Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury (updated)

Report No. R14/19

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1 Introduction

Over the last two decades, agricultural production in the Canterbury Region has grown as a result of the increasing use of inputs, such as fertilisers, supplementary feeds and irrigation water, accompanied by the conversion of plantation forests and areas of extensive sheep and beef grazing into dairy farms.

At the same time, there is increasing evidence that Canterbury's freshwater resources are becoming degraded as a result of increasing inputs of nutrients, bacteria and sediment from these changing land uses (ECan 2008). If these land-use changes continue under current management practices, modelling studies suggest that nitrate-N concentrations in shallow groundwater are likely to continue increasing in the future (Di & Cameron 2002; Bidwell et al. 2009). Faced with this pressure on the region's water resources, Environment Canterbury is reviewing its approach to managing the cumulative effects of land use, especially diffuse nutrient inputs, on water quality.

Initially, Environment Canterbury undertook a preliminary study to examine the effects of agricultural land uses on water quality between the Rakaia and Waimakariri rivers (Di & Cameron 2004). More recently, the Canterbury Mayoral Forum (2009), as a result of concern over the consequences of intensifying agricultural land uses in the region, commissioned modelling at a regional scale to assess the potential changes to water quality (Bidwell et al*.* 2009).

The Proposed Natural Resources Regional Plan set measurable water quality objectives for surface waters and groundwater, addressed point-source discharges, and set limits for nutrient losses from irrigated properties in inland areas of Canterbury. However, the plan did not include provisions to adequately address the cumulative effects of nutrient loads from intensifying land uses and multiple point-source discharges.

To remedy this problem, Bidwell (2008, 2009) proposed an allocation approach, based on a 'first in first served' basis to address the effects of nitrate-N discharges on shallow groundwater in relation to drinking water quality. A consent application to use water for irrigation would be assessed against existing land uses within a predetermined distance from the property where the proposed activity was going to take place. The discharge of nitrate-N from the proposed activity would be assessed in combination with the estimated nitrate-N leaching from land uses within the 'area of interest'.

The proposed approach required:

- A Geographical Information System (GIS) map of the principal land uses in the region (Hill et al. 2012).
- A long-term average nitrate-N leaching rate for each of the land uses under different soil types and rainfall zones in the region. The leaching rates would be attached to the GIS layer as a 'lookup table'.

Because of concern over the suitability of using the nitrate-N values for assessing resource consent applications, no further work was done to develop this tool (see Section 2). However, information on land uses and nitrate-N leaching rates was also required to model the cumulative effects of nitrate-N discharges from land uses on deeper groundwater and spring-fed surface waters.

Environment Canterbury staff, with assistance from Landcare Research, began work on developing a regional GIS land use map, using data derived from the AgriBase™ dataset, supplemented by information from the Land Cover Data Base 2 (LCDB2), topographical maps, satellite imagery, and the Environment Canterbury consent database (Pairman & North 2010; Hill et al. 2012). Fieldwork was carried out in the Culverden Basin to verify that the mapping data are of acceptable accuracy.

Environment Canterbury also commissioned some farm-scale modelling work with the aim of developing a nitrate-N leaching rate lookup table (Appendix 1). This work is summarised by Lilburne et al. (2010), who then go onto describe the approach used to develop a set of nitrate-N leaching rates for a range of land uses in Canterbury, henceforth referred to as the 'lookup table'.

The regional GIS land use map and the lookup table (i.e. nitrate-N discharge rates from Lilburne et al. (2010)) were used to model, at a regional scale, the potential changes to water quality of changing agricultural land uses for the Canterbury Water Management Strategy (Bidwell et al. 2009). Environment Canterbury also used information in this report, as part of a case study, to model the effects of changing land uses on water quality in the middle and upper reaches of the Hurunui Catchment, North Canterbury (Lilburne et al. 2011). Since 2011 there has been a series of Zone Committee consultative processes tasked with defining nutrient load limits for their zones. Modelling information to support this process for the Selwyn–Waihora Zone relied on the regional land use map and the nitrate leaching rates from the 2010 version of the lookup table. The lookup table information has also been used in other regions (Otago[1] and Southland).

Here we describe this update of the 2010 lookup report (Lilburne et al. 2010), which was based on some new farm-scale modelling using OVERSEER® 6.

2 Project history

At the outset, it was recognised that the key New Zealand researchers working on nitrate leaching and modelling would need to be brought together to pool their knowledge and reach a consensus on nitrate-N leaching values. Environment Canterbury would use this information on the basis that these values represent the best scientific information that was available at the time.

It was not possible to derive the lookup table from measured values. The available and relevant experimental data are summarised in Webb (2009). There are only a very small number of long-term experimental studies of nitrate leaching, and these cover only one or two soil types and rainfall zones. Accurate measurements of leaching are also difficult to obtain (Weihermuller et al. 2007; Webb 2009). Modelling of nitrate-N leaching under various land uses is the only practical way of deriving a comprehensive lookup table suitable for the variety of conditions found on the alluvial plains of Canterbury. The experimental studies do, however, provide useful data for calibrating leaching models, which can be used to simulate leaching on a range of soil types and rainfall zones under various land management practices.

A series of workshops were held to define the modelling parameters, present and review the results, and to resolve inconsistencies in the modelling results.

2.1 Workshop 1 (May 2008)

The first science workshop was held at Environment Canterbury to discuss what were appropriate land use categories and values for long-term nitrate-N leaching rates for different land uses in the region. Participants (see Appendix 2) consisted of Environment Canterbury staff and scientists with interest in nitrate leaching. The workshop concluded that existing information on nitrate-N leaching across a range of farm systems, climate and soil types was inadequate, and that modelling was required to develop a comprehensive and robust set of values. The parameters for this modelling were defined. This work would represent the ‘best science’ available at the time, and would be updated as research became available and/or new models were developed. A follow-up workshop would be held to discuss the results.

HortResearch, Crop & Food Research and AgResearch were contracted by Environment Canterbury to model leaching under lifestyle blocks, turf grass – golf courses, outdoor pigs (Green & Clothier 2009); arable farming (Brown & Zyskowski 2009) and pastoral farming (Snow et al. 2008) respectively. An estimate of nitrate-N leaching under forestry in Canterbury was provided by Davis and Watt (2008). Table 2.1 summarises the principal features of the models.

[1] http://www.orc.govt.nz/Documents/Publications/Regional/Water/Plan%20Change%206A/August%202012/Nitrogen%20sensitive%20zones%20-%20re-evaluation%20in%20the%20light%20of%20submissions%20and%20computer%20modelling_part%204.pdf

Table 2.1 Description of the models used to estimate nitrate-N leaching

Model	Agency	Availability	Type	Scale		Inputs & processing	Outputs
OVERSEER® v 5.2	AgResearch	Freely available	Empirical	Farm/ Farm Block	?	Inputs derived farm systems. Internal databases & empirical relationships	Nutrient budget. No drainage data
SPASMO	HortResearch – now Plant & Food)	Research model	Process	Paddock	Daily time-step	Algorithms simulate physical & chemical processes	Nutrients and drainage
LUCI	Crop & Food Research – now Plant & Food)	Research model	Process	Paddock	Daily time-step		Nutrients and drainage
SWatBal	Scion	Research model	Process	100-m cell	Daily time-step	National-scale climate and soil data	Drainage

To ensure a consistent set of inputs for the modelling, the Canterbury Region was divided into four coastal rainfall zones (650 mm/y, 750 mm/y, 850 mm/y and 950 mm/y) and two inland rainfall zones (550 mm/y, 900 mm/y). The region's soils were grouped into seven categories, according to their profile available water storage and drainage characteristics, and the soil properties were summarised for each category (Webb & Lilburne 2008). The soil properties were subsequently amended as a result of further fieldwork (Webb 2009, see Appendix 3).

2.2 Workshop 2 (16 October 2008)

A follow-up workshop with most of the participants from Workshop 1 and representatives from the arable and dairy industry was held in mid-October at Environment Canterbury to peer-review and assess confidence in the results of the modelling (Green & Clothier 2008, Snow et al*.* 2008; Brown & Zyskowski 2009). A number of issues with the results were identified, including discrepancies resulting from the use of different models (Webb & Lilburne 2008), the datasets used by the modellers, and the need to provide values for both standard and best land management practices so as to define a range of leaching rates.

In response to the matters raised at Workshop 2, Landcare Research and Lincoln Ventures critically reviewed the modelling results, and recommended that the SPASMO model be used to estimate nitrate-N leaching from pastoral farming (Bidwell & Webb 2009). Consequently, a contract was let to Plant & Food Research to model nitrate-N leaching from pastoral farm systems and to include the rainfall zones and soil types that had been omitted from the earlier work (Green & Clothier 2009). The arable modelling was also rerun to fix some internal errors and to cover the 950-mm rainfall zone (Brown & Zyskowski 2009).

Landcare Research was asked to expand on its initial review (Bidwell & Webb 2009), and to critically review all the modelling work that had been carried out to date prior to the third science workshop (Webb 2009).

2.3 Workshop 3 (5 November 2009)

A further workshop was held to discuss different results from the various models and to see if agreement could be reached on a set of nitrate-N discharge values.

Some outstanding issues were identified: the different responses of the models to soil, climate and management; the use of different assumptions to define 'best' and typical management practices; and use of a single value to represent nitrate-N leaching rates (as opposed to a range). The primary sector expressed concern at the criticism of OVERSEER®, as various industry bodies have committed to supporting the future development of the model. It was agreed at the workshop that Environment

Canterbury would work with primary-sector representatives to finalise a set of nitrate-N leaching values.

2.4 Caucus meeting (9 February 2010)

Following Workshop 3, a caucus meeting, facilitated by Bruce Thorrold (DairyNZ), was held with Environment Canterbury staff, scientists, modellers and industry representatives to try and reach an agreement on a set of nitrate-N leaching values that could be used to complete the pastoral parts of the 'lookup table'. The approach taken was to use all available data, expert opinion, and modelling trends in a technical discussion aimed at consensus. It was agreed that the data from the Lincoln University Dairy Farm (LUDF) (unavailable before this date) fitted well with expert opinion (on the basis of on past research), and these results were used as the starting point for assessing the modelling results. These results were extrapolated to dairy farms with higher and lower stocking rates on different soils and rainfall zones. These results were then extrapolated to sheep and beef systems by making some simple assumptions about the relative rates of nitrate-N leaching (Table 3.1).

At the Caucus meeting, there was insufficient time to complete the table or to do some internal consistency checking. Following the meeting, a smaller group of scientists[2] filled in some of the gaps and tidied up some inconsistencies. This involved obtaining and analysing additional leaching and drainage information from the LUDF and ECan respectively. The main additions and changes done by this smaller group were to specify all the dryland drainage values (using Environment Canterbury's lysimeter data as a starting point), simplify the relationship between soil type (i.e. drainage) and nitrate-N leached (see section 3), add the relative ratios for 3 cows/ha and pigs, add border-dyke irrigation, and finally add rates for high country leaching.

The key leaching-rate assumptions relative to the LUDF data (4 cows/ha, winter-off) are as follows: increasing the stocking rate to 5 cows/ha increases the nitrate-N leaching rate (concentration & load) by 15%; reducing stocking rates to 3 cows/ha reduces the leaching rate by 25%. Wintering-on of dairy cows increases the nitrate-N leaching rate by 25%. Beef are assumed to be the equivalent of 3 dairy cows/ha. Pigs are assumed to leach the same as 4 cows/ha, winter-off. Sheep are assumed to leach 50% less (than 4 cows/ha, winter-off)[3]. Deer are assumed to leach 20% more than sheep. The stocking rate of the dryland land is assumed to be half that of the equivalent irrigated land.

In September the revised table and report was sent to the meeting participants for their comments and final agreement. The final report was released as Lilburne et al. (2010).

2.5 Updated farm-scale modelling (January–June 2013)

In 2012, a new version of OVERSEER® was released (version 6) that addressed some of the issues identified in the earlier workshops. In particular, the model was now more responsive to soil. As OVERSEER® has been identified by a number of councils as the model to be used to develop farm nutrient budgets, Environment Canterbury commissioned some new OVERSEER® 6 modelling with a view to updating the lookup table. The same OVERSEER® input files as used in the original pastoral modelling work (Snow et al. 2008) with the addition of data for the new soil parameters, were run through OVERSEER® 6. These results were then extrapolated following a similar set of rules and trends as were used in the previous version of the lookup table.

[2] From LVL, Landcare Research and Ravensdown.
[3] Stu Ledgard's Taupo data compared sheep & cattle and about 50–60% difference in the leaching ratio. OVERSEER® results are 60% less (Betteridge et al. 2005; Monaghan et al. 2010).

3 Final set of nitrate-N leaching values for the 'look-up table'

3.1 Introduction

The final results are based on a combination of key assumptions and rules that were agreed at the February Caucus meeting (see previous section) and some new modelling results from OVERSEER® 6. Nitrate losses and drainage values are taken from the OVERSEER® 6, LUCI and SPASMO modelling, and interpolated to obtain missing values (climates and soils). Some of the relative differences between farm types from the previous report are applied again to obtain values for a greater range farm types than was simulated. Data were extrapolated to cover border-dyke irrigation. Note that the 'heavy' soil from Lilburne et al. (2010) is now referred to as a 'deep' (D) soil.

3.1.1 Nitrate-N load for non-pastoral land uses

The results from the LUCI and SPASMO modelling were used for the non-pastoral land uses (i.e. arable, lifestyle blocks, berry and pip fruit, grapes) (Brown & Zyskowski 2009; Green & Clothier 2009). Golf values were taken from Green & Clothier (2008) since these were not listed in the Green & Clothier (2009) report. Both the standard management (represented by rotorainer irrigation) and best management (represented by precise water deficit irrigation) arable values are provided. The SCION SWatbal results were used for exotic and native forestry, since forests drain less annual water compared with pasture because of foliage interception of rainfall and plant uptake from their larger root area (Davis & Watt 2008). As in the previous report, denitrification is estimated to reduce the leachate by 50% on poorly drained soils (see Appendix 4).

3.1.2 Nitrate-N load for pastoral land uses

The 'base' result from which other land uses (that were not explicitly modelled) were extrapolated was taken to be dairying with 3 cows/ha, winter-on. This farm type was selected rather than results from 4 cows/ha winter-off (as in the previous report) to avoid an anomaly in the winter on/off results. Not all climates and soil types were simulated so results for the Darfield climate zone, and VL and M soil types, were interpolated from adjacent climate zones and soil types, e.g. a value for Darfield on an Medium soil was calculated as the average of the Hororata and Lincoln, Deep and Light results.

Table 3.1 shows the method used to derive nitrate-N losses for each of the farm types.

Table 3.1 Derivation of the nitrate-N leached values for different farm types

Land use/management	Source	Assumptions
Base = nitrate-N load (mass) of 3 cows/ha winter-on		From OVERSEER® 6 modelling
3 cows/ha, winter-off	OVERSEER®	
4 cows/ha, winter-off	OVERSEER®	
4 cows/ha, winter-on	OVERSEER®	
5 cows/ha, winter-off[4]	OVERSEER®	
Beef 100% (irrigated)	= base	Same as 3 dairy cows/ha, winter-on
Beef 100% (dryland)	= base with dryland drainage	Same N concentration as irrigated 100% beef, but a lower N mass
Sheep 100% (irrigated & dryland)	OVERSEER®	
Deer 100% (irrigated & dryland)	OVERSEER® (sheep) + 20%	20% more than sheep
Dairy support (irrigated)	= base + 25%	Stock is there for only part of the year, but are concentrated in a smaller area. Add 25%
Dairy support (dryland)	= base + 25%	Same as irrigated as it involves

[4] Assumed that at 5 cows/ha, farms have to winter-off their cows.

		winter grazing
Pigs	= base	Report by LEL (2001) equates an annual nitrogen load limit of 150 kg/ha (pig) to 200 kg/ha (dairy) in terms of permitted-activity rules, so this leads to pigs = base + 33%. The Pork industry argues that pigs should have the same leaching threshold as cows in the regional rules. So it is assumed that pigs = base
Arable	LUCI 09	LUCI modelling results (best management practice) (Brown & Zyskowski 2009)
Vegetables	SPASMO 09	Horticulture NZ is commissioning further modelling (C. Keenan, pers. comm.). Use SPASMO modelling in the meantime
Lifestyle	SNB(10%) + 7 kg	Same as the dryland 10% sheep and beef losses + septic tank losses of 7 kgN/ha/y
Fruit trees & Golf	SPASMO 09	SPASMO modelling results for best management practice (Green & Clothier 2009)
Exotic and native forestry	SwatBal	SWatBal modelling results (Davis & Watts 2008)

Nitrate-N losses from farms with mixed proportions of sheep and beef are calculated as weighted averages based on the stock units specified in Hill et al. (2009) and sourced from MAF[5]. For example, in a 20% beef, 80% sheep operation, 20% of the head count is beef but they require 56.8% of the land so the nitrate-N load is calculated as 0.568 × beef mass NO_3 load + 0.432 × sheep mass NO_3 load.

In contrast to the previous report, all pastoral dryland and spray-irrigated drainage is now taken from OVERSEER® 6 predictions. Values are more influenced by rainfall and less by soil type than in the previous lookup table (Table 3.2). As in the previous report, drainage under border-dyke irrigation was extrapolated from IRRICALC modelling results by Aqualinc (2008) where an irrigation return period of 14–18 days was assumed.

Table 3.2 Drainage under different irrigation conditions for sheep. Spray-irrigated and dryland drainage values were obtained from OVERSEER® 6 modelling; border-dyke was obtained from Aqualinc (2008)

Climate	Soil type	Irrigated drainage	Dryland drainage	Border dyke
Lincoln (650 mm)	XL	229	164	1060
	VL	216	146	690
	L	203	127	610
	M	204	125	610
	D	204	123	610
Darfield (750 mm)	XL	346	271	1150
	VL	317	240	760
	L	288	210	670

[5] http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/best-management-practices/reassessment-of-the-stock-management-system/re-assessment-of-stock-unit-system08.htm

	M	284	208	660
	D	280	206	660
Hororata (850 mm)	XL	462	377	1200
	VL	418	335	820
	L	373	292	740
	M	364	290	710
	D	355	288	710

In the previous report (Lilburne et al. 2010), nitrate-N losses under border-dyke irrigation were assumed to have the same concentration as spray irrigation, which resulted in very high nitrate mass losses due to the increased drainage. While border-dyke irrigation is expected to result in higher nitrate-N mass losses, these may not be proportional to the increased drainage as there may not be sufficient nitrate-N in the profile. A more conservative estimate was made in this report by averaging the results from an equal-concentration assumption and an equal-mass assumption. This leads to an increase in mass nitrate-N losses under border-dyke irrigation but a dilution in the nitrate-N concentration.

The extrapolation approach used means that some of the more extreme values should be treated with caution. For example, a border-dyke 4 cows/ha winter-on system on an XL soil, if it exists or is used in a scenario, may need to also take into account other activities such as feed-lot effluent capture.

3.2 Derivation of nitrate-N leaching values for high country soils in Hurunui Catchment

Determination of values for leaching of nitrate-N for the hill and steepland soils in the Hurunui Catchment is based on the relationship between Land Use Capability classes and nitrate-N leaching (table 2 in Carran et al*.* 2007). Stocking rates (SU) for the Land Use Capability classes are based on Fletcher (1987). A relationship of SU x 1.2 = kg N leached/ha/y was found by combining information from Carran et al. (2007) and Fletcher (1987). This relationship was then applied to the stocking rate derived from Agribase™ to estimate annual nitrate-N leaching for land areas in the Hurunui Catchment. The stocking rate per hectare was calculated using the number of beef, sheep and deer, each multiplied by the relative stock units given in Hill et al. (2012).

3.3 Summary of pastoral lookup values

Figure 3-1[6] shows the drainage rates under irrigated and dryland conditions in the different areas and on the various soils. Figures 3-2 and 3-3 shows nitrate losses under sheep and beef farm-types.

[6] The H label in the graphs refers to both heavy and deep soils

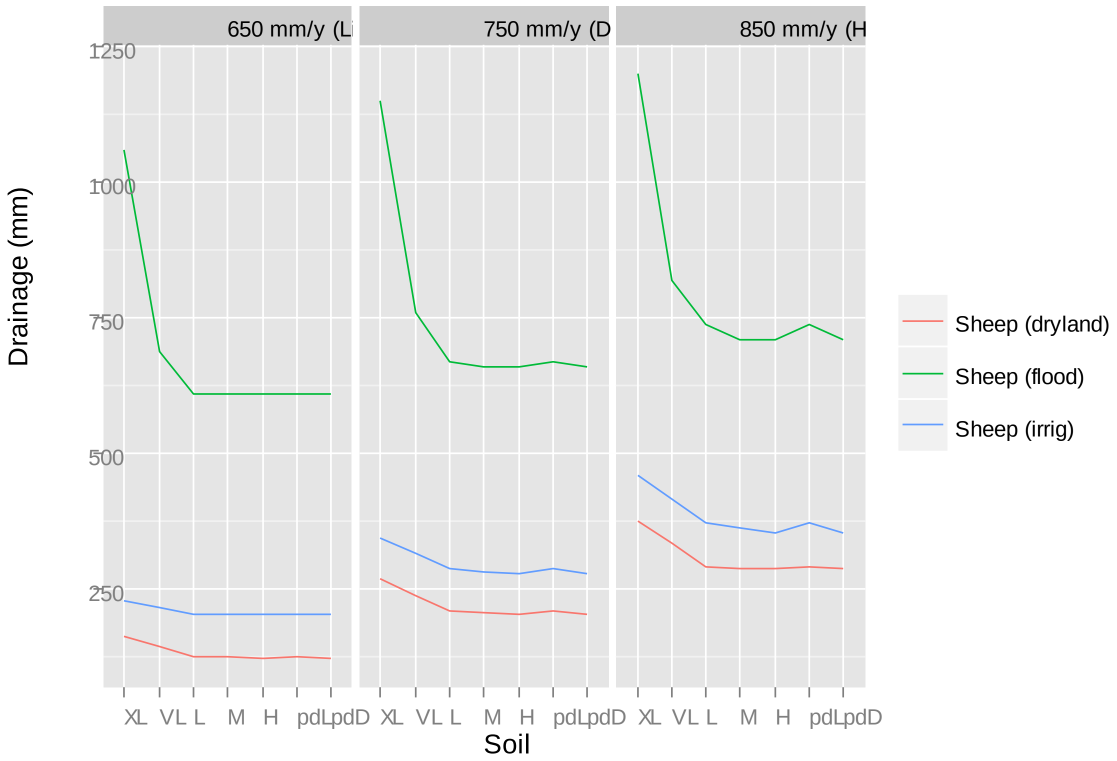

Figure 3-1 Drainage under irrigation (spray and border-dyke) and dryland.

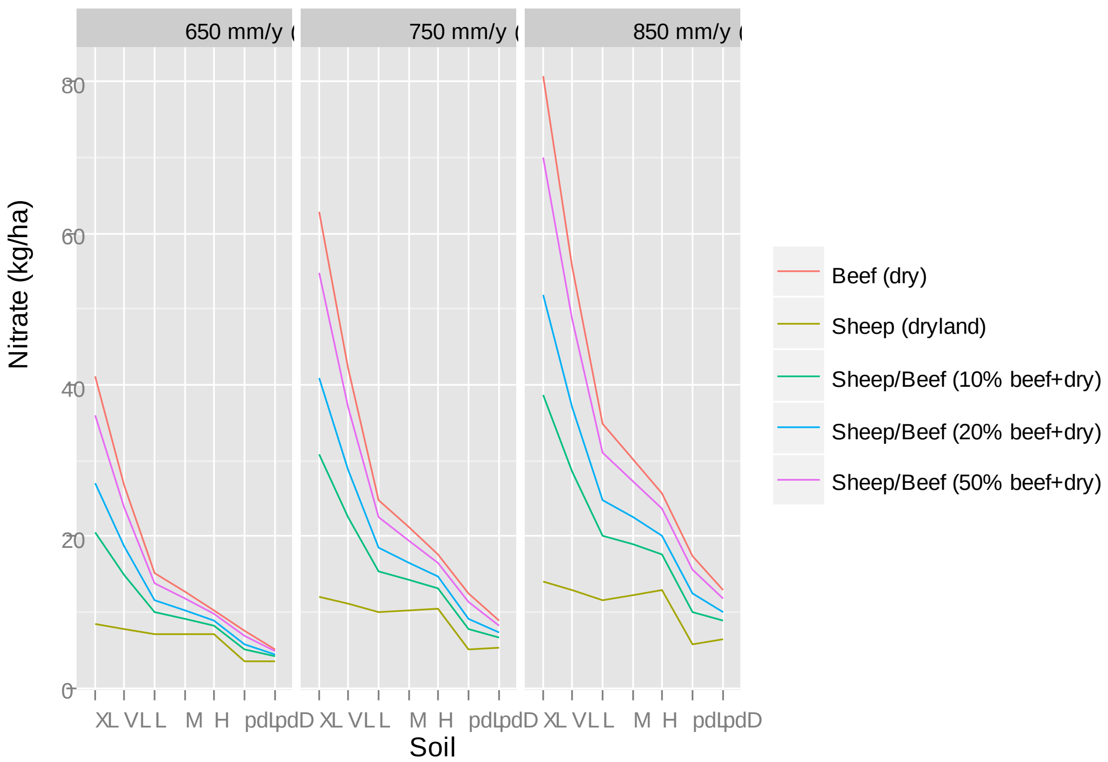

Figure 3-2 Nitrate losses (mass) under dryland sheep and beef.

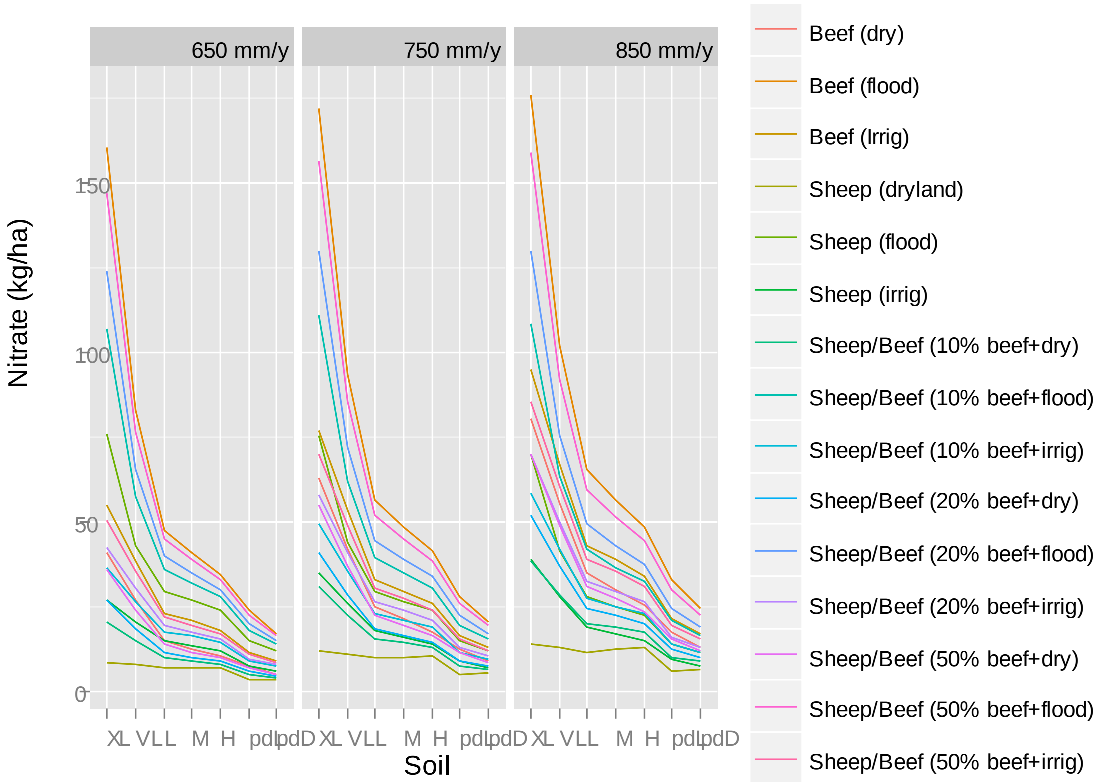

Figure 3-3 Nitrate losses (mass) for all sheep and beef farm types.

Figures 3.4 to 3.8 show the nitrate-N mass and concentration losses, and drainage lookup values for the dairy related farm types by soil type and climate zone.

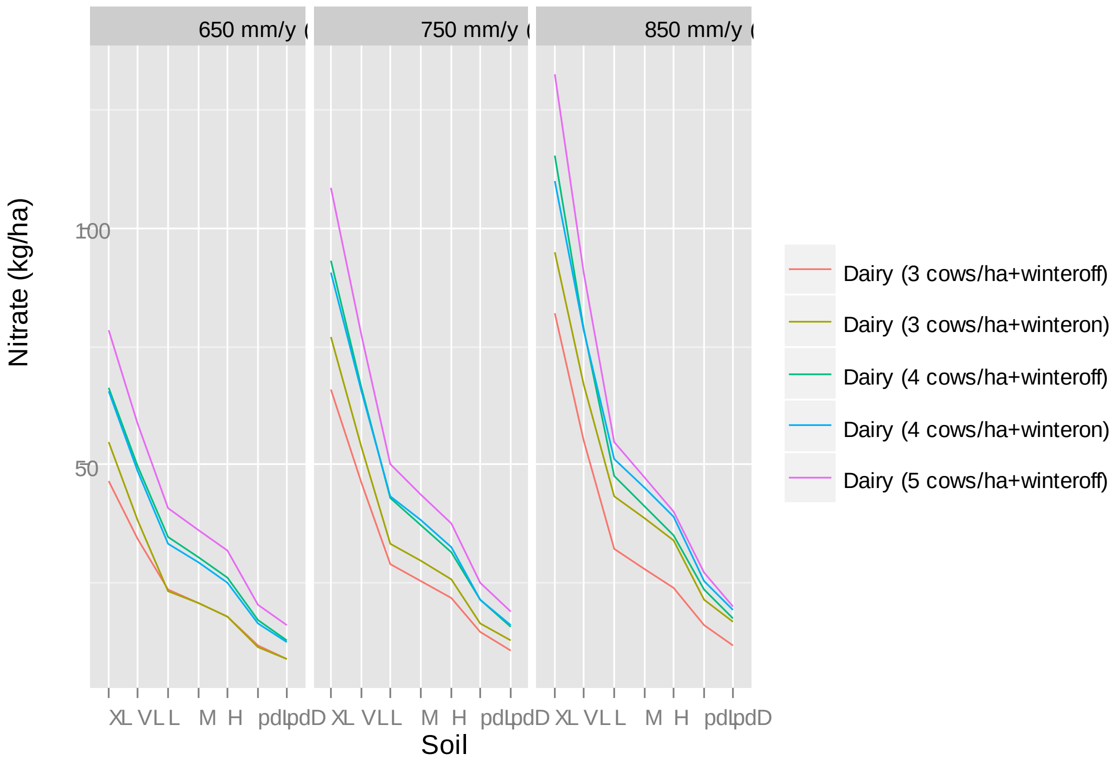

Figure 3-4 Nitrate losses (mass) for dairy platforms.

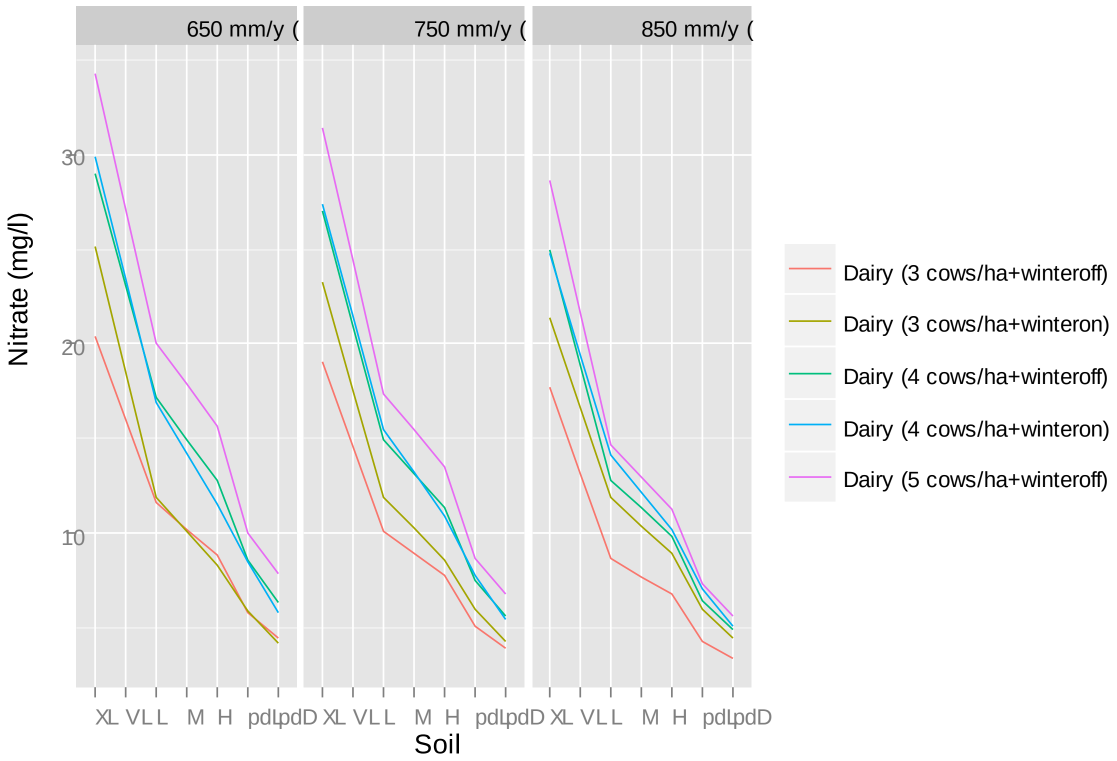

Figure 3-5 Nitrate losses (concentration) for dairy platforms.

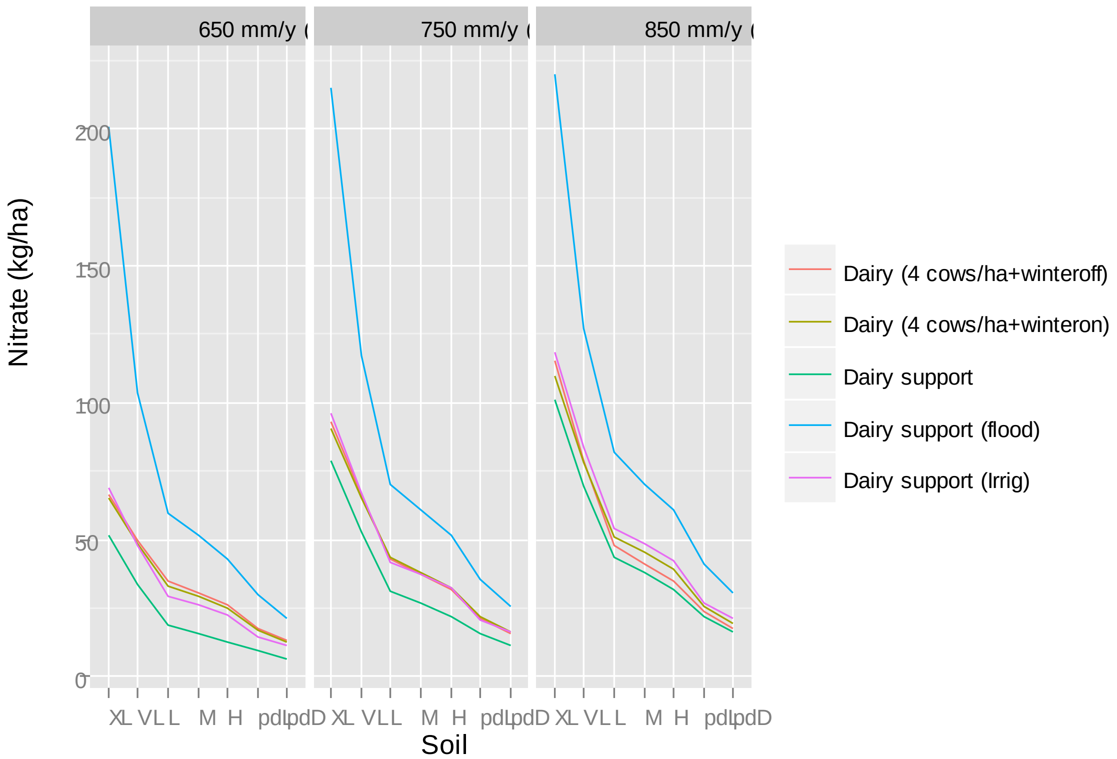

Figure 3-6 Nitrate losses (mass) for dairy related farm types.

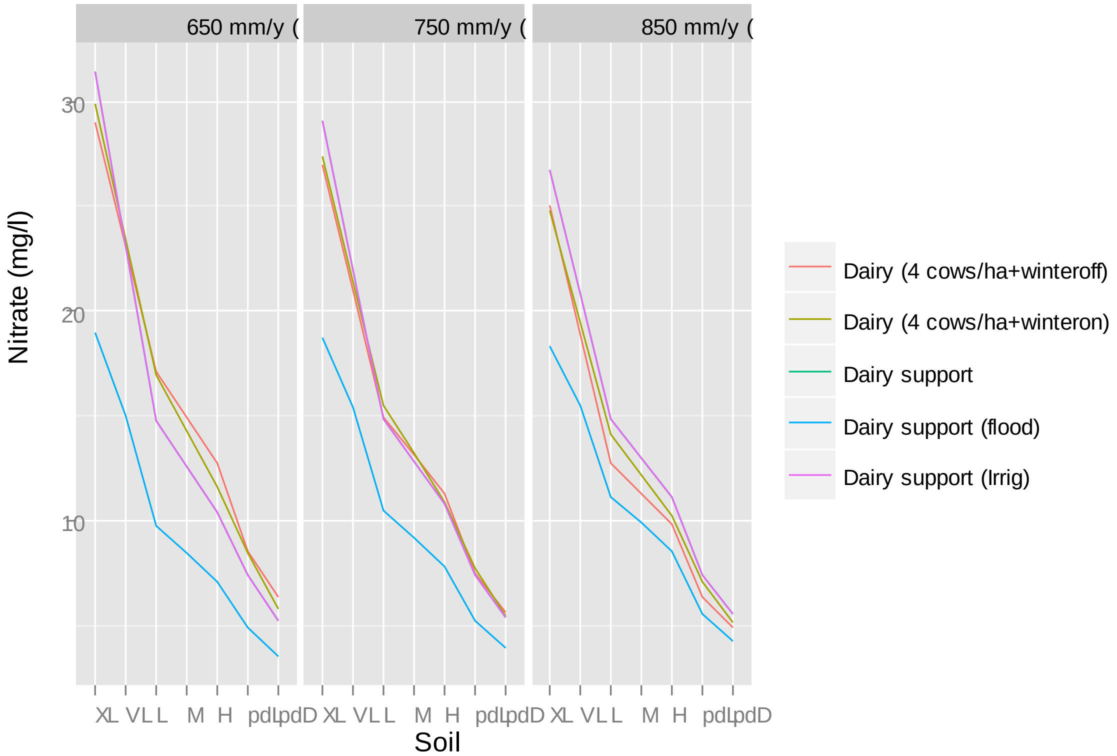

Figure 3-7 Nitrate losses (concentration) for dairy related farm types.

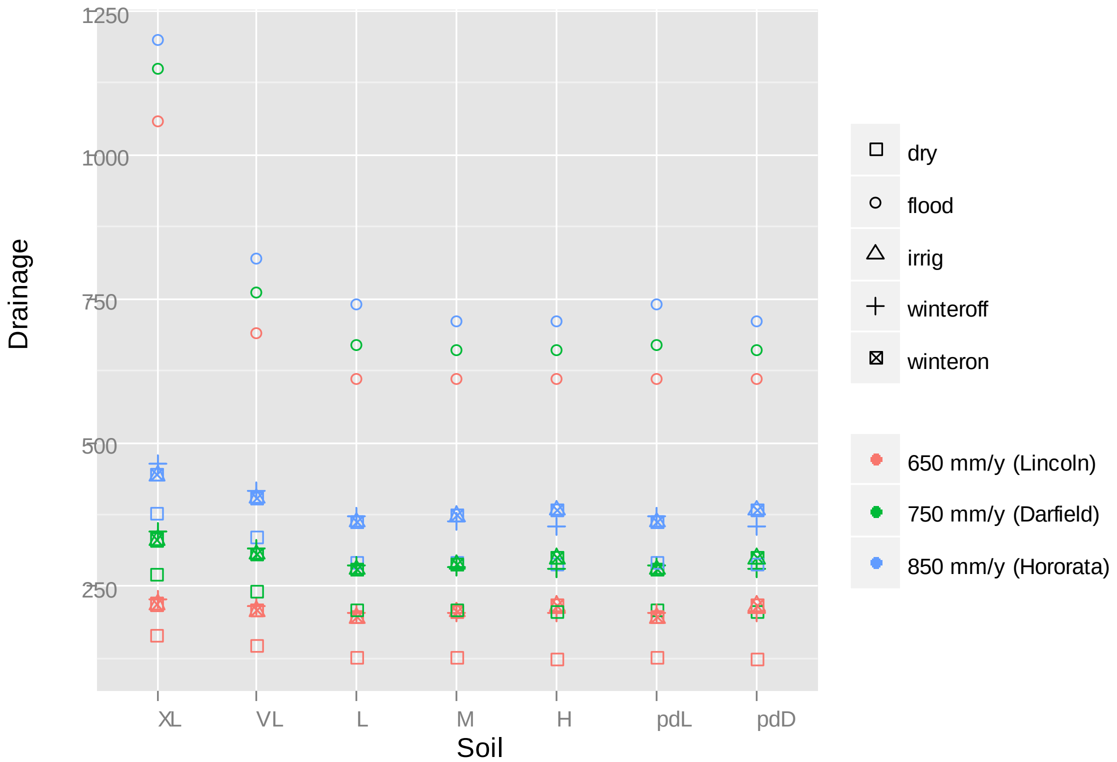

Figure 3-8 Drainage below the dairy related farm types by soil and climate.

Figures 3.9 to 3.11 shows losses (nitrate and water) from arable farms.

Figure 3-9 Nitrate losses (mass) for arable farms under deficit irrigation.

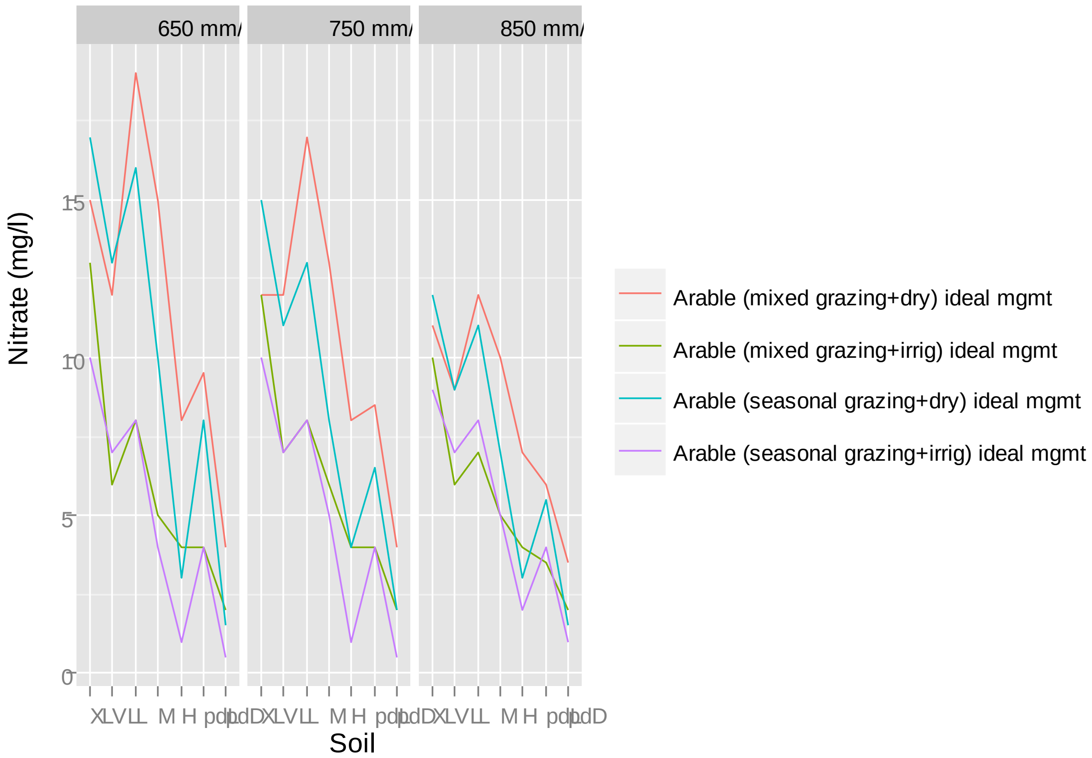

Figure 3-10 Nitrate losses (concentration) for arable farms under deficit irrigation.

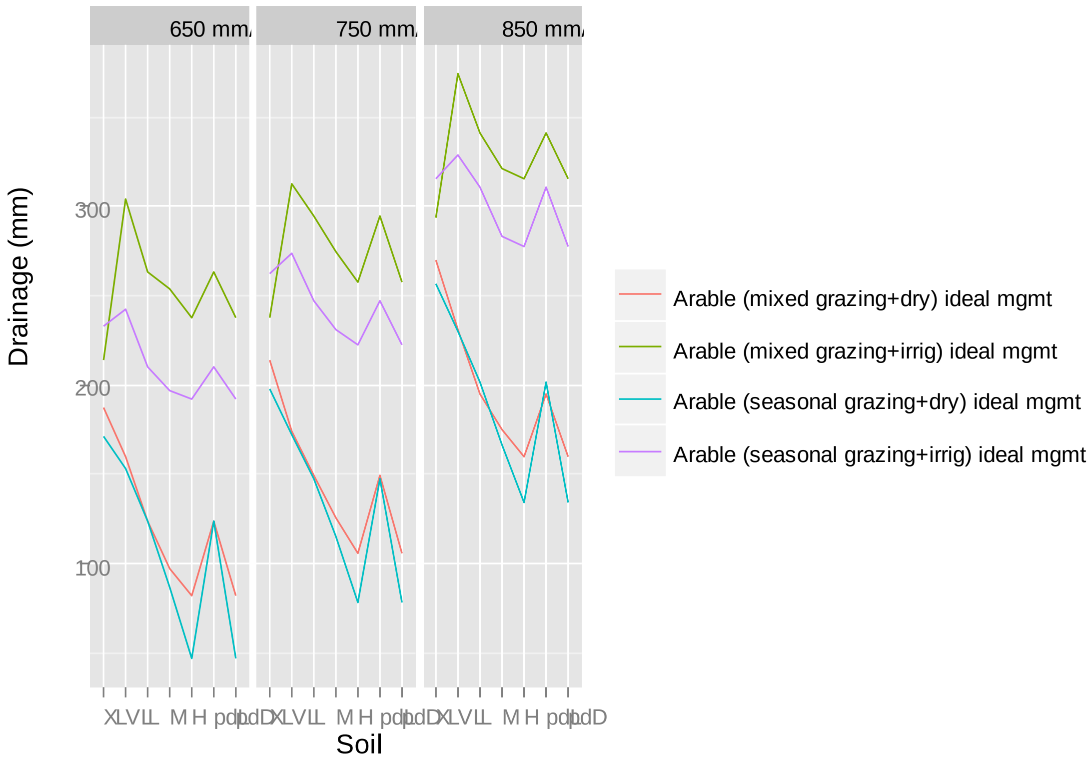

Figure 3-11 Drainage from arable farms under deficit irrigation.

Figures 3-12 to 3-14 compare nitrate and water losses across the agricultural sectors

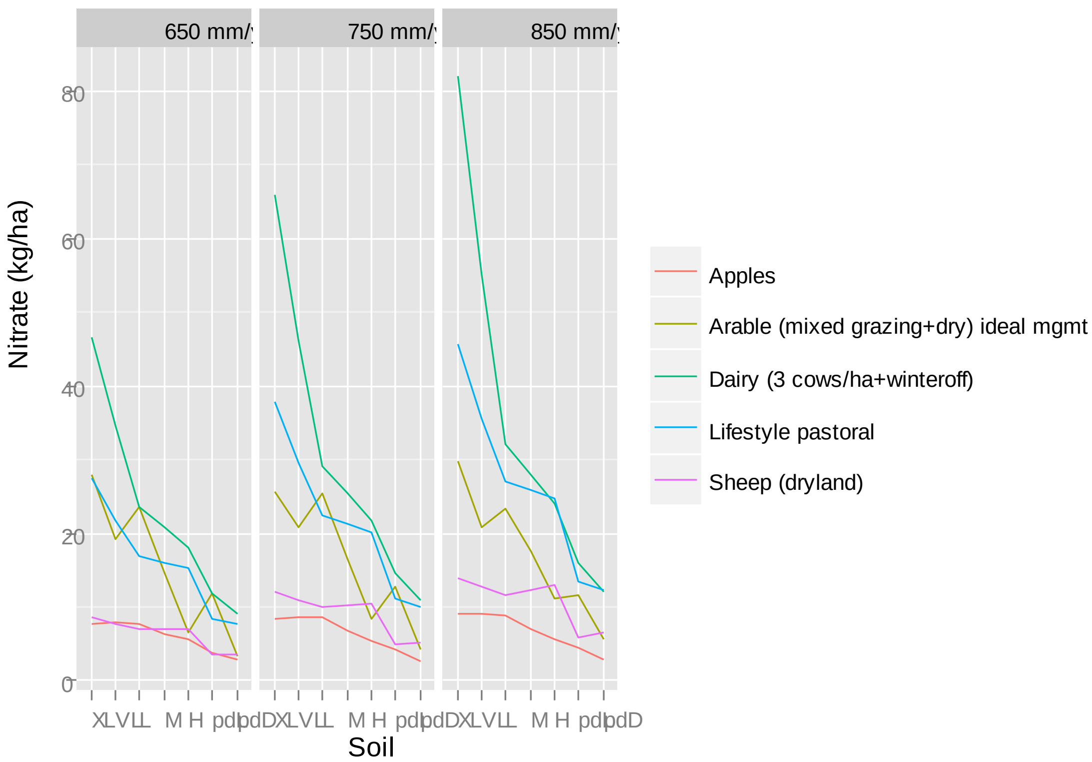

Figure 3-12 Nitrate losses (mass) between agricultural sectors.

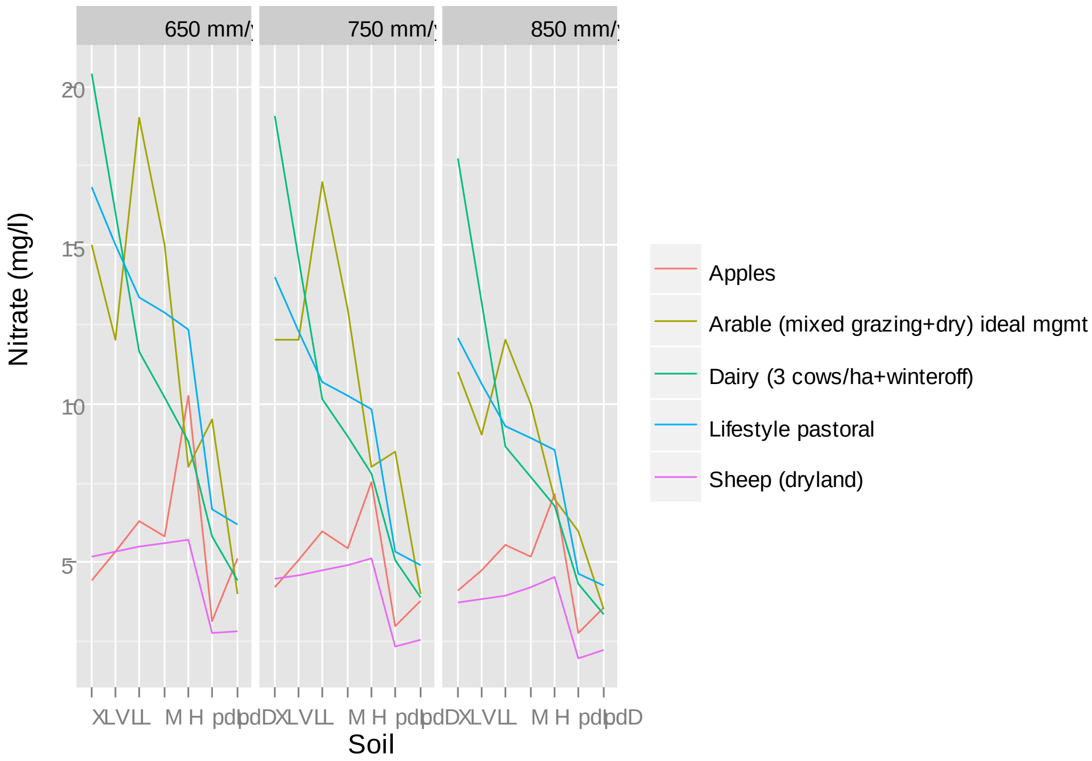

Figure 3-13 Nitrate losses (concentration) between agricultural sectors.

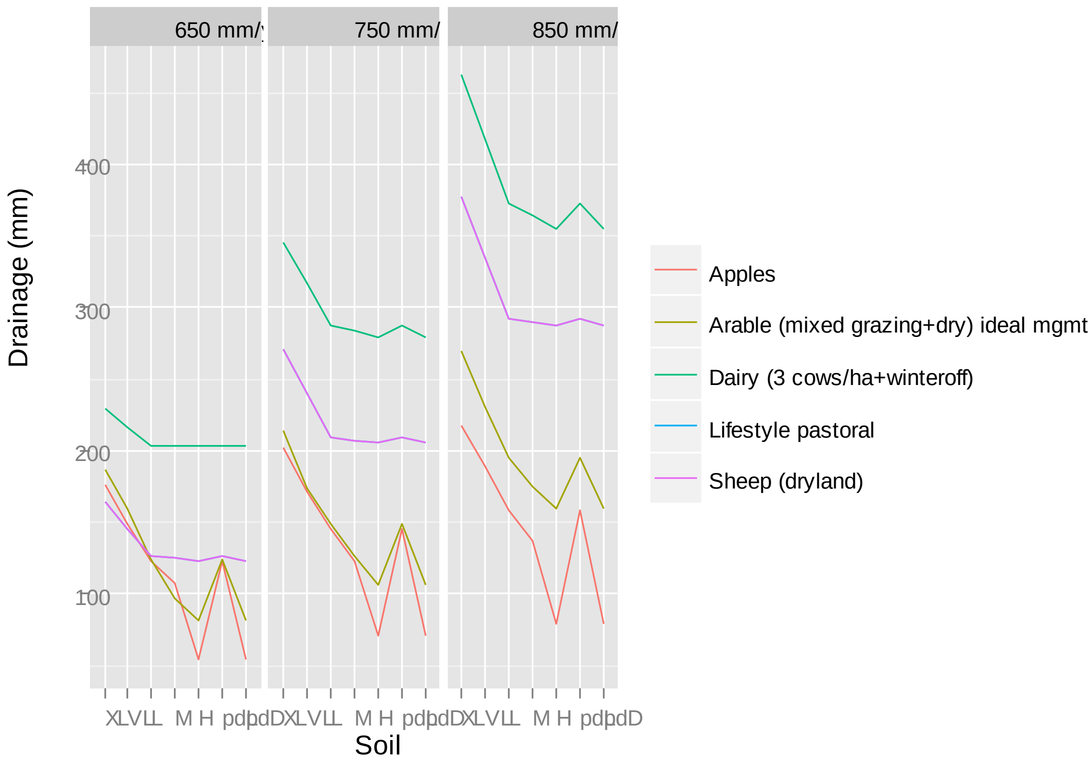

Figure 3-14 Drainage below farms from different agricultural sectors.

4 Conclusions

There are many difficult issues in estimating nitrate-N leaching rates for the main land uses on different soils and rainfall zones, including the rarity of good long-term measured data, which means that models cannot be reliably calibrated for Canterbury conditions. A combined modelling and expert-knowledge approach was used to extend model results from OVERSEER®, SPASMO, and WheatCalculator to a range of soils, climates and other land uses. More data on both drainage and nitrate-N leaching rates are required, particularly on the shallow and stony soils. This will contribute to improvements in the nutrient leaching models.

In the meantime, the values in this report are a reasonable starting point to gain an understanding of the regional implications of land use in relation to nitrate-N leaching. An important point that was raised and agreed by participants at the Caucus Workshop was that while these values are suitable for exploration of regional or large-catchment scale, land-use scenarios and for screening the effects of proposed changes in land uses, they are not suitable for use at the farm scale (e.g. in a consent process) as these values are simple long-term annual estimates that do not take into account the many management practices that can minimise or add to the actual leaching. Also the extrapolation does not take into account the feasibility of some of the soil–climate–land-use combinations (e.g. dryland sheep and beef on extra light soils in the Lincoln climate).

5 Acknowledgements

The authors acknowledge the input from Val Snow in working through some of the issues posed by the new modelling results. This report was prepared for Environment Canterbury by Landcare Research (LC1759).

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Appendix 1: Final table of leaching values

Table A.1 Lookup values for pastoral land uses

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
3 cows/ha winter off	Irrigated	Lincoln	XL	229	20.4	46.7	1060	12.4	131.4
			VL	216	16.0	34.6	690	10.5	72.5
			L	203	11.6	23.6	610	7.8	47.3
			M	204	10.2	20.8	610	6.8	41.6
			D	204	8.8	18.0	610	5.9	35.9
			PdL	203	5.8	11.8	610	3.9	23.6
			Pd	204	4.4	9.0	610	2.9	18.0
		Darfield	XL	346	19.1	65.9	1150	12.4	142.5
			VL	317	14.6	46.2	760	10.3	78.6
			L	288	10.1	29.2	670	7.2	48.5
			M	284	9.0	25.4	660	6.4	42.3
			D[7]	280	7.8	21.8	660	5.5	36.6
			PdL	288	5.1	14.6	670	3.6	24.3
			Pd	280	3.9	10.9	660	2.8	18.3
		Hororata	XL	462	17.7	81.9	1200	12.3	147.3
			VL	418	13.2	55.0	820	9.9	81.6
			L	373	8.6	32.2	740	6.5	48.0
			M	364	7.7	28.0	710	5.8	41.3
			D	355	6.8	24.0	710	5.1	36.0
			PdL	373	4.3	16.1	740	3.2	24.0
			Pd	355	3.4	12.0	710	2.5	18.0
3 cows/ha winter on	Irrigated	Lincoln	XL	219	25.1	55.0	1060	15.1	160.6
			VL	208	18.5	38.3	690	12.0	82.9
			L	196	11.8	23.2	610	7.8	47.7
			M	206	10.1	20.8	610	6.7	41.2
			D	216	8.3	18.0	610	5.6	34.4
			PdL	196	5.9	11.6	610	3.9	23.9
			Pd	216	4.2	9.0	610	2.8	17.2
		Darfield	XL	331	23.3	77.0	1150	15.0	172.2
			VL	305	17.6	53.6	760	12.3	93.5
			L	280	11.9	33.2	670	8.4	56.4
			M	289	10.2	29.6	660	7.4	48.6
			D	299	8.6	25.8	660	6.3	41.3
			PdL	280	5.9	16.6	670	4.2	28.2
			Pd	299	4.3	12.9	660	3.1	20.7
		Hororata	XL	443	21.4	94.8	1200	14.7	175.8

[7] The term D (Deep) now covers what was originally classified as H (Heavy) and D (Deep) soils

Farm type	Irrigation	Climate	Soil	Drainage	Calc. conc	Trend mass	Border-dyke irrigation		
				(mm/y)	(mg N/L)	(kg N/ha/y)	Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			VL	403	16.7	67.1	820	12.4	101.8
			L	363	11.9	43.2	740	8.9	65.6
			M	373	10.4	38.7	710	7.9	56.3
			D	382	8.9	34.0	710	6.8	48.6
			PdL	363	6.0	21.6	740	4.4	32.8
			Pd	382	4.5	17.0	710	3.4	24.3
4 cows/ha winter off	Irrigated	Lincoln	XL	229	29.0	66.4	1060	17.6	186.9
			VL	216	23.1	49.8	690	15.1	104.5
			L	203	17.1	34.8	610	11.4	69.7
			M	204	14.9	30.4	610	10.0	60.8
			D	204	12.8	26.0	610	8.5	51.9
			PdL	203	8.6	17.4	610	5.7	34.8
			Pd	204	6.4	13.0	610	4.3	26.0
		Darfield	XL	346	27.0	93.3	1150	17.6	201.9
			VL	317	21.0	66.4	760	14.9	112.9
			L	288	15.0	43.1	670	10.7	71.6
			M	284	13.1	37.3	660	9.4	62.0
			D	280	11.3	31.6	660	8.0	53.1
			PdL	288	7.5	21.5	670	5.3	35.8
			Pd	280	5.7	15.8	660	4.0	26.6
		Hororata	XL	462	25.0	115.5	1200	17.3	207.8
			VL	418	18.9	78.8	820	14.2	116.8
			L	373	12.8	47.6	740	9.6	71.0
			M	364	11.3	41.2	710	8.6	60.7
			D	355	9.9	35.0	710	7.4	52.5
			PdL	373	6.4	23.8	740	4.8	35.5
			Pd	355	4.9	17.5	710	3.7	26.3
4 cows/ha winter on	Irrigated	Lincoln	XL	219	29.9	65.5	1060	18.0	191.3
			VL	208	23.4	48.6	690	15.2	105.1
			L	196	16.9	33.2	610	11.2	68.3
			M	206	14.3	29.4	610	9.5	58.2
			D	216	11.6	25.0	610	7.8	47.8
			PdL	196	8.5	16.6	610	5.6	34.1
			Pd	216	5.8	12.5	610	3.9	23.9
		Darfield	XL	331	27.4	90.5	1150	17.6	202.5
			VL	305	21.4	65.4	760	15.0	114.1
			L	280	15.5	43.4	670	11.0	73.6
			M	289	13.2	38.2	660	9.5	62.7
			D	299	10.9	32.6	660	7.9	52.2
			PdL	280	7.8	21.7	670	5.5	36.8

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc' (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			Pd	299	5.4	16.3	660	4.0	26.1
		Hororata	XL	443	24.8	109.8	1200	17.0	203.7
			VL	403	19.4	78.3	820	14.5	118.9
			L	363	14.1	51.1	740	10.5	77.7
			M	373	12.1	45.2	710	9.3	65.7
			D	382	10.2	39.0	710	7.9	55.8
			PdL	363	7.0	25.6	740	5.2	38.8
			Pd	382	5.1	19.5	710	3.9	27.9
5 cows/ha winter off	Irrigated	Lincoln	XL	229	34.2	78.4	1060	20.8	220.7
			VL	216	27.1	58.6	690	17.8	123.0
			L	203	20.1	40.7	610	13.4	81.5
			M	204	17.9	36.4	610	11.9	72.7
			D	204	15.7	32.0	610	10.5	63.9
			PdL	203	10.0	20.4	610	6.7	40.8
			Pd	204	7.8	16.0	610	5.2	31.9
		Darfield	XL	346	31.5	108.7	1150	20.4	235.2
			VL	317	24.4	77.3	760	17.3	131.4
			L	288	17.4	50.0	670	12.4	83.2
			M	284	15.4	43.8	660	11.0	72.8
			D	280	13.5	37.7	660	9.6	63.3
			PdL	288	8.7	25.0	670	6.2	41.6
			Pd	280	6.7	18.8	660	4.8	31.7
		Hororata	XL	462	28.7	132.4	1200	19.8	238.2
			VL	418	21.7	90.5	820	16.4	134.1
			L	373	14.7	54.8	740	11.0	81.8
			M	364	13.0	47.3	710	9.8	69.7
			D	355	11.3	40.0	710	8.5	60.0
			PdL	373	7.3	27.4	740	5.5	40.9
			Pd	355	5.6	20.0	710	4.2	30.0
100% beef	dry	Lincoln	XL	164	25.1	41.2			
			VL	146	18.5	26.9			
			L	127	11.8	15.0			
			M	125	10.1	12.6			
			D	123	8.3	10.3			
			PdL	127	5.9	7.5			
			Pd	123	4.2	5.1			
		Darfield	XL	271	23.3	62.9			
			VL	240	17.6	42.2			
			L	210	11.9	24.9			
			M	208	10.2	21.3			

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc' (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			D	206	8.6	17.7			
			PdL	210	5.9	12.4			
			Pd	206	4.3	8.9			
		Hororata	XL	377	21.4	80.7			
			VL	335	16.7	55.7			
			L	292	11.9	34.8			
			M	290	10.4	30.2			
			D	288	8.9	25.6			
			PdL	292	6.0	17.4			
			Pd	288	4.5	12.8			
100% beef	Irrigated	Lincoln	XL	219	25.1	55.0	1060	15.1	160.6
			VL	208	18.5	38.3	690	12.0	82.9
			L	196	11.8	23.2	610	7.8	47.7
			M	206	10.1	20.8	610	6.7	41.2
			D	216	8.3	18.0	610	5.6	34.4
			PdL	196	5.9	11.6	610	3.9	23.9
			Pd	216	4.2	9.0	610	2.8	17.2
		Darfield	XL	331	23.3	77.0	1150	15.0	172.2
			VL	305	17.6	53.6	760	12.3	93.5
			L	280	11.9	33.2	670	8.4	56.4
			M	289	10.2	29.6	660	7.4	48.6
			D	299	8.6	25.8	660	6.3	41.3
			PdL	280	5.9	16.6	670	4.2	28.2
			Pd	299	4.3	12.9	660	3.1	20.7
		Hororata	XL	443	21.4	94.8	1200	14.7	175.8
			VL	403	16.7	67.1	820	12.4	101.8
			L	363	11.9	43.2	740	8.9	65.6
			M	373	10.4	38.7	710	7.9	56.3
			D	382	8.9	34.0	710	6.8	48.6
			PdL	363	6.0	21.6	740	4.4	32.8
			Pd	382	4.5	17.0	710	3.4	24.3
100% sheep	Dry	Lincoln	XL	164	5.2	8.5			
			VL	146	5.4	7.8			
			L	127	5.5	7.0			
			M	125	5.6	7.0			
			D	123	5.7	7.0			
			PdL	127	2.8	3.5			
			Pd	123	2.8	3.5			
		Darfield	XL	271	4.5	12.1			
			VL	240	4.6	11.0			

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			L	210	4.7	9.9			
			M	208	4.9	10.2			
			D	206	5.1	10.5			
			PdL	210	2.4	5.0			
			Pd	206	2.6	5.2			
		Hororata	XL	377	3.7	14.0			
			VL	335	3.8	12.8			
			L	292	3.9	11.5			
			M	290	4.2	12.3			
			D	288	4.5	13.0			
			PdL	292	2.0	5.8			
			Pd	288	2.3	6.5			
100% sheep	Irrigated	Lincoln	XL	229	11.8	27.0	1060	7.2	76.0
			VL	216	9.5	20.6	690	6.3	43.2
			L	203	7.3	14.8	610	4.9	29.6
			M	204	6.6	13.4	610	4.4	26.8
			D	204	5.9	12.0	610	3.9	23.9
			PdL	203	3.6	7.4	610	2.4	14.8
			Pd	204	2.9	6.0	610	2.0	12.0
		Darfield	XL	346	10.1	35.0	1150	6.6	75.6
			VL	317	8.1	25.8	760	5.8	43.8
			L	288	6.2	17.8	670	4.4	29.5
			M	284	5.6	15.9	660	4.0	26.5
			D	280	5.1	14.1	660	3.6	23.8
			PdL	288	3.1	8.9	670	2.2	14.8
			Pd	280	2.5	7.1	660	1.8	11.9
		Hororata	XL	462	8.4	39.0	1200	5.8	70.1
			VL	418	6.7	28.1	820	5.1	41.7
			L	373	5.0	18.8	740	3.8	28.1
			M	364	4.6	16.9	710	3.5	24.9
			D	355	4.2	15.0	710	3.2	22.5
			PdL	373	2.5	9.4	740	1.9	14.0
			Pd	355	2.1	7.5	710	1.6	11.3
100% Deer	Dry	Lincoln	XL	164	6.2	10.2			
			VL	146	6.4	9.4			
			L	127	6.6	8.4			
			M	125	6.7	8.4			
			D	123	6.8	8.4			
			PdL	127	3.3	4.2			
			Pd	123	3.4	4.2			

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
		Darfield	XL	271	5.3	14.5			
			VL	240	5.5	13.2			
			L	210	5.7	11.9			
			M	208	5.9	12.2			
			D	206	6.1	12.6			
			PdL	210	2.8	5.9			
			Pd	206	3.1	6.3			
		Hororata	XL	377	4.5	16.8			
			VL	335	4.6	15.4			
			L	292	4.7	13.8			
			M	290	5.1	14.7			
			D	288	5.4	15.6			
			PdL	292	2.4	6.9			
			Pd	288	2.7	7.8			
100% Deer	Irrigated	Lincoln	XL	229	14.1	32.4	1060	8.6	91.2
			VL	216	11.4	24.7	690	7.5	51.9
			L	203	8.7	17.8	610	5.8	35.6
			M	204	7.9	16.1	610	5.3	32.1
			D	204	7.1	14.4	610	4.7	28.7
			PdL	203	4.4	8.9	610	2.9	17.8
			Pd	204	3.5	7.2	610	2.4	14.4
		Darfield	XL	346	12.1	41.9	1150	7.9	90.8
			VL	317	9.8	30.9	760	6.9	52.6
			L	288	7.4	21.3	670	5.3	35.4
			M	284	6.7	19.1	660	4.8	31.8
			D	280	6.1	17.0	660	4.3	28.5
			PdL	288	3.7	10.7	670	2.6	17.7
			Pd	280	3.0	8.5	660	2.2	14.3
		Hororata	XL	462	10.1	46.8	1200	7.0	84.2
			VL	418	8.1	33.8	820	6.1	50.0
			L	373	6.0	22.6	740	4.5	33.7
			M	364	5.6	20.3	710	4.2	29.9
			D	355	5.1	18.0	710	3.8	27.0
			PdL	373	3.0	11.3	740	2.3	16.8
			Pd	355	2.5	9.0	710	1.9	13.5
Dairy Support	Dry	Lincoln	XL	164	31.4	51.5			
			VL	146	23.1	33.6			
			L	127	14.8	18.8			
			M	125	12.6	15.8			
			D	123	10.4	12.8			
			PdL	127	7.4	9.4			

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			Pd	123	5.2	6.4			
		Darfield	XL	271	29.1	78.6			
			VL	240	22.0	52.7			
			L	210	14.8	31.1			
			M	208	12.8	26.6			
			D	206	10.8	22.1			
			PdL	210	7.4	15.5			
			Pd	206	5.4	11.1			
		Hororata	XL	377	26.8	100.9			
			VL	335	20.8	69.6			
			L	292	14.9	43.4			
			M	290	13.0	37.7			
			D	288	11.1	32.0			
			PdL	292	7.4	21.7			
			Pd	288	5.6	16.0			
Dairy Support	Irrigated	Lincoln	XL	219	31.4	68.7	1060	18.9	200.7
			VL	208	23.1	47.9	690	15.0	103.6
			L	196	14.8	29.0	610	9.8	59.6
			M	206	12.6	26.0	610	8.4	51.4
			D	216	10.4	22.5	610	7.0	43.0
			PdL	196	7.4	14.5	610	4.9	29.8
			Pd	216	5.2	11.3	610	3.5	21.5
		Darfield	XL	331	29.1	96.2	1150	18.7	215.3
			VL	305	22.0	67.0	760	15.4	116.9
			L	280	14.8	41.5	670	10.5	70.4
			M	289	12.8	37.0	660	9.2	60.8
			D	299	10.8	32.2	660	7.8	51.6
			PdL	280	7.4	20.7	670	5.3	35.2
			Pd	299	5.4	16.1	660	3.9	25.8
		Hororata	XL	443	26.8	118.5	1200	18.3	219.8
			VL	403	20.8	83.9	820	15.5	127.3
			L	363	14.9	54.0	740	11.1	82.0
			M	373	13.0	48.4	710	9.9	70.4
			D	382	11.1	42.5	710	8.6	60.7
			PdL	363	7.4	27.0	740	5.5	41.0
			Pd	382	5.6	21.3	710	4.3	30.4
50% beef; 50% sheep	dry	Lincoln	XL	164	21.9	36.0			
			VL	146	16.4	23.8			
			L	127	10.8	13.8			

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc' (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			M	125	9.4	11.7			
			D	123	7.9	9.7			
			PdL	127	5.4	6.9			
			Pd	123	4.0	4.9			
		Darfield	XL	271	20.3	54.8			
			VL	240	15.5	37.2			
			L	210	10.7	22.5			
			M	208	9.4	19.5			
			D	206	8.1	16.6			
			PdL	210	5.4	11.2			
			Pd	206	4.0	8.3			
		Hororata	XL	377	18.6	70.0			
			VL	335	14.6	48.8			
			L	292	10.6	31.0			
			M	290	9.4	27.3			
			D	288	8.2	23.6			
			PdL	292	5.3	15.5			
			Pd	288	4.1	11.8			
50% beef; 50% sheep	Irrigated	Lincoln	XL	219	23.0	50.3	1060	13.9	147.0
			VL	208	17.0	35.4	690	11.1	76.5
			L	196	11.1	21.8	610	7.3	44.8
			M	206	9.5	19.6	610	6.4	38.9
			D	216	7.9	17.2	610	5.4	32.8
			PdL	196	5.6	10.9	610	3.7	22.4
			Pd	216	4.0	8.6	610	2.7	16.4
		Darfield	XL	331	21.2	70.0	1150	13.6	156.7
			VL	305	16.1	49.0	760	11.3	85.5
			L	280	11.0	30.6	670	7.8	52.0
			M	289	9.5	27.5	660	6.8	45.1
			D	299	8.0	24.1	660	5.8	38.6
			PdL	280	5.5	15.3	670	3.9	26.0
			Pd	299	4.0	12.0	660	2.9	19.3
		Hororata	XL	443	19.3	85.6	1200	13.2	158.8
			VL	403	15.1	60.7	820	11.2	92.1
			L	363	10.8	39.2	740	8.1	59.6
			M	373	9.5	35.3	710	7.2	51.3
			D	382	8.2	31.2	710	6.3	44.5
			PdL	363	5.4	19.6	740	4.0	29.8
			Pd	382	4.1	15.6	710	3.1	22.3
20% Beef;	Dry	Lincoln	XL	164	16.5	27.1			

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
80% Sheep									
			VL	146	12.8	18.6			
			L	127	9.1	11.6			
			M	125	8.1	10.2			
			D	123	7.2	8.8			
			PdL	127	4.6	5.8			
			Pd	123	3.6	4.4			
		Darfield	XL	271	15.1	41.0			
			VL	240	12.0	28.7			
			L	210	8.8	18.4			
			M	208	7.9	16.5			
			D	206	7.1	14.6			
			PdL	210	4.4	9.2			
			Pd	206	3.5	7.3			
		Hororata	XL	377	13.8	51.9			
			VL	335	11.1	37.2			
			L	292	8.5	24.7			
			M	290	7.7	22.4			
			D	288	7.0	20.2			
			PdL	292	4.2	12.4			
			Pd	288	3.5	10.1			
20% Beef; 80% Sheep	Irrigated	Lincoln	XL	219	19.4	42.4	1060	11.7	123.8
			VL	208	14.6	30.3	690	9.5	65.6
			L	196	9.9	19.4	610	6.5	39.8
			M	206	8.6	17.7	610	5.7	35.0
			D	216	7.3	15.7	610	4.9	30.0
			PdL	196	4.9	9.7	610	3.3	19.9
			Pd	216	3.6	7.9	610	2.5	15.0
		Darfield	XL	331	17.6	58.2	1150	11.3	130.2
			VL	305	13.5	41.2	760	9.5	71.9
			L	280	9.4	26.3	670	6.7	44.7
			M	289	8.2	23.8	660	5.9	39.1
			D	299	7.1	21.2	660	5.1	33.9
			PdL	280	4.7	13.2	670	3.3	22.3
			Pd	299	3.5	10.6	660	2.6	17.0
		Hororata	XL	443	15.8	70.0	1200	10.8	129.8
			VL	403	12.4	49.9	820	9.2	75.7
			L	363	8.9	32.4	740	6.7	49.3
			M	373	7.9	29.5	710	6.0	42.8
			D	382	6.9	26.3	710	5.3	37.6

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			PdL	363	4.5	16.2	740	3.3	24.7
			Pd	382	3.4	13.2	710	2.6	18.8
10% Beef; 90% Sheep	Dry	Lincoln	XL	164	12.5	20.6			
			VL	146	10.2	14.8			
			L	127	7.8	10.0			
			M	125	7.3	9.1			
			D	123	6.7	8.2			
			PdL	127	3.9	5.0			
			Pd	123	3.3	4.1			
		Darfield	XL	271	11.4	30.8			
			VL	240	9.4	22.5			
			L	210	7.4	15.4			
			M	208	6.9	14.3			
			D	206	6.4	13.2			
			PdL	210	3.7	7.7			
			Pd	206	3.2	6.6			
		Hororata	XL	377	10.2	38.6			
			VL	335	8.6	28.6			
			L	292	6.9	20.1			
			M	290	6.5	18.9			
			D	288	6.1	17.7			
			PdL	292	3.4	10.0			
			Pd	288	3.1	8.8			
10% Beef; 90% Sheep	Irrigated	Lincoln	XL	219	16.7	36.6	1060	10.1	106.8
			VL	208	12.8	26.6	690	8.3	57.6
			L	196	9.0	17.6	610	5.9	36.1
			M	206	7.9	16.2	610	5.3	32.1
			D	216	6.8	14.7	610	4.6	28.0
			PdL	196	4.5	8.8	610	3.0	18.1
			Pd	216	3.4	7.3	610	2.3	14.0
		Darfield	XL	331	15.0	49.5	1150	9.6	110.8
			VL	305	11.6	35.5	760	8.1	61.9
			L	280	8.3	23.1	670	5.9	39.3
			M	289	7.3	21.2	660	5.3	34.7
			D	299	6.4	19.0	660	4.6	30.5
			PdL	280	4.1	11.6	670	2.9	19.6
			Pd	299	3.2	9.5	660	2.3	15.3
		Hororata	XL	443	13.2	58.6	1200	9.1	108.6
			VL	403	10.4	41.9	820	7.8	63.6

Farm type	Irrigation	Climate	Soil	Drainage (mm/y)	Calc. conc (mg N/L)	Trend mass (kg N/ha/y)	Border-dyke irrigation		
							Drainage (mm/y)	Conc. (mg N/L)	Mass (kg N/ha/y)
			L	363	7.6	27.5	740	5.6	41.8
			M	373	6.8	25.2	710	5.2	36.6
			D	382	6.0	22.7	710	4.6	32.5
			PdL	363	3.8	13.7	740	2.8	20.9
			Pd	382	3.0	11.4	710	2.3	16.3
Pigs	Dry	Lincoln	XL	164	25.1	41.2			
			VL	146	18.5	26.9			
			L	127	11.8	15.0			
			M	125	10.1	12.6			
			D	123	8.3	10.3			
			PdL	127	5.9	7.5			
			Pd	123	4.2	5.1			
		Darfield	XL	271	23.3	62.9			
			VL	240	17.6	42.2			
			L	210	11.9	24.9			
			M	208	10.2	21.3			
			D	206	8.6	17.7			
			PdL	210	5.9	12.4			
			Pd	206	4.3	8.9			
		Hororata	XL	377	21.4	80.7			
			VL	335	16.7	55.7			
			L	292	11.9	34.8			
			M	290	10.4	30.2			
			D	288	8.9	25.6			
			PdL	292	6.0	17.4			
			Pd	288	4.5	12.8			

Table A.2 Lookup values for arable land uses

Farm type	Climate	Soil	Irrigated			Dry		
			Drainage mm/y	Calc. conc. mg N/L	Trend mass kg N/ha/y	Drainage mm/y	Calc conc. mg N/L	Trend mass kg N/ha/y
Arable – mixed Precise deficit irrigation	Lincoln	XL	214	13	27.82	187	15	28.05
		VL	304	6	18.24	160	12	19.2
		L	263	8	21.04	124	19	23.56
		M	254	5	12.7	97	15	14.55
		D	238	4	9.52	82	8	6.56
		PdL	263	4.0	10.5	124	9.5	11.8
		Pd	238	2.0	4.8	82	4.0	3.3
	Darfield	XL	238	12	28.56	149	17	25.33
		VL	313	7	21.91	126	13	16.38
		L	295	8	23.6	106	8	8.48

		M	275	6	16.5	214	12	25.68
		D	258	4	10.32	174	12	20.88
		PdL	295	4.0	11.8	149	8.5	12.7
		Pd	258	2.0	5.2	106	4.0	4.2
	Hororata	XL	294	10	29.4	270	11	29.7
		VL	374	6	22.44	231	9	20.79
		L	341	7	23.87	195	12	23.4
		M	321	5	16.05	175	10	17.5
		D	316	4	12.64	160	7	11.2
		PdL	341	3.5	11.9	195	6.0	11.7
		Pd	316	2.0	6.3	160	3.5	5.6
Arable – seasonal Precise deficit irrigation	Lincoln	XL	233	10	23.3	171	17	29.07
		VL	242	7	16.94	153	13	19.89
		L	210	8	16.8	124	16	19.84
		M	197	4	7.88	87	10	8.7
		D	192	1	1.92	47	3	1.41
		PdL	210	4.0	8.4	124	8.0	9.9
		Pd	192	0.5	1.0	47	1.5	0.7
	Darfield	XL	262	10	26.2	198	15	29.7
		VL	274	7	19.18	172	11	18.92
		L	247	8	19.76	148	13	19.24
		M	231	5	11.55	115	8	9.2
		D	223	1	2.23	78	4	3.12
		PdL	247	4.0	9.9	148	6.5	9.6
		Pd	223	0.5	1.1	78	2.0	1.6
	Hororata	XL	316	9	28.44	257	12	30.84
		VL	329	7	23.03	230	9	20.7
		L	311	8	24.88	202	11	22.22
		M	283	5	14.15	167	7	11.69
		D	278	2	5.56	134	3	4.02
		PdL	311	4.0	12.4	202	5.5	11.1
		Pd	278	1.0	2.8	134	1.5	2.0
Arable – mixed Rotorainer irrigation	Lincoln	XL	533	5.0	26.7	188	13.0	24.4
		VL	527	4.0	21.1	160	12.0	19.2
		L	469	5.0	23.5	124	17.0	21.1
		M	424	5.0	21.2	97	15.0	14.6
		D	378	4.0	15.1	82	8.0	6.6
		PdL	469	2.5	11.7	124	8.5	10.5
		Pd	378	2.0	7.6	82	4.0	3.3
	Darfield	XL	545	5.0	27.3	214	12.0	25.7
		VL	562	4.0	22.5	175	11.0	19.3
		L	491	5.0	24.6	149	15.0	22.4
		M	436	5.0	21.8	126	12.0	15.1
		D	390	5.0	19.5	107	8.0	8.6
		PdL	491	2.5	12.3	149	7.5	11.2
		Pd	390	2.5	9.8	107	4.0	4.3

	Hororata	XL	579	5.0	29.0	270	9.0	24.3
		VL	621	4.0	24.8	232	8.0	18.6
		L	531	5.0	26.6	196	11.0	21.6
		M	486	5.0	24.3	176	9.0	15.8
		D	455	4.0	18.2	162	7.0	11.3
		PdL	531	2.5	13.3	196	5.5	10.8
		Pd	455	2.0	9.1	162	3.5	5.7
Arable – seasonal Rotorainer irrigation	Lincoln	XL	392	8.0	31.4	172	16.0	27.5
		VL	380	6.0	22.8	153	10.0	15.3
		L	309	8.0	24.7	125	12.0	15.0
		M	290	5.0	14.5	87	8.0	7.0
		D	273	2.0	5.5	48	3.0	1.4
		PdL	309	4.0	12.4	125	6.0	7.5
		Pd	273	1.0	2.7	48	1.5	0.7
	Darfield	XL	427	8.0	34.2	199	13.0	25.9
		VL	414	7.0	29.0	173	9.0	15.6
		L	351	9.0	31.6	148	11.0	16.3
		M	316	6.0	19.0	116	7.0	8.1
		D	296	3.0	8.9	79	3.0	2.4
		PdL	351	4.5	15.8	148	5.5	8.1
		Pd	296	1.5	4.4	79	1.5	1.2
	Hororata	XL	484	8.0	38.7	259	10.0	25.9
		VL	481	6.0	28.9	230	8.0	18.4
		L	421	8.0	33.7	202	9.0	18.2
		M	389	6.0	23.3	168	6.0	10.1
		D	354	3.0	10.6	135	2.0	2.7
		PdL	421	4.0	16.8	202	4.5	9.1
		Pd	354	1.5	5.3	135	1.0	1.4

Table A.3 Lookup values for the other land uses

Farm type	Climate	Soil	Drainage mm/y	Calc conc. mg N/L	Trend mass kg N/h/y
Forestry – exotic on developed land	Lincoln	XL	49	1.1	0.5
		VL	32	3.4	1.1
		L	14	5.7	0.8
		M	12	7.9	0.9
		D	10	10.0	1.0
		PdL	14	2.9	0.4
		Pd	10	5.0	0.5
	Darfield	XL	84	1.2	1.0
		VL	62	2.8	1.7
		L	39	4.4	1.7
		M	30	6.1	1.8
		D	21	7.7	1.6
		PdL	39	2.2	0.9
		Pd	21	3.9	0.8
	Hororata	XL	119	1.3	1.6
		VL	92	2.2	2.0
		L	64	3.1	2.0
		M	48	4.3	2.0
		D	31	5.5	1.7
		PdL	64	1.6	1.0
		Pd	31	2.7	0.9
Forestry – exotic on undeveloped land	Lincoln	XL	49	1.1	0.5
		VL	32	1.1	0.3
		L	14	1.1	0.2
		M	12	1.1	0.1
		D	10	1.1	0.1
		PdL	14	0.5	0.1
		Pd	10	0.6	0.1
	Darfield	XL	82	1.1	0.9
		VL	58	1.1	0.6
		L	33	1.1	0.4
		M	23	1.1	0.3
		D	13	1.1	0.1
		PdL	33	0.5	0.2
		Pd	13	0.5	0.1
	Hororata	XL	119	1.1	1.3
		VL	119	1.1	1.3
		L	64	1.1	0.7
		M	48	1.1	0.5
		D	31	1.1	0.3
		PdL	64	0.5	0.4
		Pd	31	0.6	0.2
Forestry – native	Lincoln	XL	357	0.0	0.0
		VL	275	0.0	0.0
		L	192	0.0	0.0
		M	143	0.0	0.0

Farm type	Climate	Soil	Drainage mm/y	Calc conc. mg N/L	Trend mass kg N/h/y
		D	93	0.0	0.0
		PdL	192	0.0	0.0
		Pd	93	0.0	0.0
	Darfield	XL	246	0.0	0.0
		VL	173	0.0	0.0
		L	99	0.0	0.0
		M	69	0.0	0.0
		D	39	0.0	0.0
		PdL	99	0.0	0.0
		Pd	39	0.0	0.0
	Hororata	XL	147	0.0	0.0
		VL	95	0.0	0.0
		L	42	0.0	0.0
		M	36	0.0	0.0
		D	30	0.0	0.0
		PdL	42	0.0	0.0
		Pd	30	0.0	0.0
Viticulture	Lincoln	XL	206	2.4	5.0
		VL	171	3.3	5.6
		L	144	13.9	20.0
		M	119	10.2	12.1
		D	96	18.4	17.7
		PdL	111	10.4	11.6
		Pd	63	16.1	10.1
	Darfield	XL	236	2.2	5.2
		VL	198	3.0	5.9
		L	170	12.3	20.8
		M	145	9.1	13.2
		D	122	14.5	17.6
		PdL	132	10.0	13.2
		Pd	84	11.9	10.0
	Hororata	XL	261	1.9	4.9
		VL	222	2.6	5.8
		L	193	11.9	23.1
		M	174	8.4	14.6
		D	147	12.8	18.8
		PdL	143	9.6	13.8
		Pd	92	12.0	11.1
Apple	Lincoln	XL	176	4.4	7.8
		VL	150	5.4	8.0
		L	124	6.3	7.8
		M	108	5.8	6.3
		D	55	10.3	5.6
		PdL	124	3.2	3.9
		Pd	55	5.1	2.8
	Darfield	XL	202	4.2	8.5
		VL	171	5.1	8.7
		L	145	6.0	8.7
		M	123	5.4	6.7

Farm type	Climate	Soil	Drainage mm/y	Calc conc. mg N/L	Trend mass kg N/h/y
		D	71	7.5	5.3
		PdL	145	3.0	4.4
		Pd	71	3.8	2.7
	Hororata	XL	218	4.1	9.0
		VL	189	4.8	9.0
		L	159	5.6	8.8
		M	138	5.2	7.1
		D	80	7.1	5.7
		PdL	159	2.8	4.4
		Pd	80	3.6	2.9
Berryfruit	Lincoln	XL	197	5.9	11.7
		VL	167	7.3	12.1
		L	135	8.7	11.7
		M	113	6.9	7.8
		D	77	14.9	11.5
		PdL	135	4.3	5.9
		Pd	77	7.4	5.8
	Darfield	XL	225	5.8	13.1
		VL	192	6.8	13.0
		L	158	8.2	12.9
		M	131	6.8	8.9
		D	97	11.6	11.2
		PdL	158	4.1	6.5
		Pd	97	5.8	5.6
	Hororata	XL	250	5.6	13.9
		VL	213	6.6	14.0
		L	176	7.8	13.7
		M	147	6.7	9.8
		D	113	10.8	12.2
		PdL	176	3.9	6.9
		Pd	113	5.4	6.1
Summer fruit	Lincoln	XL	174	4.6	8.0
		VL	145	5.3	7.7
		L	121	6.0	7.2
		M	106	4.5	4.8
		D	51	10.9	5.5
		PdL	121	3.0	3.6
		Pd	51	5.4	2.8
	Darfield	XL	197	4.5	8.9
		VL	167	5.0	8.4
		L	140	5.6	7.9
		M	120	4.3	5.2
		D	66	7.9	5.2
		PdL	140	2.8	4.0
		Pd	66	3.9	2.6
	Hororata	XL	213	4.4	9.3
		VL	184	4.9	8.9
		L	153	5.4	8.3
		M	131	4.4	5.8

Farm type	Climate	Soil	Drainage mm/y	Calc conc. mg N/L	Trend mass kg N/h/y
		D	74	7.5	5.6
		PdL	153	2.7	4.2
		Pd	74	3.8	2.8
Lifestyle	Lincoln	XL	164	16.8	27.6
		VL	146	15.0	21.8
		L	127	13.4	17.0
		M	125	12.9	16.1
		D	123	12.4	15.2
		PdL	127	6.7	8.5
		Pd	123	6.2	7.6
	Darfield	XL	271	14.0	37.8
		VL	240	12.3	29.5
		L	210	10.7	22.4
		M	208	10.3	21.3
		D	206	9.8	20.2
		PdL	210	5.4	11.2
		Pd	206	4.9	10.1
	Hororata	XL	377	12.1	45.6
		VL	335	10.7	35.6
		L	292	9.3	27.1
		M	290	8.9	25.9
		D	288	8.6	24.7
		PdL	292	4.6	13.5
		Pd	288	4.3	12.3
Golf	Lincoln	XL	184	6.6	12.1
		VL	138	8.4	11.6
		L	111	8.8	9.7
		M	82	9.0	7.4
		D	64	21.5	13.8
		PdL	111	4.4	4.9
		Pd	64	10.8	6.9
	Darfield	XL	207	6.1	12.7
		VL	157	7.7	12.1
		L	128	8.2	10.5
		M	97	8.3	8.1
		D	81	16.2	13.1
		PdL	128	4.1	5.3
		Pd	81	8.1	6.6
	Hororata	XL	226	5.8	13.1
		VL	168	7.4	12.4
		L	138	7.8	10.7
		M	105	8.5	8.9
		D	88	17.4	15.3
		PdL	138	3.9	5.4
		Pd	88	8.7	7.7
Vegetables	Lincoln	XL	262	21.6	56.6
		VL	168	20.4	34.3
		L	111	20.8	23.1

Farm type	Climate	Soil	Drainage mm/y	Calc conc. mg N/L	Trend mass kg N/h/y
		M	92	20.3	18.7
		D	63	26.8	16.9
		PdL	111	10.4	11.5
		Pd	63	13.4	8.4
	Darfield	XL	299	21.7	64.9
		VL	190	19.9	37.8
		L	132	20.0	26.4
		M	117	18.3	21.4
		D	84	23.8	20.0
		PdL	132	10.0	13.2
		Pd	84	11.9	10.0
	Hororata	XL	334	20.7	69.1
		VL	212	19.3	40.9
		L	143	19.2	27.5
		M	129	17.2	22.2
		D	92	20.3	18.7
		PdL	143	9.6	13.7
		Pd	92	10.2	9.3

Appendix 2: Science Workshop participants

Workshop 1: 15 May 2008, held at Environment Canterbury Christchurch

Participants:
Ross Monaghan (AgResearch), Phil Abraham (ECan), Jan Hania (Environment Waikato), Reece Hill (Environment Waikato), Nick Pyke (Foundation for Arable Research), Brent Clothier (HortResearch), Steve Greene (HortResearch), Val Snow (AgResearch), Pam Guest (Consultant, ECan), Trevor Webb (Landcare Research), Steve Thomas (Crop & Food), Raymond Ford (ECan), Christina Robb (ECan), Keith Cameron (Lincoln University), Hong Di (Lincoln University), Hamish Brown (Crop & Food), Linda Lilburne (Landcare Research), Vince Bidwell (Lincoln Ventures), Barry Loe (Consultant, ECan) Ian Whitehouse (Facilitator), Tina von Pein (Project Manager).

Workshop 2: 16 October 2008, held at Environment Canterbury, Christchurch

Participants:
Carl Hanson (ECan), Shirley Hayward (ECan), Keith Cameron (Lincoln University), Rachel Millar (Environment Southland), Ross Monaghan (AgResearch), Linda Lilburne (Landcare Research), Steve Green (Hort Research), Brent Clothier (Hort Research), Nick Pyke (Foundation for Arable Research), Ken Robertson (Horticulture New Zealand), John Glennie (ECan), Hamish Brown (Crop & Food), Raymond Ford (ECan), Viv Smith (ECan), Barry Loe (Consultant, ECan), Val Snow (AgResearch), Jeremy Bryant (AgResearch), Miriam Eagle (Ministry for the Environment), Steve Thomas (Crop & Food), Vince Bidwell (LVL), Trevor Webb (Landcare Research), Reece Hill (Environment Waikato), Pam Guest (ECan), Dawn Dalley (Dairy NZ), Ken T (ECan – for the introduction), Ian Whitehouse (Facilitator), Tina von Pein (Project Manager).

Workshop 3: 5 November 2009, held at the Netball Centre, Christchurch

Participants:
Vince Bidwell (Lincoln Environmental), Val Snow (AgResearch), Ross Monaghan (AgResearch), Steve Thomas (Plant & Food), Hamish Brown (Plant & Food), Steve Green (HortResearch), Brent Clothier (HortResearch), Sonia Whiteman (Horticulture New Zealand), Nick Pyke, (Foundation for Arable Research), Linda Lilburne (Landcare Research), Trevor Webb (Landcare Research), Rachael Millar (Environment Southland), Michael Bennett (Environment Southland), Viv Smith (ESR), Shirley Hayward (DairyNZ), Murray Davis (Scion), Penny Nelson (DairyNZ), Piotre Swierczynski (Ministry for the Environment), Lionel Hulme (Federated Farmers), Pam Guest (Consultant, ECan), , Raymond Ford (ECan), Christina Robb (ECan), Barry Loe (Consultant, ECan), Ken Taylor (ECan), Carl Hanson (ECan), Ian Whitehouse (Facilitator), Tina von Pein (Project Manager).

Caucus: February 2010, held at Environment Canterbury, Christchurch

Participants:
Bruce Thorrold (DairyNZ), Vince Bidwell (Lincoln Environmental), Val Snow (AgResearch), Ross Monaghan (AgResearch), Mark Shepherd (AgResearch), David Wheeler (AgResearch), Alister Metherell (Ravensdown), Hamish Brown (Plant & Food), Steve Green (Plant & Food), Linda Lilburne (Landcare Research, ECan), Trevor Webb (Landcare Research), Shirley Hayward (DairyNZ), Penny Nelson (DairyNZ), Raymond Ford (ECan), Christina Robb (ECan), Ken Taylor (ECan), Tim Mallet (ECan), Carl Hanson (ECan), Tina von Pein (Project Manager).

Appendix 3: Webb (2009): Soil data for land overlying alluvial aquifers in Canterbury

February 2009

These notes are to accompany soil physical data for typifying profiles for land overlying alluvial aquifers.

Objective

'To identify a core set of soil groups for the irrigable parts of the Canterbury Region to be used as a basis for developing a GIS map of nitrate leaching predictions.'

Reason for new soil dataset

The data provided in July 2008 have been amended (Tables A3.1–A3.4). Since that time I have sampled 12 stony to very stony profiles in Canterbury to determine available water content. This work indicates that stony horizons have significantly greater field capacity than previously estimated. This means that I underestimated profile available water for stony soils in my July report.

The previous data were limited to the upper 100 cm soil depth because this is an adequate depth to consider under irrigated conditions. There is a possibility of needing to analyse for deeper soils under dryland conditions, so I have added a deep profile that extends to 150 cm. I have also increased the depth of deep poorly drained soils to 150 cm as these soils are almost always very deep.

I have also added a further column in Table A3.3 to provide Ksat values. Initially I only sent these under request to HortResearch because they needed them for their model. The Ksat values will be needed if analysis is undertaken to estimate denitrification. The Ksat values are median values to overcome the skew in lognormal data. Ksat was measured from 100-mm-diameter cores, derived from the same soil dataset as the other data. Most of my sites were from long-term pasture or short-term pasture after cropping and do not represent what may be found under dairy to long-term arable so I have added in a guestimate of Ksat for topsoils under moderate compaction.

NB The estimate of denitrification in poorly drained soils is more related to a rising water table than to soil permeability. In Canterbury, water tables tend to rise in poorly drained soils over the late winter/spring period. I would be very pleased if someone had monitoring data on this!!

Method

1. Define soil groups on the basis of significant difference in profile available water storage and the separation of soils with poor drainage. The target soil groups are shown in Table A3.1.
2. Find soils in Landcare Research databases that have water holding characteristics.
3. Classify profiles into soil groups.
4. Create typifying profiles by grouping similar horizons.
5. Average required soil attributes for horizons for typifying horizons.

Attributes for soil groups L, M, H, D and Pd were derived from a dataset of eight soil series from the Canterbury Plains, held at Lincoln, containing nine profiles for each of the soil series.

Attributes for soil groups XL, VL, PdL were derived from profiles in the National Soils Database and from sampling and analysis of a range of stony soils in 2008 (field capacity for stony horizons was derived from field moisture content in spring).

Separate data for chemical analyses were provided for soils under cropping than for soils suited to arable use. These data illustrate the large differences in carbon and nitrogen evident between long-term pasture and long-term cropping.

Results

Data for Canterbury Plains soils are recorded in Table A3.3. Table A3.4 contains a description of headings for Table 3.

Table A3.1 Target characteristics of typifying profiles

Soil group	Code	PAW (mm)
Well-drained profiles		
Extremely light	XL	45 (<50)
Very Light	VL	70 (50–80)
Light	L	95 (80–110)
Medium	M	125 (110–150)
Heavy	H	170 (150–200)
Deep	D	235 (>200)
Poorly drained profiles		
Poorly drained	Pd	270 (>110)
Poorly drained, light	PdL	100 (<110)

Table A3.2 List of main soil series

Class	Soil series	Upland series
XL	Waimakariri very stony sand	Tasman very stony sand
VL	Waimakariri and Eyre stony silt loam, Lismore and Balmoral very stony silt loam	Mackenzie, Acheron stony loamy sand
L	Chertsey, Lismore shallow and stony silt loam	Mackenzie shallow sandy loam
M	Hatfield, Templeton, Wakanui mod deep silt loam	Pukaki mod deep sandy loam
H	Hatfield, Templeton, Wakanui (100 cm deep)	Dobson, Braemar, Curroughmore
D	Barrhill, Templeton, Wakanui (150 cm deep)	Uncommon
Pd	Temuka deep clay loam (150 cm)	Uncommon
PdL	Waterton, Taitapu shallow/stony silt loam	Uncommon

Table A3.3 Typifying profiles for Canterbury Plains. Numbers in parenthesis in the final column are guestimates of Ksat under moderately compacted conditions.

Soil	**Horizon attributes**									**Pasture**		**Cropping**		
	Top	Base	Thick	BD	TP	FC	WP	TAW	Stones	C	N	C	N	Ksat
	(cm)	(cm)	(cm)	(g/cc)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	mm/h
Extremely light														
XL	0	10	10	1.25	52	35	8	27	40	2.3	0.21			100 (40)
XL	10	20	10	1.37	43	20	5	15	60	0.9	0.1			100
XL	20	100	80	1.6	43	12	2	10	70	0.4	0.04			100
Very Light														
VL	0	15	15	1.25	52	37	11	27	30	2.6	0.22			100 (40)
VL	15	35	20	1.37	45	32	8	24	50	1.2	0.1			60
VL	35	100	65	1.6	43	12	2	10	65	0.4	0.04			100
Light														
L	0	18	18	1.28	50	37	15	22	0	2.72	0.22	2.2	0.21	60 (20)
L	18	33	15	1.45	45	32	15	17	0	1.38	0.12	1.1	0.09	15
L	33	45	12	1.5	45	15	3	12	50	0.85	0.8	0.64	0.06	30
L	45	100	55	1.6	43	12	2	10	60	0.67	0.05	0.48	0.03	100
Medium														
M	0	20	20	1.34	49	38	16	22	0	2.9	0.24	2.09	0.17	60(10)
M	20	50	30	1.6	39	32	15	17	0	1.38	0.11	1.02	0.09	6
M	50	60	10	1.7	38	32	17	15	0	0.51	0.05	0.47	0.05	3
M	60	100	40	1.6	43	12	2	10	60		0.02		0.02	100
Heavy														
H	0	20	20	1.34	49	38	16	22	0	2.9	0.24	2.09	0.17	30 (10)
H	20	50	30	1.6	39	32	15	17	0	1.38	0.11	1.02	0.09	6
H	50	100	50	1.7	38	35	20	15	0	0.51	0.05	0.47	0.05	1
Deep														
D	0	20	20	1.34	49	38	16	22	0	2.9	0.24	2.09	0.17	30 (10)
D	20	50	30	1.6	39	32	15	17	0	1.38	0.11	1.02	0.09	6
D	50	100	50	1.7	38	35	20	15	0	0.51	0.05	0.47	0.05	1
D	100	150	50	1.6	40	35	22	13	0	0.35	0.04	0.35	0.04	3
Poorly drained														
Pd	0	20	20	1.25	50	47	27	20	0	4.96	0.45	2.85	0.23	100 (10)
Pd	20	50	30	1.5	46	42	27	15	0	1.92	0.17	1.36	0.11	3
Pd	50	100	50	1.45	44	43	23	20	0	1.03	0.08	0.6	0.04	3
Pd	100	150	50	1.45	44	43	26	17	0	0.6	0.05	0.6	0.04	6
Poorly drained, light														
PdL	0	20	20	1.25	50	42	16	26	0	4	0.38	2.55	0.21	100 (10)
PdL	20	50	30	1.45	46	35	15	20	30	1.6	0.14	1.25	0.1	10
PdL	50	100	50	1.6	44	14	3	11	60	0.67	0.05	0.07	0.05	100

Table A3.4 Description of Table headings in Table A3.3.

Heading	Description
Top	Depth to top of horizon
Base	Depth to base of horizon
Thick	Thickness of horizon
BD	Bulk density of fines
TP	Total porosity
FC	Field Capacity of fines (water at 10 kPa)
WP	Wilting Point of fines (water at 1500 kPa)
TAW	Total available water of fines (FC-WP)
Stones	Percentage of particles > 2-mm diameter
C	Total carbon
N	Total nitrogen
Ksat	Saturated hydraulic conductivity

Appendix 4: Effect of poor drainage on leaching of nitrates

Trevor Webb
February 2009

There are limited research data available to compare nitrate leaching under poorly drained and well-drained sites. It is, after all, rather difficult to measure leaching under a water table.

Measurements
Stenger et al. (2008) found very low N concentrations under poorly drained soils at Toenepi in the Waikato. Denitrification largely removed all nitrogen from these sites. Water tables rose into the upper 1 m of soil earlier in the year and remained there for longer than would occur in most areas in Canterbury. There is also a confounding effect of abiotic denitrification related to reduction via presence of Fe2+ minerals – but this will largely occur below the root zone. Toenepi has deep fine-textured materials extending into the aquifer and denitrification occurs within the vadose zone and within the aquifer.

Work on denitrification rates (as in de Klein et al. (2003) and Rappoldt & Corre (1997)) also indicate significant effects of poor drainage.

Application to Canterbury
The effect of poor drainage is very difficult to model due to the seasonal fluctuation of water tables. In Canterbury, there is likely to be some leaching of nitrates in the summer-autumn-early winter period – but late-winter and spring will have high denitrification rates in the root zone. Poorly drained soils in the lower plains will also have significant denitrification in the vadose and aquifer zones because these are fine-textured.

Recommendation
In the absence of a water table, poorly drained soils are very similar in profile features to heavy soils. The additional effect of a fluctuating water table could be accounted for by reducing this value from heavy soils. It is my recommendation that nitrate leaching for poorly drained soils be calculated as 0.5 x the value from heavy soils and for 'light poorly drained' be calculated as 0.5 x the value from light soils. I think that this will be a conservative estimate of the reduction in leaching due to poor drainage.

References
Stenger R, Barkle G, Burgess C, Wall A, Clague J 2008. Low nitrate contamination of shallow groundwater in spite of intensive dairying: the effect of reducing conditions in the vadose zone–aquifer continuum. Journal of Hydrology (NZ) 47: 1–24.

Seven well transects were established in this rolling downlands catchment. (The catchment has artificial drainage.) The monitoring wells were typically only 2.5 to 3.0 m deep. The 34 wells were sampled monthly for 2 years. Relative to the land-use intensity on the dairy farms (avg. 3.1 cows/ha, 99 kg/ha/y N fertiliser), NO_3-N concentrations in the shallow groundwater were generally very low. Eighty percent of the 843 samples had concentrations below the ANZECC trigger value for eutrophication of surface water (0.44 mg NO_3-N/litre). The results indicated that nitrate reduction through heterotrophic and/or autotrophic denitrification is widespread in this catchment in the vadose zone and/or in the shallow aquifer. The overall mean of all samples analysed from the 34 wells was only 0.53 mg NO_3-N/litre. Consistently very low concentrations came from sites underlying poorly drained soils. Average NO_3-N concentrations at 30 cm and 60 cm depth were predominantly substantially lower at the poorly drained sites compared with the well-drained sites.

de Klein CAM, Barton L, Sherlock RR, Li Z, Littlejohn RP 2003. Estimating a nitrous oxide emission factor for animal urine from some New Zealand pastoral soils. Australian Journal of Soil Research 41:381–399

de Klein et al.(2003) studied emission of N_2O from urine patches on four soil types and found that poorly drained soils had the largest emission of nitrous oxides caused by denitrification, even though this soil had lowest rainfall and temperature.

Rappoldt C, Corre WJ 1997. Spatial pattern in soil oxygen content and nitrous oxide emissions from drained grassland. In: Jarvis SC, Pain BF eds Gaseous nitrogen emissions from grassland. Wallingford, UK, CAB International. Pp. 165–172.

Rappoldt and Corre (1997) found emissions of N_2O were 10 times greater at 6 m from drains than at 1 m distance.