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A STUDY OF THE LEACHING OF NON-REACTIVE SOLUTES AND NITRATE UNDER LABORATORY AND FIELD CONDITIONS

A thesis presented in partial fulfilment of the requirements for
the degree of
Doctor of Philosophy in Soil Science
at Massey University

Gujjaiah Nanjaiah MAGESAN
1992

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DEDICATION

This thesis is dedicated to my late parents,
G. Nanjaiah and G.N. Raniammal,
who have never been to school.

ABSTRACT

Leaching of solutes such as nitrate from soil to surface water and groundwater is of environmental and economic concern. Leaching experiments were conducted both in the laboratory using large intact soil cores (230 mm diameter; 250 mm depth) and in the field using a mole-pipe drained Tokomaru silt loam soil under pasture.

In the laboratory experiments 'tracers' (tritium, bromide or chloride) were applied as pulse or step-change inputs to the soil surface during steady flow. A transfer function model, based on a probability density function (pdf), which characterised solute travel between inlet and outlet surfaces in terms of cumulative drainage, was used to predict solute movement. Using tracer model parameters, leaching of indigenous chloride was reasonably predicted, but the leaching of indigenous nitrate could not be modelled satisfactorily. This was apparently due to the dynamic nature and spatial variability of the biological transformations to which nitrate is subject in soil.

In the field experiment solid sodium bromide and urea were applied in autumn 1990 to adjacent drained paddocks, each 0.125 ha in area. Soil, suction-cup and drainage samples were collected regularly during the drainage seasons of 1990 and 1991. The average amounts of drainage collected were 250 mm in 1990 and 320 mm in 1991, but the average amounts of nitrate leached were 47 and 20 kg N/ha, respectively. The results indicate the importance of source-strength for nitrate in N leaching loss. The nitrate-N concentration was around 35 g N m^{-3} in the early drainage, well above the WHO limit of 10 g N m^{-3}, but dropped to around 2 g N m^{-3} later in the drainage season. About 8 % of the applied N, but 52 % of the applied bromide, was leached during the 1990 drainage season. This shows the important effect that biological reactions such as immobilization can have in reducing nitrate leaching.

Comparisons were made between solute concentrations of suction-cup solution, soil extracted solution, and the drainage. For non-reactive solutes such as bromide (an applied solute) and chloride (an indigenous solute) the suction cup data provided better estimates of the solute concentration in the drainage than did the soil solution data. For nitrate, neither of these two measurements could estimate accurately solute concentrations in the drainage.

The solute leaching data obtained in the field were modelled using transfer functions. The bromide and chloride data were used to calculate the pdf of solute travel times. For chloride, an exponential pdf fitted the data slightly better than a lognormal pdf, despite it having only one rather than two fitted parameters. The chloride pdf appeared to be similar for both 1990 and 1991. For bromide, the inferred pdf conformed to a log-normal distribution and was quite different from the pdf derived from the chloride data. It seems that assuming a pulse (Dirac delta) flux input for a surface-applied solid fertilizer is not valid, and that this is the reason for the discrepancy between the pdfs obtained using the bromide and chloride data. When the pdf derived from the chloride data was used to model nitrate leaching, the result was generally disappointing.

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LIST OF SYMBOLS

Roman letters

f = fraction of solute that is washed below a depth in cm (Chap 1)
= porosity of the soil (Chap 3)

$f(I)$ = net applied water probability density function (pdf) (L^{-1})

h = depth cm (L)

m = sample mean (Chap 2)

n = number of observations in a sample.

q_m = water flux density in the mobile volume ($L\ T^{-1}$)

s = amount adsorbed per unit surface ($M\ M^{-1}$)

= standard deviation (Chap 2)

t = time (T)

x_i = ith observation,

z = depth (L)

C = flux-averaged solute concentration ($M\ L^{-3}$)

C_a = Initial uniform soil solution concentration ($M\ L^{-3}$)

C_b = Source-sink term ($M\ L^{-3}$)

C_{ent} = flux-averaged solute concentration at the entrance surface ($M\ L^{-3}$)

C_{ex} = flux-averaged solute concentration at the exit surface ($M\ L^{-3}$)

C_{im} = solute concentration in the immobile volume ($M\ L^{-3}$)

C_m = solute concentration in the mobile volume ($M\ L^{-3}$)

C_o = flux concentration for solute front inputs ($M\ L^{-3}$)

D = diffusion-dispersion coefficient ($L^2\ T^{-1}$)

H_w = height of water from the base of the V-notch weir (L)

I = Drainage (L)

I_a = Mean drainage (L)

I_m = Median drainage (L)

K_w = a constant relating to the weir flow calculation

M_o = a pulse of mass applied to the soil surface at $I = 0$ (M L^{-2})

M_n = net mineralization over drainage season (M L^{-2})

P = percolation of rain in cm (L)

$P(I)$ = cumulative density function

Q_w = flow rate in the weir [L^3 T^{-1}]

V = mean pore water velocity (L T^{-1})

Greek letters

α = a rate coefficient (T^{-1})

ε = gas-filled porosity

μ = mean of a distribution

ρ_b = bulk density (M L^{-3})

ρ_s = particle density (M L^{-3})

θ = volumetric water content (L^3 L^{-3})

θ_f = volumetric moisture content of the soil at ‘field capacity’

θ_m = a mobile water content

θ_{im} = an immobile water content

θ_{st} = transport volume fraction

Φ = a source (or sink) term for solute (M L^{-3} T^{-1})

σ^2 = variance of a distribution