End of Project Report
Project 4482

MONITORING OF POTENTIAL N LOSSES FROM DAIRY AND ORGANIC FARMING SYSTEMS

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MONITORING OF POTENTIAL N LOSSES FROM DAIRY AND ORGANIC FARMING SYSTEMS

END OF PROJECT REPORT

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SUMMARY

The project was carried out at Johnstown Castle and was concerned with monitoring potential nitrogen (N) leaching losses from organic and dairy farming systems. Some plots were cut for silage in year one; only grazed plots were used in year two. There were low input manure N plots in the organic system with low and high input fertiliser N plots in the dairy system.

Soil samples, in 15 cm intervals from the surface to 90cm deep, were taken in triplicate from one plot of each treatment on three successive days per month from October to March in year 1 and from September to March in year 2. Extraction of nitrate-N (NO_3-N) and ammonium-N (NH_4-N) was carried out on un-bulked soil cores by taking a 20 g sub-sample and using 100 ml 2 molar KCl. A 20 g sub-sample of each day`s bulked replicates was dried at 105 degrees C overnight for moisture determination. The concentrations of NO_3-N and NH_4-N in the extracts were determined on an automatic analyser and the results were converted to kg per ha using the following bulk densities for the soil layers: 0-15, 15-30, 30-60, 60-90, 1.3, 1.4, 1.6, 1.75 g per cm^3, respectively. In year 1 the results showed no significant difference between treatments in the level of NO_3-N, NH_4-N and total mineral N in the soil layers and total amounts to 90 cm. On four of the six dates, November, December, January, early-March, the level of total mineral N was lowest in the low N treatment. Among treatments, NH_4-N was lowest in the low N treatment on four dates, November, December, January, early-March while NO_3-N was also lowest on four dates, November, December, early-March and late-March. At the November, December, January and early-March sampling, the organic farm NH_4-N data to 90 cm was highest which was reflected in the total mineral N results to 90 cm for November, December and early-March. In year 2 the results showed no significant difference between treatments in the level of NO_3-N, NH_4-N and total mineral N in the soil layers and total amounts to 90 cm. In September, October, November, December and February, total mineral N to 90 cm was highest in the high N treatment. This was a reflection of high NO_3-N levels in that treatment for those sampling dates. Among treatments, total mineral N to 90 cm was lowest in the organic farm samples in September, October, November, December and February. This result reflected, among treatments, lowest NH_4-N levels in September, October, November, December, February and lowest NO_3-N levels in November and December.

Estimates of the amounts of applied N leached, averaged over the two years of the experiment, were 22% for the Low N treatment and 12% for the High N treatment.

An equation, developed from studies carried out in County Cork (Richards, 1999), gave predictions of N available for leaching in November from the N treatments in year 2 which were in very good agreement at low N and within 23% of those actually recorded at high N.

Assessment of available N leaching models led to the conclusion that the relatively simple UK `N Cycle` model was most adaptable to Irish conditions since other European and US models require input parameters not readily available including those for soil texture, soil hydrology and soil organic matter.

CONCLUSIONS

The level of spatial variation in soil concentrations of NO_3-N, NH_4-N in grazed plots is well-known. In the case of this experiment, treatments with wide diversity, especially in year 2, gave results which were not significantly different from one another. This creates difficulty in drawing conclusions that must be scientifically based. The null hypothesis was very rarely violated by the data. The results suggest that more intensive sampling would be necessary in order to reduce within-plot variation and perhaps obtain statistical significance in differences produced by treatments. Trends can be seen in the data, the clearest being that the low N and organic farm treatments resulted in the lowest amounts of N available for leaching at almost all dates in both years. In the fertiliser-free period of year 1 (October to January) the highest amounts of N recorded as being available for leaching occurred in January for both N fertiliser treatments and in November for the organic farm treatment. Similarly for year 2, the highest amounts of N available for leaching were recorded in October for both N fertiliser treatments and in September for the organic farm treatment. The November data showing N available for leaching agreed well at low N and reasonably well at high N fertiliser input with work carried out in Cork which produced an indicative relationship for prediction purposes.

The second year estimates of N leached were considerably higher than those for year 1, but when averaged over the two years, estimated leaching was low and similar to results previously reported. The limitations of a two- year study, i.e., short-term research must be kept in mind in reviewing the results.

A preliminary survey of suitable models for predicting leaching under grazing indicated that the N-CYCLE model would be simplest and easiest to operate in an Irish context.

INTRODUCTION

Nutrient loss from farming, in particular, N loss, is of singular interest now that concern about eutrophication of surface waters and contamination of ground waters has come to the fore. High NO_3-N in surface water, in combination with other nutrients, is a causal factor in promoting algal and weed growth, to the detriment of potential users. Consumption of elevated nitrate concentrations in drinking water has been linked to increased risk of non-Hodgkin`s lymphoma in studies carried out in the USA and with geno-toxic risk in the Netherlands (Ryan, 1998).

Since more information was needed, in an Irish context, on the effects of farming systems and N inputs on the NO_3-N risk to ground water, an experiment was set up at Johnstown Castle to investigate this problem.

OBJECTIVES, METHODOLOGY, TREATMENTS

The objective of the experiment was to determine the amount of mineral N, including NO_3-N and NH_4-N, available for leaching from farming systems that use different inputs of N. Assessment of leaching models was another objective of the study.

Potential losses, from grassed organic farm plots (1.4 ha) together with low (0.96 ha) and high (0.72 ha) N application plots in the dairy farm, were measured during the winter-spring of 1998-99 and 1999-00. Plots selected to represent the treatments were on similar soils and there were three representative plots per treatment for sampling purposes. The organic-farm plots were located, predominantly, on an imperfectly drained gley, of fine loamy texture; the low N treatment in the dairy farm was also located on that soil while the high N dairy farm N treatment was located on well to moderately well drained brown earth, of fine loamy texture, on moderate to imperfectly drained gley, of coarse loamy over fine loamy texture and imperfectly drained gley of fine, loamy texture. Levels of organic carbon (C), total N and C/N ratios in the soils (0-15cm) for three replicates per plot for the three plots per treatment were as shown in Appendix, Table 1. Sampling took place 14 - 17 September, 18 - 20 October 1999 and 20-22 March, 2000.

In the first year, the organic farm plots were cut for silage in May and were subsequently grazed by suckler cows, calves and yearlings until 4 November, 1998. These plots received a mean input of 6.6 kg N per hectare as farm yard manure in the spring; white clover content was excellent.

The low N plots in the dairy farm were cut for silage on 26 May, 1998 having received 22 m^3 cow slurry per hectare supplying 70 kg N per hectare, 50 kg per hectare fertiliser N in February and 62.5 kg per hectare fertiliser N in March. These plots received a further 22 m^3 per hectare cow slurry supplying 79 kg N per hectare in June 1998. The total N applied was 261.5 kg per hectare which, allowing half value for slurry N, as is the convention, came to 187.0 kg per hectare. Plots were grazed until the cows were housed, day and night, on 26 November, 1998.

The high N plots in the dairy received 50 kg fertiliser N per hectare in February, on 16 April, 14 May, 16 June and 34 kg per hectare fertiliser N on 21 July, 14 August, 9 September, i.e., a total of 302 kg per hectare. Plots were grazed from springtime until the cows were housed, day and night, on 11 November, 1998. Both sets of plots received basal PK in February.

Soil samples, in 15 cm intervals, from the surface to 90 cm, were taken in triplicate from one plot of each treatment on three successive days in the months September 1998 to March 1999. There were therefore, six 15 cm cores per location in three locations per plot in three treatment plots per sampling day giving a total of 54 soil samples to be extracted per day for each of the three days. This gave 3*3 = 9 replications per core depth per treatment per month. A Dutch soil auger was employed to collect the samples except where excessive stoniness was encountered in some plots. In those instances, a screw auger was used.

The samples collected in September were extracted in the laboratory using 100 g soil and 100 ml 2 molar KCl. The amount of soil used was subsequently reduced to 20 g to ensure better extraction. (The September results are not presented). A 20 g sub-sample of three bulked replicates per treatment per day was dried at 105 degrees C overnight for moisture determination. The concentrations of NO_3-N and NH_4-N in the extracts were determined on an automatic analyser and the results were converted to kg per hectare using the following bulk densities (g/cm^3) for the soil layers 0-15, 15-30, 30-60, 60-90 cm of 1.3, 1.4, 1.6 and 1.75. Soil samples were extracted on a monthly basis, in both years from September to March, inclusive.

The year 2 treatments differed from those applied in year 1 in that, two of the organic farm plots received farmyard manure supplying a mean application overall to the plots of 13.2 kg N per hectare in the spring of 1999. Thereafter, all three plots were cut for silage on 9 June. The third plot received farmyard manure on 23 June at an overall rate of

3.3 kg N per hectare after which all plots were grazed by yearlings, heifers and a bull until 28 October, 1999. No N application or grazing took place prior to completion of soil sampling in spring 2000. The total N input to the organic plots therefore was 16.5 kg per hectare.

The low N plots in the dairy received 58 kg fertiliser N per hectare on 8 February, 1999 and 47 kg N per hectare on 31 January, 2000. Day and night grazing commenced, on average, on 19 April and ended on 21 October, 1999.

The high N plots were given 58 kg fertiliser N per hectare on 8 February, 31 March; 51 kg N per hectare on 3 May, 8 June; 34 kg N per hectare on 6 July, 51 kg N per hectare on 18 August and 34 kg N per hectare on 15 September 1999 which amounted to a total of 337 kg per hectare. In 2000 these plots received 47 kg N per hectare on 31 January. Day and night grazing commenced, on average, on 27 April and ended on 11 October, 1999. The April grazing followed limited half-day grazing in February and March. Similar half-day grazing took place in late-October to 18 November, 1999. In 2000, grazing took place for both treatments after soil sampling was completed in March. Double-ring infiltration rates were measured in all plots in the period September to November, 2000.

Data were statistically analysed separately for each depth for each treatment for each date and for the total of all depths to 90 cm with regard to NH_4-N, NO_3-N and their sum. The ANOVA was carried out using the 1995 Genstat Statistical Package of the Lawes Agricultural Trust (Rothamsted Experimental Station).

RESULTS

Infiltration

Six replicates per plot gave the following mean infiltration rates (mm/hr) for the three plots per treatment: low N- 39, 62, 81; high N- 2, 4, 6; organic farm- 4 (one plot). The rates for the low N plots were high, possibly because these plots were ploughed and re-seeded in May, 2000. Rates similar to those seen in the high N and organic plots were recorded in other areas of the Research Centre.

Soil Mineral N levels

Tables 1 to 6 show the levels of NO_3-N, NH_4-N and their added total in the soil layers in years 1, 2.

Table 1: Effect of treatment on NO_3-N level (kg/ha) in soil layers at dates in year 1.

	Depth(cm)	11/10/98	09/11/98	14/12/98	19/01/99	01/03/99	22/03/99
Low N	0 - 15	3.40	2.68	2.45	4.39	2.62	2.88
	15 - 30	2.91	2.30	2.63	4.93	3.00	2.79
	30 - 45	2.27	2.42	2.48	4.63	2.24	2.34
	45 - 60	3.37	3.03	3.12	5.26	2.59	2.57
	60 - 75	3.55	2.76	2.89	5.74	3.52	3.45
	75 - 90	3.68	2.80	2.79	5.45	4.23	3.26
High N	0 - 15	2.73	3.63	3.25	3.57	4.23	4.28
	15 - 30	4.23	2.75	1.98	3.94	3.24	5.37
	30 - 45	5.31	3.27	3.15	4.92	3.90	4.26
	45 - 60	2.88	2.88	4.12	5.48	4.50	3.86
	60 - 75	3.36	3.22	4.53	5.93	4.86	4.70
	75 - 90	3.20	5.66	3.93	5.44	5.35	4.74
Organic	0 - 15	1.81	3.96	1.75	3.60	2.89	2.12
	15 - 30	0.91	3.10	2.21	3.18	3.49	2.97
	30 - 45	2.42	3.51	5.06	4.49	5.51	4.48
	45 - 60	2.31	4.41	4.70	5.18	5.33	3.90
	60 - 75	3.81	4.76	3.61	3.88	5.04	3.22
	75 - 90	3.63	4.11	2.18	3.98	4.70	2.50
F ratio	0 - 15	0.567	0.802	0.783	0.846	0.581	0.355
	15 - 30	0.152	0.851	0.960	0.339	0.970	0.248
	30 - 45	0.311	0.795	0.627	0.959	0.430	0.205
	45 - 60	0.868	0.738	0.892	0.991	0.517	0.674
	60 - 75	0.974	0.671	0.844	0.551	0.758	0.587
	75 - 90	0.966	0.479	0.758	0.811	0.909	0.463
CV (%)	0 - 15	79.3	66.6	85.7	45.2	48.6	40.7
	15 - 30	86.8	63.5	70.5	35.1	40.7	45.3
	30 - 45	79.2	37.2	72.5	50.1	36.4	65.0
	45 - 60	82.6	101.4	97.1	36.1	35.1	55.4
	60 - 75	80.2	55.3	67.5	33.6	40.1	53.3
	75 - 90	88.1	70.0	63.7	51.6	46.2	53.4

In Table 1, the effect of treatment on NO_3-N levels in the soil layers at different dates in the first year is shown. Differences between treatments on those dates were not significant. All treatments showed an increase in NO_3-N level from the surface to 90 cm. Peak levels, > 5 kg per hectare, in the low N treatment at the lower depths (>45 cm), were recorded at the 19 January sampling; the largest difference between the 0-15 cm and the 75-90 cm depths, 1.61 kg per hectare, occurred on 1 March, 1999. Similar peaks were seen at the same lower depths in the high N treatment at the same sampling date; the largest difference between the 0-15 cm and the 75-90 cm depths, 2.03 kg per hectare, occurred on 9 November, 1998. The organic farm samples showed peak values >5 kg per hectare at depths below 30 cm at the March sampling; this also coincided with the largest difference between the surface and the lowest depth in NO_3-N levels.

Table 2: Effect of treatment on NH_4-N level (kg/ha) in soil layers at dates in year 1.

	Depth(cm)	11/10/98	09/11/98	14/12/98	19/01/99	01/03/99	22/03/99
Low N	0 - 15	4.86	7.10	4.76	3.47	2.51	6.37
	15 - 30	3.96	3.94	7.40	2.96	2.08	5.23
	30 - 45	2.65	3.13	2.56	1.40	0.37	2.96
	45 - 60	2.10	2.47	2.46	1.18	0.43	2.15
	60 - 75	1.97	1.76	2.26	1.29	0.29	2.83
	75 - 90	2.17	1.52	2.18	1.40	0.40	2.39
High N	0 - 15	5.36	7.29	4.28	8.11	2.84	21.34
	15 - 30	2.10	5.45	6.18	6.41	2.48	6.31
	30 - 45	1.57	2.93	3.92	1.77	1.05	2.85
	45 - 60	1.10	3.32	2.57	1.42	0.90	2.02
	60 - 75	2.14	2.75	2.38	0.86	0.92	2.16
	75 - 90	2.36	3.54	12.69	1.03	1.32	2.12
Organic	0 - 15	3.57	8.49	14.25	5.25	3.37	3.44
	15 - 30	3.17	10.14	9.04	5.96	3.66	3.64
	30 - 45	2.42	10.20	2.30	4.99	1.92	2.57
	45 - 60	2.88	3.30	1.28	3.50	1.75	1.79
	60 - 75	2.10	3.32	1.20	1.31	3.01	1.75
	75 - 90	1.91	2.96	1.13	2.05	2.05	1.06
F ratio	0 - 15	0.493	0.887	0.386	0.014	0.873	0.391
	15 - 30	0.119	0.607	0.692	0.214	0.712	0.539
	30 - 45	0.418	0.483	0.830	0.239	0.172	0.979
	45 - 60	0.524	0.892	0.796	0.446	0.189	0.965
	60 - 75	0.988	0.704	0.804	0.723	0.049	0.754
	75 - 90	0.921	0.678	0.829	0.468	0.262	0.609
CV (%)	0 - 15	40.9	75.7	145.8	51.9	43.2	271.6
	15 - 30	46.2	166.5	126.2	81.6	48.1	90.9
	30 - 45	66.0	236.2	87.9	139.4	94.3	59.5
	45 - 60	91.1	79.3	84.4	208.5	91.6	41.5
	60 - 75	91.4	46.3	74.4	63.0	119.2	68.7
	75 - 90	77.0	81.1	79.6	86.7	85.6	63.9

Table 2 shows the effect of treatment on NH_4-N levels in soil layers at six dates in 1998-99. Differences between treatments were not significantly different. In contrast to the NO_3-N data, all treatments showed a decrease in NH_4-N levels from the surface to 90 cm deep. At corresponding dates, the levels of NH_4-N, at 0-15 cm, tended higher than for NO_3-N. All NH_4-N levels, at 75-90 cm deep, were lower than the corresponding NO_3-N levels seen in Table 1. This meant that the differences between the surface and lowest layers were greater than for NO_3-N.

With the low and high N treatments, the highest values were seen in the uppermost layers, i.e., 0-30 cm, with no values greater than 4 kg per hectare below this depth. This was also true of the organic farm samples, apart from those collected in November and January, which had high levels at 30 -45 cm deep. This pattern contrasted with the NO_3-N data where the highest levels occurred in the middle and lower depths. Peak values in the surface layer (0-15 cm) of 7.1, 21.34, 14.25 kg per hectare occurred in November, March and December for the low N, high N and organic farm samples. Minima occurred for these treatments, at that depth, in March 1999.

Table 3: Effect of treatment on NO_3-N + NH_4-N level (kg/ha) in soil layers at dates in year 1.

	Depth(cm)	11/10/98	09/11/98	14/12/98	19/01/99	01/03/99	22/03/99
Low N	0 - 15	8.26	9.78	7.22	7.86	5.13	9.25
	15 - 30	6.87	6.24	7.32	7.89	5.08	8.02
	30 - 45	4.92	4.55	5.03	6.03	2.61	5.03
	45 - 60	5.47	5.50	5.58	6.44	3.02	4.71
	60 - 75	5.52	4.51	5.15	`7.03	3.81	6.27
	75 - 90	5.85	4.32	4.97	6.85	4.63	5.65
High N	0 - 15	8.09	11.03	10.73	11.68	7.08	25.62
	15 - 30	6.33	3.20	8.17	10.35	5.72	11.69
	30 - 45	6.88	6.20	7.06	6.69	4.95	7.11
	45 - 60	3.98	6.20	6.69	6.90	5.40	5.88
	60 - 75	5.51	5.97	6.91	6.79	5.78	6.86
	75 - 90	5.57	9.19	5.62	6.47	6.67	6.86
Organic	0 - 15	5.38	12.45	16.01	8.85	6.26	5.56
	15 - 30	4.08	13.24	11.25	9.13	7.15	6.61
	30 - 45	4.84	13.71	7.36	9.48	7.43	7.05
	45 - 60	5.18	7.72	5.98	8.69	7.08	5.69
	60 - 75	5.91	8.08	4.81	5.19	8.04	4.97
	75 - 90	5.54	7.07	3.31	6.03	6.76	3.55
F ratio	0 - 15	0.078	0.776	0.476	0.149	0.734	0.353
	15 - 30	0.165	0.555	0.761	0.351	0.698	0.198
	30 - 45	0.496	0.453	0.882	0.421	0.198	0.439
	45 - 60	0.708	0.843	0.976	0.753	0.240	0.866
	60 - 75	0.965	0.643	0.886	0.703	0.230	0.773
	75 - 90	0.973	0.549	0.824	0.966	0.548	0.506
CV (%)	0 - 15	30.2	69.4	114.0	39.2	32.0	207.6
	15 - 30	45.5	123.5	90.2	45.7	33.5	60.3
	30 - 45	52.6	151.2	55.0	59.3	40.3	46.8
	45 - 60	52.4	86.3	82.5	74.5	34.4	42.4
	60 - 75	46.8	47.7	60.6	32.4	44.7	50.5
	75 - 90	53.1	71.7	61.2	51.6	44.1	48.2

Table 3 gives the effect of treatment on total mineral N levels in the soil layers in year 1. Differences between treatments were not significantly different. For the low and high N treatments, total mineral N declined from the surface to the lower depths at all dates. This was also true for the organic farm samples, apart from those taken in October and early March. With the low N treatment, the surface layers, 0-30 cm, showed the highest mineral N levels at all sampling times; this was only true for the December, January and late March samples at high N and for November, December samples taken from the organic farm. The high N treatment had the highest levels, 11.68, 7.08, 25.62 kg per hectare, among treatments, at 0-15 cm, in January and March ; the low N treatment had the lowest levels, 9.78, 7.22, 7.86, 5.13 kg per hectare, among treatments, at 0-15 cm, in November, December, January and early March. The highest values recorded for the low N, high N and organic farm treatments, at 0-15 cm, were 9.78, 25.62 and 16.01 kg per hectare, respectively.

Table 4: Effect of treatment on NO_3-N level (kg/ha) in soil layers at dates in year 2.

	Depth (cm)	14/09/99	16/10/99	15/11/99	13/12/99	10/01/00	23/02/00	20/03/00
Low N	0 - 15	4.32	4.41	22.59	3.64	1.90	5.42	1.71
	15 - 30	4.39	5.18	1.85	2.01	1.54	4.03	2.69
	30 - 45	6.69	4.07	1.48	1.83	3.01	4.48	2.81
	45 - 60	7.10	5.14	1.96	3.45	3.30	4.04	3.59
	60 - 75	5.79	5.59	2.49	3.45	2.71	4.42	2.27
	75 - 90	5.20	4.38	2.14	1.99	1.59	5.43	2.45
High N	0 - 15	12.54	19.57	4.83	3.06	2.61	5.20	3.54
	15 - 30	7.77	15.13	6.05	3.05	2.69	5.62	2.85
	30 - 45	6.44	14.30	10.15	4.41	5.62	8.69	2.50
	45 - 60	4.11	10.15	14.46	4.11	3.72	5.98	3.81
	60 - 75	5.45	6.54	10.95	5.81	3.94	8.64	4.23
	75 - 90	5.64	4.85	5.19	7.97	8.23	9.13	4.62
Organic	0 - 15	5.29	4.37	2.22	1.11	3.45	3.86	3.28
	15 - 30	5.12	4.16	2.77	1.27	4.29	4.30	2.27
	30 - 45	6.39	5.79	3.29	1.22	7.05	3.91	3.89
	45 - 60	4.90	4.56	2.74	1.17	5.76	4.27	3.67
	60 - 75	6.67	6.02	3.00	1.65	4.71	4.89	3.21
	75 - 90	6.41	4.13	2.81	1.51	5.89	2.80	3.34
F ratio	0 - 15	0.107	0.251	0.482	0.150	0.394	0.736	0.629
	15 - 30	0.661	0.175	0.046	0.535	0.086	0.718	0.963
	30 - 45	0.993	0.339	0.202	0.376	0.308	0.444	0.831
	45 - 60	0.636	0.575	0.444	0.095	0.514	0.663	0.994
	60 - 75	0.864	0.977	0.464	0.497	0.456	0.018	0.758
	75 - 90	0.855	0.975	0.601	0.217	0.367	0.078	0.796
CV (%)	0 - 15	91.2	235.9	362.6	107.2	84.4	40.2	73.2
	15 - 30	89.5	165.6	74.9	123.2	51.3	49.5	99.9
	30 - 45	49.6	146.4	110.6	87.5	82.0	79.7	67.2
	45 - 60	44.7	120.9	214.7	95.8	67.3	60.1	87.0
	60 - 75	50.3	48.8	189.9	120.3	63.1	76.7	80.0
	75 - 90	52.8	31.4	92.9	205.7	172.7	94.4	106.9

Table 4 shows the effect of treatment on NO_3-N levels in soil layers at various dates in year 2. Differences between treatments were not significant, apart from the 60-75 cm layer on 23 February, 2000, when the NO_3-N levels were 4.42, 8.64, 4.89 kg per hectare (F=0.018) in the low N, high N and organic farm treatments, respectively. The expected increase in NO_3-N levels at 75-90 cm compared to 0-15 cm materialised at two, five and four sampling dates for the low N, high N and organic farm treatments, respectively. Peak levels for those treatments in the surface 0-15 cm, were 22.59, 19.57 and 5.29 kg per hectare at the November, October and September sampling dates. The corresponding peaks at the 75-90 cm depth for those treatments were 5.43, 9.13 and 6.41 kg per hectare at the February, February and September sampling dates.

Table 5: Effect of treatment on NH_4-N level (kg/ha) in soil layers at dates in year 2.

	Depth (cm)	14/09/99	16/10/99	15/11/99	13/12/99	10/01/00	23/02/00	20/03/00
Low N	0 - 15	6.38	9.27	12.05	5.77	3.48	3.10	3.90
	15 - 30	4.77	7.63	0.87	4.60	3.55	0.92	4.46
	30 - 45	3.12	6.29	0.61	2.95	5.25	0.22	3.11
	45 - 60	3.37	9.30	0.80	3.20	0.88	0.02	2.49
	60 - 75	3.08	7.98	0.93	1.69	0.94	0.05	1.65
	75 - 90	2.43	6.81	0.80	3.18	0.43	1.20	2.45
High N	0 - 15	9.16	15.30	2.44	6.11	3.81	3.45	4.92
	15 - 30	10.93	5.46	2.84	4.35	2.46	1.03	3.36
	30 - 45	3.79	2.94	4.16	2.02	1.37	0.59	2.34
	45 - 60	2.02	2.52	5.93	1.59	0.64	0.83	1.32
	60 - 75	2.28	2.28	4.11	2.20	0.44	0.66	1.76
	75 - 90	2.20	2.36	1.95	1.87	0.37	0.51	2.04
Organic	0 - 15	6.04	3.54	1.12	4.79	7.81	2.19	6.27
	15 - 30	3.76	2.74	1.30	3.97	5.04	1.16	2.64
	30 - 45	2.32	1.49	1.35	1.95	2.86	0.32	1.87
	45 - 60	1.86	1.51	1.13	1.63	1.43	0.31	2.29
	60 - 75	2.54	1.13	1.12	1.65	1.14	0.49	2.48
	75 - 90	2.70	0.98	1.05	1.96	1.75	0.45	2.95
F ratio	0 - 15	0.216	0.419	0.424	0.466	0.488	0.485	0.487
	15 - 30	0.415	0.310	0.046	0.744	0.470	0.952	0.345
	30 - 45	0.267	0.260	0.203	0.543	0.574	0.749	0.740
	45 - 60	0.165	0.189	0.444	0.021	0.357	0.394	0.660
	60 - 75	0.717	0.250	0.464	0.912	0.313	0.471	0.767
	75 - 90	0.714	0.235	0.602	0.376	0.097	0.640	0.782
CV (%)	0 - 15	45.6	164.9	348.0	35.5	154.0	84.6	88.9
	15 - 30	163.5	61.4	74.9	51.7	93.8	108.3	73.4
	30 - 45	64.5	44.6	110.6	81.9	248.6	291.6	81.0
	45 - 60	51.6	94.9	214.7	77.4	65.2	328.5	96.1
	60 - 75	58.5	111.9	190.0	77.9	111.7	276.0	68.8
	75 - 90	72.4	67.8	92.8	87.1	138.6	255.2	92.0

The effect of treatment on NH_4-N level, in the soil layers, in year 2, is seen in Table 5. Apart from two dates, differences were not significant. On 15 November, 1999, at 15-30 cm deep, NH_4-N levels for low N, high N and organic farm treatments were 0.87, 2.84, 1.30 kg per hectare (F=0.046). On 13 December, 1999 a significant difference (F=0.021) was also recorded at 45-60 cm for those treatments- the NH_4-N levels were 3.20, 1.59, 1.63 kg per hectare. As in year 1, all treatments showed no change or a decrease in NH_4-N levels from the surface to 90 cm deep. The tendency for NH_4-N levels at 0-15 cm to be higher than equivalent NO_3-N levels, seen in year 1 was not repeated in year 2. Forty three percent had lower values. All NH_4-N levels, at 75-90 cm deep, for the high N treatment were lower than the corresponding NO_3-N levels shown in Table 4. This was true for all but one date with the organic farm treatment and for four dates with the low N treatment. The highest values were generally recorded in the uppermost layers (0-30 cm). Exceptions to this occurred with the low N treatment in October when high levels were recorded down the profile to 90 cm and also in January when a high value was seen at 30-45 cm deep. On this theme, the high N treatment showed a substantial increase in levels below 30 cm deep in November while the organic farm treatment showed virtually no change down the profile to 90 cm, in the same month. Peak values in the surface layer (0-15 cm) of 12.05, 15.30, 7.81 kg per hectare occurred in November, October and January for the low N, high N and organic farm samples. Minima were seen for those treatments, at that depth, in February, 2000 and November, 1999.

Table 6: Effect of treatment on NO_3-N + NH_4-N level (kg/ha) in soil layers at dates in year 2.

	Depth (cm)	14/09/99	16/10/99	15/11/99	13/12/99	10/01/00	23/02/00	20/03/00
Low N	0 - 15	10.70	13.68	34.65	9.41	5.39	8.52	5.60
	15 - 30	9.17	12.81	2.72	6.61	5.09	4.95	7.15
	30 - 45	9.81	10.36	2.09	4.78	8.26	4.70	5.93
	45 - 60	10.47	14.45	2.76	6.65	4.18	4.06	6.08
	60 - 75	8.87	13.57	3.43	5.14	3.65	4.47	3.92
	75 - 90	7.64	11.19	2.94	5.17	2.02	6.64	4.90
High N	0 - 15	21.71	34.88	7.27	9.17	6.42	8.65	8.46
	15 - 30	18.70	20.58	8.88	7.40	5.16	6.64	6.21
	30 - 45	10.23	17.25	14.32	6.43	6.99	9.28	4.84
	45 - 60	7.13	12.65	20.38	5.69	4.36	6.77	5.12
	60 - 75	7.73	8.81	15.06	8.00	4.38	9.31	5.99
	75 - 90	7.84	7.21	7.14	9.84	8.60	9.63	6.66
Organic	0 - 15	11.33	7.91	3.34	5.91	11.26	6.05	9.65
	15 - 30	8.89	6.90	4.07	5.24	9.33	5.46	4.91
	30 - 45	8.71	7.29	4.63	3.18	9.90	4.23	5.76
	45 - 60	6.76	6.07	3.87	2.80	7.19	4.58	5.96
	60 - 75	9.20	7.15	4.12	3.30	5.85	5.38	5.69
	75 - 90	9.12	5.11	3.87	3.47	7.64	4.25	6.29
F ratio	0 - 15	0.091	0.312	0.462	0.149	0.443	0.452	0.574
	15 - 30	0.502	0.137	0.046	0.396	0.191	0.669	0.783
	30 - 45	0.895	0.265	0.202	0.484	0.758	0.459	0.954
	45 - 60	0.464	0.291	0.444	0.059	0.469	0.566	0.952
	60 - 75	0.887	0.301	0.464	0.608	0.540	0.030	0.834
	75 - 90	0.841	0.105	0.601	0.304	0.371	0.208	0.905
CV (%)	0 - 15	63.5	199.5	357.4	49.2	104.4	48.1	80.5
	15 - 30	127.2	120.0	74.9	58.6	53.0	54.9	76.9
	30 - 45	45.1	105.8	110.6	55.0	112.4	90.6	67.4
	45 - 60	43.1	83.8	214.7	62.4	57.3	63.1	87.1
	60 - 75	50.2	51.1	190.0	87.2	61.3	77.1	64.0
	75 - 90	55.3	29.7	92.9	137.7	155.7	94.1	85.1

Total mineral N levels, in the soil layers, as affected by treatment, are shown in Table 6. Differences between treatments were not significantly different apart from two sampling dates. On 15 November, 1999 in the 15-30 cm layer, the total mineral N levels for the low N, high N and organic farm treatments, at 2.72, 8.88, 4.07 kg per hectare were significantly different (F=0.046). Similarly for those treatments on 23 February, 2000 in the 60-75 cm layer when the levels were 4.47, 9.31, 5.38 kg per hectare (F=0.030). Total mineral N levels declined from the surface layer to the lowest depth in the low N treatment at all sampling dates but only at four and six dates in the high N and organic farm treatments. In the low N treatment, there were high total mineral N levels present to 60 cm in September and throughout the profile at the October sampling. In the high N treatment there were high total mineral N levels to 45 cm in September, to 60 cm in October and from 30 to 75 cm in November. Such observations did not apply to the organic farm treatment. The high N treatment had the highest levels, among treatments, at 0-15 cm, in September and October. The values, 21.71, 34.88 kg per hectare, were noticeably higher than those recorded for the other treatments. The high N treatment never had the lowest value at the 75-90 cm depth- it was always shared by the other treatments. A high level, 34.65 kg per hectare, was recorded at 0-15 cm in the low N treatment in November.

Table 7: Effect of treatment on soil mineral N to 90cm at dates in year 1.

	12/10/98	09/11/98	14/12/98	19/01/99	01/03/99	22/03/99
	Total NO_3-N (kg/ha) 0 - 90cm					
Low N	19.18	15.99	16.36	30.39	18.19	17.29
High N	21.71	21.41	20.95	29.28	26.09	27.22
Organic	14.88	23.86	19.51	24.31	26.95	19.19
F ratio	0.767	0.749	0.951	0.828	0.746	0.490
CV (%)	51.4	31.1	44.5	27.4	24.2	28.0
	Total NH_4-N (kg/ha) 0 - 90cm					
Low N	17.71	18.93	18.91	11.70	6.09	21.65
High N	14.64	25.68	24.23	19.60	9.51	36.80
Organic	16.04	38.41	29.21	23.06	15.77	14.25
F ratio	0.866	0.658	0.841	0.281	0.348	0.269
CV (%)	29.1	99.1	99.0	65.4	31.1	120.0
	Total NO_3-N + NH_4-N (kg/ha) 0 - 90cm					
Low N	36.89	34.91	35.27	42.09	24.28	38.94
High N	36.35	46.79	45.18	48.87	35.60	64.02
Organic	30.92	62.27	48.72	47.37	42.72	33.44
F ratio	0.640	0.610	0.873	0.838	0.351	0.240
CV (%)	31.0	59.1	63.1	31.7	19.1	68.3

The summary of the effect of treatment on NO_3-N, NH_4-N and total soil mineral N to 90 cm for year 1 is presented in Table 7. There were no significant differences in treatment effects on any of the three parameters presented. With regard to NO_3-N, across all dates, the lowest level always alternated between the low N and organic farm treatments; this was also true for NH_4-N and total mineral N, apart from NH_4-N in October.

Similarly for year two (Table 8) - differences caused by treatments in the three parameters measured were not significant at any date.

Table 8: Effect of treatment on soil mineral N to 90cm at dates in year 2.

	14/09/99	16/10/99	15/11/99	13/12/99	10/01/00	23/02/00	20/03/00
				Total NO_3-N (kg/ha) 0 - 90cm			
Low N	33.50	28.78	32.51	16.37	14.06	27.82	15.52
High N	42.96	70.53	51.63	28.4	26.82	43.21	21.55
Organic	34.78	29.04	16.83	7.93	31.15	25.03	19.67
F ratio	0.766	0.274	0.588	0.276	0.271	0.251	0.905
CV (%)	32.2	121.6	140.3	80.2	41.00	43.6	50.5
				Total NH_4-N (kg/ha) 0 - 90cm			
Low N	23.15	47.28	16.07	21.39	14.52	5.51	18.07
High N	30.39	30.86	21.42	18.13	9.09	7.07	15.74
Organic	19.22	11.38	7.07	15.96	20.03	4.93	18.59
F ratio	0.428	0.254	0.611	0.134	0.424	0.692	0.919
CV (%)	55.6	73.1	146.4	32.4	106.1	94.8	41.6
				Total NO_3-N + NH_4-N (kg/ha) 0 - 90cm			
Low N	56.65	76.06	48.58	37.76	28.58	33.34	33.59
High N	73.35	101.38	73.05	46.53	35.91	50.28	37.29
Organic	54.01	40.43	23.90	23.89	51.17	29.96	38.25
F ratio	0.628	0.092	0.597	0.269	0.241	0.231	0.971
CV (%)	37.8	96.4	141.9	45.2	52.0	42.9	37.9

It can be seen from Table 8 that the lowest values for NO_3-N, NH_4-N and total mineral N were never associated with the high N treatment, with two exceptions, NH_4-N in January, March 2000. This, though not a statistically significant effect, is worthy of note.

The mineral N in the profile to 90 cm in October of year 1, at 37, 36, 31 kg/ha for the low N, high N and organic farm, was low and comparable to the mean level found at harvest in the profile to 75 cm in soil at Rothamsted which had grown wheat. Total N leached at Rothamsted was low even though the maximum concentration of NO_3-N in drainage water exceeded the EU Maximum Admissible Concentration (Goulding et al., 2000). The mineral N in the profile to 90 cm in September of year 2, at 57, 73, 54 kg/ha for those treatments, was lower for the low N and organic farm treatments but comparable, for the high N treatment, with autumn soil mineral N in the profile of a sandy loam arable soil in central England. Over two years the soil had grown winter barley and winter wheat and had a mean soil water

NO_3-N concentration of 21 mg/l. This high concentration was a reflection of low and very low drainage volumes of 170 mm and 86 mm for the two winters (Williams et al., 2000).

Changes in NO_3-N over the Winter

By calculating NO_3-N, in each soil layer in kg/ha cm at each sampling date, it is possible to note increases or decreases in NO_3-N in the soil profiles between different dates and obtain a comparison of treatments in N movement towards groundwater. The NO_3-N data are presented in this form for the two years in Figures 1, 2.

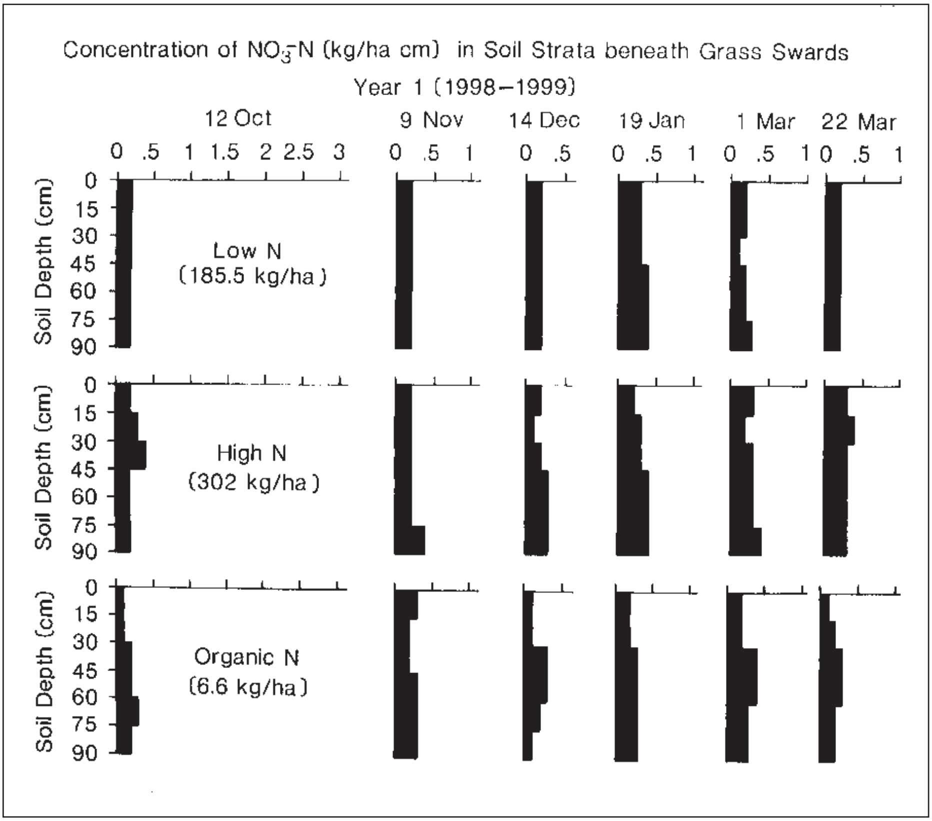

Figure 1: Effect of treatment on NO_3-N concentrations in soil strata in year 1.

In year 1 (Figure 1), the NO_3-N in the lower strata of the low and high N treatments was at its highest in January which suggests some downward movement and loss by leaching of N which had been mineralised close to the surface. A further decline between January and March suggests more leaching. In the organic treatment the highest NO_3-N in the profile, below 30 cm deep, was seen on March 1, indicating some leaching with subsequently lower levels by March 22, suggesting further leaching.

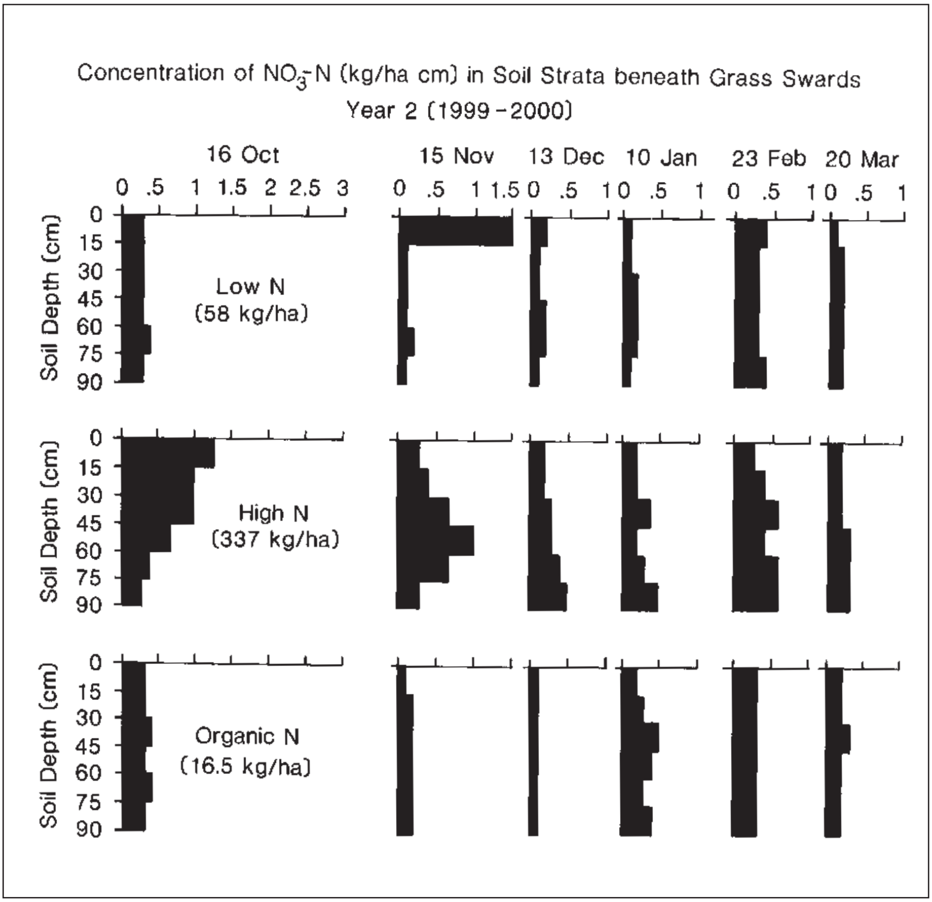

Figure 2. Effect of treatment on NO_3-N concentrations in soil strata in year 2.

In year 2 (Figure 2), there was little NO_3-N in the profile of the low N and organic farm treatments in October - the levels present were comparable to those reported by Watson et al. (1993) for the soil layers under a newly sown grass/white clover ley and a recently ploughed grass/red clover ley at Brynllys, Wales. The high N treatment had much higher NO_3-N levels present in the profile. In the latter, evidence of downward movement was obvious in that the amount in the surface 45 cm showed an overall decline between October and March with concomitant increases at the lower depths in December, January and February. The low N plots had their lowest amounts of NO_3-N in the profile in December-January indicating that leaching had taken place. An increase shown by late February could have been due to fertiliser applied in late January combined with increased mineralisation. The organic farm treatments showed an overall decline in profile NO_3-N between October and December suggesting leaching. Increased levels in the profile by 10 January, comparable to those in the high N profile, are puzzling but profile NO_3-N levels comparable to those in the low N plots by 23 February and even lower levels by 20 March suggest leaching between January and March.

At all sampling dates there was more NO_3-N in the soil profile of the high N treatment compared with the others, the exception being the organic farm plots, 10 January, 2000.

Estimated Annual Leaching

An estimate of the average annual loss of nitrate from the experimental treatments can be obtained by relating the mean NO_3-N content of soil samples at the start of drainage from depths 0-90 cm to the soil bulk density (mean 0-90 cm) and to an estimate of the annual rate of water movement through the profile (Ryden et al., 1984; Barraclough et al., 1992). In year 1, a total of 409 mm drainage was estimated to have occurred, derived from rainfall minus evapotranspiration in the period 12 October 1998 to 22 March 1999. Based on a mean profile volumetric water content (water filled porosity), of 0.36 (Diamond, Personal Communication) at 60 cm tension, which is about field capacity for the related Rathangan Series and assuming piston flow, it is estimated that the rate of water movement through the profile in that year was 1.136 m and that the leaching front in year 1 would have reached 1.136m.

The average amounts of N leached (kg/ha) in the year are calculated from the expression:

Mean profile NO_3-N content (mg N/kg) * rate of water movement (m) * mean profile bulk density (kg/m^3) * 10^4 m^2/ha * 10^{-6}

In year 1, this turned out to be {1.35*1.136*1570*10^{-2}} for Low N= 24.1 kg/ha. For High N and Organic Farm treatments the estimated amounts leached were 27.3 and 18.0 kg/ha.

In year 2, estimated drainage from 14 September 1999 to 20 March 2000 was 388 mm. By the same method, the estimated moisture displacement was 1.078 m and the estimated N leached (kg/ha) was: Low N 39.5, High N 53.2, Organic Farm 41.2 - all reflecting higher mineral N in the profile.

The proportion of applied N leached, averaged over the two years, was Low N 22%, High N 12%, i.e., an average of 17%, which is in agreement with the findings of Ryan and Fanning (1999) who found that a mean 16% of applied N was leached, over a range of well drained soils, in a lysimeter study. These are unexceptional levels of leaching.

A second estimate of N leached was carried out by determining, for each sampling date, the concentration of NO_3-N (mg/l) in the soil water of the lowest soil layer (75-90 cm). This was achieved by using the level of NO_3-N and gravimetric moisture measured in that soil layer, generated in the KCl extraction procedure. The mean concentration of all sampling dates was then multiplied by the drainage estimate to give kg/ha N leached. This procedure gave estimates of N leached which, averaged over the two years, were 5 kg/ha greater for the low and high N treatments and 8 kg/ha lower for the organic farm treatment than those obtained by the method previously described. When averaged over the three treatments the amount leached using the second method of estimation was only 0.6 kg/ha greater than the first method used.

In a contemporaneous study in the dairy and organic farms, Bartley et al. (1999) found that the NO_3-N concentrations in the groundwater under the dairy were low, the annual mean range of concentrations being from 0.7 to 3.2 mg per l. The concentrations at depth were higher under the organic farm and were in the range 0.3 to 5.3 mg per l.

Models

Richards (1999), investigating the effect of applied N on N available for leaching in a freely drained profile to 75 cm in November, derived the following simple relationship:

Y = 0.157 X + 32.5, i.e., Y = N available for leaching (kg/ha); X= total N applied for grazing (kg/ha).

Using this relationship for the November 1999 data, at the low and high rate of N in the dairy, gave predicted values of 45.7, 85.4 kg per ha available for leaching compared to recorded values of 48.6, 65.9 kg per ha which were within 6 and 23% of predicted. The prediction slightly underestimated at low N and overestimated at high N inputs.

Many sophisticated simulation models of nitrate transport, used for predicting the potential of nitrate to leach from the root zone, have been developed during the past thirty years. These include Leaching Estimation and Chemical Model (LEACHM) (Hutson and Wagenet, 1992), Nitrogen and Carbon cycling in Soil, Water And Plant (NCSWAP) (Molina and Richards, 1984) and Root Zone Water Quality Model (RZWQM) (USDA-ARS, 1992). Several were evaluated for nitrate leaching under corn and the sub-model, LEACHN, of LEACHM was tested for ability to predict nitrate leaching losses below 1m from N-fertilised pasture over 2 years in Pennsylvania. Results demonstrated the potential of LEACHN to predict nitrate leaching under pasture conditions, using N transformation rate constants determined through the calibration process, in corn fields on similar soils (Jabro et al, 1997).

LEACHM consists of five independent sub-models that deterministically describe the one-dimensional storage, transport and distribution of water and solute within the soil profile. The sub-models include LEACHN, which describes N transport, transformation and uptake. The model solves numerically the Richards` equation for water flow and the convection-dispersion equation for chemical transport in a layered soil profile.

The model requires input data for soil physical, hydraulic and chemical characteristics for each layer or horizon; soil N transformation rate constants; hydrological and environmental data with crop and management information for the simulation site for each year. Daily precipitation, minimum, mean and maximum daily air temperatures and weekly pan evaporation are also required.

Such a demand for data on input parameters would limit the usefulness of the model under Irish conditions, due to a severe lack of reliable information on parameters for many soils.

Other important leaching models are mechanistic, implying that they describe the chemistry and physics of processes. Examples of such are SOIL-N (a C, N turnover model), ANIMO, SWATNIT and DAISY, which treat water and nitrate processes.

Many factors must be considered. The water may infiltrate or run off along the surface. If the water infiltrates it may move uniformly through the soil or part of it may follow preferential pathways due to various macropore types. At deeper levels the process may be accelerated by drainage systems and affected by the hydrological properties of geological layers. Nitrogen might be added in mineral or organic form, as aerial deposition or as a pollutant in irrigation water. The time of application will affect leaching and N may leave the field as ammonia through volatilisation. Mineral N may be taken up by plants or immobilized and mineralised later. Denitrification may take place and nitrate may be stored temporarily in the root zone or leached out of the root zone. Below the root zone, denitrification may be negligible in the aerated part, whereas nitrate reduction due to the presence of organic matter, pyrite or iron-silicates must be expected in the saturated part. Most of these processes are dependant on the temperature and some depend on carbon pools or the water/oxygen content.

A comparison of 14 models (de Willigen, 1991) showed that for soil water and mineralisation simulations, detailed mechanistic models, such as the four mentioned above, were not necessarily better than simpler models. The mechanistic models require detailed information about soil hydraulic and chemical properties and are generally very sensitive to parameter values. These models apply to a wide range of conditions. Simple models are generally applicable to a limited range of conditions only and cannot be used for extreme conditions. A higher degree of reliability is not necessarily gained from choosing the most complicated model available.

Other models mainly associated with arable systems but with, perhaps, limited application to grassland include MACRO - a model of water movement and solute transport in macroporous soils; CREAMS, a field -scale model for chemical runoff and erosion from agricultural management systems and its extension GLEAMS. The latter consider both the movement through the soil column and the transport in the runoff and eroded material. Models are available from several

European countries, but for Irish conditions it is considered that, at present, N-CYCLE is likely to be the most suitable to predict nitrate leaching from grassland.

The N-CYCLE model, to predict transformations and losses of N in UK pastures, grazed by beef cattle, was developed by Scholefield et al (1991) at the Institute of Grassland and Environmental Research, North Wyke, Devonshire. The model simulates the cycling of N in grassland systems grazed by beef cattle and predicts the annual amount of N in liveweight gain and the amounts lost through ammonia volatilisation, denitrification and leaching on the basis of fertiliser application and soil/site characteristics. It is an empirical, mass-balance model, which calculates the average annual fluxes of N per hectare within a beef grazing system. It can also be operated in "dairy cattle" and "cutting only" modes.

Importantly, only a small number of basic parameters is used: soil texture, drainage conditions, land use history, age of sward, climatic zone and atmospheric zone- the latter indicating the amount of N deposited from the atmosphere. The parameters can easily be altered during a simulation. This model is user-friendly and does not require detailed knowledge of soil layer hydrology, N transformations or computing.

The model has been constructed from the average annual amounts of N passing through various stages of the N cycle in ten field systems grazed by beef cattle. Amounts were either measured directly or were calculated from empirical sub-models, assuming a balance between "inputs to" and "outputs from" the soil inorganic N pool. The model is given wide applicability through the inclusion of a mineralisation sub-model, which is sensitive to soil texture, sward age, previous cropping and climatic zone. Another important sub-model determines the partitioning of soil inorganic N to plant uptake or the processes of loss; the proportion partitioned to plant uptake decreases as the total amount of soil inorganic N increases.

Outputs from the model indicate that fertiliser has a strong influence on ammonia volatilisation, denitrification and leaching at a given site. Over a range of sites, with a given fertiliser N rate, total N lost and the proportions lost by the three processes are greatly influenced by the amount of N mineralised by the soil. The model indicates how fertiliser N should be matched with mineralisation to limit gaseous and leaching losses and to achieve optimum efficiency of N-use in grazing systems.

The key sub-model in N-CYCLE uses a linear regression to partition the annual throughput of soil inorganic N between "plant N" and the processes of N loss via ammonia volatilisation, denitrification and leaching. The greater the throughput, the greater the proportion that is lost. Other important sub-models are those that determine the annual additions of N to the soil inorganic pool due to mineralisation; it is these that respond to inputs specifying sward age and management, soil physical conditions and climatic zone. The proportion of "plant N" ingested by grazing animals may be adjusted continuously according to grazing pressure but defaults to 62%-a value determined using the best available data for good farming practice. Ingested N is then partitioned between "product N", which is exported from the system and "dung N" and "urine N", which are returned to the organic and inorganic soil N pools, respectively. The N deemed lost is partitioned as follows: N volatilised as ammonia is subtracted at 15% of urinary N plus 3% of "dung N"; then N lost by denitrification is calculated using a sub-model based on soil texture and drainage state and subtracted to leave that potentially leached as nitrate.

Thus N-CYCLE predicts the average annual amount of N leachable from the soil but it is insensitive to seasonal patterns of weather and because it lacks a nitrate transport sub-model, gives no information on the concentration of nitrate in leachate.

North Wyke are contracted to develop N-CYCLE (IRL) for Teagasc as part of its contract agreed with the EPA within the project "Eutrophication from Agricultural Sources"- in particular "Effects of agricultural practices on nitrate leaching" (Ref. 2000-LS-2.3-M2).

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APPENDIX

Appendix Table 1: Total N (%), Organic C (%) and C/N ratios for the various treatments.

Plot/rep	Treat	Sep-99 %N	Sep-99 %C	Sep-99 C/N	Oct-99 %N	Oct-99 %C	Oct-99 C/N	Mar-00 %N	Mar-00 %C	Mar-00 C/N
10RN-A	Low N	0.20	1.99	9.95	0.22	2.34	10.88	0.18	2.84	15.78
10RN-B	Low N	0.16	1.62	10.13	0.21	2.16	10.24	0.26	3.26	12.54
10RN-C	Low N	0.26	2.75	10.58	0.26	2.54	9.81	0.18	2.22	12.33
11RN-A	Low N	0.22	2.31	10.50	0.28	2.72	9.61	0.17	2.19	12.88
11RN-B	Low N	0.21	1.81	8.62	0.23	2.16	9.47	0.19	2.61	13.74
11RN-C	Low N	0.20	1.84	9.20	0.21	1.83	8.67	0.21	2.34	11.14
12RN-A	Low N	0.28	2.37	8.46	0.30	2.81	9.30	0.20	2.37	11.85
12RN-B	Low N	0.27	2.40	8.89	0.27	2.44	9.07	0.24	3.01	12.54
12RN-C	Low N	0.23	2.14	9.30	0.24	2.03	8.49	0.20	2.51	12.55
10PM-A	High N	0.39	3.76	9.64	0.29	2.57	8.83	0.28	3.41	12.18
10PM-B	High N	0.38	3.69	9.71	0.41	3.86	9.39	0.30	3.26	10.87
10PM-C	High N	0.45	3.90	8.67	0.42	3.73	8.90	0.33	3.34	10.12
11PM-A	High N	0.22	2.22	10.09	0.32	3.56	11.30	0.22	2.84	12.91
11PM-B	High N	0.32	2.74	8.56	0.33	2.87	8.64	0.26	2.94	11.31
11PM-C	High N	0.35	3.03	8.66	0.30	2.55	8.64	0.29	3.46	11.93
8PL-A	High N	0.24	2.22	9.25	0.25	3.11	12.49	0.23	2.87	12.48
8PL-B	High N	0.22	2.19	9.95	0.39	4.43	11.33	0.18	2.19	12.17
8PL-C	High N	0.23	2.31	10.04	0.22	2.13	9.59	0.21	2.64	12.57
OR1-A	Organic	0.16	1.83	11.44	0.23	2.51	10.96	0.19	2.28	12.00
OR1-B	Organic	0.24	2.75	11.46	0.25	2.48	9.76	0.18	2.57	14.38
OR1-C	Organic	0.26	3.21	12.35	0.25	2.58	10.49	0.18	2.44	13.56
OR2-A	Organic	0.23	2.49	10.83	0.32	3.15	9.81	0.22	2.68	12.18
OR2-B	Organic	0.19	1.77	9.32	0.27	2.63	9.77	0.21	2.79	13.29
OR2-C	Organic	0.18	1.78	9.89	0.23	2.31	10.09	0.25	3.24	12.96
OR3-A	Organic	0.36	3.43	9.53	0.32	3.35	10.57	0.30	3.81	12.70
OR3-B	Organic	0.32	2.71	8.47	0.33	3.36	10.28	0.26	3.37	12.96
OR3-C	Organic	0.24	2.39	9.96	0.32	3.21	10.13	0.23	2.79	12.13
Mean										
Low N		0.23	2.14	9.47	0.25	2.34	9.49	0.20	2.59	12.76
High N		0.31	2.90	9.31	0.33	3.20	9.85	0.26	2.99	11.72
Organic		0.24	2.48	10.26	0.28	2.84	10.20	0.22	2.89	12.96
Standard Deviation										
Low N		0.04	0.36	0.80	0.03	0.32	0.75	0.03	0.37	1.31
High N		0.09	0.72	0.63	0.07	0.75	1.43	0.05	0.42	0.90
Organic		0.06	0.61	1.24	0.04	0.42	0.41	0.04	0.49	0.75
CV (%)										
Low N		17.19	16.66	8.43	13.61	13.84	7.89	14.55	14.31	10.30
High N		27.86	24.97	6.76	21.53	23.27	14.52	19.08	13.94	7.69
Organic		26.82	24.59	12.08	14.94	14.78	4.02	17.98	17.07	5.80