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**SOLUTE MOVEMENT ASSOCIATED WITH
INTERMITTENT SOIL WATER FLOW**

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

RUSSELL WOODFORD TILLMAN

1991

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ABSTRACT

The movement of nutrients within the root zone of orchard crops is important in determining both fruit yield and quality. Currently much of the research on solute movement in field soils concerns movement of chemicals to ground water. Little attention has been paid to smaller scale movement. In this study the movement of solutes in response to intermittent soil water flow was investigated in columns of repacked silt loam in the laboratory and in a similar soil in the field.

In the laboratory study a 5mm pulse of a solution of potassium bromide and urea in tritiated water was applied to columns of repacked soil, left for three or ten days, and then leached with 30 mm of distilled water. Twelve days after the solute pulse was applied, the distributions of water, tritiated water, applied and resident nutrients and pH were measured.

The bulk of the bromide and tritiated water was moved to between 50 and 150 mm depth in both water treatments. As the nitrogen applied in urea was mainly in the form of ammonium after three days, the water applied then caused little movement of nitrogen. But the water applied after 10 days caused the nitrogen, now in the form of nitrate, to move in a similar fashion to the bromide.

The soil solution anion concentration determined the amount of cations leached. Calcium and magnesium were the dominant cations accompanying the nitrate and bromide downwards. The added potassium remained near the soil surface.

Given the soil hydraulic properties, the behaviour of water and solutes could be simulated by coupling the water flow equations with the convection-dispersion equation, and by using solute dispersion, diffusion and adsorption parameters derived from the literature. The model assumed the Gapon relationship for cation exchange, and that hydrogen ion production during nitrification reduced the effective cation exchange capacity. It was able to simulate closely the experimental data.

Two field experiments were conducted. The first involved application of a 5 mm pulse of potassium bromide solution followed by 50 mm of water to pasture plots of contrasting initial water content. Twenty-four hours later core samples of soil were collected and the distribution of water and bromide measured. Bromide applied to initially dry soil was much more resistant to leaching than bromide applied to moist soil.

The second experiment lasted 12 days and was essentially an analogue of the laboratory experiment. The final nutrient distributions however differed considerably from those obtained in the laboratory, due to non-uniform flow in the structured field soil.

Coupling a mobile-immobile variant of the convection-dispersion model with a description of the water flow provided a mechanistic model. When combined with the submodels developed in the laboratory study describing nutrient interactions and transformations, this model successfully described the solute movement under the four different field regimes of water and solute application. Evaporation and plant uptake, and diffusion between mobile and immobile phases emerged as key processes affecting nutrient movement. It is suggested some control over nutrient movement is possible by varying the relative timing of water and fertiliser applications.

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LIST OF SYMBOLS

ARABIC

<i>a</i>	empirical coefficient [m]
<i>b</i>	empirical coefficient [dimensionless]
<i>C</i>	soil solution concentration [mol m ⁻³ solution]
<i>C_{ent}</i>	soil solution concentration at input surface [mol m ⁻³ solution]
<i>C_{ex}</i>	soil solution concentration at exit surface [mol m ⁻³ solution]
<i>c</i>	empirical constant [m s ⁻¹]
<i>d</i>	empirical constant [dimensionless]
<i>D</i>	molecular diffusion coefficient [m ² s ⁻¹]
<i>D_o</i>	molecular diffusion coefficient in pure solution
<i>E</i>	dispersion coefficient [m ² s ⁻¹]
<i>f</i>	probability density function [m ⁻¹] (Chapter 1)
<i>f</i>	porosity [m ³ m ⁻³] (Chapters 2 & 4)
<i>I</i>	cumulative drainage [m]
<i>j</i>	solute flux density [mol m ⁻² s ⁻¹]
<i>K</i>	hydraulic conductivity [m s ⁻¹]
<i>K_d</i>	distribution coefficient [m ³ kg ⁻¹]
<i>k_a</i>	rate constant for ammonia nitrification [s ⁻¹]
<i>k_G</i>	selectivity coefficient in Gapon equation [(mol m ⁻³) ^{1/2}]
<i>k_u</i>	rate constant for urea hydrolysis [s ⁻¹]
<i>M</i>	adsorbed plus solution solute concentration [mol m ⁻³ soil]
<i>P</i>	cation exchange capacity [mol charge m ⁻³ soil]
<i>p</i>	number of compartments in model
<i>q</i>	Darcy flux density of water [m s ⁻¹]
<i>R</i>	retardation factor [dimensionless]
<i>S</i>	sink for root water uptake [m ³ water m ⁻³ soil s ⁻¹]
<i>t</i>	time [s]
<i>v</i>	average velocity in soil [m s ⁻¹]
<i>X</i>	amount of cation charge balanced [mol m ⁻³ soil]
<i>Y</i>	adsorbed solute concentration [mol kg ⁻¹]
<i>z</i>	depth [m]

GREEK SYMBOLS

ϵ	empirical constant [dimensionless] (Chapter 2)
α	$M_k + M_a + M_s$ [mol m ⁻³ soil] (Chapter 3)
α	rate coefficient for mobile-immobile exchange [s ⁻¹] (Chapters 1,4 & 5)
β	$M_c + M_g$ [mol m ⁻³ soil]
γ	$(\alpha + 2\beta - P)/\Theta$ [mol m ⁻³ sol] (Chapter 3)
γ	empirical constant [m ⁻¹] (Chapter 4)
Θ	$\theta - \theta_x$
θ	soil water content [m ³ m ⁻³]
θ_c	water content dividing mobile and immobile water
θ_k	water content used in describing $K(\theta)$ in Chapter 2
θ_x	water content of double-layer
λ	dispersivity [m]
μ	mean
ρ_b	bulk density [kg m ⁻³]
σ	standard deviation
ψ	matric potential [m]

COMMON SUBSCRIPTS

a	ammonium
B	bivalent cations
c	calcium
g	magnesium
i	chemical species of interest (Chapters 2 and 3)
i	immobile phase (Chapters 1,4 and 5)
k	potassium
M	monovalent cations
m	mobile phase
n	nitrate or compartment number
s	sodium
u	urea