The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

1867-36

College of Soil Physics

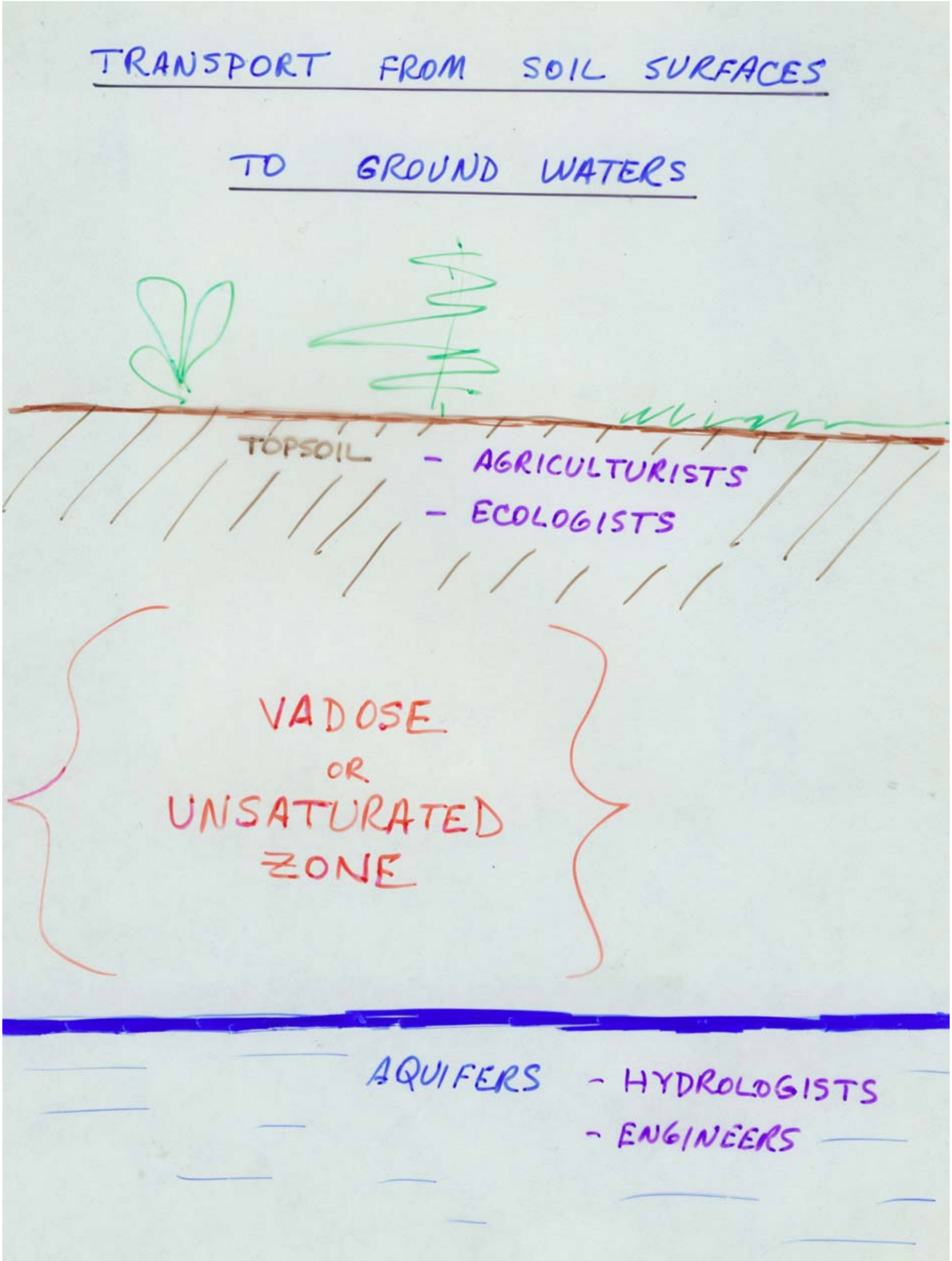
22 October - 9 November, 2007

Fundamentals of and analyzing solute transport in soils

Donald Nielsen

University of California
Davies
USA

Transport from soil to groundwater



MD Definition

FLUIDS MOVE AND DISPLACE OTHER FLUIDS WITHIN A GIVEN GEOMETRY

If the fluids do not mix or combine together

IMMISCIBLE DISPLACEMENT

air and water
air and oil
water and oil
aqueous and nonaqueous fluids

If the fluids are mixable and soluble within each other

MISCIBLE DISPLACEMENT

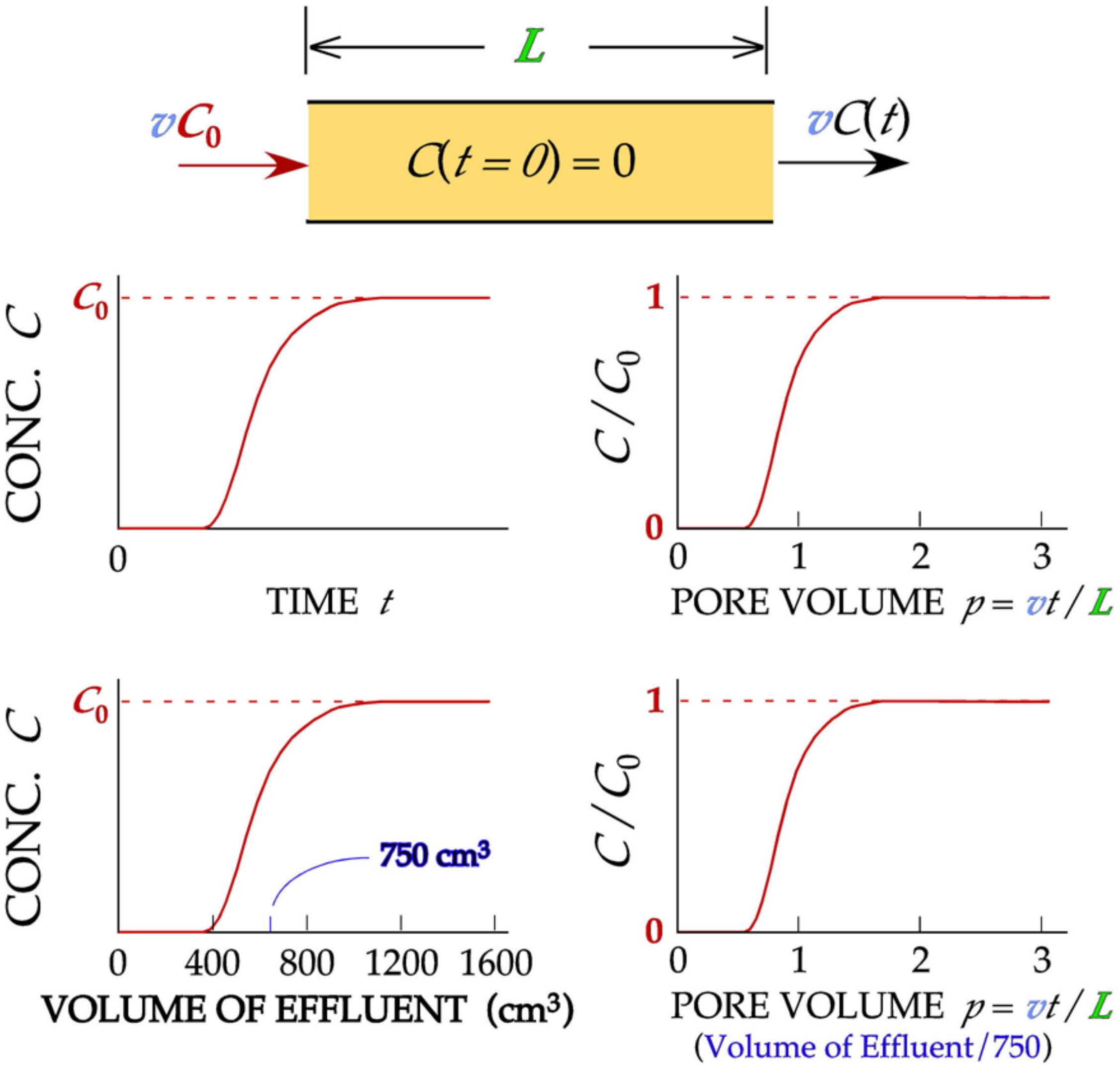
non-saline water and saline water
rain water and soil solution
alcohol and water
paint and turpentine
fresh air and smoke
gasoline and oil

BTC Definition

MISCIBLE DISPLACEMENT IN FIELD SOILS

- UNDERSTAND LEACHING PHENOMENA
- PREVENT SOIL SALINIZATION
- RETAIN FERTILIZERS FOR PLANT UPTAKE
- MANAGE WASTES, RADIOISOTOPES, ETC.
- PROTECT SURFACE & GROUND WATER QUALITY

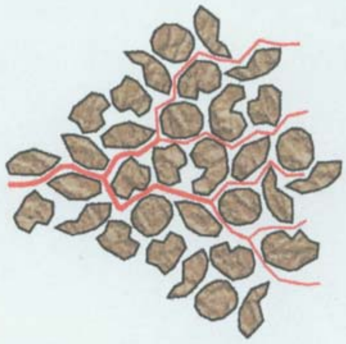
MISCIBLE DISPLACEMENT SOIL COLUMN EXPERIMENT



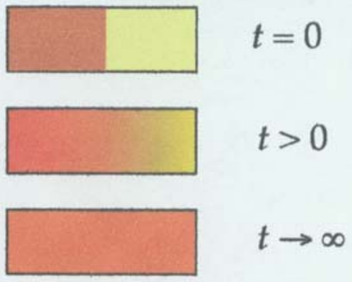
Interpreting BTC

INTERPRETING THE SHAPE OF A BREAKTHROUGH CURVE

DISPERSION CAUSED BY CONVECTION



DISPERSION CAUSED BY MOLECULAR DIFFUSION



CHEMICAL REACTIONS

PRECIPITATION
DISSOLUTION
HYDROLYSIS, ETC.

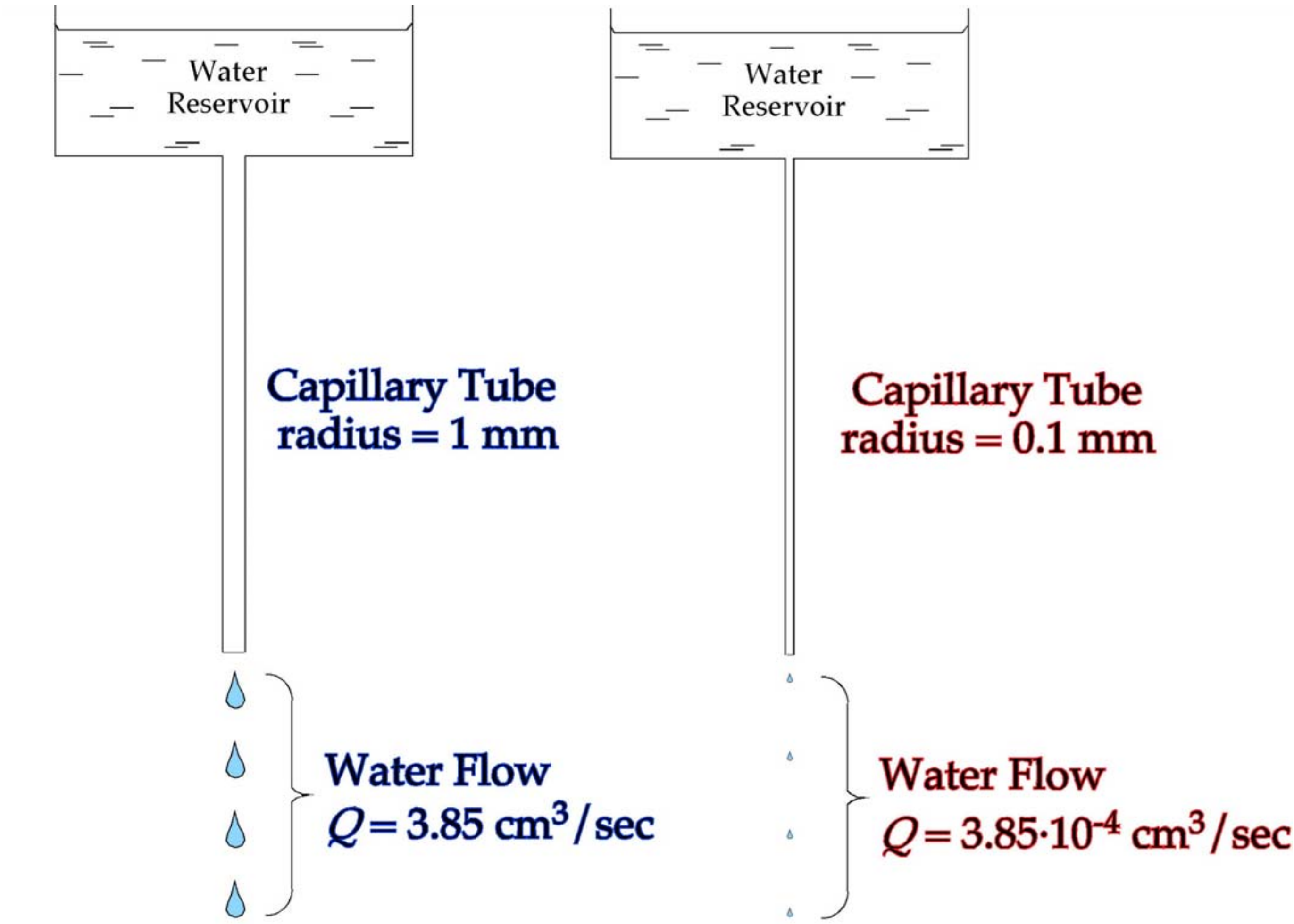
PHYSICAL REACTIONS

CATION AND ANION EXCHANGE
SWELLING & SHRINKING, ETC.

MICROBIOLOGICAL TRANSFORMATIONS

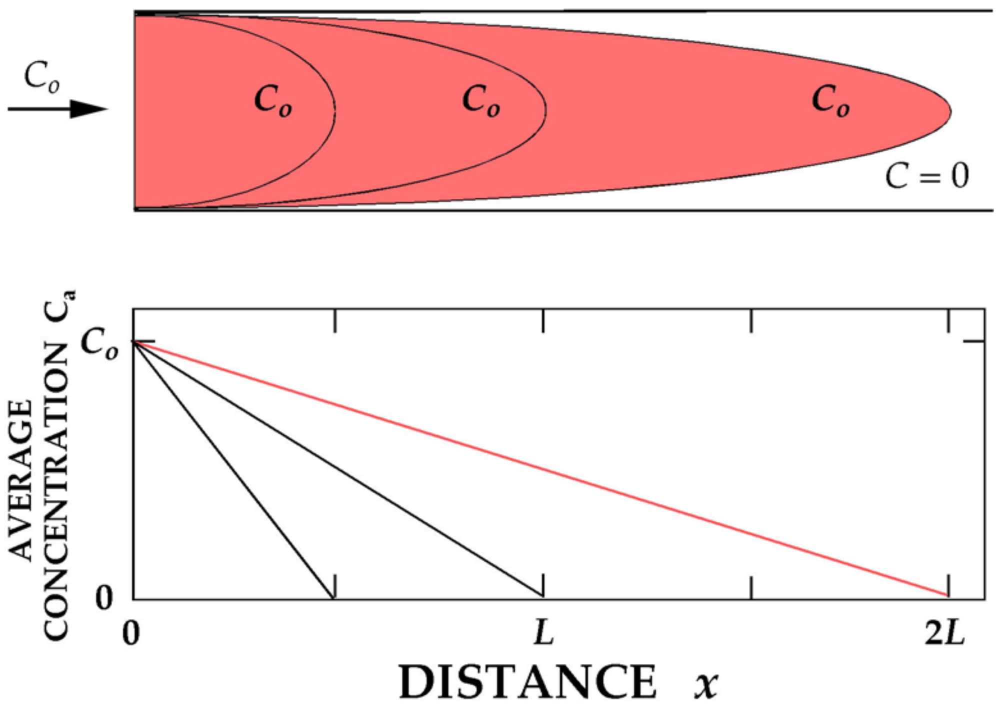
NITRIFICATION
DENITRIFUCATION, ETC.

Capillary tube flow

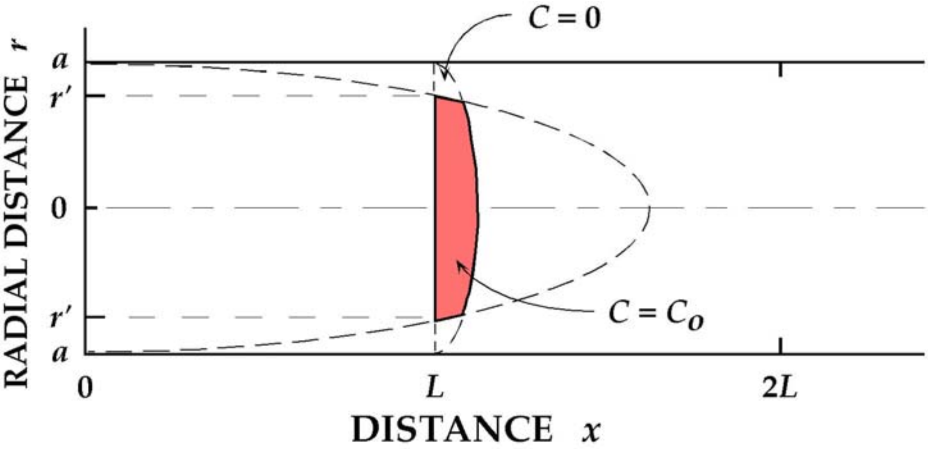


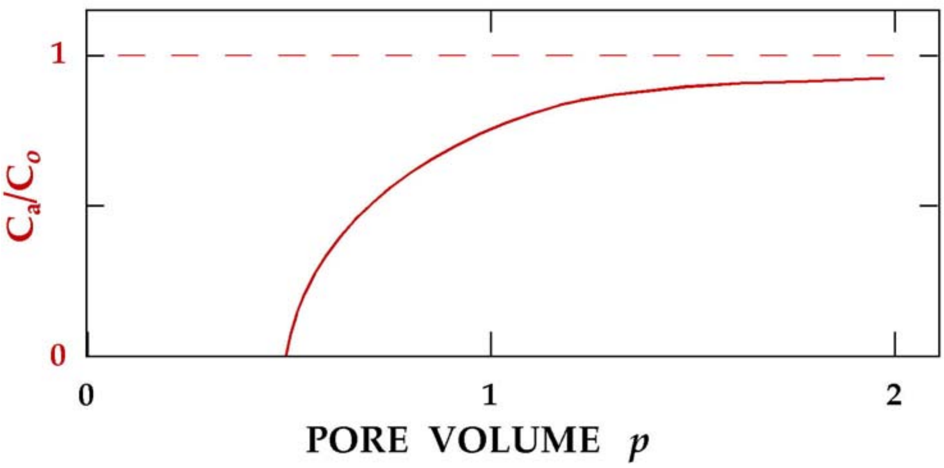
1 Capillary Tube = 10,000 Capillary Tubes

Parabolic distribution

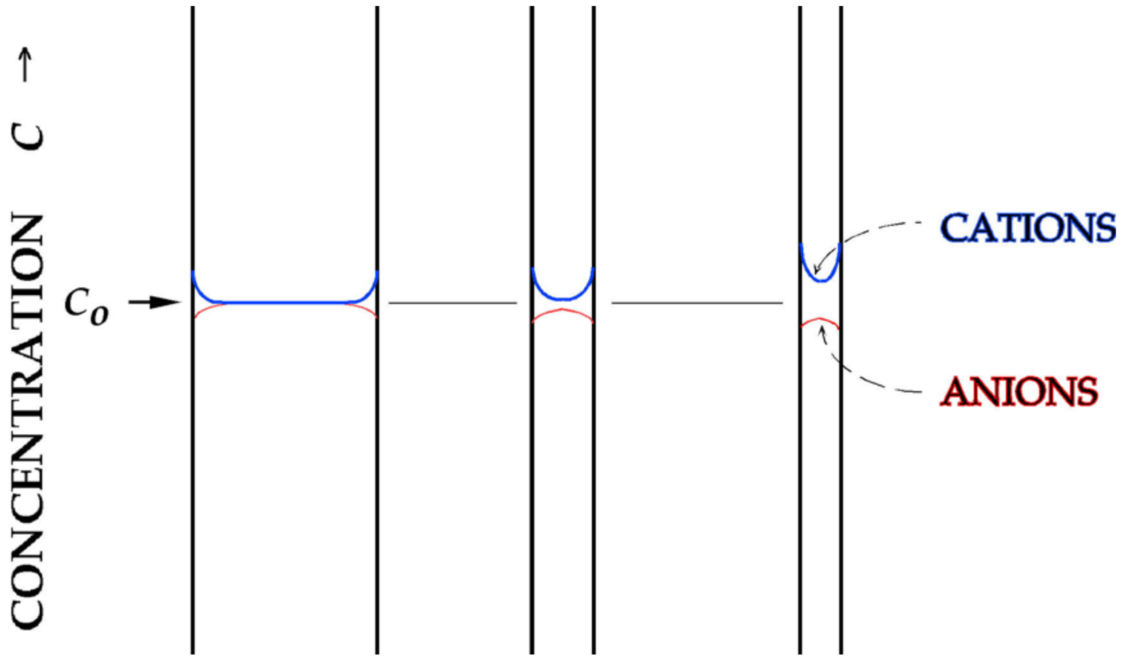


Calculating Concentration

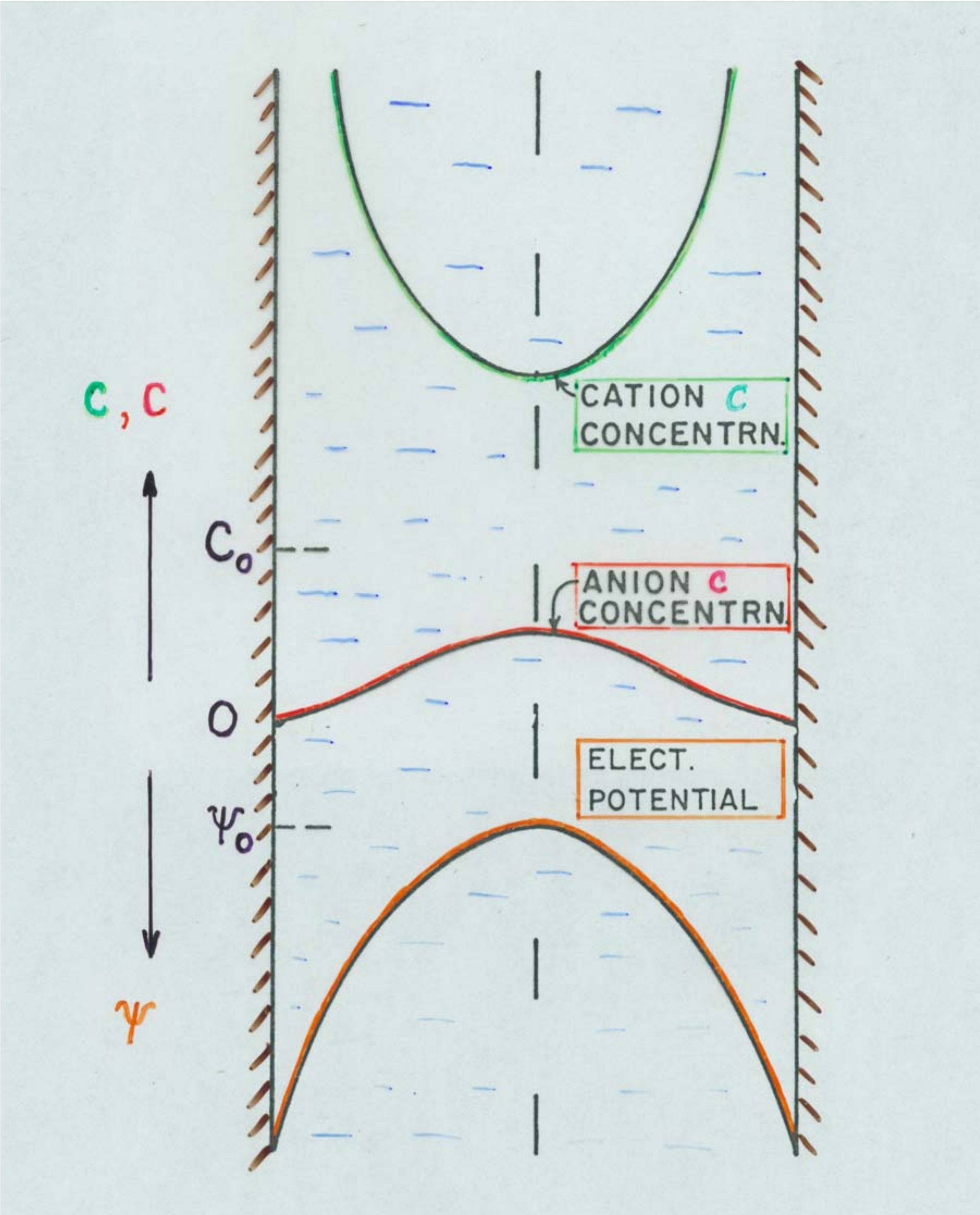




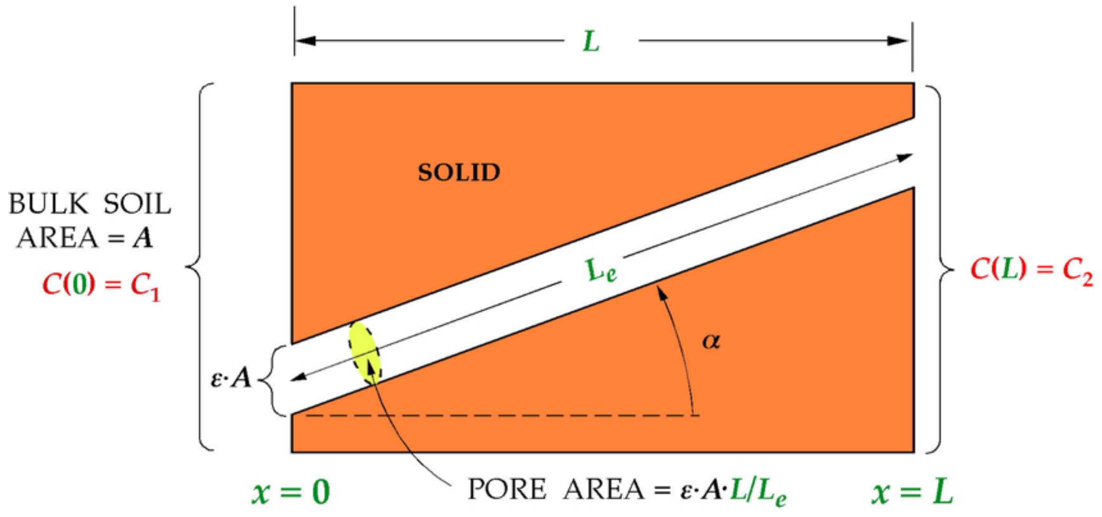
Cations&anions in capillary



Ions and pot.field in capillary



Tortuosity



FICK'S LAW OF MOLECULAR DIFFUSION

BULK SOIL

$$\left(\frac{Q}{At}\right)_{SOIL} = -D_{SOIL}\frac{C_2 - C_1}{L}$$

SOIL PORE

$$\left(\frac{Q}{\varepsilon A(L/L_e)t}\right)_{PORE} = -D_0\frac{C_2 - C_1}{L_e}$$

$$\left(\frac{Q}{At}\right)_{PORE} = -D_0\varepsilon(L/L_e)\frac{C_2 - C_1}{L_e}$$

EQUATING DIFFUSION IN BULK SOIL TO THAT IN SOIL PORE

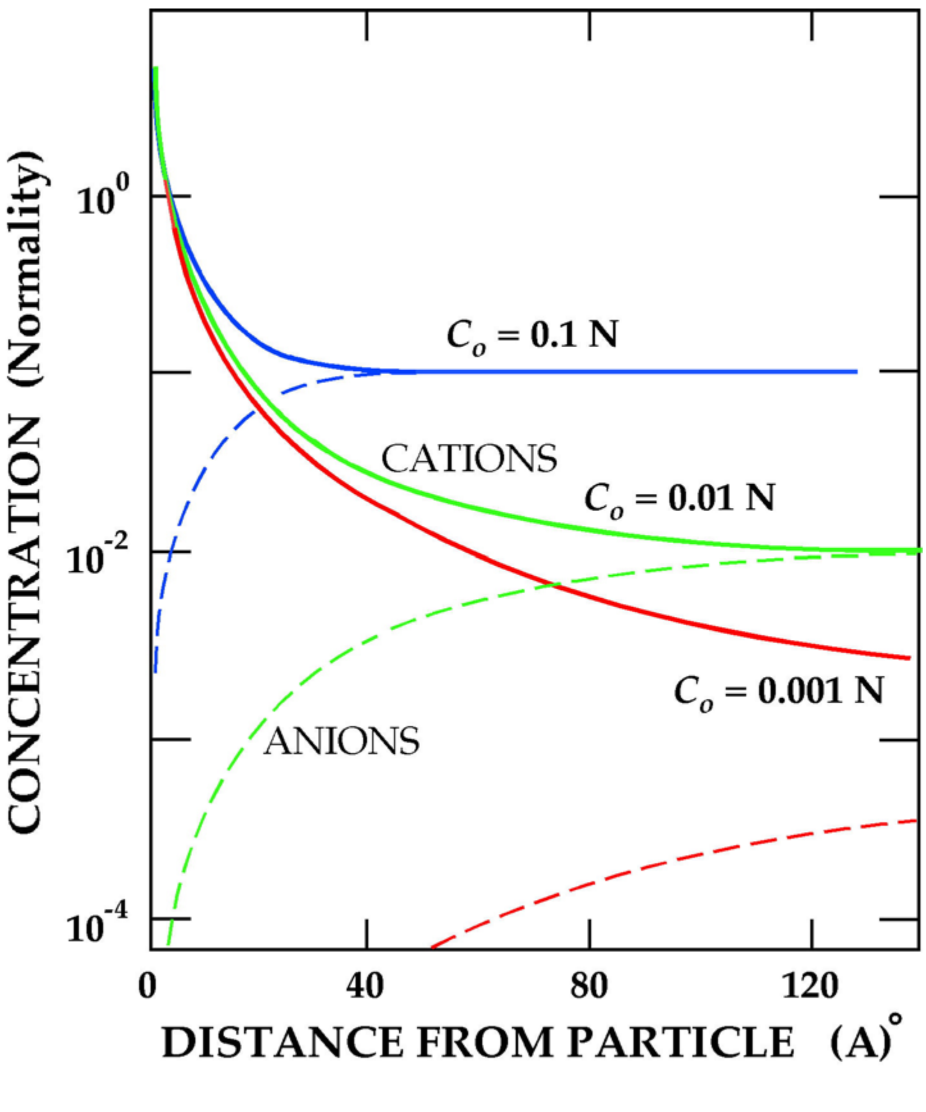
$$D_{SOIL}\frac{C_2 - C_1}{L} = D_0\varepsilon(L/L_e)\frac{C_2 - C_1}{L_e}$$

$$D_{SOIL} = D_0\varepsilon(L/L_e)^2 \quad \text{or} \quad D_{SOIL} = D_0\varepsilon^n$$

VALUES OF TORTUOSITY $(L/L_e)^2 = \cos^2\alpha$

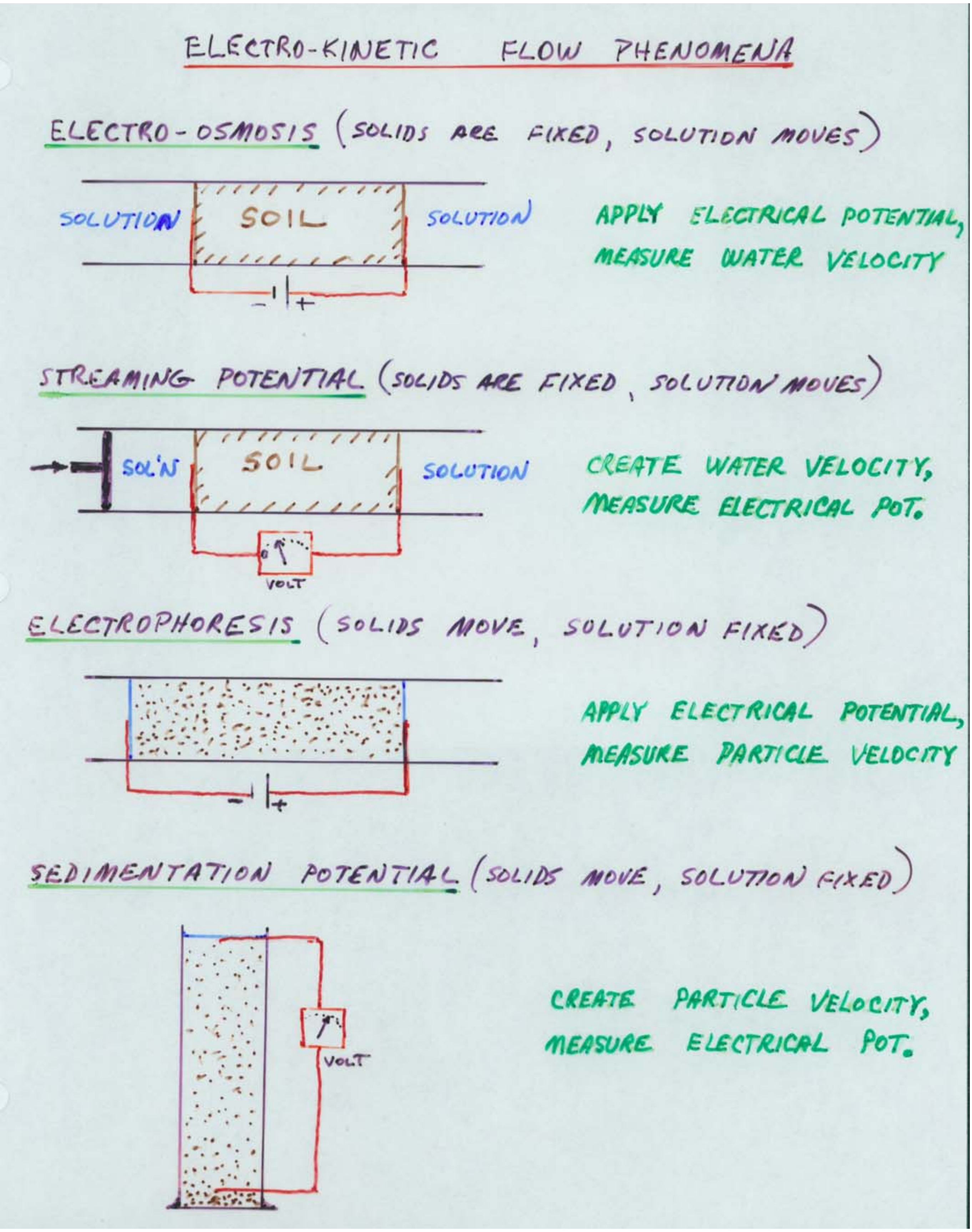
PENMAN	$(L/L_e)^2 = 0.66$	$\alpha \sim 36^o$
VAN BAVEL	$(L/L_e)^2 = 0.58$	$\alpha \sim 40^o$
MARSHALL	$n = 3/2$	$\alpha \sim 37^o$
MILLINGTON	$n = 4/3$	$\alpha \sim 31^o$

0.1,0.01, 0.001 N



CONCENTRATION (Normality)
10^0
10^{-2}
10^{-4}
C_o = 0.1 N
CATIONS
C_o = 0.01 N
C_o = 0.001 N
ANIONS
0
40
80
120
DISTANCE FROM PARTICLE (A)°

Electrokinetic processes



Chemico-physico interactions

CHEMICO-PHYSICO INTERACTIONS

pH → SOIL PARTICLE SURFACE CHARGE DENSITY

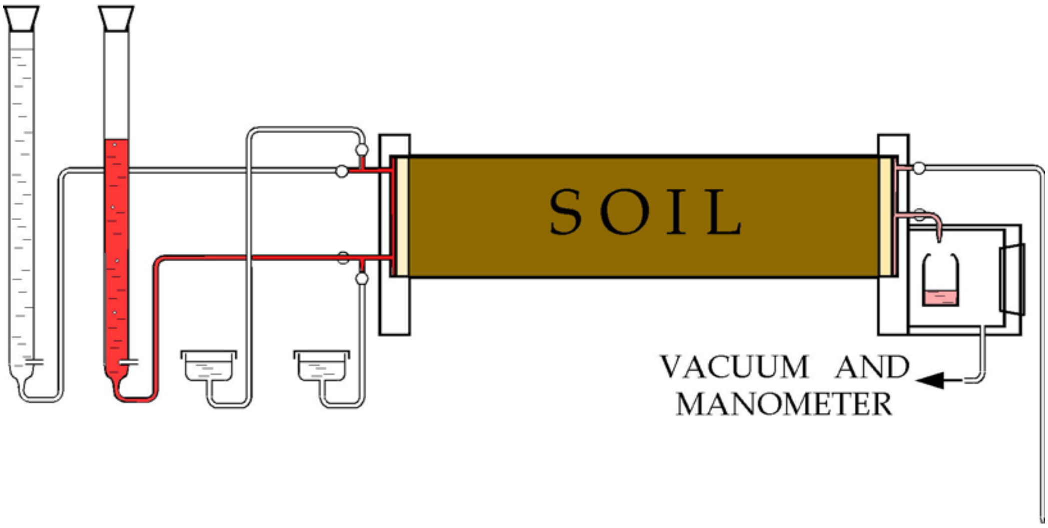
CHARGE DENSITY → ELECTRICAL FIELD

ELECTRICAL FIELD → ORIENTS CATIONS & ANIONS

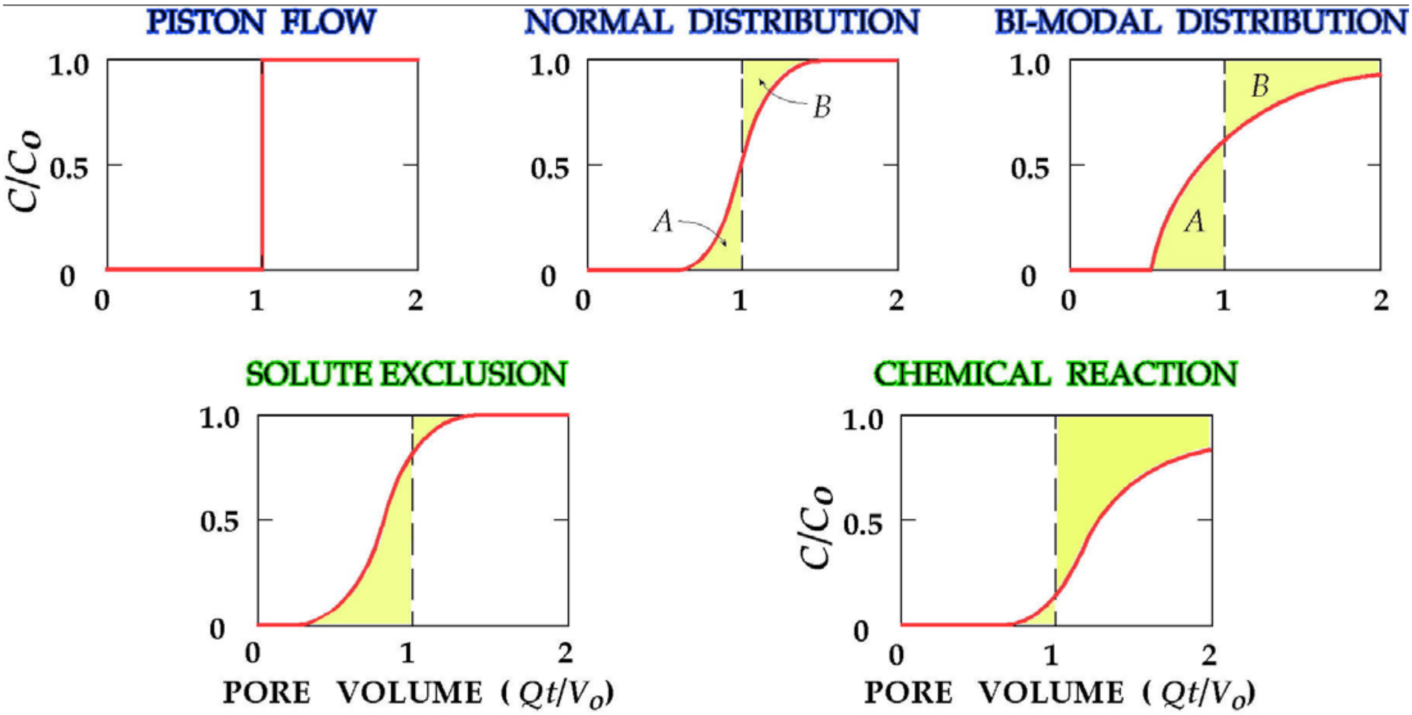
CATIONS & ANIONS → WATER MOLECULE CONFIGURATIONS

WATER CONFIGURATIONS → HYDRAULIC CONDUCTIVITY

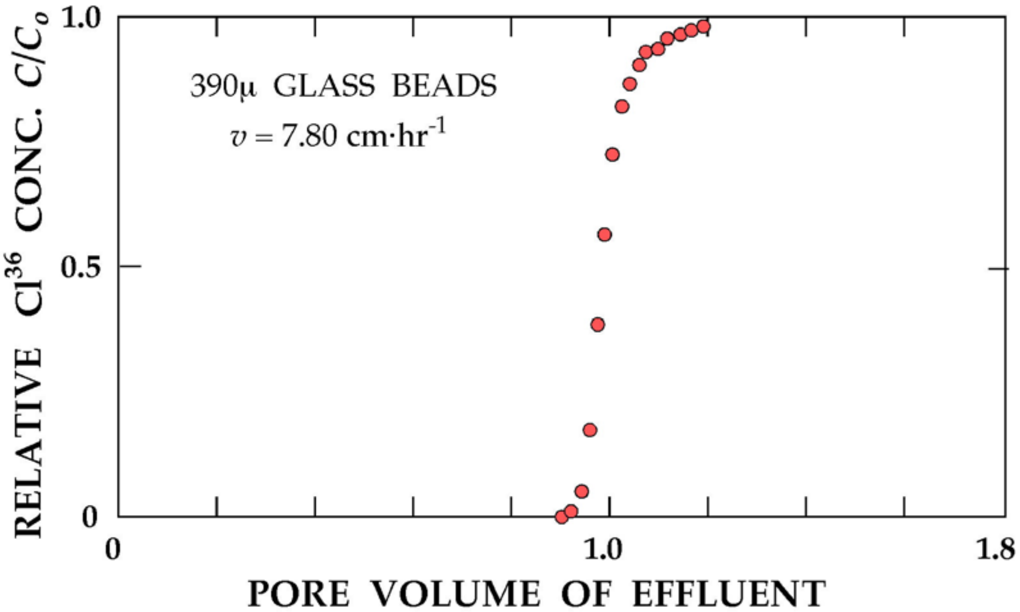
Lab apparatus



Five BTCs

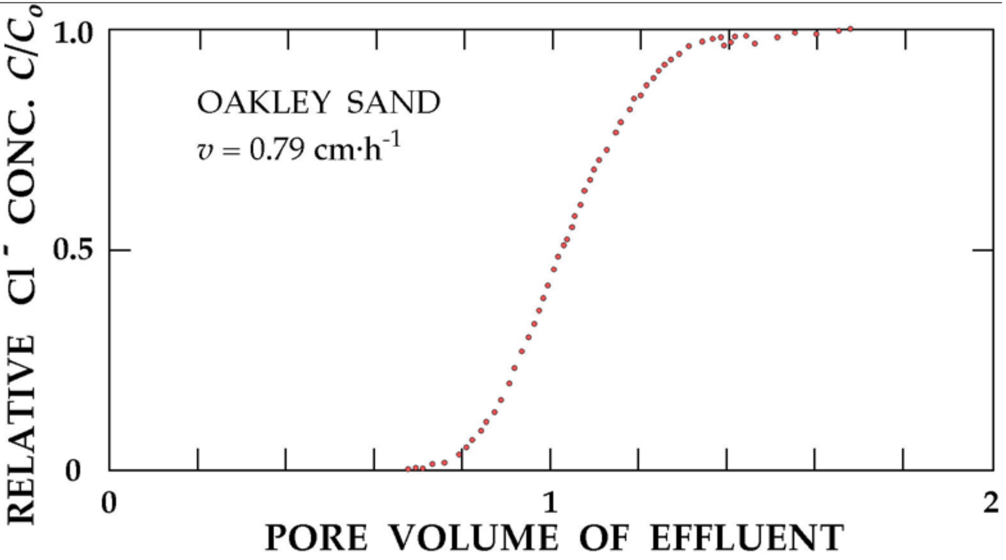

PISTON FLOW
NORMAL DISTRIBUTION
BI-MODAL DISTRIBUTION
SOLUTE EXCLUSION
CHEMICAL REACTION
C/Co
1.0
0.5
0
0
1
2
A
B
PORE VOLUME (Qt/Vo)

Piston BTC



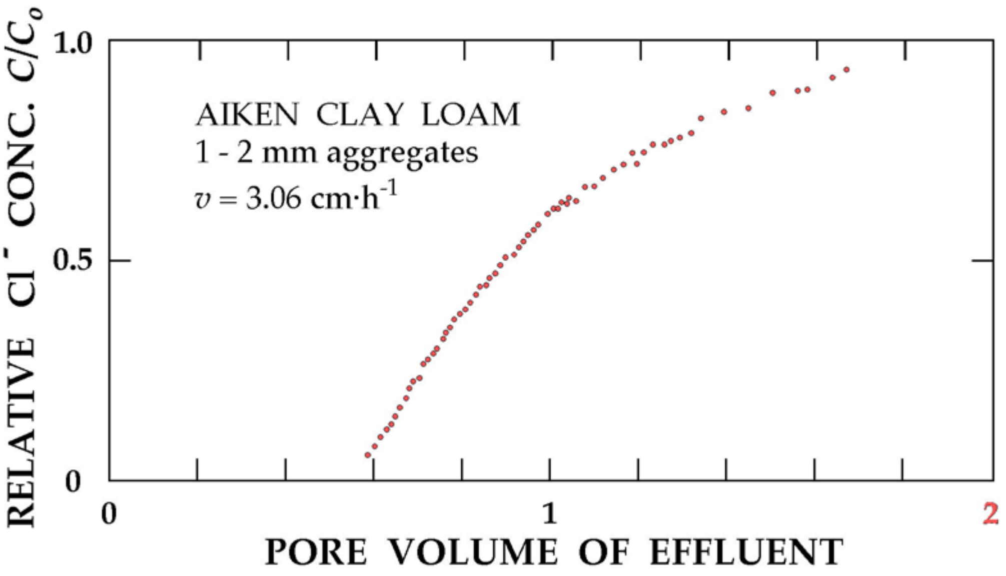
390μ GLASS BEADS
v = 7.80 cm·hr-1
RELATIVE Cl36 CONC. C/Co
1.0
0.5
0
0
1.0
1.8
PORE VOLUME OF EFFLUENT

BTC 2



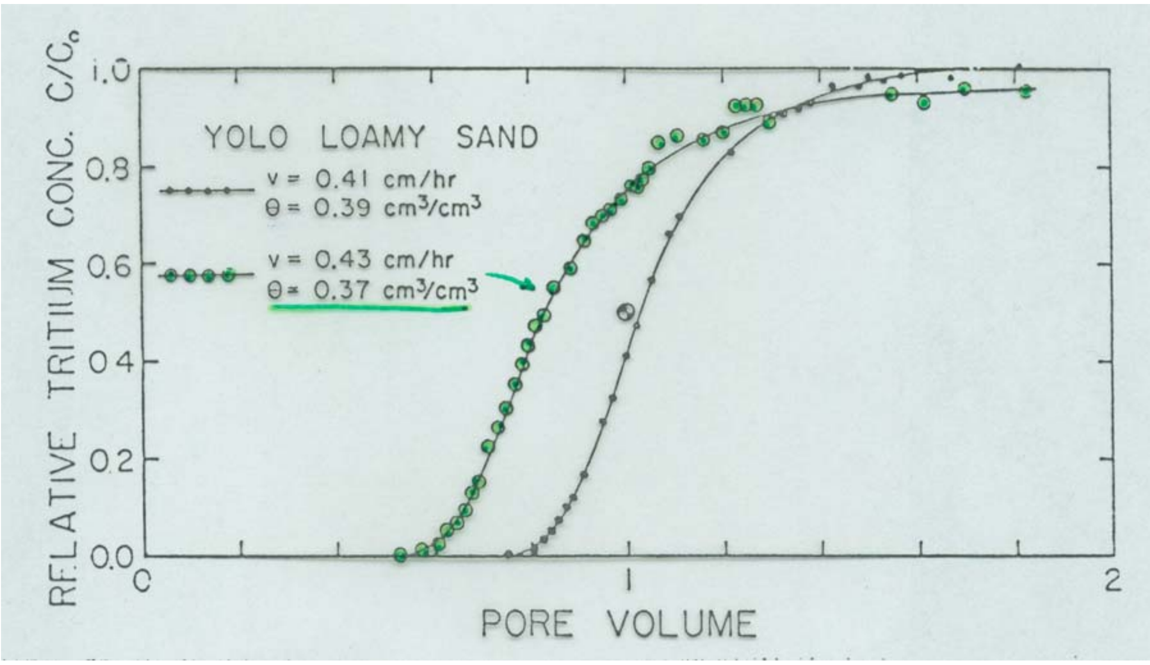
RELATIVE Cl⁻ CONC. C/Co
1.0
0.5
0
0
1
2
PORE VOLUME OF EFFLUENT
OAKLEY SAND
v = 0.79 cm·h-1

BTC 3

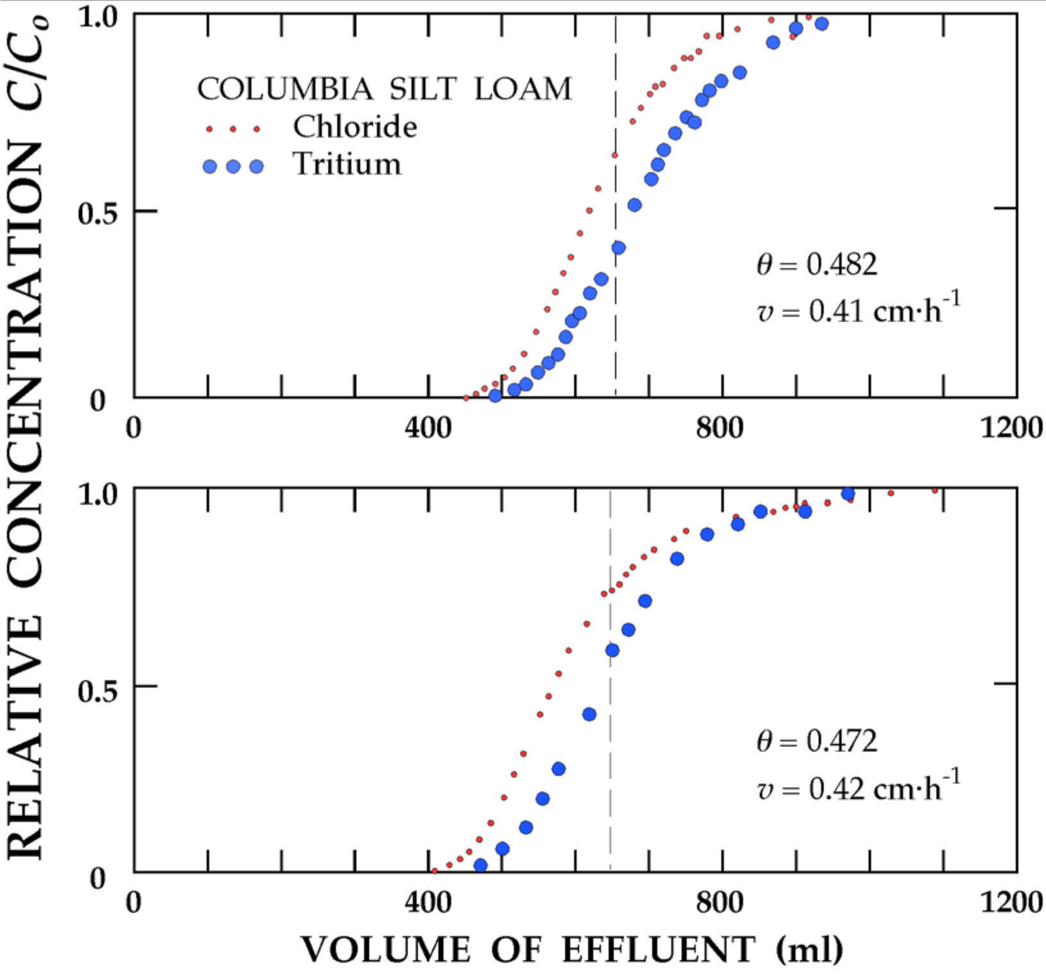


AIKEN CLAY LOAM
1 - 2 mm aggregates
v = 3.06 cm·h-1
RELATIVE Cl- CONC. C/Co
1.0
0.5
0
0
1
2
PORE VOLUME OF EFFLUENT

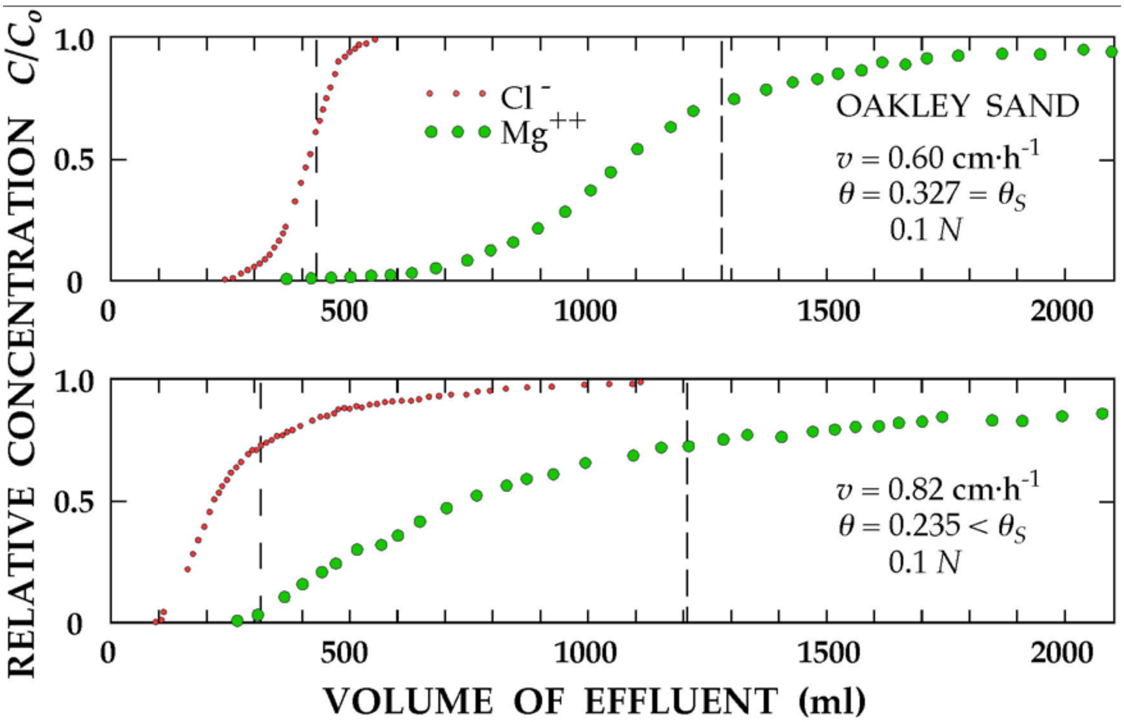
Small theta change 1



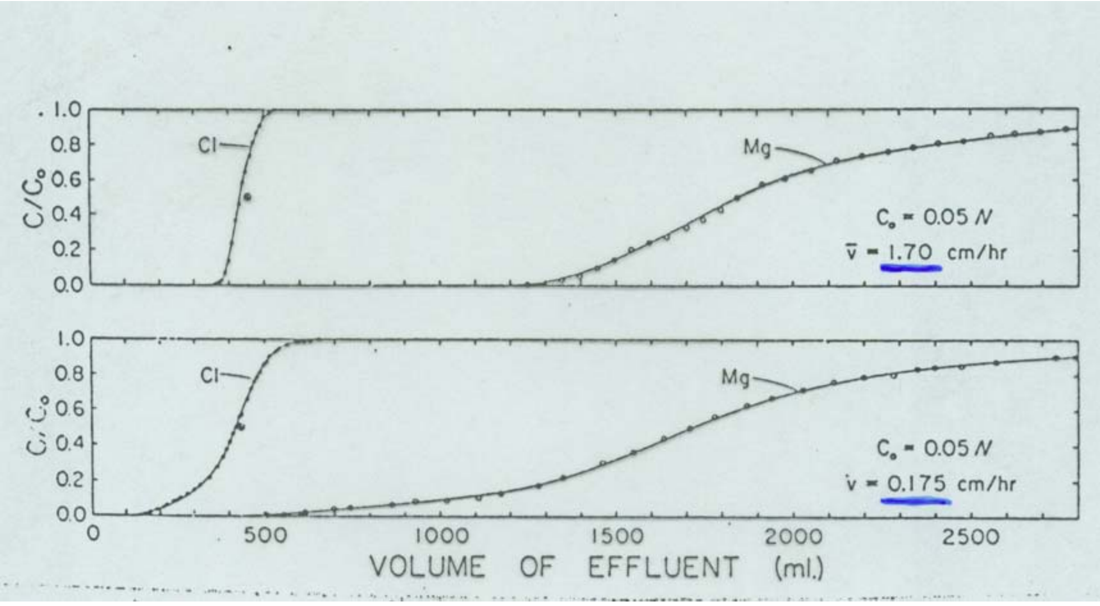
Small theta change 2



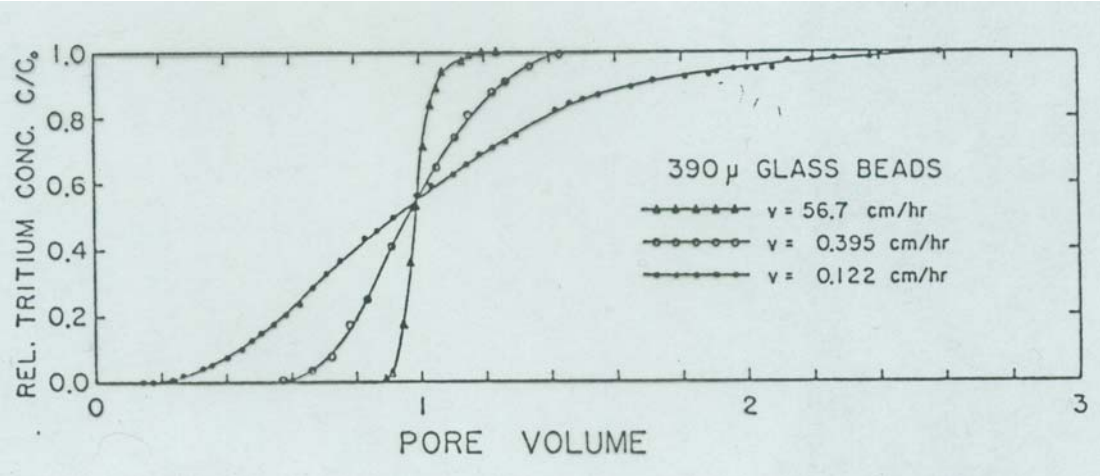
Exchange delta theta



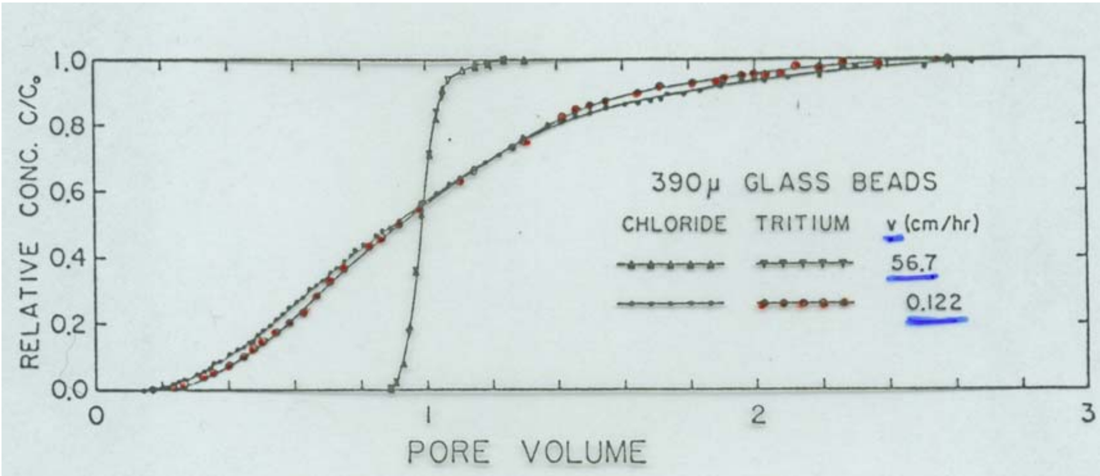
Exchange delta vel



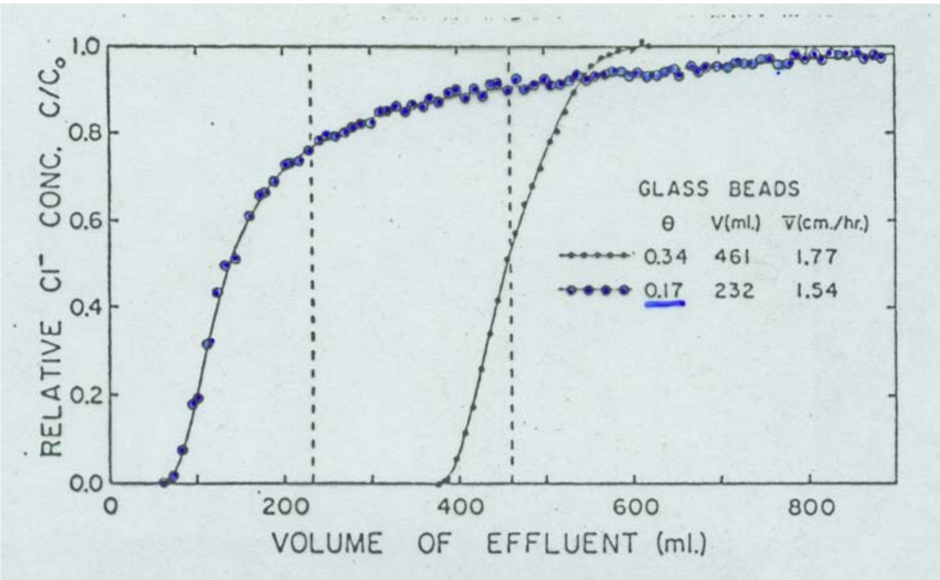
Tritium 3 velocities



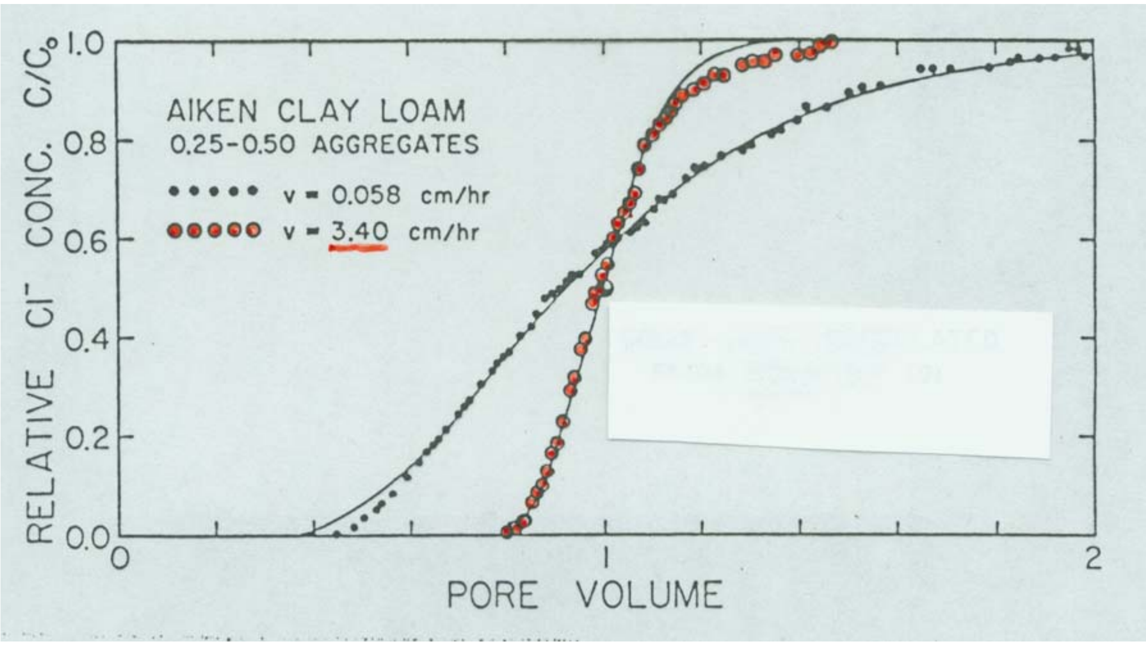
Cl & Tritium 2 velocities



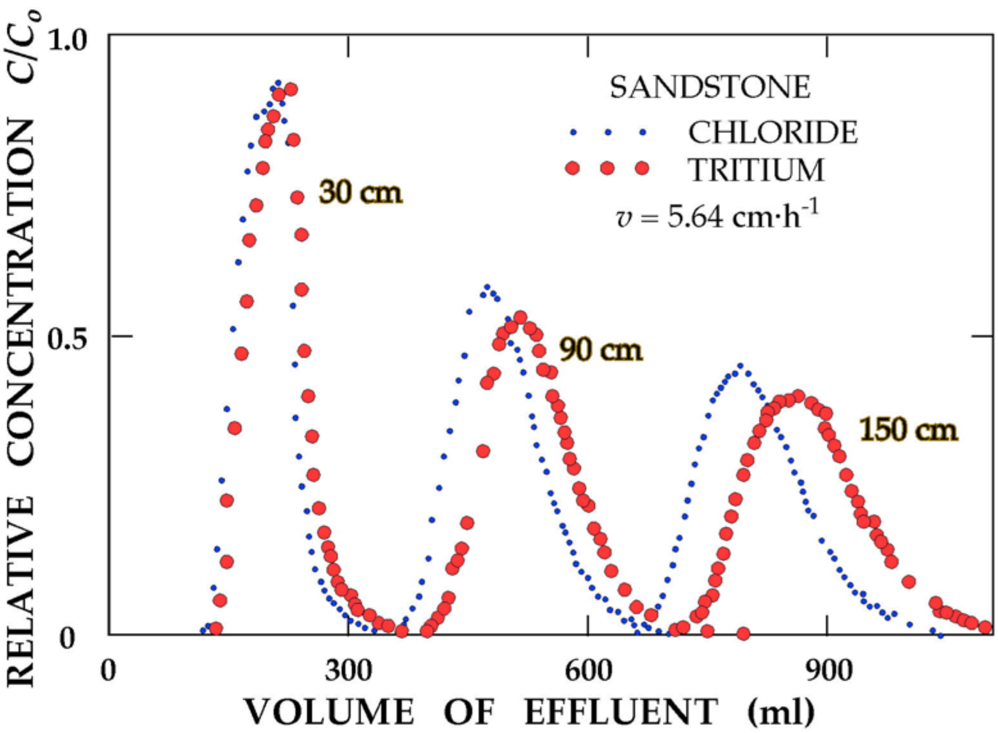
Sat & Unsat beads



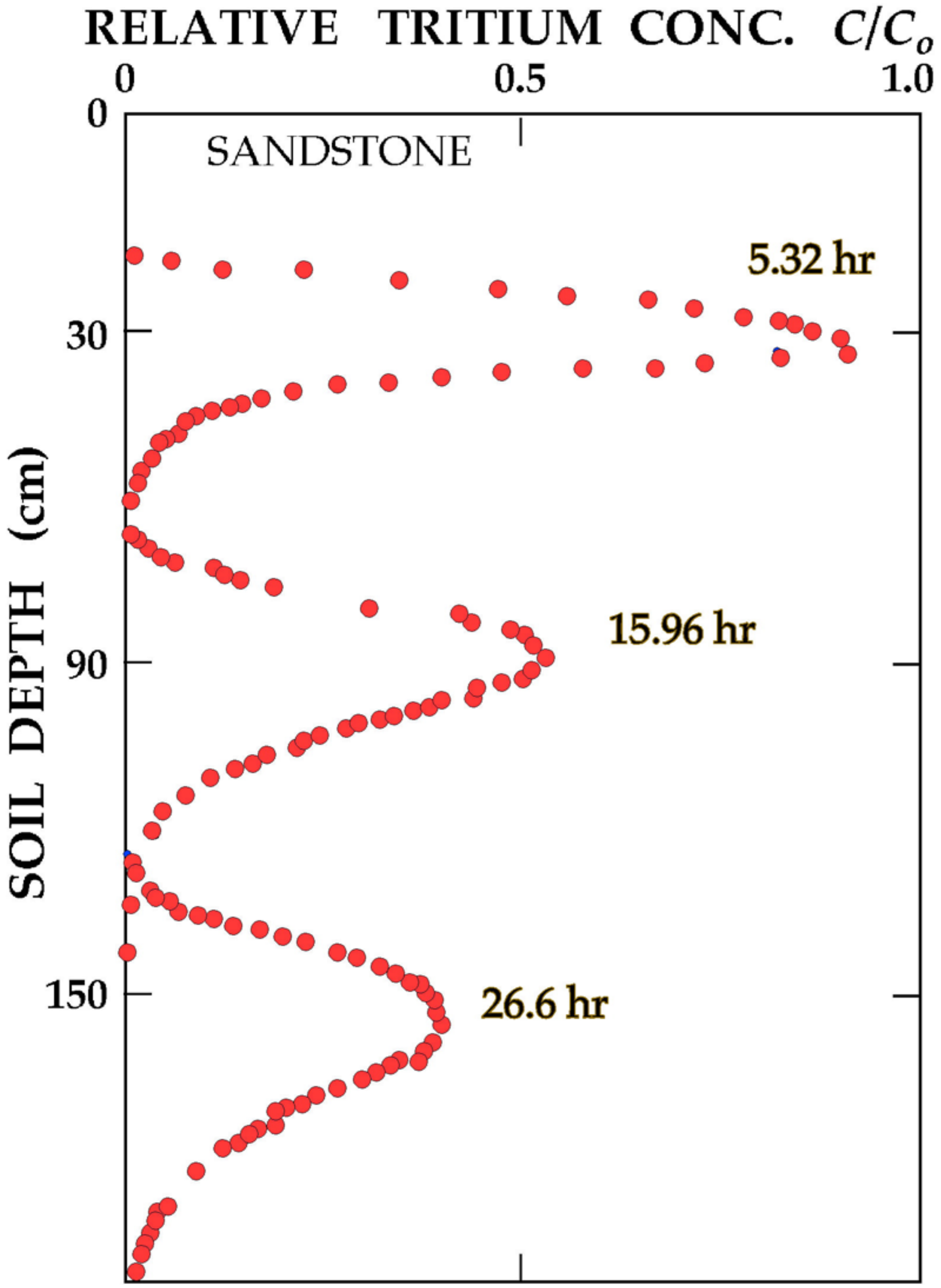
Aiken 2 velocities



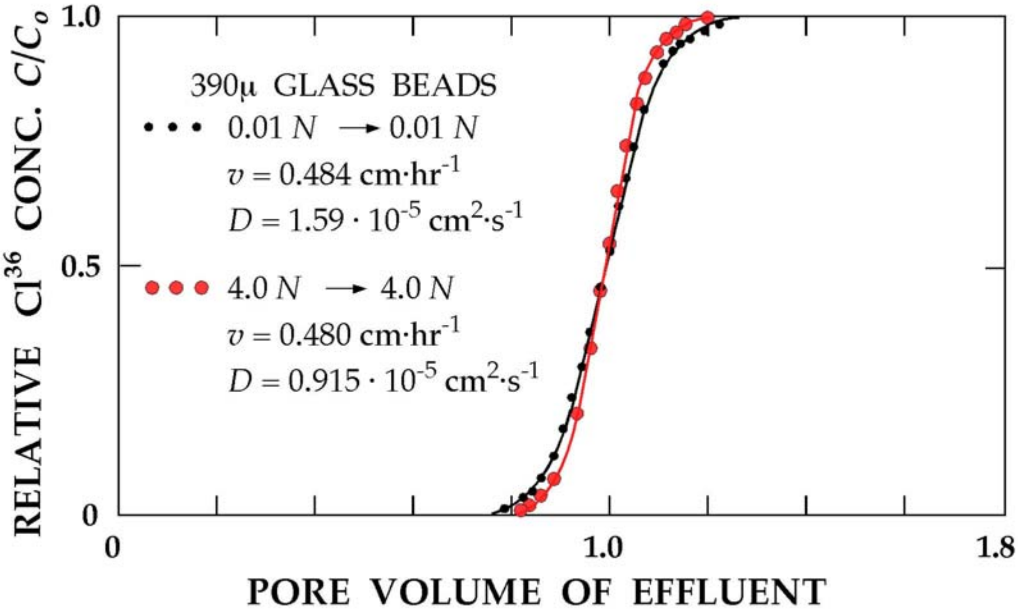
30, 90 and 120 cm



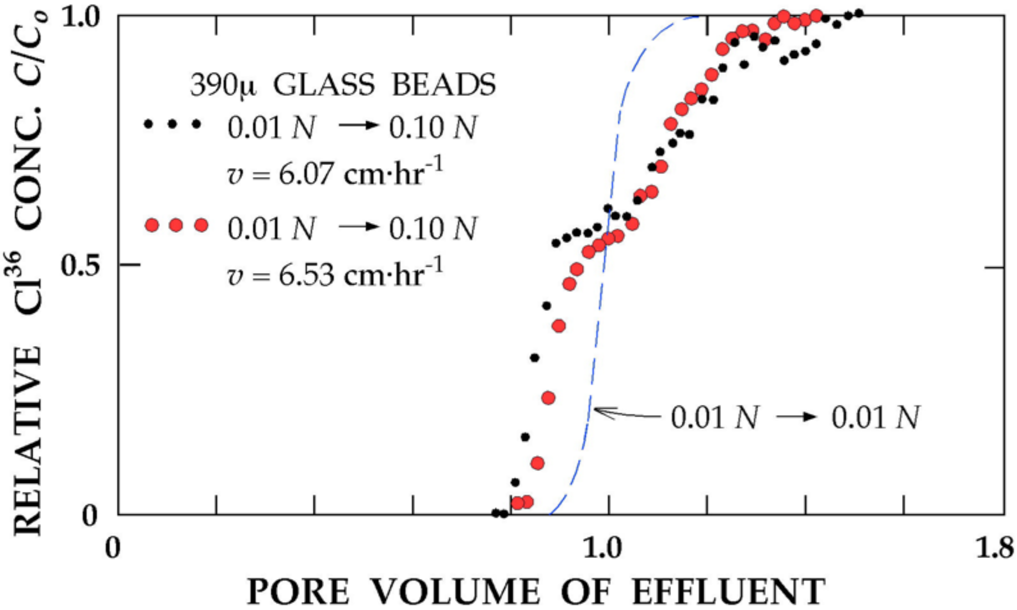
Tritium profile



Liquid density

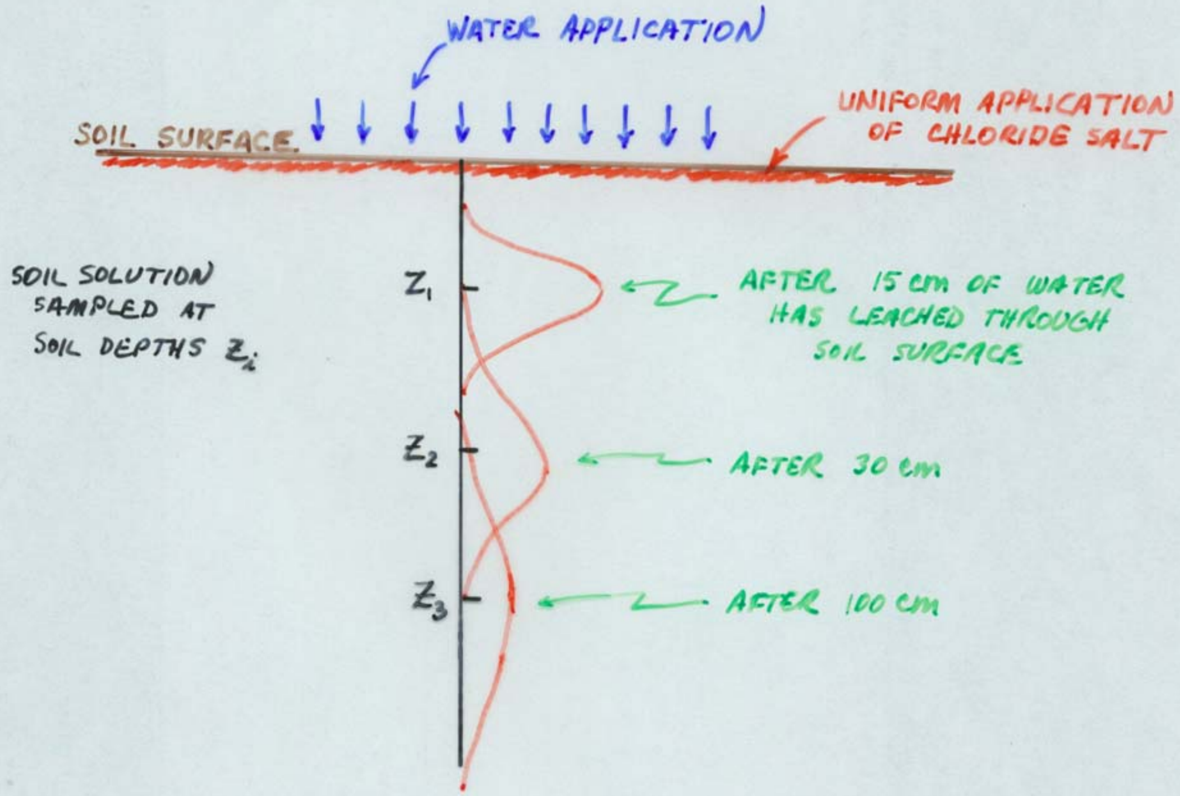


Heavy over light



Field Leaching Expt

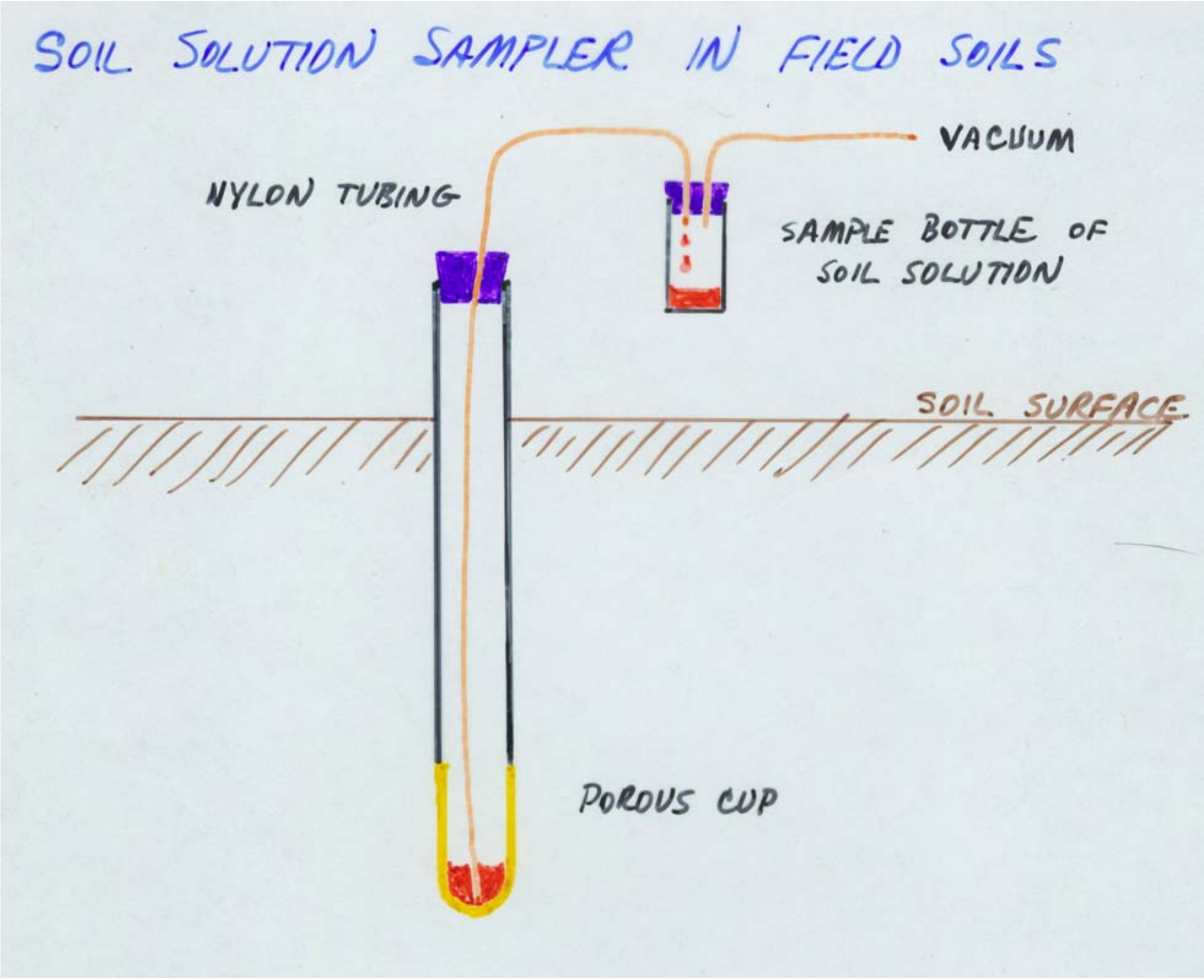
FIELD LEACHING EXPERIMENT



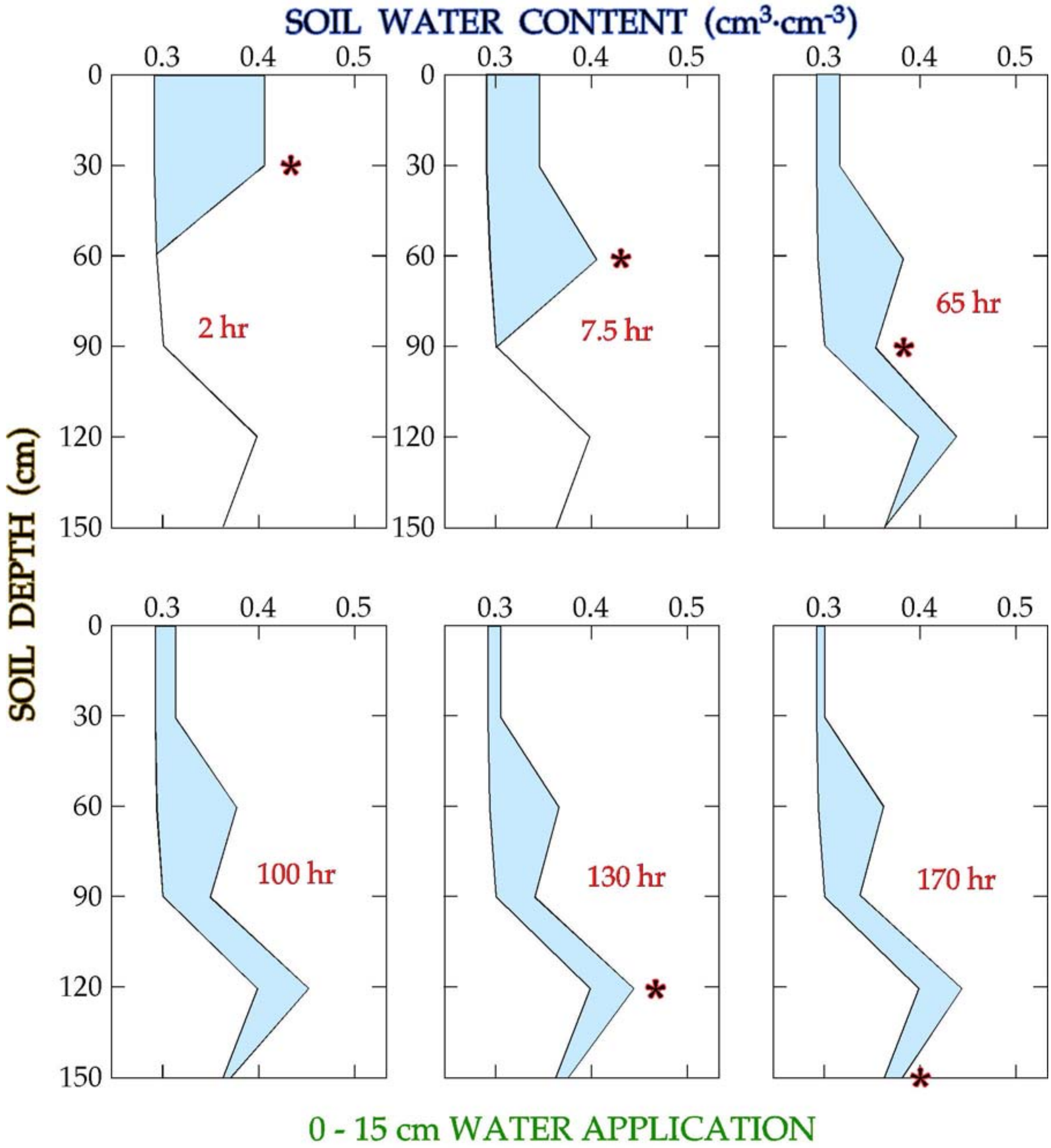
FIELD LEACHING EXPERIMENTAL CONDITIONS

- CONTINUOUS PONDING OF WATER ON SOIL SURFACE
- INTERMITTENT PONDING WITH 5 CM OF WATER ONCE EVERY WEEK
- INTERMITTENT PONDING WITH 15 CM OF WATER ONCE EVERY WEEK

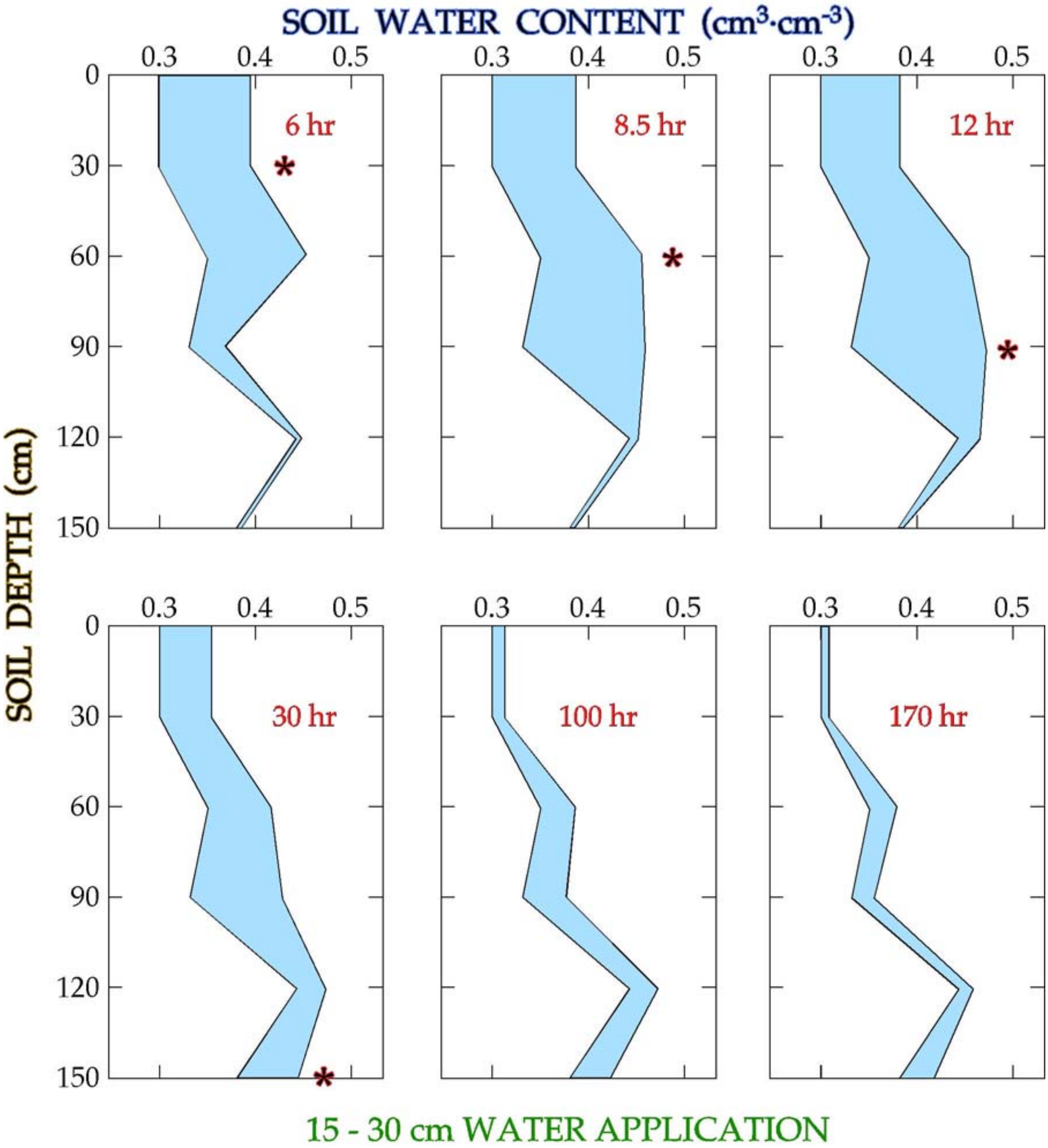
Solution sampler



0-15cm applic

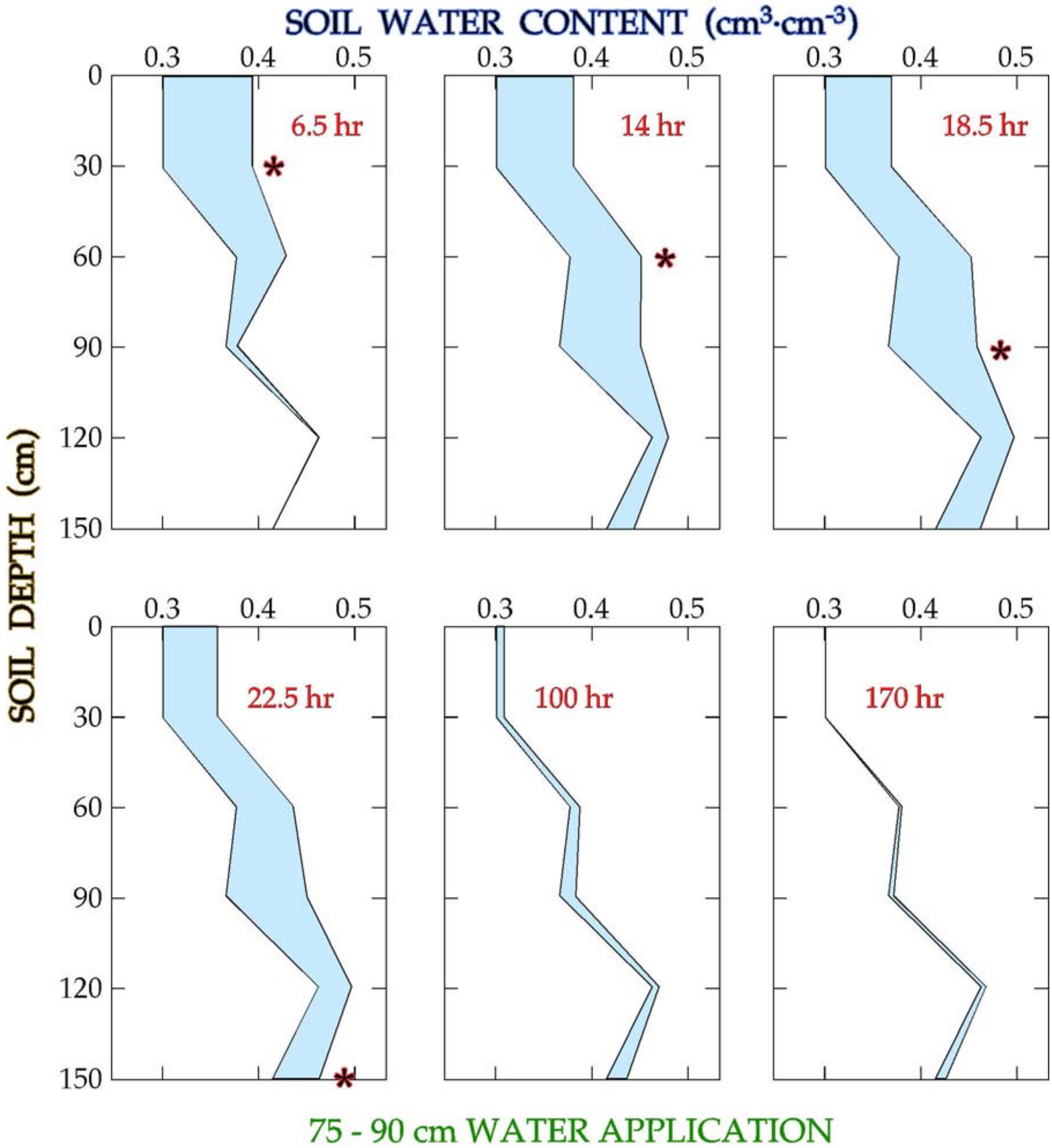


15-30cm appl



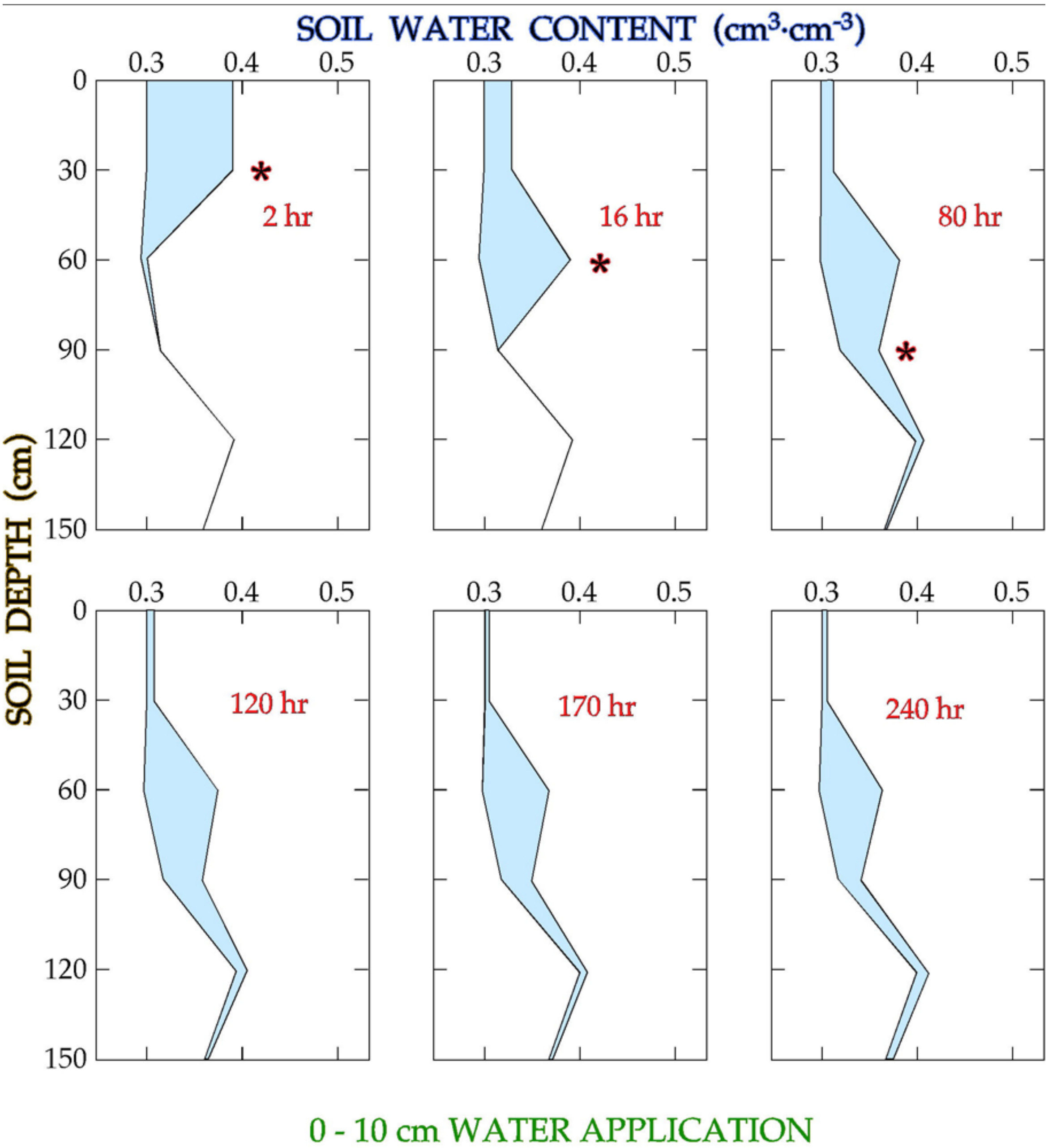
SOIL WATER CONTENT (cm³·cm⁻³)
0.3 0.4 0.5
SOIL DEPTH (cm)
0
30
60
90
120
150
6 hr
8.5 hr
12 hr
30 hr
100 hr
170 hr
*
15 - 30 cm WATER APPLICATION

75-90cm appl



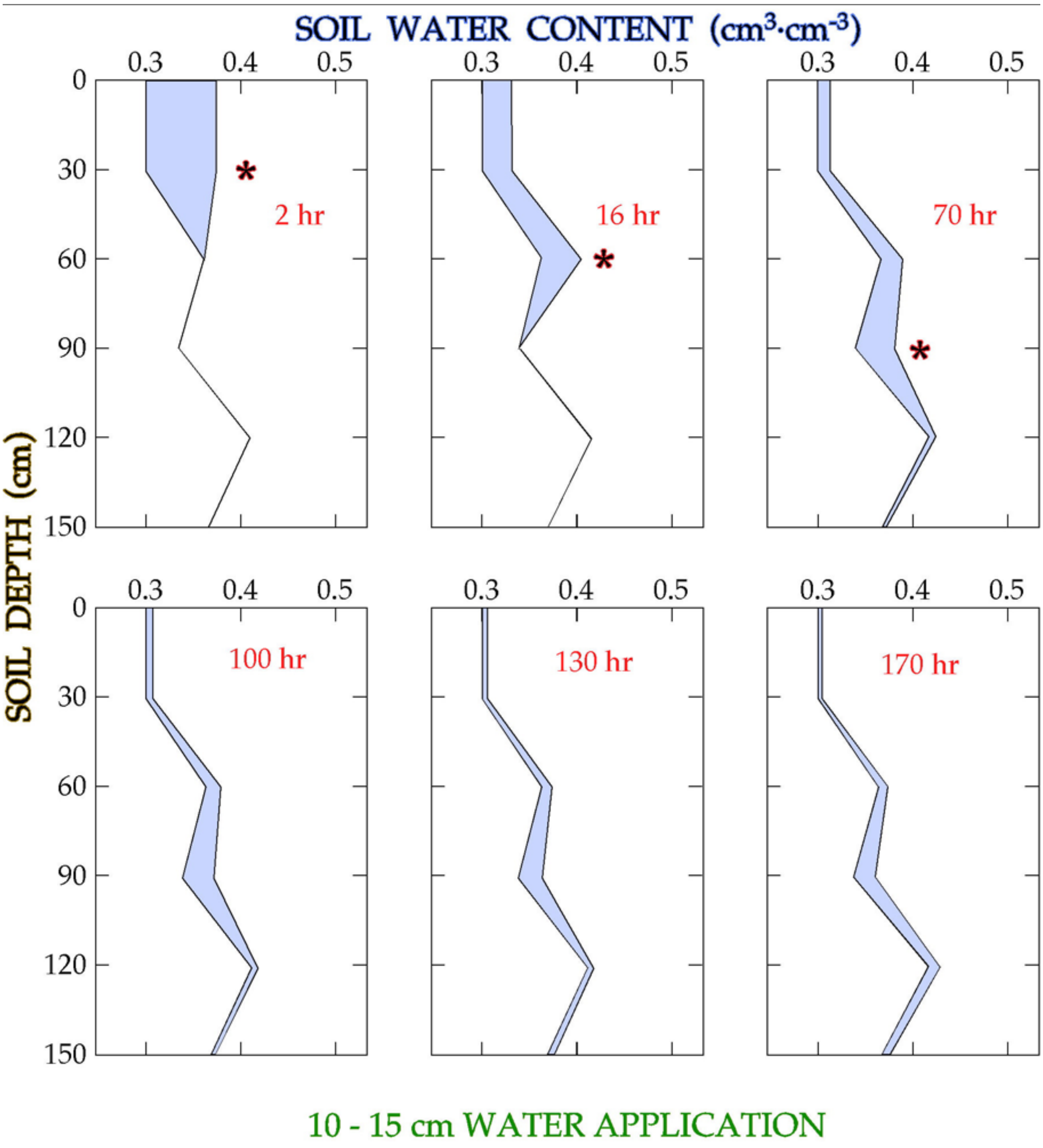
SOIL WATER CONTENT (cm³·cm⁻³)
0.3 0.4 0.5
0 30 60 90 120 150
SOIL DEPTH (cm)
6.5 hr
14 hr
18.5 hr
22.5 hr
100 hr
170 hr
75 - 90 cm WATER APPLICATION

0-10cm appl

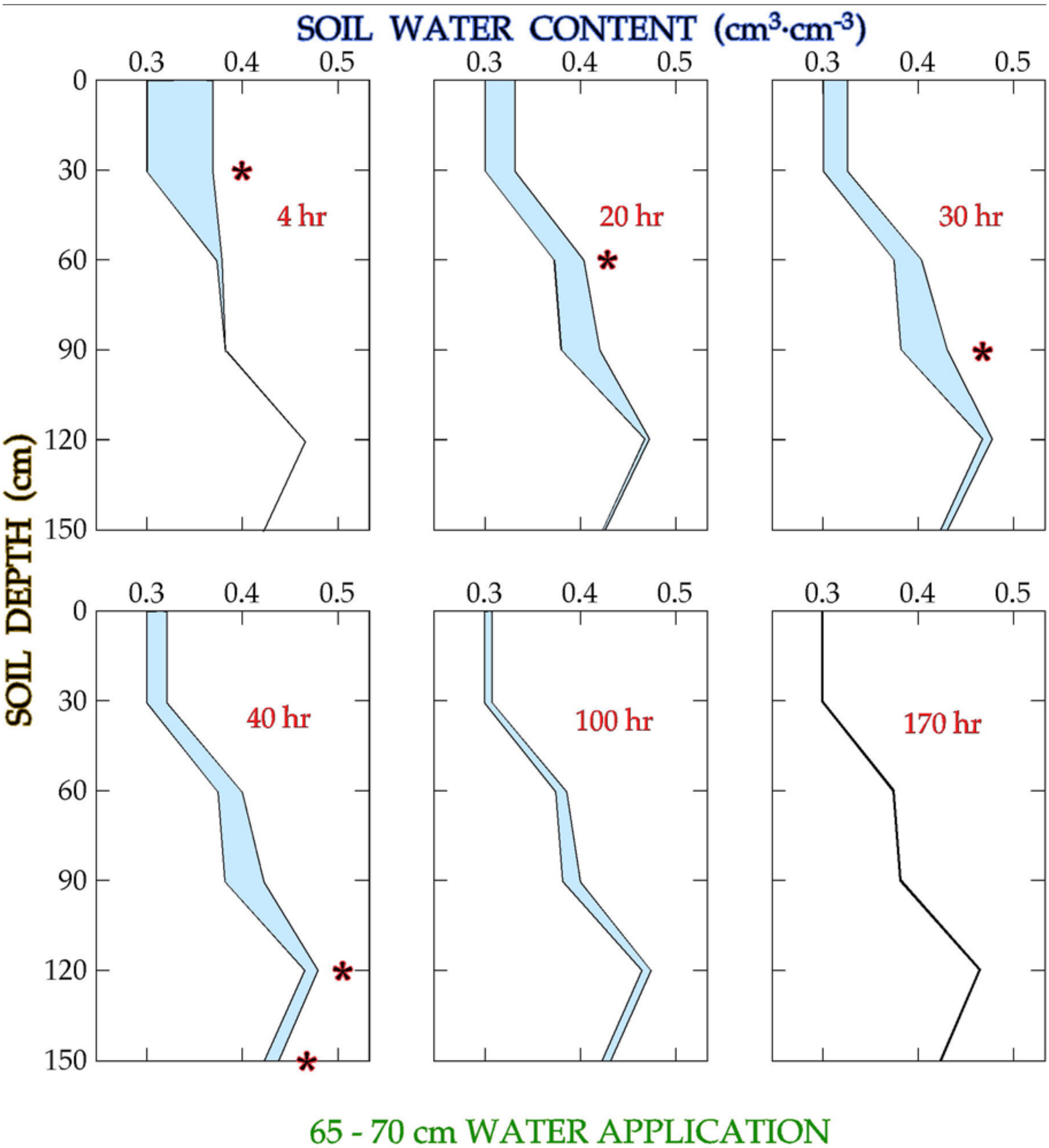


SOIL WATER CONTENT (cm³·cm⁻³)
0.3
0.4
0.5
SOIL DEPTH (cm)
0
30
60
90
120
150
2 hr
16 hr
80 hr
120 hr
170 hr
240 hr
0 - 10 cm WATER APPLICATION

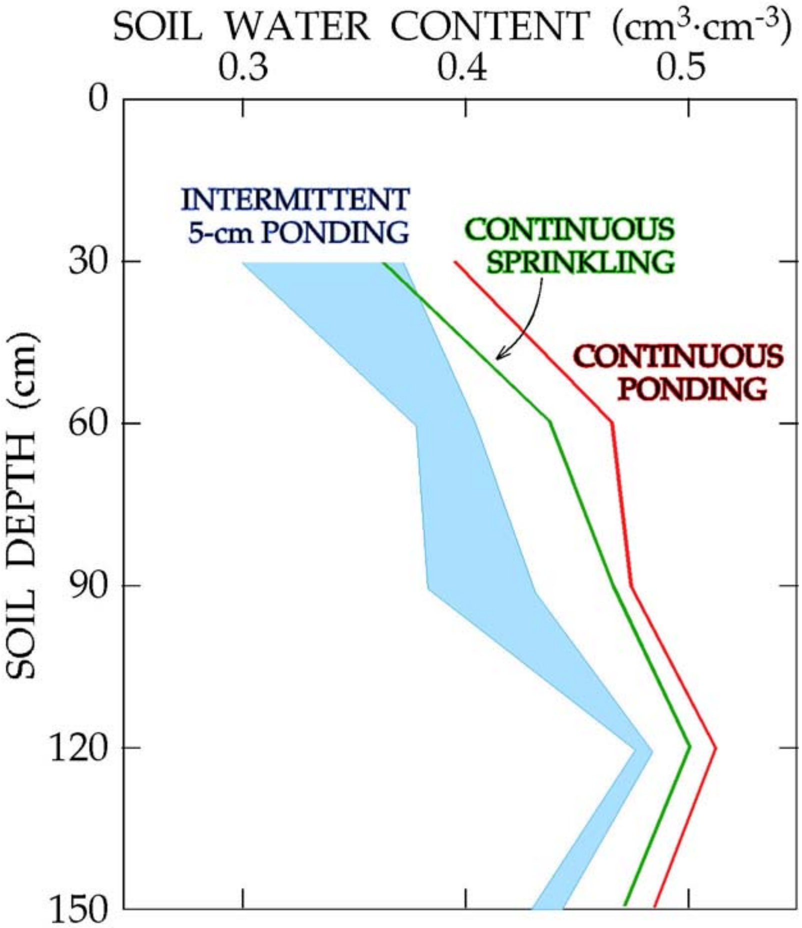
10-15cm appl


SOIL WATER CONTENT (cm³·cm⁻³)
0.3 0.4 0.5
SOIL DEPTH (cm)
0 30 60 90 120 150
2 hr
16 hr
70 hr
100 hr
130 hr
170 hr
*
10 - 15 cm WATER APPLICATION

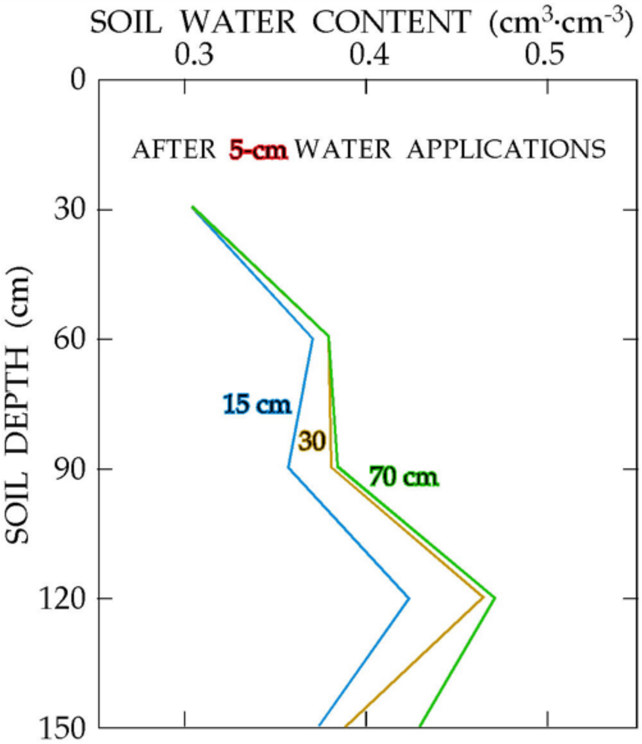
65-70cm appl

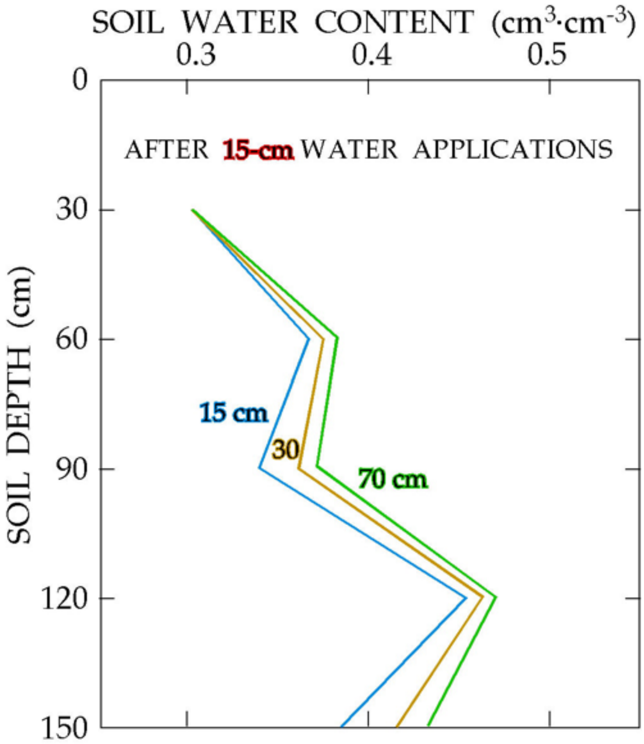

SOIL WATER CONTENT (cm³·cm⁻³)
SOIL DEPTH (cm)
0.3
0.4
0.5
0
30
60
90
120
150
4 hr
20 hr
30 hr
40 hr
100 hr
170 hr
65 - 70 cm WATER APPLICATION

Theta profiles

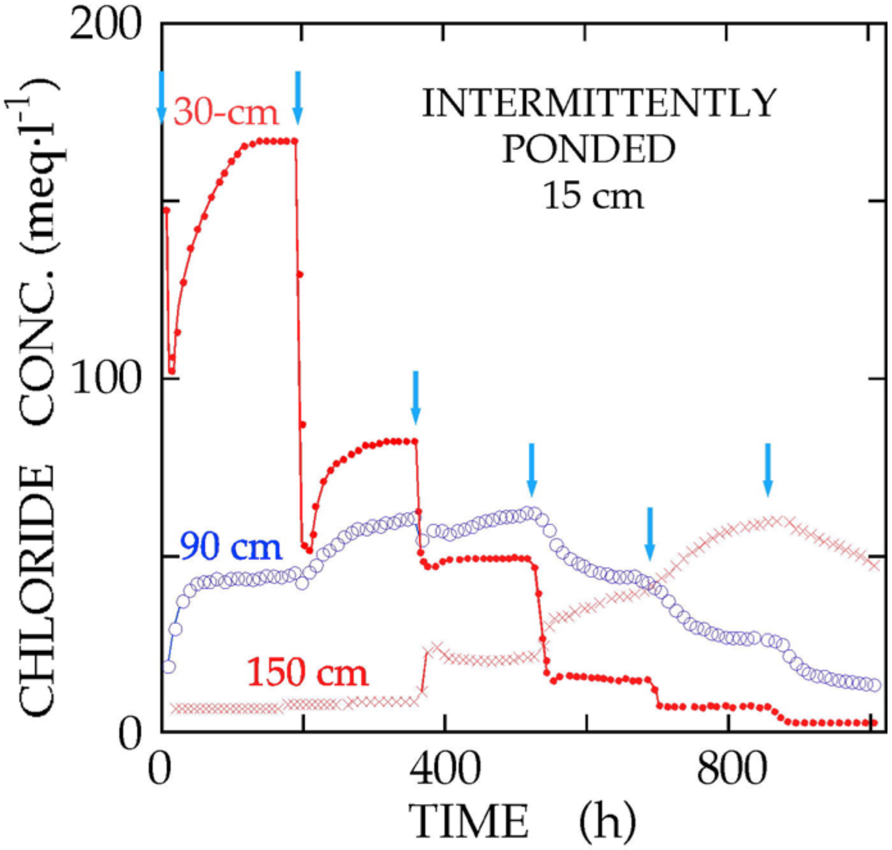


Theta increases

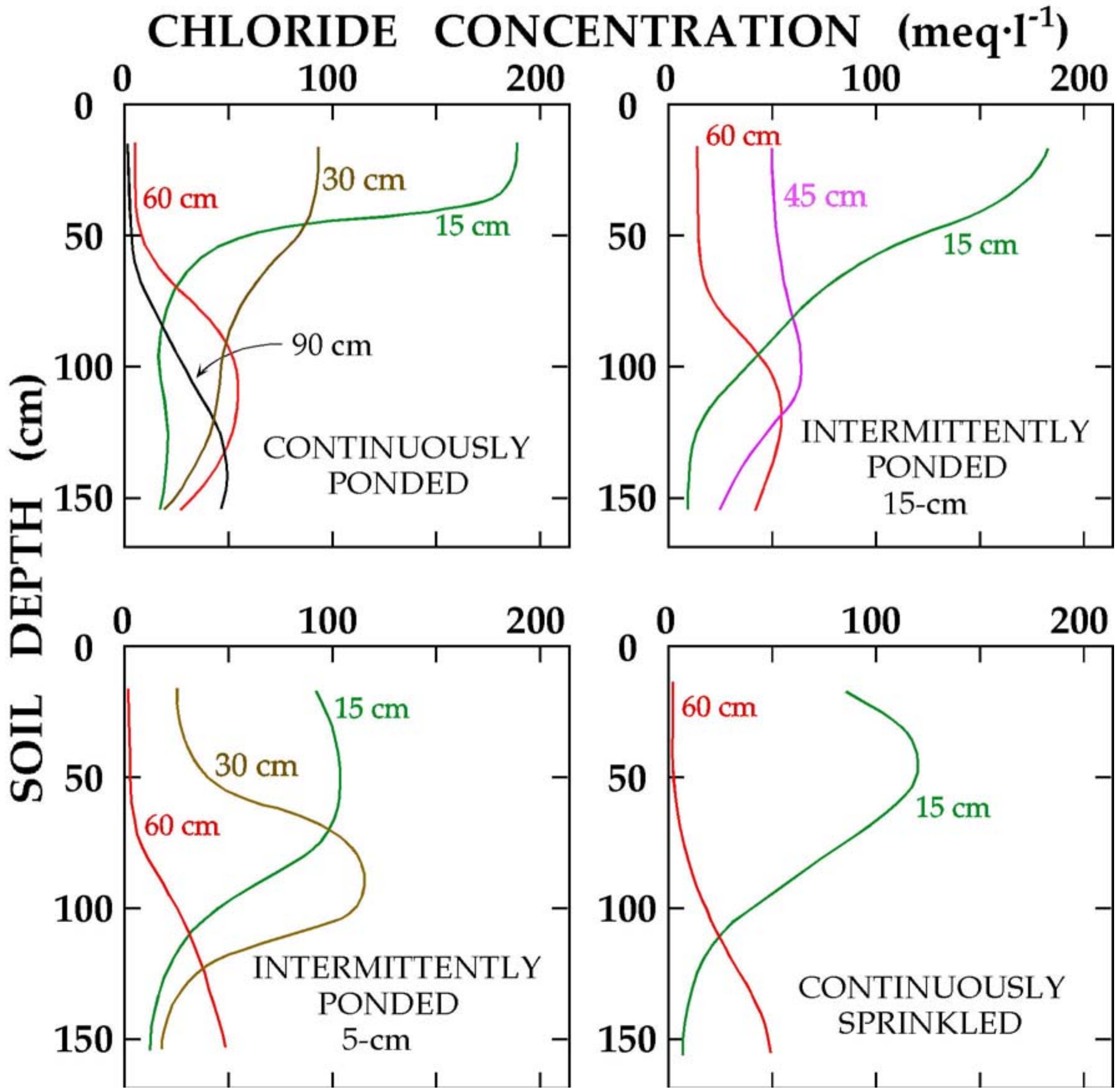




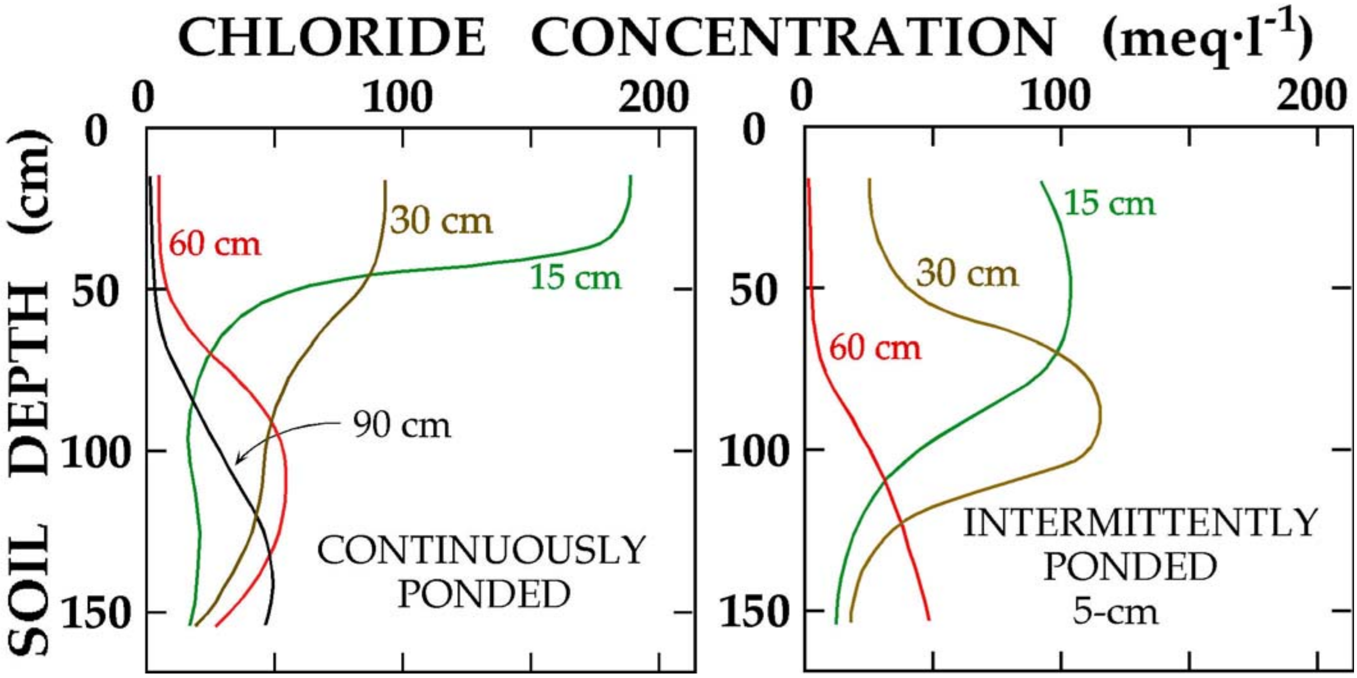
Cl at 30, 90 & 150



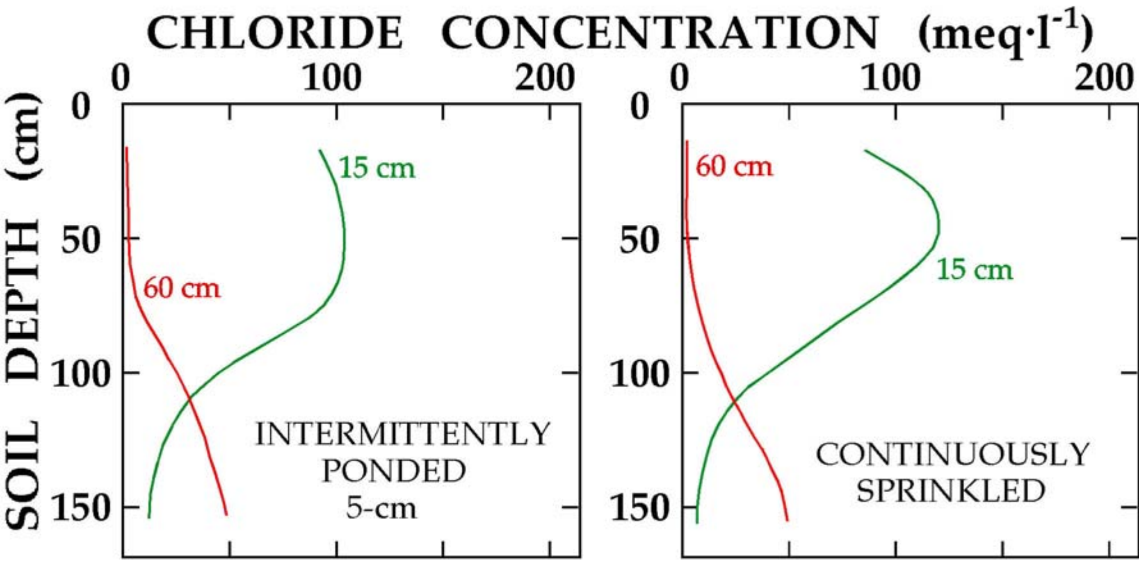
Conc profiles 1



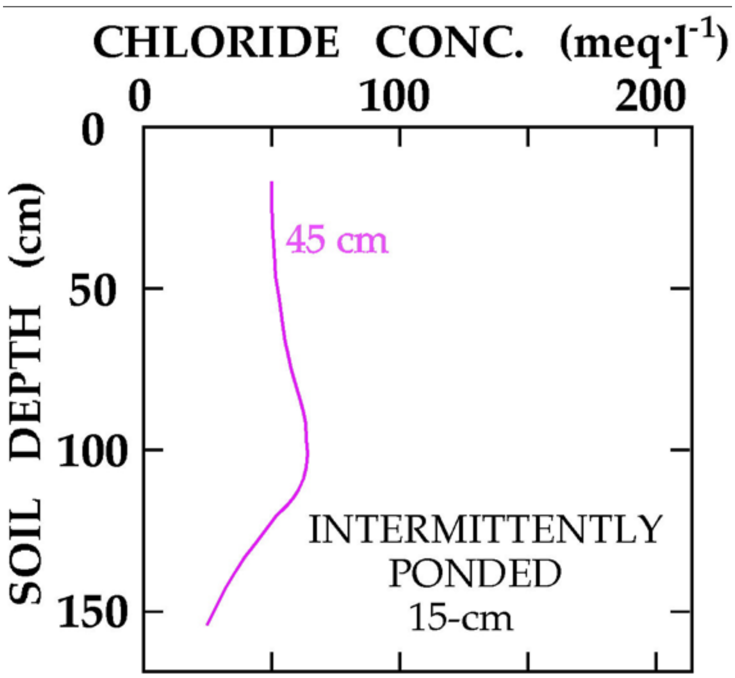
Conc profiles 2



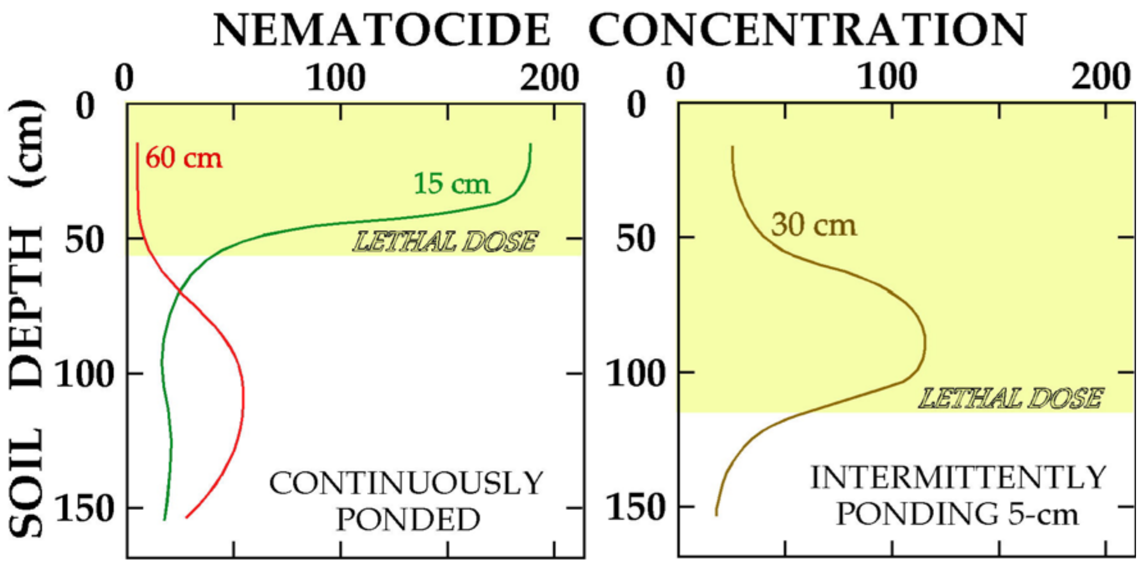
Conc profiles 3



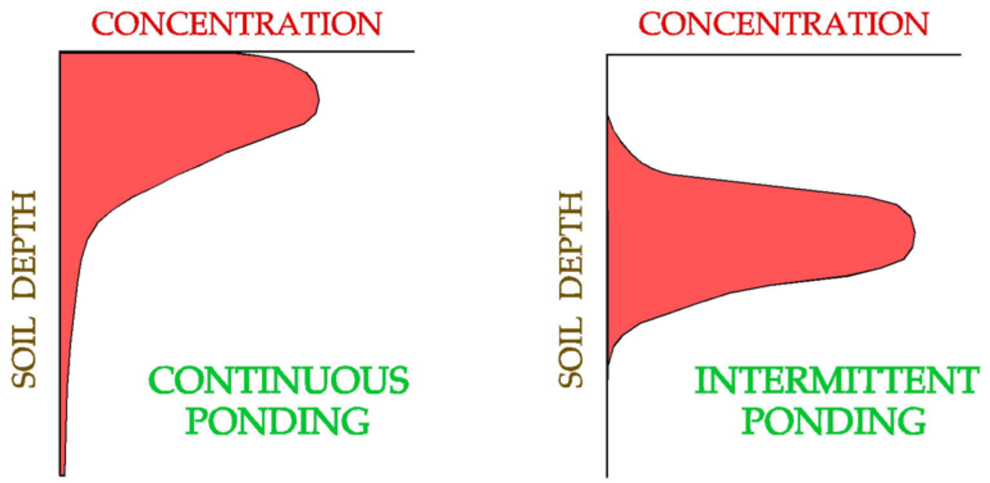
Conc profiles 4



Conc profiles 5



conclusions



SOIL SALINITY CAN BE MANAGED BY CONTROLLING THE FREQUENCY AND AMOUNTS OF IRRIGATION WATER

SOLUTE TRANSPORT DEPENDS UPON:

- LEACHING VELOCITY OF SOIL WATER
- SOIL WATER CONTENT DURING LEACHING

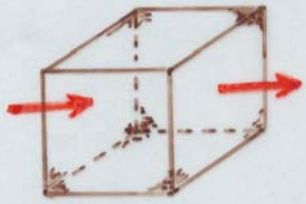
Convective Diffusion Eq.

CONVECTIVE - DIFFUSION EQUATION

INFLUX

$$J_{CONVECTION} = J_{WATER} C$$

$$J_{DIFFUSION} = -D \frac{\partial C}{\partial x}$$



ΔX

OUTFLUX

$$J_w C + \frac{\partial J_w C}{\partial x} \Delta X$$

$$-D\frac{\partial C}{\partial x} + \frac{\partial}{\partial x}\left(-D\frac{\partial C}{\partial x}\right)\Delta X$$

TIME RATE OF CHANGE OF AMOUNT OF SOLUTE IN VOLUME OF BOX = INFLUX − OUTFLUX

$$\frac{\partial \epsilon G}{\partial t} + \frac{\partial \rho S}{\partial t} + \frac{\partial \theta C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) - \frac{\partial J_w C}{\partial x} \pm \begin{matrix} \text{SOURCE} \\ \text{SINK} \end{matrix}$$

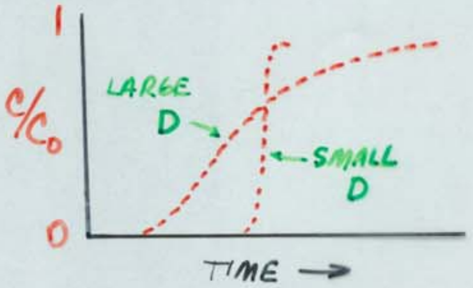
ASSUME:

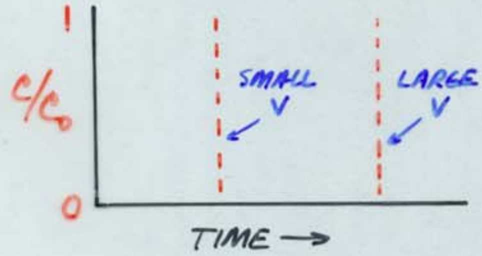
- NO SOLUTE IN GASEOUS PHASE
- NO SOURCES OR SINKS
- BULK DENSITY ρ IS CONSTANT
- SOIL WATER CONTENT θ IS CONSTANT
- SOIL WATER FLUX J_w IS CONSTANT
- APPARENT DIFFUSION COEFFICIENT IS CONSTANT
- SOIL IS HOMOGENEOUS

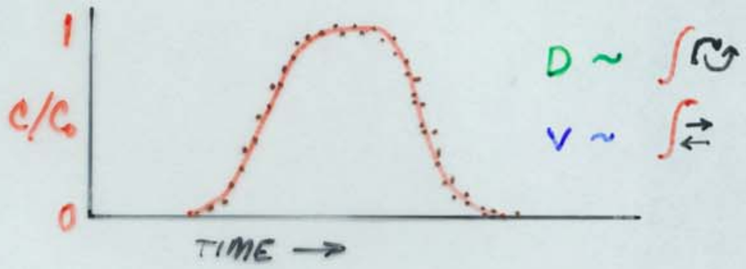
$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x} \qquad \text{WHERE} \quad V = \frac{J_w}{\theta}$$

Estimating D&v field

ESTIMATING THE VALUES OF D & V FROM FIELD-MEASURED BREAKTHROUGH CURVES

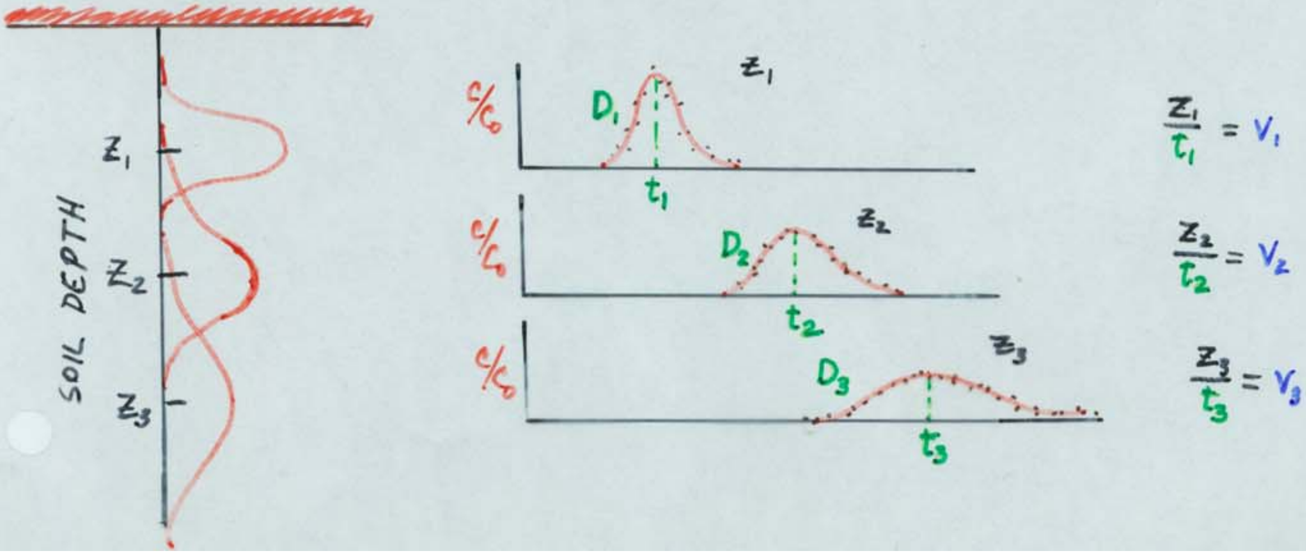




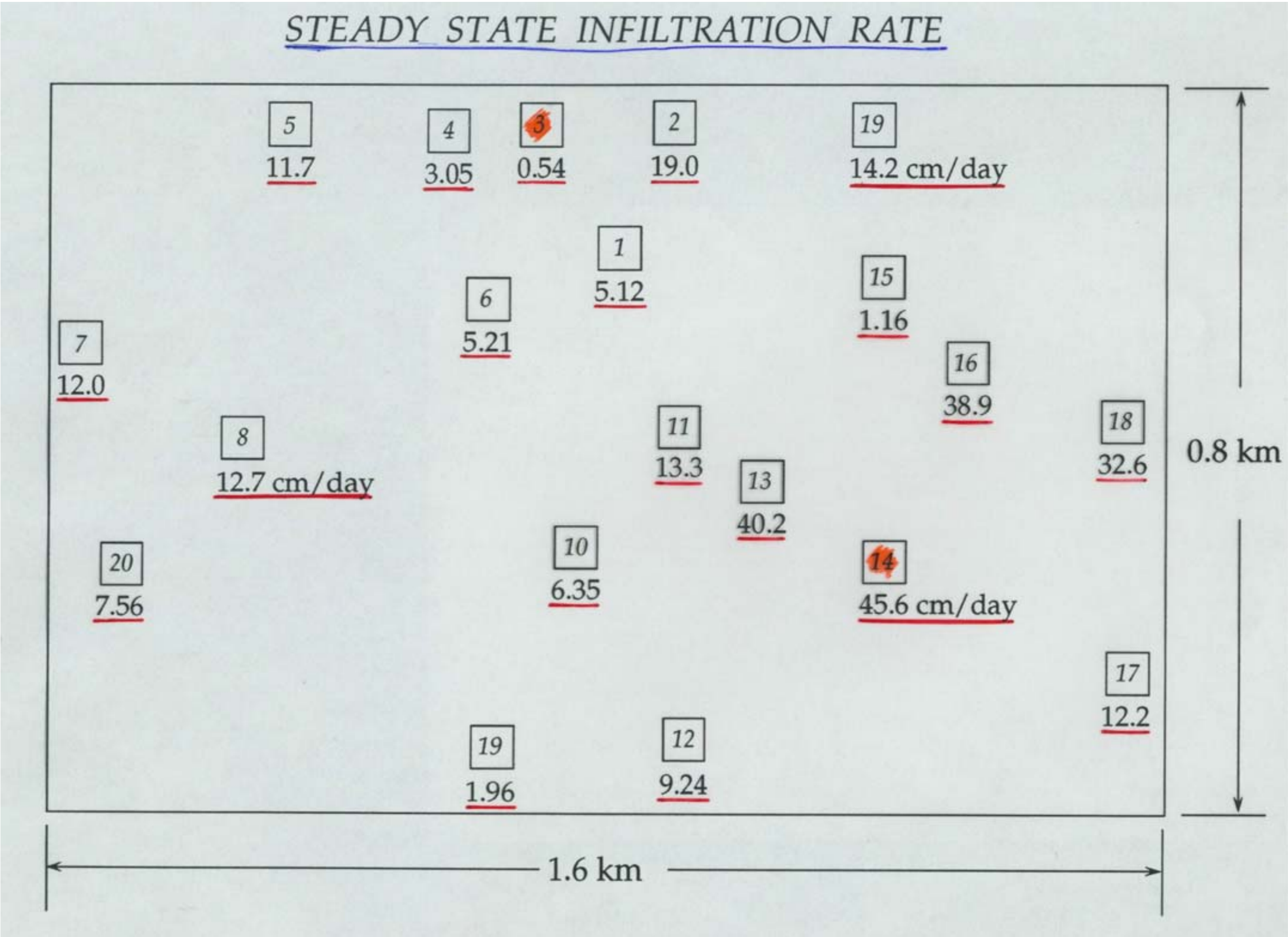


$$\frac{C}{C_0} = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{x - vt}{\sqrt{4Dt}}\right) + \exp\left(\frac{vx}{D}\right)\operatorname{erfc}\left(\frac{x + vt}{\sqrt{4Dt}}\right)\right] -$$

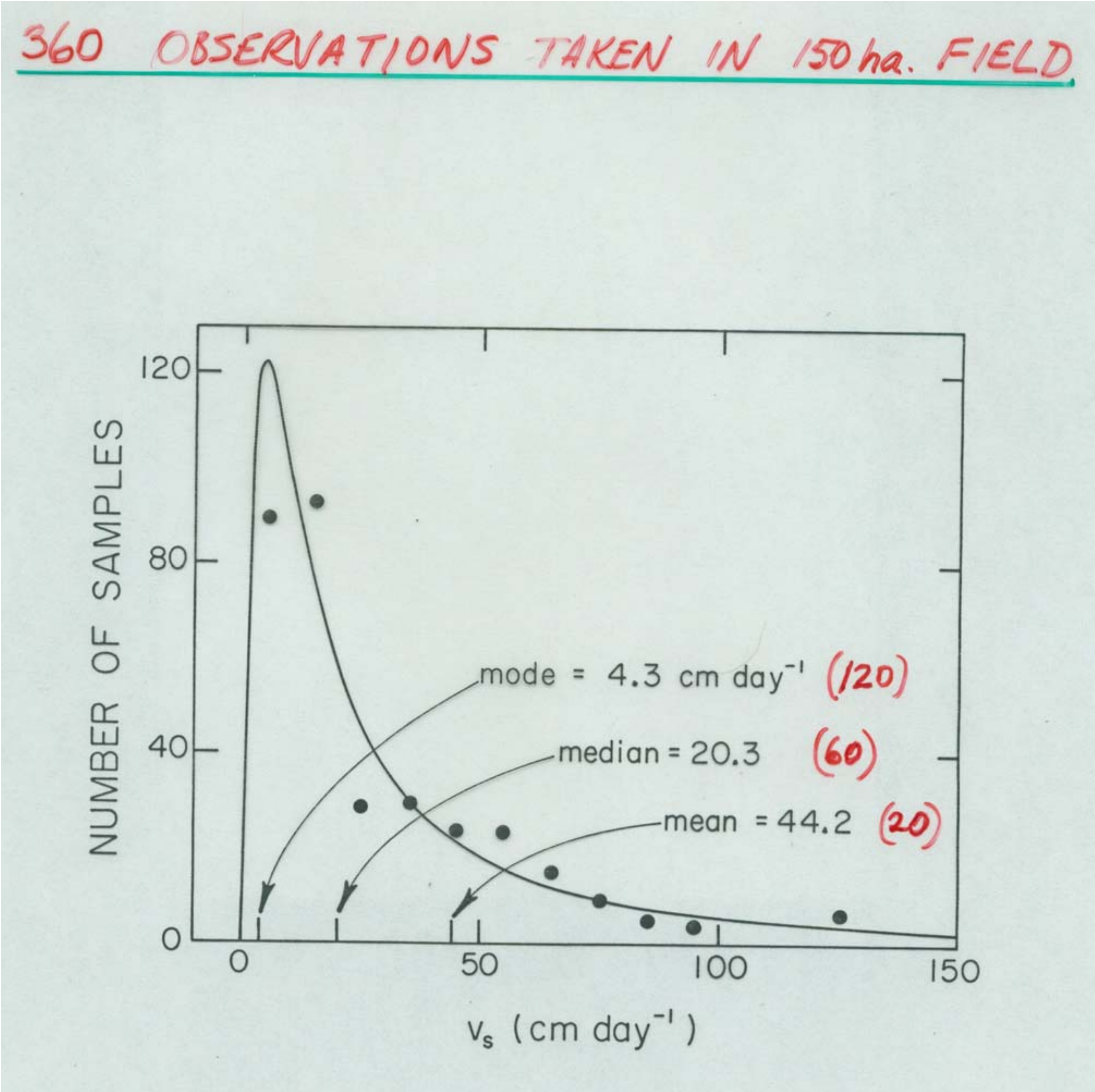
$$\frac{1}{2}\left[\operatorname{erfc}\left(\frac{x - v(t - t_I)}{\sqrt{4D(t - t_I)}}\right) + \exp\left(\frac{vx}{D}\right)\operatorname{erfc}\left(\frac{x - v(t - t_I)}{\sqrt{4D(t - t_I)}}\right)\right]$$



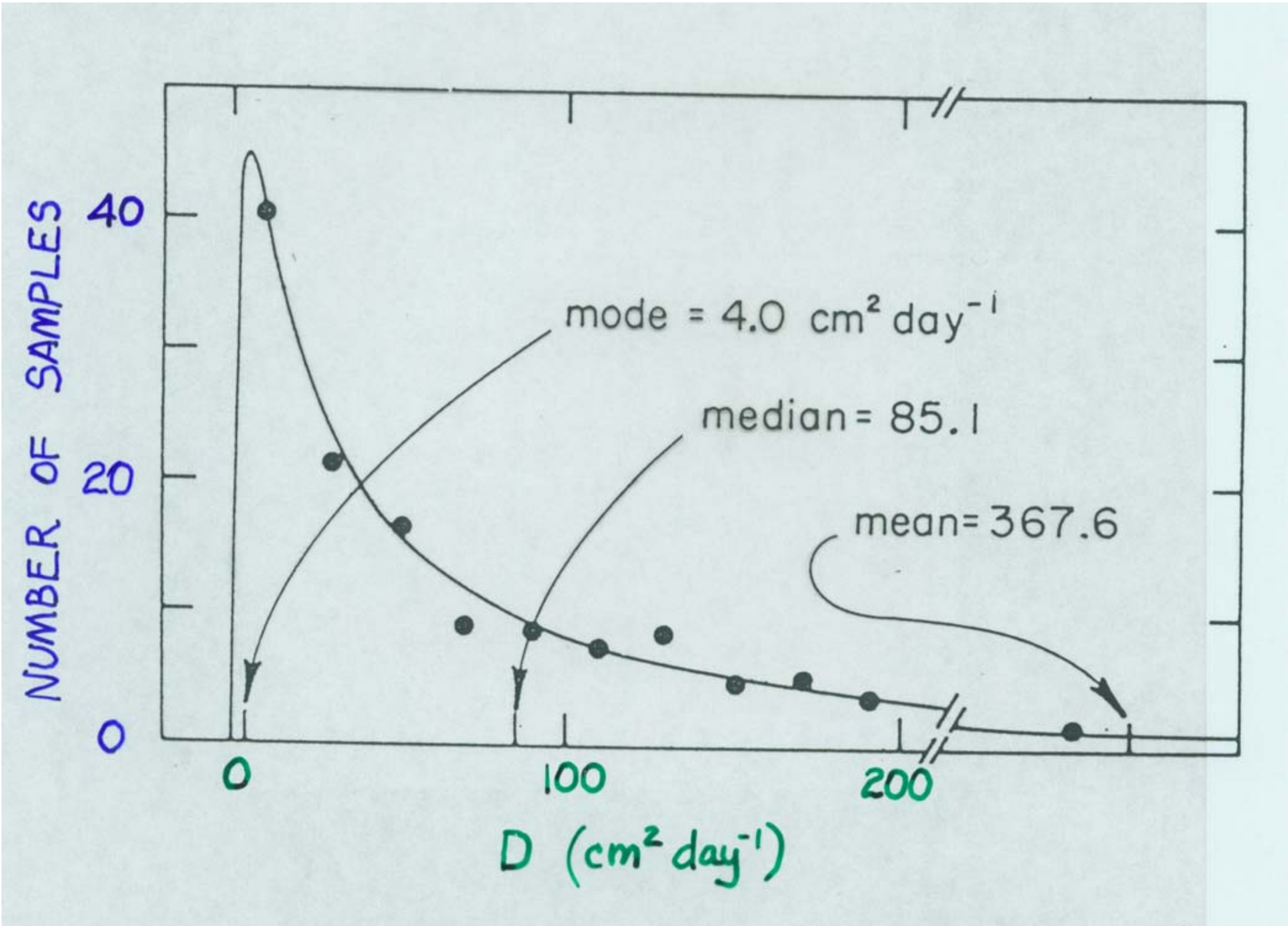
20 Field plots



Distrib of v

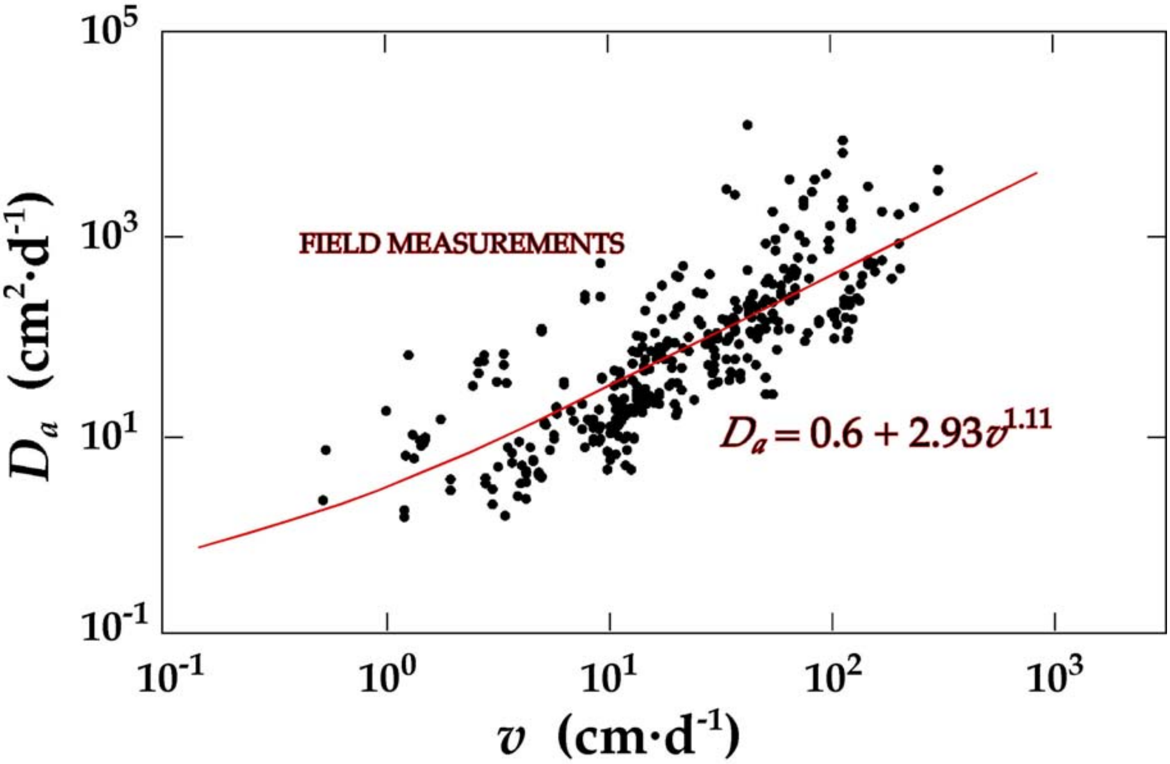

360 OBSERVATIONS TAKEN IN 150 ha. FIELD
NUMBER OF SAMPLES
120
80
40
0
mode = 4.3 cm day⁻¹ (120)
median = 20.3 (60)
mean = 44.2 (20)
0
50
100
150
Vs (cm day⁻¹)

Distrib of D

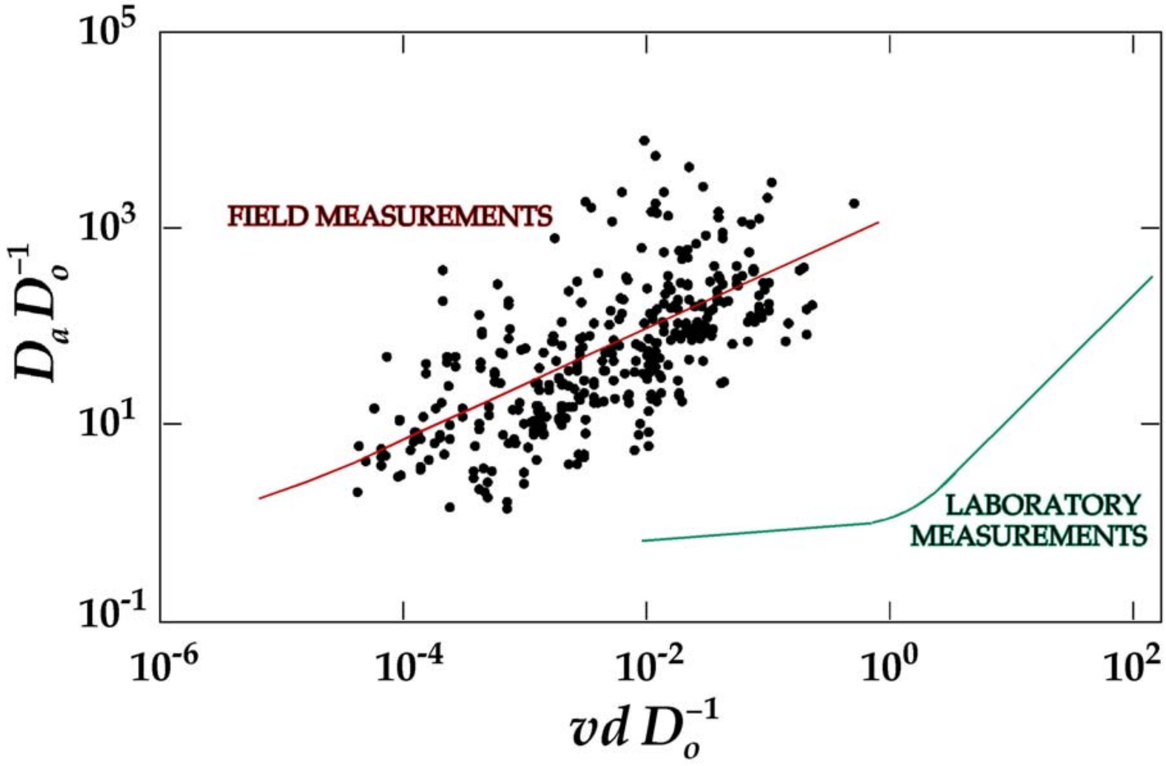


NUMBER OF SAMPLES
40
20
0
mode = 4.0 cm² day⁻¹
median= 85.1
mean= 367.6
0
100
200
D (cm² day⁻¹)

D versus v

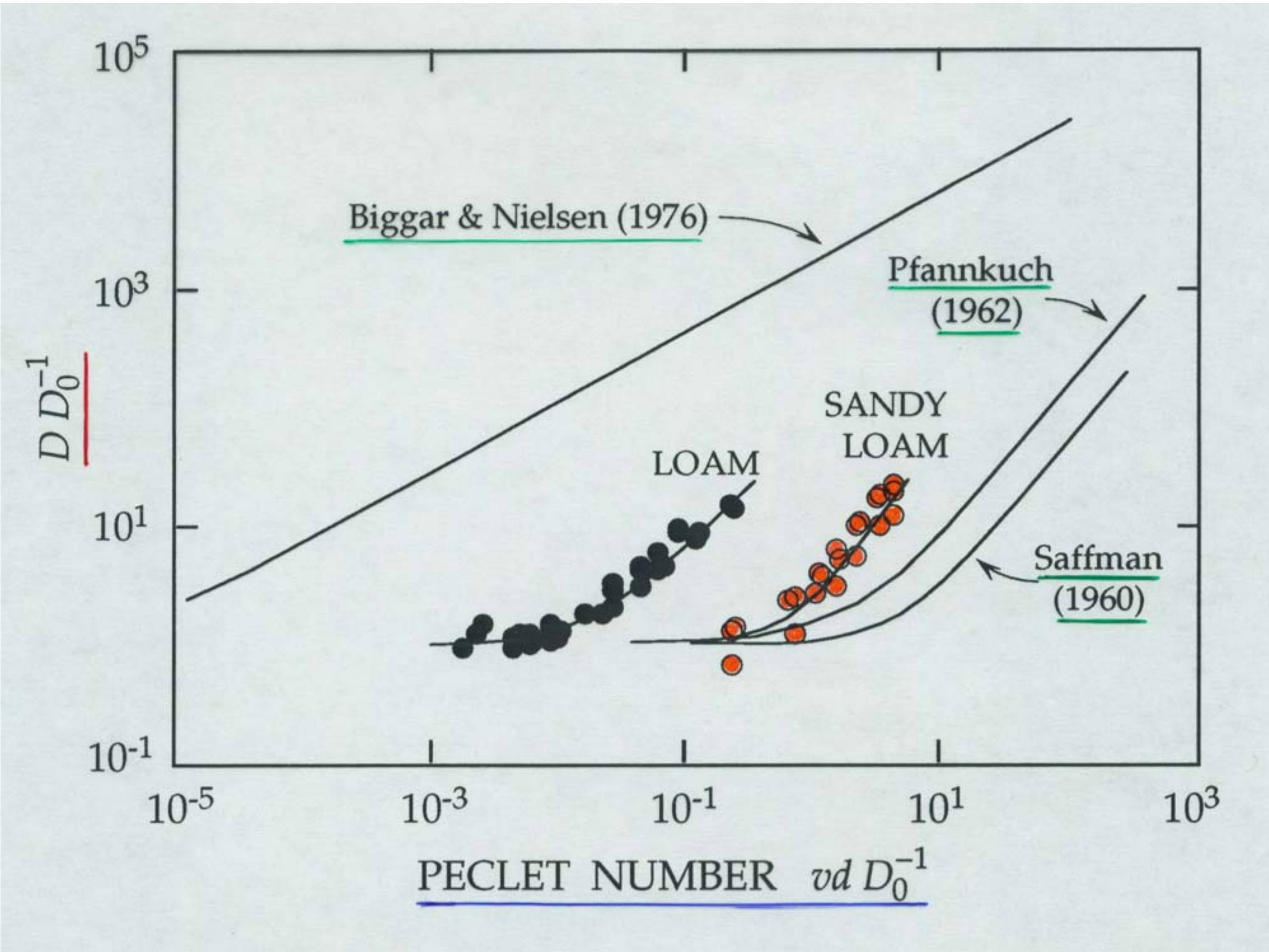


FIELD MEASUREMENTS
$D_a = 0.6 + 2.93v^{1.11}$
D_a (cm²·d⁻¹)
v (cm·d⁻¹)



FIELD MEASUREMENTS
LABORATORY MEASUREMENTS
$D_a D_o^{-1}$
$vd D_o^{-1}$

D versus Peclet

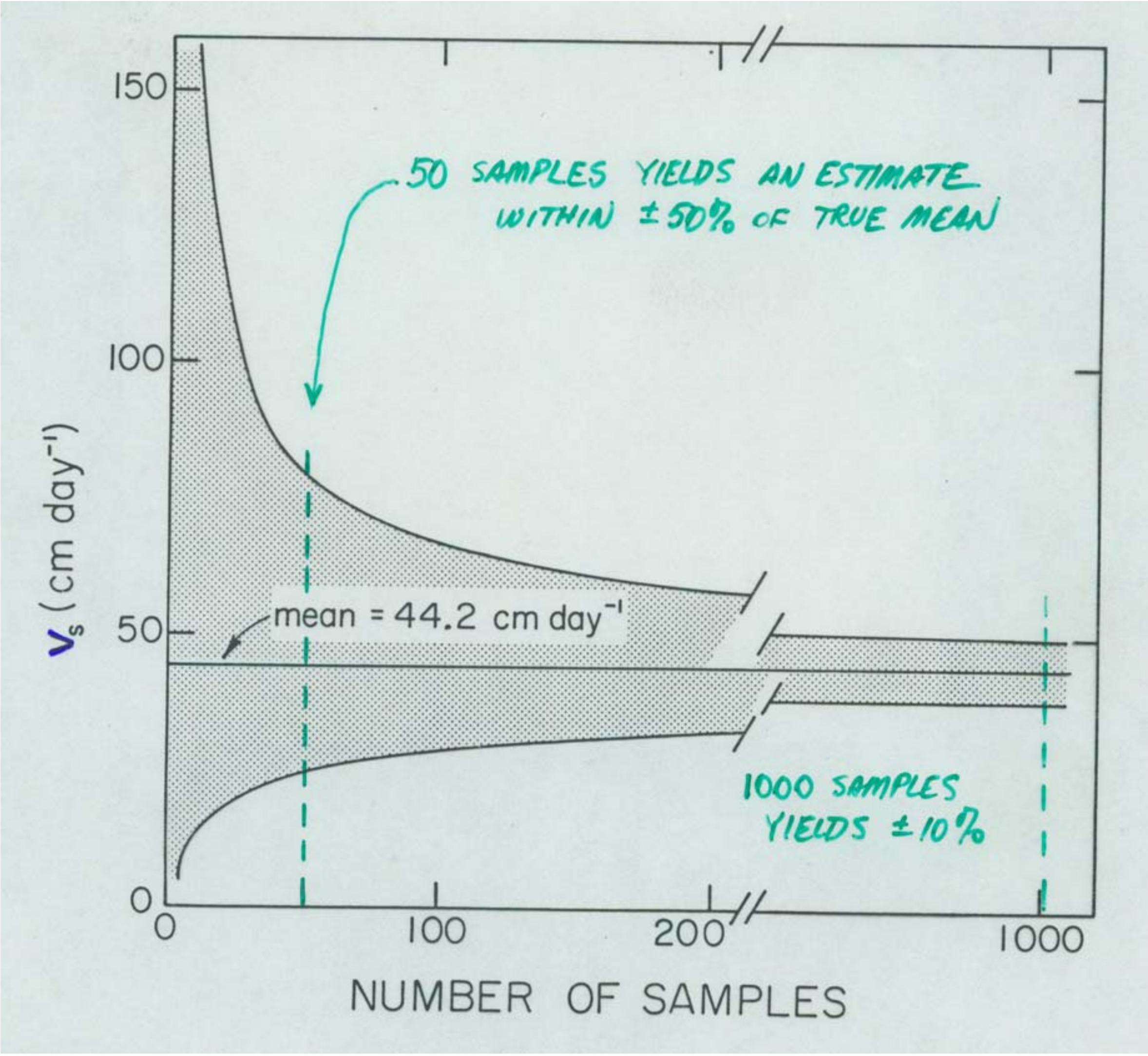


No. of sanples

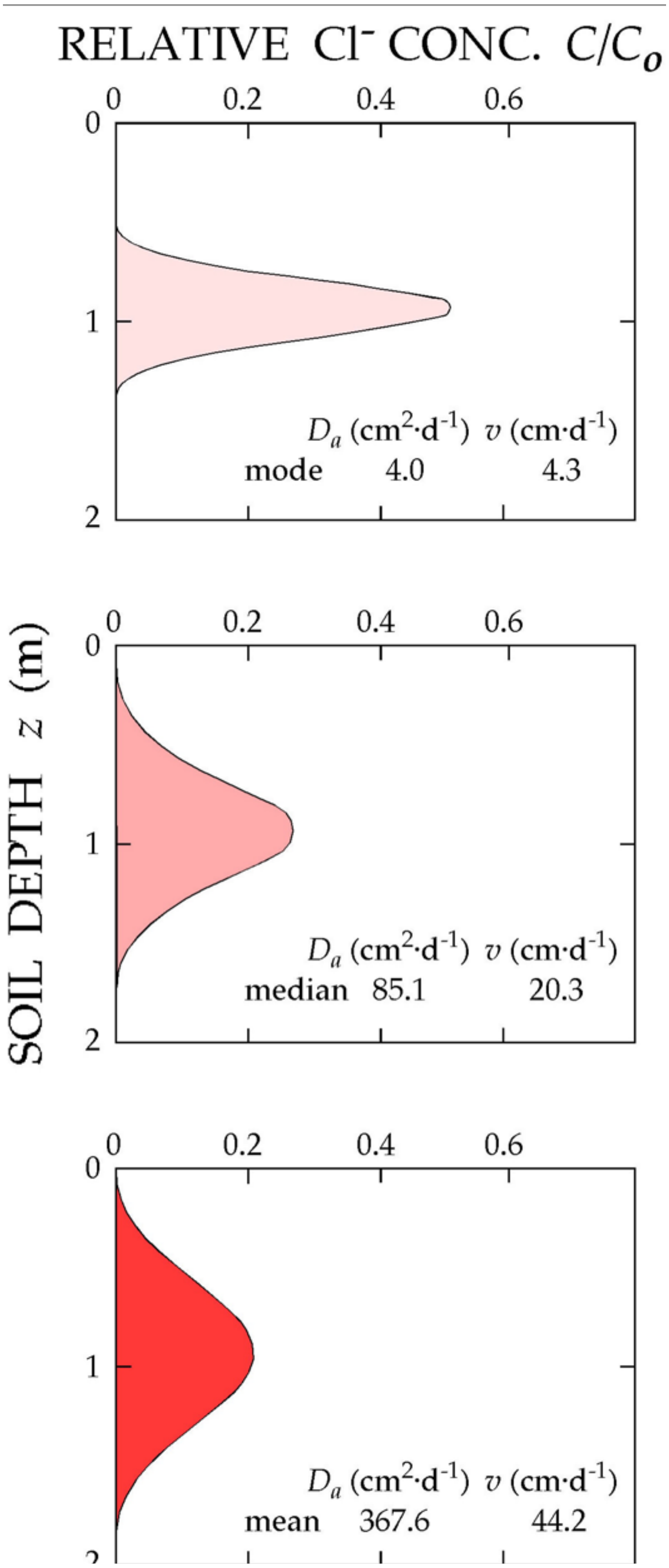
NUMBER OF SAMPLES
FOR
EQUALLY RELIABLE VALUES

$$\frac{\partial(\overset{10}{\theta}\overset{400}{C})}{\partial t}+\frac{\partial(\overset{10}{\rho}\overset{50}{S})}{\partial t}=\overset{500}{D}\frac{\partial^2 C}{\partial z^2}-\frac{\partial(\overset{200}{v}C)}{\partial z}$$

Estimating v

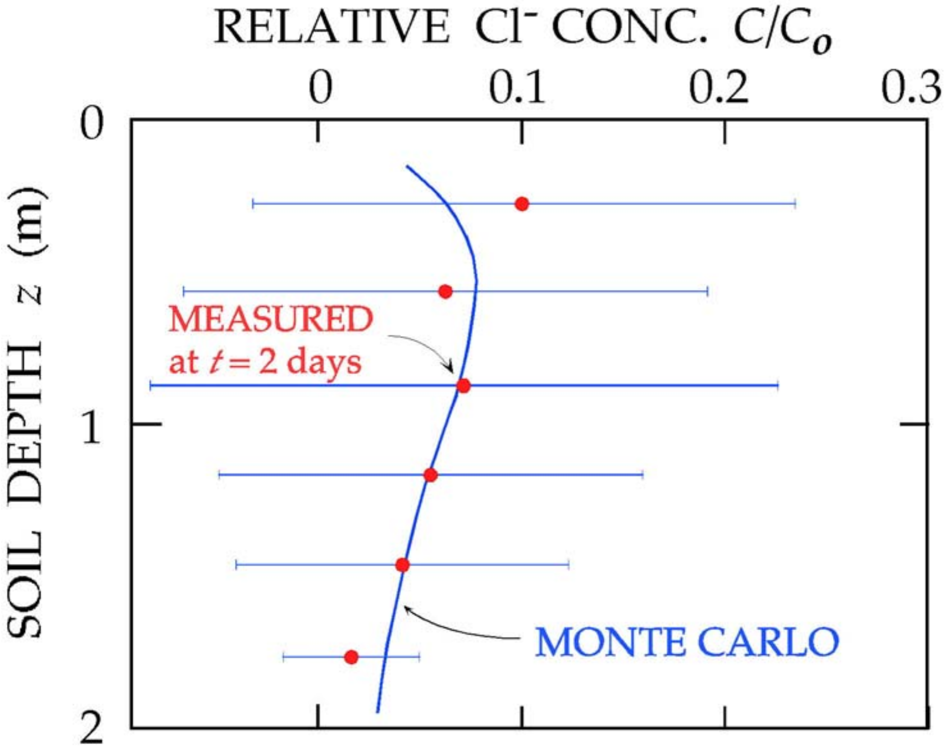


Modmedmean



RELATIVE Cl⁻ CONC. C/Co
0 0.2 0.4 0.6
0
1
2
Da (cm2·d-1) v (cm·d-1)
mode 4.0 4.3
0 0.2 0.4 0.6
0
1
2
Da (cm2·d-1) v (cm·d-1)
median 85.1 20.3
SOIL DEPTH z (m)
0 0.2 0.4 0.6
0
1
Da (cm2·d-1) v (cm·d-1)
mean 367.6 44.2

Field ave. C

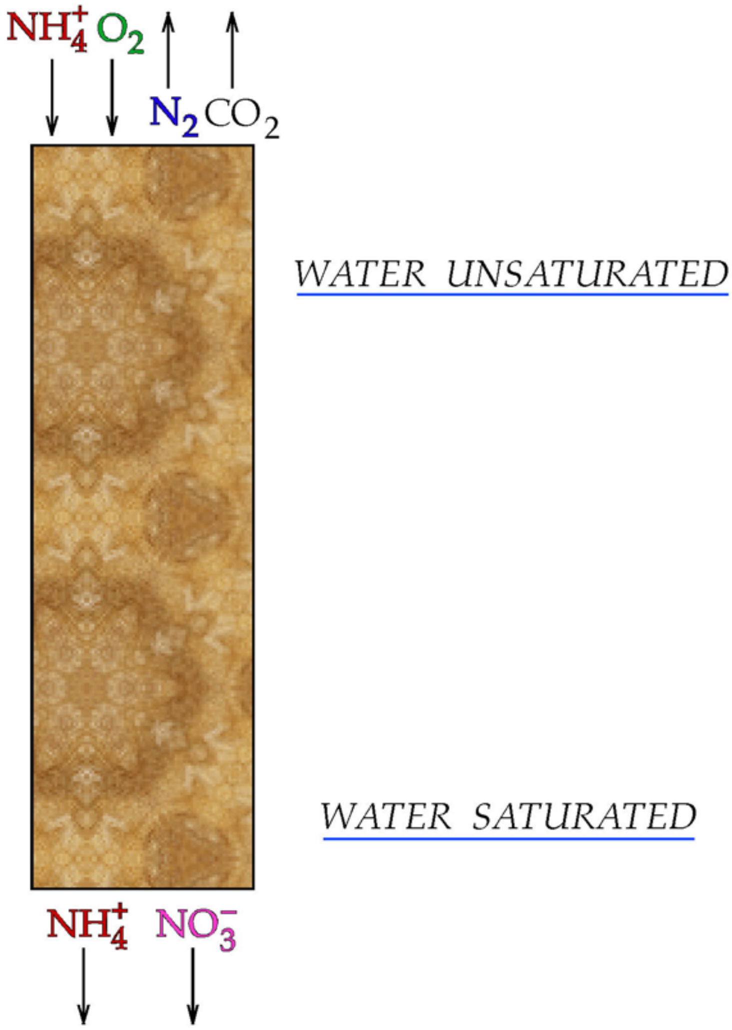


RELATIVE Cl⁻ CONC. C/Co
0
0.1
0.2
0.3
0
1
2
SOIL DEPTH z (m)
MEASURED
at t = 2 days
MONTE CARLO

Lab column

NITRIFICATION & DENITRIFICATION STEADY-STATE SOIL COLUMN EXPERIMENT

$0.01N$ $CaSO_4$ containing 50µg NH^4-N per ml
infiltrating the soil column
at a water flux density of 2 $cm\cdot day^{-1}$



Steady lab eqns

STEADY-STATE CONVECTIVE DIFFUSION EQUATIONS

AMMONIUM N
$$D_1 \frac{d^2 C_1}{dz^2} - v \frac{dC_1}{dz} - k_1 C_1 = 0$$

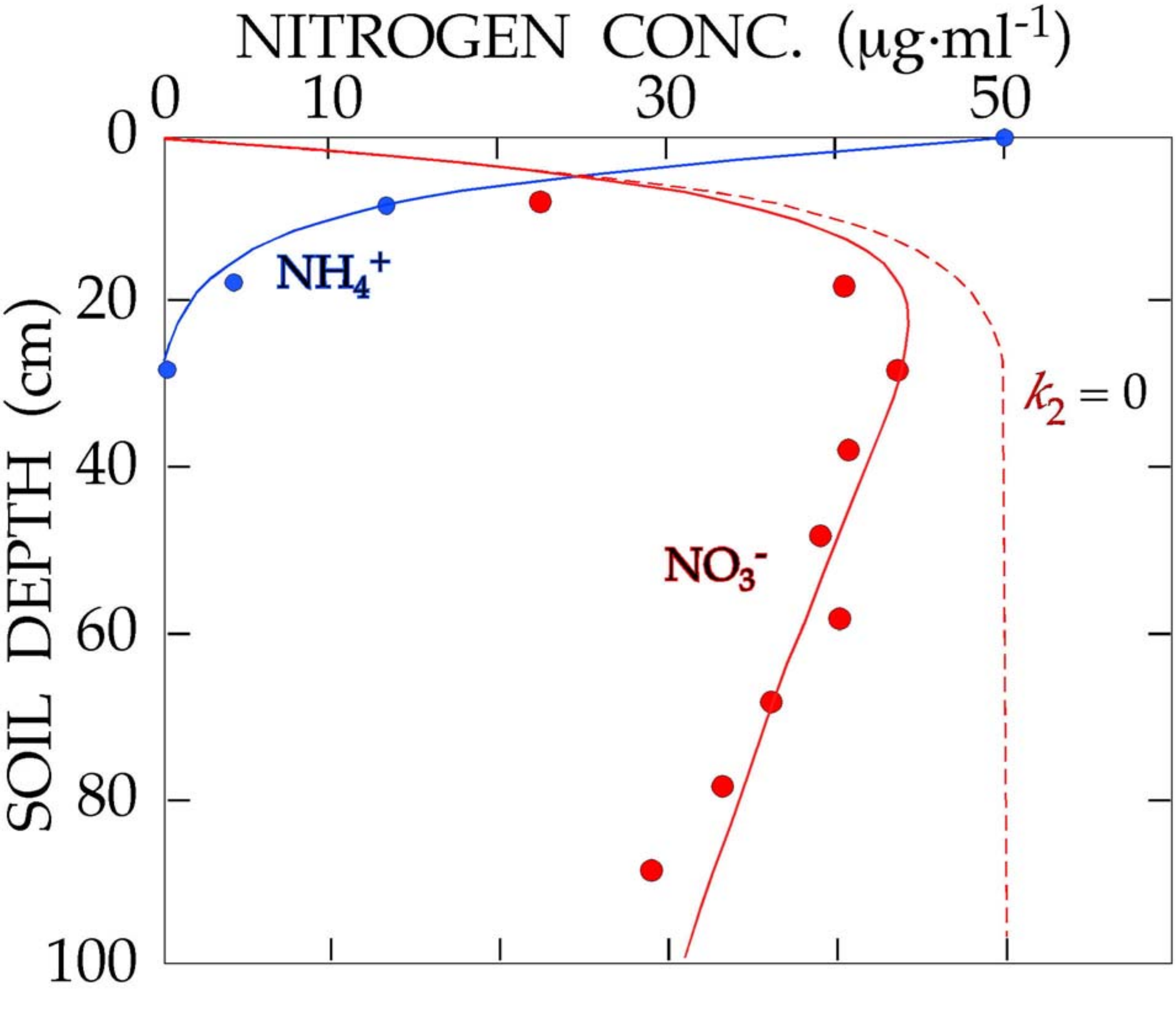
NITRATE N
$$D_2 \frac{d^2 C_2}{dz^2} - v \frac{dC_2}{dz} + k_1 C_1 - k_2 C_2 = 0$$

GASEOUS N_2
$$D_3 \frac{d^2 C_3}{dz^2} + k_2 C_2 = 0$$

AMMONIUM N
$$C_1(z) = C_1^0 \exp\left[\frac{z}{2D_1}\left(v - \sqrt{v^2 + 4D_1 k_1}\right)\right]$$

NITRATE N
$$C_2(z) = \frac{k_1 C_1^0}{k_1 - k_2}\left\{\exp\left[\frac{z}{2D_2}\left(v - \sqrt{v^2 + 4D_2 k_2}\right)\right] - \exp\left[\frac{z}{2D_1}\left(v - \sqrt{v^2 + 4D_1 k_1}\right)\right]\right\}$$

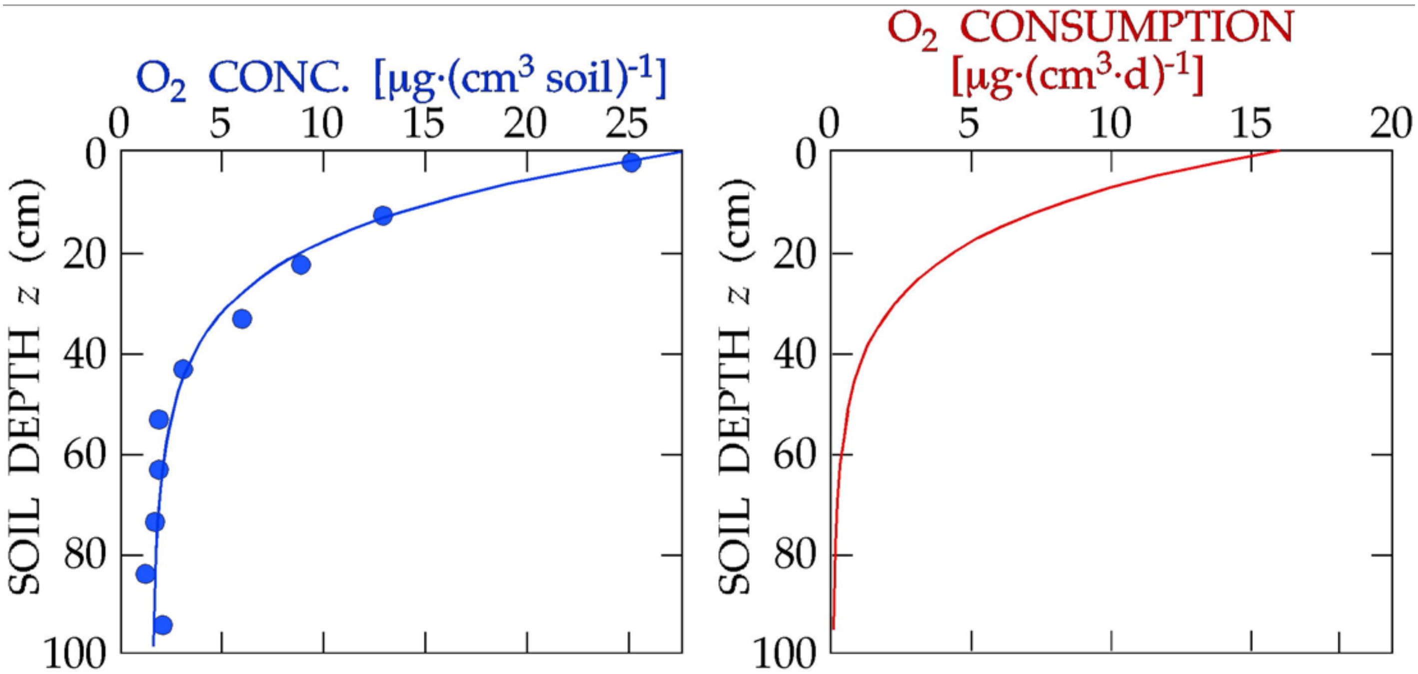
NH4+NO3



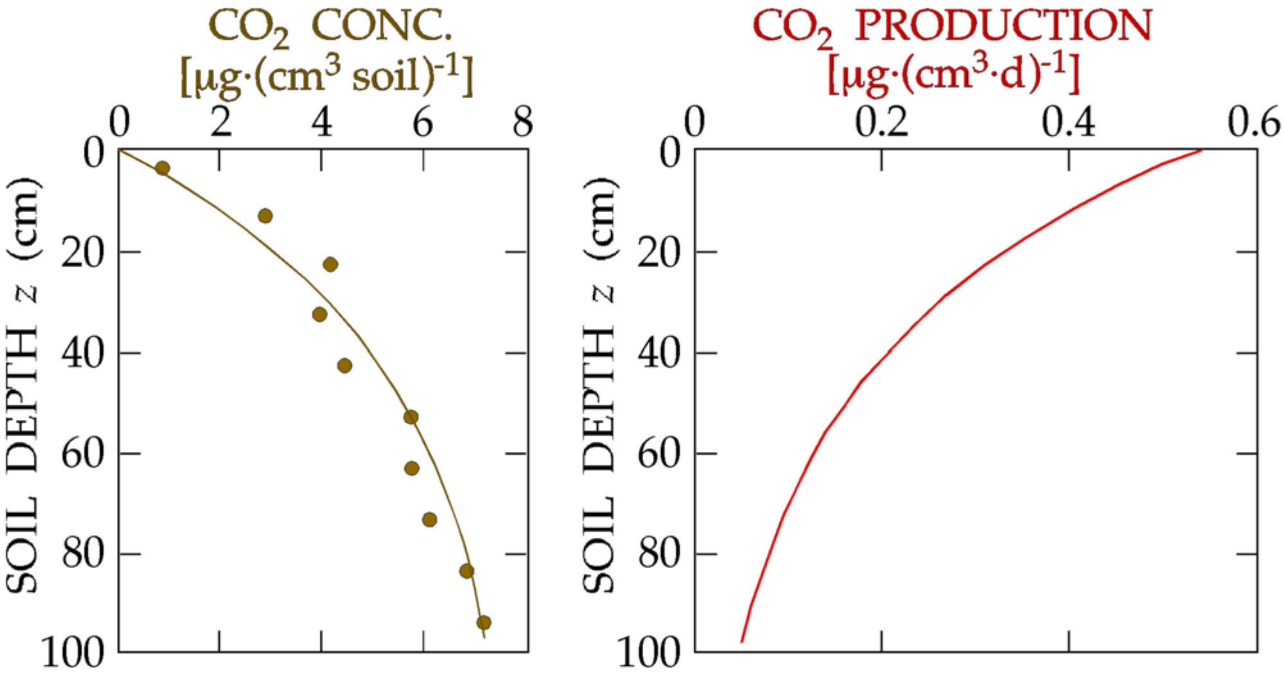
$k_1 = 1.025$ day^{-1} $v = 6$ cm·day^{-1}

$k_2 = 0.0304$ day^{-1} $D_1 = D_2 = 2.3$ cm^2·day^{-1}

O2 profiles


O2 CONC. [µg·(cm3 soil)-1]
0 5 10 15 20 25
SOIL DEPTH z (cm)
0 20 40 60 80 100
O2 CONSUMPTION [µg·(cm3·d)-1]
0 5 10 15 20
SOIL DEPTH z (cm)
0 20 40 60 80 100

CO2 profiles



Nonstdy equations

NONSTEADY-STATE CONVECTIVE DIFFUSION EQNS.

$$UREA \xrightarrow{k_1} NH_4^+ \xrightarrow{k_2} NO_3^- \xrightarrow{k_3} N_2$$

UREA -N

$$\frac{\rho}{\theta}\frac{\partial S_1}{\partial t} + \frac{\partial C_1}{\partial t} = D_1 \frac{\partial^2 C_1}{\partial z^2} - v\frac{\partial C_1}{\partial z} - k_1 C_1$$

$NH_4^+ - N$

$$\frac{\rho}{\theta}\frac{\partial S_2}{\partial t} + \frac{\partial C_2}{\partial t} = D_2 \frac{\partial^2 C_2}{\partial z^2} - v\frac{\partial C_2}{\partial z} + k_1 C_1 - k_2 C_2$$

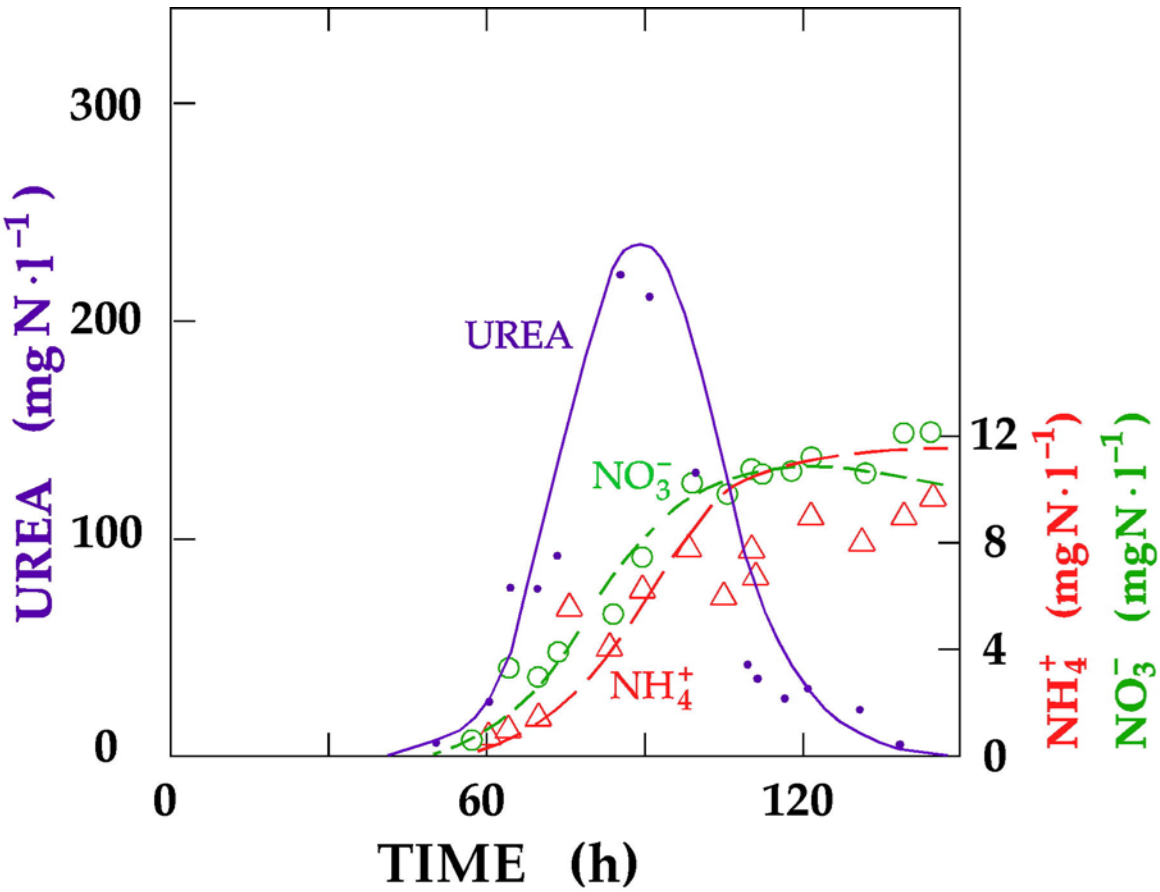
$NO_3^- - N$

$$\frac{\partial C_3}{\partial t} = D_3 \frac{\partial^2 C_3}{\partial z^2} - v\frac{\partial C_3}{\partial z} + k_2 C_2 - k_3 C_3$$

$N_2 - N$

$$\varepsilon\frac{\partial C_4}{\partial t} = D_4 \frac{\partial^2 C_4}{\partial z^2} + k_3 C_3$$

Urea,NH4,NO3



$C_1^0 = 1000 \text{ mg} \cdot l^{-1}$ $\quad k_1 = 0.016 \text{ h}^{-1}$

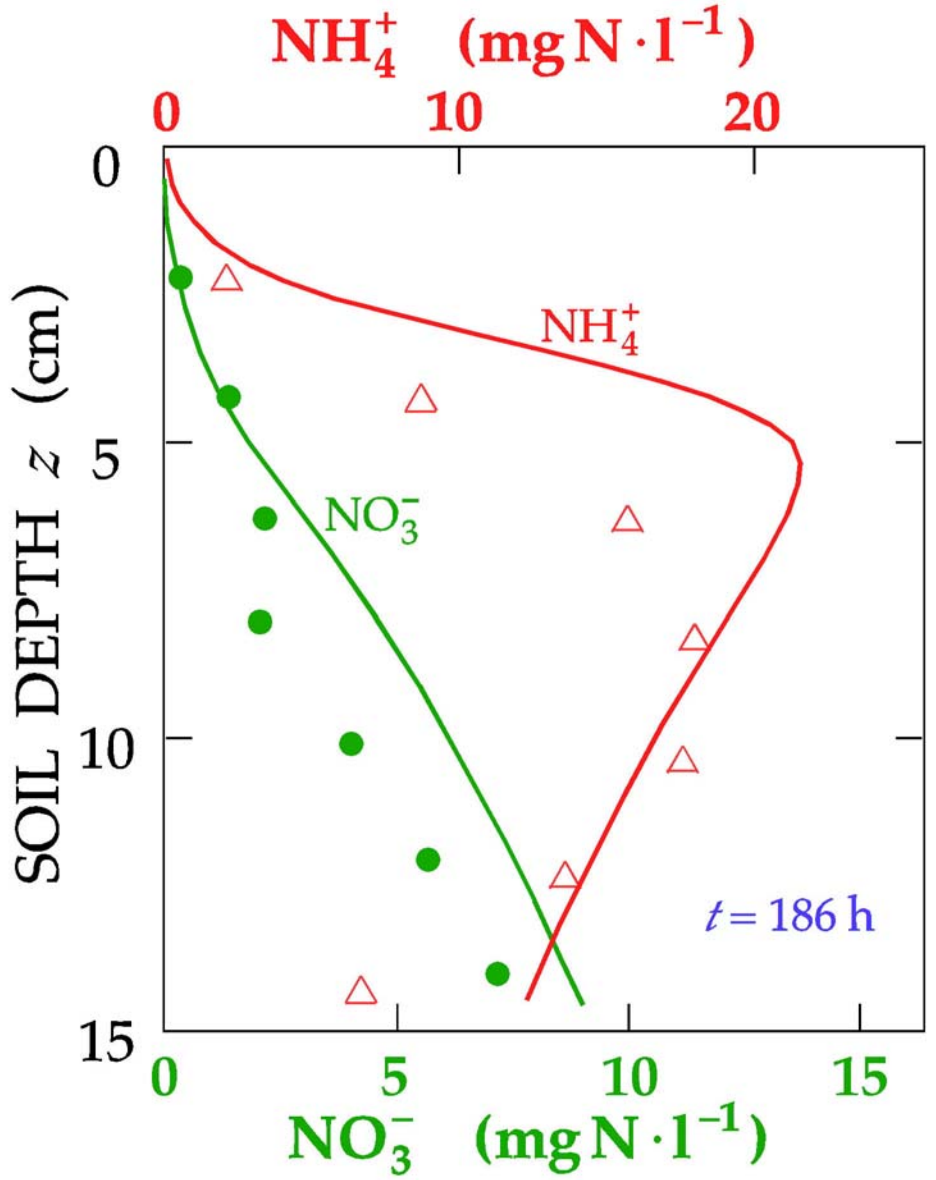
$C_2^0 = 0$ $\quad k_2 = 0.010 \text{ h}^{-1}$

$C_3^0 = 0$ $\quad k_3 = 0.001 \text{ h}^{-1}$

$v = 0.24 \text{ cm} \cdot \text{h}^{-1}$

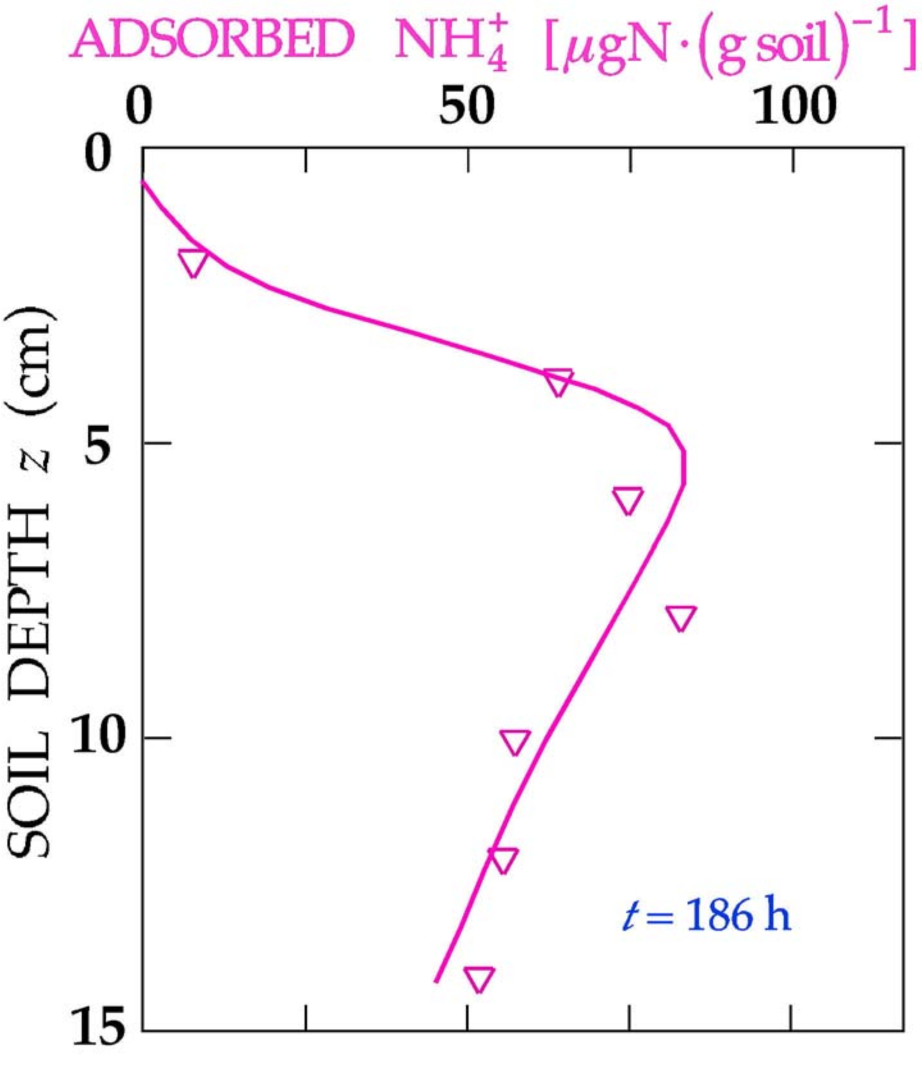
$D = 0.05 \text{ cm}^2 \cdot \text{h}^{-1}$

NO3 profile

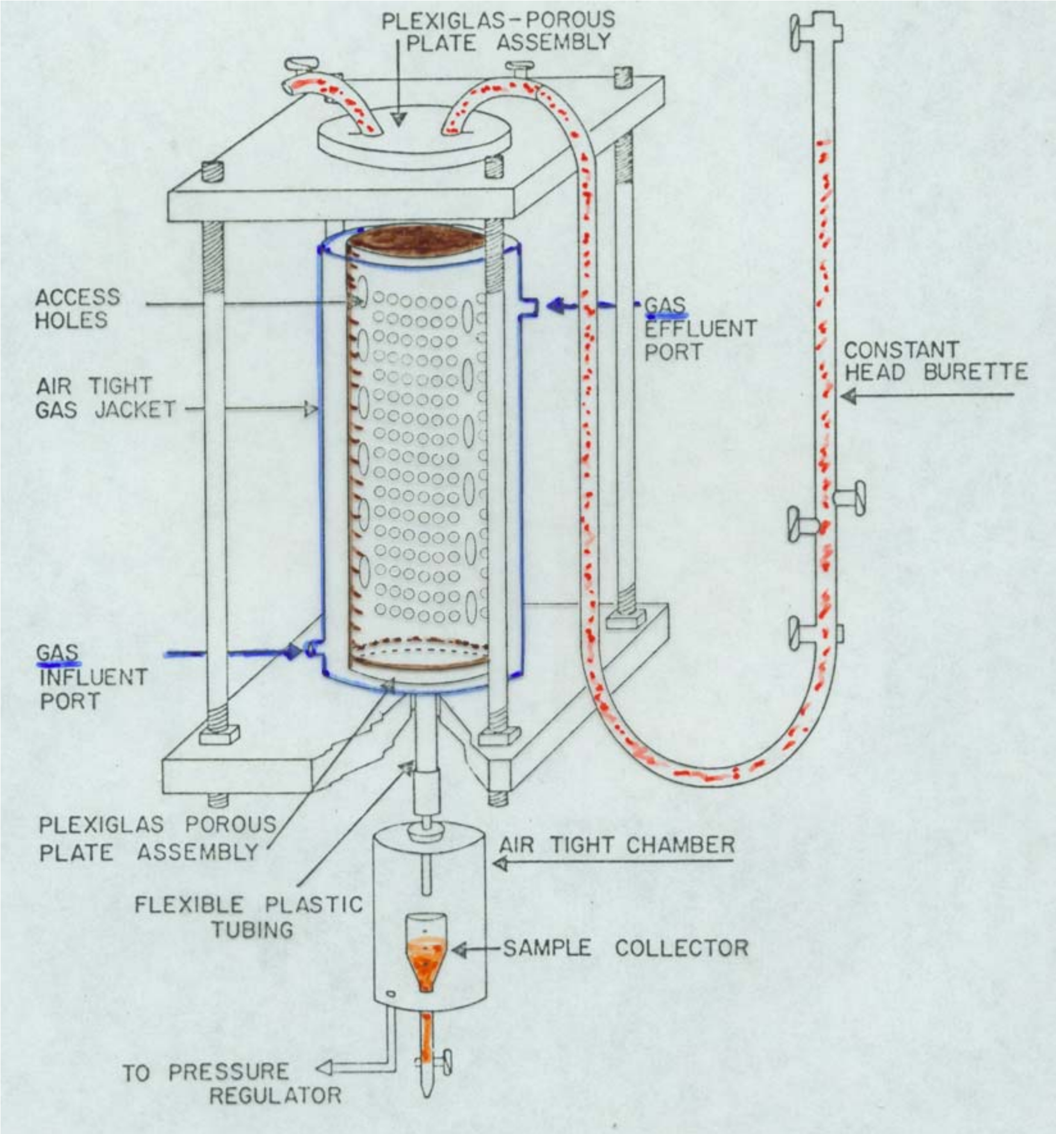


NH_4^+ $(mg\,N \cdot l^{-1})$
0
10
20
0
5
10
15
SOIL DEPTH z (cm)
NH_4^+
NO_3^-
$t = 186$ h
0
5
10
15
NO_3^- $(mg\,N \cdot l^{-1})$

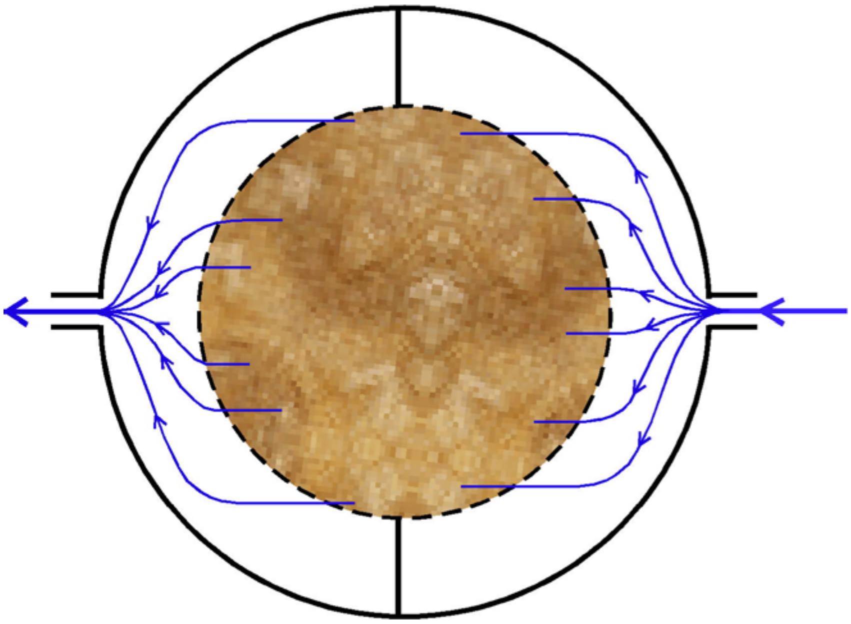
Adsorbed NH4



Control soil air



Soil air flow



Different disciplines

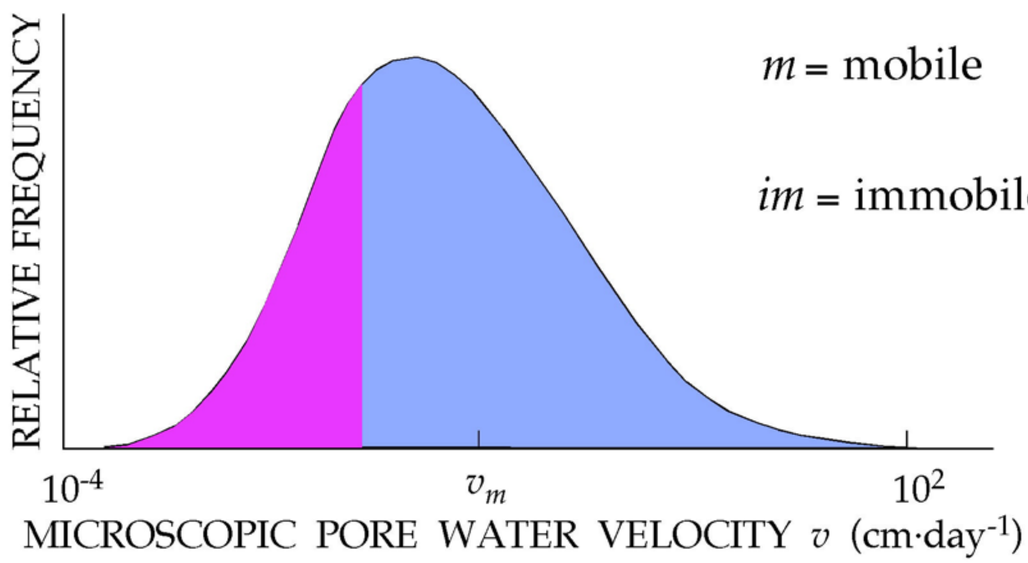
MISCIBLE DISPLACEMENT PHENOMENA ARE NOT WELL UNDERSTOOD OWING TO DIFFERENCES IN SCIENTIFIC DISCIPLINARY VIEWPOINTS

$$\frac{\partial \rho S}{\partial t} + \frac{\partial \theta C}{\partial t} = \theta D \frac{\partial^2 C}{\partial z^2} - \frac{\partial J_w C}{\partial z} \pm \phi$$

CHEMISTS	MATHEMATICIANS	PHYSICISTS	GEOHYDROLOGISTS
$S = f_1(C)$ EQUILIBRIA	PARABOLIC	$D = D_0 + \beta v^n$	IRREVERSIBLE REACTIONS
$\frac{\partial S}{\partial t} = f_2(S,C)$ KINETIC	HYPERBOLIC	MOBILE-IMMOBILE WATER	PLANT PHYSIOLOGISTS
			PLANT ROOT RELATIONS
			MICROBIOLOGISTS
			MICHAELIS-MENTEN REACTIONS

Mobile-immob.

CONCEPT OF MOBILE-IMMOBILE SOIL WATER



$$\theta_m \frac{\partial C_m}{\partial t} + \theta_{im} \frac{\partial C_{im}}{\partial t} = \theta_m D \frac{\partial^2 C_m}{\partial z^2} - v_m \theta_m \frac{\partial C_m}{\partial x}$$

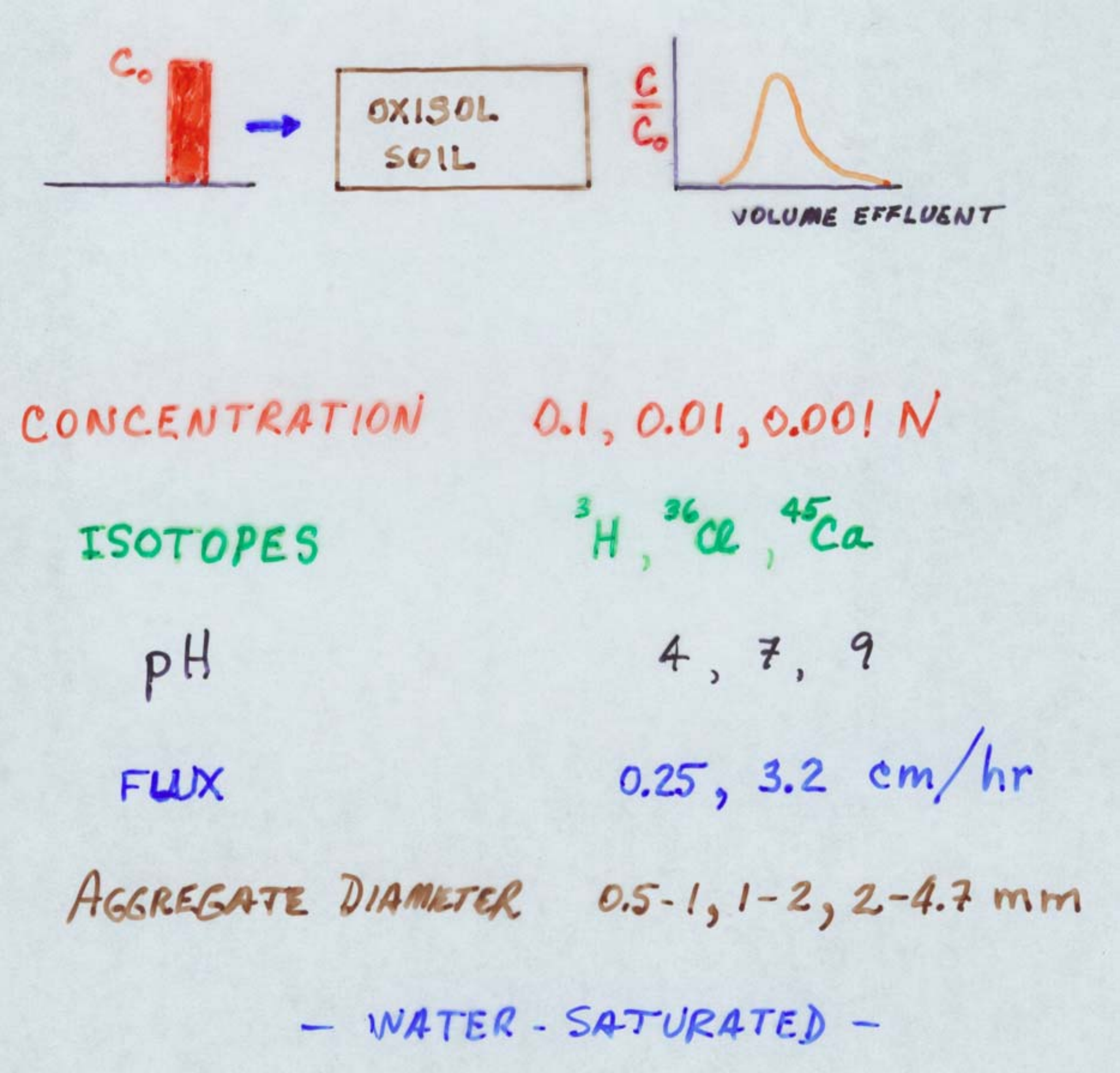
$$\theta_{im} \frac{\partial C_{im}}{\partial t} = \alpha(C_m - C_{im})$$

$\theta = \theta_m + \theta_{im}$ Total Soil Water Content

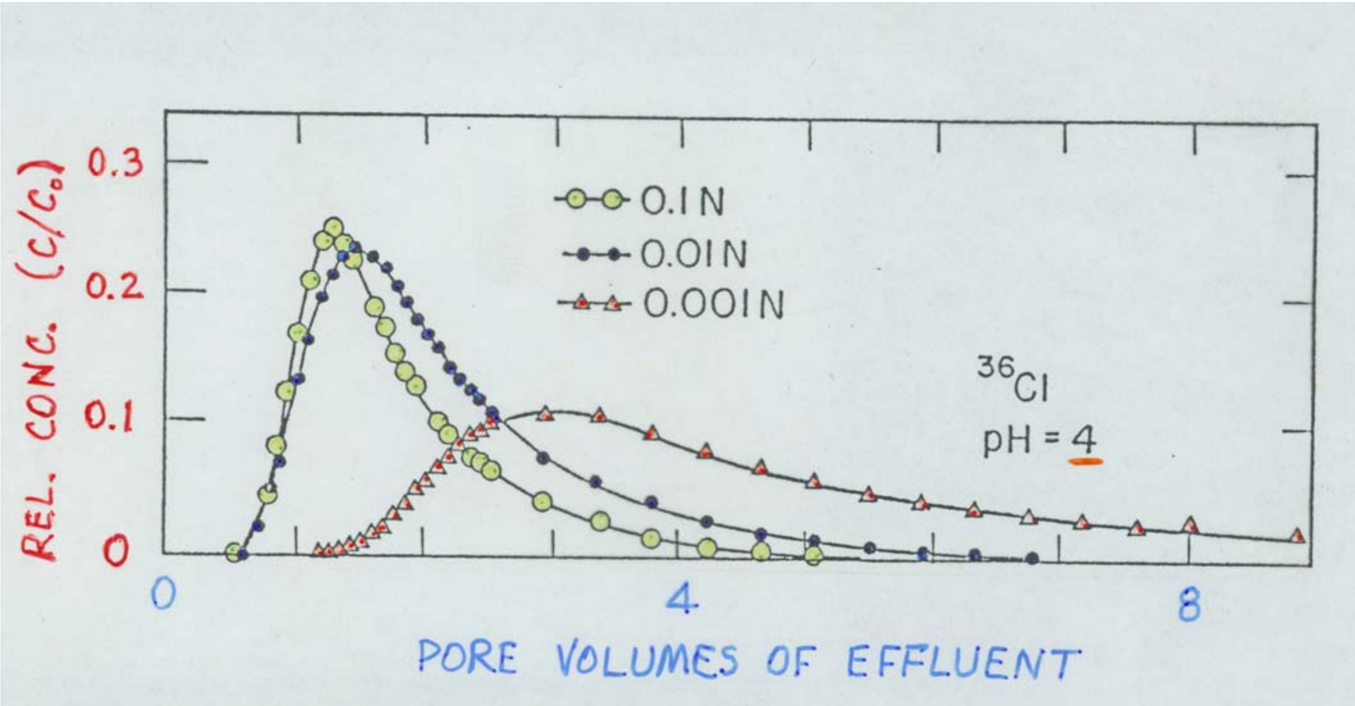
$\phi = \frac{\theta_m}{\theta}$ Fraction of Mobile Water

$1 - \phi$ Fraction of Immobile Water

Oxisol expt

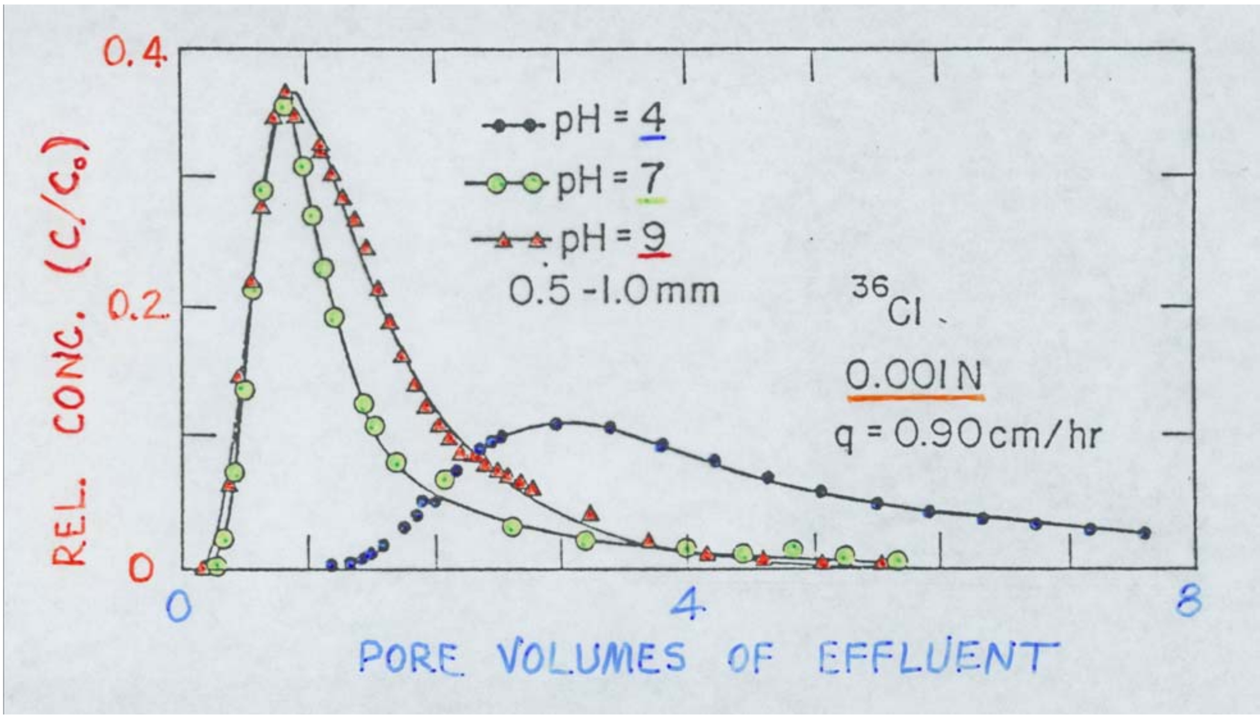

C_o
OXISOL SOIL
$\frac{C}{C_o}$
VOLUME EFFLUENT
CONCENTRATION 0.1, 0.01, 0.001 N
ISOTOPES ^{3}H, ^{36}Cl, ^{45}Ca
pH 4, 7, 9
FLUX 0.25, 3.2 cm/hr
AGGREGATE DIAMETER 0.5-1, 1-2, 2-4.7 mm
– WATER - SATURATED –

0.1,0.01,0.001



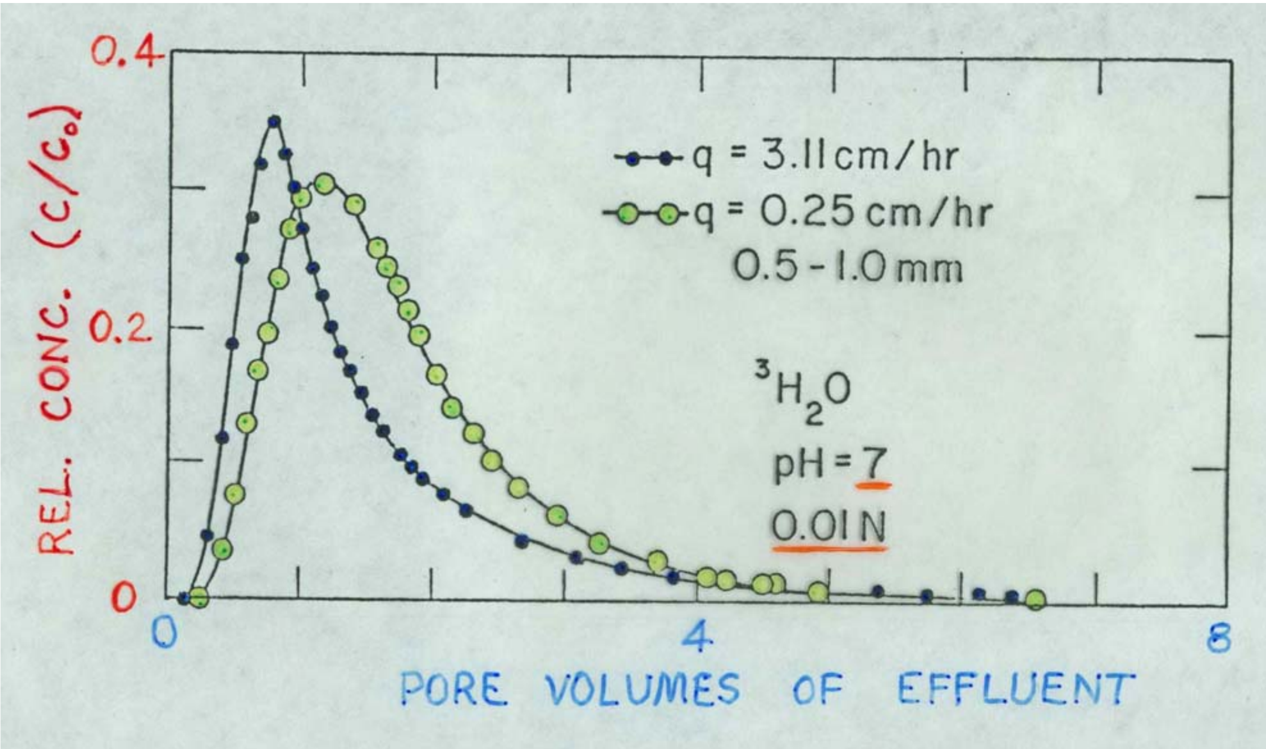
0.3
0.2
0.1
0
REL. CONC. (C/C₀)
0
4
8
PORE VOLUMES OF EFFLUENT
0.1 N
0.01 N
0.001 N
36Cl
pH = 4

pH 4, 7, 9



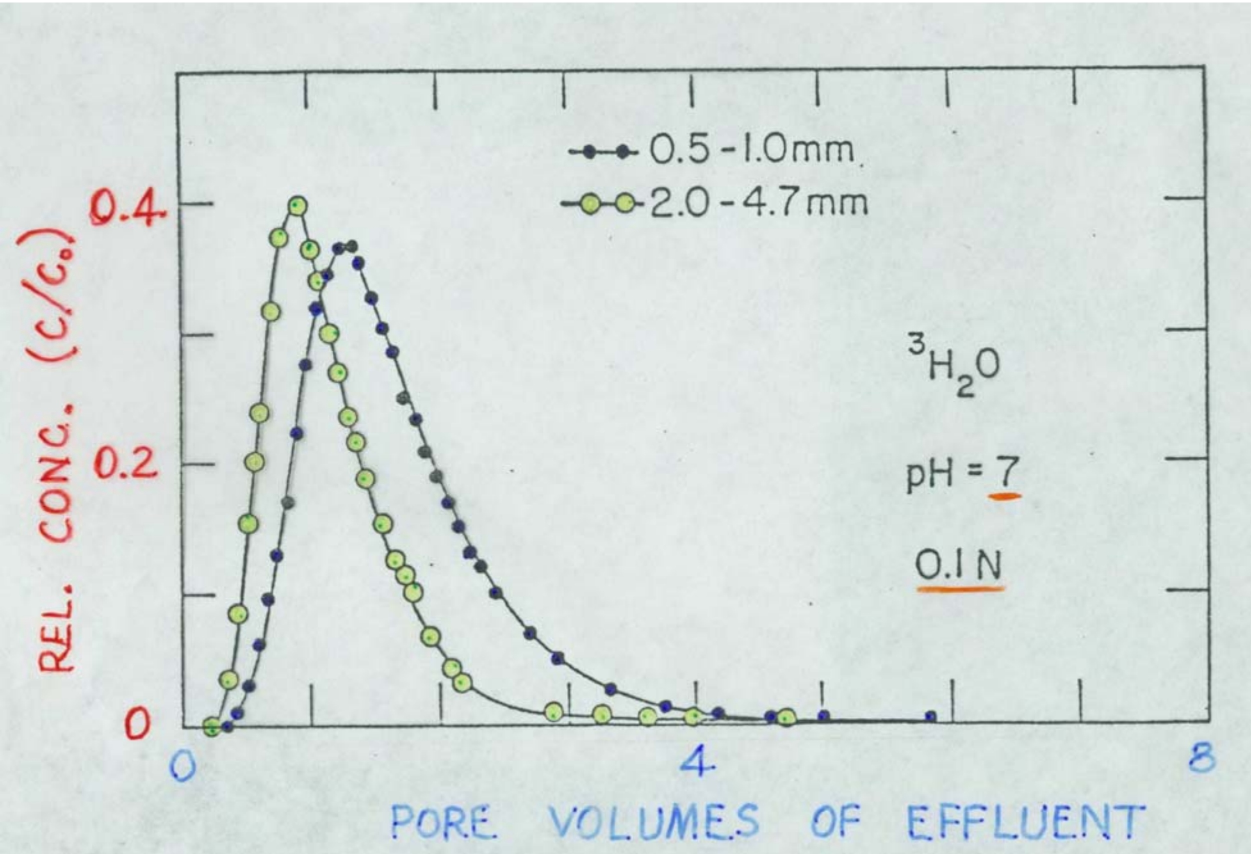
0.4
0.2
0
REL. CONC. (C/C₀)
pH = 4
pH = 7
pH = 9
0.5 -1.0 mm
36Cl
0.001 N
q = 0.90 cm/hr
0
4
8
PORE VOLUMES OF EFFLUENT

2 fluxes

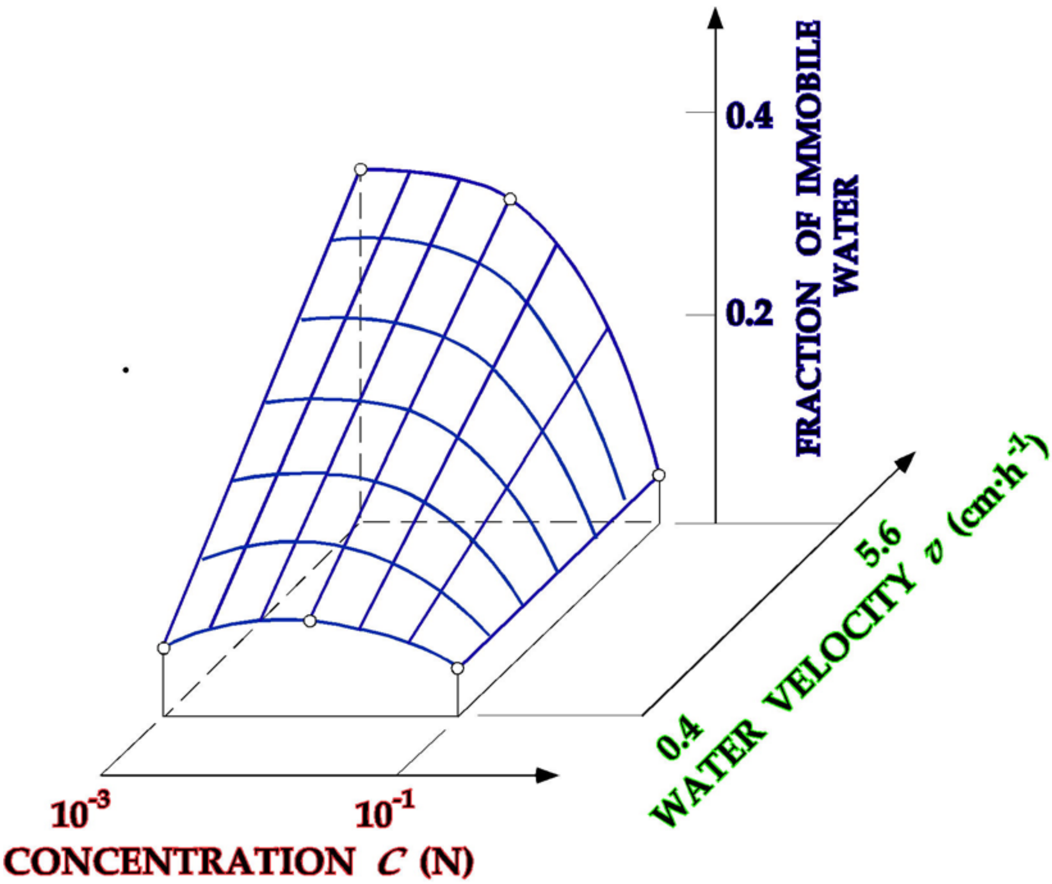


0.4
0.2
0
REL. CONC. (c/c₀)
q = 3.11 cm/hr
q = 0.25 cm/hr
0.5 - 1.0 mm
³H₂O
pH = 7
0.01 N
0
4
8
PORE VOLUMES OF EFFLUENT

2aggregate size



Immobile water



MD Theories

MISCIBLE DISPLACEMENT THEORIES

CONVECTIVE-DIFFUSION EQUATIONS

STOCHASTIC CONTINUUM APPROACHES

STOCHASTIC CONVECTION APPROACHES

TRANSFER FUNCTIONS

CHROMATOGRAPHIC APPROACHES

MARKOV PROCESSES

MONTE CARLO SIMULATIONS

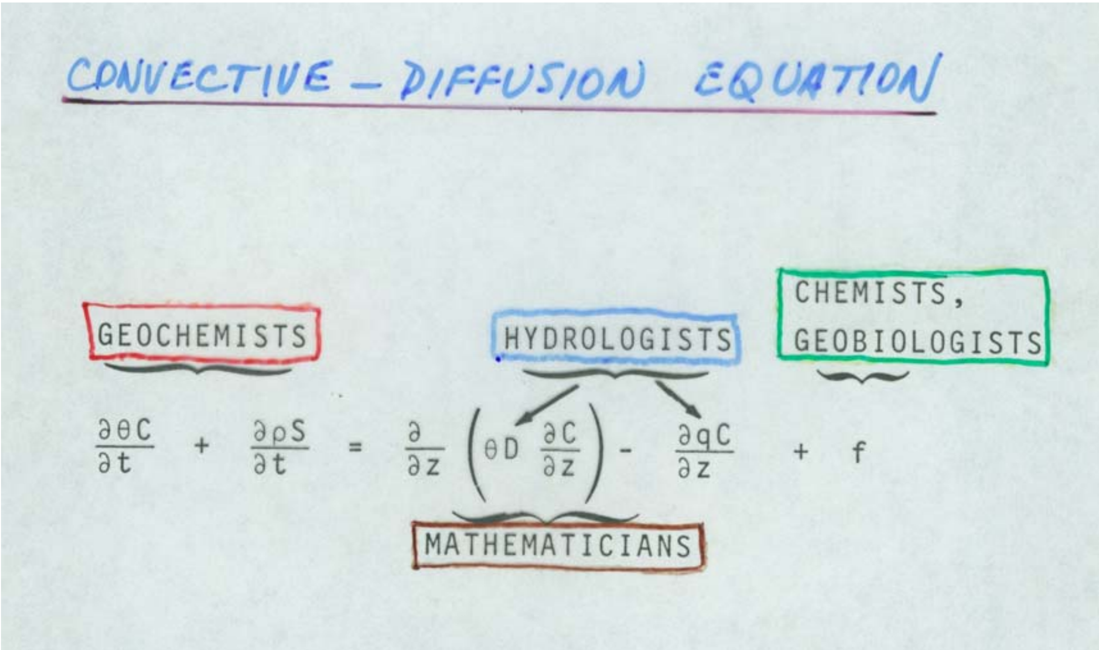
DETERMINISTIC EQUATIONS

KINEMATIC WAVE EQUATIONS

DUAL POROSITY MODELS

•
•
•
•

Conv-diffusion Eq.



Stoch-continuum

STOCHASTIC CONTINUUM APPROACH

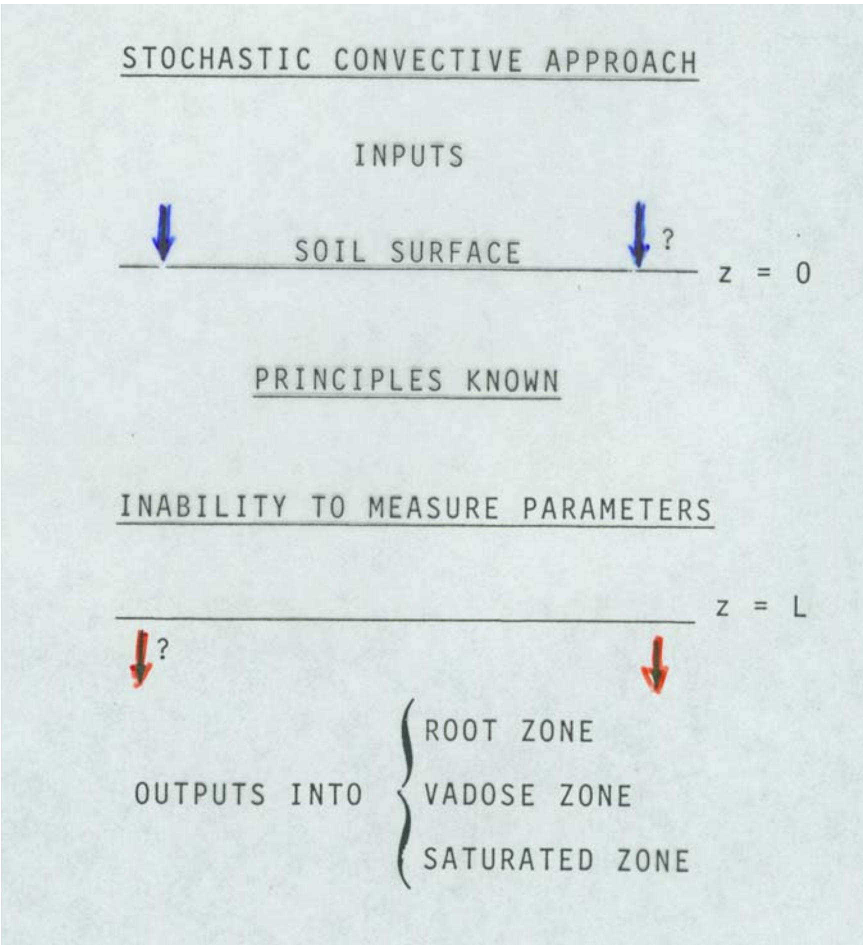
$$Q = - K \frac{dH}{dz}$$

$$Q + q = - [K + k] \frac{d[H + h]}{dz}$$

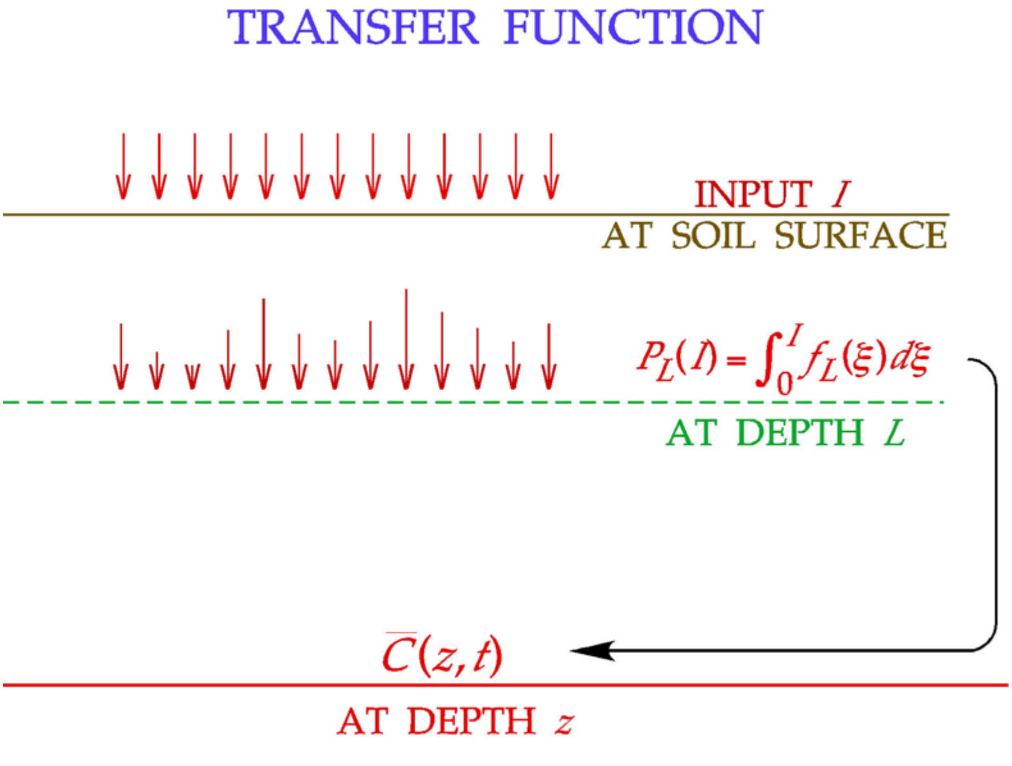
$$Q + q = - K \frac{dH}{dz} - K \frac{dh}{dz} - k \frac{dH}{dz} - k \frac{dh}{dz}$$

$$q = - K \frac{dh}{dz} - k \frac{dH}{dz} - k \frac{dh}{dz}$$

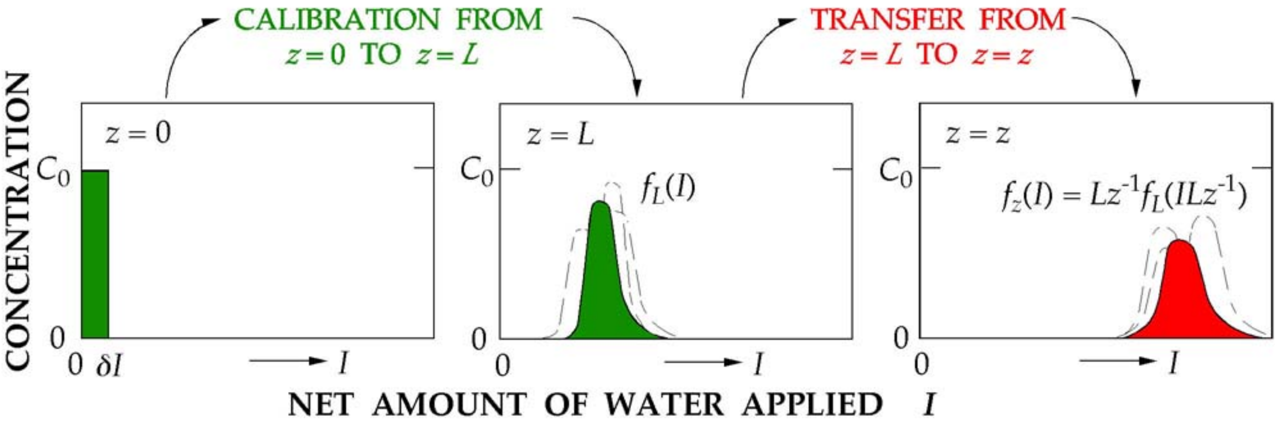
Stoch-convective



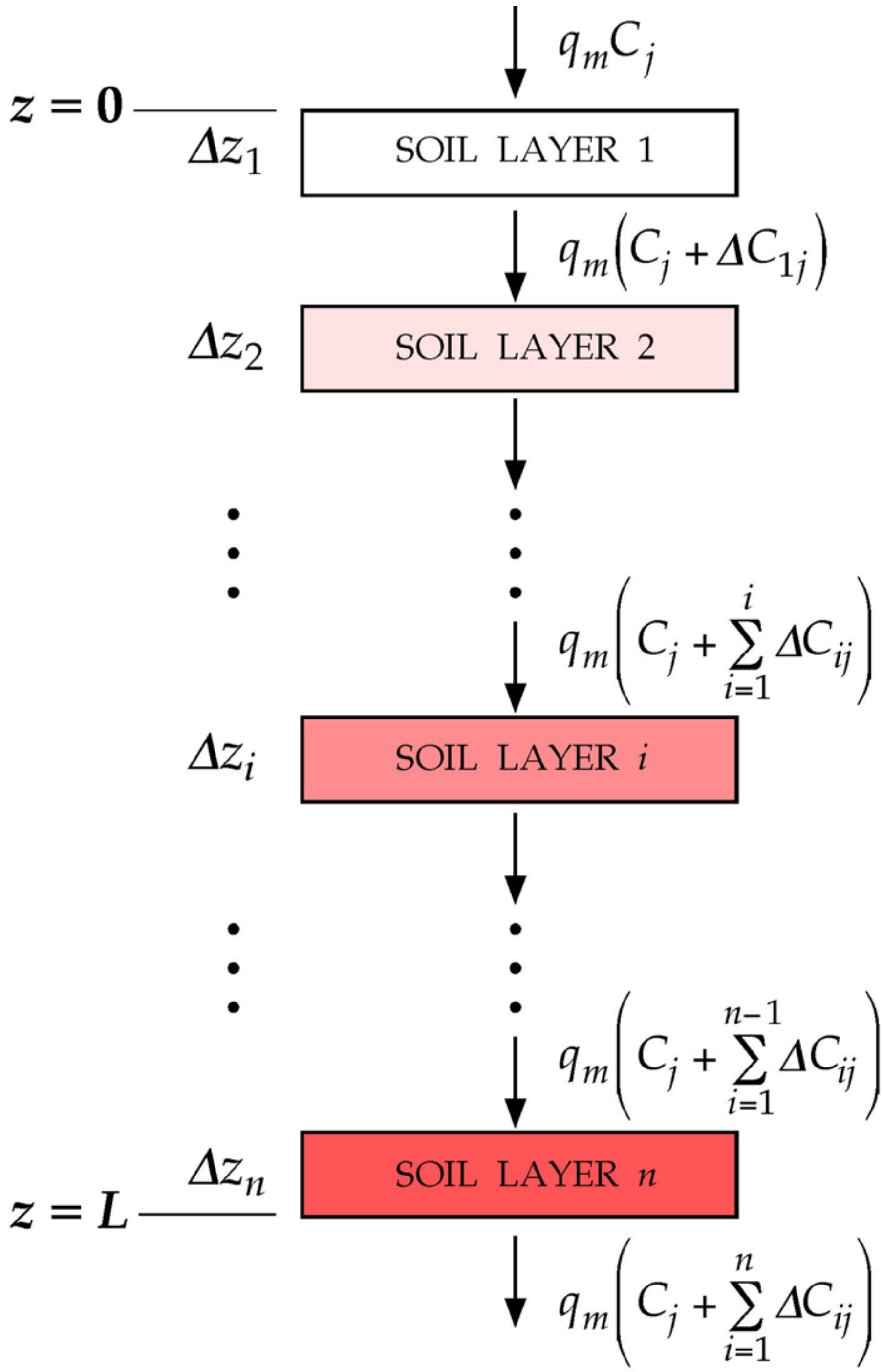
Transfer function



Trans functions

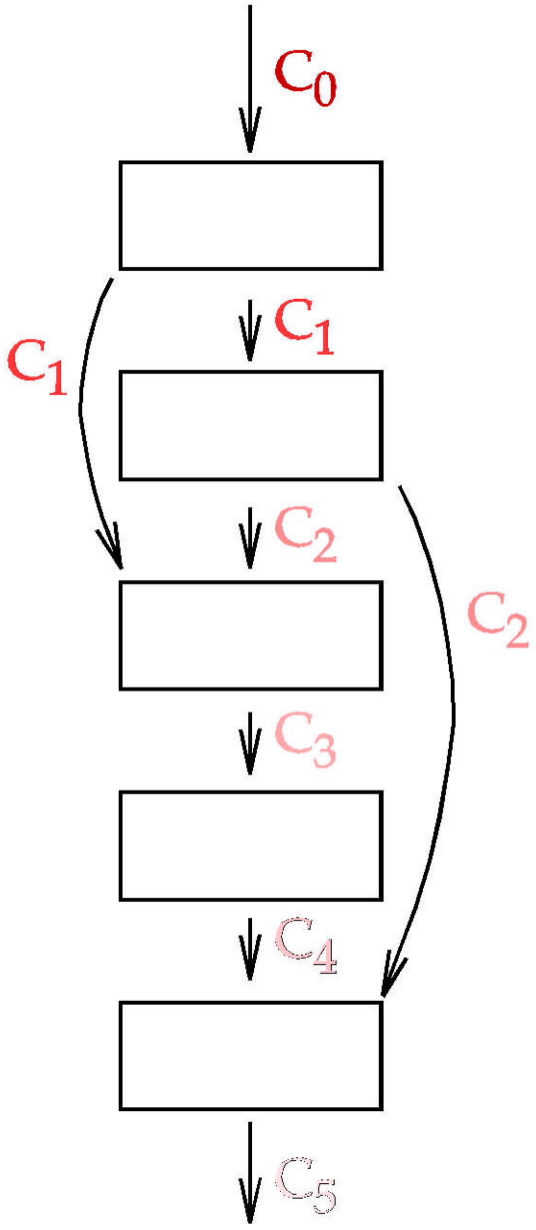


Chromatogr


$q_m C_j$
$z = 0$
Δz_1
SOIL LAYER 1
$q_m \left(C_j + \Delta C_{1j} \right)$
Δz_2
SOIL LAYER 2
$q_m \left(C_j + \sum_{i=1}^{i} \Delta C_{ij} \right)$
Δz_i
SOIL LAYER i
$q_m \left(C_j + \sum_{i=1}^{n-1} \Delta C_{ij} \right)$
Δz_n
SOIL LAYER n
$z = L$
$q_m \left(C_j + \sum_{i=1}^{n} \Delta C_{ij} \right)$

Markov Process

A RANDOM PROCESS WHOSE FUTURE PROBABILITIES ARE DETERMINED BY ITS MOST RECENT VALUES



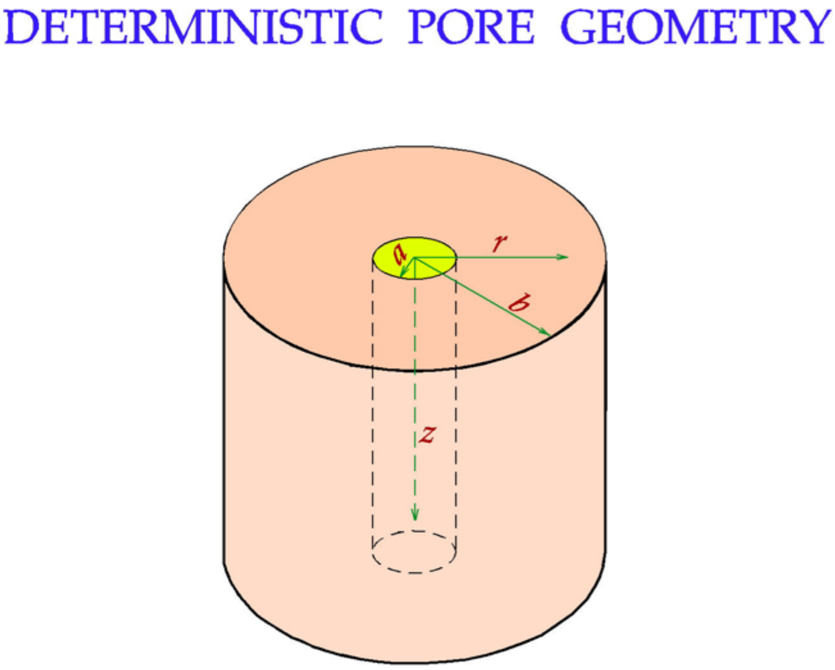
Monte carlo simulation

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - v\frac{\partial C}{\partial z}$$

$$C = C(z, t \mid D, v)$$

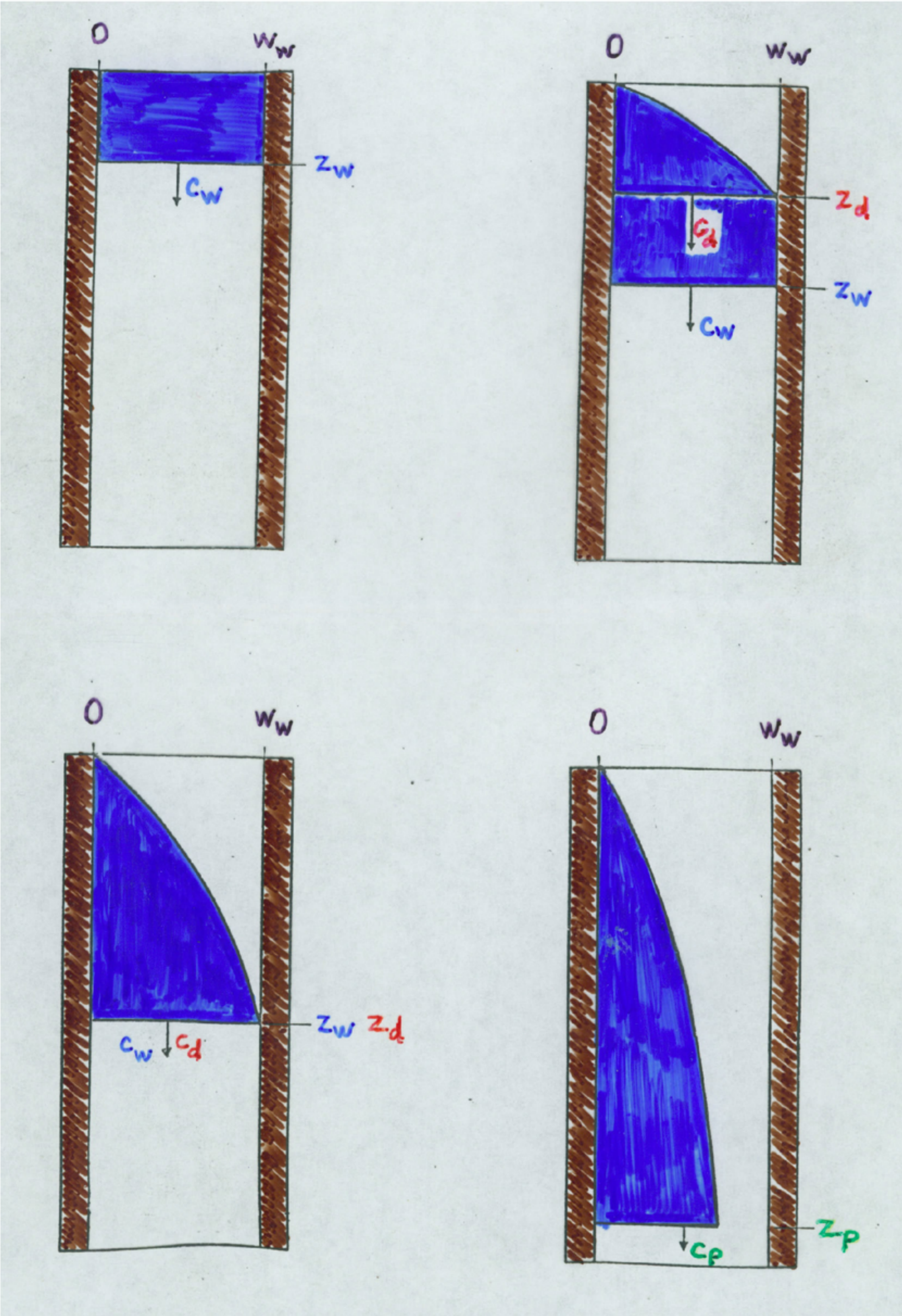
$$\overline{C}(z,t) = \int_0^{C_0} f(C \mid z,t)\, C\, dC$$

Deterministic



Kinematic wave

KINEMATIC WAVE OF INFILTRATION



Questions

BECAUSE OF MACROPORES, CAN LEACHING BE DESCRIBED BY THE CONVECTIVE - DIFFUSION EQUATION ?

BECAUSE OF SPATIAL VARIABILITY, WHAT IS THE "PROPER" NUMBER OF SAMPLES ?

WHAT ARE THE MERITS OF SOIL SOLUTION PROBES, AND DO THEY REPRESENT THE ' "REAL" SITUATION ?

WHICH ARE THE BEST MODELS TO DESCRIBE SOLUTE MOBILITY AND RETENTION ?

ARE CHEMICAL REACTIONS MORE IMPORTANT THAN PHYSICAL REACTIONS ?

HOW IS A MODEL VERIFIED ?

HOW CAN THE RESULTS FROM A SMALL EXPERIMENTAL PLOT BE EXTEND OVER AN ENTIRE FIELD ?

Important points

IMPORTANT POINTS ABOUT LEACHING

As water moves more slowly through a soil, greater opportunity exists for more complete mixing and chemical reactions to take place within the entire pore structure owing to molecular diffusion compared with convection.

Microscopic pore water velocity distributions manifest their greatest divergence for water-saturated soil conditions. Hence, under water-saturated conditions, the greatest proportion of water moves through the soil matrix within the largest pore sequences.

Under water-saturated soil conditions, when the average pore water velocity is large compared with transport by molecular diffusion, the relative amount of solute being displaced depends upon the solute concentration of the invading water.

The concept of preferential flow paths occurs at all degrees of water-unsaturation even though their existence is usually only demonstrated for macropores near water-saturation. At each progressively smaller water content, the larger pore sequences remaining full of water establish still another set of preferential flow paths.

Any attempt to measure the solute concentration based on extraction methods carried out either in the laboratory or the field will depend upon the rate of extraction and the soil water content during the extraction process.

Inasmuch as rainfall infiltration usually occurs at greater soil water contents and greater average pore water velocities than does evaporation, the amount of solutes transported near the soil surface per unit water moving through the soil surface is greater for evaporation than for infiltration.