Appropriate Slurry Application Rates and Timings: A Management Tool to Reduce Nitrate Leaching towards Groundwater

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ABSTRACT

This study was undertaken to investigate the appropriate timings and rates of slurry applications on the free draining sandy loam soils of Ireland that would not result enrichment of groundwater with nitrate-nitrogen **(**NO_3-N). Three slurry treatments such as low (15 m^3/ha), medium (30 m^3/ha), and high (45 m^3/ha) were applied during spring 2002. Before slurry application, the initial status of pore water pressures was measured using tensiometers installed at different depths. Similar measurements were taken just after application, ½ hour of application and on the following day. The water samples were collected from the ceramic samplers installed at 0.3, 0.6, 0.9, 1.2, and 1.5 m depths and from the pressure-vacuum ceramic samplers installed at 2.0, 2.5 and 3.0 m depths for NO_3-N analysis.

In general, the NO_3-N concentrations were low at deeper depths and did not exceed EU's maximum admissible concentration limits (i.e. 11.3 mg/l) except for few occasions where they were slightly high under medium and low slurry treatments, which could be due to antecedent farm management practices. Almost similar trends were observed for the high slurry treatment. Results further suggest that slurry applied during spring had little or no effect on NO_3-N concentrations at any of the depths except 3.0 m. At this depth, the NO_3-N concentrations were higher throughout the year reflecting the effect of previous farm management practices. Generally, concentrations in all slurry plots were lower than the EU's maximum admissible concentration limits. The samples collected at shallower ceramic suction cups had no effect on NO_3-N concentrations as a result of slurry applications. However, the high NO_3-N concentrations at the 2.5 and 3.0 m depths were possibly due to previous farm activity.

Key words: Slurry application, nitrate leaching, farm management practices, pore water pressure

1. INTRODUCTION

The dairy wastewaters produced by livestock represent a significant nitrogen resource and have traditionally been returned to the land. Large amounts of wastewater collected from dairy feedlots, milking parlours, runoff from yards, silos and silage pits are commonly applied on the free draining soils overlying productive aquifers in Ireland and elsewhere. The excessive applications and uneven distribution of hydraulic loads of slurry increase the potential for nitrate accumulation in the soil and consequently leaching towards deeper depths. Since, nitrate ions are negatively charged thus can easily leach to ground waters. The farmers even discount the N content in animal wastes and apply additional amounts of commercial (inorganic nitrogen) fertilizers that further increase NO_3-N loading in the soil (White and Safley, 1984). The excessive use of fertilizers in agriculture is thought to be a major contributor for water pollution (Laegreid et al., 1999). A study conducted in the central region of Thailand suggests that their application increased NO_3-N concentration at five-fold in the groundwater bodies (Pathak et al., 2004). Although, the measured NO_3-N concentration in groundwater was below the threshold value set by the world health organization for the drinking purpose, but it may pose a serious threat during the dry season when the groundwater recharge is very low. Hence, the shallow groundwater aquifers always remain at risk due to the presence of NO_3-N in the soils which continue to leach towards them. The evidences of groundwater contaminations from fertilizers and land spreading of wastes have also been witnessed throughout Europe and elsewhere. The nitrate concentrations in excess of 50 mg/l have been found in many groundwater resources in the Ireland (Rodgers et al., 2003), similar results were found in Danish aquifers where nitrate concentrations generally exceeded the EC’s drinking water directive upper limit (Duus Borgesen et al., 1997).

Ireland has an intensive livestock (dairy) farming that accounts for over 87 percent of the value of gross agricultural production (Lafferty et al., 1999) and produces huge amounts of wastewater. A study conducted by Rodgers et al., (2003) revealed that, on the average, a cow produces about 67 litres of wastewater per day as compared to 35 litres previously reported by the Agriculture Development Advisory Service (ADAS, 1985) and 49 litres estimated by the Department of Environment and Department of Agriculture, Food and Forestry (1996). Almost similar volumes of wastewater have been reported in other European countries. Mantovi et al. (2003) have estimated the wastewater production between 20 and 70 litres/cow/day in a study conducted in Italy. Though, slurry is a valuable source of the major nutrients such as; nitrogen, phosphate and potash but its proper application rate and timing is vital to avoid the aftermaths. The above estimates suggest that the wastewater containing nitrogen, organic carbon, phosphorus and suspended solids must be properly managed and applied to agricultural lands, which will not cause the ground water contamination. It is farmer’s perception that a light application of 3000 to 4000 litres/ha spread within three days after cutting, makes the best use of resource. The early applications are preferred over late applications. The winter applications lead to higher nitrogen losses due to leaching subsequently that reduces N utilisation as compared to spring application. However, the results on the effects of application timing and rates are inconclusive. This study was undertaken to investigate the appropriate rate and application timings of slurry on the free draining sandy loams underlying karstic limestone bedrocks. The specific objectives of this study were to quantify NO_3-N leaching under different application rates and suggest the appropriate volumes that would not result in enrichment of the groundwater.

2. MATERIALS AND METHODS

2.1. Location and Description of Soils

The experiments were conducted at Curtin’s Farm, Teagasc Research Centre, near Fermoy, Co. Cork, Ireland. The geophysical and topographical survey was carried out to determine the soil type. A hydraulic digger was used to excavate three pits to establish the exact soil depth to the bedrock. The geophysical survey and test pit results show that the soil depth extends to 3.0 m, beyond that bedrock starts. The samples from test pits were taken for physical analysis. Particle sizes ranging between 63 μm and 75 mm were determined using the British Standards (BS, 1990) and the sizes smaller than 63 μm were analysed using a Malvern Mastersizer Laser diffraction analyser. The physical investigations of the soil profile were conducted by removing the soil layers in small increments at three places. It was observed that the top 0.5 m layer is dark brown, friable and brittle, contained few cobbles and crumb structures. The top layer contained significant amounts of organic matter and grass roots. Roots were normally 0.3 m long but the fine roots were visible down to 0.5 to 0.6 m depths, also the wormholes were apparent at some places. Beyond 0.6 m depth, colour of soil changed from dark to brownish. The deeper soil layers were very dense, highly compact and well graded. A layer of tightly packed dense reddish brown loam soil with some sandstone and gavel lies below 0.5 m down to 1.5 m depth. This layer was so tightly packed that it was very hard to derive a spade to remove the layers or drive a core sampler. Rocks and stones with varying diameter could also be found in the profile down to 1.5 m and below. During the core sampling, evidences of wormholes, tension cracks, fractures, and/or fissures were not noticed below 0.5 m depth.

2.2. Slurry Treatments

A total of ten plots measuring 8 m x 8 m received different slurry applications. The plots contained grass, which acted as a source of nitrogen removal. The field has previously been managed through grass cover that has generally been used for animal feed. For its growth, farmers used animal waste and commercial fertilizer as a nutrient source. The plots were treated with cow slurry. The application rates and dates of slurry treatments are shown in Table 1. Plots were treated to simulate land application at the farm scale on the adjoining dairy farm. Slurry was spread using a 10-litre bucket. A 0.025 m depth was applied in two splits during March 2002. The applied slurry had a total nitrogen concentration of 3548 mg/l.

Table 1. Application dates of dairy slurry

Day of the year	Application Date	High Slurry Rate	Medium Slurry Rate	Low Slurry Rate
331	28-Mar-02	45 m^3/ha	30 m^3/ha	15 m^3/ha
695	27-Mar-03	45 m^3/ha	30 m^3/ha	15 m^3/ha

2.3. Pore water pressures and nitrate sampling

The measurements on pore water pressures were taken using tensiometers installed at various depths in a 3 m vertical soil profile. They were installed at 0.15, 0.3, 0.6, 0.9, 1.2, 1.5, 2.0, and 2.7 m depths. Before slurry application, initial status of pore water pressures was measured using tensiometers. The tensiometer readings were taken immediately after slurry application, ½ hour of application, and on the following day of application. The pore water samples were collected using ceramic samplers (1900 series, Soil Moisture Equipment Corporation, USA) installed at 0.3, 0.6, 0.9, 1.2, and 1.5 m depths and using pressure-vacuum ceramic samplers (1920 series, Soil Moisture Equipment Corporation, USA, 1997) installed at 2.0, 2.5 and 3.0 m depths. The NO_3-N, NH_4-N, PO_4-P and NO_2-N were analysed using a nutrient analyser (i.e. Konelab 30 apparatus).

3. RESULTS AND DISCUSSION

The results on particle size distribution and related soil physical properties are shown in Table 2. The data indicate that the soils are well graded with uniformity values (D_{60}/D_{10}) greater than 50. The soil at the site is classified as sandy loam containing 31 to 39% coarse sand, 5 to 23% fine sand, and 26 to 38% silt upto 2.3 m depth. The clay percentage varies from 7 to 16% that is typical of the area (Gardiner and Radford, 1980; Purcell et al., 2002). The soils from the various depths are similar in texture and D_{10} tends to decline with depth in general. Table 2 also shows dry densities measured on collected core samples. The dry densities range between 1149 and 1341 kg/m^3 in the top 0.05 to 0.25 m depth. The density values in the upper layers are low as compared to deeper ones. Lower bulk density values in suggest presence of organic matter in the soil and shallow rooting of grasses. Below 0.25 m depth, a linear increase was recorded and a maximum value of 1897 kg/m^3 was observed at 1.5 m depth. The high dry density values indicate a compact soil down to 1.5 m depth.

Table 2. Soil characteristics of Curtin's soil

Particle size distribution related parameters for the different layers					
Depth (m)	D_{10} (mm)	D_{15} (mm)	D_{30} (mm)	D_{60} (mm)	$C_u = (D_{60}/D_{10})$
0-0.13	0.0033	0.0057	0.0190	0.1753	52.52
0.14-0.35	0.0017	0.0032	0.0108	0.1280	75.83
0.36-0.80	0.0015	0.0029	0.0103	0.3835	251.32
0.81-1.50	0.0017	0.0033	0.0171	0.1958	114.69
1.51-2.30	0.0009	0.0019	0.0067	0.1258	139.91
Textural classification of different layers					
Depth (m)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Textural class
0-0.13	37	21	35	7	Sandy loam
0.14-0.35	32	19	38	11	Sandy loam
0.36-0.80	48	05	36	11	Sandy loam
0.81-1.50	39	23	26	12	Sandy loam
1.51-2.30	31	20	33	16	Sandy Loam
Some soil physical properties of different layers					
Depth (m)	Dry density (kg/m^3)	Porosity	θv at 0.25 kPa	θv at 80 kPa	($\theta v_{0.25} - \theta v_{80}$)
0.05	1149	0.57	0.55	0.32	0.23 (41.8%)
0.15	1304	0.51	0.50	0.28	0.22 (43.6%)
0.25	1341	0.49	0.49	0.28	0.21 (43.2%)
0.50	1603	0.40	0.39	0.26	0.13 (34.4%)
0.75	1688	0.36	0.36	0.25	0.11 (31.9%)
1.00	1746	0.34	0.33	0.22	0.11 (33.4%)
1.50	1897	0.28	0.26	0.18	0.08 (30.8%)

The porosity for different soil layers was calculated using measured dry density and results are shown in Table 2. In general, porosity decreased with depth and ranged between 0.57 and

0.49 at the top 0.25 m depth and between 0.49 and 0.28 down to 1.5 m depth. Lower porosity in the deeper depths is attributed to highly dense and compact soils. Such soils are result of depositional processes and the configuration of a wide range of particle sizes including coarse, fine sand, and silt compacted together.

3.1. Pore Water Pressures

The data on pore water pressures are shown in Table 3. At the end of slurry application, a significant change in pore water pressures was observed within top 0.6 m depth. Data show a quick response in the top layer and tensiometers located at 0.15, 0.3, and 0.6 m depths responded within ½ hour of application, obviously, a rapid response could be seen by a sharp reduction in negative pore water pressures as soon as the water reached the tensiometers. The pore water pressure decreased from a -0.7 m to -0.008 m at 0.15 m depth and that decreased from a – 0.8 m to -0.4 m at 0.3 m depth, whereas, a decrease of about -0.4 m in pore water pressure was also recorded at the tip of the tensiometer located at 0.6 m depth. However, the tensiometers located at 0.9, 1.2, 1.5, 2.0 and 2.7 m depths did not show any significant change. It is postulated that the soil below 0.6 m depth was fairly compacted and has relatively low water permeability. The in-situ dry density measurements support this argument and reveal that the highest dry density values were observed down to 1.5 m depth. The water under such dense soil with low permeability can only ingress through micro pores. Thus, water did not reach down to 2.7 m depth even after 24 hours.

Table 3. Changes in pore water pressure (m) before and after slurry application

	Depth (0.15 m)	Depth (0.3 m)	Depth (0.6 m)	Depth (0.9 m)	Depth (1.2 m)	Depth (1.5 m)	Depth (2.0 m)	Depth (2.7 m)
Before application	-0.7	-0.8	-1.3	-1.9	-2.5	-3.0	-4.1	-5.4
After 1st application	-0.2	-0.6	-1.1	-1.9	-2.5	-3.0	-4.1	-5.4
After 2nd application	-0.1	-0.5	-1.0	-1.8	-2.4	-3.0	-4.1	-5.4
After 1/2 hour of application	-0.008	-0.4	-0.9	-1.8	-2.4	-3.0	-4.0	-5.4
After Next day of application	-0.9	-0.9	-1.3	-2.0	-2.5	-3.1	-4.1	-5.4

3.2. Nitrate Leaching

Figures 1 through 8 show the NO_3-N concentrations observed under control and different slurry treatments at various soil depths. The slurry treatments consisted of low (15 m^3/ha with 40 kg-N/ha), medium (30 m^3/ha with 80 kg-N/ha), and high (45 m^3/ha with 120 kg-N/ha) loadings applied on March 28, 2002. In general, the nitrate-nitrogen concentrations were low and did not exceed the EU's maximum admissible concentration limits except for few instances. It was slightly higher at medium and low slurry plots at deeper depths, which could be the result of antecedent farm management practices. Almost similar trends were observed for the high slurry plots, where high NO_3-N concentrations at the 2.5 and 3.0 m depth are likely due to previous farm management practices and the travel time of pore water to reach a 3.0 m depth. It could be seen from Figures 1 through 4 that slurry application had no effect on NO_3-N concentrations observed a 1.5 m depth under any of the treatments which indicates that most of the nitrogen present in the slurry has been taken up by the grass or the untraceable amounts might have been leached down. In contrast, NO_3-N concentrations in access of 11.3 mg/l (a threshold limit set by EU) were observed under the control treatment. This is most likely due to previous farm management practices. The impact of previous farm management practices seems gradually diminishing in control plots where the concentrations have fallen below the maximum allowable limits at all depths.

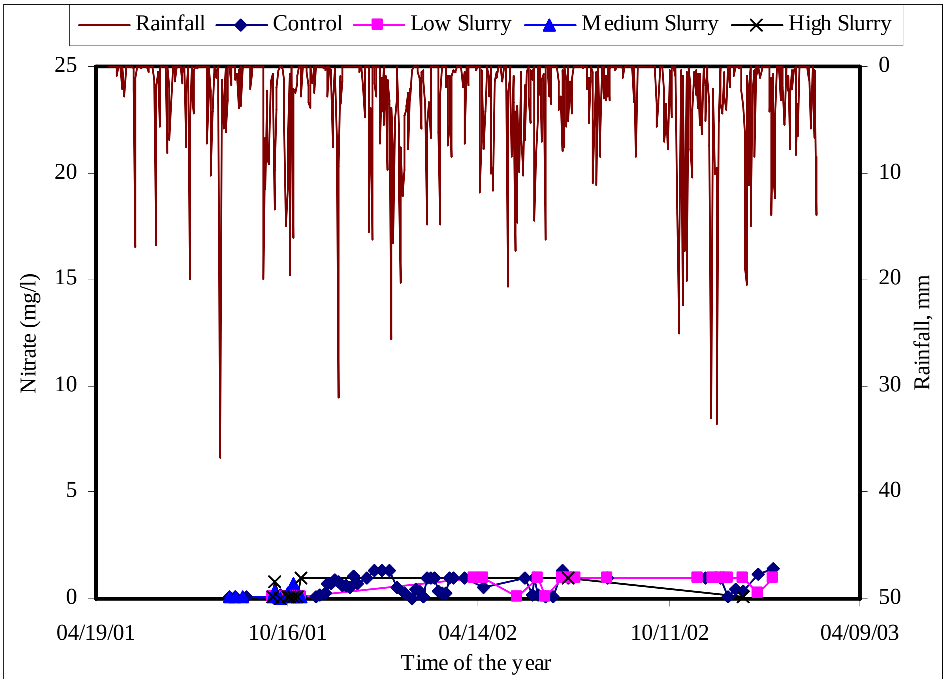

Figure 1. Nitrate concentrations observed at 0.3 m depth under various slurry treatments

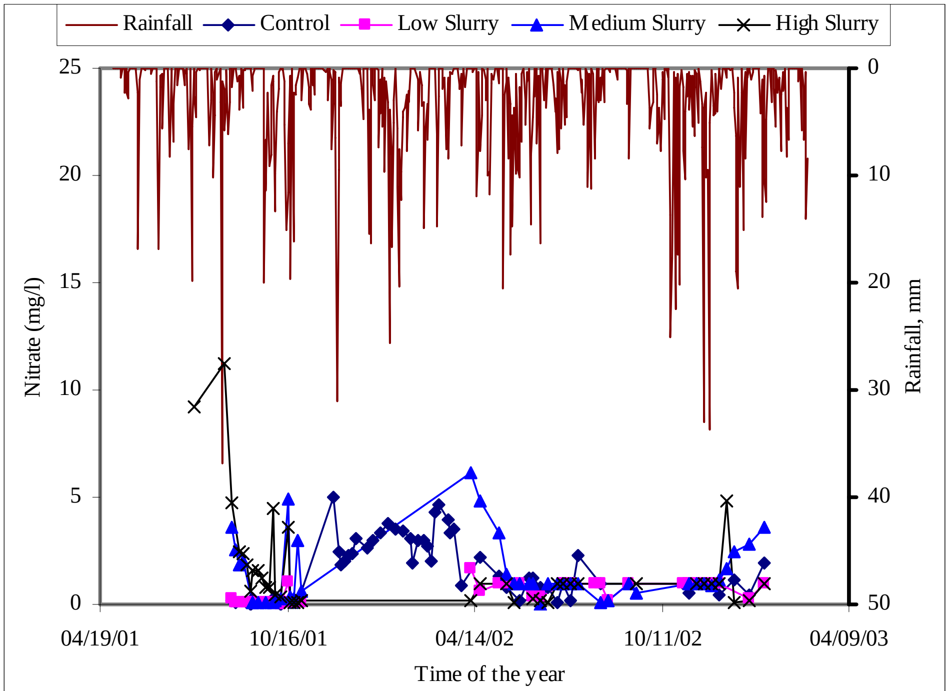

Figure 2. Nitrate concentrations observed at 0.6 m depth under various slurry treatments

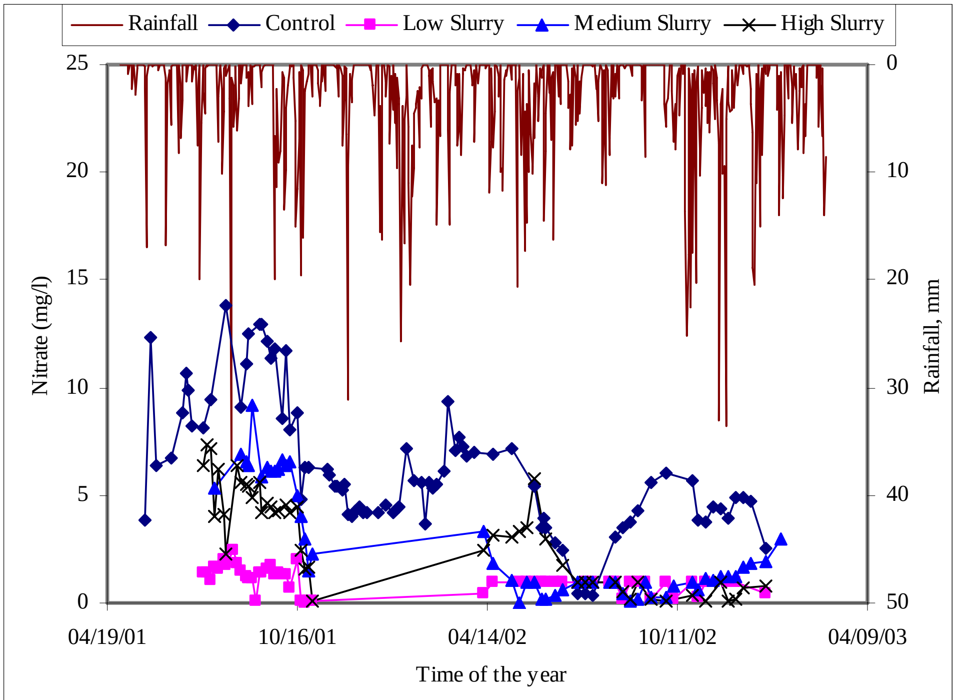

Figure 3. Nitrate concentrations observed at 0.9 m depth under various slurry treatments

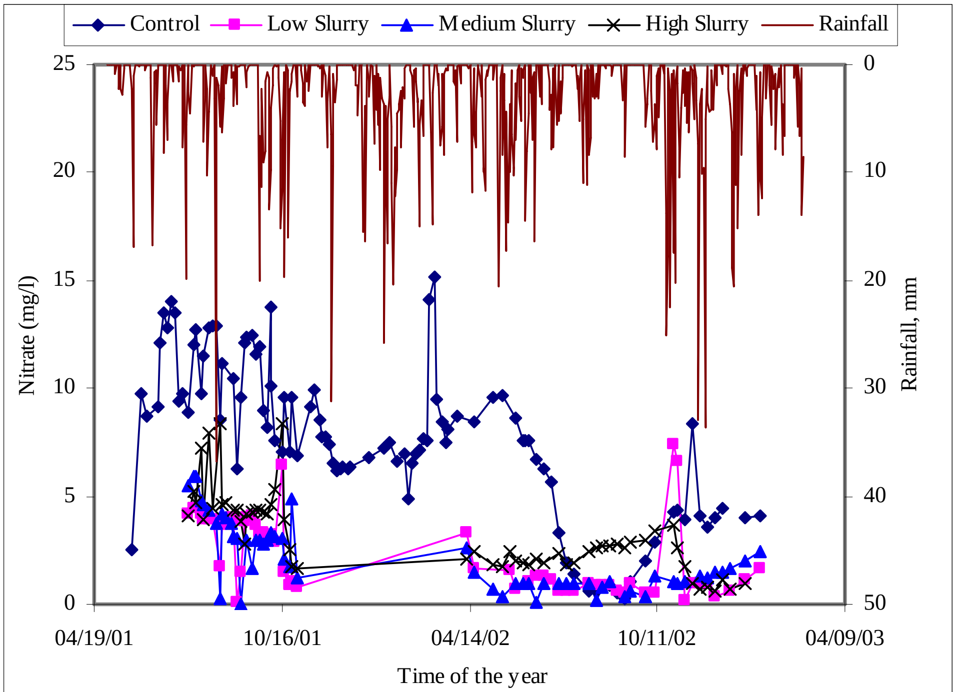

Figure 4. Nitrate concentrations observed at 1.2 m depth under various slurry treatments

Figure 5 shows the NO_3-N concentrations observed at 1.5 m depth. It is apparent from the figure that the slurry applied during March 2002 resulted leaching of NO_3-N under low and medium slurry treatments. But, the observed concentrations were well below the maximum admissible limit. However, significant amounts of NO_3-N were leaching below 2.0 m depth as could be seen in Figure 6. Figure shows that the concentration tends to increase in all three slurry treatment plots where the concentrations in excess of 50 mg/l were observed at low and high slurry plots. The concentrations sharply decreased in high slurry plots but gradually decreased at low and medium slurry plots due to downward leaching of NO_3-N. However, the concentrations in excess of threshold limit persisted until December under low and medium treatments. The long-term presence of nitrates at this depth reflects that the effects of antecedent farm management still persist and nutrients in the profile continue to leach very slowly towards deeper depths.

NO_3-N concentrations observed at 2.5 and 3.0 m depths are shown in Figures 7 and 8, respectively. It could be seen in Figure 7 that the concentrations in excess of 20 mg/l leached under low slurry plots at 2.5 m depth but interestingly the concentrations at 3.0 m depth were below threshold limit under this treatment. In contrast, significant amounts of NO_3-N concentration leached under medium slurry where the concentration peaked to 67 mg/l (Figure 8). The concentrations in excess of threshold limit persisted till the end of the year under this treatment. In general concentrations remained well above the threshold limit at both depths throughout the year.

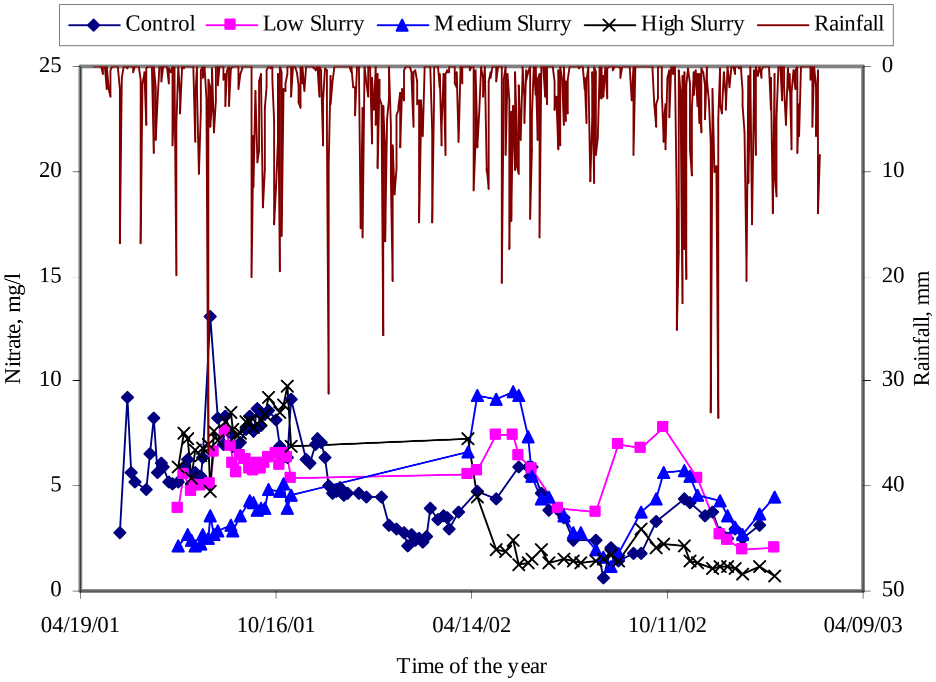

Figure 5. Nitrate concentrations observed at 1.5 m depth under various slurry treatments

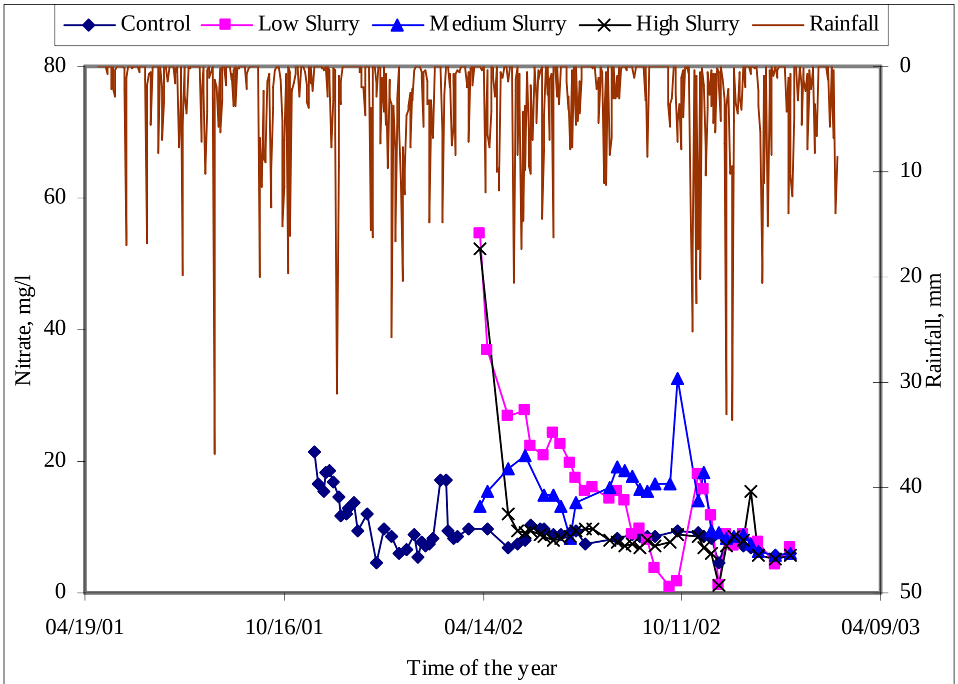

Figure 6. Nitrate concentrations observed at 2 m depth under various slurry treatments

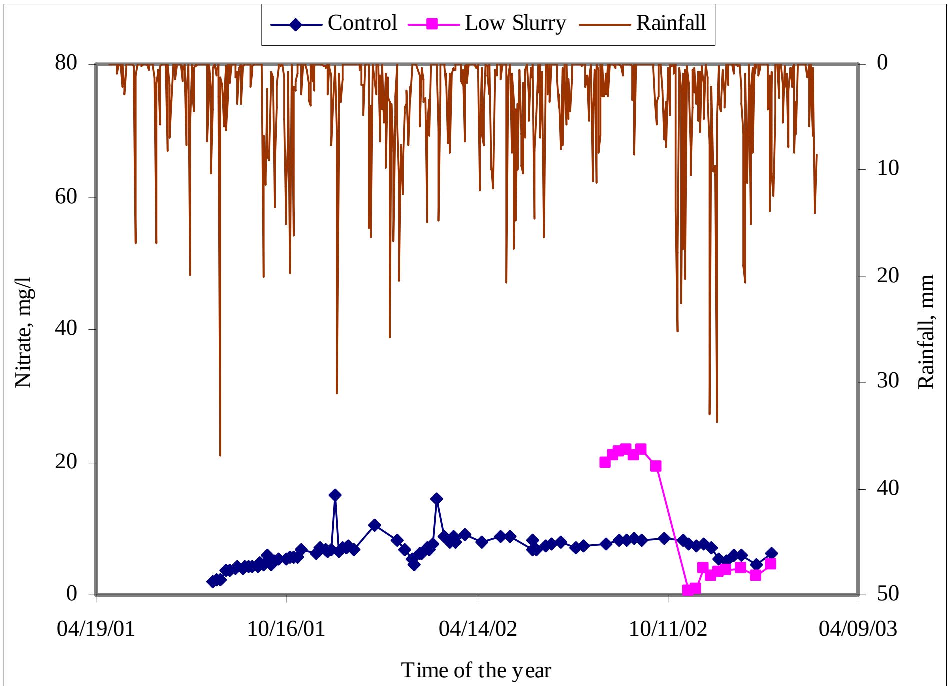

Figure 7. Nitrate concentrations observed at 2.5 m depth under various slurry treatments

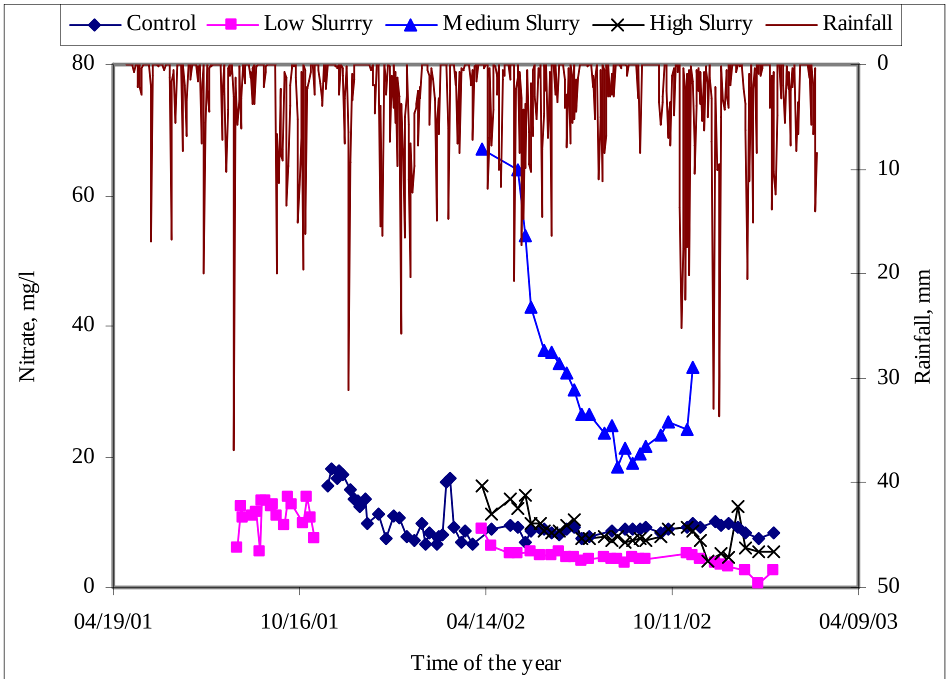

Figure 8. Nitrate concentrations observed at 3 m depth under various slurry treatments

4. CONCLUSIONS

The NO_3-N concentrations were observed under control and different slurry treatments at various soil depths. The slurry treatments consisted of low (15 m^3/ha with 40 kg-N/ha), medium (30 m^3/ha with 80 kg-N/ha), and high (45 m^3/ha with 120 kg-N/ha) loadings applied during March 2002. In general, the nitrate-nitrogen concentrations were low and did not exceed the EU's maximum admissible concentration limits except few for occasions at deeper depths where they were slightly higher at the medium and low slurry treatments, which were due to antecedent farm management practices. Almost similar trends were observed under the high slurry treatment. The high NO_3-N concentrations at the 3.0 m depth are likely due to previous farm management practices. The slower pore water velocities, requires more travel times to reach a chemical concentration to the deeper depths hence they were higher at these depths. Results of three treatments show that slurry application in spring had little or no effect on NO_3-N concentrations at any of the depths but 3.0 m. At this depth NO_3-N concentrations were higher throughout the study period reflecting the effect of previous farm management practices as well as the slow water movement through the pores. The concentrations observed at shallower depths did not show increase in any of the slurry treatments. This suggests that either the nitrogen has been taken up by the grass or it has leached towards deeper depths.

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REFERENCES

ADAS, 1985. Dirty water disposal on the farm: Farm waste management. Booklet 2390. Ministry of Agriculture, Fisheries and Food, pp 31.

BS, 1990. British standard methods of test for soils for civil engineering purposes-classification tests. BS 1377: Part-2.

Department of the Environment, Department of Agriculture, Food and Forestry, Ireland, 1996. Code of good agricultural practice to protect waters from pollution by nitrates, pp 57.

Duus Borgesen, C., A. Kyllingsbek, and J. Djurhuus. 1997. Model simulations of nitrogen leaching from Danish agriculture (in Danish with English Abstract). SP- Report No. 19. The Danish Institute of Agricultural Sciences, Tjele.

Gardiner, M.J. and T. Radford, 1980. Soil associations of Ireland and their land use potential. Explanatory Bulletin to Soil Map of Ireland. An Foras Taluntais, Dublin, pp 142 .

Laegreid, M., O.C Bockman, and O Kaarstad, 1999. Agriculture fertilizers and Environment, CABI Publ., Wallingford and Norsk Hydro ASA, Oslo.

Lafferty, S., P. Commins, and J.A. Walsh. 1999. Irish Agriculture in Transition. A Census Atlas of Agriculture in the Republic of Ireland.

Mantovi, P., M. Marmiroli, E. Maestri, S. Tagliavini, S. Piccinini, and N. Marmiroli, 2003. Application of a horizontal subsurface flow constructed wetland on treatment of dairy parlor wastewater. Bio-resource Technology 88:85-94.

Rodgers, M, P. Gibbons, and J. Mulqueen. 2003. Nitrate leaching on a sandy loam soil under different dairy wastewater applications. Proceedings of 7th International Specialised Conference on Diffuse Pollution and Basin Management held at University College Dublin from 17th - 22nd August.

Pathak, B. K., F. Kazama, and T. Iida, 2004. Monitoring of Nitrogen Leaching from a Tropical Paddy Field in Thailand". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript LW 04 015. Vol. VI. December, 2004.

Purcell, P., H. Scully, and T. Gleeson, 2002. Flow characteristics of natural soil liners for the contaminant of landfill leachate and agricultural slurries. Proceedings of the Third Inter-Celtic Colloquium on Hydrology and Management of water Resources. National University of Ireland, Galway. 8-10th July.

Soil Moisture Equipment Corporation, 1997. 1920 F1/K1 Pressure vacuum soil water samplers operating manual. Soil Moisture Equipment Corporation, Santa Barbara, CA, USA.

White, R.K. and L.M. Safley, Jr.1984. Optimum land utilization of manure. Transaction of the ASAE 27:520-524.