Environment Waikato Technical Report 2003/15

Reporoa Nitrogen Leaching Trial 1998 – 2002.

Final

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Executive Summary

As a result of increasing concerns about nitrogen (N) leaching from soils with low water holding capacity under irrigated dairying and possible contamination of receiving waters, a trial to investigate N leaching from Pumice Soils (Whenuaroa Series) was established on an irrigated commercial dairy farm at Reporoa in September 1998. The trial (which ceased in September 2002) investigated N leaching and drainage volumes over four years under four different treatments:

1. Non-irrigated dairy farming (*NonIrr*)
2. Dairy farming with effluent irrigation (*Eff*)
3. Dairy farming with water irrigation (*Irr*)
4. Dairy farming with water and effluent irrigation (*IrrEff*)

To obtain representative data from the trial farm, six barrel lysimeters (200 mm dia. x 350 mm deep) were installed in three replicate plots of each treatment, giving a total of 72 lysimeters. Leachate from barrel lysimeters was collected monthly and analysed for N (NO_3-N, NH_4-N and org. N) concentrations. To elucidate the N pathways, pasture N uptake and N inputs (fertiliser, and effluent N) were measured. Meteorological parameters allowing PET estimation, rainfall, soil moisture and soil temperature were also measured on farm. Groundwater and surface water samples were also taken and analysed for mineral N concentrations.

Management of the trial farm changed over the four years of the trial, with intensification in stocking rate and fertiliser inputs from 1998 to 2002, and also changes in grazing patterns. Drainage volumes and N leaching were influenced by drier than average annual meteorological conditions over the majority of the trial. However, results generally showed that N leaching was more related to pasture N use efficiency in the different treatments, than to the total volume of water draining through the soil.

Annual data showed that despite the *Irr* treatment having the greatest drainage volume, it did not have the greatest amount of N leaching. Instead, the *Eff* treatment showed the greatest N leaching losses, which occurred predominantly as NH_4-N and org.N in the month after dairy farm effluent applications. Despite similar N loading to the *Eff* treatment, less N was leached in the *IrrEff* treatment, as water irrigation maintained pasture growth and N uptake in dry periods, resulting in more efficient use of the N applied. The *Irr* and *NonIrr* treatments also had similar N loading, however, drainage volume from the *Irr* treatment was much greater. Despite this, there was no significant difference in N leaching between *Irr* and *NonIrr* treatments. In the water irrigated treatments (*Irr* and *IrrEff*) the constant pasture growth and N uptake throughout dry periods is thought to have prevented a build-up of N in the soil profile. In contrast, a build-up of N is likely to have occurred in the non water-irrigated treatments (*NonIrr* and *Eff*) during dry periods. This excess N was subsequently leached below the root zone when an autumn drainage flush occurred.

Data from the final year of the trial showed that a substantial increase in mineral N fertiliser inputs across all treatments did not result in an increase in pasture growth and N uptake, resulting in increased N leaching from all treatments compared to the previous three years of the trial.

In general results indicated that the nutrient budget of the Overseer decision support model (developed by AgResearch) is useful in determining N leaching trends under different farm management practices.

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1 Introduction and background

This section describes and presents a brief introduction to the potential problems associated with nitrogen leaching under dairy farming, and the reasons for this trial. The objectives of the trial and the layout of this report are also outlined.

1.1 Introduction

Nitrogen (N) is a key nutrient for plant growth in pastoral farming systems. Intensive dairy farming is an important industry in many regions of New Zealand, and N cycling plays a key role in pasture growth and milk production from dairy farms (Ledgard et al. 1996). Therefore, not only from an environmental perspective, but also from a cost-benefit point of view, retention of N in the upper soil profile where it can be utilised by pasture is important. Nitrate-nitrogen (NO_3-N) is a mobile form of N and (because of its negative charge) is readily leached when water drains through the soil and into groundwater (McLaren and Cameron 1990). The amount of N leaching is influenced by the amount of excess N in the soil profile and the volume of water draining through the soil and into groundwater (a function of rainfall, evapotranspiration and the physical characteristics of the soil). High stock density, high N loading rates, high water loading and soils with low water holding capacity may enhance N leaching into groundwater and surface water.

There are increasing pressures being placed on the quality of groundwater and surface waters as a result of land use intensification. N entering ground and surface waters can cause eutrophication of receiving waters, and also pose a health risk where water is used for drinking. Dairy farming is potentially a major contributor of non-point N, as substantial amounts of N are applied to the soil as cow urine and dung from intensive stocking, and as fertiliser. Urine from dairy cows represents a major N leaching risk, as the applied N can occur at very high rates equivalent to 1000 kg N ha^{-1} in localised patches (Haynes and Williams 1992; Ledgard et al. 1996).

A substantial body of research work has been undertaken in New Zealand investigating the dynamics of N cycling under dairy pasture on soils in the Hamilton basin (Ledgard et al. 1996). However, N dynamics under dairy pasture on irrigated Pumice Soils with low water holding capacity are insufficiently understood. Therefore, this trial was established in September 1998 on an irrigated dairy farm on Pumice Soils in the Reporoa basin. The trial was designed to provide information on drainage fluxes, N leaching, efficiency of water use under irrigation, effluent application rates and N cycling under dairy farming on Pumice Soils.

1.2 Objectives of the trial

The objectives of the trial are to:

a) Improve understanding of N dynamics in Pumice Soils over a range of different dairy farming management activities.
b) Obtain information that will help dairy farmers optimise the use of water, and N from fertiliser and effluent.
c) Provide data for landuse impact studies, and for models on dairy farming, N leaching, effluent application and water irrigation.

Fertiliser and dairy farm effluent (DFE) applications, grazings, water irrigation, meteorological conditions, drainage volumes, N leaching, soil conditions (moisture and temperature), pasture growth, pasture N uptake and groundwater NO_3-N concentrations were monitored under four different farming management activities.

1.3 Structure of this report

The body of this report introduces and describes the trial, before the summary and presentation of results. Trial results are then compared to the Overseer nutrient budgeting model developed by AgResearch. Results are then discussed, conclusions drawn and recommendations made. This report contains both hard copy and electronic appendices (on the accompanying CD). The methods used in the trial and publications relating to the trial are presented in the hardcopy appendices, while progress reports and raw data from the trial are in the electronic appendices.

2 Trial description

2.1 Introduction

This section describes the trial location, the soil under investigation and the farming operation at the site. Treatments established to accomplish the objectives of the trial and the methodologies used to evaluate treatments are also described.

2.2 Site and soil

The trial is situated on the McGillivray dairy farm, East Road, Reporoa, New Zealand (NZMS 260 U17 038 953). The trial farm is situated within the Reporoa basin at an elevation of approximately 200 mASL and consists of 100 ha of flat to gently rolling land adjacent to two streams. The Torepatutahi Stream borders the farm to the south and the Rangaakiaki Stream to the west (Figure 1).

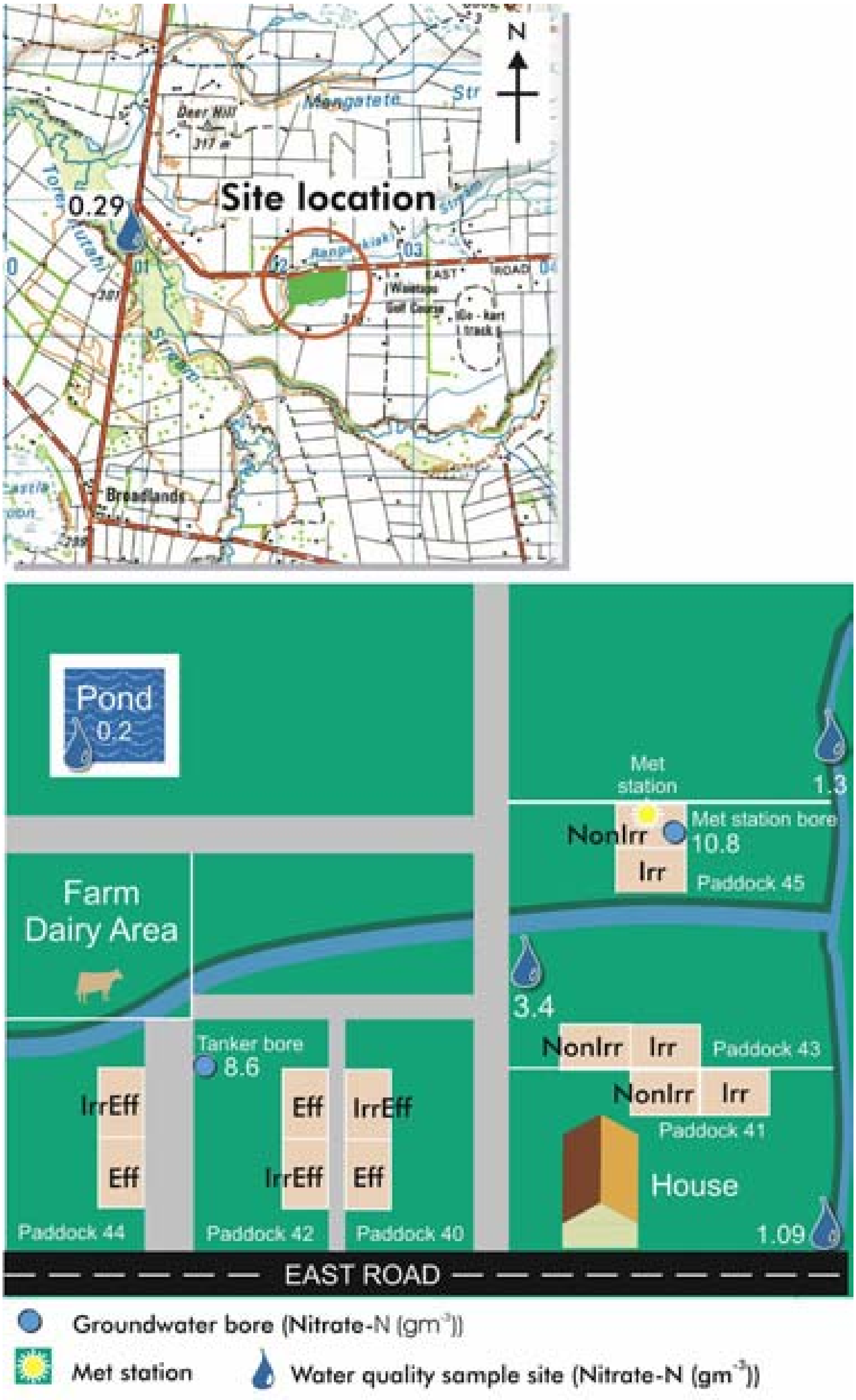

Figure 1. Location of the trial site within the Reporoa basin, and a schematic layout of the trial. Water quality data represents the average of all NO_3-N measurements taken during the four years of trial operation.

The soils on the farm are Whenuaroa series (Sparling et al. 2000), which are well drained soils formed in reworked Taupo Tephra (pumice). These soils are classified as Typic Orthic Pumice Soils in the New Zealand Soil Classification (Hewett, 1998). A brief description of a typical soil at the site is given in Table 1. Figure 2 shows a shallow soil profile at the site. Historical records from the last 20 years showed that average annual rainfall in the Reporoa district is around 1044 mm, generally the wettest month in Reporoa is July (109 mm) and the driest is January (69 mm).

Table 1. Typical soil characteristics at the trial site.

Whenuaroa Series		
Horizon	**Depth**	**Description**
Ap	0 - 15 cm	Very dark brown (10YR 2/2) sandy loam; slightly sticky, non plastic; moderately weak soil strength; friable failure; earthy; many fine roots; sharp smooth boundary,
Bw	15 - 38 cm	Yellowish brown (10YR 5/6) sandy loam; non sticky, non plastic; moderately weak soil strength; friable failure; weakly pedal; few fine roots; distinct wavy boundary,
C	38 - 100 cm+	Light grey (5Y 7/1) sand; very weak soil strength; brittle failure; many weakly weathered rounded Taupo lapilli; massive breaking to single grain; no live roots.

Figure 2. A shallow soil profile at the site.

2.3 Dairy farming operation

A herd of Jersey milking cows are grazed on the 100 ha trial farm. DFE is applied to 25 ha of the farm using a travelling effluent irrigator. Over the trial areas DFE loading was aimed at around 150 kg N ha^{-1} yr^{-1} in accordance with the rules specified in the Proposed Regional Plan. Irrigation water (taken from the Torepatutahi Stream) is applied to the farm during dry months (usually over night) using a "Van Den Bosch" movable lateral sprinkler system, which is moved by hand the day following irrigation. Each sprinkler has a circular spread of around 20 m, and the fact that sprinklers are moved to a new location by eye, means that the system is relatively random with respect to when areas of paddock get irrigated, and how much water they receive.

Fertiliser inputs on the farm, consisting predominantly of urea, potash and super phosphate, varied according to paddock and season. Stocking rate and grazing rotations have changed over the trial. Prior to June 2000 the stocking rate was intensive (up to 4.5 cows ha^{-1}) and cows were wintered on the trial farm. However, during autumn 2000 a second farm was purchased (used predominantly as a winter runoff) and stock numbers increased to around 550 cows. This meant that over winter 2000 grazing pressure on the trial farm decreased, as cows were wintered over on the runoff. There was no grazing of trial paddocks for the majority of the winter months of 2000, 2001 and 2002. The trial farm is now predominantly used for spring, summer and autumn grazing, when optimum pasture growth can be maintained by water irrigation. In the grazing rotation the herd was typically grazed in each paddock for approximately 24 hours.

2.4 Treatments and experimental design

The trial investigated N leaching and drainage volumes under four dairy farming management practices:

1. Non-irrigated dairy farming *(NonIrr)*
2. Dairy farming with effluent irrigation *(Eff)*
3. Dairy farming with water irrigation *(Irr)*
4. Dairy farming with water and effluent irrigation *(IrrEff)*.

Treatment plots (35 m x 35 m) were distributed over six paddocks, and the four treatments established in triplicate resulted in a total of 12 treatment plots (Figure 1). Treatment plots were not fenced to exclude cattle, but were defined by pegs at ground level and sprayed lines in pasture. The relative sizes of paddocks containing treatment plots are given in Table 2.

Table 2. Paddock sizes and treatment plots within each paddock. The area available for water irrigation is the area of plots not receiving water irrigation (0.12 ha.) subtracted from total paddock area.

Paddock No.	Treatments	Paddock size (ha.)	Area available for irrigation (ha.)
40	*Eff* and *IrrEff*	1.28	1.16
41	*Irr* and *NonIrr*	1.4	1.28
42	*Eff* and *IrrEff*	1.4	1.28
43	*Irr* and *NonIrr*	1.5	1.38
44	*Eff* and *IrrEff*	1.6	1.48
45	*Irr* and *NonIrr*	0.9	0.78

2.5 Trial history and measurement dates

The trial was initiated in August 1998 when plots were marked out and soil samples for N concentration analysis were taken from plots by Environment Waikato (EW), details of these initial soil samples can be found in the file "Initial Soil Samples" in Appendix 6. Installation of drainage and N leaching monitoring equipment was subsequently completed by Lincoln Environmental (LE) in September 1998. A Meteorological (Met) station was also installed in May 1999. The equipment and methods used enabled the trial to be run for several years, collecting data over a range of conditions. Details on methods and equipment used in the trial can be found in Appendix 1.

From September 1998 to October 2000 EW was responsible for trial management, while LE was contracted to perform field sampling. In Autumn 2000 a second farm was purchased, and used for growing supplementary feed, and as a winter runoff for the herd of Jersey cows. After October 2000 responsibility for trial management was contracted to LE. Several progress reports (Reports One, Two, Three and Four) have summarised trial data and provided recommendations on trial operation and management. Recommendations in Report One and Report Two included improved monitoring of farm data (fertiliser, grazings and stocking rate changes), DFE application, and water irrigation. New methods to measure pasture yield, pasture botanical composition and DFE loading to each plot were recommended and later implemented. Report Three (*"Reporoa Nitrogen Leaching Trial Progress Report 1998-2001"*) recommended a further season of measurements and also discussed the two N leaching measurement techniques originally used in the trial, providing rationale for using barrel lysimeter data only in future reports and data analysis (see Appendix 1 for a description of the methods, and Appendix 6 for a copy of the report). Soil water samples were still collected from ceramic cup soil solution samplers, and have been frozen and stored by LE, but have not been analysed since 28/6/01. Trial measurements ceased in September 2002.

In February 2002 a conference paper summarising the first three years of trial data (Appendix 2) was presented by LE at the *"Dairy Farm Soil Management"* conference held jointly by the *Fertiliser and Lime Research Centre* and the *New Zealand Fertiliser Manufacturers Research Association* at Massey University. A poster paper on denitrification work (Appendix 3 and 4) was then presented by LE at the *Land Treatment Collective Conference* at Whangamata in April 2002. An oral presentation and a poster presentation (Appendix 5), including some results from Year Four of the trial was also made by LE at the November 2002 conference of the *New Zealand Society of Soil Science* in Wellington.

Trial data has been collected over four annual periods:

1. September 1998 – August 1999 (Year One)
2. September 1999 – August 2000 (Year Two)
3. September 2000 – August 2001 (Year Three)
4. September 2001 – August 2002 (Year Four)

When examining trial data Summer was defined as including December, January and February; Autumn: March, April and May; Winter: June, July and August; and Spring September, October and November.

Leachate samples were collected approximately monthly. Pasture herbage dry matter yield and N content samples were also collected approximately monthly after these measurements began in September 2000. Collection of data from the met station has been continuous since installation. Collection of other data over the trial has been more sporadic, depending on season and farm management.

3 Trial equipment and methods: Brief introduction

The methods and equipment used in the trial are summarised in Appendix 1, reference is also made to further information on sampling dates and raw data contained in electronic appendices on the CD which accompanies this report.

4 Summary of results

4.1 Introduction

This section summarises all trial results. Water loading, N loading, drainage volumes, N leaching, and pasture N uptake results are summarised on an annual basis. Each section of results makes specific reference to relevant raw data files within Appendix 6.

4.2 Meteorological data

A variety of parameters were measured at the meteorological (Met) station installed on site (See Appendix 1 for details on the parameters and the data sets available). Only the major parameters, which affected trial results are presented here. Where possible trial data is compared to long term average data obtained from nearby sites. All raw data collected from the Met station is displayed in the "Met data" file in Appendix 6.

4.2.1 Rainfall

Cumulative rainfall over the trial is compared to 20 years of historical data (from the NIWA Sylvan lodge site, see the "Sylvan Lodge 20yr rain" file in Appendix 6 in Figure 3). Annual rainfall over the trial was generally less than average, with only Year Four (1038 mm) being close to the 20 year average rainfall (1044 mm). Figure 3 also shows low rainfall in the summer periods of Year One, Year Two and Year Four, with the summer of Year Two recording particularly low rainfall. As with the previous two years, Year Three showed low annual rainfall, but more summer rain than other years of the trial.

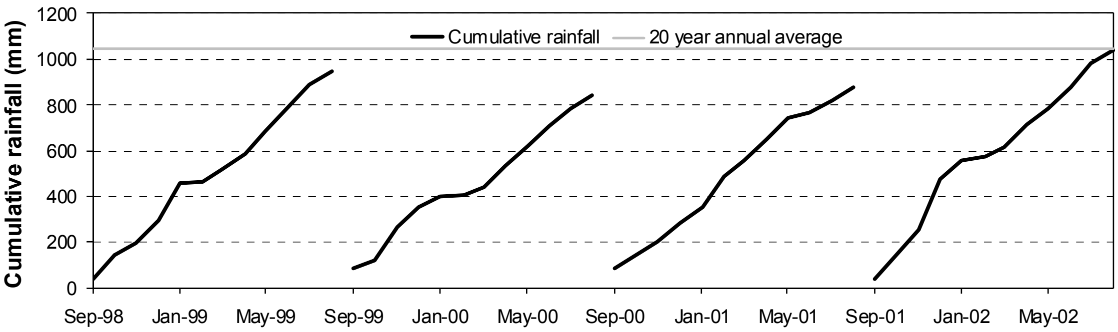

Figure 3. Cumulative rainfall over the trial compared to the 20 year annual average.

The trend of lower than average rainfall is also apparent in Figure 4, which shows that the majority of the months in the trial had below average rainfall.

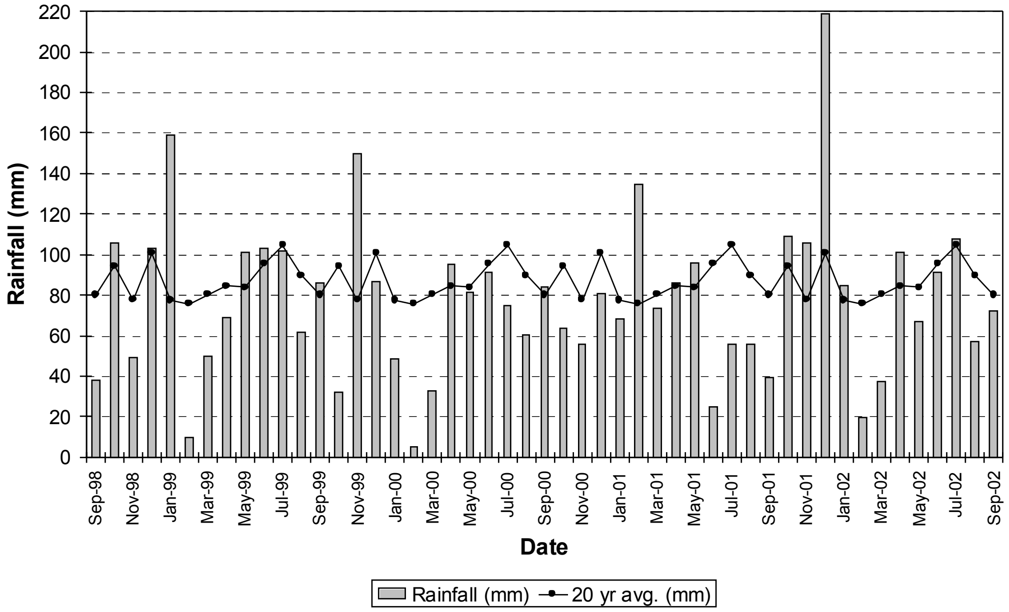

Figure 4. Monthly rainfall over the trial compared to the 20 year monthly average.

4.2.2 Potential evapotranspiration (PET)

Monthly PET over the trial is presented in Figure 5, which indicates that Year one and Year Two of the trial generally had greater PET during summer than Year Three and Year Four. This trend is also reflected in Figure 6, which displays a climatic water balance, showing that Year One and Year Two had greater summer deficits in rainfall than Year Three and Year Four.

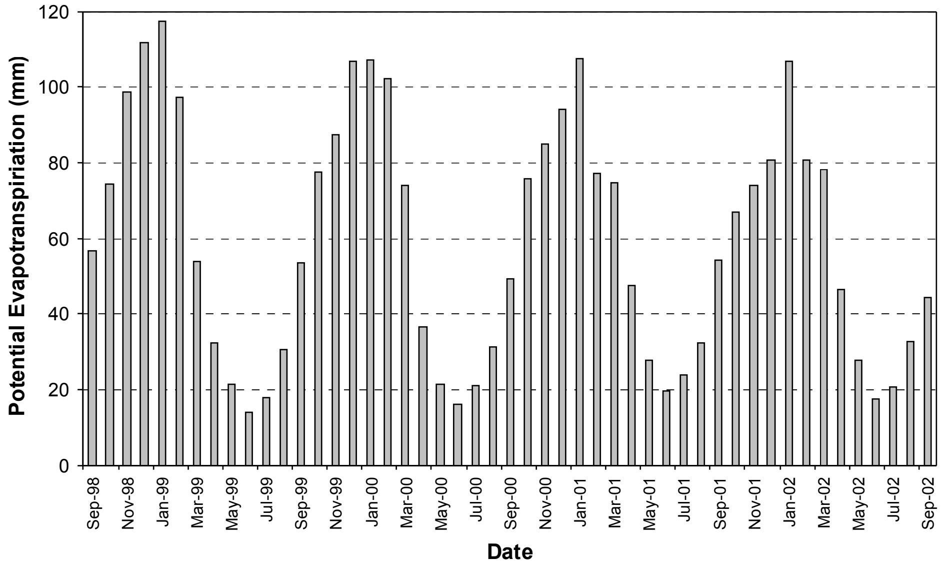

Figure 5. Monthly PET over the trial.

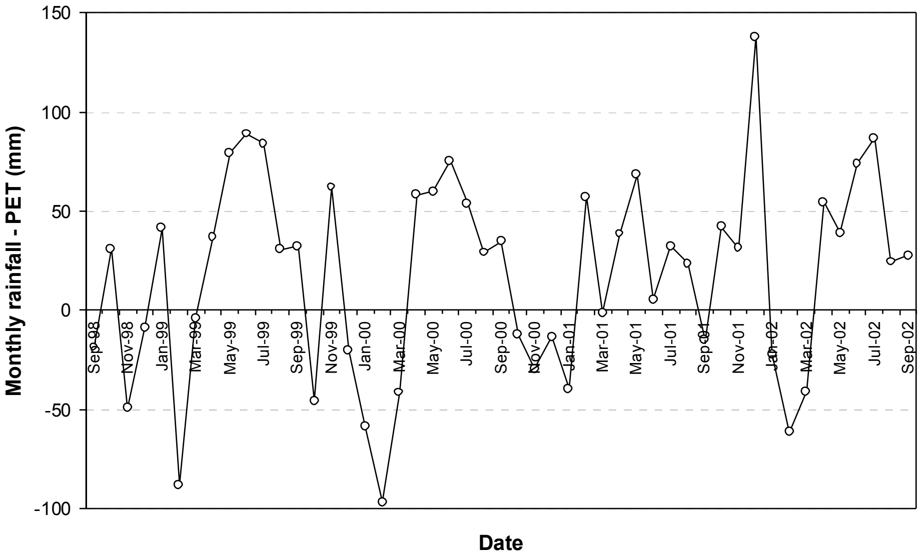

Figure 6. Monthly climatic water balance for the trial.

4.2.3 Volumetric soil water content

Soil water content in the *Irr* treatment remained relatively constant over the trial (at around 45%). Soil water content in the *NonIrr* treatment showed more seasonal fluctuation, Year Two showed low soil water content in the *NonIrr* treatment for several months over summer. Summer soil water content in the *NonIrr* treatment over Year Three also showed more re-wetting events than Year Two or Year Four (Figure 7).

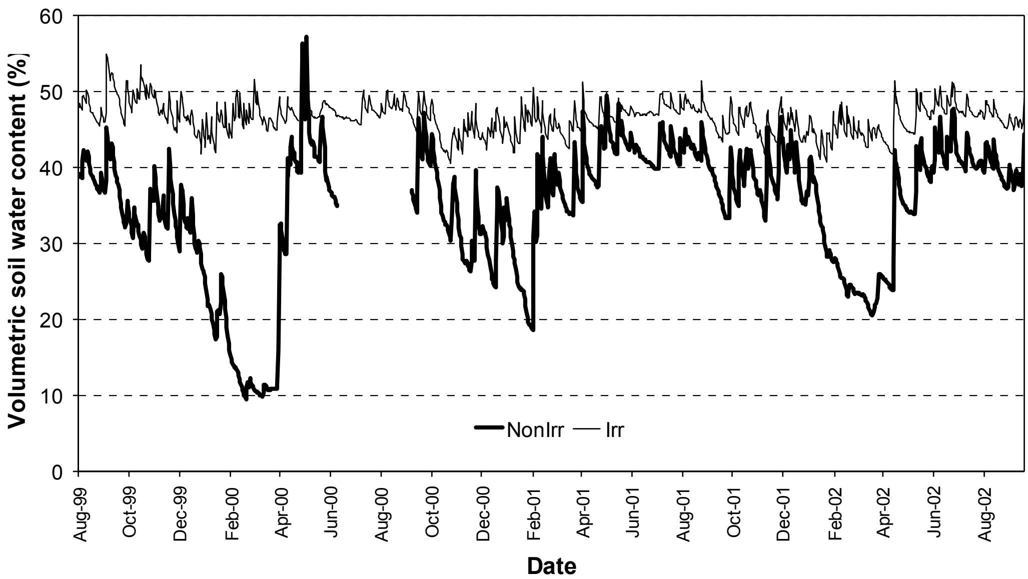

Figure 7. Average volumetric soil water content in the 7-20 cm soil depth zone. The gap in data for the *NonIrr* treatment was caused by damage to the water content probe.

4.2.4 Soil Temperature

Soil temperature showed seasonal fluctuation reaching its highest temperature in Summer of Year Two and lowest temperature in the winter of Year Three (Figure 8).

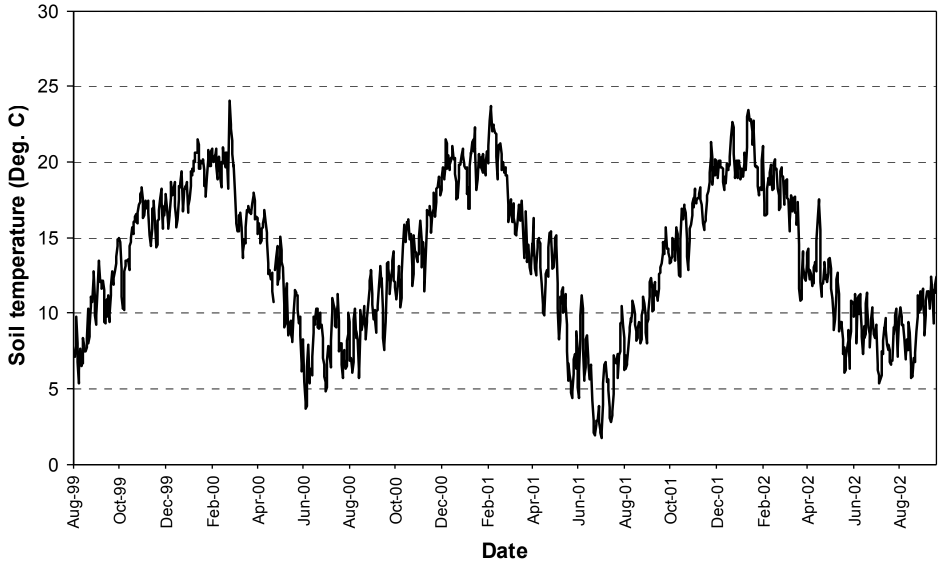

Figure 8. Soil Temperature at 15 cm soil depth.

4.2.5 Groundwater depth below soil surface

Groundwater depth at the site fluctuated around 2.4 m below the soil surface (Figure 9).

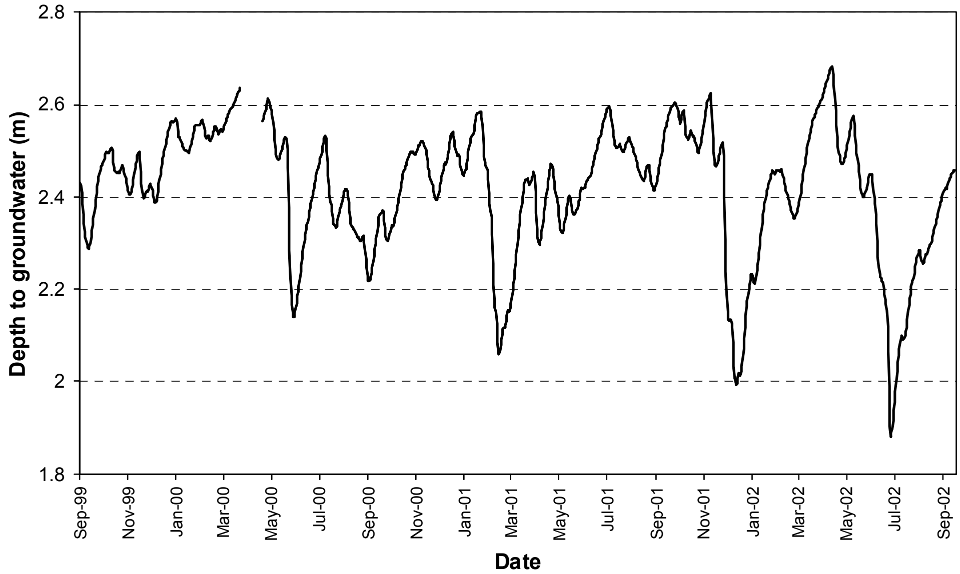

Figure 9. Groundwater depth below soil surface at the Met station bore site.

4.3 Examination of treatment replicate plots

Over the trial it was noted that there were differences in water loading, fertiliser loading and DFE application times and rates between trial paddocks/plots. These differences were related to variations in paddock size, sprinkler flow rates, and the number of sprinklers in each paddock (Reports One, Two and Three). Therefore, it was considered necessary to examine variability between paddocks in each year. A basic examination of variance in data (means, standard deviations and coefficients of variation) between plots in terms of N and water inputs and the number of grazings showed some variation (see the "Comparison of paddocks" file in Appendix 6). However, only the DFE loading to paddocks showed coefficients of variation of 40-50% (other inputs showed coefficients of variation below 30%), indicating that it was reasonable to treat the plots as replicates. Therefore, treatment plots were averaged to obtain a single result for each treatment in a given time period.

4.4 Water loading from rainfall, irrigation water and DFE

Data is presented annually and represents the treatment average loading (Table 3).

Table 3. Water loading over the trial (*, estimated loading based on standard application depth; n.a, not applicable). Totals represent replicate means.

Treatment	Rainfall (mm)	Irrigation (mm)	Water from DFE (mm)	Total loading (mm)
		——— Water loading for Year One ———		
NonIrr	940	n.a	n.a	940
Eff	940	n.a	38*	978*
Irr	940	542	n.a	1482
IrrEff	940	467	38*	1445*
		——— Water loading for Year Two ———		
NonIrr	862	n.a	n.a	862
Eff	862	n.a	32*	894*
Irr	862	528	n.a	1390
IrrEff	862	455	32*	1349*
		——— Water loading for Year Three ———		
NonIrr	861	n.a	n.a	861
Eff	861	n.a	60	921
Irr	861	294	n.a	1155
IrrEff	861	284	54	1199
		——— Water loading for Year Four ———		
NonIrr	1038	n.a	n.a	1038
Eff	1038	n.a	37*	1075
Irr	1038	170	n.a	1208
IrrEff	1038	141	40*	1219

The water irrigated treatments (*NonIrr* and *Eff)* received their greatest water loading in Year Four, while all treatments (except *Eff*) received their lowest water loading in Year Three. The volume of irrigation water applied in the first two years of the trial was also greater than that applied in the last two years of the trial. Estimated DFE hydraulic loadings are described further in the methods section of this report (Appendix 1). The files "Effluent N and Water Loading" and "Irrigation Water Loading" in Appendix 6 contain raw data on water loading.

4.5 Nitrogen loading from fertiliser and DFE

Data is presented annually and represents the treatment average loading (Table 4).

Table 4. Average annual treatment N loadings from fertiliser and DFE over the trial (*, estimated loading; n.a, not applicable). Totals represent replicate means.

Treatment	Mineral N in fertiliser (kg ha^{-1})	Mineral N in DFE (kg ha^{-1})	Mineral N loading (kg ha^{-1})	Organic N in DFE (kg ha^{-1})	Total N loading (kg ha^{-1})
			N loading for Year One		
NonIrr	200	n.a	200	n.a	200
Eff	184	38*	222*	47*	269*
Irr	200	n.a	200	n.a	200
IrrEff	184	38*	222*	47*	269*
			N loading for Year Two		
NonIrr	183	n.a	183	n.a	183
Eff	203	35*	238*	40*	278*
Irr	183	n.a	183	n.a	183
IrrEff	203	35*	238*	40*	278*
			N loading for Year Three		
NonIrr	310	n.a	310	n.a	310
Eff	261	60	321	56	377
Irr	310	n.a	310	n.a	310
IrrEff	261	60	321	65	386
			N loading for Year Four		
NonIrr	411	n.a	411	n.a	411
Eff	417	34*	451*	55*	506*
Irr	411	n.a	411	n.a	411
IrrEff	417	66*	483*	92*	575*

Mineral N loading was similar for all treatments in the first two years of the trial, but then increased in Year Three and again in Year Four, when mineral N loading was in excess of 400 kg ha^{-1} for all treatments. Estimated DFE N loadings are described further in the methods section of this report (Appendix 1). The files “Effluent N and Water Loading” and “Fert and Grazing” in Appendix 6 have further details and raw data on fertiliser and DFE applications and grazing dates in each trial paddock.

4.6 Drainage volumes

Drainage volume (mm) was calculated for each replicate plot on each sampling occasion. Data is presented annually for each treatment and represents the mean of treatment replicate plot totals for that period.

As Figure 10 shows, the *Irr* treatment had the greatest drainage volume in all four years of the trial. Trends for other treatments were less clear. However, all treatments showed their greatest drainage volumes in Year Four of the trial and their lowest drainage volumes in Year Two. Table 5 further examines drainage volume treatment means.

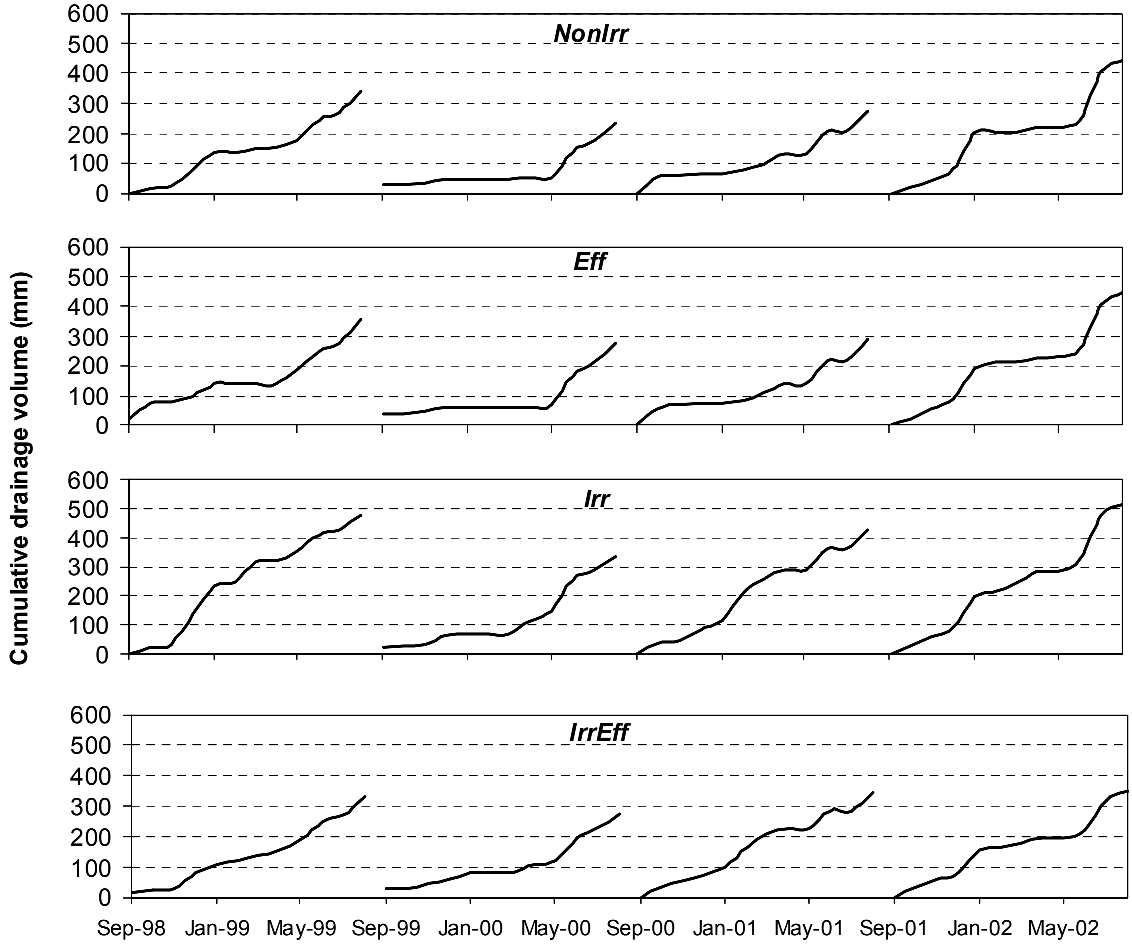

Figure 10. Cumulative drainage volumes over the trial. Totals represent replicate means.

Table 5. Examination of variability in drainage volumes over the trial. Treatment totals represent replicate means. [a], indicates significant difference (P<0.05) from other replicate means in an annual period.

Treatment	Drainage volume (mm)	Standard deviation (kg ha^{-1})	Coefficient of variation (%)
—— Drainage volume data for Year One ——			
NonIrr	352	34	10
Eff	354	76	22
Irr	480[a]	27	6
IrrEff	330	33	10
—— Drainage volume data for Year Two ——			
NonIrr	234	11	5
Eff	279	36	13
Irr	334	65	19
IrrEff	277	74	27
—— Drainage volume data for Year Three ——			
NonIrr	275	39	14
Eff	286	56	20
Irr	427	60	14
IrrEff	347	143	41
—— Drainage volume data for Year Four ——			
NonIrr	443	56	13
Eff	448	34	8
Irr	514	103	20
IrrEff	351	118	34

The *IrrEff* treatment had greatest variation in drainage volume in the last three years of the trial. Further examination of data showed that this was due to lower drainage volumes in the *IrrEff* plot in paddock 44 over the entire trial, which in turn was related to a lower irrigation water loading in this paddock compared to other *IrrEff* paddocks. The only statistically significant difference (P<0.05) in drainage volumes was recorded in Year One of the trial when the *Irr* treatment had significantly greater drainage volume than all other treatments (Table 5).

Complete drainage volume results and raw data can be found in the file "Sample Bulking" in Appendix 6.

4.7 Mineral N leaching

N leaching (kg ha^{-1}) was calculated for each replicate plot on each sampling occasion. Data is presented annually for each treatment and represents the mean of treatment replicate plot totals for that period.

Although differences were not statistically significant (P<0.05), trends showed that the *Eff* treatment consistently had the greatest mineral N leaching over the trial, which was typically greatest following DFE applications in spring and autumn (Figure 11). All treatments showed their greatest mineral N leaching in Year Four of the trial, which was a sharp increase in all treatments when compared previous years data. All treatments also showed low mineral N leaching in Year Two, with estimates from the *NonIrr* and *IrrEff* treatments being particularly low.

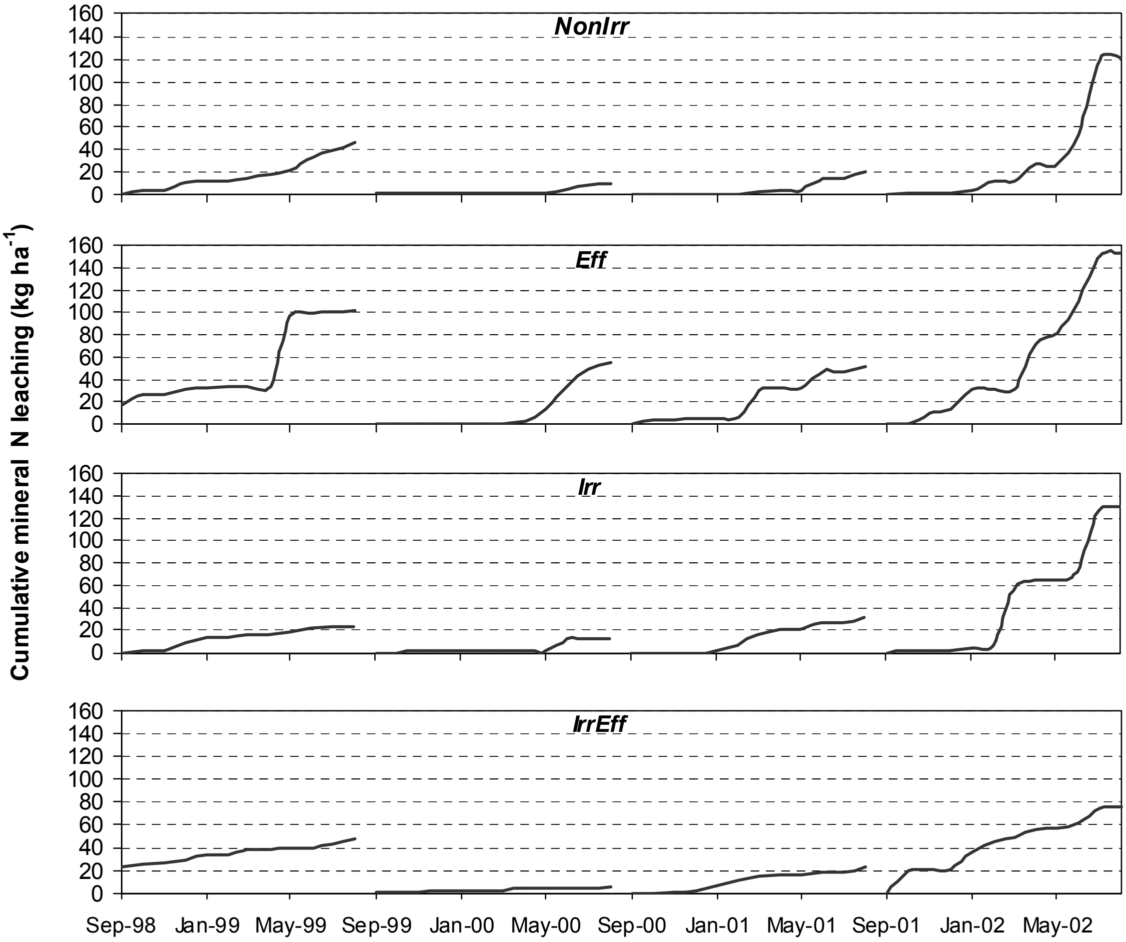

Figure 11. Cumulative mineral N leaching over the trial. Totals represent replicate means.

Mineral N leaching was characterised by high variability between replicate plots in all treatments. This was particularly apparent in plots receiving DFE as applications to different paddocks often occurred during different months, and paddocks often received variable loading rates (Table 6).

Table 6. Examination of variability in mineral N leaching over the trial. Treatment totals represent replicate means.

Treatment	Mineral N leaching (kg ha^{-1})	Standard deviation (kg ha^{-1})	Coefficient of variation (%)
	—— N leaching for Year One ——		
NonIrr	46	37	82
Eff	101	96	95
Irr	23	19	82
IrrEff	48	32	66
	—— N leaching for Year Two ——		
NonIrr	9	8	95
Eff	56	42	75
Irr	13	19	153
IrrEff	5	7	132
	—— N leaching for Year Three ——		
NonIrr	20	18	90
Eff	52	73	140
Irr	31	19	61
IrrEff	23	14	60
	—— N leaching for Year Four ——		
NonIrr	121	110	91
Eff	154	127	83
Irr	130	90	69
IrrEff	76	49	65

Complete mineral N leaching results and raw data can be found in the file "N Leaching" in Appendix 6.

4.8 Organic N leaching, Total N leaching and N species leached

Organic N leaching was measured for *Eff* and *IrrEff* treatments only, where it was considered to be a significant component of total N leaching, while mineral N (NH_4-N, NO_3-N and NO_2-N) was measured for all treatments (Appendix 1).

In Year One NH_4-N was a significant proportion of the mineral N leached from the *Eff* and *IrrEff* treatments only, while in Year Four, NH_4-N was an important component of mineral N leached from all treatments (Table 7). Organic N leaching was 49 kg ha^{-1} from the *Eff* treatment in Year One, but below 10 kg ha^{-1} for all other treatments. In Year Two and Year Three organic N leaching was minimal (both *Eff* and *IrrEff* treatments below 10 kg ha^{-1}). However, in Year four there was again significant organic N leaching with 36 kg ha^{-1} from the *Eff* treatment, and 48 kg ha^{-1} from the *IrrEff* treatment. Year Four also showed an increase in the total N leached from *Eff* and *IrrEff* treatments compared to previous years.

Table 7. Summary of N leaching and N species leached over the trial (n.d, not determined). Totals represent replicate means.

Treatment	NO_3-N + NO_2-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	Mineral N (kg ha^{-1})	Org. N (kg ha^{-1})	Total N (kg ha^{-1})
		N leaching for Year One			
NonIrr	45	1	46	n.d	n.d
Eff	13	88	101	49	150
Irr	22	1	23	n.d	n.d
IrrEff	23	25	48	5	53
		N leaching for Year Two			
NonIrr	9	0	9	n.d	n.d
Eff	40	16	56	8	64
Irr	13	0	13	n.d	n.d
IrrEff	4	1	5	4	9
		N leaching for Year Three			
NonIrr	20	0	20	n.d	n.d
Eff	46	6	52	7	59
Irr	30	1	31	n.d	n.d
IrrEff	22	1	23	6	29
		N leaching for Year Four			
NonIrr	104	17	121	n.d	n.d
Eff	120	34	154	36	190
Irr	79	51	130	n.d	n.d
IrrEff	32	44	76	48	124

Complete N leaching results and raw data can be found in the file “N Leaching” in Appendix 6.

4.9 Total nitrogen loading and nitrogen leaching.

Total N loading and N leaching for the four years of the trial is summarised in Table 8.

Table 8. Total N applied and N leached over the trial. Totals with an asterisk (*) represent estimated loadings.

Treatment	N applied as fertiliser and DFE			*N leached*	
	Fertiliser N (kg ha^{-1})	Total DFE N (kg ha^{-1})	Total N (kg ha^{-1})	*Mineral N (kg ha^{-1})*	*Total N (kg ha^{-1})*
		Year One			
NonIrr	200	n.a	200	*46*	*n.d*
Eff	184	85*	269*	*101*	*150*
Irr	200	n.a	200	*23*	*n.d*
IrrEff	184	85*	269*	*48*	*53*
		Year Two			
NonIrr	183	n.a	183	*9*	*n.d*
Eff	203	75*	278*	*56*	*64*
Irr	183	n.a	183	*13*	*n.d*
IrrEff	203	75*	278*	*5*	*9*
		Year Three			
NonIrr	310	n.a	310	*20*	*n.d*
Eff	261	116	377	*52*	*59*
Irr	310	n.a	310	*31*	*n.d*
IrrEff	261	125	386	*23*	*29*
		Year Four			
NonIrr	411	n.a	411	*121*	*n.d*
Eff	417	89*	506*	*154*	*190*
Irr	411	n.a	411	*130*	*n.d*
IrrEff	417	158*	575*	*76*	*124*

In Year One over 50% of the N applied to the *Eff* treatment was leached. In Year Two and Year Three only a small proportion of the N applied to all treatments was leached, whereas in Year Four a greater proportion of the N applied to all treatments was leached, indicating that surplus N was applied. This is also shown in Figure 12 which indicated that a strong relationship between mineral N applied and mineral N leached for the non DFE irrigated treatments (*NonIrr* and *Irr*) only developed when data from Year Four (which had high fertiliser mineral N inputs) was included.

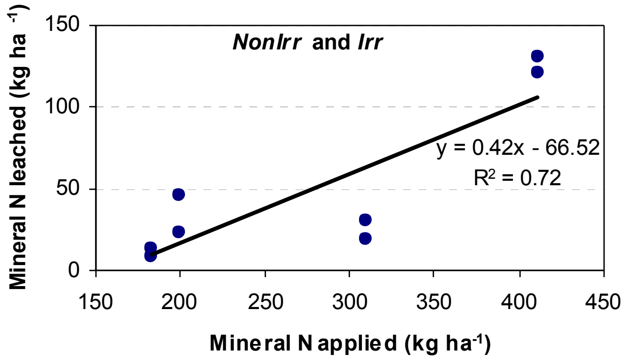

Figure 12. Relationship between mineral N applied and mineral N leached for treatments not receiving DFE irrigation (*NonIrr* and *Irr*).

The relationship between total N applied and total N leached for the DFE irrigated treatments (*Eff* and *IrrEff*) was weaker than that for non-DFE irrigated treatments (Figure 13).

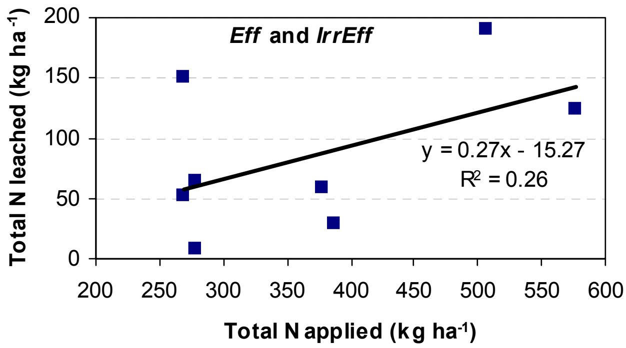

Figure 13. Relationship between estimated total N applied and total N leached for treatments receiving DFE irrigation (*Eff* and *IrrEff*).

In further data analysis drainage volumes were combined with mineral N leaching, to determine the extent to which drainage volume influenced N leaching. Trial mineral N leaching results were arbitrarily separated into annual periods when mineral N inputs were < 350 kg ha^{-1} or > 350 kg ha^{-1} (Figure 14). Results indicated no relationship between mineral N leached and drainage volume when annual mineral N inputs were < 350 kg ha^{-1} (the first three years of the trial). However, when annual mineral N inputs were > 350 kg ha^{-1} (Year Four) drainage volume became more related to mineral N leached, as there was surplus N in the soil profile which was readily leached.

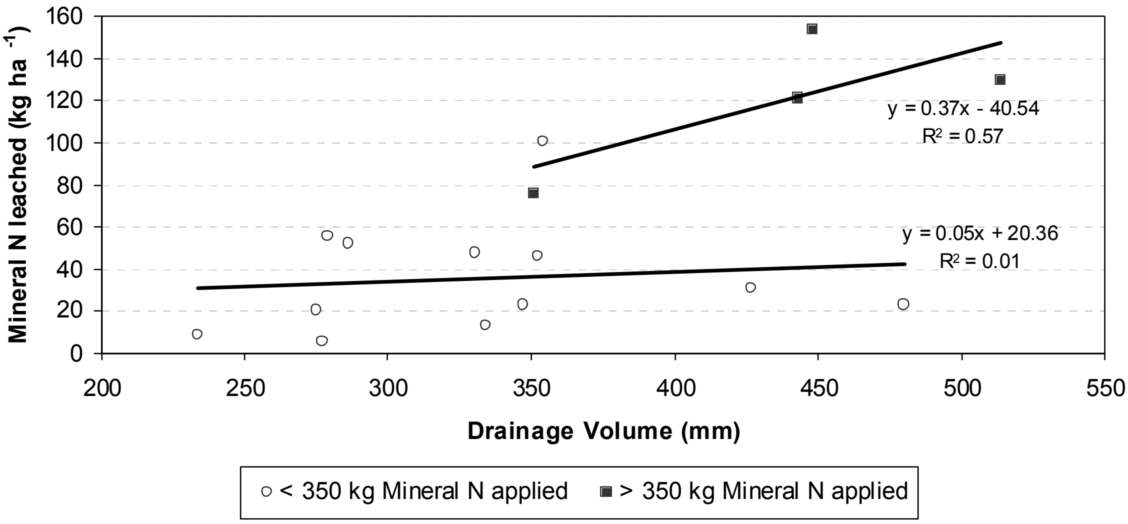

Figure 14. Relationship between mineral N leached and drainage volume for different mineral N fertiliser application rates.

4.10 Estimated annual average NO_3-N concentrations in drainage water

The annual average NO_3-N concentration in water draining from below 350 mm deep was estimated by dividing the average total NO_3-N leached by the average total drainage volume for each treatment (Table 9).

Table 9. Estimated annual average drainage water NO_3-N concentrations (g m^{-3}). *, levels above the 11.3 g m^{-3} New Zealand Drinking Water Standard for NO_3-N.

	***NonIrr* drainage water NO_3-N (g m^{-3})**	***Eff* drainage water NO_3-N (g m^{-3})**	***Irr* drainage water NO_3-N (g m^{-3})**	***IrrEff* drainage water NO_3-N (g m^{-3})**
Year One	13.2*	3.7	4.6	7.0
Year Two	3.8	14.3*	3.9	1.4
Year Three	7.2	16.1*	7.0	6.3
Year Four	23.5*	26.9*	15.4*	9.1

Water draining from the *NonIrr* treatment in Year One had estimated NO_3-N levels greater than the New Zealand Drinking Water Standard of 11.3 g m^{-3} (Ministry of Health 2000). In Year Two and Year Three NO_3-N levels in water draining from the *Eff* treatment were greater than the New Zealand drinking water standard. In Year Four water draining from the *NonIrr*, *Eff* and *Irr* treatments had NO_3-N levels above the New Zealand Drinking Water Standard, and all treatments showed an increase compared to previous years (Table 9).

4.11 Water quality at the site

4.11.1 Groundwater quality

Groundwater samples from the two wells on site showed that average NO_3-N levels have been increasing and approaching the New Zealand drinking water standard for NO_3-N (Figure 15). The Met station bore was surrounded by paddocks which received water irrigation, and the Tanker track bore was surrounded by paddocks which received both water and DFE application (See Figure 1 for well locations).

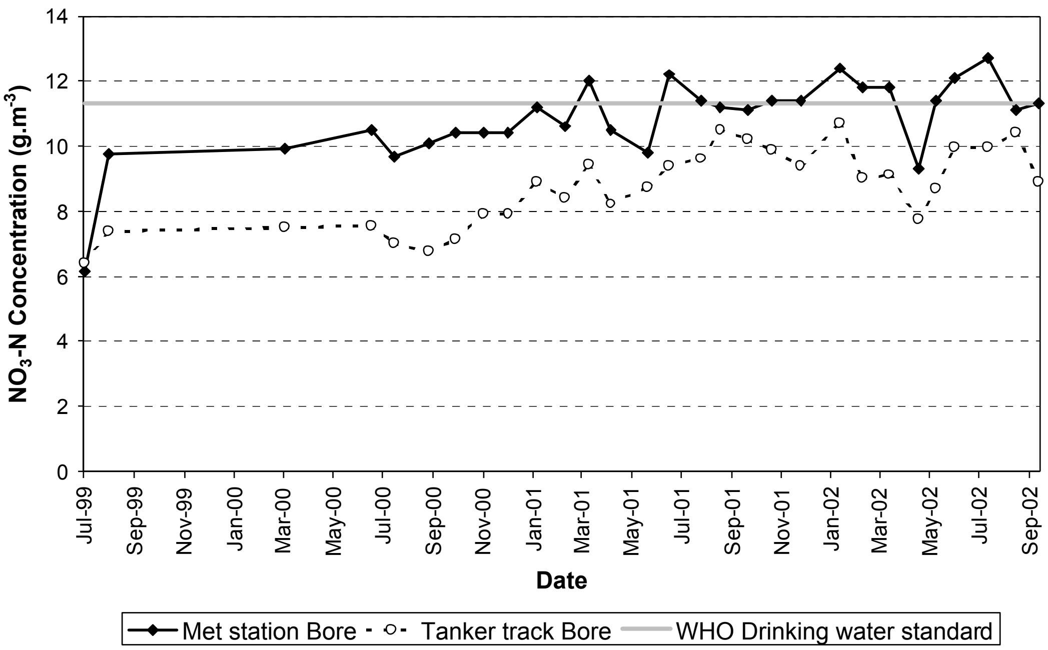

Figure 15. Groundwater NO_3-N concentrations at the site.

Complete groundwater N concentration raw data can be found in the file "Water Quality Raw Data" in Appendix 6.

4.11.2 Surface water quality

Surface water in the area generally showed slight contamination (Table 10). However, samples from the "farm creek" site showed elevated N levels compared with other sites, which were high enough to cause nuisance algae growth in waterways (Wilson, 2000). Locations of surface water sites are shown in Figure 1.

Table 10. Average surface water quality in the trial area. Superscript numbers in brackets refer to the number of samples taken at each site.

Surface water sites	Mineral N (g m^{-3})	Standard deviation (g m^{-3})
Irrigation Pond	0.2$^{(9)}$	0.1
East Road Stream	1.0$^{(22)}$	0.2
Farm creek at race	3.4$^{(30)}$	2.1
Torepatutahi @ Broadlands	0.3$^{(19)}$	0.1
Side stream at confluence	1.3$^{(23)}$	0.2

Complete surface water N concentration raw data can be found in the file "Water Quality Raw Data" in Appendix 6.

4.12 Pasture herbage yield, nitrogen uptake and botanical composition

4.12.1 Herbage yield

As part of improved trial monitoring, measurements of herbage dry matter (DM) yield and N uptake began in September 2000. Seasonal data showed variation and no consistent clear pattern between treatments. Annual data was available for Year Three and Year Four of the trial. Although trends were not significant ($P<0.05$), data from both years showed that the *IrrEff* treatment had the greatest annual herbage DM yield. The *NonIrr*, *Eff* and *IrrEff* treatments all showed slight increases in herbage DM yield From Year Three to Year Four, whereas the *Irr* treatment showed a decline (Table 11).

Table 11. Average annual herbage DM yield from treatments. Totals represent the mean of replicate plot totals.

Treatment	**DM yield (kg ha^{-1})**	Standard deviation (kg ha^{-1})	Coefficient of variation (%)
	Year Three		
NonIrr	15812	1648	10
Eff	17407	2919	17
Irr	16116	1405	9
IrrEff	17426	3381	19
	Year Four		
NonIrr	16607	561	3
Eff	17608	2096	12
Irr	15598	235	2
IrrEff	18546	953	5

Complete herbage DM yield and raw data for each pasture cut can be found in the “Raw Pasture Growth and N Uptake Data” in Appendix 6.

4.12.2 Nitrogen uptake

In Year Three trends showed that N uptake from the water irrigated treatments (*Irr* and *IrrEff)* was greater than the *NonIrr* and *Eff* treatments during summer, while in autumn this trend was reversed, there were no clear trends in spring and winter. In Year Four the *IrrEff* treatment had the greatest N uptake in spring, summer and autumn, trends for other treatments were less clear (Figure 16).

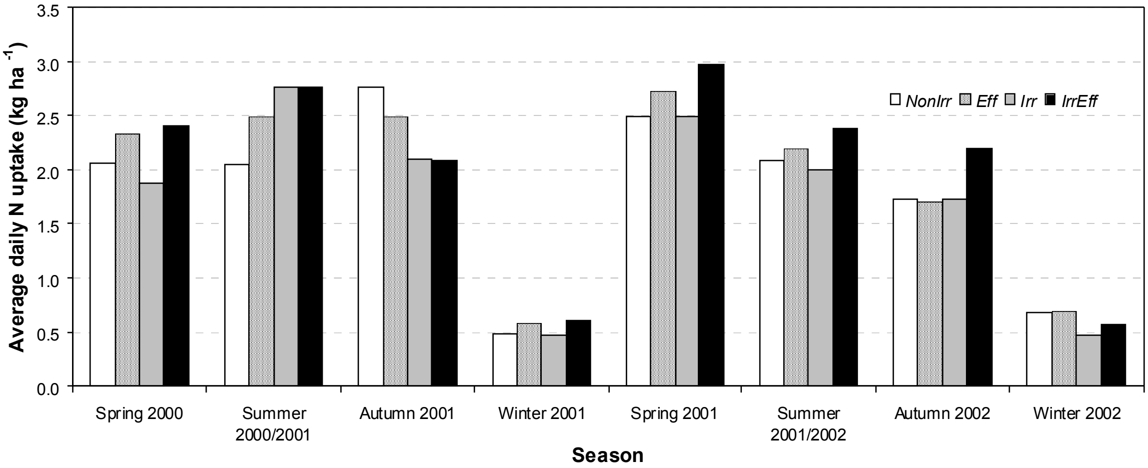

Figure 16. Seasonal N uptake over the trial. Totals represent replicate means.

Overall, the *IrrEff* treatment showed greatest N uptake over the trial. While there was a slight increase in N uptake from the *NonIrr* and *IrrEff* treatments from Year Three to Year Four, there was a decline in N uptake from the *Eff* and *Irr* treatments (Table 12). Statistics performed on average annual N uptake data showed no significant differences ($P<0.05$).

Table 12. Average annual N uptake from treatments. Totals represent the mean of replicate plot totals.

Treatment	**N uptake (kg ha^{-1})**	Standard deviation (kg ha^{-1})	Coefficient of variation (%)
Year Three			
NonIrr	**614**	72	12
Eff	**664**	109	16
Irr	**607**	44	7
IrrEff	**660**	141	21
Year Four			
NonIrr	**627**	30	5
Eff	**647**	83	13
Irr	**588**	24	4
IrrEff	**715**	61	9

4.12.3 Botanical composition

Three pasture botanical composition measurements were performed over the trial. The pasture grasses found in botanical compositions are referred to by their common names in the figures and text of this report, Table 13 gives the binomial names of the species referred to. Results (summarised in Figures 17, 18 and 19) generally showed that treatments which received irrigation water (*Irr* and *IrrEff*) had more rye grass and clover than other treatments. Full results and raw data are presented in the “Pasture Botanical Composition” file in Appendix 6.

Table 13. Names of pasture species.

Common name	Binomial
rye grass	*Lolium perenne*
annual poa	*Poa annua*
prairie grass	*Bromus wildenowii*
couch	*Agropyron repens*
cocks foot	*Dactylis glomerata*
brown top	*Agrostis capillaris*
summer grass	*Digitaria sanguinalis*

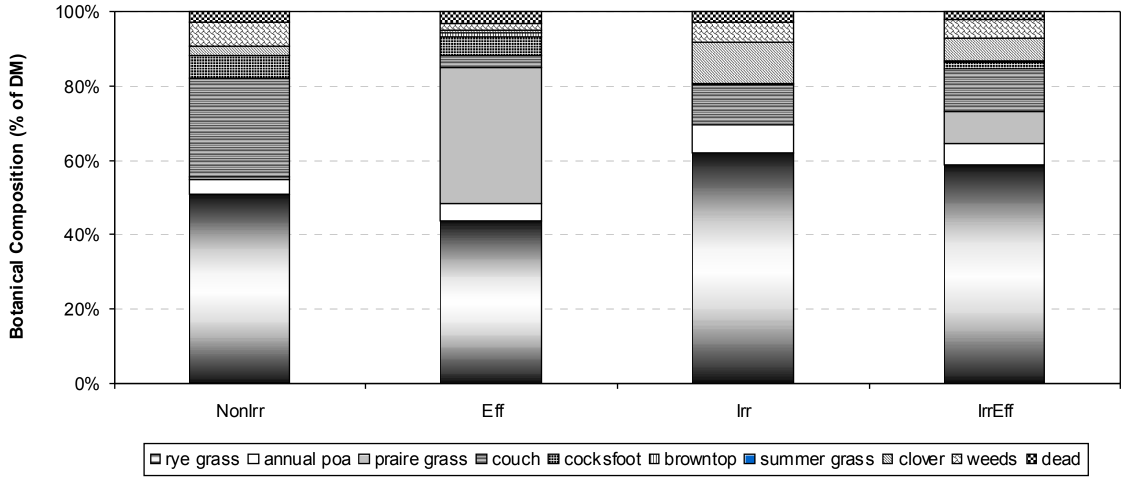

Figure 17. Botanical composition averaged for treatment 22nd March 2001.

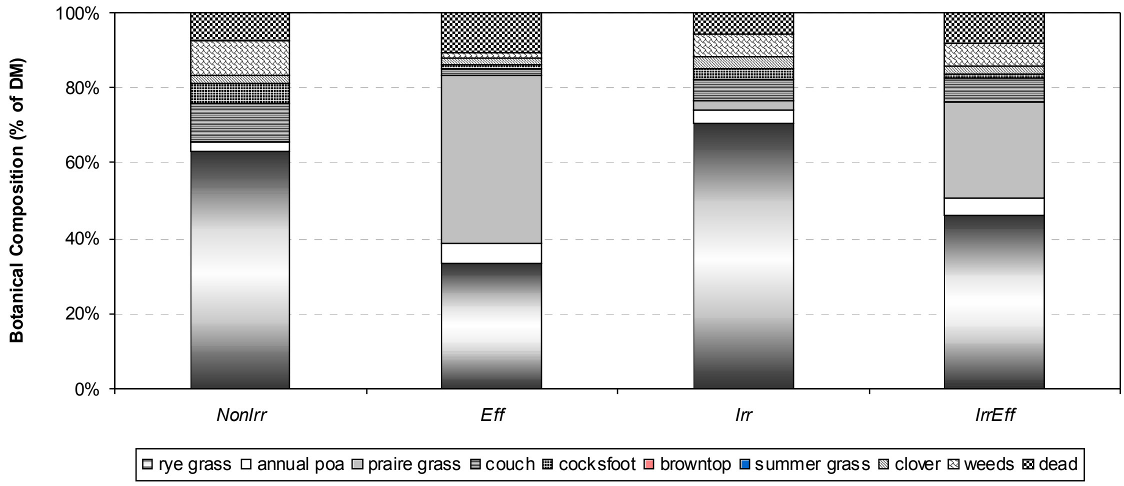

Figure 18. Botanical composition averaged for treatment 3rd June 2001.

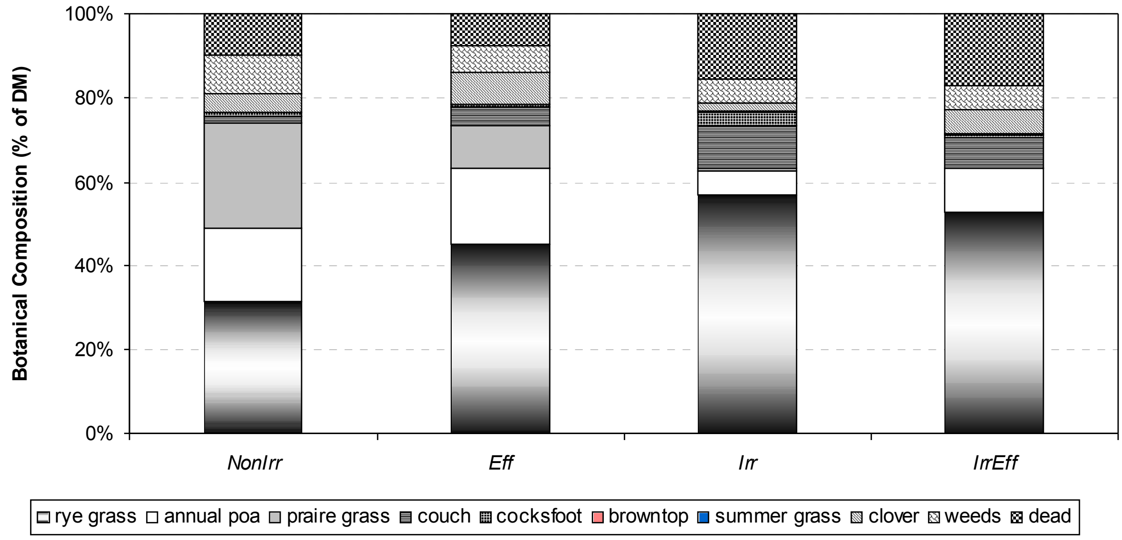

Figure 19. Botanical composition averaged for treatment 6th December 2001.

5 Comparison of trial results with Overseer

5.1 Introduction

Annual N leaching results from the trial treatments were compared to N leaching predicted by the nutrient budget in the Overseer V.4.0 (Overseer) decision support model developed by AgResearch. Given that each year of the trial was unique with respect to fertiliser inputs and grazing regimes, treatment average data were used for each annual period, with treatments set up as "blocks" in Overseer.

Several assumptions and compromises had to be made in Overseer, as it was designed for a different temporal scale than the plot data from the trial. Overseer was developed to provide information on a long term basis (over several years), rather than a single year, and also designed more to analyse entire farm systems, rather than plot areas. The changes in farm management during the four years of the trial (fertiliser applications, supplements, stocking rate and grazing patterns) also made the comparison of Overseer with trial data difficult, as the farm system was not in "steady state".

In the comparison there were two Overseer simulations:

1. Simulation One. A "standard" simulation for each treatment in each year used only data which would be readily available to farm managers and regulatory authorities. This included rainfall, stocking rate (and grazings), production (milk solids), fertiliser inputs, supplements, and volume of clean water irrigation.
2. Simulation Two. A subsequent simulation used simulation one information plus the N and hydraulic loading from DFE measured in the trial to adjust the DFE N loading (to *Eff* and *IrrEff* plots) calculated by Overseer. The DFE N loading calculated by Overseer was adjusted to within 5% of the measured DFE N loading by adjusting the area of the farm to which DFE was applied in Overseer. The measured hydraulic loading from DFE was also added as irrigation in Overseer, to achieve the same total water loading.

Unfortunately there were no records on supplements (mainly silage) bought on to the trial farm. No silage was bought onto the trial farm (from an off farm source) in Year One of the trial. In the following years of the trial a second farm was purchased, cows were wintered off the trial farm and silage was also bought in from an off farm source. Farm managers estimated that approximately 4 kg per cow of wet maize silage was fed out from September until early January in Years Two, Three and Four.

Total N leaching in the trial was measured for areas receiving DFE (*Eff* and *IrrEff* treatments), while mineral N leaching was determined for *NonIrrr* and *Irr* treatments, where Organic N leaching was considered to be minimal. Overseer makes a similar assumption that Organic N leaching is minimal from areas not receiving organic amendments.

5.2 Results

5.2.1 Simulation one

Table 14 displays measured and predicted results using standard information available to farmers and regulatory authorities.

Table 14. Trial N leaching results compared to results from Overseer 4.0 (n.d, not determined). Trial results are subtracted from Overseer results in the difference column.

Year	Measured Mineral N leaching (kg ha^{-1})	Measured Total N leaching (kg ha^{-1})	Overseer predicted Total N leaching (kg ha^{-1})	Difference (kg ha^{-1})
N leaching for the *NonIrr* treatment				
Year One	46	n.d	59	13
Year Two	9	n.d	39	30
Year Three	20	n.d	50	30
Year Four	121	n.d	85	-36
Average	***49***	**n.d**	***58***	***9***
N leaching for the *Eff* treatment				
Year One	101	150	69	-81
Year Two	56	64	57	-7
Year Three	52	59	61	2
Year Four	154	190	112	-78
Average	**91**	***116***	***75***	***-41***
N leaching for the *Irr* treatment				
Year One	23	n.d	63	40
Year Two	13	n.d	44	31
Year Three	31	n.d	52	21
Year Four	130	n.d	90	-40
Average	***49***	**n.d**	***62***	***13***
N leaching for the *IrrEff* treatment				
Year One	48	53	75	22
Year Two	5	9	63	54
Year Three	23	29	63	34
Year Four	76	124	113	-11
Average	***38***	***54***	***79***	***25***

Overseer overestimated N leaching in the *NonIrr*, *Irr* and *IrrEff* treatments in the first three years of the trial, and generally underestimated N leaching from the *Eff* treatment over the trial.

Overseer underestimated leaching from all treatments in Year Four of the trial. As the data in Figure 20 shows, Overseer generally overestimated N leaching from the trial treatments when measured N leaching was under 100 kg ha^{-1}, and underestimated N leaching when measured N leaching was over 100 kg ha^{-1} (generally in Year Four of the trial).

Averaged N leaching data for the entire trial showed closer agreement between Overseer predictions and measured N leaching from the non-DFE treatments (*NonIrr* and *Irr*), however, the DFE treatments (*Eff* and *IrrEff*) still showed a poor comparison between measured and predicted N leaching (Table 14).

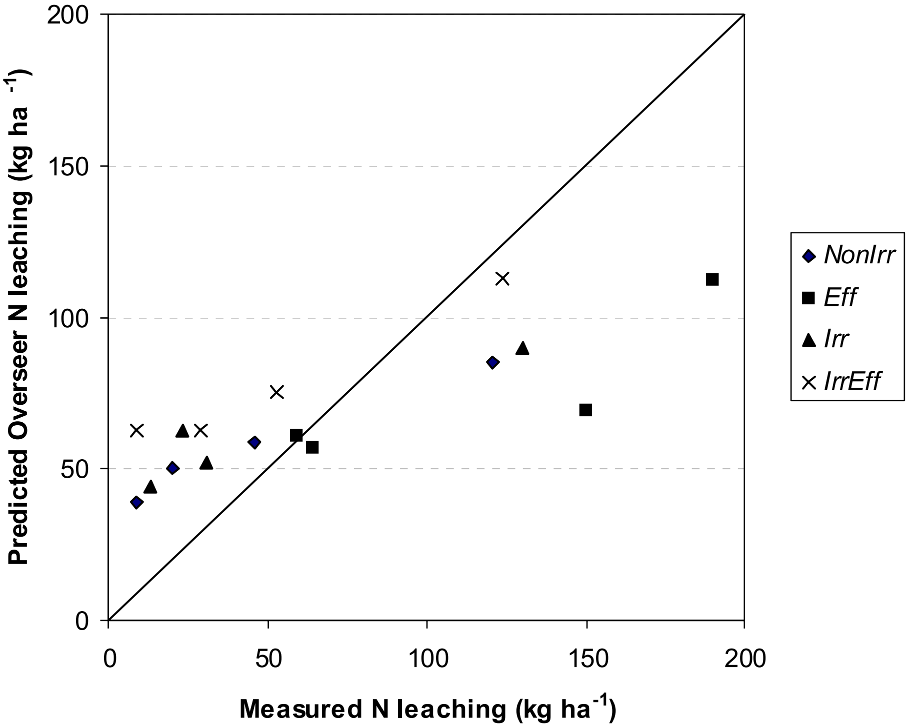

Figure 20. Comparison of measured N leaching and Overseer predicted N leaching. Line indicates a 1:1 relationship.

Although not in the scope of this report, application data for P, K and S fertilisers was also entered to the Overseer nutrient budget. Overseer predicted significant amounts of K and S leaching in all years of the trial, particularly under the DFE treatments (*Eff* and *IrrEff*).

5.2.2 Simulation two

Table 15 displays measured and predicted results when Overseer was adjusted for information on DFE N and hydraulic loading as measured for the two treatments receiving DFE in the trial (*Eff* and *IrrEff* treatments).

Table 15. Trial N leaching results compared to results from Overseer. Trial results are subtracted from Overseer results in the difference column.

Year	Measured Total N leaching (kg ha^{-1})	Overseer predicted Total N leaching (kg ha^{-1})	Difference (kg ha^{-1})
	——— N leaching for the *Eff* treatment ———		
Year One	150	63	-87
Year Two	64	47	-17
Year Three	59	53	-6
Year Four	190	94	-96
Average	**116**	**64**	**-52**
	——— N leaching for the *IrrEff* treatment ———		
Year One	53	68	15
Year Two	9	48	39
Year Three	29	56	27
Year Four	124	104	-20
Average	**54**	**69**	**15**

By adjusting of the area to which DFE was applied in Overseer it was possible to match Overseer DFE N loading with measured DFE N loading. However, the matching of DFE N loadings did not show any clear improvement in the comparison between measured and predicted N leaching results (Table 15).

6 Discussion of Results

The trial dairy farm represented an intensive operation compared to other dairy farms. Stocking rates over the majority of the trial fluctuated around 4.5 to 5.5 cows ha^{-1} compared to the national average of 2.7 cows ha^{-1} (Livestock Improvement, 2003). To support the stocking rate, farm inputs of water irrigation and fertilisers were also intensive.

Meteorological data showed that the first three years of the trial were conducted in drier than average annual conditions, with the period from spring 1999 until autumn 2000 (in Year Two) being particularly dry. Only Year Four of the trial had average annual rainfall. As noted by Ledgard et al. (1996), differences in rainfall and associated drainage can cause large differences in N leaching estimates between years, and alternating dry and wet periods can result in carryover of potentially leachable N from dry periods to wetter periods. Others have also noted that measuring N leaching over several years is vital to cover climatic variation and account for carryover effects (Ledgard et al. 1996; Scholefield et al. 1993). Carryover effects can help to explain variation between years for steady state systems. The fact that the farm system intensified over the trial also caused additional variation in results.

In examining results it can be seen that certain combinations of climatic and soil and plant conditions are more prone to producing N leaching. Dry summer climatic conditions and soil with low water holding capacity without irrigation can result in low pasture growth and plant N uptake (as observed in Year One and Year Two), this combined with low drainage volumes, can lead to a build up of excess N in the soil profile. Large drainage events after dry periods can then leach the excess N from the soil profile before pasture growth and associated pasture N uptake is possible. Optimal irrigation will maintain plant growth and N uptake over dry periods without inducing excessive drainage events, thereby minimising soil N build up and N leaching.

The climatic water balance in Year One showed a dry period during summer. Pasture in non-water irrigated treatments (*NonIrr* and *Eff*) was observed to wilt, this presumably resulted in a build up of soil N in these areas, which was then leached during the drainage flush induced by autumn rainfall. High organic N and NH_4-N leaching losses from DFE irrigated treatments (*Eff* and *IrrEff)* soon after DFE application during Year One also suggested bypass flow due to heavy DFE application. The *Eff* treatment recorded greatest leaching. Cows were also wintered on the trial farm, which could have led to more N leaching over winter (from dung and urine inputs), as opposed to subsequent years of the trial when cows were wintered off the trial farm.

Year Two and Three of the trial both recorded low annual rainfall, which was reflected in low drainage volumes from all treatments. The dry atmospheric and soil conditions in the summer and early autumn of Year Two decreased drainage volumes, this and more careful management of DFE irrigation meant that N leaching was lower than in Year One. Although no pasture herbage yield data was recorded over this period, pasture in *NonIrr* and *Eff* treatments was observed to wilt and die as soil moistures dropped to near wilting point. The low drainage volumes and wilting of pasture is thought to have resulted in a build up of soil N. The *Eff* treatment still recorded greatest measured mineral N leaching, however, NH_4-N and organic N losses were lower than in Year One.

Year Three had wetter summer conditions than Year One and Year Two, meaning that irrigation water applied was reduced compared with previous years. Once again, the *Eff* treatment recorded greatest mineral N leaching, however, organic N and NH_4-N leaching was reduced, reflecting improved DFE application management. Herbage yield and N uptake measurements provided further insight to results, suggesting that N leaching was related to pasture N use efficiency, as treatments receiving irrigation water (*Irr* and *IrrEff*) had greater pasture N uptake than *NonIrr* and *Eff* treatments over summer. However, as a result of the lack of very dry summer conditions in Year Three, the differences in pasture yield and N uptake between treatments were not as great as expected from observed differences in pasture growth in previous summers.

Rainfall in Year Four was only 6 mm below the 20 year annual average, and although irrigation water applied was lower than previous years, all treatments had their greatest drainage volumes over the entire trial, reflecting the greater water loading from rainfall. Mineral N fertiliser inputs were also greatest in Year Four (averaging 414 kg ha^{-1} across all treatments). The increase in Mineral N fertiliser inputs did not show a corresponding large increase in pasture herbage DM yields from Year Three to Year Four. The increased fertiliser inputs, the lack of significant pasture response, and probable carryover of potentially leachable N from previous dry periods resulted in excess N in the soil profile. The excess soil N combined with greater drainage volumes resulted in Year Four recording the greatest N leaching over the trial, with most treatments leaching in excess of 100 kg ha^{-1} of mineral N. Only the *IrrEff* treatment (which showed a slight increase in pasture N uptake) leached less than 100 kg ha^{-1} of mineral N.

It should be noted that trial treatment plots were not fenced off from the rest of the paddock areas. This may have enhanced soil N build-up and increased the potential for N leaching from the non-water irrigated treatments (*NonIrr* and *Eff)*, as they were fertilised and grazed in the same manner as the rest of the paddocks, which received water irrigation. This meant that despite their lower pasture growth in dry periods of the trial (particularly in the summer of Year Two) the *NonIrr* and *Eff* treatment areas received fertiliser and were grazed (with high stocking rates), when they would normally not have been.

Estimated drainage water NO_3-N levels showed potential for groundwater contamination especially from the *Eff* treatment. Groundwater NO_3-N levels at the site also indicated that groundwater contamination may be occurring, with increasing trends and some NO_3-N levels over the New Zealand limit for drinking water and above ecological health guidelines.

Data used for the Overseer model places typical N leaching losses from New Zealand dairy farms at around 30 to 45 kg ha^{-1}. Data obtained in the trial suggests that the trial management procedures used under the *Eff* treatment were of concern, generating greater N leaching than the average in all years of the trial. Results show that N leaching from other trial treatments during the first three years of the trial was not greatly different from typical leaching. In the last three years of the trial grazing management was similar with cows wintered off the trial farm, but N fertiliser inputs increased each year. In Year Four of the trial it appeared that the farm system was essentially overloaded with N fertiliser, which did not produce a significant increase in pasture yield (and therefore N uptake) resulting in excess soil N. The wetter conditions in Year Four meant that the excess soil N was leached.

Overseer generally overestimated N leaching from the non-DFE treatments (*NonIrr* and *Irr*) and the *IrrEff* treatment for the first three years of the trial, while N leaching from the *Eff* treatment was underestimated. However, it should be noted that Overseer v4.0 was not well validated for soils receiving DFE irrigation, which could account for some differences in results. Given that there was no significant difference in pasture growth and N uptake measured between DFE and non-DFE treatments, preferential flow in some cores in the *Eff* treatment could have led to greater measured N leaching, and changes in N immobilisation (not included in Overseer 4.0) in the *IrrEff* treatment could also explain its lower measured N leaching. Overseer underestimated N leaching from all treatments in Year Four, further indicating carryover of potentially leachable N from previous dry periods.

Averaging N leaching data from the trial improved the comparison between measured and Overseer predicted results for non-DFE treatments (*NonIrr* and *Irr*), but did not show any improvement for DFE treatments (*Eff* and *IrrEff*), further indicating that Overseer requires more validation for DFE areas of farms. The K and S leaching predicted by Overseer also indicates that this requires further investigation on Pumice Soils under dairy farming.

7 Conclusions and Recommendations

Several conclusions and recommendations can be inferred from trial results:

- Results showed that N leaching from treatments was more related to pasture N use efficiency, than the total volume of water draining through the soil profile when mineral N fertiliser inputs were below 320 kg ha^{-1}. Although water irrigation resulted in greater drainage volumes, it promoted more efficient use of N by encouraging pasture growth and N uptake throughout dry periods. This is thought to have prevented a build up of N in the soil profile in the water-irrigated treatments (*Irr* and *IrrEff*). In contrast N added to the non-water irrigated treatments *(Eff* and *NonIrr)* was likely to have been stored in the soil profile during dry periods. This accumulated N was then particularly prone to leaching when drainage occurred, typically caused by the first substantial autumn rain after prolonged summer dryness.

- The *Irr* and *NonIrr* treatments had similar N loading, and although the *Irr* treatment had greater drainage volume, there was no clear difference in N leaching between these treatments. The greater drainage volume under the *Irr* treatment implies that more irrigation water was applied than necessary, and improved irrigation management could still provide the same benefits to pasture, but decrease the water applied (and therefore pumping costs) and drainage volumes.

- For all four years of the trial the *Eff* treatment had the greatest mineral N leaching, and total N leaching losses were even greater (when organic N leaching was included). N leaching from the *Eff* treatment occurred predominantly in the month following DFE application, which led to variation in leaching data as DFE was applied to individual treatment plots at different times.

- Poor management of DFE application, with heavy applications and unattended pipe bursts (resulting in surface ponding) can lead to high N leaching immediately after application. This implies that to reduce the potential for N leaching, DFE application needs to be carefully managed and events like pipe bursts need to be attended to quickly. Careful DFE application management also makes more efficient use of this valuable fertiliser, meaning that N, P, K and S fertiliser inputs to DFE areas can be reduced.

- Compared to the *Eff* treatment (which had a similar N loading) irrigation water applied to the *IrrEff* treatment enhanced pasture growth and N uptake in dry periods, leading to more efficient use of the N applied. This implies that water irrigation may be beneficial to farmers already applying around 200 kg N ha^{-1} yr^{-1} as mineral N fertiliser, or as DFE and mineral N fertiliser to non-irrigated dairy farms on Pumice Soils.

- Estimated NO_3-N concentrations in drainage water showed potential for groundwater contamination, especially under the *Eff* treatment. Shallow groundwater NO_3-N levels from the site showed NO_3-N levels above the New Zealand recommended drinking water standard and ecological health guidelines.

- Applying up to 400 kg ha^{-1} of mineral N fertiliser overloaded the system in all treatments resulting in significant N leaching losses, when this level of mineral N fertiliser was applied drainage volume became more related to the amount of excess N leached.

- Overseer showed the same trends as trial results. Indicating that it is a useful tool in determining trends in N leaching under different farm management practices. Use of longer-term average N leaching data showed closer comparisons between measured and Overseer predicted data for the non-DFE treatments (*NonIrr* and *Irr*). However, results from treatments receiving DFE (*Eff* and *IrrEff*), and from Year Four indicate that Overseer requires further validation for areas receiving DFE and for farm systems when mineral N fertiliser inputs are over 400 kg ha^{-1} on Pumice Soils.

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List of Hardcopy Appendices

The following list of Appendices are presented in this report:

Appendix 1: Trial Methods

Introduction

This section describes all methods used to evaluate the treatments and to provide general information on the physical environment at the site.

Meteorological conditions, soil water content, soil temperature and groundwater level

A meteorological (Met) station, with a *Campbell Scientific CR10* data logger and associated instruments were installed on the trial farm by *Scott Technical Instruments Ltd*. (contracted to Environment Waikato) on 25/5/99. Instruments at the Met station measured rainfall, air temperature, solar radiation, humidity, and wind speed allowing Potential Evapotanspiration (PET) estimation using the Penman-Monteith method (Allen et. al, 1989, Jensen et al., 1990). Other measurements included soil moisture, soil temperature and groundwater level. A summary of the instruments used is presented in Table 16.

Table 16. Instrumentation used at the Met station and when data collection began for each parameter.

Parameter	Instrument	First data	Time series
Rainfall	*Ota 0.5 mm tipping bucket*	25/5/99	Event
Solar radiation	*LiCor LI 200SX*	25/5/99	5 mins
Air temperature	*Vaisala HUMITTER 50Y*	25/5/99	5 mins
Wind speed	*MaxHall Anemometer*	25/5/99	5 mins
Wind direction	*Maximum 200 windvane*	25/5/99	5 mins
Relative humidity	*Vaisala HUMITTER 50Y*	25/5/99	5 mins
Soil moisture	*CS 615*	11/8/99	60 mins
Soil temperature	*107*	11/8/99	60 mins
Groundwater level	*Pressure transducer ISD 10m range*	13/8/99	60 mins

Prior to the installation of the on-farm Met station, daily rainfall data was collected from an on-site manual rain gauge from 1st September 1998 until 31st December 1999 (see file "Manual Rainfall Data" in Appendix 6 for further details). Due to problems with the Met station, daily rainfall data from the 1st January 2000 until the 31st of May 2000 was obtained from the nearby Sylvan Lodge (B86534) meteorological station operated by NIWA (see file "Sylvan Lodge RF Data" in Appendix 6 for raw data). From the 1st of June 2000 until the conclusion of the trial (August 2002) rainfall data was obtained from the on-farm Met station. All historical rainfall data was obtained from the Sylvan lodge site (see file "Sylvan Lodge 20yr Rain" in Appendix 6). All other data was collected from the Met Station.

Daily PET data from the 1st Sept 1998 to 25th May 1999 was based on Penman PET estimates from the Rotorua Airport AWS site, which was the closest meteorological site with all data requirements available (see file "Rotorua ET" in Appendix 6 for raw data). The Rotorua data was then corrected to an on-farm PET estimate using correlation analysis on 3 monthly data sets over the period from May 1999 to March 2000, when both data sets were available. All other data was collected from the Met Station.

Two Campbell Scientific *CS615 Water Content Reflectometer* probes (one in an *Irr* plot and one in a *NonIrr* plot) were installed at 20 cm deep on an upward angle of approximately 30°, and integrated soil water content from approximately 7 to 20 cm deep. A soil temperature probe was also inserted horizontally, at a depth of 15 cm adjacent to the CS615 probe in the *NonIrr* plot.

Groundwater level was measured using a pressure transducer installed in a well adjacent to the met station (*Met station bore*). A second well was also installed adjacent to the tanker track leading to the milking shed (*Tanker track bore*), see Figure 1 in report site location for the locations of the two bores.

A more detailed description of the Met station and the associated equipment installation is contained in the document “Met Station Site Details” in Appendix 6.

Water loading, nitrogen loading and farm data

Irrigation water loading

Farm managers and staff kept records of water irrigator run times and dates. The flow rate of irrigators (time taken to fill a barrel of known volume with water) was then recorded for each irrigator in a paddock on several occasions. The flow rate of all irrigators in a paddock was then averaged and multiplied by run time, to obtain the total volume of water applied in a given period. The irrigatable area of paddocks was calculated as paddock area minus area of *NonIrr* or *Eff* plots. The volume of water applied was then divided by irrigatable paddock area to obtain the loading rate. Further details of irrigation water loading calculations and raw data can be found in the “Irrigation Water Loading” file in Appendix 6.

Water and nitrogen loading from dairy farm effluent (DFE) applications

Prior to spring 2000 DFE loading was estimated from a standard loading rate, and a set of effluent N concentrations, which had been measured sporadically. Loading was determined using catch cans after a single pass of the effluent irrigator. DFE N concentrations were determined from samples that were taken from the dairy shed sump at the time the irrigator was travelling over trial plots. It was realised (in Report One) that this estimation was poor, given observed variation in effluent irrigator travel speeds, nozzle spread (and therefore hydraulic loading to plots), and high variation in effluent N levels.

In spring 2000 an improved method was developed to measure the hydraulic loading, DFE concentration, and therefore total N loading applied to each treatment plot (Report Two). Catch punnets (16.5 cm x 16.5 cm wide and 19 cm deep) were spaced at two-meter intervals out to 20 m either side of the travel path of the DFE irrigator through each individual treatment plot. The volume of DFE caught in each punnet was recorded, then all volumes were bulked into a 20 Lt container for the plot, and a mixed sample taken for N concentration analysis. The volumes of DFE measured in catch punnets were used to calculate application depth, and the N concentration of the bulked sample used to determine N loading for the plot. The file “Effluent N and Water Loading” in Appendix 6 gives further details of the method and formulas used to calculate loadings.

Farm data

Farm managers and staff kept records of grazing rotation, stock numbers, milk production, fertiliser and feed applications. Raw data is detailed in the file “Fert and Grazing” in Appendix 6.

Drainage volume and N leaching estimates

N leaching from treatments in the trial was estimated using two methods: Barrel lysimeters (barrels), and Ceramic cup soil solution samplers (cups). The two methods are described in detail here.

Barrel lysimeters (barrels)

Barrel lysimeters consisted of undisturbed soil cores (190 mm diameter) taken in PVC tubing (200 mm nominal external diameter and 4 mm thick "Farmtuff culvert pipe") to the bottom of the rooting zone (350 mm deep). A metal cutting edge attached to the base of the PVC tubing created an annular gap between the undisturbed soil core and the PVC tubing, as the tubing was inserted into the soil. The annular gap was then filled with molten petroleum jelly ("Shell Snow White Petrolatum"), which was allowed to cool before core extraction, this prevented any edge flow effects in the lysimeter. A PVC collection chamber (250 mm high) was attached to the base of the core, and the entire barrel lysimeter then inserted into the soil profile, until it was flush with the surrounding soil surface. The concept is illustrated in Figure 21. The apparatus used in the trial is shown in Figures 22 and 23.

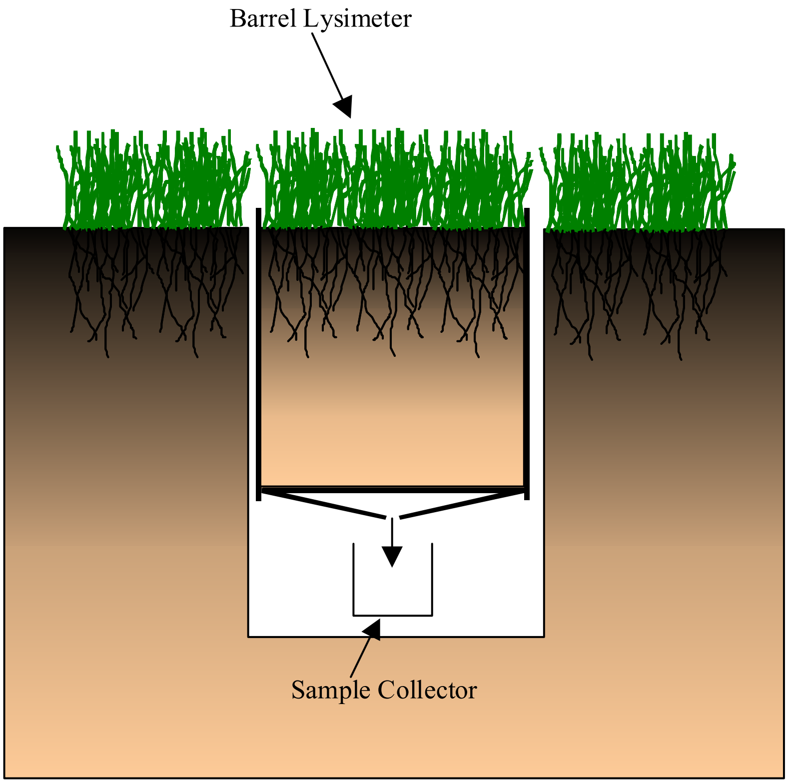

Figure 21. Concept sketch of barrel lysimeters.

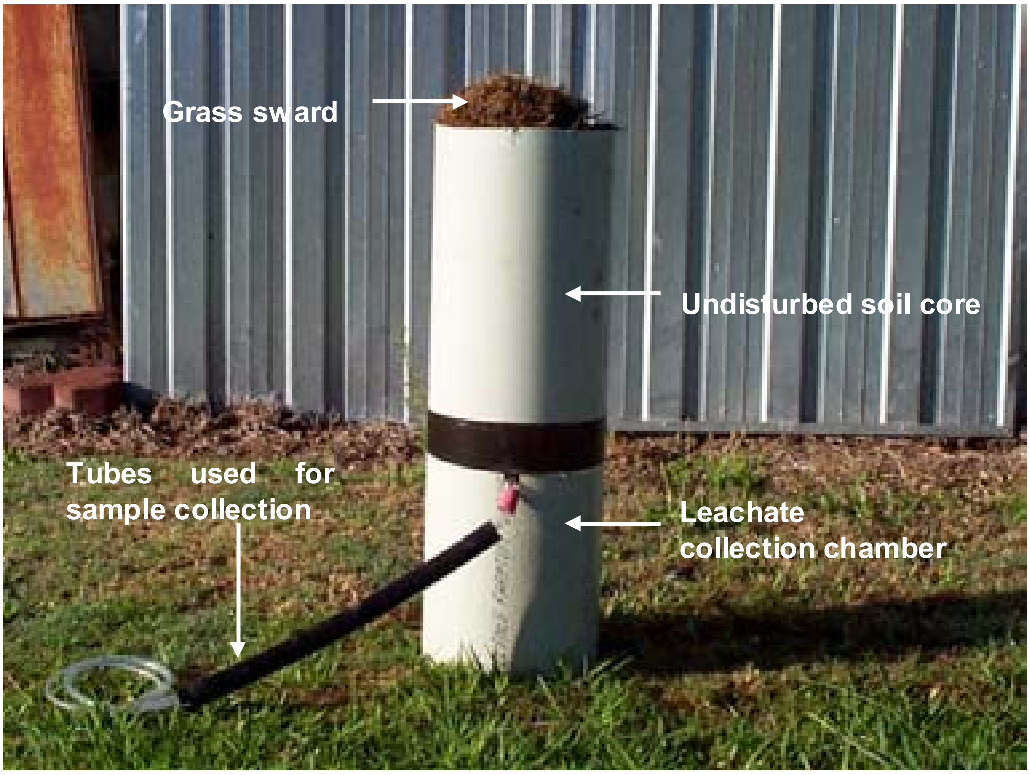

Figure 22. Barrel lysimeter used in the trial, showing undisturbed soil core, leachate collection chamber and sample collection tubing.

Figure 23. Barrel lysimeter prior to installation flush with the soil surface.

In contrast to a typical lysimeter facility, barrels were installed such that normal paddock management could proceed without any interference by the measurement system. To address the variability in soil properties, animal behaviour (such as dung and urine patches) and farming operations, six barrel lysimeters were installed in each treatment plot, giving a total of 72 barrel lysimeters in the trial. The layout of barrels within treatment plots and notes on installation of equipment can be found in the "Installation report" file in Appendix 6. Barrel lysimeters collected the volume of water draining through the soil, which was measured, bulked for each treatment plot, and then analysed for N concentration.

Ceramic cup leachate collectors (cups)

Cups consisted of a 500 mm length of 40 mm diameter "Class D Marley uPVC" pressure pipe, with a porous ceramic cup (70 mm long, 50 mm diameter) glued into one end of the PVC pipe. The other end of the cup had a bung with tubing holes, so that the instrument could be placed under vacuum (Figure 24). Using syringes 180 cc of air was removed from the internal cavity of cups to create a suction (of 24 kPa), which drew in water from the soil surrounding the ceramic cup tip. The suction was left for a period of at least 12 hours. The soil water collected in cups was bulked for treatment plots, then analysed for N concentration.

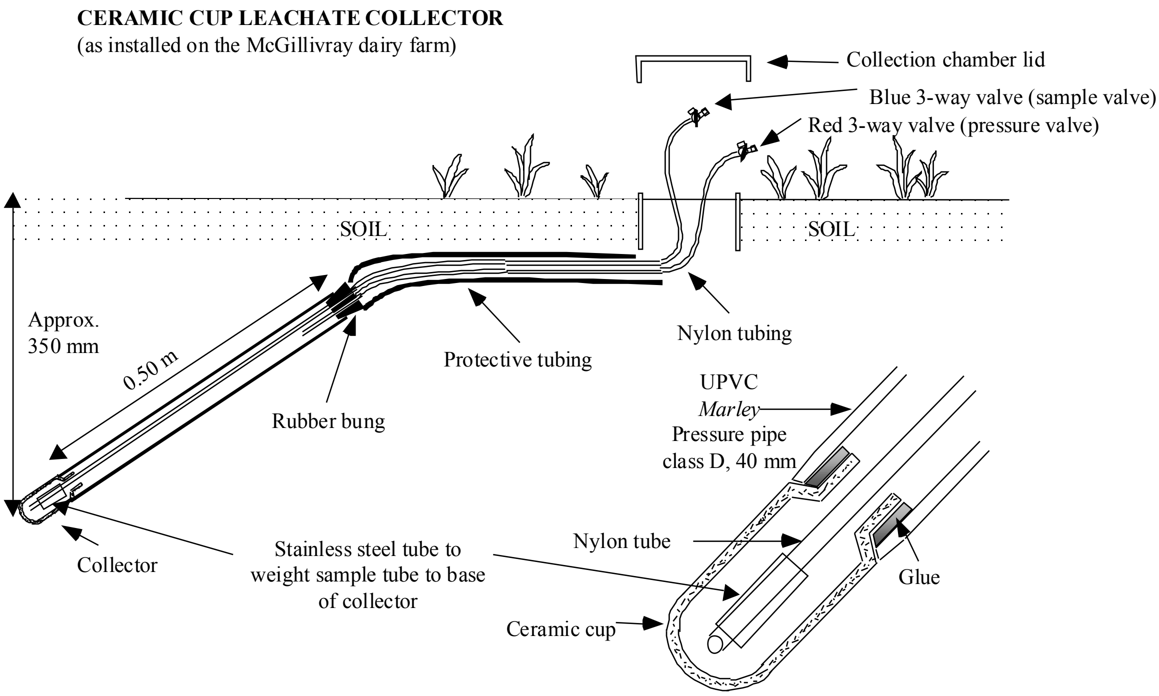

Figure 24. Ceramic cup soil solution sampler installed in the trial.

Cups were installed so that the ceramic tip was at the same 350 mm depth as the base of the undisturbed soil core in barrel lysimeters. In an attempt to cope with the field variability two cups were installed adjacent to each barrel lysimeter in the trial to form an "instrument set" (shown schematically in Figure 25, and as installed in the trial in Figure 26). Therefore, there were 12 cups in each treatment plot and 144 cups in the entire trial. Further details of the layout of plots and the instrument sets within are given in the "Installation Report" in Appendix 6.

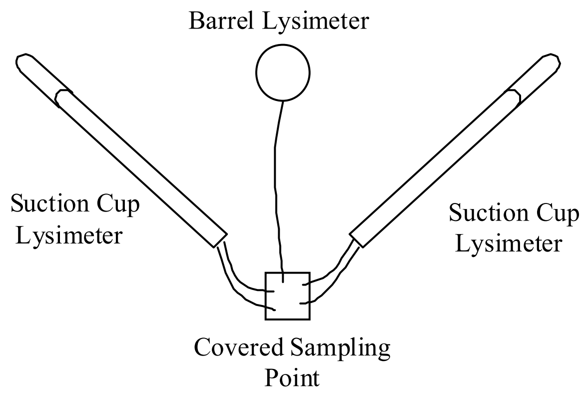

Figure 25. Schematic diagram: Plan view of instrument set showing all sampling tubes coming to the sampling point.

Figure 26. Instrument set at removal of trial equipment, also showing the Pumice Soils at the trial site.

Leachate sample collection and bulking, field and laboratory procedures.

A full description of all field leachate sample collection and subsequent handling, bulking and transportation to the laboratory can be found in the file "Sample Collection and handling" in Appendix 6. This section briefly summarises the process.

Field sampling

Sampling of the trial was performed approximately monthly, taking two days of field sampling and time in the laboratory following field sampling. On the first day of field sampling the volume of water drained from each barrel lysimeter was collected (using a vacuum pump apparatus), recorded and a sub-sample tipped into a 100 ml sample bottle (remaining sample was discarded). Equipment was rinsed with distilled water between each treatment plot. A volume of 180 cc of air was also removed from each ceramic cup soil solution sampler and vacuum left on until the following day. Barrel lysimeter leachate sub-samples were stored in a chilly bin with slicker pads during the day and then frozen at the end of the day. If time permitted groundwater and surface water samples were also taken and frozen at the end of the day.

On the second day the vacuum on the cups was released and any water sample in the cups was extracted (using syringes) and placed in a 100 ml sample bottle (any remaining sample was discarded). Equipment was rinsed with distilled water between treatment plots. Samples were stored in a chilly bin with slicker pads until sampling was complete. If they had not been taken the day before, groundwater and surface water samples were taken. All samples (including those frozen from the day before) were then transported to Hamilton and stored in a cool room over night at 3˚C.

Bulking of samples in the laboratory

The following day the sub-samples from barrels and cups were bulked for each treatment plot, and the bulked samples transported to *R. J. Hill laboratories Ltd* for N concentration analysis.

The amount of each barrel sub-sample (maximum volume 100 ml) added to the bulked barrel sample (maximum volume of 250 ml) for each plot was based on the proportion of the total plot drainage volume represented by the individual barrel drainage volume. A greater drainage volume from one barrel compared to the others in the plot meant that more of the 100 ml sub-sample from this barrel was added to the final bulked plot sample than the other barrel sub-samples. Further details of the bulking procedure and all volumes added to bulked plot samples can be found in the file "Sample Bulking" in Appendix 6. The 250 ml bulked barrel sample for each plot was then analysed for N concentration.

The amount of each cup sub-sample (maximum volume 100 ml) added to the bulked cup sample (maximum volume of 250 ml) for each plot was based on the proportion of the total plot drainage volume represented by the individual instrument set barrel drainage volume. The 250 ml bulked cup sample for each plot was then analysed for N concentration. Further details of the bulking procedure and all volumes added to bulked plot cup samples can be found in the file "Sample Bulking" in Appendix 6.

Chemical analysis of leachate and water quality samples

Samples were analysed by *R. J. Hill laboratories Ltd*. All leachate samples were analysed for mineral nitrogen (NO_3-N, NO_2-N and NH_4-N), while only samples from plots receiving DFE (*Eff* and *IrrEff*) were analysed for Total Kjeldhal Nitrogen (TKN) and Total Nitrogen (TN). DFE samples (both from the DFE irrigator or the sump at the dairy shed) were analysed for NH_4-N, TKN and TN. Water quality samples were analysed for mineral N only.

Tests used were: NH_4-N, NO_3-N, NO_2-N, NOxN (NO_3-N + NO_2-N), TKN (Total Kjeldahl Nitrogen) and TN (Total Nitrogen). Results were reported in $g.m^{-3}$.

Early in the trial TKN was not measured on some leachate samples, meaning that organic N leaching could not be calculated, details can be found in the raw data in the file "N Leaching" in Appendix 6. Mineral N measurements consisted of nitrate-N (NO_3-N), nitrite-N (NO_2-N) and ammoniacal-N (NH_4-N) until 2/10/01 when it was noted that NO_2-N in all prior samplings was virtually nil, it was then decided to cease this measurement and decrease analysis costs.

Calculations of drainage volume and N leaching

Drainage volume was determined using barrel data. The volume of water collected by the six barrels within each treatment plot was averaged, this average volume of water was then divided by the area of lysimeters (283.53 cm^2) to give an average drainage volume value for each treatment plot. The formulae used and other details can be found in the file "Sample Bulking" in Appendix 6.

Barrel N leaching was calculated for each plot on each sampling occasion by multiplying average drainage volume for each plot by the N concentration of the bulked barrel sample for that plot, and determining the amount of N leached on a per hectare basis. Further details are in the file "N Leaching" in Appendix 6. Therefore, barrel lysimeters estimated both the volume of water draining through the soil profile and the amount of N leached.

Cup N leaching was calculated for each plot on each sampling occasion by multiplying average barrel drainage volume for the plot by the N concentration of the bulked cup sample for that plot. The amount of N leached was then estimated on a per hectare basis. Further details are in the file “N Leaching” in Appendix 6. Therefore, cup N leaching calculations used independently determined drainage volumes and N concentrations.

Report One and Report Two presented results from both N leaching estimates, which gave differing results, confusing trends and made synthesis of results difficult. Report Three (See Appendix 6) discussed the two N leaching measurement techniques used in the trial in detail, providing rationale for using barrel lysimeter data only for future reporting on the trial. The poster paper presented at the New Zealand Society of Soil Science Conference (Appendix 5) and the investigation into denitrification in lysimeter leachate (Appendix 3) also investigated the problem, and present rationale for using barrel data only.

Pasture herbage yield, N uptake and botanical composition measurement methods

Pasture dry matter herbage yield and N uptake

Pasture dry matter (DM) herbage yield was measured using the rate of growth technique described by Rys and Edmeades (1984), by cutting pasture at a standard height (5 cm) with a rotary mower from single caged areas within each plot. Cages excluded cattle and defined areas for yield measurement. On each occasion the fresh herbage in each cage collected by the mower was harvested, and the fresh weight recorded using suspended weighing scales. The cage was then moved to another randomly chosen location within each plot, where pasture was trimmed to the standard height.

A representative sub-sample of the fresh herbage from caged areas was then taken for further analysis. The fresh weight of this sub-sample was recorded and the sub-sample then sent to *R. J. Hill laboratories* where it was analysed for percent dry matter and crude protein. This information was then used to calculate the plot yield in units of kg DM ha^{-1} using the following formula:

$$\frac{\text{G.Y. x } \left(\frac{\%\text{ d.m.}}{100}\right)}{\text{Area cut}} = \text{Dry matter (DM) yield}$$

Where:
G.Y. = the green yield of plots (kg).
% d.m. = the percentage dry matter of the sub-sample.
Area cut = 0.00023 hectares (area within cage, constant for all plots).

Yield measurements were performed on a routine basis, as close as practical to grazing.

To obtain an estimate of pasture N uptake, crude protein estimates were divided by 6.25 to obtain a % N estimate. The % N was then multiplied by DM herbage yield (kg DM ha^{-1}) to obtain and estimate of N uptake in kg ha^{-1}. See Appendix 6 and the file “Pasture Growth and N Uptake Data” for details.

Pasture botanical composition

Hand shears were used to clip herbage samples to ground level from 10 random locations in each plot on three occasions (Burgess et al., 2000). All clippings from each plot were placed in a bag for that plot. A representative herbage sub-sample of approximately 400 pieces from each plot was then sorted into all pasture grasses, clover, weeds and dead material of all species by staff at *AgResearch*, Ruakura. Each component was then dried overnight at 95°C and weighed before calculating the proportion of the sub sample dry weight.

Groundwater and surface water sample collection

Groundwater samples were collected from the two wells installed on the trial farm using a 12 volt battery operated in-line submersible pump (140 mm long x 35 mm diameter) with clear polyethylene tubing (13 mm internal diameter) attached. Wells were drained and allowed to re-fill three times before a sample was taken using a 250 ml unpreserved sample bottle from *R. J. Hill Laboratories*.

Surface water samples were taken from five locations (shown in Figure 1) over the trial:

1. Stream at East road (Rangaakiaki Stream)
2. Farm Creek (at race)
3. Side stream at confluence (Rangaakiaki Stream after confluence with farm creek)
4. Irrigation pond
5. Torepatutahi Stream at bridge on Broadlands Road

Samples were taken using 250 ml unpreserved sample bottles from *R. J. Hill laboratories* from 10 cm below the surface of the water (where possible).

Statistical analyses

Basic statistical analysis of treatment replicates (standard deviation and coefficient of variation values) showed variation. As indicated in *Systat v.9* this may affect the probabilities for the statistics produced by the model. Statistical analysis was performed on annual treatment means for drainage volume, mineral N leaching, pasture dry matter yield and pasture N uptake using *Systat v.9*. Using pairwise mean comparisons an ANOVA was performed on the data for each year using the Post Hoc *Tukey* method, as this was considered to give a more stringent analysis than other Post Hoc methods for multiple data groups. Probabilities of less than 0.05 were used to indicate significant differences.

Leachate Sampling dates and seasons.

The sampling on the 6/9/00 was included in the winter period, as most of the drainage volume and N leaching recorded in this sampling would have occurred in August 2000. Sampling 34 on the 2/6/01 was included in the autumn 2001 period, as most of the drainage volume and N leaching recorded in this sampling would have occurred in May 2001. Sampling 40 on the 6/12/01 is included in spring 2001 as most of the leaching would have occurred in November 2001.

Sampling number	Date	Season	Year
1	23/9/98	Spr	1
2	7/10/98	Spr	1
3	27/10/98	Spr	1
4	18/11/98	Spr	1
5	9/12/98	Sum	1
6	23/12/98	Sum	1
7	21/1/99	Sum	1
8	10/2/99	Sum	1
9	9/3/99	Aut	1
10	30/3/99	Aut	1
11	21/4/99	Aut	1
12	19/5/99	Aut	1
13	16/6/99	Wint	1
14	13/7/99	Wint	1
15	3/8/99	Wint	1
16	31/8/99	Wint	1
17	22/9/99	Spr	2
18	27/10/99	Spr	2
19	18/11/99	Spr	2
20	13/12/99	Sum	2
21	17/1/00	Sum	2
22	3/4/00	Aut	2
23	3/5/00	Aut	2
24	14/6/00	Wint	2
25	26/7/00	Wint	2
26	6/9/00	**Wint***	2
27	9/10/00	Spr	3
28	14/11/00	Spr	3
29	13/12/00	Sum	3
30	16/1/01	Sum	3
31	20/2/01	Sum	3
32	21/3/01	Aut	3
33	18/4/01	Aut	3
34	2/6/01	**Aut***	3
35	28/6/01	Wint	3
36	6/8/01	Wint	3
37	30/8/01	Wint	3
38	2/10/01	Spr	4
39	1/11/01	Spr	4
40	6/12/01	**Spr**	4
41	23/1/02	Sum	4
42	20/2/02	Sum	4
43	25/3/02	Aut	4
44	29/4/02	Aut	4
45	21/5/02	Aut	4
46	12/6/02	Wint	4
47	23/7/02	Wint	4
48	27/8/02	Wint	4

Pasture cut dates

The cut on the 13/9/01 was included in the winter period as most of the growth would have been over August 2001. The cut on the 6/3/02 was recorded in the summer period, as most of the growth over this cut period would have been in February 2002

Cut number	Date	Season	Year
1	5/10/00	Spr	3
2	2/11/00	Spr	3
3	24/11/00	Spr	3
4	19/12/00	Sum	3
5	21/1/01	Sum	3
6	16/2/01	Sum	3
7	12/3/01	Aut	3
8	11/4/01	Aut	3
9	15/5/01	Aut	3
10	13/9/01	**Wint***	3
11	8/10/01	Spr	4
12	31/10/01	Spr	4
13	19/11/01	Spr	4
14	3/1/02	Sum	4
15	1/2/02	Sum	4
16	6/3/02	**Sum***	4
17	12/4/02	Aut	4
18	24/5/02	Aut	4
19	29/8/02	Wint	4
20	30/9/02	Spr	4

Appendix 2: Paper presented at the Fertiliser and Lime Research Centre Conference in February 2002

DOES WATER AND/OR EFFLUENT IRRIGATION INCREASE NITROGEN LEACHING FROM PUMICE SOILS UNDER DAIRYING?

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Abstract
As a result of increasing concerns about nitrogen (N) leaching from soils with low water holding capacity under irrigated dairying and possible contamination of receiving waters, a trial to investigate N leaching from Pumice Soils (Whenuaroa Series) was established on an irrigated dairy farm at Reporoa. The ongoing trial investigates N leaching and drainage volumes under four different treatments.

1. Non-irrigated dairy farming (*NonIrr*)
2. Dairy farming with effluent irrigation (*Eff*)
3. Dairy farming with water irrigation (*Irr*)
4. Dairy farming with water and effluent irrigation (*IrrEff*)

To obtain representative data from the commercial farm, six barrel lysimeters (200 mm dia. x 350 mm deep) were installed in three replicate plots of each treatment, giving a total of 72 lysimeters. The leachate collected in the lysimeters is analysed for N (NO_3-N, NH_4-N and org. N) concentrations. To elucidate the N pathways, pasture N uptake and N inputs (fertiliser, and effluent N) are measured. Meteorological parameters allowing PET estimation, rainfall, soil moisture and soil temperature are also measured on farm.

Drainage volumes and N leaching have been influenced by drier than average meteorological conditions over the majority of the trial. However, results generally show that N leaching is more related to pasture N use efficiency in the different treatments, than to the total volume of water draining through the soil.

Annual data showed that despite the *Irr* treatment having the greatest drainage volume, it did not have the greatest amount of N leaching. Instead, the *Eff* treatment showed the greatest N leaching losses, which occurred predominantly after effluent applications. Despite similar N loading to the *Eff* treatment, less N was leached in the *IrrEff* treatment, as water irrigation enhanced pasture growth and N uptake in dry periods, resulting in more efficient use of the N applied. The *Irr* and *NonIrr* treatments also had similar N loading, however, drainage volume from the *Irr* treatment was much greater. Despite this, there was no significant difference in N leaching between *Irr* and *NonIrr* treatments. In *Irr* and *IrrEff* treatments the constant pasture growth and N uptake throughout dry periods is thought to have prevented a build-up of N in the soil profile. In contrast, a build-up of N is likely to have occurred in the non water-irrigated treatments (*NonIrr* and *Eff*) during dry periods. This excess N was subsequently leached below the root zone when an autumn drainage flush occurred.

INTRODUCTION

Nitrogen (N) is a key nutrient for plant growth in pastoral farming systems. Intensive dairy farming is an important industry in many regions of New Zealand, and N cycling plays a key role in pasture growth and milk production from dairy farms (Ledgard et al. 1996). Therefore, not only from an environmental perspective, but also from a cost-benefit point of view, retention of N in the upper soil profile where it can be utilised by pasture is important. Nitrate-nitrogen (NO_3-N) is a mobile form of N and (because of its negative charge) is readily leached when water drains through the soil and into groundwater (McLaren and Cameron 1990). The amount of N leaching is influenced by the amount of excess N in the soil profile and the volume of water draining through the soil and into groundwater (a function of rainfall, evapotranspiration and the physical characteristics of the soil). High stock density, high N loading rates, high water loading and soils with low water holding capacity may enhance N leaching into groundwater and surface water.

There are increasing pressures being placed on the quality of groundwater and surface waters as a result of land use intensification. N entering ground and surface waters can cause eutrophication of receiving waters, and also pose a health risk where water is used for drinking. Dairy farming is potentially a major contributor of non-point N, as substantial amounts of N are applied to the soil as cow urine and dung from intensive stocking, and as fertiliser. Urine from dairy cows represents a major N leaching risk, as the applied N can occur at very high rates of up to 1000 kg N ha^{-1} in localised patches (Haynes and Williams 1992; Ledgard et al. 1996).

A substantial body of research work has been undertaken investigating the dynamics of N cycling under dairy pasture on soils with a high water holding capacity in the Hamilton basin (Ledgard et al. 1996). However, N dynamics under dairy pasture on irrigated Pumice Soils with low water holding capacity are insufficiently understood. Therefore, a trial was established on an irrigated dairy farm on Pumice Soils in the Reporoa basin. The trial is designed to run for four years and provide information on drainage volumes, N leaching, efficiency of water use under irrigation, effluent application rates and N cycling under dairy farming on Pumice Soils.

The objectives of the trial are to:

a) Obtain information that will help dairy farmers optimise the use of water, and N from fertiliser and effluent.
b) Provide data for landuse impact studies, and for models on dairy farming, N leaching, effluent application and water irrigation.
c) Improve understanding of N dynamics in Pumice Soils over a range of different dairy farming management activities.

Fertiliser and effluent applications, grazings, irrigation, meteorological conditions, drainage volumes, N leaching, soil conditions (moisture and temperature), pasture growth, pasture N uptake and groundwater NO_3-N concentrations are monitored under four different farming management activities. This paper presents preliminary results from the first three years of the trial.

MATERIALS AND METHODS

Site and soil

The trial is situated on the McGillivray dairy farm, East Road, Reporoa, New Zealand (NZMS 260 U17 038 953). The farm is situated within the Reporoa basin at an elevation of 200 mASL and consists of 100 ha of flat to gently rolling land adjacent to two streams. The Torepatutahi Stream borders the farm to the south and the Rangaakiaki Stream to the west. The soils on the farm are Whenuaroa series (Sparling et al. 2000), which are well drained soils formed in reworked Taupo Tephra (pumice). These soils are classified as Typic Orthic Pumice Soils in the New Zealand

Soil Classification (Hewett, 1998). Average annual rainfall in the Reporoa district is 1043 mm. Generally the wettest month in Reporoa is July (109 mm) and the driest is January (69 mm).
Dairy farm effluent is applied to 25 ha of the farm using a travelling effluent irrigator, and irrigation water is applied to the entire farm during dry months using a "Van Den Bosch" movable lateral sprinkler system. Stocking rate and grazing rotations have changed over the trial. Prior to June 2000 the stocking rate was intensive (up to 4.5 cows ha^{-1}) and cows were wintered on the farm. However, during autumn 2000 the McGillivray's purchased a second farm (used predominantly as a winter runoff) and stock numbers increased to around 550 cows. This meant that over winter 2000 grazing pressure on the farm decreased, as cows were wintered over on the runoff. No grazing of any trial paddocks occurred in June and July 2000 and 2001. The farm is now predominantly used for spring, summer and autumn grazing, when optimum pasture growth can be maintained by water irrigation; cows are then wintered over on the runoff.

Treatments and experimental design

The trial investigates N leaching and drainage volumes under four dairy farming management practices:

1. Non-irrigated dairy farming *(NonIrr)*
2. Dairy farming with effluent irrigation *(Eff)*
3. Dairy farming with water irrigation *(Irr)*
4. Dairy farming with water and effluent irrigation *(IrrEff)*.

Treatment plots (35 m x 35 m) are distributed over six paddocks, and the four treatments established in triplicate result in a total of 12 treatment plots.

Drainage volume and N leaching measurements

Barrel lysimeters consisting of undisturbed soil cores (200 mm diameter) taken to the bottom of the rooting zone (350 mm deep), with a PVC collection chamber (250 mm high) at the base of the core were inserted into the soil profile, flush with the soil surface. These lysimeters collect the volume of water draining through the soil, which is measured and analysed for N concentration. In contrast to a typical lysimeter facility, lysimeters were installed such that normal paddock management could proceed without any interference by the measurement system. To address the variability in soil properties, animal behaviour (such as dung and urine patches) and farming operations, six barrel lysimeters were installed in each plot, giving a total of 72 barrel lysimeters in the trial.

Groundwater NO_3-N measurements

During the trial two wells were installed on site to examine NO_3-N concentrations in shallow groundwater (approximately 2.4 m deep). Initially, groundwater samples were collected sporadically. However, from June 2000 onwards samples have been taken approximately monthly.

Herbage yield and N content

Herbage dry matter yield is estimated by cutting pasture (to a standard stubble height of 3 cm) with a rotary mower from 2.3 m^2 caged areas (which exclude cattle) within each plot (Rys and Edmeades 1984). The fresh weight of herbage in the cage is recorded using scales, and a representative sub-sample is taken and analysed for dry matter and N content. The cage is then moved to another randomly chosen location within the plot, clear of any barrel lysimeters.

Meteorological conditions and soil water content

A meteorological station installed on the trial farm measures rainfall, air temperature, solar radiation, humidity, wind speed and soil temperature allowing PET estimation using the Penman-Monteith method.

Two Campbell Scientific *CS615* Water Content Reflectometer probes (one in an *Irr* plot and one in a *NonIrr* plot) were installed at 20 cm deep on an upward angle of approximately 30°, and integrate soil water content from approximately 7 to 20 cm deep.

Farm data records

Farm staff kept records of grazing rotation, fertiliser application, water irrigation and effluent irrigation. Water loading is determined for each season by measuring the flow rates of sprinklers in each paddock and recording their operating times. Loading from effluent irrigation is determined at each application using catch cans.

Trial history and measurement dates

The trial was established in September 1998, and monitoring over the trial has been modified and extended in an attempt to further understand N cycling on the farm. Leachate samples have been collected approximately monthly. Herbage dry matter yield and N content samples have also been collected approximately monthly since measurements began in September 2000. Collection of data from the meteorological station has been continuous since installation. Collection of other data over the trial has been more sporadic, depending on the time of year and farm management.

RESULTS

Drainage volumes and N leaching have been continuously measured from the inception of the trial in September 1998, and so, results in this paper focus on treatment differences in these data.

Trial data is presented for three annual periods:

1. September 1998 – August 1999 (Year One)
2. September 1999 – August 2000 (Year Two)
3. September 2000 – August 2001 (Year Three)

Meteorological conditions and soil water content

For the sake of brevity, rainfall is the only meteorological data presented. All three years of the trial recorded below average rainfall, with Year One having greatest rainfall (Fig. 1). The summers in Year One and Year Two showed low rainfall, with the summer period in Year Two being particularly dry. Year Three also showed low annual rainfall, but a wetter summer period than Year One and Year Two.

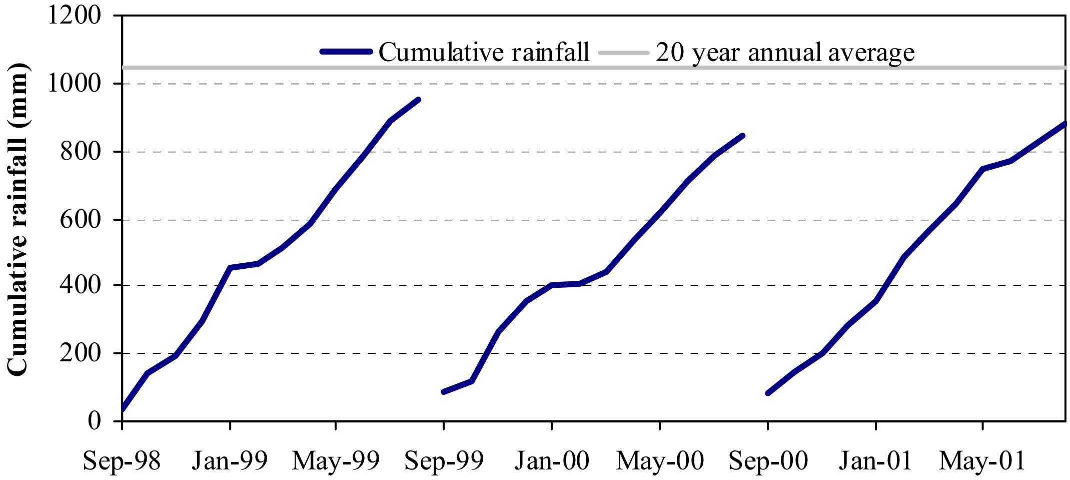

Figure 1 Cumulative rainfall over the trial compared to the 20 year annual average.

Volumetric soil water content was recorded from August 1999 onwards. Water content in the *Irr* treatment remained rather constant throughout the year, compared with the *NonIrr* treatment. Soil water content in the *NonIrr* treatment showed particularly dry conditions in 2000, reaching its lowest in March 2000 (Fig. 2).

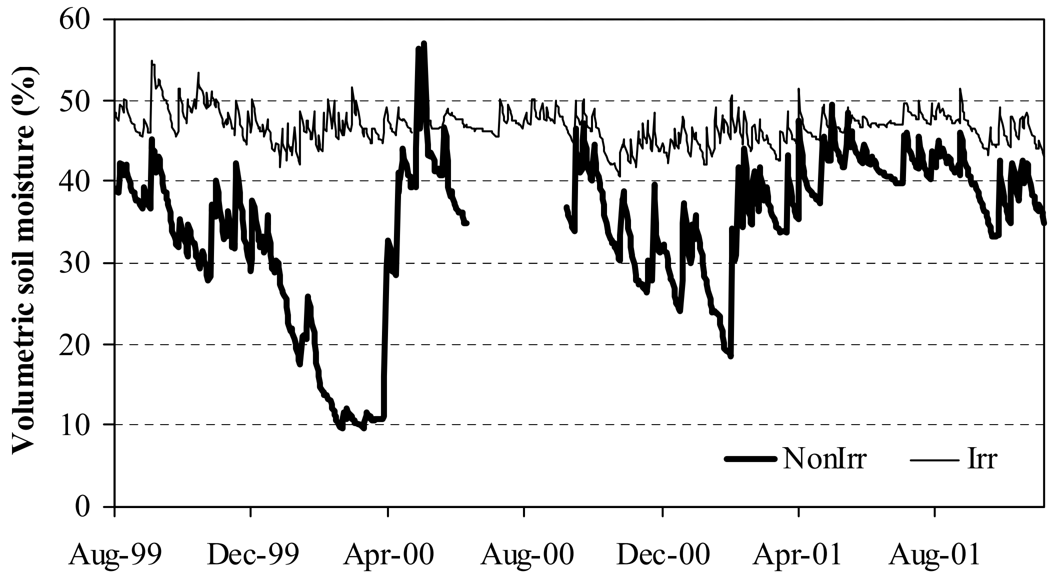

Figure 2 Average volumetric soil water content in the 7-20 cm soil depth zone. The gap in data for the *NonIrr* treatment was caused by damage to the water content probe.

N and water loading

N loading was greatest for all treatments in Year Three of the trial (Table 1). However, it should be noted that effluent N loading estimations for Year One and Year Two were based on a standard application depth and a limited set of effluent N concentration values. In Year Three effluent application depth and N concentration were measured at each effluent application.

Table 1 Annual N loadings for treatments over the trial (*, estimated loading; n.a, not applicable). Totals represent replicate means.

Treatment	**Mineral fertiliser N (kg ha^{-1})**	**Mineral effluent N (kg ha^{-1})**	**Mineral N loading (kg ha^{-1})**	**Organic effluent N (kg ha^{-1})**	**Total N loading (kg ha^{-1})**
			N loading for Year One		
NonIrr	200	n.a	200	n.a	200
Eff	184	38*	222*	47*	269*
Irr	200	n.a	200	n.a	200
IrrEff	184	38*	222*	47*	269*
			N loading for Year Two		
NonIrr	183	n.a	183	n.a	183
Eff	203	35*	238*	40*	278*
Irr	183	n.a	183	n.a	183
IrrEff	203	35*	238	40*	278*
			N loading for Year Three		
NonIrr	240	n.a	240	n.a	240
Eff	185	60	245	56	301
Irr	240	n.a	240	n.a	240
IrrEff	185	60	245	65	310

Water loading was greatest for all treatments in Year One reflecting the greater rainfall and irrigation water loading compared with the other years (Table 2).

Table 2 Water loading over the trial (*, estimated loading based on standard application depth; n.a, not applicable). Totals represent replicate means.

Treatment	**Rainfall (mm)**	**Irrigation (mm)**	**Water from effluent (mm)**	**Total loading (mm)**
		Water loading for Year One		
NonIrr	940	n.a	n.a	940
Eff	940	n.a	38*	978
Irr	940	542	n.a	1482
IrrEff	940	467	38*	1445
		Water loading for Year Two		
NonIrr	862	n.a	n.a	862
Eff	862	n.a	32*	894
Irr	862	528	n.a	1390
IrrEff	862	455	32*	1349
		Water loading for Year Three		
NonIrr	861	n.a	n.a	861
Eff	861	n.a	60	921
Irr	861	294	n.a	1155
IrrEff	861	284	54	1199

Drainage volumes and N leaching

Drainage volume

The *Irr* treatment received the greatest water loading (Table 2) and had the greatest drainage volume over each of the three years (Fig. 3). Trends for other treatments were less clear. However, the *NonIrr* treatment had the lowest drainage volume in Year Two and Year Three, and all treatments had their lowest drainage volumes in Year Two, reflecting the dry soil conditions over summer 1999/2000.

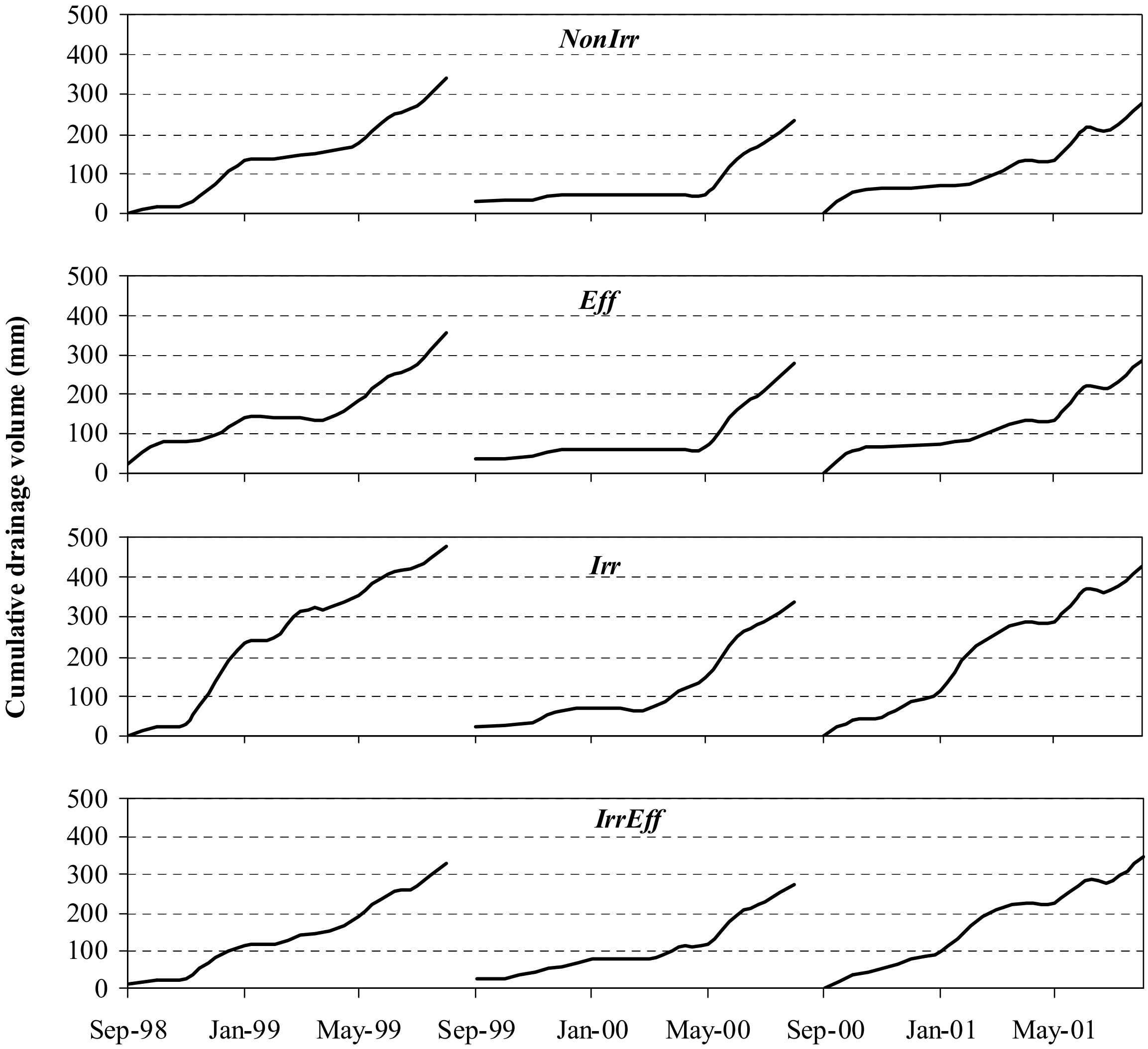

Figure 3 Cumulative drainage volumes. Totals represent replicate means.

Mineral N leaching

The *Eff* treatment consistently had the greatest mineral N leaching over the three years, which was typically greatest following effluent applications in spring and autumn (Fig. 4). Results also showed that mineral N leaching was greatest from all treatments (except *Irr*) in Year One of the trial, and that all but the *Eff* treatment recorded their lowest mineral N leaching in Year Two. Mineral N leaching from the *Eff* treatment in Year Two and Year Three was approximately half of what was recorded in Year One.

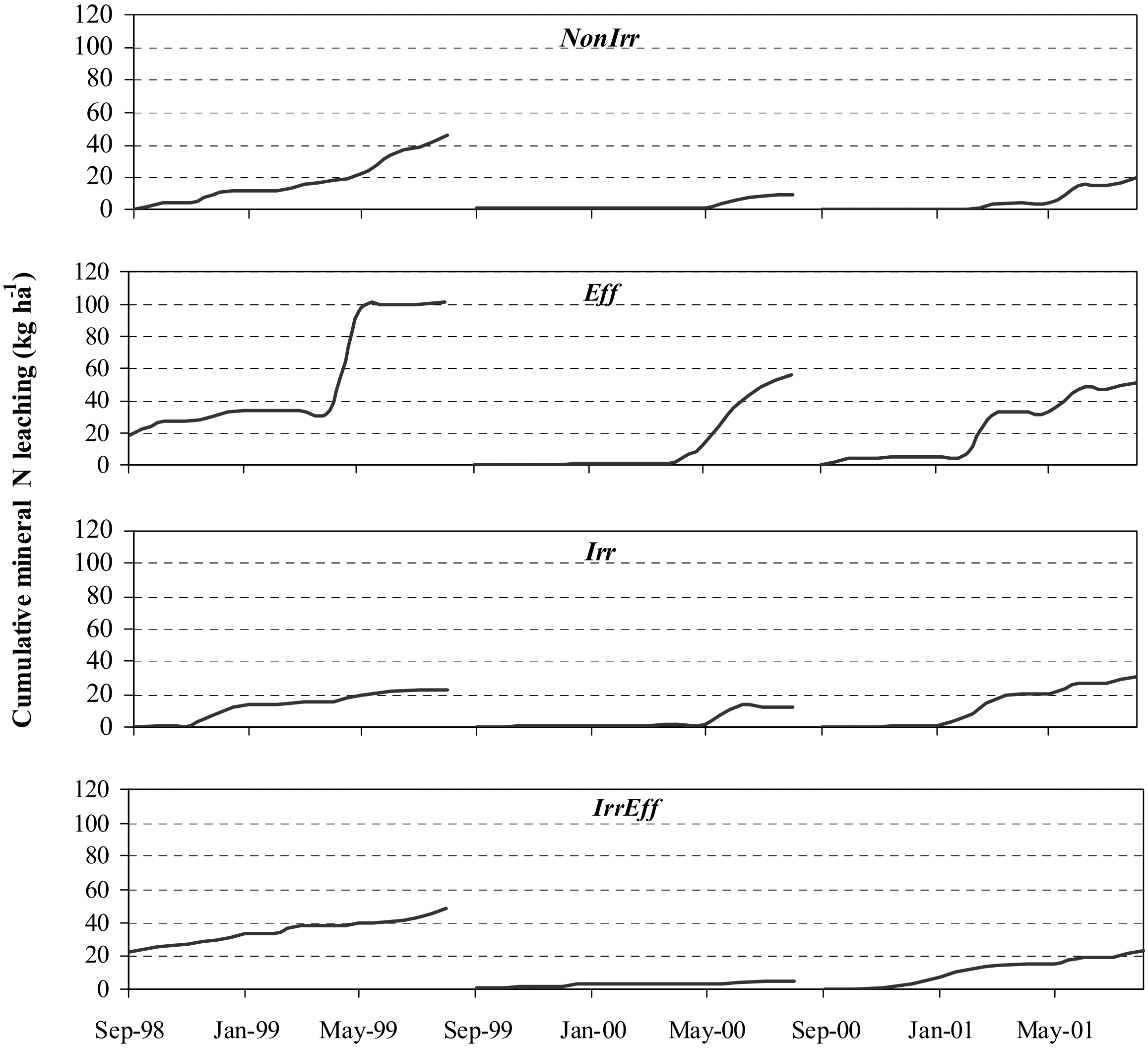

Figure 4 Cumulative mineral N leaching over the trial. Totals represent replicate means.

Organic N leaching, total N leaching and N species leached

Organic N leaching was measured for *Eff* and *IrrEff* treatments only, where it was considered to be a significant component of total N leaching, while mineral N (NH_4-N, NO_3-N and NO_2-N) was measured for all treatments. Overall, the most organic N was leached from the *Eff* treatment, and the majority of this organic N leaching occurred in Year One (Table 3). Analysis of the N species leached also showed that a large proportion of the mineral N leached from *Eff* and *IrrEff* treatments in Year One was NH_4-N.

Table 3 Summary of N leaching over the trial (n.d, not determined). Totals represent replicate means.

Treatment	**NO_3-N + NO_2-N (kg ha^{-1})**	**NH_4-N (kg ha^{-1})**	**Mineral N (kg ha^{-1})**	**Org. N (kg ha^{-1})**	**Total N (kg ha^{-1})**
	——— N leaching for Year One ———				
NonIrr	45	1	46	n.d	n.d
Eff	13	88	101	49	150
Irr	22	1	23	n.d	n.d
IrrEff	23	25	48	5	53
	——— N leaching for Year Two ———				
NonIrr	9	0	9	n.d	n.d
Eff	40	16	56	8	64
Irr	13	0	13	n.d	n.d
IrrEff	4	1	5	4	9
	——— N leaching for Year Three ———				
NonIrr	20	0	20	n.d	n.d
Eff	46	6	52	7	59
Irr	30	1	31	n.d	n.d
IrrEff	22	1	23	6	29

Estimated annual average NO_3-N concentrations in drainage water

The annual average NO_3-N concentration in water draining from below 350 mm deep was estimated by dividing the total NO_3-N leached by the total drainage volume (Table 4). Water draining from the *NonIrr* treatment in Year One had NO_3-N levels greater than the New Zealand drinking water standard of 11.3 g m^{-3} (Ministry of Health 2000). In Year Two and Year Three NO_3-N levels in water draining from the *Eff* treatment were greater than the New Zealand drinking water standard.

Table 4 Estimated drainage water NO_3-N concentrations (g m^{-3}). *, levels above the Drinking Water Standards for New Zealand.

	NonIrr	Eff	Irr	IrrEff
Year One	13.2*	3.7	4.6	7.0
Year Two	3.8	14.3*	3.9	1.4
Year Three	7.2	16.1*	7.0	6.3

Groundwater NO_3-N measurements

Groundwater samples from the two wells on site show that average NO_3-N levels have been increasing and approaching the New Zealand drinking water standard for NO_3-N (Fig. 5).

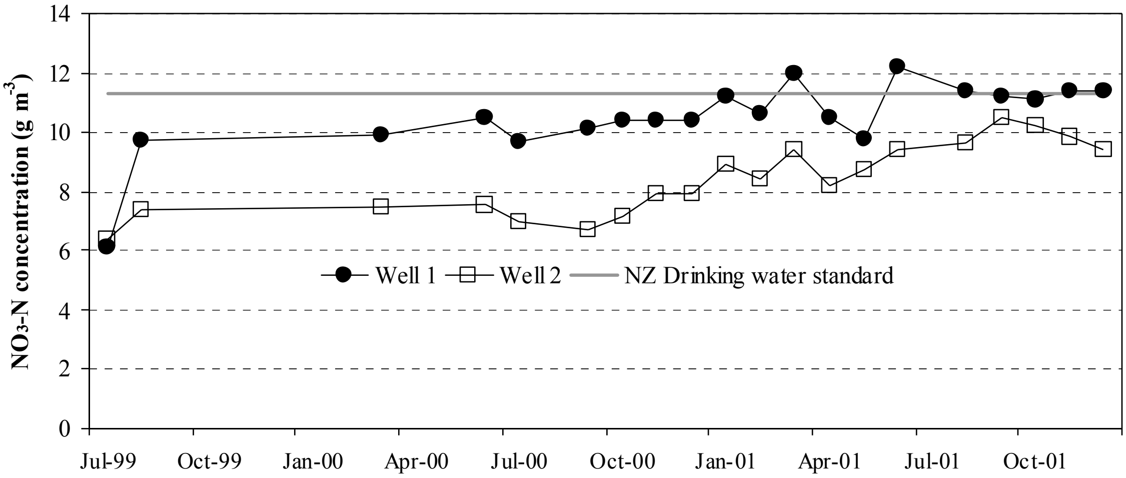

Figure 5 Groundwater NO_3-N concentrations at the site.

Herbage yield and N uptake

As part of improved trial monitoring, measurements of herbage dry matter yield and N uptake began in September 2000. For the sake of brevity, only pasture N uptake is presented. Seasonal analysis of N uptake data showed little difference between treatments in spring and winter periods. However, N uptake from the *Irr* and *IrrEff* treatments was greater than the *NonIrr* and *Eff* treatments during summer, while in autumn this trend was reversed with *NonIrr* and *Eff* treatments having greater N uptake than *Irr* and *IrrEff* treatments (Fig. 6). Overall, the *Eff* and *IrrEff* treatments showed greatest N uptake over the year (Table 5).

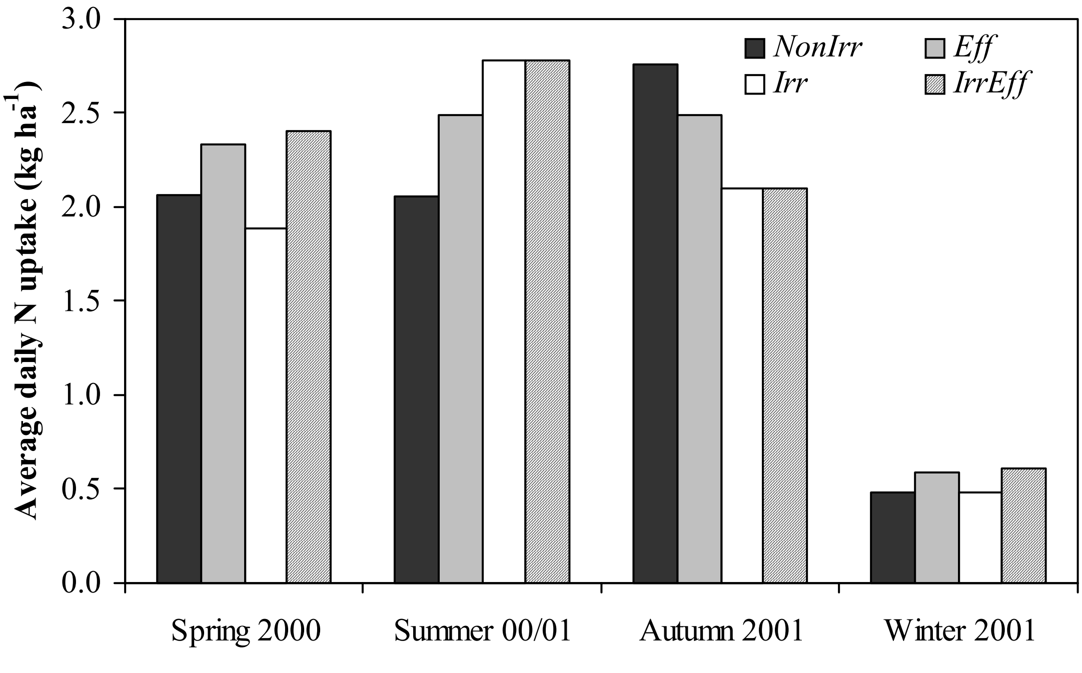

Figure 6 Seasonal N uptake over Year Three of the trial. Totals represent replicate means.

Table 5 N uptake for Year Three. N uptake totals represent replicate means.

Treatment	N uptake for Year Three (kg ha^{-1})	Standard deviation
NonIrr	614	72
Eff	664	109
Irr	604	44
IrrEff	660	141

Discussion

Meteorological data showed that the majority of the trial has been conducted in drier than average conditions, with the period from spring 1999 until autumn 2000 (in Year Two) being particularly dry. As noted by Ledgard et al. (1996), differences in rainfall and associated drainage can cause large differences in N leaching estimates between years, and alternating dry and wet periods can result in carryover of potentially leachable N from dry periods to wetter periods. As noted by others (Ledgard et al. 1996; Scholefield et al. 1993) measuring N leaching over several years is vital to cover climatic variation.

It can be seen that certain combinations of climatic, soil and plant conditions are more prone to producing N leaching. Dry summer conditions without irrigation can result in low pasture growth and plant N uptake combined with low drainage volumes, which leads to a build up of excess N in the soil profile. Large drainage events after dry periods then leach the excess N from the soil profile before pasture growth and associated pasture N uptake is possible. Optimal irrigation will maintain plant growth and N uptake over dry periods without inducing excessive drainage events, thereby minimising soil N build up and N leaching.

Annual rainfall in the trial was greatest in Year One, and as a result all treatments recorded their greatest drainage volumes for the three years. However, there was a dry period in the summer of Year One when pasture in the *NonIrr* and *Eff* treatments was observed to wilt. This appears to have resulted in a build up of soil N in these treatments, as pasture growth and N uptake were minimal. Rainfall over autumn in Year One then caused drainage from *NonIrr* and *Eff* treatments, leaching the excess N. As a result of this pattern the *NonIrr*, *Eff* and *IrrEff* treatments recorded their greatest mineral N leaching in Year One. The high organic N and NH_4-N leaching losses from *Eff* and *IrrEff* treatment plots soon after effluent application also suggested bypass flow due to management problems with effluent irrigation during Year One.

The dry conditions in the summer of Year Two decreased drainage volumes compared with Year One. The continuation of dry conditions into autumn and more careful management of effluent irrigation also meant that N leaching was lower than in Year One. Although no herbage yield data was recorded, pasture in *NonIrr* and *Eff* treatments was observed to wilt and die over this period as soil moistures dropped to near wilting point. The *Eff* treatment still recorded greatest mineral N leaching, however, NH_4-N and organic N losses were lower than in Year One.

The lack of very dry summer conditions in Year Three meant that irrigation water applied in this year was reduced compared with Year One and Year Two. The wetter summer conditions in Year Three also appeared to prevent a build up of N in *Eff* and *NonIrr* treatments by maintaining pasture growth and N uptake over summer. Once again, the *Eff* treatment recorded greatest mineral N leaching, however, organic N and NH_4-N leaching was reduced, reflecting improved effluent application management. Herbage yield and N uptake measurements provided further insight to results, suggesting that N leaching was related to pasture N use efficiency, as treatments receiving irrigation water (*Irr* and *IrrEff*) had greater pasture N uptake than *NonIrr* and *Eff* treatments over summer. However, as a result of the lack of very dry summer conditions in Year Three, the differences in pasture yield and N uptake between treatments were not as great as expected from observed differences in pasture growth in previous summers.

Estimated drainage water NO_3-N levels showed potential for groundwater contamination especially from the *Eff* treatment. Groundwater NO_3-N levels at the site also indicated that groundwater contamination may be occurring, with NO_3-N levels close to the New Zealand limit for drinking water and above ecological health guidelines.

Preliminary Conclusions and Recommendations

In general, results showed that N leaching from the different treatments was more related to pasture N use efficiency, than the total volume of water draining through the soil profile. Although water irrigation resulted in greater drainage volumes, it promoted more efficient use of N, by encouraging pasture growth and N uptake throughout dry summer periods, this is thought to have prevented a build up of N in the soil profile in *Irr* and *IrrEff* treatments. In contrast N added to *Eff* and *NonIrr* treatments was likely to have been stored in the soil profile during dry periods. This accumulated N is then particularly prone to leaching when drainage occurs, typically caused by the first substantial autumn rain after prolonged summer dryness.

The *Irr* and *NonIrr* treatments had similar N loading, and although the *Irr* treatment had greater drainage volume, there was no clear difference in N leaching between these treatments. The greater drainage volume under the *Irr* treatment implies that more water was applied than necessary, and improved irrigation management could still provide the same benefits to pasture, but decrease the water applied (and therefore pumping costs) and drainage volumes.

For all three years of the trial the *Eff* treatment had the greatest mineral N leaching, and total N leaching losses were even greater when organic N leaching was included. N leaching from the *Eff* treatment occurred predominantly immediately after effluent application, which led to variation in the data as effluent was applied to individual treatment plots at different times.

Poor management of effluent application, with heavy applications and unattended pipe bursts can lead to high N leaching immediately after application. This implies that to reduce the potential for N leaching, effluent application needs to be carefully managed and events like pipe bursts need to be attended to quickly. Careful effluent application management also makes more efficient use of this valuable high N fertiliser, meaning that mineral N fertiliser inputs to effluent areas can be reduced.

Compared to the *Eff* treatment, which had a similar N loading, irrigation water applied to the *IrrEff* treatment enhanced pasture growth and N uptake in dry periods, leading to more efficient use of the N applied. This implies that water irrigation may be beneficial to farmers already applying over 200 kg N ha^{-1} yr^{-1} as mineral N fertiliser, or as effluent and mineral N fertiliser to non-irrigated dairy farms on Pumice Soils.

Estimated NO_3-N concentrations in drainage water showed potential for groundwater contamination, especially under the *Eff* treatment. Shallow groundwater NO_3-N levels from the site showed NO_3-N levels above the New Zealand recommended drinking water standard and ecological health guidelines.

Applying water and nutrient budgeting software to the farm may refine nutrient and water inputs making the farm system more efficient.

Acknowledgements

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Appendix 3: Report investigating denitrification in lysimeter leachates

Reporoa Denitrification Study Report

Abstract
The possibility of Nitrogen (N) loss (through denitrification) in lysimeter leachate from the *Reporoa Nitrogen Leaching Trial* was investigated in a laboratory study, which involved monitoring leachate at a constant temperature over time. Leachate from plots receiving dairy farm effluent (DFE), and plots which received no DFE was collected, amended with nitrate–nitrogen (NO_3-N) and monitored for 28 days. Results showed that denitrification, and loss of NO_3-N in leachate from treatments receiving DFE can occur rapidly. However, results also showed that leachate from treatments which do not receive DFE was unaffected. The experiment indicated that N leaching from areas of the farm which receive DFE is underestimated, as some NO_3-N is lost through denitrification. The experiment also showed that N leaching estimates from the majority of the farm (areas which do not receive DFE) are not affected by denitrification losses.

Introduction
In September 1998 the *Reporoa Nitrogen Leaching Trial* was instigated by Environment Waikato to investigate nitrogen (N) leaching from porous Pumice Soils in the Reporoa district (Report One). Examination of data raised concerns about the possibility of denitrification losses decreasing N leaching estimates from the *Reporoa Nitrogen Leaching Trial*. In the trial, leachate is collected and stored in field lysimeters for up to a month before being sampled for chemical analysis (Report One and Report Three). Due to environmental, health and safety and logistical concerns, leachate is not amended to ensure its chemical stability. During storage in the field, biological and chemical denitrification in leachate may decrease leachate N concentrations, and therefore decrease the calculated N leaching.

Nitrate-nitrogen (NO_3-N) is the most mobile form of N and is easily leached from soil, which can cause contamination of ground and surface waters. In situations where low oxygen levels exist (such as in leachate stored in lysimeters) biological denitrification is possible. In these conditions facultative anaerobic bacteria can use NO_3-N as an electron acceptor in place of oxygen during their metabolic reactions, resulting in the production of N gases. The rate of denitrification depends on several factors, one of the most important being the availability of carbon. Chemical denitrification can occur when ammonium (NH_4-N) levels are high. High NH_4-N levels can restrict the activity of bacteria, resulting in a build up of nitrite (NO_2-N), and a volatile loss of N gas independent of microbial activity. However, N losses by chemical denitrification are generally considered minor (McLaren and Cameron, 1990).

This report presents a brief study, which aims to determine whether denitrification can occur in lysimeter leachate from the *Reporoa Nitrogen Leaching Trial,* and if so, what effect it may have on N leaching results from the trial. Leachate was collected from the Effluent (*Eff*) and Non-Irrigated (*NonIrr*) treatments of the *Reporoa Nitrogen Leaching Trial* for the denitrification study. Leachate from the *Eff* treatment was considered important, because of its high carbon and NH_4-N levels. The denitrification study was also performed at the highest monthly average soil temperature recorded during the *Reporoa Nitrogen Leaching Trial*, to represent optimal (or "worst case") conditions for any denitrification that may occur.

Materials & Methods

Soil temperature determination

Lysimeter leachate collection chambers are installed to 60 cm deep in the Pumice Soils (Whenuaroa Series) at Reporoa (Report One). Therefore, leachate collected in lysimeters was stored at approximately 60 cm below the soil surface. As soil temperature at Reporoa is recorded at 15 cm deep only (Report One), this required estimating temperature at 60 cm deep.

At a lysimeter facility near Hamilton, Lincoln Environmental (LE) had previously installed soil temperature probes at 10 and 50 cm deep in an Atiamuri Pumice Soil. Using daily Atiamuri soil temperature data, soil temperature measured at 10 cm deep was correlated to soil temperature measured at 50 cm deep. This correlation was then applied to Reporoa soil temperature data recorded at 15 cm deep, to obtain an estimate of Reporoa soil temperature at 60 cm deep. Estimated Reporoa soil temperatures at 60 cm deep were then examined for the highest average monthly temperature. The highest average monthly soil temperature was found to be 19.7°C, which occurred in February/March.

Collection of leachate samples

To obtain leachate which was likely to have high N levels it was decided to collect samples in early spring, a traditional time for NO_3-N leaching in New Zealand (McLaren and Cameron, 1990), and also when the first DFE was applied after winter.

Samples for the denitrification study were collected in conjunction with a routine sampling of the *Reporoa Nitrogen Leaching Trial* on 2/11/01, immediately after DFE application on several plots. Leachate sub samples were collected into 100 ml sample bottles, as per usual sampling methods for the *Reporoa Nitrogen Leaching Trial* (Report One). Any extra leachate sample from each lysimeter was then tipped into a 20 L container (a plastic bucket with sealable lid) for each treatment (*NonIrr* or *Eff*) to obtain a sample for the denitrification study. Collection of leachate samples for this denitrification study continued until routine sampling was completed on 2/11/01. Approximately 12 L of *Eff* leachate, and 10 L of *NonIrr* leachate was collected. Samples were shaken to ensure they were well mixed.

Sub samples of the *NonIrr* and *Eff* leachate collected for the denitrification study were then taken in smaller specimen containers for an initial analysis of mineral, organic and total N, and biological and chemical oxygen demand. The 20 L containers and sub samples of leachate were then sealed, frozen, and transported back to Hamilton the following day, where they were stored in a freezer.

Amending leachate with NO_3-N

The initial analysis of the denitrification study leachate showed high organic N and NH_4-N levels in the *Eff* leachate, but low NO_3-N levels in both leachates. Therefore, it was decided to amend or "spike" both leachates with Sodium nitrate ($NaNO_3$), to enhance NO_3-N levels.

It was decided to use only 5 L of leachate from each treatment and keep the remainder in storage, in case further investigations were required. Leachate was defrosted, well mixed and 5 L of both *NonIrr* and *Eff* leachate tipped into separate sterile 20 L containers. The remaining leachate in original containers was then deep frozen immediately and stored.

The 5 L samples were then amended with NaNO3. A total of 0.903 g of $NaNO_3$ was added to the *NonIrr* treatment leachate, while 0.934 g was added to the *Eff* treatment leachate. Samples were then well shaken and mixed.

Immediately after mixing sub samples (approximately 200 ml volume) of the amended *Eff* and *NonIrr* leachate were taken for mineral, organic, and total N analysis.

Monitoring leachate in a constant temperature environment

To represent a worst case situation, the experiment was conducted in a dark, constant temperature room at 20°C. A *HOBO* temperature logger was used to record a temperature profile for the experiment.

Immediately after spiking and sub sampling, three 1.5 L aliquots of leachate from each treatment were tipped into three replicate lysimeter bases for that treatment (six replicates in total; three for the *Eff* treatment and three for the *NonIrr* treatment). Lysimeter bases were used so that conditions were identical to those in the field. A plastic wrap (with ventilation holes) was then secured over the top of each lysimeter base, to simulate limited oxygen diffusion through the soil core, which would occur in the field.

Sub samples for analysis were then taken from each replicate at; 2 hrs, 6 hrs, 7 days, 16 days and 28 days after spiking of effluent. At each sampling the plastic wrap was removed, and leachate in each lysimeter base was stirred for at least 30 seconds, when leachate was well mixed a sub sample was collected in a sample vial and deep frozen immediately. Samples were then transported to the laboratory for analysis as soon as possible.

Samples and analyses for the constant temperature study were:

- After 2 hrs samples of approximately 100 ml were taken from each replicate and analysed for mineral, organic and total N.
- After 6 hrs samples of approximately 100 ml were taken from each replicate and analysed for mineral, organic and total N.
- On day 7 samples of approximately 100 ml were taken from each replicate and analysed for mineral, organic and total N.
- On day 16 samples of approximately 100 ml were taken from each replicate and analysed for mineral, organic and total N. In addition, bulked samples were taken for biological and chemical oxygen demand.
  - Samples of 133 ml from each *NonIrr* replicate were taken and bulked to attain sufficient volume for a biological oxygen demand sample, 35 ml samples were also taken from each *NonIrr* replicate and bulked for a chemical oxygen demand sample.
  - Two separate samples of 40 ml were taken from each *Eff* replicate and bulked for both biological and chemical oxygen demand.
- On day 28 samples of approximately 100 ml were taken from each replicate and analysed for mineral, organic and total N. In addition, bulked samples were taken for biological and chemical oxygen demand.
  - Samples of 135 ml from each replicate of each treatment were taken and bulked to attain sufficient volume for a biological oxygen demand sample for each treatment.
  - Samples of 40 ml were also taken from each replicate of each treatment and bulked for a chemical oxygen demand sample for each treatment.

Sample analysis

All samples were analysed by *R. J. Hill laboratories*. Samples were analysed for mineral nitrogen, organic nitrogen, total nitrogen, and chemical and biological oxygen demand using their methods. Tests used were: NH_4-N, NO_3-N, NO_2-N, NOxN (NO_3-N + NO_2-N), TKN (Total Kjeldahl Nitrogen), TN (Total Nitrogen), Carbonaceous Biochemical Oxygen Demand ($cBOD_5$) and Total Chemical Oxygen Demand (COD).

Results

As the objective of this study was to determine possible NO_3-N losses, results focus on NO_3-N dynamics. Figure 1 summarises results, and full results are displayed in Tables 1 and 2.

Initial analysis of leachate showed low levels of NO_3-N in both *NonIrr* and *Eff* leachate. Leachate was then amended with $NaNO_3$, which raised NO_3-N levels immediately after amendment to 31.6 g.m^{-3} in the *NonIrr* leachate, and 29.1 g.m^{-3} in the *Eff* leachate (Figure 1).

As Figure 1 shows, there was a rapid decline in NO_3-N levels in the *Eff* leachate after amendment, as denitrification began to occur, this was also associated with an initial slight increase in NO_2-N levels as the reduction of NO_3-N began (Table 2). After 6 hours NO_3-N levels in the *Eff* leachate had dropped by around 16%, and after 7 days all NO_3-N added to the *Eff* leachate was utilised. Chemical and biological oxygen demand of the *Eff* leachate also decreased with time, indicating that the carbon available in the *Eff* leachate was utilised by bacteria in the denitrification process (Table 2).

In contrast to the *Eff* leachate, NO_3-N levels in the *NonIrr* leachate remained relatively constant over the experiment (Figure 1). Biological and chemical oxygen demand in the *NonIrr* leachate also remained similar reflecting the lack of carbon (Table 1).

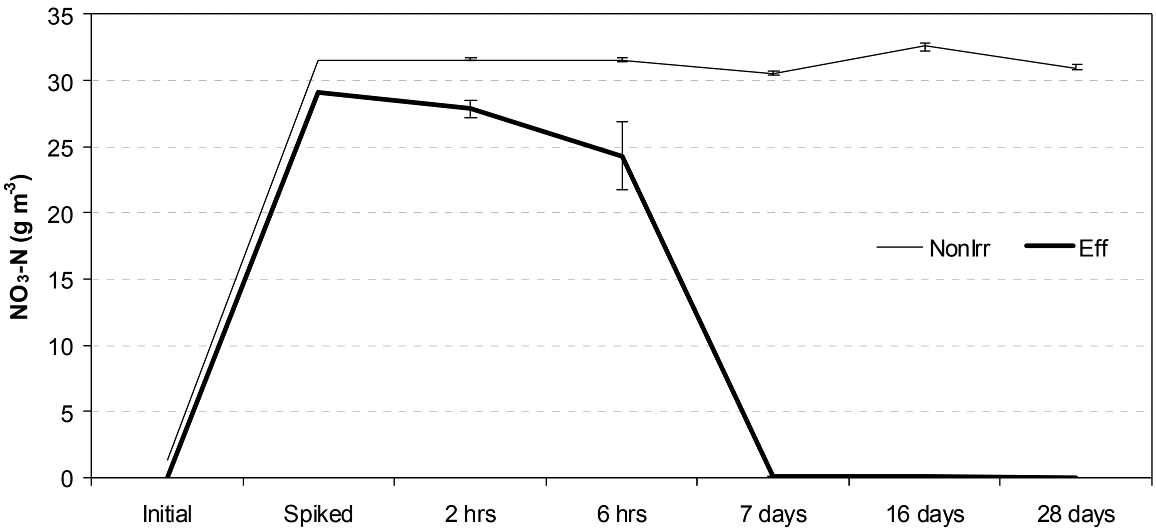

Figure 7 NO_3-N dynamics over the experiment. Bars represent one standard deviation around replicate means.

Table 6 *NonIrr* leachate over the experiment

	NH_4-N (g.m^{-3})	TN (g.m^{-3})	TKN (g.m^{-3})	NOxN (g.m^{-3})	NO_3-N (g.m^{-3})	NO_2-N (g.m^{-3})	$CBOD_5$ (g.O~2^.m^{-3})	CODH (g.O~2^.m^{-3})
Initial	0.05	3.2	1.8	1.31	1.31	0.002	2	74
Spiked	0.05	33.3	1.7	31.6	31.6	< 0.002		
2 hrs	0.05	33.43	1.83	31.60	31.60	0.00		
6 hrs	0.06	33.23	1.70	31.53	31.53	0.00		
7 days	0.06	32.30	1.83	30.53	30.50	0.00		
16 days	0.19	34.30	1.73	32.60	32.60	0.01	< 1	< 400
28 days	0.54	33.07	2.07	31.00	31.00	0.01	1	86

Table 7 *Eff* leachate over the experiment.

	NH_4-N (g.m^{-3})	TN (g.m^{-3})	TKN (g.m^{-3})	NOxN (g.m^{-3})	NO_3-N (g.m^{-3})	NO_2-N (g.m^{-3})	$CBOD_5$ (g.O~2^.m^{-3})	CODH (g.O~2^.m^{-3})
Initial	76.3	193	192	0.23	0.05	0.176	1090	3210
Spiked	79.3	205	175	30.1	29.1	1.02		
2 hrs	80.53	208.33	179.33	29.07	27.80	1.30		
6 hrs	78.80	208.67	180.33	28.33	24.30	4.02		
7 days	68.07	186.67	186.67	0.08	0.07	0.01		
16 days	62.97	144.00	144.00	0.10	0.09	0.01	326	2880
28 days	51.43	133.0	133.0	0.10	0.08	0.02	295	2310

Discussion

The results from this denitrification experiment imply that N leaching from the *Eff* and *IrrEff* (Effluent and water irrigation) treatments in the *Reporoa Nitrogen Leaching Trial* can be underestimated by using barrel lysimeter data. If lysimeters contain leachate with NO_3-N, and applied DFE drains through the soil core, the addition of carbon (from the DFE) to the leachate already present can cause rapid denitrification. As *Reporoa Nitrogen Leaching Trial* results often showed high N leaching estimates from barrel lysimeters (mainly NH_4-N) from the *Eff* and *IrrEff* treatments, it is important to note that these losses may be greater as some NO_3-N may have been denitrified. However, N leaching estimates from the *NonIrr* and *Irr* (Irrigated) treatments in the *Reporoa Nitrogen Leaching Trial* are not likely to be underestimated by using leaching estimates based on barrel lysimeter data.

The rapid nature of the denitrification losses found in *Eff* leachate suggests that a significant amount of denitrification after DFE application may occur in "hot spots" in the soil matrix, as water drains through the lysimeters. Therefore, a significant amount of NO_3-N may be lost before water has drained from the profile, and may not be lost when leachate is in storage. It should also be noted that the denitrification experiment was carried out at a temperature of 20°C, and this was a "worst case" scenario, where bacteria were active. As most leaching in the field occurs in wetter, usually colder winter periods, denitrification losses are not likely to be as great under these conditions as bacterial activity is slowed.

Although no denitrification was recorded from *NonIrr* and *Irr* treatments it was difficult to determine how "fresh" the leachate from these treatments was. Whereas DFE application on the *Eff* and *IrrEff* treatments meant that leachate was fresh as the DFE application immediately prior to leachate collection resulted in drainage. Therefore it could be useful if this denitrification experiment was repeated after a heavy rainfall event, when leachate from all treatments is "fresh".

Conclusions and Recommendations

- Loss of NO_3-N in leachate can occur rapidly from lysimeters receiving DFE

- The high concentration of available carbon in DFE provides suitable conditions for denitrification in *Eff* leachate.

- If bypass flow of applied DFE (or effluent with high available C levels) occurs, then leaching may be under estimated as NO_3-N can be rapidly lost.

- Leachate from treatments not receiving DFE was shown to be unaffected by N loss through denitrification. However, further investigation of "fresh" NonIrr leachate is required to determine if it behaves in the same manner as the leachate used in the denitrification experiment.

References

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Report One: Environment Waikato. 2000: *Reporoa Nitrogen Leaching Trial Progress Report 1999/2000.* Environment Waikato Technical Report 2000/14. Environment Waikato, PO Box 4010, Hamilton East.

Report Two: Environment Waikato 2000: *Reporoa Nitrogen Leaching Trial Six Monthly Report June – December 2000*. Environment Waikato, PO Box 4010, Hamilton East.

Report Three: Environment Waikato 2001: *Reporoa Nitrogen Leaching Trial Progress Report 1998-2001*. Environment Waikato, PO Box 4010, Hamilton East.

Appendix 4: Poster paper presented at the Land Treatment Collective Conference in April 2002

Do nitrogen losses and changes in nitrogen species occur in lysimeter leachate?

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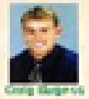
Two common questions that arise in lysimeter leaching trials are the possibility of nitrogen (N) losses through denitrification and whether changes in the nitrogen species occur in collected leachate between samplings? These questions were investigated in a laboratory study, which involved monitoring nitrogen species over 28 days in spiked leachates maintained at a constant temperature. Leachates collected from plots receiving dairy farm effluent (DFE) and from control plots, were spiked with nitrate–nitrogen (NO_3-N). Results showed that denitrification, and thus loss of NO_3-N, can occur rapidly in the DFE leachate. However, it also showed that no nitrate losses occurred in the leachate from the control treatment. Presumably, it is the high concentration of available carbon in the DFE leachate that provides suitable conditions for denitrification to occur. In addition, both the organic and ammonium N concentrations in the DFE leachate also decreased, reducing the total nitrogen concentration by 35% over the 28 days. In the control leachate, the total nitrogen concentration remained unchanged with only a very small decrease in organic N concentration concomitant to an increase in the ammonium concentration.



Do losses and changes in nitrogen species occur in lysimeter leachate?

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1. Introduction

Practical and safety concerns often mean that field lysimeter leachate is not amended to ensure chemical stability. Questions about N loss through denitrification and possible changes in leachate N species often arise. These questions were investigated in a laboratory study.

2. Experimental setup

Fresh leachate was collected from lysimeters receiving dairy farm effluent (DFE) and from grazed dairy pasture (GDP) lysimeters.

Leachates were "spiked" with $NaNO_3$, and then monitored at 20 °C for 28 days.

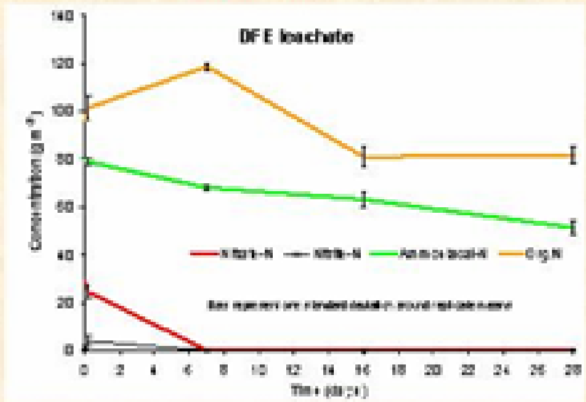
Samples were taken at 0, 2 hrs, 6 hrs, 7 days, 16 days and 28 days and analysed for:

- Nitrate-N (NO_3-N)
- Nitrite-N (NO_2-N)
- Ammoniacal-N (NH_4-N)
- Organic N (Org.N)
- Total N (TN)

BOD and COD samples were taken at 0 and 28 days.

3. Results

There was a decline in NO_3-N and NH_4-N in the DFE leachate.

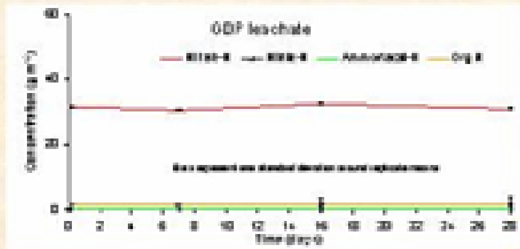


After 6 hrs NO_3-N had decreased by 16%, and after 7 days all NO_3-N was utilised.

As with mineral N, Org.N concentrations in the DFE leachate decreased.

TN was reduced by 35% over the 28 days.

In contrast to the DFE leachate, mineral N and Org.N levels in the GDP leachate were relatively constant.



BOD and COD of the DFE leachate decreased, as microbial available C was utilised. In the GDP leachate BOD and COD were relatively constant.

DFE leachate			GDP leachate		
Time (days)	BOD ($g.O_2m^{-3}$)	COD ($g.O_2m^{-3}$)	Time (days)	BOD ($g.O_2m^{-3}$)	COD ($g.O_2m^{-3}$)
0	1090	3210	0	2	74
28	295	2310	28	1	86

4. Take home messages

- **Loss of NO_3-N in leachate can occur rapidly from lysimeters receiving DFE.**
- **High concentration of available carbon in DFE leachate provides suitable conditions for denitrification.**
- **If bypass flow of applied DFE (or effluent with high C levels) occurs, then N leaching may be underestimated as NO_3-N can rapidly be lost.**

Appendix 5: Poster paper presented at the New Zealand Society of Soil Science conference in November 2002

LYSIMETERS VERSUS CERAMIC CUP SOIL SOLUTION SAMPLERS:
WHICH NITROGEN LEACHING ESTIMATE IS BEST?

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Lysimeters and ceramic cup soil solution samplers (*cups*) are two techniques commonly used to estimate nitrogen (N) leaching in field trials. Lysimeters yield both the drainage volume (ml) and the drainage water N concentration (g N l^{-1}), allowing for a straightforward calculation of the N mass flux (kg ha^{-1}) during a sampling period. While *cups* can be used to measure the N concentration in the soil solution at specific sampling dates, these concentrations need to be multiplied by separately determined drainage volumes to obtain an estimate of N leaching mass flux. These drainage volumes are either estimated through water balance calculations, or measured in a few lysimeters considered to be representative of the treatment. Often researchers prefer the combination of many *cups* (concentrations) with few lysimeters (volumes), as *cups* are less intrusive and cumbersome to use than a high number of lysimeters.

Our corresponding paper *"Does water and/or effluent irrigation increase nitrogen leaching from pumice soils under dairying?"* describes a trial where a great number of lysimeters and *cups* were both used to investigate N leaching. Seventy-two lysimeters were installed to the base of the B horizon (350 mm deep) with leachate volumes and N concentrations being measured. In addition, two *cups* (70 mm long by 50 mm diameter) were installed to the same depth on either side of each lysimeter (total 144 *cups*).

Due to the remote location of the site, sampling could only be performed approximately monthly, taking two days. On the first day, the drainage volumes of the lysimeters were recorded and a sample for N analysis taken, while a vacuum was placed on *cups*. On the second day, the soil solution samples accumulated in the *cups* were collected.

The leaching estimates obtained by either using exclusively the lysimeter data, or by combining the lysimeter drainage volumes with cup concentrations differed vastly. Over a period of 34 months, combining lysimeter drainage volumes with *cup* N concentrations yielded greater absolute N leaching estimates.

On the poster, we will discuss why we regard the N leaching estimate using lysimeter data as the most appropriate N leaching estimate under the given conditions. Among the crucial issues in determining the best N leaching estimate are: Length of the sampling intervals, the most appropriate way to combine concentrations with volumes, gaps in the *cup* data due to dry soil conditions, the appropriate tension to apply to *cups*, the possibility of denitrification in lysimeter leachate collection vessels, and the exclusion of organic N by *cups*.

Lysimeters vs. ceramic cup soil solution samplers: Which nitrogen leaching estimate is best?

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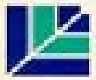

1. Introduction

Potential disadvantages of *lysimeters*

- Zero tension at the lysimeter base
- Denitrification occurring in leachate collection chambers

Potential disadvantages of suction *cups*

- Snapshot concentration vs. leachate volume of a period
- Data gaps due to dry soil conditions at time of sampling
- Non-defined volume of soil sampled
- Discrimination against Org-N and NH_4-N by suction cups
- Independent estimate of the leachate volume is required

2. Methods

In a field trial with four treatments, six ***lysimeters*** (200mm diameter, 350mm depth) were installed in each of three replicate plots. Two ceramic ***cups*** were also installed in the same depth adjacent to each lysimeter:

Due to the remote location, sampling was performed approx. monthly. The leachate volume of each ***lysimeter*** was determined and an aliquot taken for nitrogen analysis. An initial suction of 24 kPa was applied onto each of the suction ***cup*** samplers and the resulting soil solution sample collected approx. 24 hours thereafter for N analysis.

The trial investigated four treatments:

1. **Non-irrigated dairy farming (*Nonirr*)**
2. **Dairy farming with effluent irrigation (*Eff*)**
3. **Dairy farming with water irrigation (*Irr*)**
4. **Dairy farming with water and effluent irrigation (*IrrEff*)**

3. Results and Discussion

Leaching of mineral N (NO_3-N + NH_4-N) was calculated over a 22-months period (26 samplings) either using exclusively the lysimeter data or multiplying cup sample concentrations by lysimeter leachate volumes.

Treatment	*lysimeter* (kg ha^{-1})	*cup* (kg ha^{-1})	difference (as % of lys.)
Nonirr	69	129	+ 87
Eff	206	326	+ 54
Irr	62	132	+ 113
IrrEff	73	202	+ 117

Not only the absolute values, but also the relative contribution of the different N species differed markedly between the lysimeters and the cups, as shown for the ***effluent treatment***:

	lysimeter (kg ha^{-1})	*cup* (kg ha^{-1})	*lysimeter* (% of total N)	*cup* (% of total N)
Total N	267	320	-	-
NO_3-N	96	312	36	96
NH_4-N	110	3	41	1
Org-N	62	14	23	4

Different concentrations in the two samples:

All nitrogen species:

- Are different fractions of the soil solution sampled?

Nitrate nitrogen:

- Lower concentration in lysimeters due to denitrification?
  ⇒ A separate lab study indicates that this may occur where carbon is supplied through effluent, but it appears to be negligible elsewhere (Burgess *et al.*, NZLTC 2002 Conference Proceedings, p. 195).

Ammonium and organic nitrogen:

- Higher concentrations in lysimeter samples due to preferential flow, which is not captured by suction cup sampling?
- Lower concentration in suction cup samples due to discrimination of the ceramic cups against ammonium and organic N?

Different number of obtainable samples:

- In approx. 30% of all samplings in the drier treatments (*Nonirr* and *Eff*), and approx. 10% in the wetter treatments (*Irr* and *IrrEff*), leachate was collected from the lysimeters, but no suction cup sample could be taken due to dry soil conditions at the time of sampling.

4. Conclusion

For our trial, with monthly sampling intervals and potential for preferential flow, ***lysimeters*** were considered to be the method of choice.

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