AN EXPERIMENTAL STUDY OF SOIL CONTAMINATION IN WESTERN IRELAND

UNE ETUDE EXPERIMENTALE DE LA CONTAMINATION DU SOL DANS L'OUEST DE L'IRLANDE

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SYNOPSIS: This study consisted of an examination of the potential for contamination of groundwater from the land application of agricultural slurries on shallow unsaturated soils which overlie fissured limestone and where there is evidence that groundwater pollution occurs. Instrumentation consisting of tensiometers, neutron probe access tubes and pore water ceramic samplers were installed in four experimental plots at a selected test site. Agricultural slurry was applied to the plots on five occasions over a thirteen month period. Results from the instrumentation and the pore water samples indicated that leaching of nitrate-nitrogen into the underlying geological strata can occur. Results from a finite difference model, which was used to predict the leaching effects from the application of the slurry, compared favourably with the field results.

INTRODUCTION

In the West of Ireland, groundwater is the source for many drinking water supplies. In the recent past, some of these supplies have been found to be contaminated.

This paper presents details of a study on the contamination of soil pore water from the land application of agricultural slurries at a selected test site in East Galway. The study was carried out where there are shallow soils overlying fissured limestone and where there is evidence that groundwater pollution occurs, resulting in the contamination of the local drinking water supplies. The geological stratification at the test site is common in the West of Ireland . The study area has high rainfall.

The objectives of the study were:
1) To assess, on an experimental basis, the potential for contamination of groundwater from the land application and subsequent leaching of agricultural slurries at the selected test site .
2) To model the solute flow under unsaturated conditions in order to predict contaminant concentration in the soil pore water at the selected test site .

SITE CHARACTERISTICS

The test site was at Athenry Agricultural College Farm which is located about 20km east of Galway City. The farm consists of approximately 290 hectares, most of which is grassland. The agricultural facilities at the farm include dairy and pig fattening units. These units generate large quantities of agricultural slurries which are spread on the land between April and October of each year.

The depth of soil overburden at the farm varies from 0.3m to 3m and overlies Burren limestone rock which has extensive fissures that facilitate the rapid flow of water through the rock. The site water table is well below the bottom of the soil overburden.
At the selected test site, four experimental plots, each measuring 3m by 3m approximately, were located and fenced off. Two of the four plots were made fallow by a herbicide and the remaining two had grass as a crop. One fallow and one grass plot were used as a control set. No application of slurry or fertilizer of any description was made on these control plots during the course of the experiment. The other fallow and grass plots were treated with pig slurry on five separate dates throughout the thirteen month duration of the experiment.

The surface soil at the test site is a dark brown loam with a well developed granular structure. The subsoil is a grey limestone glacial drift. The bedrock is about 3m below the soil surface . Details of the soil characteristics are given in Table 1.

Table 1. Characteristics of the Soils

Depth(m)	0.0-0.1	0.1-0.2	0.2-0.5	0.5+
Coarse sand(%)	20	20	21	21
Fine sand(%)	25	26	23	26
Silt(%)	39	38	38	34
Clay(%)	16	16	18	19
pH	7.0	7.5	7.5	8.0
C.E.C*	15.8	10.9	6.1	2.6
Organic Carbon(%)	4.1	2.5	1.5	0.2
Nitrogen(%)	0.4	0.3	0.2	0.0

*C.E.C is the cation exchange capacity in milli-equivalents/100g

FIELD EQUIPMENT

In order to examine the behaviour of soil pore water and contaminants in the soils, field instruments were installed in all of the plots. These instruments consisted of jet fill tensiometers, multi-point mercury manometer tensiometers, pore water samplers and neutron probe access tubes and were inserted at random positions in each plot.

Tensiometers provide a measure of the soil hydraulic potential which can be used to compute the soil water flux. The essential parts of a tensiometer include a porous ceramic cup, placed in contact with the soil at depth, through which water movement can take place and a pressure measuring device which can be a vacuum Bourdon gauge, a mercury manometer or an electrical pressure transducer. In this study, Bourdon gauge and mercury manometers were used. Tensiometers were installed carefully at selected depths at the test site (Hosty, 1991) and these were maintained in good working order for the duration of the study.

Ceramic water samplers were installed at selected depths at the test site so that pore water samples, when available, could be obtained for analysis. It was decided to examine the presence of nitrogen in the soil pore water since the effects of some of its compounds are damaging to the environment and human health and since soluble nitrogen can flow through the ceramic cup into the sampler (Morrison, 1983).

A neutron probe was used to provide estimates of the moisture content of the soil. One neutron probe access tube was installed at each of the experimental plots. The neutron probe has the advantage that it provides quick soil moisture content measurements with no soil disturbance once the access tube is in place.

Bentonite seals were placed around all of the instrumentation tubes at ground surface so that rain or slurry did not flow down along the tubes.

Rainfall data for the duration of the experiment were available from a meteorological station which is located at the Athenry Agricultural College Farm.

FIELD AND LABORATORY TESTS

Five applications of pig slurry were made on the test plots during the thirteen month test period, which started on June 1st.,1990. The slurry had the following characteristics: pH-7.4; biochemical oxygen demand (BOD)-9330mg/l; ammonium nitrogen (NH4-N)-1826mg/l; nitrate nitrogen (NO3-N)-3.1mg/l; phosphorus (P)-89mg/l. The slurry was applied as shown in Table 2.

TABLE 2. Dates and Rates of Application of Slurry

Dates	Day Number	Rate(m^3/hectare)
14th.June, 1990	14	100
27th.July, 1990	57	50
11th.Sept., 1990	103	50
13th.March, 1991	286	30
24th.May, 1991	358	30

In Irish agricultural practice the rate of $30m^3$/hectare is a typical value of slurry application but the high rate of $100m^3$/hectare could occur where there is excessive or non-uniform application rates. In the experiments, the slurry was spread manually from buckets to ensure an even distribution over the plot. Since there was little volatilization, there was little or no loss of ammonia, so that virtually all the nitrogen in the slurry reached the crop and soil. This typically happens in practice with the more modern application techniques of band spreading and soil injection which are used to minimize volatilization and smell.

Measurements from the tensiometers and neutron probe were frequently taken during the test period. The jet fill tensiometers had an accuracy of 0.1m to 0.2m of water and the mercury manometers had an accuracy of 10mm to 20mm of water. The neutron probe enabled the soil volumetric moisture content to be determined. High energy neutrons are emitted from a radioactive source in the probe. These neutrons are reduced in energy and rebound when they collide with the atomic nuclei in the soil pore water. The resulting low energy or thermalized neutrons are then counted and recorded by the probe. Calibration charts for a range of soils are available which relate the number of counts per second of the thermalized neutrons to the volumetric moisture content of the soil and these charts were used throughout the study.

Water samples were obtained by creating a vacuum in the ceramic soil water samplers which induced the soil pore water to flow into the samplers. The accumulated pore water samples were then withdrawn through access tubing for analysis. The volume of samples obtained in a given time depended on the soil moisture conditions. The water samples were analysed in the laboratory for the presence of a number of chemicals which included nitrate nitrogen (NO3-N).

RESULTS

Results From The Fallow Plots

Figure 1 shows NO3-N concentrations with time in the fallow control plot at the three depths 0.2m, 0.3m, and 0.6m.

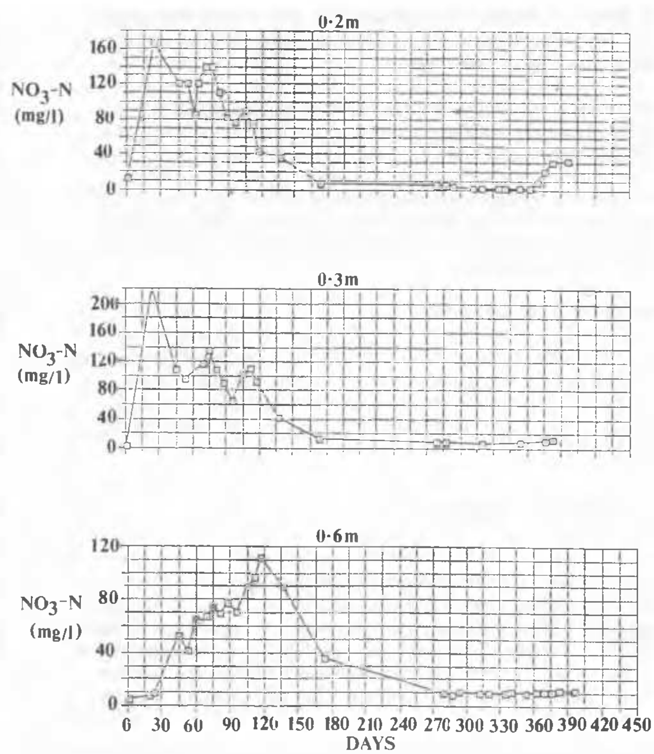

Figure 1. Nitrate nitrogen concentrations on the fallow control plot.

These curves show a steady translation of the peak concentration to a later time with increase in depth. This corresponds to a steady downward movement of a plume of high NO_3-N concentration starting at 0.2m in the topsoil at the end of June and progressing to 0.6m at the end of September over a period of about 93 days. The rate of downward movement is about 1.5m per annum for the above depths and time period. A similar downward progression of the plume of NO_3-N was found in the treated plot. Since the Zero Flux Plane was at or near ground surface for practically all the summer season, as a result of high rainfall and low evaporation (Figure 2), soil moisture was always draining in the unsaturated state to the ground watertable . This drainage brings with it the plume of high NO_3-N concentrations which continues downwards unless it is otherwise transformed or attenuated. This downward movement of NO_3-N is consistent with the report of Tinker (1988).

After mid-October there was a decline in NO_3-N levels to about 10mg/l or less at all depths until early June when levels began to build up again at the 0.2m depth .

While peak levels in the treated fallow plot were higher by up to 50 mg/l than in the control plot and persisted for a longer time, nevertheless, the bulk of the NO_3-N in the pore water came from mineralization of organic nitrogen. In order to minimise leaching of NO_3-N, it is advantageous to maintain a crop cover and active growth as long as possible throughout the growing season.

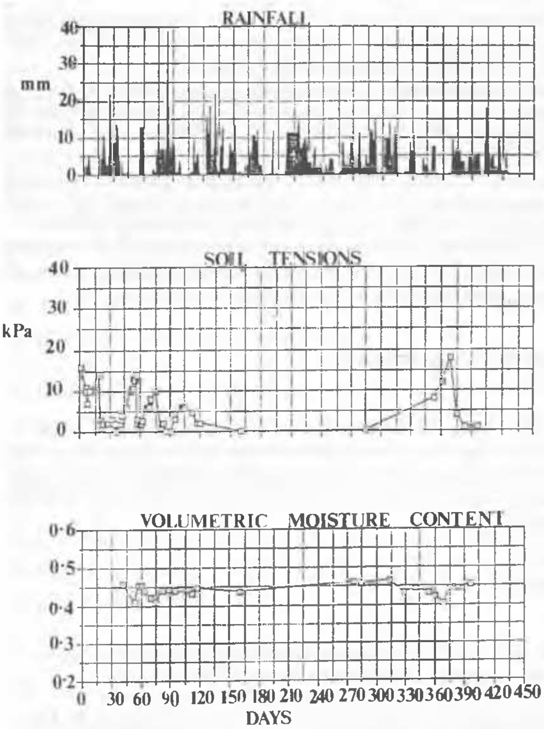

Figure 2. Field results from a fallow control plot at 0.3m depth

Results From The Grassed Plots

In the grassed control plots, NO_3-N levels only reached a maximum of 20mg/l in mid-June at 0.2m depth and declined to a level of 5mg/l or less after the end of September. There was evidence of some downward movement to deeper depths over the season but with losses to plant uptake, levels at 0.6m were never more than 8mg/l throughout the test period.

On the treated plots, slurry applications resulted in high NO_3-N levels (Figure 3). Even at the 0.8m depth, levels of NO_3-N exceeded 30mg/l during three time periods. This level greatly exceeds the World Health Organisation limit of 10mg/l NO_3-N in drinking water. A plume of NO_3-N was moved downwards by drainage water as in the case of the fallow plots. However, there was attenuation with depth. High rates of slurry application in the middle of the growing season and normal rates applied in early or late season and followed by heavy rainfall caused substantial leaching of NO_3-N into the underlying layers. From the field measurements the tensions in the grass plots were much greater than in the fallow plots and this was due to transpiration (Figure 4).

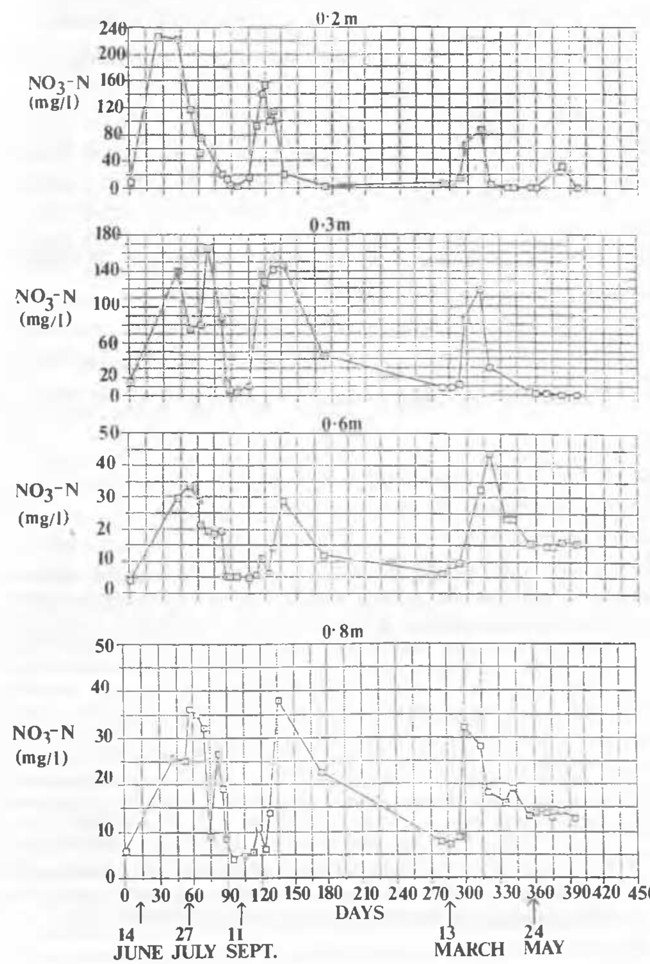

Figure 3. Nitrate nitrogen concentrations on the treated grass plot.

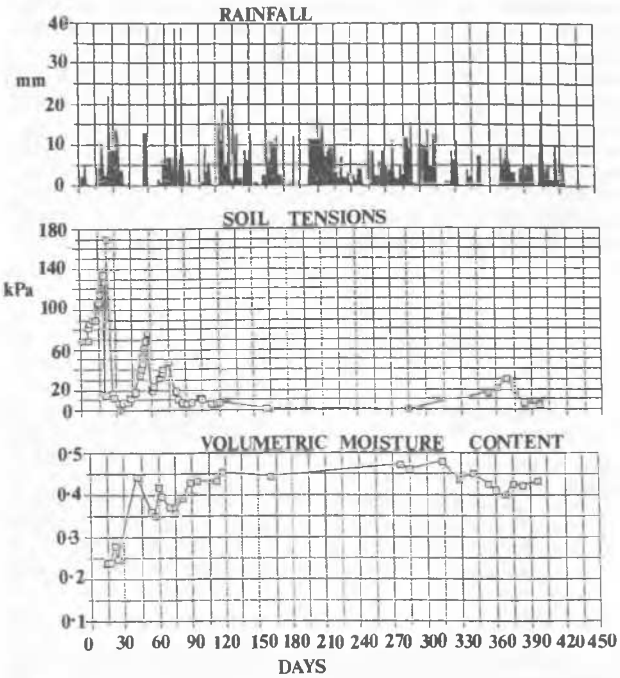

Figure 4. Field results from a treated grass plot at 0.3m depth.

Simulation

A finite difference mathematical model named LEACHM, which is an acronym for Leaching Estimation And CHemistry Model (Wagenet and Hutson,1989), was used to simulate the water and solute movement transformations, plant uptake and chemical reactions in the unsaturated zone. The LEACHN version of the model was used to simulate what happened to nitrogen over the entire study period from June 1st., 1990 to July 1st., 1991. Dates for output results were specified corresponding to dates when samples were retrieved from the field for analysis and when soil moisture readings were recorded. The results from the model and from the field for the treated grass plot at a depth of 0.6m are presented in Figure 5. The soil tension values produced by the model compare well with the actual recorded values. The NO3-N levels produced by the model are similar to the field data but the model results do not fluctuate as much as the field results. The fluctuations in the field data could be due to preferential flow.

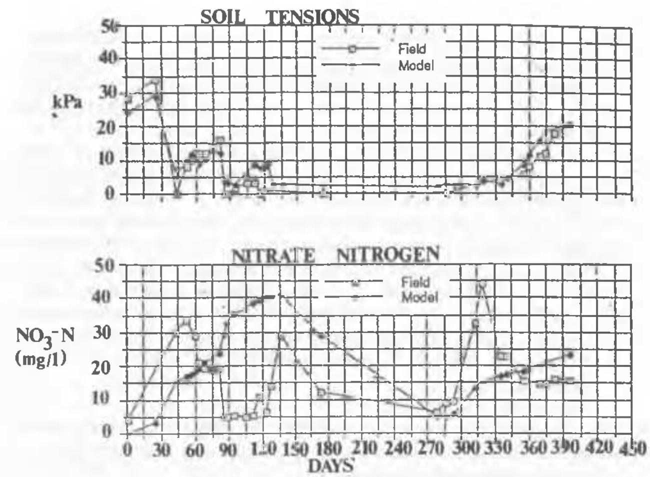

Figure 5. Comparison of field and model results at 0.6m depth on a treated grass plot.

CONCLUSIONS

1) Shallow unsaturated soils similar to those in this study, with a grass crop, may permit the leaching of nitrate-nitrogen from the land application of slurries and sludges into the underlying geological strata. This is most likely to occur if the land application takes place outside the high nitrogen demand period for the grass crop and if the soil moisture tensions are low.
2) Shallow unsaturated soils which are fallow, similar to those in this study, may experience an accumulation of nitrate-nitrogen by mineralization. This accumulated nitrate-nitrogen may then be leached into the underlying geological strata.
3) The results from the finite difference model compared favourably with the field data. Differences between the model results and the field data could be attributed to preferential flow.
4) The methodology used in this study is applicable to the study of land spreading of any type of liquid wastes, including sewage sludge, in order to establish the feasibility of such practices.

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