NITRATE LEACHING ON A SANDY LOAM SOIL UNDER DIFFERENT DAIRY WASTEWATER APPLICATIONS

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ABSTRACT
Much of the intensive dairy farming in Ireland is located on free-draining soils overlying productive aquifers. The concentrations of nitrate-nitrogen (NO_3-N) in some groundwaters are rising. This study was undertaken to investigate the leaching of NO_3-N from dairy wastewaters on a free-draining sandy loam overlying karstic limestone bedrocks. The two objectives of this field study were (i) to quantify the leaching of NO_3-N from different irrigation depths of dairy wastewaters and (ii) to identify sustainable depths of irrigation that would not cause enrichment of groundwaters with NO_3-N. Three experimental field plots, each 8 m x 8 m, were geotechnically investigated, and instrumented to 3 metres depth as follows: suction samplers to provide pore water samples for analysis; tensiometers for soil porewater pressure measurements; and neutron probe access tubes for soil water contents. Dairy wastewater was applied to the three plots at low (10 mm), medium (25 mm) and high (50 mm) application depths throughout a twelve-month period, to simulate applications on an intensively managed dairy farm. Water samples were taken weekly during the summer and twice weekly during the winter and analysed; porewater pressures and soil water content were measured at the same time as the sampling. Using the data obtained, it was possible to establish the concentrations of nitrate moving through the soil to the groundwater. There was significant leaching from the high dairy wastewater plot, with concentrations in excess of 100 mg NO_3-N /l at the 0.3 m depth and in excess of 11.3 mg NO_3-N/l at 0.9 m depth. It appears that there was not significant leaching in the medium and low dairy wastewater plot at depths below 0.9 m in the grazing season. It appears that wastewater hydraulic loads in excess of 25 mm applied at any time of the year, and loads in excess of 10 mm in winter caused significant nitrate leaching in this study. Recommendations are made in relation to the uniformity of application, minimisation of wastewater and control of discharges from farmyards.

Keywords: dairy wastewater; field plots; nitrate leaching; sandy loam soil; soil suction

INTRODUCTION
Nitrogen loss from intensively managed dairy farms is of particular concern since the introduction of the European Community's Nitrate Directive in 1991 (Council Directive 91/676/EEC). Under the directive, EU member states are obliged to reduce the nitrate concentrations in surface and groundwaters resulting from agricultural practices. Each member state must designate 'nitrate vulnerable zones' where the nitrate concentration in groundwater exceeds 50 mg/l (11.3 mg/l NO_3-N) or could exceed 50 mg/l if no action is taken. Article 3.5 of Directive 91/676/EEC provides an exemption from the obligation to designate nitrate vulnerable zones if the member state applies action programmes (as described in Article 5) throughout the entire territory; such action programmes should set specific limits for the application of livestock manure and shall include monitoring of the nitrate content of surface and ground waters at selected points. The Nitrate Directive also states that there should be a balance between the nitrogen supply, animal manures and chemical fertilisers and the nitrogen demand of the crop. In response to the Nitrate Directive, the Irish Government launched a Code of Good Agricultural Practice (1996), which outlined procedures to reduce nutrient losses through good agricultural practices.

On intensive dairy farms, large volumes of wastewater are produced, consisting of washings from milking parlours, dairies, run-off from yards, silos and silage pits. All these sources increase the biochemical oxygen demand (BOD) in wastewater. The most common method of disposal of wastewater is by land spreading using a spray irrigator or tractor drawn tanker spreaders; but application of water to the soil may not be evenly distributed and hydraulic loads are commonly high.

The volume of wastewater produced depends on the frequency of milking, yard area and individual cleaning practices. The unit production of wastewater may decrease by increasing the number of cows in the herd as the volume of wastewater is not directly proportional to the number of cows being milked (USDA-Soil Conservation Service, 1992). The Dept. of the Environment and Dept. of Agriculture, Food and Forestry (1996) in the code of Good Agricultural Practice estimated the average volume of wastewater produced on a daily basis as 49 litres/cow/day. The Agriculture Development Advisory Service (ADAS, 1985) reported that the amount of wastewater produced is 35 litres/cow/day. In Italy, Mantovi et al (2003) estimated the wastewater production as 20 – 70 litres/cow/day. At the experimental farm in Moorepark, the average volume of wastewater produced was 67 litres/cow/day.

Most of the inorganic nitrogen in wastewater is in the NH_4-N form with low concentrations of NO_3-N. Richards (1999) tested wastewater over a period of 13 months reporting seasonal variations. The highest NH_4-N value was 284 mg/l in mid-August. Ryan (1990) reported that the NH_4-N concentrations were 43 to 126 mg/l in winter and summer respectively. ADAS et al. (1994) in the UK reported winter concentrations of NH_4-N in wastewater of 94 mg/l and summer concentrations of 586 mg/l in dairy wastewaters. The average NH_4-N concentration of wastewaters in this study was 84.8 mg/l with the highest value being 346 mg/l; the BOD of wastewater varied from 1800 to 6000 mg/l with an average of 2208 mg/l.

This study was undertaken to investigate the leaching of NO_3-N from dairy wastewaters on a free-draining sandy loam overlying karstic limestone bedrocks. The two objectives of this field study were (i) to quantify the leaching of NO_3-N from different irrigation depths of dairy wastewaters and (ii) to identify sustainable depths of irrigation that would not cause enrichment of groundwaters with NO_3-N.

METHODS

A 0.4 hectare site was chosen at Curtin's Farm, Teagasc Moorepark Research Centre, Fermoy, Co. Cork for field experiments. A geophysical and topographical survey was carried out in January 2001. The survey gave an estimate of the depth of soil to bedrock. Three test pits were excavated on the site to calibrate the geophysical survey and to determine the exact depth to bedrock. Soil samples from the test pits were taken for physical and chemical analyses. Particle size analyses, plastic and liquid limit tests were measured in accordance with BS 1377 (1990). Soil density and permeability measurements were also made. Four 8 m x 8 m plots were marked out on site, with a buffer strip of 3.0 m between the plots. Boreholes for porewater samplers, 60 mm in diameter were augered using a mechanical augering machine. Ceramic samplers (1900 series, Soil Moisture Equipment Corporation, USA) were installed in all four plots vertically at depths of 0.3, 0.6, 0.9, 1.2 and 1.5 m. Pressure-vacuum ceramic samplers (1920 series, Soil Moisture Equipment Corporation, USA) were installed at 2.0, 2.5 and 3.0 m. A viscous slurry suspension of native soil was poured into the hole to ensure good hydraulic contact between the sampler and the surrounding soil. A bentonite plug was placed around the sampler at the soil surface to prevent surface water flowing down the side of the sampler. Tensiometers were installed at depths of 0.15, 0.3, 0.6, 0.9, 1.2, 1.5, 2.0 and 3.0 m in the control plot and the high wastewater plot to measure porewater pressures. An aluminium neutron probe access tube was installed in the high wastewater and control plots for volumetric water content measurements using a CPN Model DR 503 Hydroprobe. Rainfall was recorded in a weather station approximately 1 km from the experimental site and evapotranspiration was calculated by the Penman-Monteith (FAO 1998) method using data from the same weather station. Treatments for the wastewater plots were at a low (10 mm per application), medium (25 mm) and a high (50 mm) hydraulic load using 10 litre buckets. The low load of 10 mm was based on an application depth recommended in the Code of Good Agricultural Practice (1996). The medium load was 25 mm, which corresponds to a load that was in operation at Curtin's farm in October, 2001. The high load of wastewater application was 50 mm, which represents an extreme load similar to a load spread by a malfunctioning irrigator. There were three applications in total: November 6th 2001, May 5th 2002 and November 24th 2002. Before wastewater was applied, grass was cut at a height of 7 cm to simulate grazing of the plot.

RESULTS AND DISCUSSIONS

The soil at the experimental site is a sandy loam and exhibits good drainage characteristics. The geophysical survey and test pits showed the depth of soil in the range of 2.4 – 3.0 m. The soil at the plots is typical of many free draining soils. Rooting depths are normally 30 cm but fine roots were found to 60 cm. Soils are well graded with uniformity values (D_{60}/D_{10}) greater than 50 (Table 1).

Table 1. Sizes and uniformity coefficients (C_u) for soil layers in Curtin's Farm

	Layer (cm)				
	0-13	14 - 35	36 - 80	81 - 150	151 - 300
D_{60}	0.175	0.128	0.383	0.196	0.126
D_{10}	0.003	0.002	0.002	0.002	0.001
C_u (D_{60}/D_{10})	52.52	75.83	251.32	114.69	139.91

Dry densities of the soil were measured using a Humboldt nuclear compaction gauge and ranged from 700 kg/m^3 in the surface layer to 1870 kg/m^3 at 1.8 m deep. Porosity was high in the topsoil layer at 70% and varied from 30 to 50% in the deeper layers. Density and porosity measurements are presented in Figure 1. They both show a cyclical variation with depth. This is due to the fact that measurements were in 0.3 m layers after which each layer was excavated away allowing for rebound of the underlying layer.

Hydraulic potentials were measured down to depths of 3.0 m. In a normal summer season, suctions are high in the upper layers (Hosty and Mulqueen, 1995), but in late autumn and winter, suctions decrease as the soil water content approaches field capacity. Hydraulic potentials (Figure 2), demonstrate that May 2002 was wet as also shown by rainfall data in Figures 4-6 inclusive.

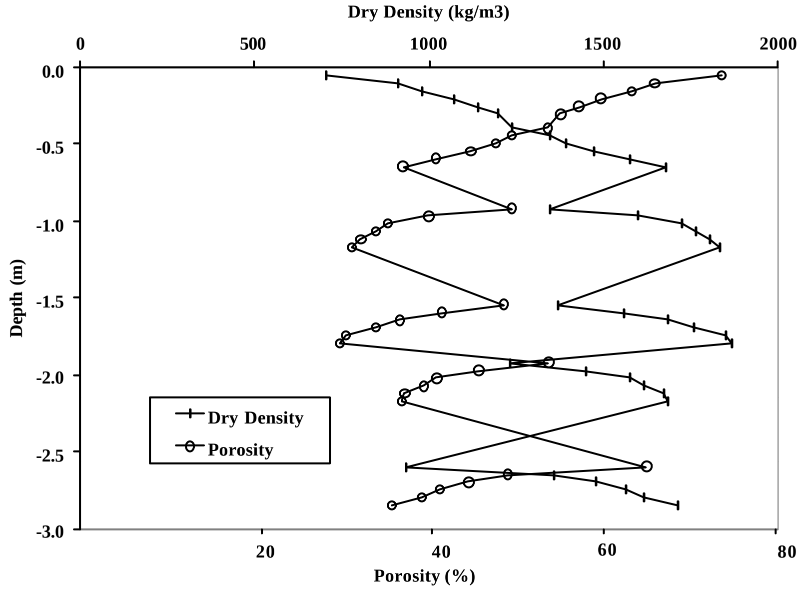

Figure 1. Dry density and porosity values at different depths

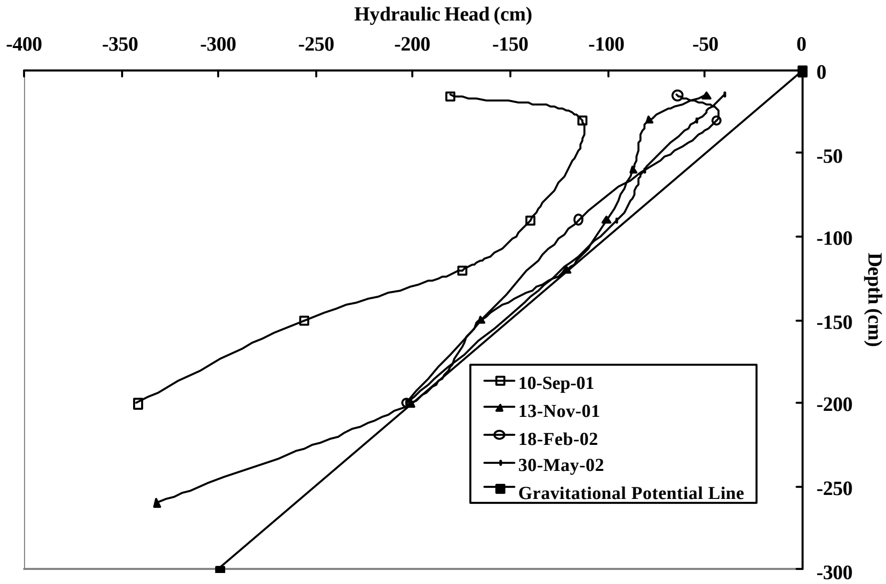

Figure 2. Hydraulic potentials at different dates in the control plot

Porewater samples were taken from the ceramic cups weekly in the summer months and twice weekly in the winter months because of the increased water movement through the soil. Samples were analysed using a nutrient analyser (Konelab 30) for NO_3-N, NH_4-N, PO_4-P and NO_2-N. Samples of the dairy wastewater were taken on each occasion before application and analyses are shown in Table 2 - in broad agreement with Ryan (1990).

Table 2. Nutrient concentrations of wastewater

Date	NO_3-N mg/l	NH_4-N mg/l	NO_2-N mg/l
06-Nov-01	<0.1	346	< 0.1
05-May-02	0.8	63.8	< 0.1
24-Nov-02	<0.1	217	< 0.1

Measurements of porewater pressures before, during and after application of dairy wastewater were taken to determine the response time of the soil porewater to a high hydraulic load. These porewater pressures (Figure 3) show that the soil became field saturated to 0.9 m during and following hydraulic loads of 25 and 50 mm. Applications of 50 mm depths were made in two 25 mm depth amounts with an interval of 10 minutes between them to enable porewater pressure measurements to be carried out.

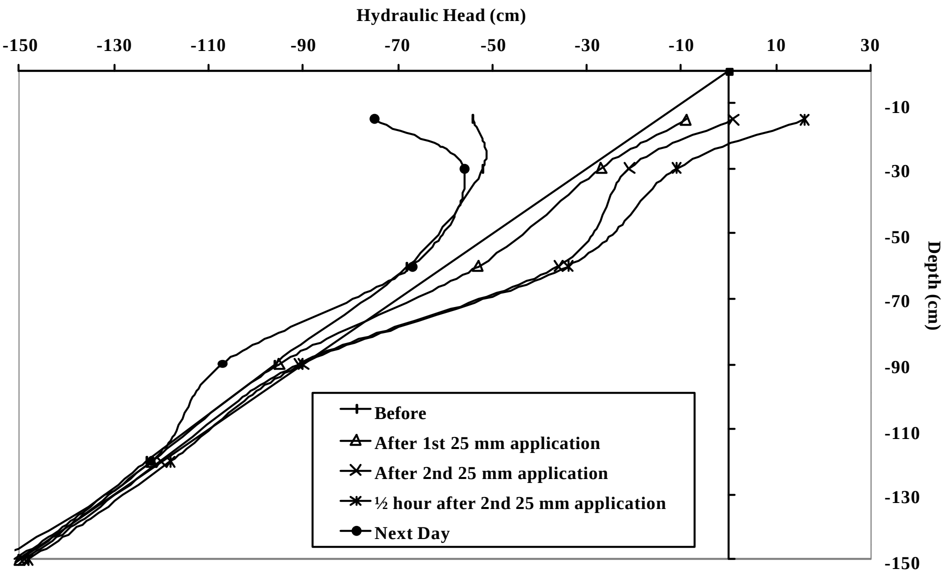

Figure 3. Hydraulic potentials showing the response to dairy wastewater applications in November 2002

Figure 4 shows the NO_3-N values in the porewater of the low wastewater plot. From the graph it can be seen that application of wastewater on November 6th, 2001 and May 5th, 2002 had little effect on the concentrations of NO_3-N at any depths. The porewater NO_3-N concentrations at 1.5 m and at 3.0 m (not shown) at up to 20 mg/l are high (above the EU maximum admissible concentration (MAC) value of 11.3 mg/l NO_3-N but most likely due to previous farm management practices).

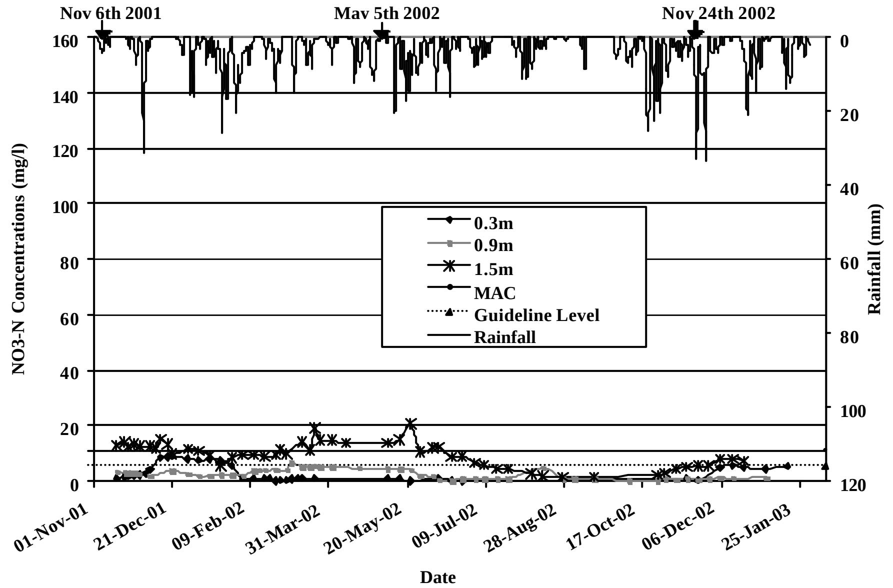

Figure 4. NO_3-N concentrations in the low wastewater plot with rainfall and application dates on top of graph

Figure 5 shows the NO_3-N concentrations in porewater to 1.5 m depth following the medium wastewater loads. It is apparent that the November 6th, 2001 load resulted in high NO_3-N concentrations at 1.5 m after about 120 days and these persisted throughout March – July inclusive. The May 5th, 2002 application appeared to have little or no effect on the NO_3-N concentrations in the porewater. Porewater NO_3-N concentrations appear to be rising again at 0.9 m and 1.5 m, about 45 days after the November 24th, 2002 loading.

The NO_3-N concentrations in the porewater for the high wastewater plot are presented in Figure 6. There is a rapid response to the high loading of wastewater with concentrations peaking at 140 mg/l at 0.3 m depth. There is attenuation and phase shift of the peak with depth due to rainfall, dilution with resident porewater and dispersion/diffusion. Similar effects follow the November 24th, 2002 loading. These high concentrations are reflected in 0.9 m and 1.5 m cups as time goes on. The application of wastewater on May 5th, 2002 appears to have had little effect on NO_3-N concentrations which indicates that most of the nitrogen in the wastewater has been taken up by the grass and that advection was minimal.

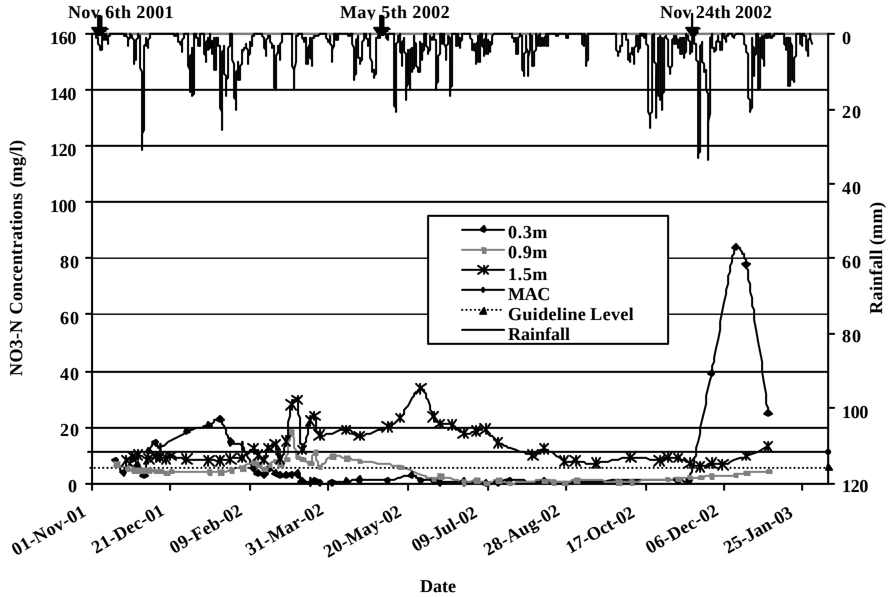

Figure 5. NO_3-N concentrations in the medium wastewater plot with rainfall and application dates on top of graph

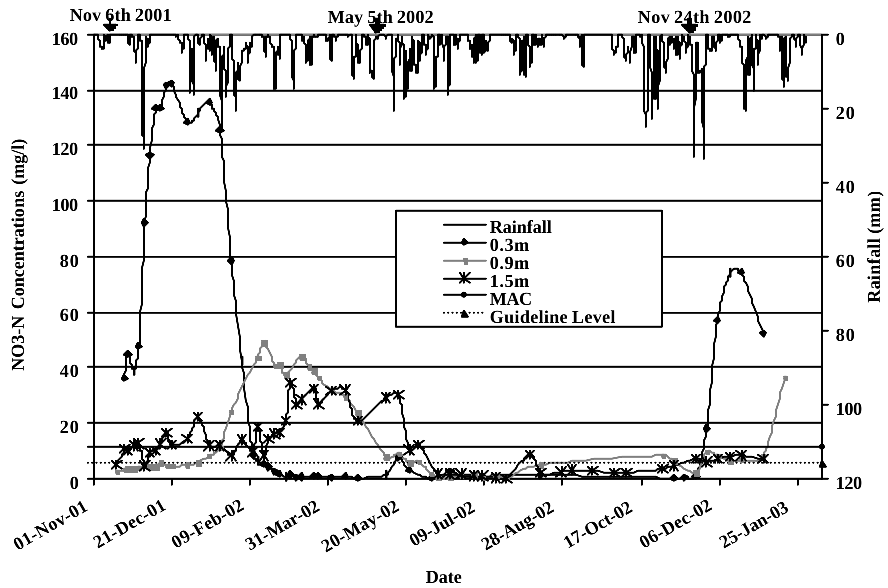

Figure 6. NO_3-N concentrations in the high wastewater plot with rainfall and application dates on top of graph

CONCLUSIONS

Hydraulic potentials show that positive porewater pressures and field saturation developed in the top 0.9 m soil following medium and heavy loading in November 2002. These conditions are reflected in the high porewater NO_3-N concentrations at 1.5 m in the medium load plot and at 0.3, 0.9 and 1.5 m depths under heavy loading, indicating that under saturated conditions NO_3-N is leached. Accordingly, in this study, it appears that wastewater hydraulic loads in excess of 25 mm applied at any time of the year, and loads in excess of 10 mm in winter caused significant nitrate leaching. There is a need to minimise volumes of wastewater, consistent with adequate cleansing and hygiene, to control hydraulic loads. All leakages and overflows from farm yards should be eliminated by proper controls of drainage discharges. To prevent excessive loading, irrigation equipment must be properly operated and maintained.

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