
change inorg pool	88	18	32	31	39	39	13	10	39	36	30	40	63

Appendix 2.4.4 cont'd

NON-EFFLUENT	1985-1993	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Soil QT result		17	16	21	22	20	28	17	11	11	11	19	40
INPUTS													
fertiliser	56	7	19	19	27	27	0	0	30	32	26	26	52
effluent	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	40	5	5	5	5	5	5	5	5	5	5	5	5
irrigation	0	0	0	0	0	0	0	0	0	0	0	0	0
slow release	16	2	2	2	2	2	2	2	2	2	2	2	2
supplements	152	19	19	19	19	19	19	19	19	19	19	19	19
OUTPUTS													
product	16	2	2	2	2	2	2	2	2	2	2	2	2
transfer	48	6	6	6	6	6	6	6	6	6	6	6	7
supp removed	0	0	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0
leaching	264	33	33	32	33	33	32	38	32	33	33	31	28
immobilisation	0	0	0	0	0	0	0	0	0	0	0	0	0
change inorg pool	-120	-8	4	5	11	12	-15	-19	16	18	11	13	40

Appendix 2.5 Accumulation of Potassium at Site A

This figure was calculated in the same manner as those in Figure 5.7, where the non-effluent QT result for K was used as a starting point in OVERSEER[®] for the effluent paddock. The predicted increase or decrease was recorded and the corrected QT result entered, giving a new nutrient budget. This was iterated for 20 years of effluent application. The site A graph presented in Figure 5.7 was calculated from the annual nutrient budgets produced using the provided nutrient history.



(Cumulative leaching ■ , accumulation in the inorganic pool ▲)

APPENDIX THREE: **OVERSEER[®] Input Parameters**

Appendix 3.1 User-Defined General Information

The general farm information required by OVERSEER[®] Nutrient Budgets 2 (v.5.0.14.0) and the responses of each farm studied is detailed in the following table.

Appendix 3.2 Effluent Block Input Variables

The details of the effluent paddocks studied are shown. OVERSEER[®] calculates separate nutrient budgets and recommendations for each block of farm, as specified in the general information.

Appendix 3.3 Non-Effluent Block Input Variables

The information required by OVERSEER[®] for the rest of the farm.

Appendix 3.1 User-Defined General Information

Parameter	Site A	Site B	Site C	Site D (sand)	Site D (mud)	Site E	Site F
Region	Waikato	Waikato	Bay of Plenty	Bay of Plenty	Bay of Plenty	Bay of Plenty	Waikato
Area							
Effluent (ha)	10	30	20	20	20	25	6
Non-effluent (ha)	40	150	100		240	165	34
Stock							
# Cows	170	760	310	820	820	510	121
Breed	FxJ	FxJ	Friesian	Friesian	Friesian	Friesian	FxJ
Milk Solids (kg)	52000	310000	102000	267000	267000	170000	48391
Yearlings Grazed	off	off	off	off	off	off	off
Effluent disposal method	spray	spray	spray	spray	spray	spray	spray
Animal Health Supplements	28kg MgO/ha/yr 21kg lime flour/ha/yr	None	30g MgO/cow/day for 16 weeks	30g MgO/cow/day for 16 weeks	30g MgO/cow/day for 16 weeks	None	25kg MgO/ha/yr 7kg lime flour/ha/yr
Supplements added	Maize Silage 100T	Palm kernal meal 210T	Average pasture silage 40T	Maize Silage 300T Average pasture silage 20T	Maize Silage 300T Average pasture silage 20T	None	None

Appendix 3.2 Effluent Block Input Variables

Parameter		Site A	Site B	Site C	Site D (sand)	Site D (mud)	Site E	Site F
Block General	Topography	Flat	Flat	Rolling	Flat	Rolling	Rolling	Flat
	Distance from coast (km)	50	50	50	50	50	50	50
	Rainfall (mm)	1200	1500	2000	1500	1500	2000	1200
	Drainage (mm)	444	725	1340	725	725	1340	444
	Application Rate	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	Development status	Developed	Developed	Developed	Developed	Developed	Developed	Developed
	Pasture type	Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover
Soil	Soil Order	Allophanic	Granular	Podzols	Recent	Allophanic	Podzols	Allophanic
	Soil Type	Horotiu silt loam	Te Kowhai silt loam	Mangorewa sandy loam	Te Ngae loamy sand	Rotomahana sandy loam	Mangorewa sandy loam	Kereone silt loam
	Olson P	34	36	32	90	40	72	67
	QT K	40	31	10	11	31	18	31
	Organic S	11	8	22.6	6	6	6	11.3
	QT Ca	15	25	23	11	19	7	24
	QT Mg	38	64	41	43	41	34	59
	QT Na	7	4	3	4	4	5	5
Fertiliser	N	41	30	0	0	0	80	190
	P	19	59	0	0	0	26	64
	S	25	100	0	0	0	62	78
	K	0	0	0	0	0	0	74
	Ca	44	137	0	0	0	0	151
	Mg	51	0	0	0	0	0	20
	Na	0	0	0	0	0	0	0
	N added, M, J, J	0	0	0	0	0	0	59
Soluble P added May-Oct	0	0	0	0	0	0	39	
Supplements Removed	None	None	None	None	None	None	None	Silage 14T

Appendix 3.3 Non-Effluent Block Input Variables

Parameter		Site A	Site B	Site C	Site D (sand)	Site D (mud)	Site E	Site F	
Block General	Topography	Flat	Flat	Rolling		Rolling	Rolling	Rolling	
	Distance from coast (km)	50	50	50		50	50	50	
	Rainfall (mm)	1200	1500	2000		1500	2000	1200	
	Drainage	444	725	1340		725	1340	444	
	Development status	Developed	Developed	Developed		Developed	Developed	Developed	
	Pasture type	Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover		Ryegrass/white clover	Ryegrass/white clover	Ryegrass/white clover	
Soil	Soil Order	Allophanic	Granular	Podzols		Allophanic	Podzols	Allophanic	
	Soil Type	Horotiu silt loam	Te Kowhai silt loam	Mangorewa sandy loam		Rotomahana sandy loam	Mangorewa sandy loam	Kereone silt loam	
	Olson P	30	40	35		38	42	75	
	QT K	14	13	7		12	6	13	
	Organic S	11	17	22.6		7	6	23.8	
	QT Ca	19	19	19		15	16	24	
	QT Mg	40	21	29		36	37	35	
	QT Na	7	4	3		10	5	7	
	Fertiliser	N	40	31	180		160	200	190
		P	19	59	50		62	72	64
S		24	98	40		93	70	78	
K		19	95	30		40	87	74	
Ca		42	135	110		0	22	151	
Mg		52	0	30		22	23	20	
Na		0	0	0		0	0	0	
N added, M, J, J		0	0	25		50	0	59	
Soluble P added May-Oct	0	0	15		15	15	39		
Lime/dolomite applications	None	None	None		160 kg/ha/yr Lime	160 kg/ha/yr Lime	None		
Supplements Removed	None	None	Silage 18T		Silage 100T	None	Silage 7T		

APPENDIX FOUR: Nutrient Budgets for Sites A-F

The following budgets have been taken from OVERSEER[®] Nutrient Budgets 2 (v. 5.0.14.0) output data for each site, using the input information gathered in Appendix three.

Appendix 4.1 Site A

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ⁺
Inputs								
Fertiliser	41	19	0	25	44	51	0	0.0
Effluent Added	199	23	219	14	43	30	5	-4.4
Atmospheric / clover N	93	0	2	4	2	5	17	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	10	0	2	2	8	0.0
Supplements	23	4	18	2	11	19	3	-0.8
Outputs								
Product	85	15	19	5	22	2	5	-0.6
Transfer	52	6	56	4	10	7	1	-1.1
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	62	0	0	0	0	0	0	-0.4
Leaching/runoff	41	0	259	35	163	34	78	-3.2
Immobilisation/absorption	115	29	0	1	0	0	0	-0.8
Change in inorganic soil pool	0	-1	-84	0	-93	63	-52	0.9

Effluent block

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ⁺
Inputs								
Fertiliser	40	19	19	24	42	52	0	0.0
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	155	0	2	4	2	5	17	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	17	0	2	2	8	0.0
Supplements	23	4	18	2	11	19	3	-0.8
Outputs								
Product	85	15	19	5	22	2	5	-0.6
Transfer	51	6	52	3	10	7	1	-1.1
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	36	0	0	0	0	0	0	0.0
Leaching/runoff	28	0	45	21	156	28	50	-2.0
Immobilisation/absorption	18	25	0	0	0	0	0	-0.1
Change in inorganic soil pool	0	-20	-60	0	-131	40	-29	3.0

Non-effluent block

Appendix 4.2 Site B

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	30	59	0	100	137	0	0	0.0
Effluent Added	287	35	320	31	63	26	3	-6.0
Atmospheric / clover N	158	0	2	4	3	6	21	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	4	0	4	7	8	0.0
Supplements	28	6	14	5	1	3	1	-0.3
Outputs								
Product	136	24	31	8	33	3	9	-1.1
Transfer	65	7	69	5	14	7	1	-1.2
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	89	0	0	0	0	0	0	-0.6
Leaching/runoff	64	1	180	102	203	13	45	-4.9
Immobilisation/absorption	149	22	0	24	0	0	0	-1.0
Change in inorganic soil pool	0	49	60	0	-43	19	-21	2.5

Effluent block

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	31	59	95	98	135	0	0	0.0
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	252	0	2	4	3	6	21	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	19	0	4	7	8	0.0
Supplements	28	6	14	5	1	3	1	-0.3
Outputs								
Product	136	24	31	8	33	3	9	-1.1
Transfer	62	7	65	7	13	5	1	-1.2
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	50	0	0	0	0	0	0	0.0
Leaching/runoff	43	1	48	88	139	18	43	-3.0
Immobilisation/absorption	19	22	0	4	0	0	0	-0.1
Change in inorganic soil pool	0	14	-14	0	-42	-10	-23	5.1

Non-effluent block

Appendix 4.3 Site C

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ⁺
Inputs								
Fertiliser	0	0	0	0	0	0	0	0.0
Effluent Added	137	17	133	15	31	16	1	-3.0
Atmospheric / clover N	114	0	2	5	4	8	28	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	8	0	1	0	3	0.0
Supplements	12	2	10	1	3	6	1	-0.2
Outputs								
Product	70	13	15	4	18	1	4	-0.6
Transfer	31	4	33	3	7	4	0	-0.6
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	38	0	0	0	0	0	0	-0.2
Leaching/runoff	36	7	85	37	144	19	87	-2.7
Immobilisation/absorption	89	47	0	-24	0	0	0	-0.6
Change in inorganic soil pool	0	-49	20	0	-131	6	-59	1.5

Effluent block

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ⁺
Inputs								
Fertiliser	180	50	30	40	110	30	0	-0.3
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	94	0	2	5	4	8	28	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	15	0	1	0	3	0.0
Supplements	12	2	10	1	3	6	1	-0.2
Outputs								
Product	70	13	15	4	18	1	4	-0.6
Transfer	31	4	28	3	7	3	0	-0.7
Supplements removed	5	1	4	1	1	0	0	0.0
Atmospheric	59	0	0	0	0	0	0	0.0
Leaching/runoff	58	8	40	59	130	20	86	-4.1
Immobilisation/absorption	63	52	0	-21	0	0	0	-0.1
Change in inorganic soil pool	0	-23	-29	0	-38	19	-59	4.8

Non-effluent block

Appendix 4.4 Site D

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	0	0	0	0	0	0	0	0.0
Effluent Added	225	29	245	15	43	26	7	-4.9
Atmospheric / clover N	101	0	2	4	3	6	21	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	4	0	4	7	8	0.0
Supplements	24	4	20	2	5	8	2	-0.4
Outputs								
Product	79	14	17	5	20	2	5	-0.7
Transfer	46	5	47	2	8	5	1	-0.8
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	60	0	0	0	0	0	0	-0.5
Leaching/runoff	43	1	50	21	69	8	34	-3.3
Immobilisation/absorption	122	34	0	-7	0	0	0	-1.0
Change in inorganic soil pool	0	-19	158	0	-43	33	-2	0.8

Effluent block (sand)

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	0	0	0	0	0	0	0	0.0
Effluent Added	225	29	245	15	43	26	7	-4.9
Atmospheric / clover N	101	0	2	4	3	6	21	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	7	0	2	2	8	0.0
Supplements	24	4	20	2	5	8	2	-0.4
Outputs								
Product	79	14	17	5	20	2	5	-0.7
Transfer	44	5	47	2	8	5	1	-0.8
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	54	0	0	0	0	0	0	-0.4
Leaching/runoff	47	1	201	21	188	38	85	-3.7
Immobilisation/absorption	127	31	0	-7	0	0	0	-1.0
Change in inorganic soil pool	0	-16	9	0	-164	-2	-51	1.2

Effluent block (mud)

(kg/ha)	N	P	K	S	Ca	Mg	Na	H*
Inputs								
Fertiliser	160	62	40	93	56	23	0	-2.8
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	113	0	2	4	3	6	21	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	38	0	2	2	8	0.0
Supplements	24	4	20	2	5	8	2	-0.4
Outputs								
Product	79	14	17	5	20	2	5	-0.7
Transfer	41	5	42	3	7	5	1	-0.9
Supplements removed	12	2	10	1	3	1	1	0.1
Atmospheric	56	0	0	0	0	0	0	0.0
Leaching/runoff	53	1	42	76	145	33	67	-3.7
Immobilisation/absorption	56	32	0	14	0	0	0	-0.1
Change in inorganic soil pool	0	15	-11	0	-109	-2	-42	2.0

Non-effluent block (mud)

Appendix 4.5 Site E

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ^a
Inputs								
Fertiliser	80	26	0	62	0	0	0	0.0
Effluent Added	161	21	161	9	32	16	3	-3.6
Atmospheric / clover N	89	0	2	5	4	8	28	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	12	0	1	0	3	0.0
Supplements	0	0	0	0	0	0	0	0.0
Outputs								
Product	74	13	16	5	19	1	5	-0.6
Transfer	29	4	33	2	4	3	1	-0.6
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	56	0	0	0	0	0	0	-0.3
Leaching/runoff	49	14	168	56	51	18	107	-3.7
Immobilisation/absorption	120	88	0	14	0	0	0	-0.7
Change in inorganic soil pool	0	-69	-42	0	-37	1	-78	2.4

Effluent block

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ^a
Inputs								
Fertiliser	200	72	87	70	78	24	0	-2.8
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	97	0	2	5	4	8	28	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	12	0	1	0	3	0.0
Supplements	0	0	0	0	0	0	0	0.0
Outputs								
Product	74	13	16	5	19	1	5	-0.6
Transfer	30	4	27	2	6	3	0	-0.6
Supplements removed	0	0	0	0	0	0	0	0.0
Atmospheric	63	0	0	0	0	0	0	0.0
Leaching/runoff	64	9	46	55	108	16	83	-4.4
Immobilisation/absorption	66	62	0	14	0	0	0	-0.1
Change in inorganic soil pool	0	-13	12	0	-50	11	-57	3.0

Non-effluent block

Appendix 4.6 Site F

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ⁺
Inputs								
Fertiliser	190	64	74	78	151	20	0	0.0
Effluent Added	170	23	190	22	39	22	3	-3.7
Atmospheric / clover N	81	0	2	4	2	5	17	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	10	0	2	2	8	0.0
Supplements	16	2	14	1	6	16	0	0.1
Outputs								
Product	96	17	21	6	24	2	6	-0.7
Transfer	34	4	36	3	7	4	0	-0.6
Supplements removed	72	11	65	5	17	7	2	0.3
Atmospheric	93	0	0	0	0	0	0	-0.4
Leaching/runoff	65	0	197	82	233	30	60	-4.9
Immobilisation/absorption	97	52	0	10	0	0	0	-0.5
Change in inorganic soil pool	0	8	-29	0	-79	23	-39	3.2

Effluent block

(kg/ha)	N	P	K	S	Ca	Mg	Na	H ⁺
Inputs								
Fertiliser	190	64	74	78	151	20	0	0.0
Effluent Added	0	0	0	0	0	0	0	0.0
Atmospheric / clover N	131	0	2	4	2	5	17	0.0
Irrigation	0	0	0	0	0	0	0	0.0
Slow Release	0	3	16	0	2	2	8	0.0
Supplements	16	2	14	1	6	16	0	0.1
Outputs								
Product	96	17	21	6	24	2	6	-0.7
Transfer	36	5	38	5	8	4	1	-0.7
Supplements removed	6	1	5	1	1	1	0	0.0
Atmospheric	75	0	0	0	0	0	0	0.0
Leaching/runoff	57	1	54	88	216	31	49	-4.0
Immobilisation/absorption	66	55	0	-16	0	0	0	-0.1
Change in inorganic soil pool	0	-9	-12	0	-88	5	-30	5.6

Non-effluent block

APPENDIX FIVE: Conversion and Accumulation Calculations

Appendix 5.1 Conversion of Exchangeable Cation Results

Calculations were made to convert the raw exchangeable cation results for potassium, calcium and magnesium (in milliequivalents per 100g (meq/100g)) to a weight by area basis (kg ha^{-1}). This would then allow comparison between the soil results and OVERSEER[®] output (also in kg ha^{-1}).

The meq data was first converted to milligrams of cation in the 75 mm segment of soil (equation 1), then to kilograms, and then divided by the area of the core in hectares, to give values in kg ha^{-1} (equation 2). The difference was measured by subtracting the non-effluent paddock values from the effluent paddock values (equation 3).

$$((\text{conc (meq/100 g)/100})/\text{charge of cation} \times \text{weight (g)}) \times \text{atomic weight}^* = \text{mg} \quad (1)$$

$$(\text{mg}/1,000,000)/0.0000001887 \text{ ha}^\# = \text{kg ha}^{-1} \quad (2)$$

$$\text{Effluent (kg ha}^{-1}) - \text{Non-Effluent (kg ha}^{-1}) = \text{Difference (kg ha}^{-1}) \quad (3)$$

* Atomic weights are K=39.1; Ca=40; Mg=24

Area of smaller corer used at site D (mud) = 0.00000009048 ha

Appendix 5.1.1 Conversion of Potassium Results

Site	Depth	EFFLUENT					NON-EFFLUENT					Difference (E-N)	
		K conc (meq)	Weight (g)	mg	kg	kg K/ha	K conc (meq)	Weight (g)	mg	kg	K kg/ha	kg K/ha	
A	75mm	2.35	112.38	103.13	0.0001031	546.89	0.87	108.02	36.61	0.0000366	194.16	352.73	
	150mm	1.25	113.18	55.23	0.0000552	292.91	0.53	110.20	22.80	0.0000228	120.91	172.00	
	225mm	1.04	105.51	42.97	0.0000430	227.88	0.30	113.38	13.20	0.0000132	70.01	157.88	
	300mm	1.29	107.69	54.34	0.0000543	288.18	0.34	113.75	15.30	0.0000153	81.12	207.06	
	375mm	1.20	113.93	53.63	0.0000536	284.39	0.37	117.77	17.15	0.0000172	90.97	193.42	
	450mm	0.84	117.89	38.87	0.0000389	206.14	0.34	120.97	16.01	0.0000160	84.93	121.21	
	total					1846.41					642.11	1204.30	
B	75mm	2.11	96.49	79.68	0.0000797	422.54	0.81	108.44	34.25	0.0000342	181.63	240.91	
	150mm	0.88	91.12	31.47	0.0000315	166.88	0.28	125.33	13.85	0.0000138	73.42	93.46	
	225mm	0.55	108.46	23.17	0.0000232	122.88	0.24	134.36	12.82	0.0000128	68.01	54.86	
	300mm	0.48	106.78	19.85	0.0000199	105.28	0.32	145.82	18.33	0.0000183	97.21	8.07	
	375mm	0.59	118.07	27.26	0.0000273	144.58	0.33	140.45	18.15	0.0000182	96.26	48.32	
	450mm	0.42	119.95	19.64	0.0000196	104.16	0.20	127.98	10.10	0.0000101	53.53	50.63	
	total					1066.32					570.08	496.25	
C	75mm	0.77	84.49	25.27	0.0000253	134.03	0.55	87.44	18.71	0.0000187	99.22	34.81	
	150mm	0.61	86.67	20.65	0.0000206	109.48	0.33	86.20	11.09	0.0000111	58.80	50.69	
	225mm	0.50	91.58	17.82	0.0000178	94.51	0.24	89.35	8.40	0.0000084	44.56	49.95	
	300mm	0.35	88.00	12.01	0.0000120	63.68	0.16	87.01	5.36	0.0000054	28.41	35.27	
	375mm	0.16	87.09	5.33	0.0000053	28.26	0.06	99.08	2.31	0.0000023	12.25	16.01	
	450mm	0.07	95.94	2.64	0.0000026	13.99	0.03	106.08	1.34	0.0000013	7.12	6.87	
	total					443.95					250.35	193.59	
D (sand)	75mm	0.75	97.35	28.44	0.0000284	150.80	0.33	110.79	14.10	0.0000141	74.76	76.04	
	150mm	0.31	123.94	15.15	0.0000151	80.32	0.11	139.96	5.84	0.0000058	30.96	49.36	

Appendix 5.1.1 cont'd

Site	Depth	EFFLUENT					NON-EFFLUENT					Difference (E-N)	
		K conc (meq)	Weight (g)	mg	kg	kg K/ha	K conc (meq)	Weight (g)	mg	kg	kg K/ha	kg K/ha	
D (sand)	225mm	0.26	140.06	14.42	0.0000144	76.46	0.08	143.02	4.74	0.0000047	25.16	51.30	
	300mm	0.35	144.96	20.05	0.0000201	106.33	0.14	144.49	7.77	0.0000078	41.18	65.14	
	375mm	0.53	167.74	34.71	0.0000347	184.09	0.29	144.90	16.51	0.0000165	87.56	96.53	
	450mm	0.83	149.24	48.40	0.0000484	256.69	0.59	147.59	34.19	0.0000342	181.33	75.36	
	total					854.68					440.96	413.73	
D (mud)	75mm	1.39	69.20	37.68	0.0000377	416.48	0.60	64.49	15.11	0.0000151	166.98	249.51	
	150mm	0.84	71.89	23.65	0.0000237	261.41	0.48	74.88	13.95	0.0000140	154.18	107.22	
	300mm	0.52	70.27	14.31	0.0000143	158.21	0.37	72.38	10.43	0.0000104	115.32	42.88	
	375mm	0.39	41.77	6.29	0.0000063	69.51	0.23	66.57	6.12	0.0000061	67.60	1.92	
	total					905.61					504.08	401.53	
E	75mm	1.61	72.68	45.63	0.0000456	241.96	0.59	66.90	15.30	0.0000153	81.16	160.81	
	150mm	0.53	87.73	18.20	0.0000182	96.53	0.11	79.95	3.56	0.0000036	18.86	77.66	
	225mm	0.47	79.96	14.68	0.0000147	77.85	0.08	74.07	2.35	0.0000024	12.47	65.39	
	300mm	0.29	74.34	8.36	0.0000084	44.35	0.06	61.40	1.56	0.0000016	8.27	36.08	
	375mm	0.12	78.96	3.70	0.0000037	19.63	0.05	62.36	1.34	0.0000013	7.11	12.52	
	450mm	0.08	87.70	2.83	0.0000028	15.02	0.05	71.85	1.34	0.0000013	7.10	7.92	
	total					495.34					134.97	360.38	
F	75mm	1.60	128.58	80.38	0.0000804	426.24	0.87	99.96	34.04	0.0000340	180.53	245.71	
	150mm	1.08	125.65	52.90	0.0000529	280.56	0.56	118.37	25.77	0.0000258	136.67	143.88	
	225mm	0.80	129.12	40.53	0.0000405	214.92	0.54	131.89	27.94	0.0000279	148.18	66.74	
	300mm	0.59	133.67	30.68	0.0000307	162.69	0.51	130.83	26.05	0.0000260	138.14	24.54	
	375mm	0.39	149.22	22.99	0.0000230	121.90	0.42	134.02	22.00	0.0000220	116.67	5.23	
	450mm	0.32	140.67	17.85	0.0000179	94.66	0.29	125.93	14.49	0.0000145	76.85	17.81	
	total					1300.96					797.05	503.91	

Appendix 5.1.2 Conversion of Calcium Results

Site	Depth	EFFLUENT					NON-EFFLUENT					Difference (E-N) kg Ca/ha
		Ca conc (meq)	Weight (g)	mg	kg	kg Ca/ha	Ca conc (meq)	Weight (g)	mg	kg	kg Ca/ha	
A	75mm	10.72	112.38	240.85	0.0002408	1277.22	14.39	108.02	310.97	0.0003110	1649.07	-371.85
	150mm	7.85	113.18	177.78	0.0001778	942.78	6.87	110.20	151.36	0.0001514	802.69	140.09
	225mm	4.13	105.51	87.07	0.0000871	461.76	3.25	113.38	73.58	0.0000736	390.22	71.54
	300mm	2.73	107.69	58.81	0.0000588	311.86	3.49	113.75	79.38	0.0000794	420.98	-109.12
	375mm	3.19	113.93	72.65	0.0000726	385.25	4.00	117.77	94.28	0.0000943	499.97	-114.73
	450mm	3.68	117.89	86.71	0.0000867	459.84	4.18	120.97	101.23	0.0001012	536.84	-77.00
	total					3838.70					4299.76	-461.06
B	75mm	20.65	96.49	398.58	0.0003986	2113.69	13.74	108.44	297.93	0.0002979	1579.96	533.73
	150mm	13.34	91.12	243.15	0.0002431	1289.42	6.93	125.33	173.75	0.0001737	921.41	368.02
	225mm	6.46	108.46	140.22	0.0001402	743.58	4.25	134.36	114.08	0.0001141	605.00	138.58
	300mm	4.53	106.78	96.72	0.0000967	512.90	3.63	145.82	105.87	0.0001059	561.43	-48.53
	375mm	4.91	118.07	115.88	0.0001159	614.50	4.21	140.45	118.35	0.0001183	627.60	-13.10
	450mm	4.55	119.95	109.22	0.0001092	579.22	4.29	127.98	109.90	0.0001099	582.81	-3.58
	total					5853.31					4878.19	975.12
C	75mm	21.64	84.49	365.57	0.0003656	1938.66	17.10	87.44	299.12	0.0002991	1586.24	352.42
	150mm	11.05	86.67	191.58	0.0001916	1015.95	9.77	86.20	168.50	0.0001685	893.59	122.36
	225mm	5.95	91.58	109.02	0.0001090	578.16	5.65	89.35	100.90	0.0001009	535.08	43.08
	300mm	2.37	88.00	41.74	0.0000417	221.34	2.88	87.01	50.14	0.0000501	265.89	-44.55
	375mm	1.19	87.09	20.69	0.0000207	109.73	1.30	99.08	25.82	0.0000258	136.93	-27.20
	450mm	0.83	95.94	15.96	0.0000160	84.62	0.71	106.08	14.99	0.0000150	79.52	5.10
	total					3948.46					3497.25	451.21
D (sand)	75mm	8.88	97.35	172.81	0.0001728	916.44	4.70	110.79	104.18	0.0001042	552.49	363.95
	150mm	2.73	123.94	67.58	0.0000676	358.38	1.94	139.96	54.39	0.0000544	288.46	69.92
	225mm	2.09	140.06	58.60	0.0000586	310.76	1.65	143.02	47.08	0.0000471	249.66	61.11

Appendix 5.1.2 cont'd

Site	Depth	EFFLUENT					NON-EFFLUENT					Difference (E-N)	
		Ca conc (meq)	Weight (g)	mg	kg	kg Ca/ha	Ca conc (meq)	Weight (g)	mg	kg	kg Ca/ha	kg Ca/ha	
D (sand)	300mm	1.19	144.96	34.41	0.0000344	182.45	0.81	144.49	23.50	0.0000235	124.61	57.84	
	375mm	1.24	167.74	41.74	0.0000417	221.33	1.01	144.90	29.20	0.0000292	154.86	66.47	
	450mm	2.29	149.24	68.34	0.0000683	362.42	0.95	147.59	28.06	0.0000281	148.78	213.64	
	total					2351.79					1518.86	832.93	
D (mud)	75mm	10.39	69.20	143.81	0.0001438	1589.42	8.87	64.49	114.41	0.0001144	1264.51	324.91	
	150mm	8.33	71.89	119.74	0.0001197	1323.39	7.43	74.88	111.31	0.0001113	1230.16	93.22	
	225mm	7.34	70.27	103.10	0.0001031	1139.43	6.96	72.38	100.70	0.0001007	1112.96	26.47	
	300mm	6.08	41.77	50.82	0.0000508	561.72	4.94	66.57	65.83	0.0000658	727.58	-165.86	
	total					4613.96					4335.21	278.75	
E	75mm	7.81	72.68	113.55	0.0001135	602.16	19.04	66.90	254.74	0.0002547	1350.91	-748.75	
	150mm	3.48	87.73	61.12	0.0000611	324.15	7.15	79.95	114.31	0.0001143	606.19	-282.04	
	225mm	2.43	79.96	38.82	0.0000388	205.86	2.69	74.07	39.85	0.0000399	211.34	-5.48	
	300mm	1.50	74.34	22.36	0.0000224	118.60	1.35	61.40	16.55	0.0000166	87.77	30.83	
	375mm	0.85	78.96	13.44	0.0000134	71.29	0.91	62.36	11.40	0.0000114	60.44	10.85	
	450mm	0.61	87.70	10.62	0.0000106	56.30	0.53	71.85	7.69	0.0000077	40.76	15.54	
	total					1378.36					2357.41	-979.05	
F	75mm	14.71	128.58	378.39	0.0003784	2006.65	19.08	99.96	381.36	0.0003814	2022.37	-15.72	
	150mm	10.70	125.65	268.94	0.0002689	1426.22	8.93	118.37	211.38	0.0002114	1120.96	305.25	
	225mm	7.75	129.12	200.16	0.0002002	1061.47	6.30	131.89	166.30	0.0001663	881.90	179.57	
	300mm	6.17	133.67	164.89	0.0001649	874.43	5.87	130.83	153.60	0.0001536	814.53	59.90	
	375mm	5.79	149.22	172.67	0.0001727	915.66	6.78	134.02	181.70	0.0001817	963.58	-47.92	
	450mm	5.93	140.67	166.72	0.0001667	884.12	7.41	125.93	186.66	0.0001867	989.85	-105.73	
	total					7168.55					6793.19	375.36	

Appendix 5.1.3 Conversion of Magnesium Results

Site	Depth	EFFLUENT					NON-EFFLUENT					Difference (E-N)	
		Mg conc (meq)	Weight (g)	mg	kg	kg Mg/ha	Mg conc (meq)	Weight (g)	mg	kg	kg Mg/ha	kg Mg/ha	
A	75 mm	1.79	112.38	24.09	0.0000241	127.76	2.00	108.02	25.92	0.0000259	137.45	-9.69	
	150mm	0.76	113.18	10.38	0.0000104	55.07	0.58	110.20	7.67	0.0000077	40.66	14.41	
	225mm	0.33	105.51	4.19	0.0000042	22.24	0.20	113.38	2.79	0.0000028	14.78	7.46	
	300mm	0.25	107.69	3.24	0.0000032	17.16	0.19	113.75	2.58	0.0000026	13.71	3.45	
	375mm	0.34	113.93	4.61	0.0000046	24.45	0.28	117.77	3.92	0.0000039	20.80	3.65	
	450mm	0.38	117.89	5.41	0.0000054	28.71	0.27	120.97	3.88	0.0000039	20.58	8.14	
	total					275.40					247.97	27.43	
B	75 mm	3.54	96.49	40.98	0.0000410	217.33	1.05	108.44	13.68	0.0000137	72.56	144.76	
	150mm	1.61	91.12	17.58	0.0000176	93.23	0.48	125.33	7.25	0.0000073	38.46	54.77	
	225mm	0.72	108.46	9.42	0.0000094	49.94	0.32	134.36	5.16	0.0000052	27.34	22.60	
	300mm	0.64	106.78	8.19	0.0000082	43.45	0.28	145.82	4.95	0.0000049	26.24	17.21	
	375mm	0.80	118.07	11.34	0.0000113	60.11	0.38	140.45	6.42	0.0000064	34.04	26.07	
	450mm	0.84	119.95	12.08	0.0000121	64.09	0.43	127.98	6.62	0.0000066	35.12	28.97	
	total					528.15					233.76	294.39	
C	75 mm	2.61	84.49	26.44	0.0000264	140.22	1.75	87.44	18.40	0.0000184	97.60	42.63	
	150mm	0.83	86.67	8.62	0.0000086	45.74	0.66	86.20	6.87	0.0000069	36.42	9.32	
	225mm	0.53	91.58	5.78	0.0000058	30.67	0.38	89.35	4.05	0.0000040	21.45	9.22	
	300mm	0.23	88.00	2.46	0.0000025	13.05	0.26	87.01	2.70	0.0000027	14.30	-1.25	
	375mm	0.14	87.09	1.47	0.0000015	7.79	0.16	99.08	1.92	0.0000019	10.17	-2.38	
	450mm	0.08	95.94	0.96	0.0000010	5.07	0.08	106.08	1.04	0.0000010	5.51	-0.45	
	total					242.54					185.46	57.08	
D (sand)	75 mm	2.37	97.35	27.66	0.0000277	146.70	0.74	110.79	9.78	0.0000098	51.86	94.84	
	150mm	0.65	123.94	9.60	0.0000096	50.93	0.28	139.96	4.63	0.0000046	24.58	26.35	

Appendix 5.1.3 cont'd

Site	Depth	EFFLUENT					NON-EFFLUENT					Difference (E-N)	
		Mg conc (meq)	Weight (g)	mg	kg	kg Mg/ha	Mg conc (meq)	Weight (g)	mg	kg	kg Mg/ha	kg Mg/ha	
D (sand)	225mm	0.48	140.06	8.05	0.0000081	42.71	0.23	143.02	4.02	0.0000040	21.33	21.39	
	300mm	0.29	144.96	5.01	0.0000050	26.58	0.12	144.49	2.15	0.0000021	11.38	15.20	
	375mm	0.32	167.74	6.37	0.0000064	33.79	0.19	144.90	3.25	0.0000033	17.26	16.54	
	450mm	0.62	149.24	11.15	0.0000111	59.11	0.19	147.59	3.41	0.0000034	18.07	41.03	
	total					359.82					144.47	215.34	
D (mud)	75 mm	1.52	69.20	12.59	0.0000126	139.20	1.41	64.49	10.92	0.0000109	120.73	18.47	
	150mm	0.92	71.89	7.92	0.0000079	87.57	0.87	74.88	7.81	0.0000078	86.27	1.30	
	225mm	0.71	70.27	6.03	0.0000060	66.62	0.57	72.38	4.96	0.0000050	54.86	11.76	
	300mm	0.59	41.77	2.97	0.0000030	32.83	0.36	66.57	2.89	0.0000029	31.94	0.89	
	total					326.22					293.80	32.43	
E	75 mm	2.50	72.68	21.80	0.0000218	115.59	2.97	66.90	23.86	0.0000239	126.52	-10.94	
	150mm	0.68	87.73	7.13	0.0000071	37.82	0.65	79.95	6.23	0.0000062	33.06	4.75	
	225mm	0.42	79.96	4.06	0.0000041	21.51	0.23	74.07	2.01	0.0000020	10.66	10.86	
	300mm	0.33	74.34	2.90	0.0000029	15.37	0.11	61.40	0.83	0.0000008	4.42	10.95	
	375mm	0.20	78.96	1.89	0.0000019	10.02	0.05	62.36	0.39	0.0000004	2.05	7.97	
	450mm	0.14	87.70	1.45	0.0000014	7.68	0.01	71.85	0.07	0.0000001	0.35	7.33	
	total					207.99					177.06	30.93	
F	75 mm	2.46	128.58	38.03	0.0000380	201.69	1.86	99.96	22.32	0.0000223	118.35	83.35	
	150mm	1.50	125.65	22.67	0.0000227	120.24	0.95	118.37	13.44	0.0000134	71.25	48.99	
	225mm	1.10	129.12	17.06	0.0000171	90.46	0.54	131.89	8.51	0.0000085	45.12	45.34	
	300mm	0.97	133.67	15.62	0.0000156	82.86	0.53	130.83	8.28	0.0000083	43.92	38.94	
	375mm	0.95	149.22	17.04	0.0000170	90.39	0.73	134.02	11.69	0.0000117	61.99	28.40	
	450mm	1.01	140.67	17.10	0.0000171	90.70	1.10	125.93	16.64	0.0000166	88.24	2.47	
	total					676.34					428.86	247.48	

Appendix 5.2 Conversion of Total Nitrogen and Phosphorus

The total nitrogen (N) and phosphorus (P) found in the soil samples were converted from mg g^{-1} to kg ha^{-1} by multiplying the concentration found from the analysis by the weight of soil in that segment of core (75 mm depth) (equation 4). This was then converted to kilograms and divided by the area of the core in hectares (equation 5). The difference between the effluent and non-effluent paddocks was calculated by subtracting the non-effluent values from the effluent values (equation 6).

$$\text{concentration (mg g}^{-1}\text{) x weight (g) = mg} \quad (4)$$

$$(\text{mg/ 1,000,000})/0.00000018857 \text{ ha}^* = \text{kg ha}^{-1} \quad (5)$$

$$\text{Effluent (kg ha}^{-1}\text{) - Non-Effluent (kg ha}^{-1}\text{) = Difference (kg ha}^{-1}\text{)} \quad (6)$$

* Area of smaller corer used at site D (mud) = 0.00000009048 ha

Appendix 5.2.1 Conversion of Total Nitrogen Results

Site	Depth (mm)	N conc (mg/g)	EFFLUENT			NON-EFFLUENT			Difference (E-N) (kg/ha)			
			Weight (g)	mg	kg	kg N/ha	Weight (g)	mg		kg	kg N/ha	
A	0-75	6.21	112.38	697.86	0.00069786	3698.27	6.89	108.02	743.89	0.00074389	3942.18	-243.91
	75-150	5.12	113.18	579.48	0.00057948	3070.91	4.92	110.20	542.31	0.00054231	2873.94	196.97
	150-225	3.45	105.51	364.02	0.00036402	1929.08	3.15	113.38	357.62	0.00035762	1895.16	33.93
	225-300	2.01	107.69	216.14	0.00021614	1145.41	1.69	113.75	192.20	0.00019220	1018.56	126.85
	300-375	1.22	113.93	138.99	0.00013899	736.57	1.03	117.77	121.09	0.00012109	641.69	94.88
	375-450	0.64	117.89	75.45	0.00007545	399.85	0.72	120.97	87.42	0.00008742	463.27	-63.42
B	0-75	6.91	96.49	666.77	0.00066677	3533.49	4.80	108.44	520.59	0.00052059	2758.82	774.67
	75-150	5.45	91.12	496.59	0.00049659	2631.62	2.61	125.33	327.58	0.00032758	1735.98	895.63
	150-225	2.32	108.46	251.62	0.00025162	1333.44	1.63	134.36	218.60	0.00021860	1158.44	175.00
	225-300	1.31	106.78	139.88	0.00013988	741.29	0.73	145.82	106.93	0.00010693	566.67	174.62
	300-375	0.78	118.07	92.09	0.00009209	488.03	0.65	140.45	91.54	0.00009154	485.09	2.94
	375-450	0.49	119.95	58.41	0.00005841	309.54	0.68	127.98	87.10	0.00008710	461.60	-152.07
C	0-75	7.18	84.49	606.71	0.00060671	3215.23	7.37	87.44	644.41	0.00064441	3414.99	-199.75
	75-150	4.15	86.67	359.40	0.00035940	1904.59	4.49	86.20	387.32	0.00038732	2052.56	-147.97
	150-225	2.99	91.58	274.27	0.00027427	1453.45	3.03	89.35	270.72	0.00027072	1434.66	18.79
	225-300	2.32	88.00	203.85	0.00020385	1080.28	2.27	87.01	197.52	0.00019752	1046.74	33.54
	300-375	1.41	87.09	123.03	0.00012303	651.97	1.13	99.08	111.92	0.00011192	593.12	58.85
	375-450	0.95	95.94	91.05	0.00009105	482.50	0.64	106.08	67.84	0.00006784	359.51	122.99
D (sand)	0-75	5.49	97.35	534.92	0.00053492	2834.76	3.41	110.79	378.08	0.00037808	2003.60	831.16
	75-150	2.20	123.94	273.21	0.00027321	1447.83	2.02	139.96	282.38	0.00028238	1496.47	-48.63
	150-225	1.36	140.06	190.12	0.00019012	1007.54	1.63	143.02	233.31	0.00023331	1236.40	-228.86
	225-300	0.59	144.96	84.84	0.00008484	449.60	0.53	144.49	75.95	0.00007595	402.50	47.10
	300-375	0.36	167.74	60.48	0.00006048	320.51	0.49	144.90	70.76	0.00007076	374.96	-54.46
	375-450	0.19	149.24	28.91	0.00002891	153.23	0.29	147.59	42.50	0.00004250	225.21	-71.99

Appendix 5.2.1 cont'd

Site	Depth (mm)	N conc (mg/g)	Weight (g)	EFFLUENT			NON-EFFLUENT			Difference (E-N)		
				mg	kg	kg N/ha	N conc (mg/g)	Weight (g)	mg	kg	kg N/ha	(kg/ha)
D (mud)	0-75	4.93	69.20	340.97	0.00034097	3768.41	4.52	64.49	291.52	0.00029152	3221.89	546.52
	75-150	3.04	71.89	218.54	0.00021854	2415.32	3.55	74.88	265.68	0.00026568	2936.35	-521.03
	150-225	2.49	70.27	174.81	0.00017481	1932.00	2.60	72.38	188.08	0.00018808	2078.74	-146.74
	225-300	2.32	41.77	96.73	0.00009673	1069.03	1.86	66.57	123.81	0.00012381	1368.42	-299.39
E (long-term)	0-75	9.04	72.68	657.18	0.00065718	3482.67	9.95	66.90	665.50	0.00066550	3526.77	-44.11
	75-150	5.20	87.73	456.59	0.00045659	2419.67	4.89	79.95	391.27	0.00039127	2073.48	346.18
	150-225	3.86	79.96	308.88	0.00030888	1636.88	3.79	74.07	280.57	0.00028057	1486.84	150.03
	225-300	2.97	74.34	220.80	0.00022080	1170.10	3.35	61.40	205.99	0.00020599	1091.62	78.48
	300-375	2.23	78.96	175.99	0.00017599	932.63	2.82	62.36	175.78	0.00017578	931.52	1.11
	375-450	1.58	87.70	138.27	0.00013827	732.77	1.63	71.85	117.35	0.00011735	621.88	110.89
E (short-term)	0-75	7.63	79.63	607.74	0.00060774	3220.68	9.95	66.90	665.50	0.00066550	3526.77	-306.09
	75-150	5.02	94.58	475.14	0.00047514	2517.97	4.89	79.95	391.27	0.00039127	2073.48	444.49
	150-225	3.89	90.80	353.20	0.00035320	1871.73	3.79	74.07	280.57	0.00028057	1486.84	384.89
	225-300	2.59	84.32	218.38	0.00021838	1157.30	3.35	61.40	205.99	0.00020599	1091.62	65.68
	300-375	2.19	88.44	193.39	0.00019339	1024.85	2.82	62.36	175.78	0.00017578	931.52	93.33
	375-450	1.79	79.19	141.53	0.00014153	750.01	1.63	71.85	117.35	0.00011735	621.88	128.13
F	0-75	5.28	128.58	678.32	0.00067832	3594.72	6.27	99.96	626.27	0.00062627	3318.87	275.85
	75-150	3.58	125.65	450.25	0.00045025	2386.08	3.77	118.37	446.47	0.00044647	2366.06	20.02
	150-225	2.63	129.12	339.83	0.00033983	1800.90	1.74	131.89	229.46	0.00022946	1215.98	584.92
	225-300	1.45	133.67	193.32	0.00019332	1024.51	0.78	130.83	101.63	0.00010163	538.56	485.94
	300-375	0.95	149.22	141.43	0.00014143	749.52	0.64	134.02	85.74	0.00008574	454.37	295.14
	375-450	0.60	140.67	83.84	0.00008384	444.32	0.59	125.93	74.30	0.00007430	393.74	50.58

Appendix 5.2.2 Conversion of Total Phosphorus Results

Site	Depth (mm)	P conc (mg/g)	Weight (g)	EFFLUENT			NON-EFFLUENT					Difference (E-N) (kg/ha)
				mg	kg	kg P/ha	P conc (mg/g)	Weight (g)	mg	kg	kg P/ha	
A	0-75	2.23	112.38	250.60	0.00025060	1328.04	2.42	108.02	261.64	0.00026164	1386.53	-58.49
	75-150	1.72	113.18	194.67	0.00019467	1031.64	1.69	110.20	186.17	0.00018617	986.59	45.04
	150-225	1.12	105.51	118.17	0.00011817	626.25	1.01	113.38	114.99	0.00011499	609.37	16.88
	225-300	0.57	107.69	61.38	0.00006138	325.30	0.57	113.75	65.01	0.00006501	344.51	-19.22
	300-375	0.37	113.93	42.15	0.00004215	223.39	0.36	117.77	42.84	0.00004284	227.03	-3.64
	375-450	0.22	117.89	25.94	0.00002594	137.45	0.30	120.97	36.40	0.00003640	192.88	-55.43
	B	0-75	2.20	96.49	212.29	0.00021229	1124.99	1.25	108.44	135.27	0.00013527	716.87
	75-150	1.62	91.12	147.61	0.00014761	782.24	0.50	125.33	62.36	0.00006236	330.47	451.77
	150-225	0.42	108.46	45.55	0.00004555	241.40	0.25	134.36	33.45	0.00003345	177.25	64.15
	225-300	0.23	106.78	24.57	0.00002457	130.23	0.10	145.82	13.96	0.00001396	73.98	56.26
	300-375	0.21	118.07	24.79	0.00002479	131.39	0.09	140.45	13.10	0.00001310	69.44	61.96
	375-450	0.18	119.95	21.34	0.00002134	113.08	0.14	127.98	17.42	0.00001742	92.34	20.74
C	0-75	1.88	84.49	158.74	0.00015874	841.25	2.31	87.44	201.98	0.00020198	1070.37	-229.12
	75-150	0.89	86.67	76.86	0.00007686	407.31	1.15	86.20	99.13	0.00009913	525.33	-118.02
	150-225	0.54	91.58	49.35	0.00004935	261.53	0.52	89.35	46.46	0.00004646	246.21	15.31
	225-300	0.34	88.00	29.61	0.00002961	156.90	0.36	87.01	31.32	0.00003132	166.00	-9.11
	300-375	0.24	87.09	21.06	0.00002106	111.62	0.24	99.08	23.98	0.00002398	127.06	-15.45
	375-450	0.21	95.94	19.84	0.00001984	105.14	0.16	106.08	17.34	0.00001734	91.92	13.22
	D (sand)	0-75	1.57	97.35	153.05	0.00015305	811.05	1.45	110.79	160.40	0.00016040	850.03
	75-150	0.93	123.94	114.86	0.00011486	608.69	0.94	139.96	131.88	0.00013188	698.87	-90.18
	150-225	0.56	140.06	78.12	0.00007812	413.97	0.65	143.02	93.35	0.00009335	494.69	-80.72
	225-300	0.28	144.96	40.53	0.00004053	214.78	0.38	144.49	54.40	0.00005440	288.27	-73.48
	300-375	0.23	167.74	38.97	0.00003897	206.53	0.33	144.90	47.17	0.00004717	249.97	-43.44
	375-450	0.23	149.24	34.13	0.00003413	180.89	0.23	147.59	34.35	0.00003435	182.05	-1.16

Appendix 5.2.2 cont'd

Site	Depth (mm)	P conc (mg/g)	EFFLUENT				NON-EFFLUENT				Difference (E-N) (kg/ha)	
			Weight (g)	mg	kg	kg P/ha	Weight (g)	mg	kg	kg P/ha		
D (mud)	0-75	1.48	69.20	102.09	0.00010209	1128.28	1.32	64.49	85.10	0.00008510	940.57	187.71
	75-150	0.94	71.89	67.45	0.00006745	745.49	1.09	74.88	81.93	0.00008193	905.52	-160.03
	150-225	0.64	70.27	45.06	0.00004506	498.01	0.67	72.38	48.23	0.00004823	533.07	-35.07
	225-300	0.60	41.77	25.01	0.00002501	276.43	0.47	66.57	31.12	0.00003112	343.93	-67.50
E (long-term)	0-75	2.85	72.68	207.20	0.00020720	1098.06	2.35	66.90	157.33	0.00015733	833.73	264.33
	75-150	1.17	87.73	102.88	0.00010288	545.18	0.78	79.95	62.12	0.00006212	329.20	215.98
	150-225	0.55	79.96	43.88	0.00004388	232.54	0.75	74.07	55.21	0.00005521	292.60	-60.07
	225-300	0.46	74.34	34.32	0.00003432	181.87	0.56	61.40	34.53	0.00003453	183.00	-1.14
	300-375	0.38	78.96	30.04	0.00003004	159.17	0.45	62.36	28.00	0.00002800	148.40	10.77
	375-450	0.29	87.70	25.00	0.00002500	132.50	0.30	71.85	21.60	0.00002160	114.49	18.01
E (short-term)	0-75	2.48	79.63	197.28	0.00019728	1045.48	2.35	66.90	157.33	0.00015733	833.73	211.75
	75-150	1.43	94.58	135.13	0.00013513	716.11	0.78	79.95	62.12	0.00006212	329.20	386.91
	150-225	0.74	90.80	67.18	0.00006718	356.02	0.75	74.07	55.21	0.00005521	292.60	63.41
	225-300	0.46	84.32	38.88	0.00003888	206.05	0.56	61.40	34.53	0.00003453	183.00	23.05
	300-375	0.38	88.44	33.28	0.00003328	176.39	0.45	62.36	28.00	0.00002800	148.40	27.99
	375-450	0.32	79.19	25.25	0.00002525	133.81	0.30	71.85	21.60	0.00002160	114.49	19.32
F	0-75	2.15	128.58	276.64	0.00027664	1466.01	2.76	99.96	275.64	0.00027564	1460.75	5.26
	75-150	0.96	125.65	120.69	0.00012069	639.60	1.31	118.37	155.49	0.00015549	824.03	-184.43
	150-225	0.56	129.12	72.66	0.00007266	385.06	0.47	131.89	61.90	0.00006190	328.02	57.05
	225-300	0.37	133.67	49.84	0.00004984	264.10	0.28	130.83	36.30	0.00003630	192.37	71.73
	300-375	0.32	149.22	48.03	0.00004803	254.53	0.28	134.02	37.61	0.00003761	199.32	55.21
	375-450	0.30	140.67	41.62	0.00004162	220.54	0.19	125.93	24.47	0.00002447	129.69	90.85

Appendix 5.3 Accumulation

The amount of nutrient (N, P, K, Ca, Mg) accumulated in the soil over the period of farm dairy effluent (FDE) application was calculated from the output given in the nutrient budgets prepared by OVERSEER[®]. Since the fertiliser history for each site (except site A) was incomplete, the rates of accumulation were based on the current nutrient regime, even though fertiliser inputs may have been different (and hence different nutrient budgets produced) in the past. The estimated amount of nitrogen immobilised each year for each of the paddocks was taken and multiplied by the number of years of effluent application (equation 7). The output variables from OVERSEER[®] used were the amount of phosphorus absorbed by the soil, and the change in the inorganic pool. These were summed and then multiplied by the number of years of application (equation 8). To calculate the accumulation of the cations (K⁺, Ca²⁺, Mg²⁺) in the soil, the estimated change in the inorganic pool was used, multiplied by the number of years of effluent irrigation (equation 9). For each of these nutrients, the difference between the effluent and non-effluent paddocks was also calculated (equation 10).

$$\text{Yrs of application} \times \text{N immobilised (kg ha}^{-1} \text{ yr}^{-1}) = \text{N accumulated (kg ha}^{-1}) \quad (7)$$

$$\text{Yrs of application} \times (\text{P absorbed} + \text{inorganic pool}) \text{ (kg ha}^{-1} \text{ yr}^{-1}) = \text{P accumulated (kg ha}^{-1}) \quad (8)$$

$$\text{Yrs of application} \times \text{change inorganic pool (kg ha}^{-1} \text{ yr}^{-1}) = \text{Accumulated cation} \quad (9)$$

$$\text{Effluent (kg ha}^{-1}) - \text{Non-Effluent (kg ha}^{-1}) = \text{Difference (kg ha}^{-1}) \quad (10)$$

The calculation of accumulation of P, K, Ca and Mg for site A was achieved through the summation of the annual nutrient budgets produced (see Appendix two) not through the multiplication of the current values. The current values of absorption, and change in inorganic pool are shown and are based on the most recent inputs, while the total values given are the nutrient budget addition figures.

Appendix 5.3.1 Accumulation of Nitrogen

Site	Years of application	EFFLUENT		NON-EFFLUENT		Difference (kg/ha)
		N immobilised (kg/ha/yr)	Total immobilised (kg/ha)	N immobilised (kg/ha/yr)	Total immobilised (kg/ha)	
A	20	115	2300	18	360	1940
B	6	142	852	20	120	732
C	6	89	534	63	378	156
D (sand)	16	122	1952	56	896	1056
D (mud)	16	127	2032	56	896	1136
E	10	120	2088	66	660	1428
F	7	97	679	66	462	217

Appendix 5.3.2 Accumulation of Phosphorus

Site	Years of application	EFFLUENT				NON-EFFLUENT				Difference (kg/ha)
		P immobilised (kg/ha/yr)	Change in org pool (kg/ha/yr)	Net gain/loss P (kg/ha/yr)	Total accum/lost (kg/ha)	P immobilised (kg/ha/yr)	Change in org pool (kg/ha/yr)	Net gain/loss P (kg/ha/yr)	Total accum/lost (kg/ha)	
A	20	29	-1	28	960	25	-20	5	466	494
B	6	33	39	72	432	22	14	36	216	216
C	6	47	-49	-2	-12	52	-23	29	174	-186
D (sand)	16	34	-19	15	240	32	15	47	752	-512
D (mud)	16	31	-16	15	240	32	15	47	752	-512
E	10	88	-69	19	190	62	-13	49	490	-300
F	7	52	8	60	420	55	-9	46	322	98

Appendix 5.3.3 Accumulation of Potassium

Site	Years of application	EFFLUENT		NON-EFFLUENT		Difference (kg/ha)
		Change inorganic pool (kg/ha/yr)	Total accum/lost (kg/ha)	Change inorganic pool (kg/ha/yr)	Total accum/lost (kg/ha)	
A	20	-84	2352	-60	-1036	3388
B	6	60	360	-14	-84	444
C	6	20	120	-29	-174	294
D (sand)	16	158	2528	-11	-176	2704
D (mud)	16	9	144	-11	-176	320
E	10	-42	-420	12	120	-540
F	7	-29	-203	-12	-84	-119

Site	Years of application	EFFLUENT		NON-EFFLUENT		Difference in inputs (kg/ha)	Difference found in soil (kg/ha)	Difference in leaching (kg/ha)	Total (soil+leaching) (kg/ha)
		K inputs (kg/ha/yr)	Total inputs (kg/ha)	K inputs (kg/ha/yr)	Total inputs (kg/ha)				
A	20	249	5571	56	1473	4098	1204	672	1876
B	6	340	2040	130	780	1260	496	792	1288
C	6	153	918	57	342	576	194	270	464
D (sand)	16	271	4336	100	1600	2736	414		
D (mud)	16	274	4384	100	1600	2784	402	2544	2946
E	10	175	3558	101	1010	2548	360	1948	2308
F	7	290	2030	106	742	1288	504	1001	1505

Appendix 5.3.4 Accumulation of Calcium

Site	Years of application	EFFLUENT		NON-EFFLUENT		Difference (kg/ha)
		Change inorganic pool (kg/ha/yr)	Total accum/lost (kg/ha)	Change inorganic pool (kg/ha/yr)	Total accum/lost (kg/ha)	
A	20	-93	801	-131	345	456
B	6	-43	-258	-42	-252	-6
C	6	-131	-786	-38	-228	-558
D (sand)	16	-43	-688	-109	-1744	1056
D (mud)	16	-164	-2624	-109	-1744	-880
E	10	-37	-370	-50	-500	130
F	7	-79	-553	-88	-616	63

Appendix 5.3.5 Accumulation of Magnesium

Site	Years of application	EFFLUENT		NON-EFFLUENT		Difference (kg/ha)
		Change inorganic pool (kg/ha/yr)	Total accum/lost (kg/ha)	Change inorganic pool (kg/ha/yr)	Total accum/lost (kg/ha)	
A	20	63	478	40	-32	510
B	6	19	114	-10	-60	174
C	6	6	36	19	114	-78
D (sand)	16	33	528	-2	-32	560
D (mud)	16	-2	-32	-2	-32	0
E	10	1	10	11	110	-100
F	7	23	161	5	35	126