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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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# TABLE OF CONTENTS

ABSTRACT ................................................................. iii
ACKNOWLEDGEMENTS .................................................. v
TABLE OF CONTENTS ................................................... vii
LIST OF TABLES ......................................................... xiv
LIST OF FIGURES ......................................................... xvii
LIST OF PLATES .......................................................... xxiii
LIST OF SYMBOLS ........................................................ xxiv

## CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION ...................................................... 1

1.2. REVIEW OF LITERATURE ON LEACHING ........................ 2
1.2.1. Sources and transformation processes of N ........................ 2
1.2.1.1. Mineralization ........................................... 3
1.2.1.2. Immobilization .......................................... 3
1.2.2. Processes involving N losses .................................. 3
1.2.2.1. Ammonia volatilization .................................. 3
1.2.2.2. Denitrification .......................................... 3
1.2.2.3. Leaching .................................................. 4
1.2.3. Methods of measuring solute leaching ........................ 4
1.2.3.1. Indirect methods (soil sampling and porous cup sampling) ............................................... 5
1.2.3.2. Direct methods (lysimeters and mole-pipe drainage system) ........................................ 6
1.2.4. Factors affecting solute leaching .............................. 7
1.2.4.1. Climatic conditions ....................................... 7
1.2.4.2. Properties of soils ........................................ 8
1.2.4.3. Fertilizers ............................................... 9
1.2.4.4. Soil management ......................................... 9

1.3. MODELLING SOLUTE LEACHING: Principles and philosophy ... 10
1.3.1. Functional models of solute transport ........................ 12
1.3.2. Piston flow model of solute transport ........................ 12
1.3.3. Convection-dispersion equation for solute transport ........ 13
1.3.4. Mobile-immobile model of solute transport ................. 14
1.3.5. Transfer function model of solute transport ................. 16
1.3.5.1. Measurement of transfer function parameters .......... 16
1.3.6. Solute transport models for mole-pipe drained fields ....... 18

1.4. PURPOSE AND STRUCTURE OF THIS PRESENT STUDY ........... 20
# CHAPTER 2. MATERIALS AND METHODS FOR LABORATORY AND FIELD EXPERIMENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>INTRODUCTION</td>
</tr>
<tr>
<td>2.2</td>
<td>SITE AND SOIL DESCRIPTION</td>
</tr>
<tr>
<td>2.3</td>
<td>LABORATORY EXPERIMENT</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Corers used for large core extraction</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Core collection</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Soil pretreatment</td>
</tr>
<tr>
<td>2.3.4</td>
<td>Leaching apparatus</td>
</tr>
<tr>
<td>2.3.5</td>
<td>Leaching experiments</td>
</tr>
<tr>
<td>2.4</td>
<td>FIELD EXPERIMENT</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Field instrumentation</td>
</tr>
<tr>
<td>2.4.1.1</td>
<td>Drainage sample collectors</td>
</tr>
<tr>
<td>2.4.1.2</td>
<td>Rainfall recorders</td>
</tr>
<tr>
<td>2.4.1.3</td>
<td>Suction cup samplers</td>
</tr>
<tr>
<td>2.4.2</td>
<td>Fertilizer application</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Sample collection</td>
</tr>
<tr>
<td>2.4.3.1</td>
<td>Drainage and rainfall</td>
</tr>
<tr>
<td>2.4.3.2</td>
<td>Suction cup samples</td>
</tr>
<tr>
<td>2.4.3.3</td>
<td>Soil samples</td>
</tr>
<tr>
<td>2.4.3.4</td>
<td>Herbage samples</td>
</tr>
<tr>
<td>2.5</td>
<td>PHYSICAL AND CHEMICAL ANALYSES</td>
</tr>
<tr>
<td>2.5.1</td>
<td>Water content measurements</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Preparation of chemical analyses</td>
</tr>
<tr>
<td>2.5.2.1</td>
<td>Soil extraction</td>
</tr>
<tr>
<td>2.5.2.2</td>
<td>Herbage extraction</td>
</tr>
<tr>
<td>2.5.3</td>
<td>Chemical analyses</td>
</tr>
<tr>
<td>2.5.3.1</td>
<td>Nitrate</td>
</tr>
<tr>
<td>2.5.3.2</td>
<td>Chloride</td>
</tr>
<tr>
<td>2.5.3.3</td>
<td>Bromide</td>
</tr>
<tr>
<td>2.5.3.4</td>
<td>Tritium</td>
</tr>
<tr>
<td>2.5.4</td>
<td>Expression of results</td>
</tr>
<tr>
<td>2.5.4.1</td>
<td>Soil solute and drainage concentrations</td>
</tr>
<tr>
<td>2.5.4.2</td>
<td>Data transformation</td>
</tr>
</tbody>
</table>
CHAPTER 3. RESULTS AND DISCUSSION OF LABORATORY CORE EXPERIMENTS

3.1. INTRODUCTION ................................................................. 42
3.2. LIQUID-FILLED PORE VOLUME ............................................. 42
3.3. MASS BALANCE OF WATER AND SOLUTES ................................. 43
   3.3.1. Water ................................................................. 43
   3.3.2. Nitrate ............................................................... 43
       3.3.2.1. Experiment 1: no pretreatment (cores A and B) . 44
       3.3.2.2. Experiment 3: with field pretreatment (cores E and F) 44
   3.3.3. Chloride ............................................................ 45
       3.3.3.1. Experiment 1: no pretreatment (cores A and B) . 45
       3.3.3.2. Experiment 3: with field pretreatment (cores E and F) 45
3.4. DYE APPLICATION ............................................................. 46
3.5. SOIL AND LEACHING DATA .................................................. 49
   3.5.1. Experiment 1: No leaching pretreatment .......................... 49
   3.5.2. Experiment 2: Laboratory preleaching ............................... 55
   3.5.3. Experiment 3: Pretreatment in the field ............................ 55
       3.5.3.1. First phase of the experiment ............................... 58
       3.5.3.2. Second phase of the experiment .............................. 62
3.6. CONCLUSIONS .................................................................. 66

CHAPTER 4. MODELLING THE MOVEMENT OF NON-REACTION SoluteS THROUGH UNDISTURBED SOIL CORES

4.1. INTRODUCTION ................................................................. 67
4.2. THEORY ........................................................................ 67
4.3. ESTIMATION OF MODEL PARAMETERS ..................................... 70
4.4. RESULTS AND DISCUSSION ............................................... 70
   4.4.1. Experiment 1. .......................................................... 70
       4.4.1.1. Using tritium BTC to characterize solute pdf ........ 70
       4.4.1.2. Modelling resident chloride and nitrate concentrations 70
   4.4.2. Experiment 2. .......................................................... 74
       4.4.2.1. Using bromide BTC to characterize solute pdf ........ 74
       4.4.2.2. Modelling the leaching of resident tritium ............. 76
4.4.3. Experiment 3. ......................................................... 78
  4.4.3.1. Using tritium and chloride BTCs to characterize solute
            pdfs ......................................................... 78
  4.4.3.2. Modelling the leaching of resident chloride and nitrate .... 78
  4.4.3.3. Modelling the leaching of resident tritium ................. 81
4.4.4. Estimation of model parameters .................................. 83
4.4.5. Estimation of the solute transport volume ...................... 85
4.5. CONCLUSIONS ......................................................... 85

CHAPTER 5.  SOIL, HERBAGE AND METEOROLOGICAL
             MEASUREMENTS FOR THE FIELD EXPERIMENT

5.1.   INTRODUCTION ..................................................... 88
5.2.   RAINFALL AND POTENTIAL EVAPOTRANSPIRATION DATA ......... 88
5.3.   SOIL MOISTURE DATA ............................................. 91
5.4.   SOLUTE CONCENTRATIONS IN SOIL ............................... 91
  5.4.1. Bromide ...................................................... 91
  5.4.2. Chloride ..................................................... 97
  5.4.3. Nitrate-N .................................................... 101
  5.4.4. Ammonium-N ................................................ 105
5.5.   EFFECTS OF SHEEP GRAZING .................................... 105
  5.5.1. Time effects ................................................ 105
  5.5.2. Depth effects ............................................... 108
5.6.   SUCTION CUP SAMPLING ......................................... 108
  5.6.1. Bromide ..................................................... 110
  5.6.2. Chloride ................................................... 110
  5.6.3. Nitrate-N .................................................. 110
5.7.   COMPARISON OF SOLUTE CONCENTRATIONS IN SOIL SOLUTION 113
5.8.   HERBAGE PRODUCTION .......................................... 116
5.9.   PLANT UPTAKE .................................................. 117
  5.9.1. Bromide .................................................... 117
  5.9.2. Chloride ................................................... 117
  5.9.3. Nitrogen ................................................... 120
5.10.  CONCLUSIONS ..................................................... 120
CHAPTER 6. LEACHING RESULTS AND MASS BALANCES FOR FIELD EXPERIMENTS

6.1. INTRODUCTION .......................................................... 122
6.2. DRAINAGE AND LEACHING RESULTS .................................. 122
   6.2.1. Bromide ......................................................... 123
   6.2.2. Chloride ......................................................... 125
       6.2.2.1. 1989 Spring ............................................. 125
       6.2.2.2. 1990 Drainage season ................................ 125
       6.2.2.3. 1991 Drainage season ................................. 128
   6.2.3. Nitrate ......................................................... 130
       6.2.3.1. 1989 Spring ............................................. 130
       6.2.3.2. 1990 Drainage season ................................ 130
       6.2.3.3. 1991 Drainage season ................................ 134
6.3. DRAINFLOW RATE AND SOLUTE CONCENTRATIONS ................. 136
   6.3.1. Effects of drainage flow rate on solute concentrations in the drainage 136
       6.3.1.1. Applied solutes ........................................ 136
       6.3.1.2. Resident solutes ...................................... 139
6.4. COMPARISON OF SOLUTE CONCENTRATIONS IN DRAINAGE AND SOIL SOLUTION ......................................................... 139
6.5. MASS BALANCE OF SOLUTES .......................................... 143
   6.5.1. Bromide ......................................................... 143
   6.5.2. Chloride and nitrogen ...................................... 143
6.6. CONCLUSIONS .......................................................... 145

CHAPTER 7. MODELLING LEACHING OF NON-REACTIVE SOLUTES UNDER FIELD CONDITIONS

7.1. INTRODUCTION .......................................................... 147
7.2. THEORY ................................................................. 148
7.3. BOUNDARY AND INITIAL CONDITIONS ............................... 150
   7.3.1. Source-sink term ............................................ 151
       7.3.1.1. Rainfall input ......................................... 151
       7.3.1.2. Herbage uptake ....................................... 151
       7.3.1.3. $C_s$ for bromide and chloride .................... 151
7.4. RESULTS AND DISCUSSION ........................................... 151
   7.4.1. Evaluating $f(I)$ ............................................. 151
   7.4.2. The stationarity of $f(I)$ .................................. 160
7.5. FRACTIONAL SOLUTE TRANSPORT VOLUME ......................... 163
7.6. CONCLUSIONS .......................................................... 163
REFERENCES ................................................................. 189

APPENDICES
Appendix 1 ................................................................. 205
Appendix 2 ................................................................. 207
Appendix 3 ................................................................. 209
Appendix 4 ................................................................. 210
Appendix 5 ................................................................. 212
Appendix 6 ................................................................. 214
Appendix 7 ................................................................. 216
## LIST OF TABLES

### CHAPTER 2

| Table 2.1 | Dates of soil, suction-cup and herbage data collection. Also included is grazing duration and stocking rate | 37 |

### CHAPTER 3

| Table 3.1 | Volumetric water content before and during each experiment and liquid filled pore volume for each experiment | 42 |

### CHAPTER 4

| Table 4.1 | Model parameters for step-change input solutes | 84 |
| Table 4.2 | Model parameters for pulse input solutes | 84 |
| Table 4.3 | Estimation of the fractional transport volume for step-change input solutes | 86 |
| Table 4.4 | Estimation of the fractional transport volume for pulse input solutes | 86 |

### CHAPTER 5

| Table 5.1 | Mean concentration of mineral N and chloride for all samples and concentration of solutes for site 9 in different layers on 28 May 1990 | 109 |
| Table 5.2 | Cumulative herbage production during the 1990 drainage season (kg dry matter/ha) | 116 |

### CHAPTER 6

| Table 6.1 | Average solute concentrations in the drainage at some events of the 1990 drainage season for both paddocks (standard errors are given in the parenthesis) | 142 |
Table 6.2  Predicted and measured leaching losses of solutes during the 1990 drainage season. Prediction was made using average values of solute concentration of upper and lower depths separately ........................................ 142

Table 6.3  Predicted and measured leaching losses of solutes during the 1990 drainage season. Prediction was made using average values of solute concentration of upper and lower depths . 142

Table 6.4  Bromide recovery (kg Br/ha) for various periods of the 1990 drainage season for paddock A ............... 144

Table 6.5  Chloride and nitrogen mass balance for 1990 (between 29 May and 10 October 1990). The units are kg/ha .......... 144

CHAPTER 7

Table 7.1  Estimation of the fractional transport volume .............. 163

CHAPTER 8

Table 8.1  Measured and predicted leaching losses of nitrate (kg N/ha) for the 1990 and 1991 drainage seasons ............... 179
LIST OF FIGURES

CHAPTER 2

Fig. 2.1. A schematic diagram of the experimental site. Square and rectangular boxes in paddocks C and D are the sites of soil taken for laboratory experiment. Dotted and solid lines represent the moles and pipes respectively .............................................. 23

Fig. 2.2. A schematic diagram of the sampling site for the first experiment (a) and for the third experiment with field pretreatment (b) showing extraction locations for the large and small soil cores ............ 26

CHAPTER 3

Fig. 3.1. The estimated distribution of nitrate (a and b) and chloride (c and d) in the soil solution for cores A and B before leaching on 5 July 1989 50

Fig. 3.2. The volume outflow rates (a and b) and the breakthrough curves of tritium (c and d) for cores A and B ............................................. 51

Fig. 3.3. The concentration of indigenous nitrate (a and b) and chloride (c and d) in the effluent from cores A and B ............................................. 53

Fig. 3.4. The distribution of nitrate (a and b) and tritium (c and d) in the soil solution of cores A and B, respectively, after leaching .......... 54

Fig. 3.5. The volume outflow rates (a and b) and the breakthrough of bromide (c and d) for cores C and D after the pulse application of 500 g Br m$^3$ in 30 mm of input solution .............................................. 56

Fig. 3.6. The breakthrough curve of the tritium which had been applied during the pretreatment (a and b), and the distribution of tritium in the soil after leaching (c and d) .............................................. 57

Fig. 3.7. The distribution of nitrate (a and b) and chloride (c and d) in the soil solution after preleaching but before phase one of the leaching experiment, in the soil surrounding large cores E and F ........ 59
Fig. 3.8. The volume outflow rates (a and b) and the breakthrough curves of the applied tritium (c and d) for cores E and F for the first phase of the experiment ........................................... 60

Fig. 3.9. The concentration of nitrate (a and b) and chloride (c and d) in the effluent during the first phase of the experiment for cores E and F 61

Fig. 3.10. The volume outflow rates (a and b) and breakthrough of nitrate pulse (c and d) for the second phase of the experiment for cores E and F 63

Fig. 3.11. The breakthrough curve of applied chloride (a and b) and resident tritium (c and d) in the second phase of the experiment for cores E and F ........................................... 64

Fig. 3.12. The distribution of nitrate (a and b) and chloride (c and d) in the soil solution after the leaching experiment ........................................... 65

CHAPTER 4

Fig. 4.1. Measured (■) and fitted (---) relative concentration of tritium in the effluent for cores A and B ........................................... 71

Fig. 4.2. Measured and predicted concentrations of resident chloride (a and b) and nitrate (c and d); measured (■), predicted using the estimated soil solution concentration (--), and predicted assuming $C_i$ as the concentration in first effluent sample (--->) for cores A and B .... 72

Fig. 4.3. Measured (■) and fitted (---) bromide concentrations (a and b) for cores C and D. Also shown are the measured (■) and resolution of the components of bromide pdf (---) for core C (c and d) .... 75

Fig. 4.4. Details for (a) and (b) are given in the text. (c) and (d) show the predicted using parameters derived from the bromide pdf (---) and measured (■) relative concentrations of resident tritium in the drainage from cores C and D ........................................... 77

Fig. 4.5. Measured (■) and fitted (---) relative concentration of tritium (a) and (b) in the first part of the experiment; and chloride (c) and (d) in the second part of the experiment for cores E and F ................. 79
Fig. 4.6. Measured and predicted concentrations of chloride (a) and (b) and nitrate (c) and (d) for cores E and F; measured (■), predicted with the estimated soil solution concentration (——), predicted assuming C, from the concentration in first effluent (----).......................... 80

Fig. 4.7. Measured (■) and predicted (——) concentration of tritium (a) and (b) and nitrate (c) and (d) in the effluent during the second part of the experiment. The prediction was carried out with parameters derived from a step input of chloride during the second part of the experiment82

CHAPTER 5

Fig. 5.1. Monthly rainfall, together with the long term average, for 1990 and 1991 ........................................ 89

Fig. 5.2. Penman longterm evapotranspiration data (NZ Meteorological Service)90

Fig. 5.3. The mean volumetric water content profiles for the first three soil samplings in 1990 for paddocks A (●) and B (○) ................. 92

Fig. 5.4. The mean volumetric water content profiles for the last three soil samplings in 1990 for paddocks A (●) and B (○) ...................... 93

Fig. 5.5. The mean volumetric water content profiles for three soil samplings in 1991 for paddocks A (●) and B (○) .......................... 94

Fig. 5.6. The distribution of bromide in the soil profile of paddock A in 1990 for the first three soil samplings after Br application (means and standard errors are shown) .................................................. 95

Fig. 5.7. The distribution of bromide in the soil profile of paddock A in 1990 for the last soil sampling after Br application (means and standard errors are shown) ............................. 96

Fig. 5.8. The distribution of chloride in the soil profiles of paddocks A (●) and B (○) in 1990 for the first three soil samplings (means and standard errors are shown) ............................. 98
Fig. 5.9. The distribution of chloride in the soil profiles of paddocks A (●) and B (○) in 1990 for the last three soil samplings (means and standard errors are shown) .............................................. 99

Fig. 5.10. The distribution of chloride in the soil profiles of paddocks A (●) and B (○) in 1991 for all soil samplings (means and standard errors are shown) .................................................. 100

Fig. 5.11. The distribution of nitrate in the soil profiles of paddocks A (●) and B (○) in 1990 for the first three soil samplings (means and standard errors are shown) ........................................... 102

Fig. 5.12. The distribution of nitrate in the soil profiles of paddocks A (●) and B (○) in 1990 for the last three soil samplings (means and standard errors are shown) ........................................... 103

Fig. 5.13. The distribution of nitrate in the soil profiles of paddocks A (●) and B (○) in 1991 for all soil samplings (means and standard errors are shown) .................................................. 104

Fig. 5.14. The distribution of ammonium in the soil profiles of paddocks A (●) and B (○) in 1990 for the first three soil samplings (means and standard errors are shown) ........................................... 106

Fig. 5.15. The distribution of ammonium in the soil profiles of paddocks A (●) and B (○) in 1990 for the last three soil samplings (means and standard errors are shown) ........................................... 107

Fig. 5.16. Bromide and chloride concentrations in suction cup samples at 200 mm depth (●) and 450 mm depth (○) of paddock A and paddock B, respectively (means and standard errors are shown) ........................................... 111

Fig. 5.17. Nitrate concentrations in suction cup samples at 200 mm depth (●) and 450 mm depth (○) of paddocks A and B (means and standard deviations are shown) ........................................... 112

Fig. 5.18. Relationship between suction cup solution concentration and soil solution concentration for applied bromide (paddock A) and indigenous chloride (paddock B) at 200 mm depth (●) and 450 mm depth (○) ........................................... 114
CHAPTER 7

Fig. 7.1. Bromide (a) and chloride (b) uptake by pasture as a function of drainage for paddocks A (●) and B (○) .................. 152

Fig. 7.2. Measured (■) and fitted (——) bromide concentrations in the drainage for the 1990 drainage season with (a) lognormal and (b) exponential pdfs .............................................. 154

Fig. 7.3. Measured (■) and fitted (——) chloride concentrations in the drainage of paddock A for the 1990 drainage season with (a) lognormal and (b) exponential pdfs .............................................. 155

Fig. 7.4. Measured ( ■ ) and fitted (——) chloride concentrations in the drainage of paddock B for the 1990 drainage season with (a) lognormal and (b) exponential pdfs .............................................. 156

Fig. 7.5. Measured ( + and ◦ ) and fitted (——) chloride concentrations in the drainage of paddocks A and B (data pooled together) for the 1990 drainage season with (a) lognormal and (b) exponential pdfs ... 157

Fig. 7.6. Comparison of pdfs of bromide (---) and chloride (——) with (a) lognormal and (b) exponential .............................................. 158

Fig. 7.7. Measured ( ■ ) and predicted (——) chloride concentrations in the drainage from paddock A for 1991 using 1990 chloride model parameters with (a) lognormal and (b) exponential pdf .......................... 161

Fig. 7.8. Measured ( ■ ) and predicted (——) chloride concentrations in the drainage from paddock B for 1991 using 1990 chloride model parameters with (a) lognormal and (b) exponential pdf .......................... 162

CHAPTER 8

Fig. 8.1 Schematic diagram of travel pathways used in numerical solution of the Transfer Function Model .............................................. 168

Fig. 8.2. Nitrogen uptake as a function of drainage for the 1990 drainage season
Fig. 8.3. Measured (■) and predicted, using analytical (---) and numerical solutions (—), nitrate concentrations for paddock A for the 1990 drainage season. (a) assumes the plant N uptake is as nitrate and (b) assumes plant uptake is half as nitrate and half as ammonium ... 173

Fig. 8.4. Measured (■) and predicted, using analytical (---) and numerical solutions (—), nitrate concentrations for paddock B for the 1990 drainage season. (a) assumes the plant uptake is as nitrate and (b) assumes plant uptake is half as nitrate and half as ammonium ... 174

Fig. 8.5. Measured (■) and predicted, using analytical (---) and numerical (—) solutions, nitrate concentrations for paddocks A (a) and B (b) for the 1991 drainage season .................................................. 178
LIST OF PLATES

CHAPTER 2

| Plate 2.1 | Experimental set-up for the intact core leaching experiments | 30 |
| Plate 2.2 | Uniform distribution of dye indicating uniform application of tritiated water to the soil surface | 30 |
| Plate 2.3 | V-notch weir and a pipe draining in pit A | 34 |
| Plate 2.4 | Flow meter and plotter | 34 |

CHAPTER 3

| Plate 3.1 | Some root channels connected with earthworm channels | 47 |
| Plate 3.2 | Root channels | 47 |
| Plate 3.3 | Vertical view of dye movement | 48 |
| Plate 3.4 | Edge flow due to a stone which cut a groove during core collection | 48 |
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)

\( f(l) \) = 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\(^{-3}\))

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

\( C_{en} \) = 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)
\( I_m \) = 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**

\( \alpha \) = a rate coefficient (T\(^{-1}\))
\( \varepsilon \) = gas-filled porosity
\( \mu \) = mean of a distribution
\( \rho_b \) = bulk density (M L\(^{-3}\))
\( \rho_s \) = particle density (M L\(^{-3}\))
\( \theta \) = volumetric water content (L\(^3\) L\(^{-3}\))
\( \theta_f \) = volumetric moisture content of the soil at 'field capacity'
\( \theta_m \) = a mobile water content
\( \theta_{im} \) = an immobile water content
\( \theta_{st} \) = transport volume fraction
\( \Phi \) = a source (or sink) term for solute (M L\(^{-3}\) T\(^{-1}\))
\( \sigma^2 \) = variance of a distribution