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Estimates of nitrogen and phosphorus leaching under various land uses in Canterbury

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A report prepared for
AquaLinc for Central Plains Water

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1 Executive summary

This report was undertaken for AquaLinc because of the company's concern about nitrogen (N) and phosphorus (P) leaching from various Canterbury soils under various rainfall conditions and land uses. Of particular concern was the water-holding capacities of those soils.

Our approach was to provide estimates of seasonal leaching under arable, vegetable, dairy and forestry production using the best current technologies – OVERSEER™ software and crop calculators. The available software varies in complexity and capability for the different land uses, and this affects the type of estimates that can be made, e.g. pastoral estimates are based on long-term means whereas arable and vegetable estimates are based on daily data where simulations are aggregated over several years.

To generate estimates we made a number of assumptions about seasonal patterns of rainfall, evapotranspiration from land, soil status (e.g. soil organic content, soil mineral content, soil texture), seasonal variation in mineral leaching, plant growth, and crop management practices (irrigation, fertilisation, etc.)

Key findings include:

Dairy farming: N leached was 32 kg/ha/year under average conditions. The risk of P leaching is very low but is increased by irrigation.

Sheep/beef farming: N leached was 5 kg/ha/year under average conditions. The risk of P leaching is low.

Arable land: N leached under dryland wheat production was 41 kg N/ha/year and under irrigated production it was 45 kg/ha/year; under sweet corn it was 11-22 kg N/ha/year; under potato it was 10-20 kg N/ha/year. Losses of P from arable lands is very low compared with that of N.

Forestry land: 1-2 kg N/ha/year.

2 Introduction

Leaching of nitrogen (N) and phosphorus (P) from land under intensive agricultural practices is an increasing threat to sustainable crop production and an increasing concern to land managers and the community. Central Plains Water approached Crop & Food Research with a request that we provide them with some estimates of the extent of the issue in Canterbury across a range of soil types, land use practices and rainfall conditions.

The objective of this project was to apply OVERSEER™ and crop calculators software to generate estimates of leached kg N/ha/year and P/ha/year under a range of land uses. To generate estimates we made a number of assumptions about seasonal patterns of rainfall, evapotranspiration from land, soil status (e.g. soil organic content, soil mineral content, soil texture), plant growth, and crop management practices (irrigation, fertilisation, etc.). This report describes our findings.

3 Methods

3.1 Weather

The seasonal pattern of rainfall and evapotranspiration (ET) (Figure 1) determines seasonal variation in N leaching. Most N leaching occurs in winter when rainfall exceeds ET and plant growth is slow.

Annual totals of rainfall are an input to OVERSEER™ – a standard nutrient budgeting tool for pastoral systems in New Zealand. The inherent variability in Canterbury rainfall allowed the selection of groups of years of daily data from Lincoln to meet the required mean annual rainfall criteria of between 640 and 840 mm. At Lincoln, mean annual rainfall is 680 mm, potential evapotranspiration (ET) 1030 mm, and average annual temperature 11.0°C.

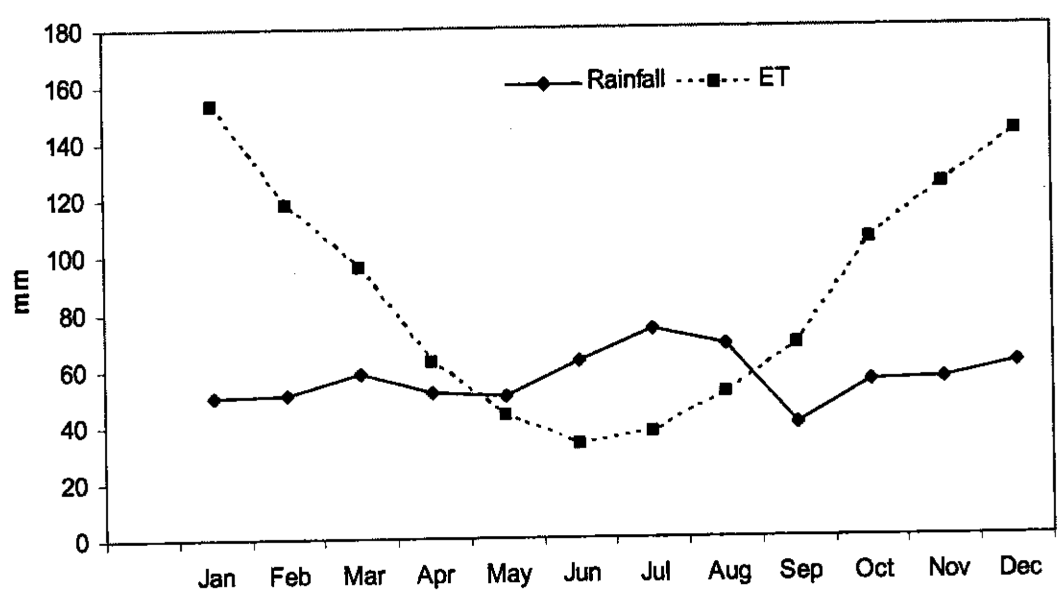

Figure 1: Rainfall and Penman evapotranspiration patterns for Lincoln (1985-2004).

3.2 Soil

Soil depth and texture determine plant-available water-holding capacity (PAW). Nitrogen leached is defined as the amount of N that is carried below 1.5 m depth.

For arable land, four soil profiles were defined with PAW (to 1.5 m depth) specified as 60, 90, 120 and 150 mm and, consequently, different organic matter contents. Organic N (t/ha) was set at 2.0, 3.5, 5.0 and 5.0 respectively. On the basis of surveys in Canterbury, we set the mineral N (nitrate and ammonium) content of the soils at 90 kg N/ha at sowing/planting.

For pastures, the calculations were done for two typical soil types on the Canterbury plains – Templeton (depth to gravel ~150 cm) and Lismore (depth to gravel ~30 cm).

3.3 Management

In all cases typical management was assumed. Relevant practices are described briefly below.

3.4 Software

OVERSEER™ (www.agresearch.co.nz/overseerweb) is the *de facto* standard nutrient budgeting tool for pastoral systems is New Zealand (Ledgard et al. 1999). It was used to calculate N leaching from pastures for the various pastoral scenarios. OVERSEER™ uses long-term average weather data and generic soil and management information, plus production data to generate estimates. These estimates are annual averages; there is no seasonal output. Estimates of N in arable and intensive vegetable production were made using simulation model-based crop calculators (the Sirius Wheat Calculator, Armour et al. 2002; the Potato Calculator, Jamieson et al. 2003; the AmaizeN Calculator, new) developed by Crop & Food Research. Maize was used as a surrogate for sweet corn. These systems require quite detailed soil descriptions and daily weather data for their calculations. They produce daily estimates of leaching and from these the seasonality of leaching patterns can be estimated. For these crops, a selection of weather records for Lincoln was sorted into annual rainfall classes to give groups of years with annual totals of 640, 750, 800 and 840 mm as required. Simulations were run from the beginning of the sowing month through a full year in all cases.

Nitrogen leaching estimates from forests were obtained from existing literature. Phosphorus leaching estimates were made using OVERSEER™.

4 Results

4.1 Dairy farm

Assumptions

Based on a typical, average dairy farm in the Canterbury Central Plains (Livestock Improvement Corporation 2005; MAF 2005).

- 200 ha developed ryegrass/white clover pasture and 620 cows,
- 350 mm irrigation (to match potential ET shortfall of rainfall). This was varied from 140 to 560 mm to provide a total water value of between 80% and 120% of potential ET,
- fertilisation: 150 kg N DAP, 38 P DAP/DCP, 28 S-elemental, K 9, 52 Ca. Medium effluent application rate,
- year-round grazing; no wintering pads, no graze-off; 700 tonnes supplements imported; and no supplements removed,
- production is 1128 kg milk solid/ha (based on the stocking rate of 3.1 cows/ha).

Results

N leaching from the farm was 32 kg/ha/year in average conditions. Leaching losses were insensitive to the 140-560 mm variation of irrigation (losses changed by only 2 kg/ha/year) and therefore to variations in mean rainfall. There was little change in leaching losses due to soil type, even though the Templeton and Lismore soils are very different in their depth and water-holding capacity.

Leaching was very sensitive to the development stage of the pastures. For example, highly developed ryegrass/white clover pasture may leach 41 kg/ha/year under average climate and management conditions, while the pastures in development or recently cultivated leach only 26 kg/ha/year. Leaching is also sensitive to the amount of N fertiliser applied. The amount of N leached varies from 20 to 45 kg/ha/year, depending on the N fertilisation applications of 0 to 250 kg/ha/year.

These simulations indicate that the risk of P leaching is very low under average conditions, but the risk increases to medium when the irrigation rate is equivalent to 120% ET.

4.2 Sheep/beef farm

Assumptions

The estimation is based on an average farm in Canterbury (the model farm monitored by MAF (2005, www.maf.govt.nz/mafnet/rural-nz/statistics-and-fore casts/farm-monitoring) with less cultivation and occasional irrigation with the following average conditions:

- 1003 ha developed ryegrass/white clover pasture, 6242 sheep equivalents (wintered), of which 71% are sheep and 29% are cattle, of which half are male.
- average annual rainfall of 900 mm and average annual temperature 10.0°C.
- rolling topography, Eyre silt loam,
- no irrigation. Irrigation never amounts to more than about 20-50 ha on these farms and therefore has not been included in the analysis,
- fertiliser application: 35 kg urea/ha in conjunction with maintenance P and S applications of 13 kg P/ha, 21 kg S/ha, 8 kg Ca/ha,
- animals graze on the pasture all year round without wintering pads or graze-off, 40 t supplements (hay and cereal) are added into the farm, and none are removed,
- the farm produces 19 812 kg wool in total.

Results

The amount of N leached was estimated to be 5 kg/ha/year under the average conditions, and varied between 4 and 6 kg/ha/year in response to fertilisation rate of 20-60 kg urea/ha; and 3-12 kg/ha/year depending on the development stage of the pasture.

The risk of P leaching is low.

4.3 Arable land

4.3.1 General seasonal pattern of nitrogen leaching

The annual average N leached from fallow land on Templeton soil was estimated as 17 ± 13 kg/ha/year (mean ± standard deviation) during 1985-2004 with a minimum of 1.1 kg and maximum of 59.0 kg N/ha, of which 72% occurs during winter (Jul-Sep) when rainfall exceeds potential ET (Figure 2). The Templeton soil is deep and has a high PAW (320 mm).

A summary of N leaching under the 4 weather conditions × 4 soil water holding capacities × 2 dry/irrigated are summarised for each crop in Table 1.

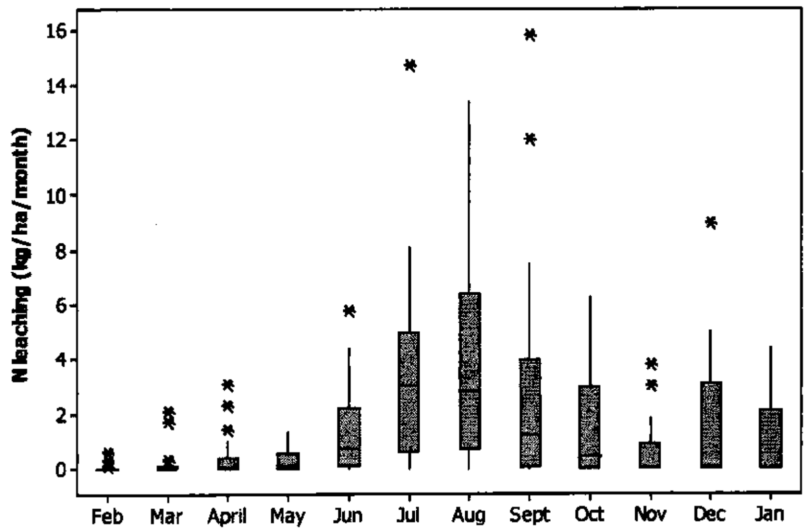

*Figure 2: Simulated seasonal variation of the N leaching on fallow land at Lincoln, 1985-2004. Box plot: vertical lines indicate the range, boxes indicate the quartile (Q1), median and third quartile (Q3). The * indicate outliers.*

Table 1: Estimated N leaching for wheat, potato and sweet corn crops under variable weather and soil conditions and irrigation availability.

Rainfall (mm)	Soil PAW (mm)	Irrigation?	N Leaching (kg/ha) Wheat	Potato	Sweet corn
640	60	Dry	34	7	17
		Irrigated	66	70	61
	90	Dry	34	9	14
		Irrigated	47	51	32
	120	Dry	35	12	11
		Irrigated	49	33	23
	150	Dry	33	11	9
		Irrigated	45	24	20
750	60	Dry	43	10	20
		Irrigated	66	89	54
	90	Dry	46	13	24
		Irrigated	47	60	30
	120	Dry	47	20	16
		Irrigated	47	33	18
	150	Dry	44	16	10
		Irrigated	44	31	16
800	60	Dry	39	12	23
		Irrigated	73	82	56
	90	Dry	42	15	16
		Irrigated	42	58	29
	120	Dry	43	18	14
		Irrigated	43	34	18
	150	Dry	40	16	11
		Irrigated	40	29	16
840	60	Dry	46	10	27
		Irrigated	95	85	51
	90	Dry	49	13	15
		Irrigated	49	70	22
	120	Dry	50	17	18
		Irrigated	50	32	16
	150	Dry	46	16	17
		Irrigated	46	28	15

4.4 Wheat

Estimated N leaching from wheat crops on a Templeton soil for the past 20 years at Lincoln is shown in Figure 3, giving an average N leaching of 11 ± 10 kg N/ha/year. Nitrogen uptake by crops results in less leaching than from fallow, but has the same seasonal pattern (mainly during winter). The major management assumptions were that management was guided by the Wheat Calculator, i.e. irrigation was scheduled according to a running soil moisture budget (or no irrigation) and N fertiliser was applied in spring to coincide with high crop demand. There was no shortage of other elements such as P, K, S, Ca, Mg. The crop was sown on 8 May each year.

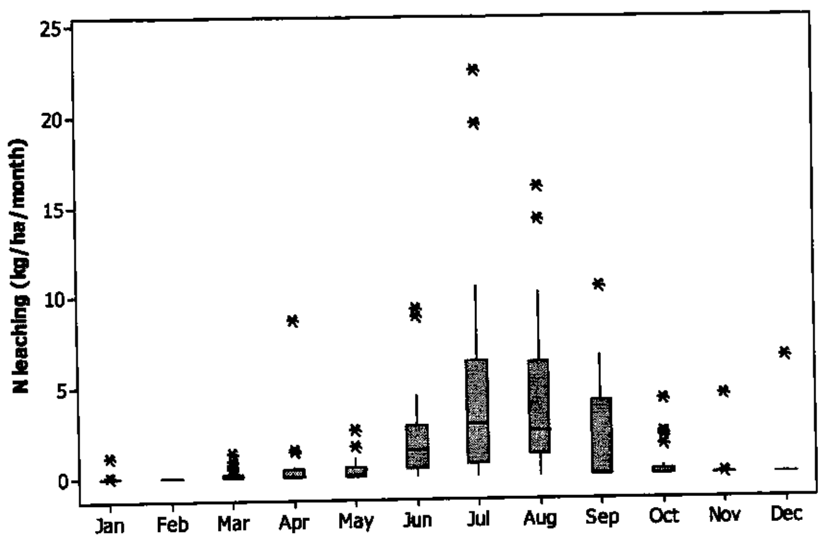

*Figure 3: Simulated seasonal variation of N leaching under irrigated wheat at Lincoln during 1985-2004. Box plot: vertical lines indicate the range, boxes indicate the quartile (Q1), median and third quartile (Q3). The * indicate outliers.*

Results

Dryland: Leaching of 41 kg N/ha is average, with little variation among the soil types. Leaching is most prevalent in winter, before fertiliser application. Average N fertilisation of 125 kg/ha (115-135 kg/ha) produced a grain yield of 5-9 t/ha.

Irrigated: Average leaching of 45 kg/ha/year for the three deeper soils (PAW = 90, 120, 150 mm) for a grain yield close to the potential of 12 t/ha, with 220 mm irrigation and 240 kg N/ha fertiliser applied on average. In these cases, most N leaching was in winter before fertiliser application. On the extremely shallow soil (PAW = 60 mm), a higher irrigation rate (430 mm) was required to maintain soil moisture for maximum crop growth. This increased leaching to 69 kg N/ha for high grain yield (10 t/ha). In reality, lower irrigation rates are likely with less N leaching and lower yields (Figure 4).

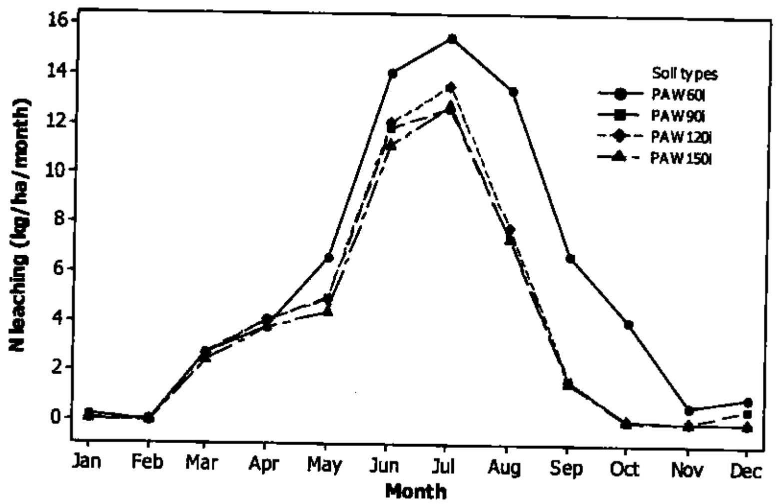

Figure 4: Seasonal patterns of N leaching from irrigated wheat crops on four soils.

4.5 Sweet corn

The major management assumptions for sweet corn were as for wheat, with a sowing date of 20 October each year.

Results

Without irrigation, estimated average N leaching from the four specified soils was 11-22 kg N/ha/year, again dominated by winter leaching after crop harvest. A catch crop (say wheat or oats) might be used to decrease that leaching. With irrigation the range was 17-55 kg N/ha/year. Leaching increased as PAW decreased and increased with water supply (R^2 = 0.74, 34 df) and N supply (R^2 = 0.43, 34 df) (Table 2). For irrigated crops, leaching occurred during crop growth, and was substantial in shallow soils (Figure 5).

Table 2: Summary of estimated N leaching from sweet corn crops under the different combination of soil types, irrigation and N fertilisation rate, and predicted biomass production.

Irrigation (mm)	Soil PAW (mm)	N fertilisation (kg/ha)	N leaching (kg/ha)	Biomass (t/ha)
0	60	9	21	5
0	90	70	18	11
0	120	84	15	12
0	150	96	12	13
1089	60	179	55	20
400	90	70	28	21
256	120	84	19	21
217	150	96	17	21

The high drainage and leaching from the shallow soils (of low PAW), are associated with high N fertilisation and irrigation to maintain the crop's requirement for N and soil moisture. This might not be the case in practice because these soils would either be avoided for sweet corn production or the grower would accept a yield penalty.

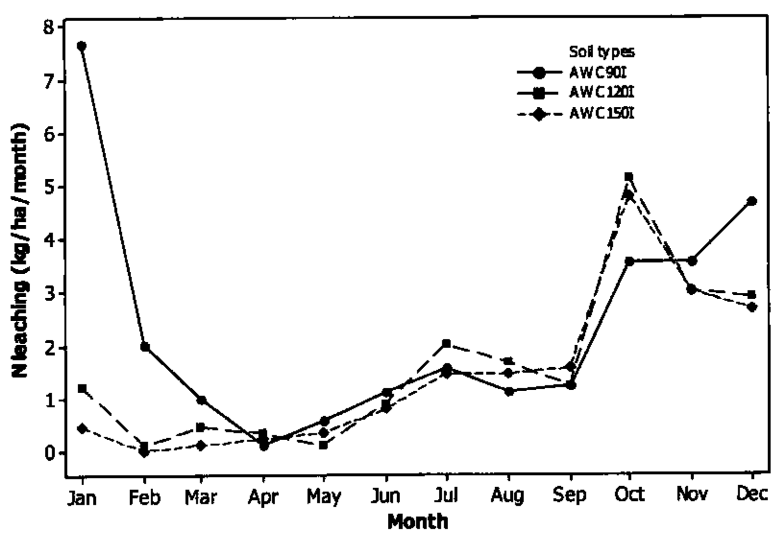

Figure 5: Seasonal pattern of estimated N leaching from maize. Substantially more leaching may occur in the shallowest soil (not shown) but at unrealistic irrigation levels.

4.6 Potato

The fertiliser and irrigation management of shallow-rooted potato crops were assumed to be optimum. Initial measured mineral N profiles were taken into account and practices were assumed to be according to current best management. That meant frequent, small (10 mm) irrigations, as would be applied with a centre pivot irrigator. Crops were planted on 10 October each year.

Results

Under dry conditions, estimated N leaching was 10-20 kg/ha/year. Nitrogen fertiliser applications were 150 kg/ha. Note that dryland production of processing potatoes is not economic in Canterbury so this is an unlikely land use.

Under irrigated conditions, around 350 kg N/ha was applied. Nitrogen leaching could be much larger if irrigation is applied to meet the ET and drainage on very shallow soils (of low PAW). The seasonal pattern of N leaching from irrigated potatoes is shown in Figure 6, with peak leaching in the growing season.

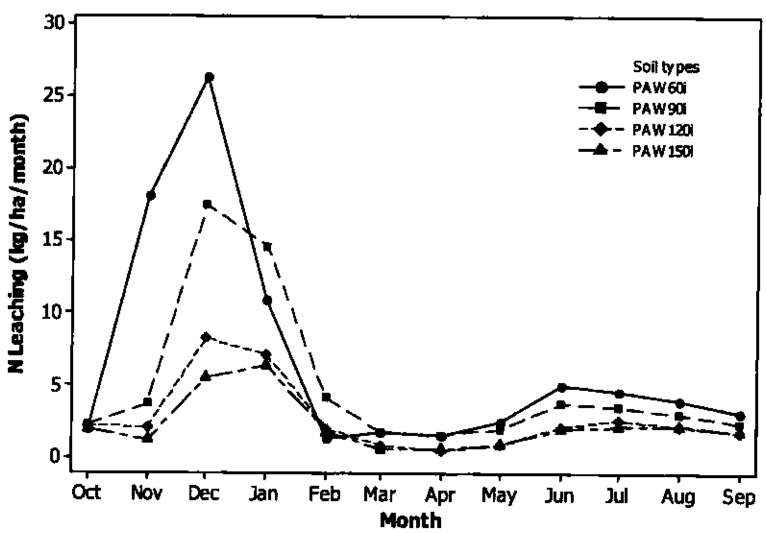

Figure 6: Seasonal patterns of the estimated N leaching from potato crops with irrigation to meet ET and drainage.

5 Phosphorus leaching from arable lands

The estimated losses of P from various land use types was very low compared to that of N, with a value of 0.11-1.6 kg P/ha/year. The P loss is principally by surface runoff into waterways instead of into the vadose from the bottom of the root zone (Menne et al. 2004). In addition, the majority (80%) of the P loss in run-off is particle-bound P instead of dissolved P, so the risk of indirect P leaching from the waterways into vadose seems also low.

The P loss is more likely in hill countries than in plains. The P leaching from the land use types in Canterbury plains is very small based on the available knowledge.

The nutrient budgeting tool OVERSEER™ also suggests low P leaching risk under standard management.

6 Forest

Some research has been done on N leaching from forests in New Zealand, but no published data were found for forests in Central Canterbury. Pine forest was reported to leach 1-2 kg N/ha/year, and generally 1 kg/ha/year is used to calculate the N leaching from native forest in New Zealand (Parfitt & Baisden 2005).

7 References

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