INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR/147 - 33

COLLEGE ON SOIL PHYSICS

15 April - 3 May 1985

COLLOQUIUM ON ENERGY FLUX AT THE SOIL ATMOSPHERE INTERFACE

6 - 10 May 1985

MOVEMENT OF SOLUTES: MISCIBLE DISPLACEMENT

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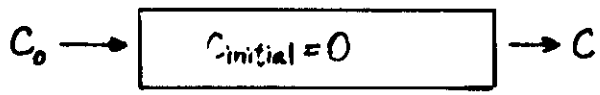
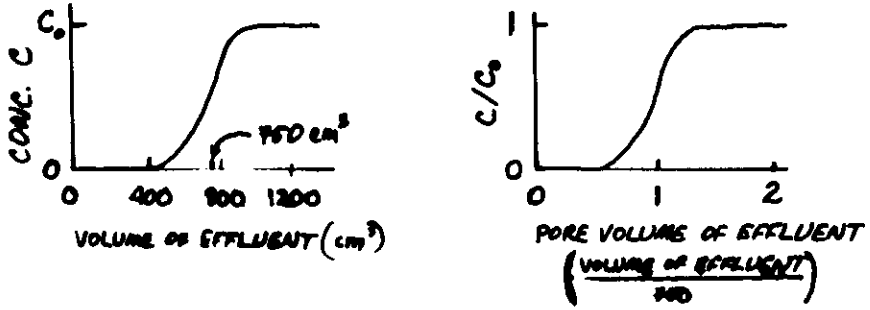
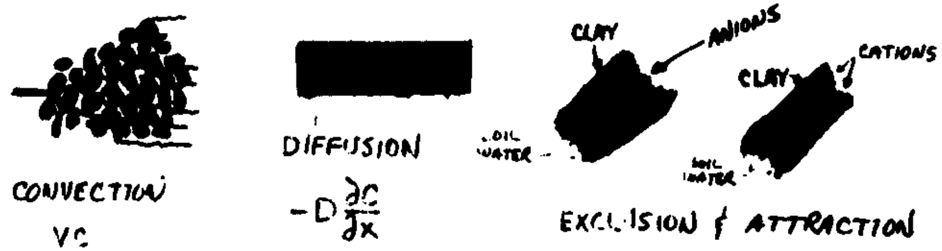
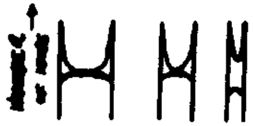
MISCIBLE DISPLACEMENT

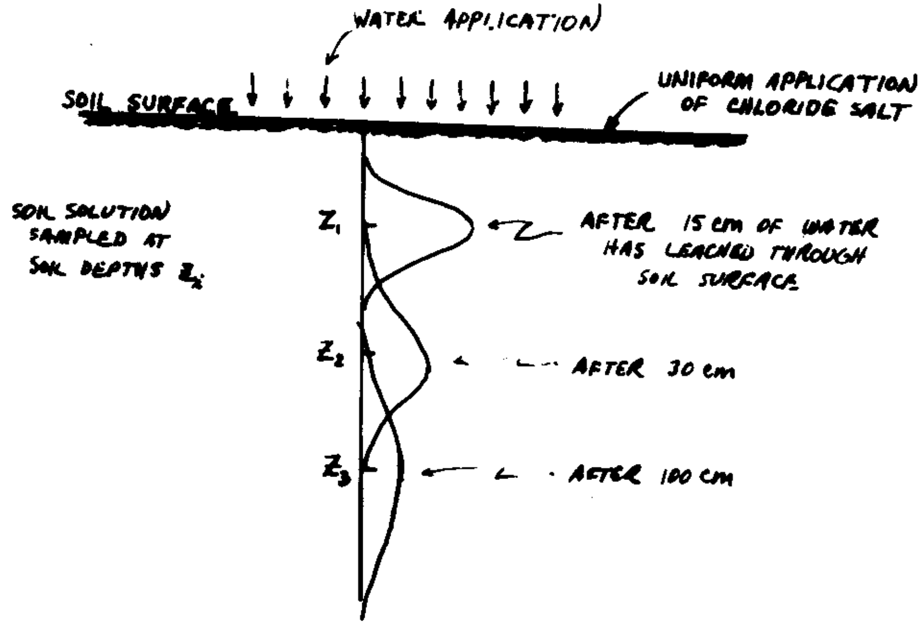








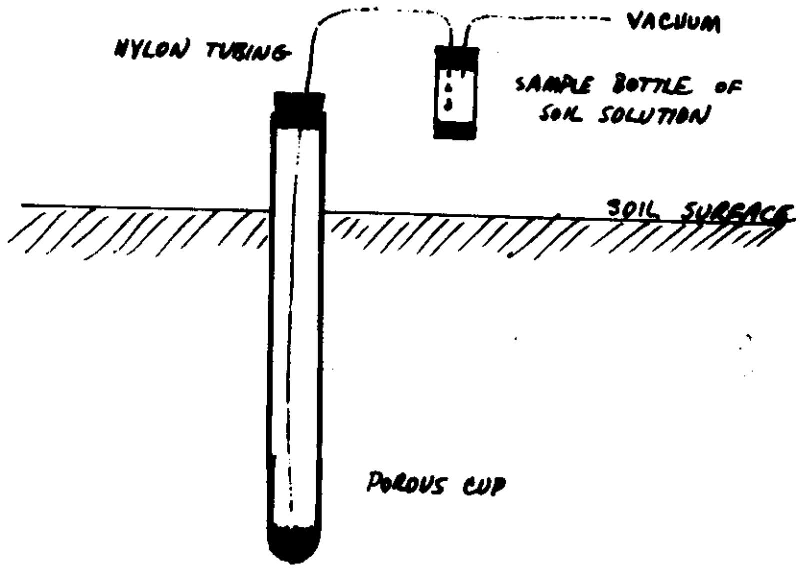
FIELD LEACHING EXPERIMENT



FIELD LEACHING EXPERIMENTAL CONDITIONS

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

SOIL SOLUTION SAMPLER IN FIELD SOILS

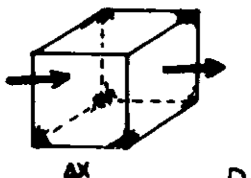


CONVECTIVE - DIFFUSION EQUATION

INFLUX

$J_{convection} = J_{water} C$

$J_{diffusion} = -D \dfrac{\partial C}{\partial x}$



OUTFLUX

$J_w C + \dfrac{\partial J_w C}{\partial x} \Delta x$

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

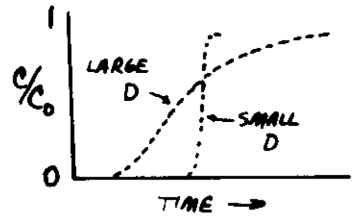
TIME RATE OF CHANGE OF AMOUNT OF SOLUTE IN VOLUME OF BOX = INFLUX − OUTFLUX

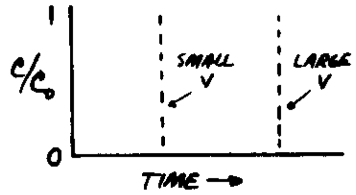
$$\frac{\partial \varepsilon G}{\partial t} + \frac{\partial \rho S}{\partial t} + \frac{\partial \theta C}{\partial t} = \frac{\partial}{\partial x}\left(D \frac{\partial C}{\partial x}\right) - \frac{\partial J_w C}{\partial x} \begin{array}{l} + \text{SOURCE} \\ - \text{SINK} \end{array}$$

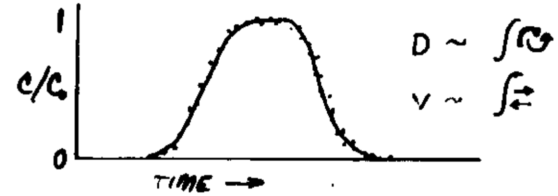
ASSUME:
- NO SOLUTE IN GASEOUS PHASE
- NO SOURCES OR SINKS
- BULK DENSITY ρ IS CONSTANT
- SOIL WATER CONTENT θ IS CONSTANT
- SOIL WATER FLUX J_w IS CONSTANT
- APPARENT DIFFUSION COEFFICIENT IS CONSTANT
- SOIL IS HOMOGENEOUS

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

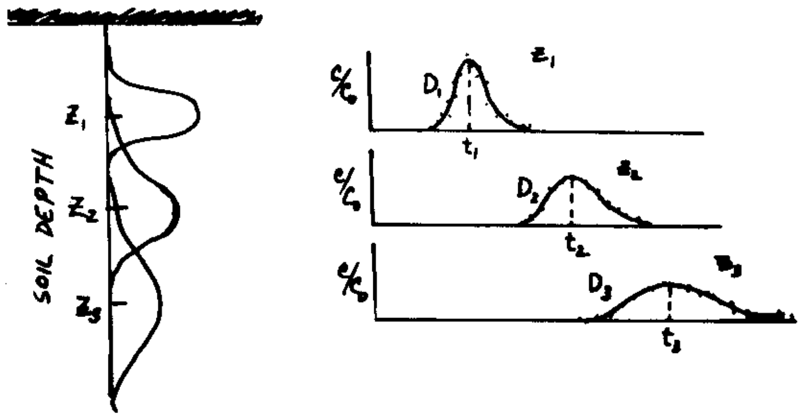
ESTIMATING THE VALUES OF D & V FROM FIELD-MEASURED BREAKTHROUGH CURVES







$$\frac{C}{C_0} = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{x - vt}{\sqrt{4Dt}}\right) + \exp\left(\frac{vx}{D}\right)\operatorname{erfc}\left(\frac{x + vt}{\sqrt{4Dt}}\right)\right] - \frac{1}{2}\left[\operatorname{erfc}\left(\frac{x - v(t - t_1)}{\sqrt{4D(t - t_1)}}\right) + \exp\left(\frac{vx}{D}\right)\operatorname{erfc}\left(\frac{x - v(t - t_1)}{\sqrt{4D(t - t_1)}}\right)\right]$$

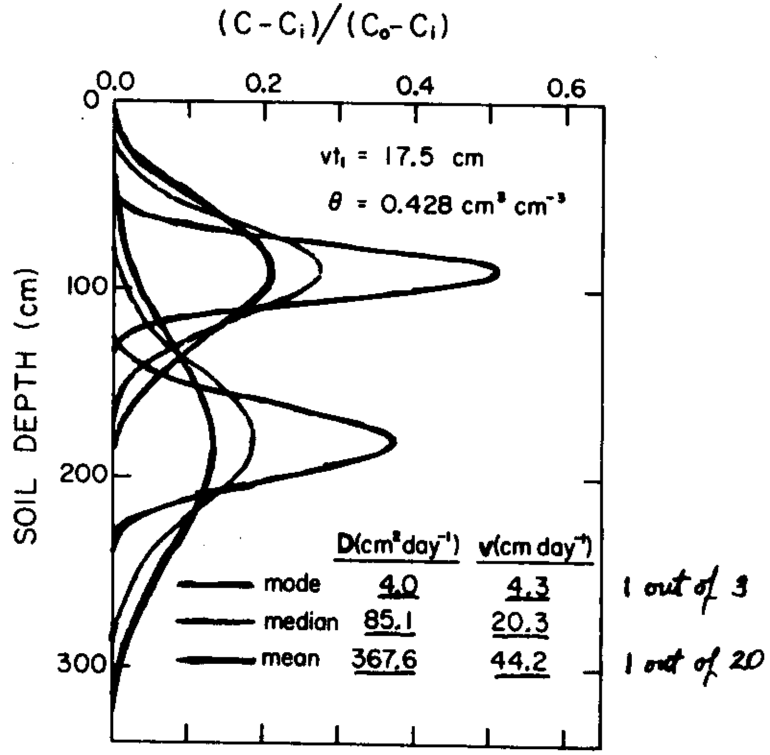


$\dfrac{z_1}{t_1} = v_1$

$\dfrac{z_2}{t_2} = v_2$

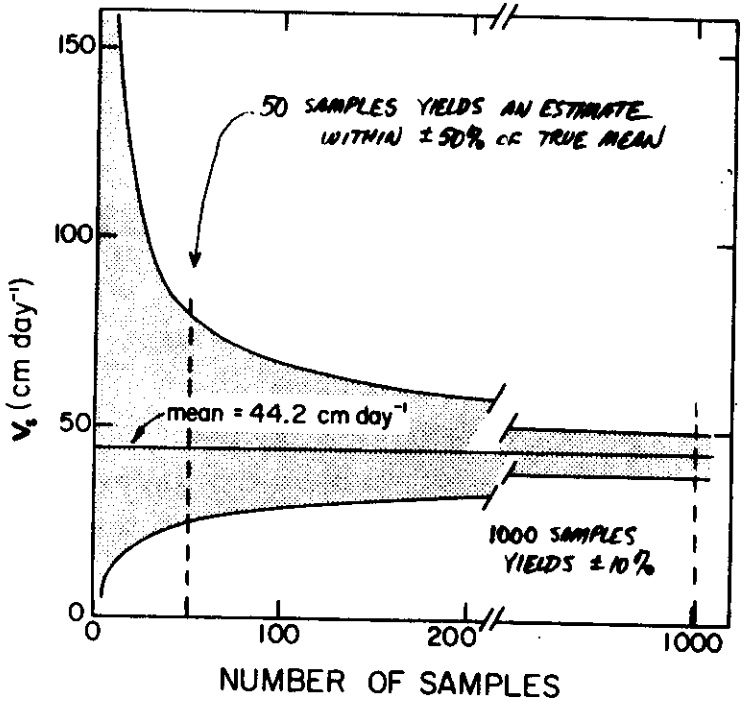
$\dfrac{z_3}{t_3} = v_3$

⑥



(C - C_i)/(C_o - C_i)
0.0
0.2
0.4
0.6
0
100
200
300
SOIL DEPTH (cm)
vt_1 = 17.5 cm
θ = 0.428 cm³ cm⁻³
D(cm² day⁻¹)
v(cm day⁻¹)
mode 4.0 4.3
median 85.1 20.3
mean 367.6 44.2
1 out of 3
1 out of 20

⑦



150
100
50
0
V_s (cm day⁻¹)
50 SAMPLES YIELDS AN ESTIMATE WITHIN ±50% OF TRUE MEAN
mean = 44.2 cm day⁻¹
1000 SAMPLES YIELDS ±10%
0
100
200
1000
NUMBER OF SAMPLES

[redacted]

(8)

AMMONIUM APPLIED TO THE SOIL SURFACE & LEACHED THROUGH THE SOIL PROFILE

NH_4^+ (C_1) IS OXIDIZED BY SOIL MICROBES UNDER AEROBIC CONDITIONS TO NO_3^- (C_2)

$$-\left.\frac{dC_1}{dt}\right|_{ox.} = \frac{dC_2}{dt} = -\frac{k_1 C_1}{K_1 + C_1}$$

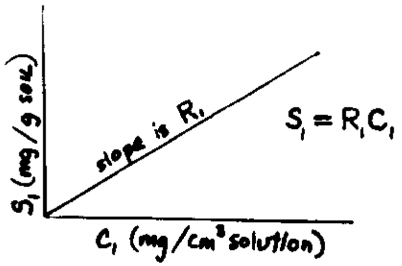
IF: $C_1 \ll K_1$

$$-\left.\frac{dC_1}{dt}\right|_{ox.} = \frac{-k_1 C_1}{K_1} = -k_1 C_1 \quad \text{FIRST-ORDER}$$

IF: $C_1 \gg K_1$

$$-\left.\frac{dC_1}{dt}\right|_{ox.} = \frac{-k_1 C_1}{C_1} = -k_1 \quad \text{ZERO-ORDER}$$

NH_4^+ TAKES A PART OF THE CATION EXCHANGE PROCESS

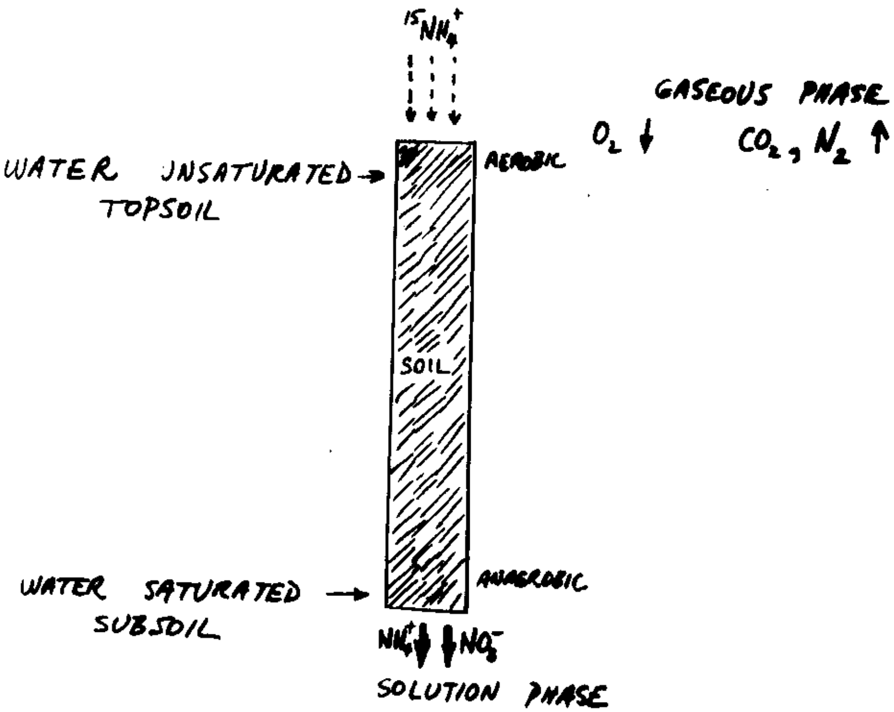


$$\frac{\partial \rho S_1}{\partial t} + \frac{\partial \theta C_1}{\partial t} = \theta D_1 \frac{\partial^2 C_1}{\partial x^2} - \frac{\partial J_w C_1}{\partial x} - \left.\frac{\partial \theta C_1}{\partial t}\right|_{ox.}$$

$$\frac{\partial}{\partial t}[(\rho R_1 + \theta)C_1] = \theta D_1 \frac{\partial^2 C_1}{\partial x^2} - \frac{\partial J_w C_1}{\partial x} - \theta k_1 C_1$$

(9)

STEADY-STATE EXAMPLE



STUDY RATES, NOT CAPACITIES

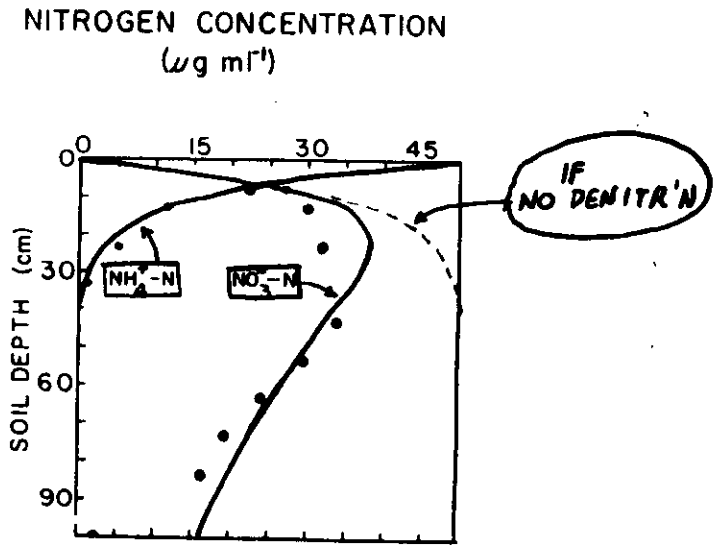
STEADY-STATE LEACHING CONDITIONS

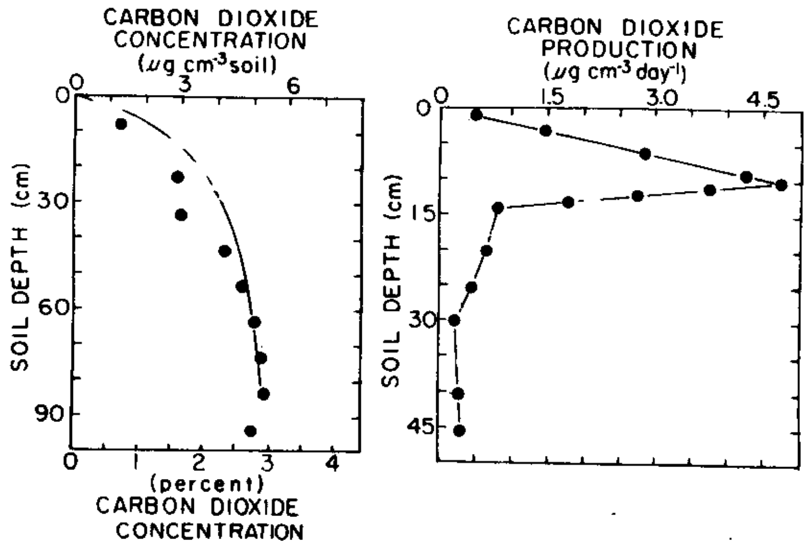
- CONSTANT INFILTRATION OF WATER INTO SOIL SURFACE
- WATER CONTAINS A CONSTANT CONCENTRATION OF NH_4^+

AMMONIUM $$D_1 \frac{\partial^2 C_1}{\partial x^2} - \frac{\partial v C_1}{\partial x} - k_1 C_1 = 0$$

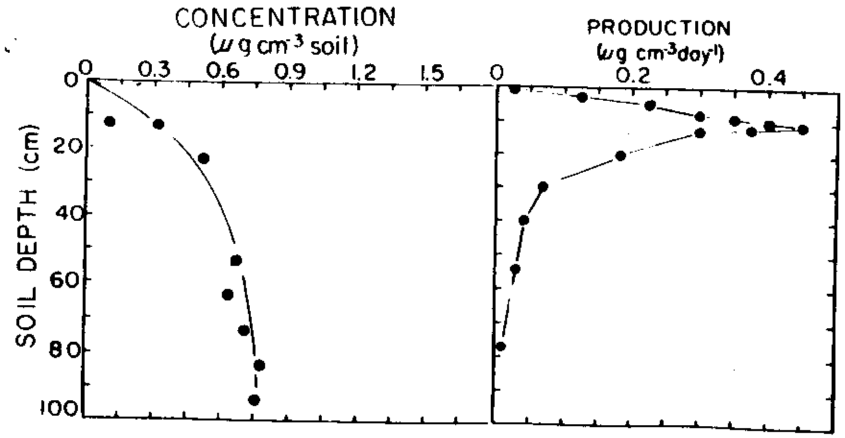
NITRATE $$D_2 \frac{\partial^2 C_2}{\partial x^2} - \frac{\partial v C_2}{\partial x} + k_1 C_1 - k_2 C_2 = 0$$

DINITROGEN GAS $$D_3 \frac{\partial^2 C_3}{\partial x^2} + k_2 C_2 = 0$$





GASEOUS ^{15}N



NON STEADY STATE EXAMPLE

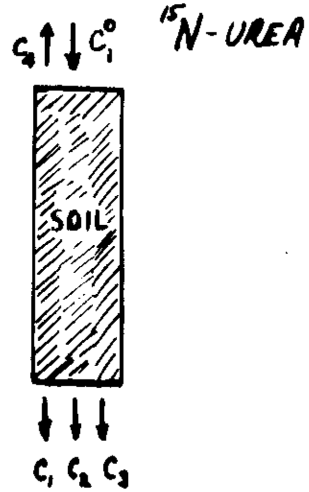
$$\underset{C_1}{UREA} \xrightarrow{k_1} \underset{C_2}{NH_4^+} \xrightarrow{k_2} \underset{C_3}{NO_3^-} \xrightarrow{k_3} \underset{C_4}{N_2}$$

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

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

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

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



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

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

HEMISTS

$S = f_1(C)$ EQUILIBRIA

$\frac{\partial S}{\partial t} = f_2(S, C)$ KINETIC

PHYSICISTS

MOBILE-IMMOBILE WATER

$D = D_0 + \beta V^{n}$

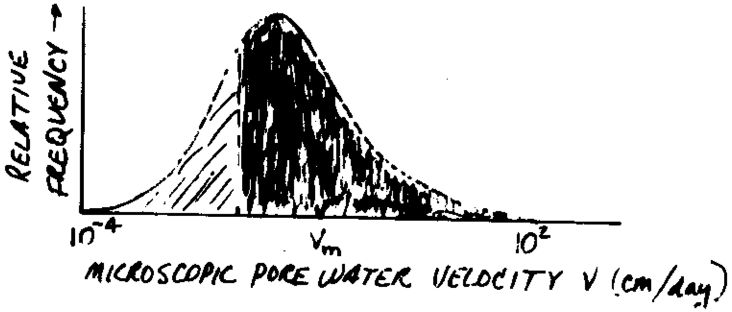
PLANT PHYSIOLOGISTS

MICROBIOLOGISTS

PLANT ROOT RELATIONS

MICHAELIS-MENTEN REACTIO

MOBILE - IMMOBILE WATER



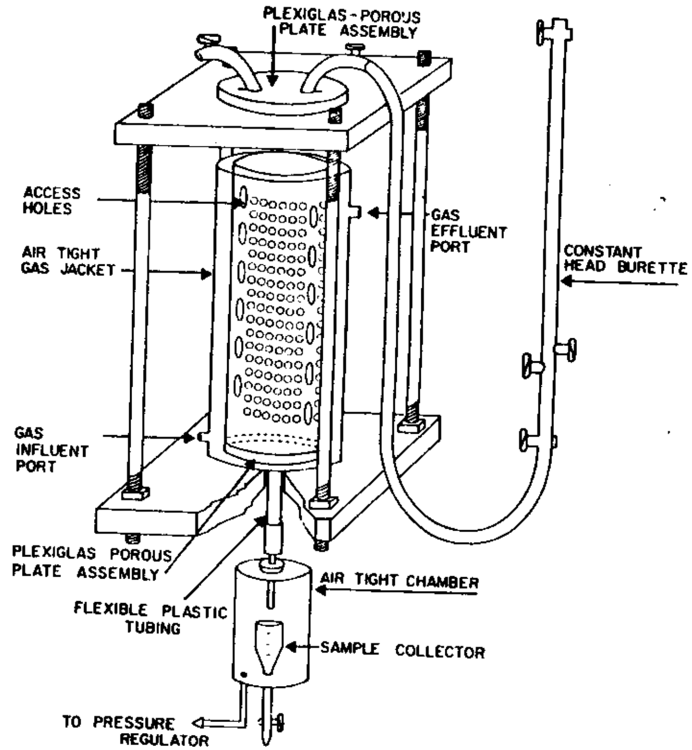
$$\theta_m \frac{\partial C_m}{\partial t} + \theta_{im} \frac{\partial C_{im}}{\partial t} = \theta_m D \frac{\partial^2 C_m}{\partial x^2} - V_m \theta_m \frac{\partial C_m}{\partial x}$$

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

$\phi = \frac{\theta_m}{\theta}$ MOBILE FRACTION OF WATER

$1 - \phi$ IMMOBILE FRACTION OF WATER

(15)



(16)

^{15}N-COORDINATED PROGRAM JOINT FAO/IAEA

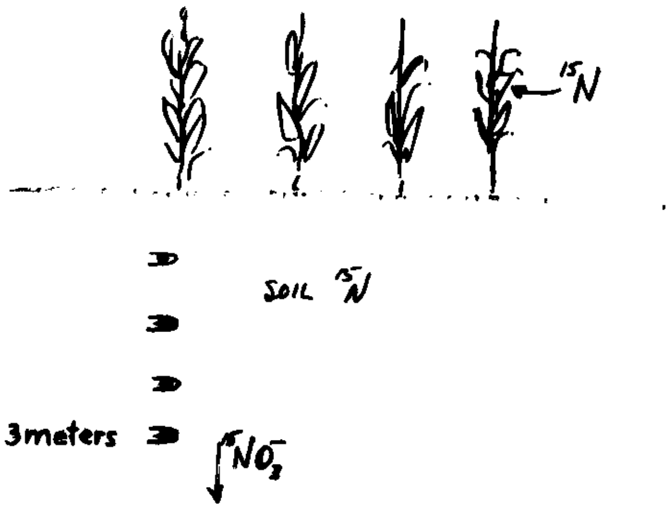
PERRY R STOUT – ^{15}N AVAILABLE FOR ALL OF US.

– FIRST METRIC TON OF ^{15}N

– 500 gm ^{15}N

IRRIGATION
1/3, 3/3, 5/3 ET

FERTILIZER 0, 90, 180, 360 kg N/ha.



(17)

INORGANIC N IN 0-3m SOIL PROFILE AFTER MAIZE HARVEST (3/3 ET)

	FERTILIZER APPLICATION (kg N/ha)			
AR	0	90	180	360
'74	123 (43.8%)	104 (41.0)	153 (11.7)	331 (22.4)
'75	120 (11.8)	138 (4.8)	139 (11.2)	409 (19.5)
'76	109 (4.2)	116 (11.6)	107 (7.5)	394 (48.9)

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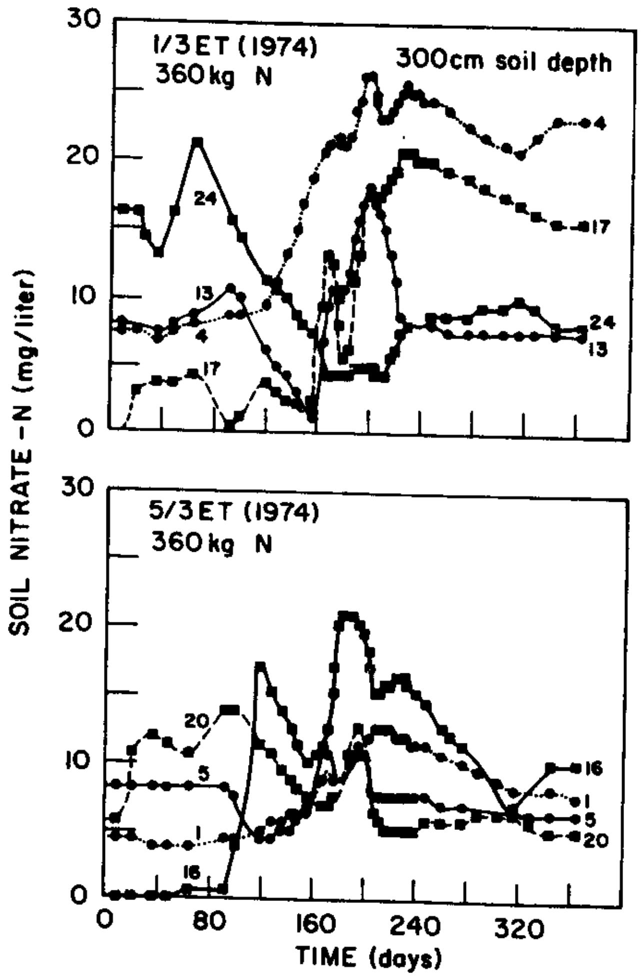

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THE FUTURE

- MULTIDISCIPLINARY RESEARCH INCREASES
- GREATER INTENSITY OF FIELD MEASUREMENTS
- NEW SAMPLING STRATEGIES
- DETERMINISTIC METHODS ↓, STOCHASTIC METHODS ↑.
- SOIL MAPPING UNITS LINKED WITH THEORETICAL MODELS