SIMULATING WITHIN-PADDOCK VARIABILITY OF NITRATE LEACHED FROM A MIXED CROPPING PADDOCK

L Lilburne[1], T Webb[1], P Jamieson[2] and R Zyskowski[2]

[1] *Landcare Research, PO Box 69, Lincoln 8152, Canterbury*
[2] *Crop & Food Research, Private Bag 4704, Christchurch*

Abstract

A one-dimensional biophysical simulation model, combining crop growth, soil water, and chemical dynamics, was used to investigate the effects on nitrate leaching due to likely variations in (1) water and fertiliser applications, (2) the initial amount and distribution of mineral soil nitrogen, and (3) soil water holding capacity. The aim of the investigation was to assess what level of aggregation was appropriate for attaining a reasonable degree of accuracy in prediction at the paddock scale. Any non-linearity in the response of the combined plant–soil model may require some degree of partitioning and combination of simulations to provide sufficient accuracy in scaled-up result.

This involved selecting a set of 36 cropping/soil type/climate scenarios, then determining the likely variability within each of these scenarios due to mechanical variability in fertiliser and irrigation application, variability in soil hydraulic properties, and patch-scale variability in initial nitrate. Expert knowledge and experimental data were used to derive a likely distribution for each of these factors. Three land-uses were considered: cropping, mixed-crop/cow, mixed-crop/sheep. The model was run 3000 times for each land use to determine the variability of nitrate leached within a single paddock under the different soil, climate and land-use scenarios.

Results show that the response is non-linear with significant differences between deep and shallow soils, and whether the prior land use involved grazing or not. Partitioning the paddock into urine v. non-urine patches is an appropriate way to scale up results to the paddock.

Introduction

Nitrate in groundwater is recognised as a major environmental contaminant internationally. In New Zealand, regulatory authorities (regional councils), vested with responsibility to maintain environmental quality, have found nitrate levels in groundwater and surface water that exceed the acceptable drinking standard (11.3 mg/L NO_3-N) (Smith 1993; Selvarajah et al. 1994). It is believed that increases in nitrate are mainly related to non-point contamination from agricultural land uses (Burden 1982). Research is therefore being undertaken to determine risks of groundwater pollution from agriculture, and to provide a rationale for targeting land-use change to minimise contamination effects on groundwater.

A large number of factors affect the ultimate concentration of nitrate measured in the groundwater at any particular place and time. The main domains of variability affecting leaching to groundwater are land use, management, soil type, climate, and aquifer characteristics. As experimental data are only available for a few combinations of these factors, simulations models are often developed and applied for the purpose of making predictions over larger areas. A mechanistic approach can be used where plot-scale process understanding and data are encapsulated in a model, which is then scaled up to paddock, farm

Lilburne, L., Webb, T., Jamieson, P. and Zyskowski, R. (2006) Simulating within-paddock variability of nitrate leached from a mixed cropping paddock. Number: Occas. Report No. 19, Fertiliser and Lime Research Centre, Palmerston North, pp. 356-363.

and eventually region. This preliminary study investigates the effect of within-paddock variability and its potential impact on scaling up.

The model used was derived from the wheat simulation model Sirius (Jamieson et al. 1998b; Jamieson & Semenov 2000). This uses a version of the Addiscott and Whitmore (1991) percolation and leaching model to describe nitrogen and water movement through the soil, and has a simplified nitrogen mineralisation model where the mineralisation rate is modified by soil moisture, temperature and soil organic N content. The model has been well validated both locally (Jamieson et al. 1998a) and internationally (Jamieson & Semenov 2000). The model was originally developed to simulate the growth, water and N relations, yield and quality of a single wheat crop from sowing until harvest. In order to be suitable for more general scenarios, the model was modified so that it could start on an arbitrary date in the absence of any crop (fallow or post cultivation) and to be able to run past the harvest of the initial crop and to continue with a second crop, keeping track of soil water and N status throughout on a daily timestep.

Methods

A Monte Carlo approach was used to simulate likely variability within a paddock. This involved selecting a set of cropping scenarios, then determining the likely variability within each of these scenarios due to mechanical variability in fertiliser and irrigation application, variability in soil hydraulic properties, and patch-scale variability in initial N. The model (version May 2005) was run 3000 times for each of the following three land uses: cropping, mixed-crop with prior grazing by cows, mixed-crop with prior grazing by sheep. These simulations were used to determine the variability of nitrate leached within a single paddock under the different soil, climate, and land use scenarios.

Thirty-six scenarios were chosen covering a range of climate, sowing date, soil type and prior land use options. Each scenario was simulated with 2 years of wheat. The unique combinations of the boxes make up the 36 scenarios (Fig. 1). Each scenario was set up to achieve a reasonable yield through optimal irrigation and fertiliser applications.

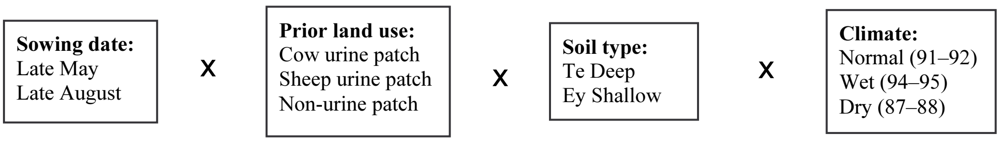

Fig. 1 The set of sowing date, climate, soil, and land use options that make up the 36 scenarios.

Soil variability

Soil variability was represented by variability in horizon thickness, wilting point, field capacity, and total porosity, within a given soil type. These variables were simulated by random selection from a small set of profiles from the Canterbury plains (Webb et al. 2000). Fifteen profiles were used for the deep Templeton soil and ten for the shallow Eyre soil.

Irrigation variability

Within-paddock variability in irrigation is due to overlap between irrigation strips and unevenness of application under sprinklers. Table 1 gives the likely variability (Dan Bloomer pers. comm.). It is assumed that multiple applications are correlated due to use of the same wheel tracks, i.e. if the first application is very low, the second will also be very low, etc. Therefore, the same random value was used for both years of the simulation.

Lilburne, L., Webb, T., Jamieson, P. and Zyskowski, R. (2006) Simulating within-paddock variability of nitrate leached from a mixed cropping paddock. Number: Occas. Report No. 19, Fertiliser and Lime Research Centre, Palmerston North, pp. 356-363.

Fertiliser variability

Variability is due to unevenness of application by fertiliser spreaders. Table 1 gives the likely variability (Russell Horrell, pers. comm.). It is assumed that multiple applications are correlated due to use of the same wheel tracks, i.e. if the first application is very low, the second will also be very low, etc. Therefore, the same random value was used for both years of the simulation.

Table 1 Variability of application within a paddock

Application	Value	Probability distribution function
All irrigators	0.6 DU	Triangle (0.4, 1, 1.6) × application
Urea fertiliser	20% CoV	N(50, 10), N(100, 20) etc.

(DU = distribution uniformity; CoV = coefficient of variation)

Initial N variability

Table 3 records the range of nitrogen loading used in simulations for prior grazing scenarios. Based on Whitehead (1995) urine patches for cows are assumed to comprise 8% of a paddock at 600 kg/ha (after one grazing event of a pasture or greenfeed crop prior to sowing). Urine patches for sheep are based on patch distribution over 12 months' grazing. Variability in leaching is related to the lapse of time since urine was added to the soil surface. We assumed a baseline value of 20 kg N/ha for areas of the paddock without urine patches.

Table 2 Nitrate levels in urine patches and their proportional area in a paddock

Land use	N kg/ha	Area %
Sheep	270	8
	200	8
	130	8
	60	8
	20	68
Cows	600	8
	20	92
Wheat	40	100

Crop management variability

Crop management variables are assumed to be spatially invariant within a paddock.

Results

Patch simulations

The simulated results of leached nitrate under a urine patch (cow and sheep) or with no urine are given in Table 3 and Fig. 2. No other within-paddock variability is simulated. The graph in particular shows the clear differences between the deep and shallow soil scenarios, the importance of initial nitrate level, and some difference due to climate on shallow soils.

Paddock simulations

Table 4 shows the variability of leached N in a paddock grazed by cows or sheep, or with no animals. The mean value is the mean annual nitrate leached from the whole paddock (i.e. including urine patches).

Table 3 Amount of leached N (kg/ha) under cow and sheep urine patches, and under cropping for each of the 36 scenarios (i.e. no soil, fertiliser or irrigation application variability).

Prior land use	Sow date	Soil	Climate	Leached N y1	Leached N y2
Cow urine patch	April	Deep	Wet	53.58	0.0
			Avg	42.91	63.30
			Dry	43.17	0.0
		Shallow	Wet	175.76	172.09
			Avg	214.45	207.79
			Dry	144.48	0.0
	August	Deep	Wet	63.22	0.0
			Avg	44.28	0.0
			Dry	48.88	0.0
		Shallow	Wet	241.25	151.54
			Avg	206.06	198.12
			Dry	190.70	0.0
Sheep urine patch	April	Deep	Wet	29.57	0.0
			Avg	24.37	27.28
			Dry	24.17	0.0
		Shallow	Wet	97.96	74.83
			Avg	119.39	82.46
			Dry	83.21	0.0
	August	Deep	Wet	35.34	0.0
			Avg	25.24	0.0
			Dry	27.38	0.0
		Shallow	Wet	133.66	60.01
			Avg	115.58	80.62
			Dry	107.74	0.0
Crop	April	Deep	Wet	12.83	0.0
			Avg	11.44	5.04
			Dry	10.92	0.0
		Shallow	Wet	43.73	16.14
			Avg	53.13	11.69
			Dry	40.51	0.0
	August	Deep	Wet	15.90	0.0
			Avg	11.96	0.0
			Dry	12.39	0.0
		Shallow	Wet	58.67	19.27
			Avg	52.53	16.59
			Dry	49.92	0.0

There are large differences between deep and shallow soils in year 1, and small differences between prior land use on shallow soils. There is little difference between the means of the three scenarios in the dry years or between the deep-soil scenarios. In the wetter years, prior grazing increases leaching on the shallow soils by approximately 20%. In Year 2 the only substantial leaching is in the shallow paddocks (under wettish conditions; Year 2 of the average climate sequence was in fact quite wet over winter). In all the scenarios, prior grazing led to a huge increase in the range.

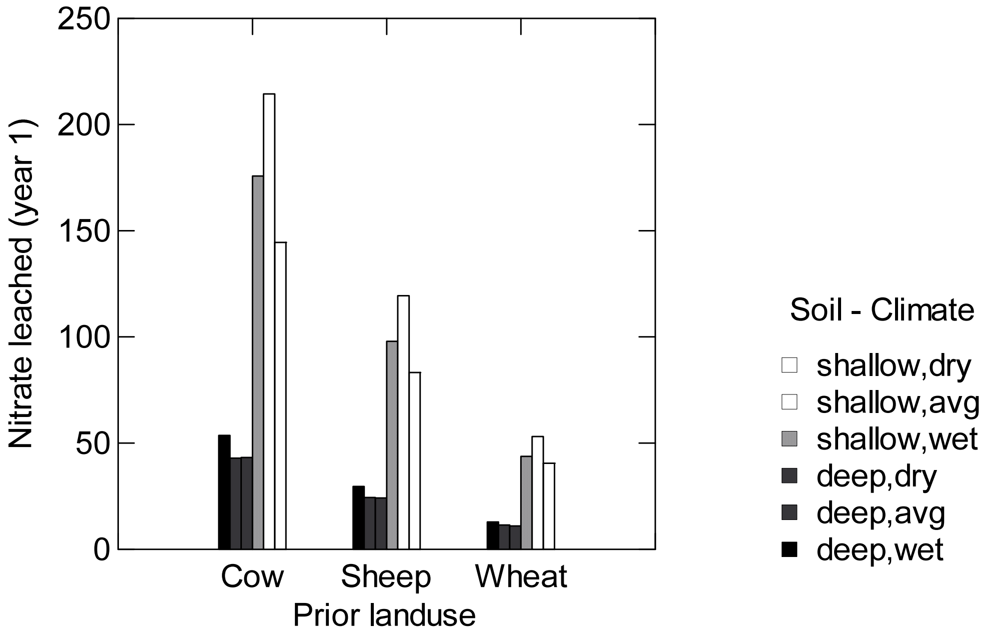

Fig. 2 Amount leached (kg/ha) under the April (n = 18) sowing scenarios.

Table 4 Statistics describing annual simulated leached nitrate-N (kg/ha) from a paddock under various scenarios (April sowing date only)

Scenario				Leaching year 1			Leaching year 2		
Prior land use	Sow	Soil	Climate	Mean	SD	Range	Mean	SD	Range
Crop	April	Deep	Wet	16	3.4	11	3	5.1	30
			Avg	15	4.6	24	8	5.8	29
			Dry	14	3.2	11	0	0.3	4
		Shallow	Wet	46	5.9	33	23	15.2	89
			Avg	53	6.1	38	21	15.2	84
			Dry	41	3.1	9	0	1.2	11
Cow	April	Deep	Wet	16	15.4	100	4	8.4	65
			Avg	18	17.7	113	15	24.4	161
			Dry	18	20.9	92	0.1	0.8	8
		Shallow	Wet	54	47.5	286	37	53	279
			Avg	62	51.5	234	37	58	263
			Dry	42	26.9	141	0.1	0.7	9
Sheep	April	Deep	Wet	16	8.4	48	4	7.3	44
			Avg	18	10.3	62	13	13.2	75
			Dry	18	10.4	45	0	1	8
		Shallow	Wet	56	25.1	127	33	25.5	132
			Avg	61	26.5	109	32	29.4	132
			Dry	43	23.9	66	0	0.7	9

Figure 3 shows the shape of the distribution of nitrate leached from a wheat paddock that was previously grazed by cows.

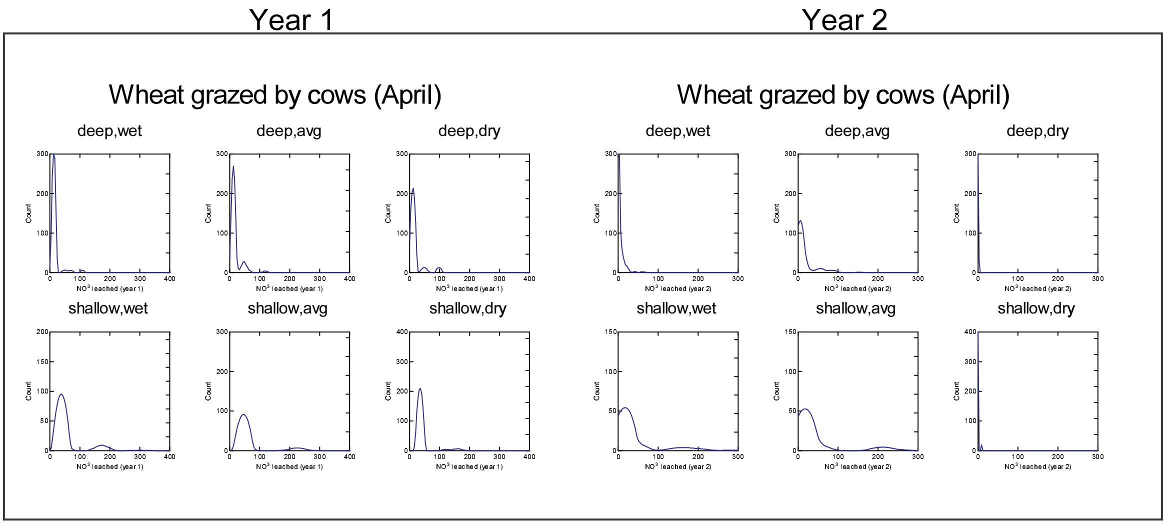

Fig. 3 Variability of nitrate leached in Years 1 and 2 from a whole paddock grazed by cows prior to sowing, under the various climate and soil scenarios.

These histograms show the likely variability (due to variation in fertiliser and irrigation applications and soil properties) in a single paddock of wheat that has been grazed by cows prior to sowing in April. Each histogram relates to a climate/soil scenario. As expected there is a small amount of very high leaching (under the urine patches).

Figure 4 shows the shape of the distribution of nitrate leached from a wheat paddock that was previously grazed for a year by sheep.

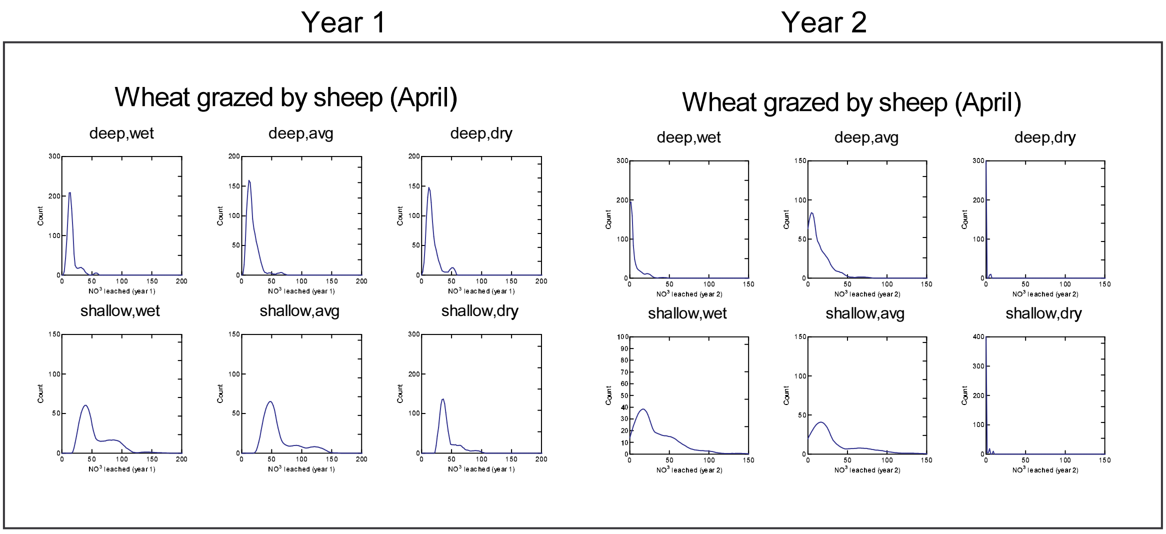

Fig. 4 Variability of nitrate leached in Years 1 and 2 from a whole paddock grazed by sheep for a year prior to sowing, under the various climate and soil scenarios.

As before there are large differences between the shallow and deep soils in the first year of leaching.

Figure 5 shows the shape of the distribution of nitrate leached from a wheat paddock that was not previously grazed. Unlike the mixed-crop scenarios (i.e. Figs 3 and 4), variability is predominantly within ±10 kg/ha for all of the various climate and soil scenarios.

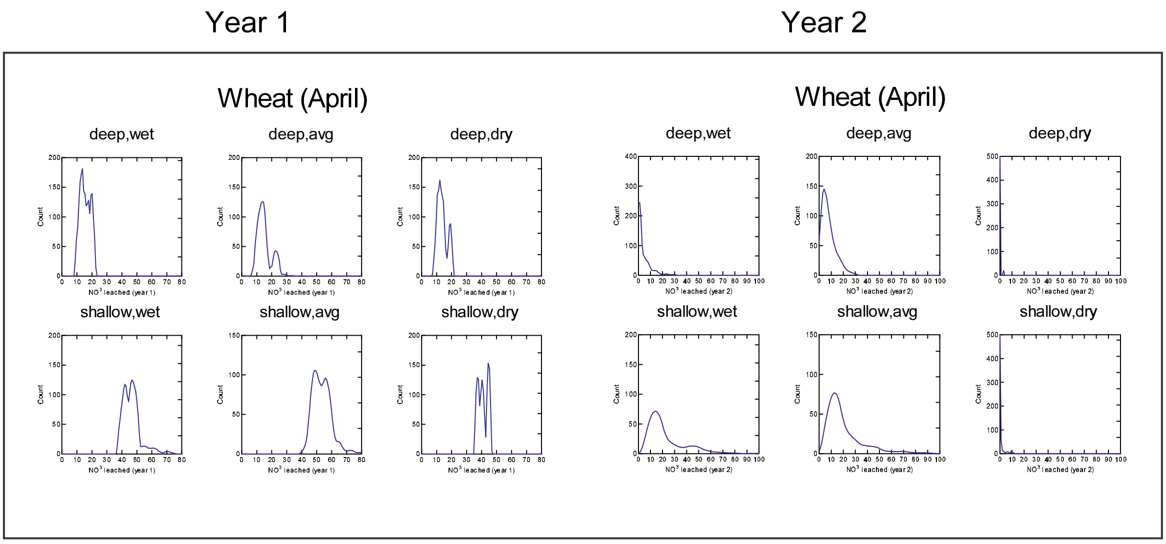

Fig. 5 Variability of nitrate leached in Years 1 and 2 within a whole paddock of wheat due to variability of soil properties and in fertiliser and irrigation applications, under the various climate and soil scenarios.

The August sowing date scenarios (not shown) produce similar results to the April sowing date scenarios.

Discussion

One of the benefits of employing a Monte Carlo approach is the methodical simulation of a wide variety of scenarios. Checking the plausibility of the various simulation results can help build confidence in the model, or conversely indicate aspects of the model that need further evaluation. For example, the similarity of the April and August sowing date results was found to be due to initial N being set at the simulation start date in February. There is no provision in the version of model used here for the initial N to be set on a specific date before sowing (e.g., when the paddock is grazed) without changing the simulation start date. This will be changed so that this scenario can be tested.

As expected, the results show that soil depth is an important factor when predicting leached N. The drainage curve is defined on the basis of the fraction of mobile water (Kq) that drains each day (after Addiscott & Whitmore 1991). A preliminary sensitivity analysis has shown that this drainage parameter Kq is also an important factor. In this study Kq was kept constant between soils. Work is currently underway to determine appropriate values for Kq based on water retention data for the various soils in the area of interest.

Variability in paddocks with prior grazing by cows has a bimodal distribution. The distributions in a pure cropping paddock in year 1 are generally symmetrical, and those in paddocks grazed by sheep are asymmetrical. Mean values are generally not a good representation of bimodal or asymmetrical distributions. Nor are they necessarily appropriate when there is a very large range of values as in the mixed-crop scenarios. If the simulation results are to be used for risk assessment, it would be more appropriate to use the maximum value or a quantile (e.g. 80% quantile). Similarly, where there is an asymmetrical or non-linear response, it may be more appropriate to scale up leaching results to the paddock and farm by partitioning the paddock according to the largest sources of variability, in this case into urine and non-urine patches. Once an output distribution for a paddock has been established through simulation, the most appropriate scaling strategy can be determined by simply comparing the effect of using mean values or a partitioning strategy with the output distribution.

Acknowledgements

This work is funded by the Foundation for Research, Science and Technology (contract C09X0304).

References

Addiscott TM, Whitmore AP 1991. Simulation of solute leaching in soils of differing permeabilities. Soil Use and Management 7: 94–101.

Burden RJ 1982. Nitrogen contamination of New Zealand aquifers: a review. New Zealand Journal of Science 25: 205–220.

Jamieson PD, Semenov MA 2000. Modelling nitrogen uptake and redistribution in wheat. Field Crops Research 68: 21–29.

Jamieson PD, Porter JR, Goudriaan J, Ritchie JT, van Keulen H, Stol W 1998a. A comparison of the models AFRCWHEAT2, CERES-Wheat, Sirius, SUCROS2 and SWHEAT with measurements from wheat grown under drought. Field Crops Research 55: 23–44.

Jamieson PD, Semenov MA, Brooking IR, Francis GS 1998b. Sirius: a mechanistic model of wheat response to environmental variation. European Journal of Agronomy 8: 161–179.

Selvarajah N, Maggs GR, Crush JR, Ledgard SF 1994. Nitrate in groundwater in the Waikato region. In: Currie LD, Loganathan P (eds) The efficient use of fertilisers in a changing environment: reconciling productivity and sustainability. Occasional Report no. 7, Fertilizer and Lime Research Centre, Palmerston North. Pp. 160–185.

Smith VR 1993. Groundwater quality in Canterbury, results of the summer 1992/1993 survey. No. 93. Canterbury Regional Council, Christchurch.

Webb TH, Claydon JJ, Harris SR 2000. Quantifying variability of soil physical properties within map units to address modern land-use issues on the Canterbury Plains, New Zealand. Australian Journal of Soil Research 38: 1115–1129.

Whitehead DC 1995. Grasslands nitrogen. CAB International, Wallingford.