INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR/104-19

COLLEGE ON SOIL PHYSICS

19 September - 7 October 1983

SOIL MOISTURE STUDIES

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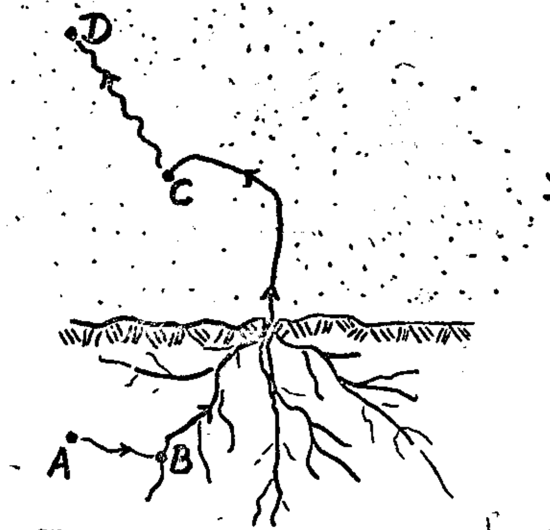
SOIL MOISTURE STUDIES
SEIBERSDORF MAY/JUNE 83
KLAUS REICHARDT



SPAC

[A, B SOIL] ⇄ ⇄ [C, D ATMOSPHERE]

- TEXTURE
- BULK DENSITY
- HYDRAULIC CONDUCTIVITY
- SOIL WATER CONTENT
- SOIL WATER ENERGY STATUS
- ⋮

ROOT ACTIVITY
LENGTH
DEPTH
⋮

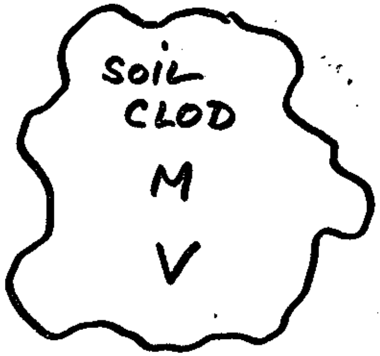
- PLANT ANATOMY, HEALTH
- XILEM
- STOMATA
- ⋮

LEAF ACTIVITY
AREA
SHAPE
⋮

- RELATIVE HUMIDITY
- SUNSHINE
- WIND
- ⋮

NUTRIENT UPTAKE

DIFFUSION; MASS FLOW; ROOT INTERSEPTION



$$M = m_s + m_l + m_g$$

$$V = v_s + v_l + v_g$$

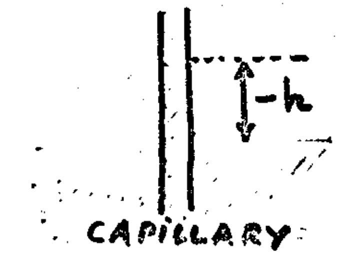
ENERGY STATUS OF WATER (HYDRAULIC HEADS)

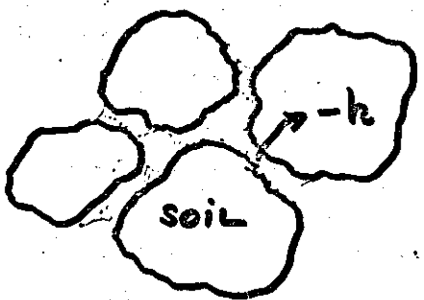
1. PRESSURE HEAD h

a) FREE WATER $h = 0$

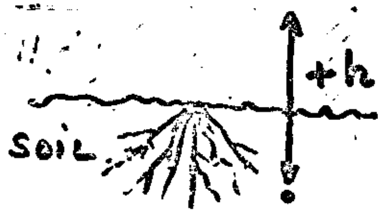
b) WATER UNDER TENSION, [illegible]

[illegible]

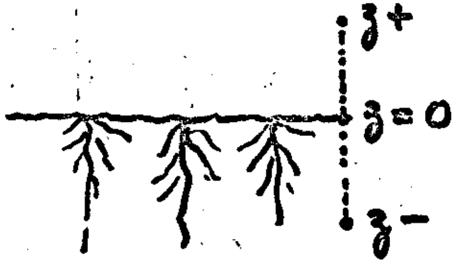




c) [illegible]



2. [illegible]

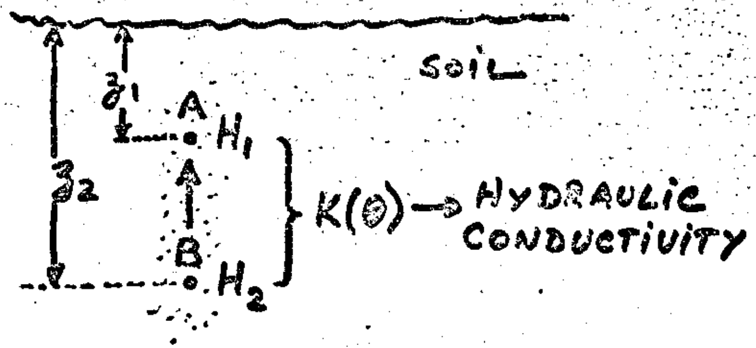


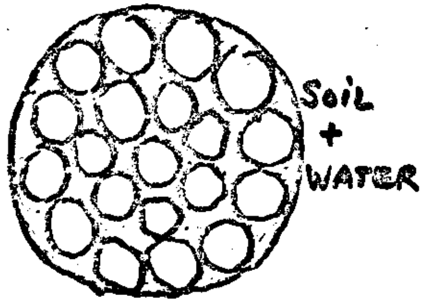
3. T[illegible] HEAD

$$\boxed{H = h + z}$$

TRANSPORT OF WATER

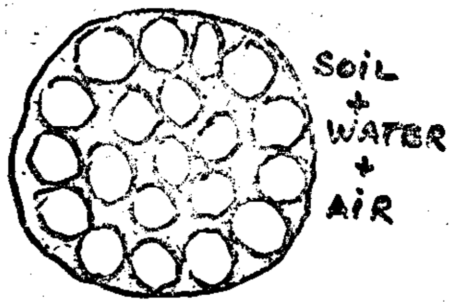
$$q = -K(\theta)\frac{\partial H}{\partial z}$$





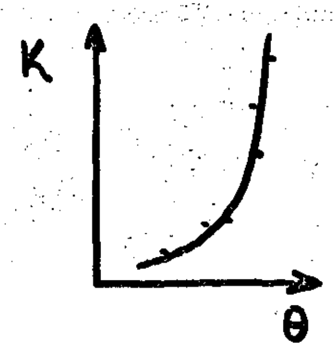
CROSS SECTION OF A SOIL WITH $\alpha = 0.5$ and $\theta = 0.5$

50% OF AREA AVAILABLE FOR FLOW

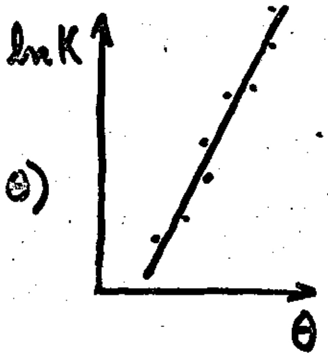


CROSS SECTION OF A SOIL WITH $\alpha = 0.5$ and $\theta = 0.25$

25% OF AREA AVAILABLE FOR FLOW



$K = K_o \exp(a\theta)$

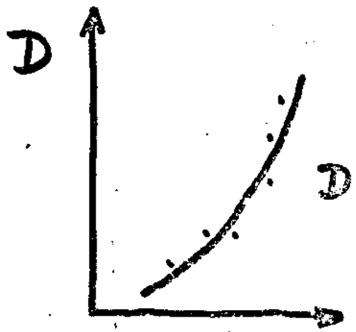


$$q = -K(\theta)\frac{\partial H}{\partial x}$$

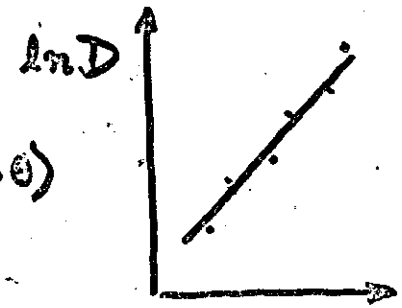
$$\downarrow$$

$$q = -D(\theta)\frac{\partial \theta}{\partial x}$$

$D(\theta)$ = SOIL WATER DIFFUSIVITY



$D = D_o \exp(b\theta)$



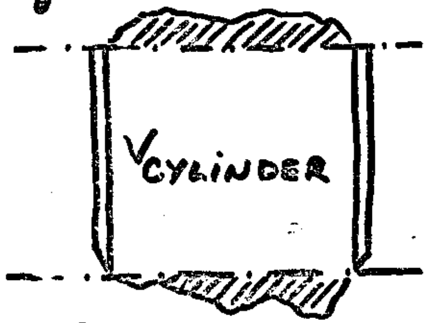
CLASSICAL METHODS

2.1. DIRECT SAMPLING

- AUGER SAMPLES

$$u = \frac{W_{ws} - W_{ds}}{W_{ds}}$$

- CYLINDER SAMPLES

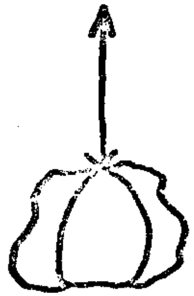


$$\theta = \frac{W_{ws} - W_{ds}}{V_{CYLINDER}}$$

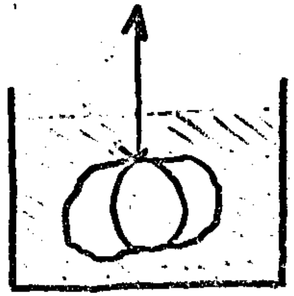
$$BD_d = \frac{W_{ds}}{V_{CYLINDER}}$$

$$BD_w = \frac{W_{ws}}{V_{CYLINDER}}$$

- PARAFIN SAMPLES



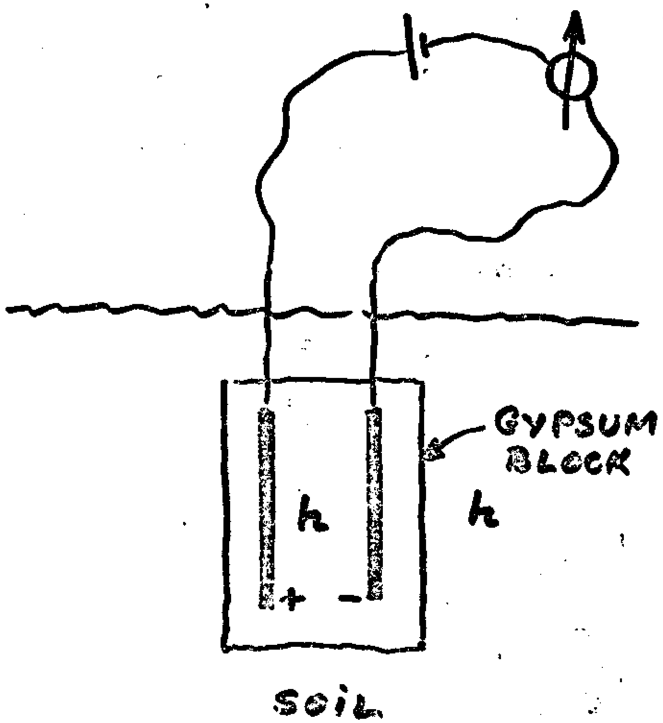
$W_{in\ AIR}$



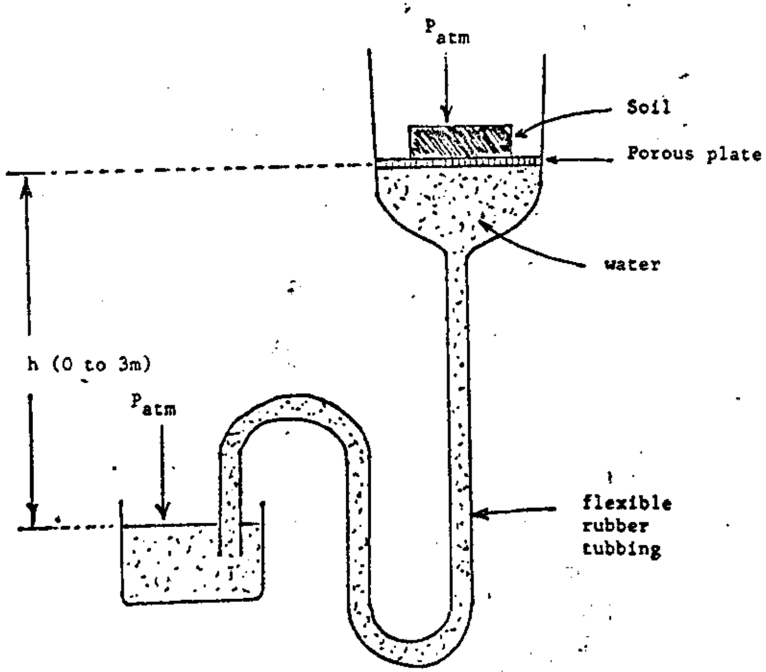
$W_{in\ WATER}$

2.2. SENSORS

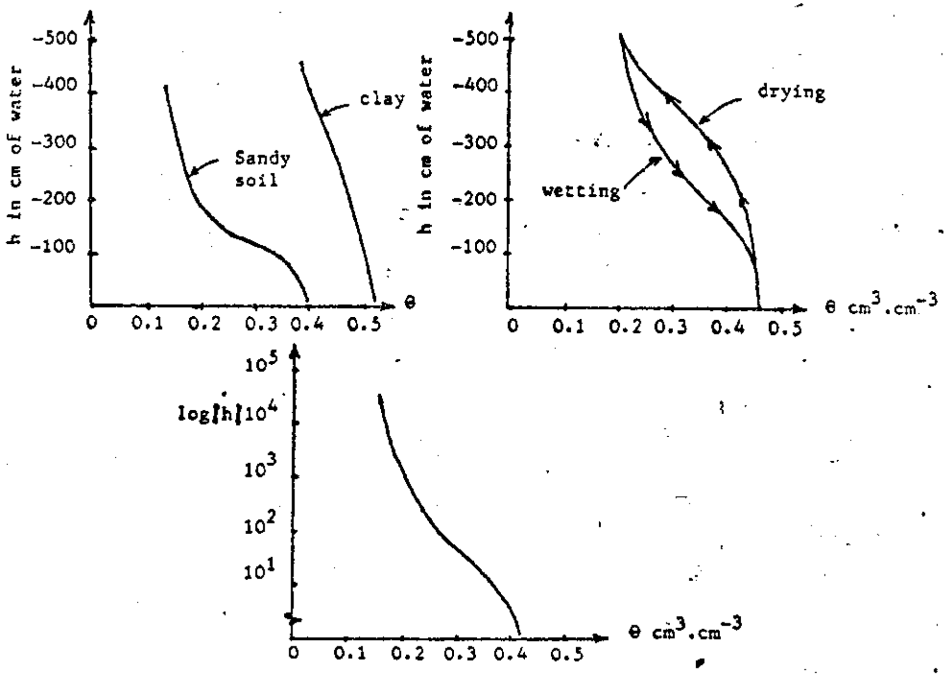
- POROUS RESISTANCE BLOCKS



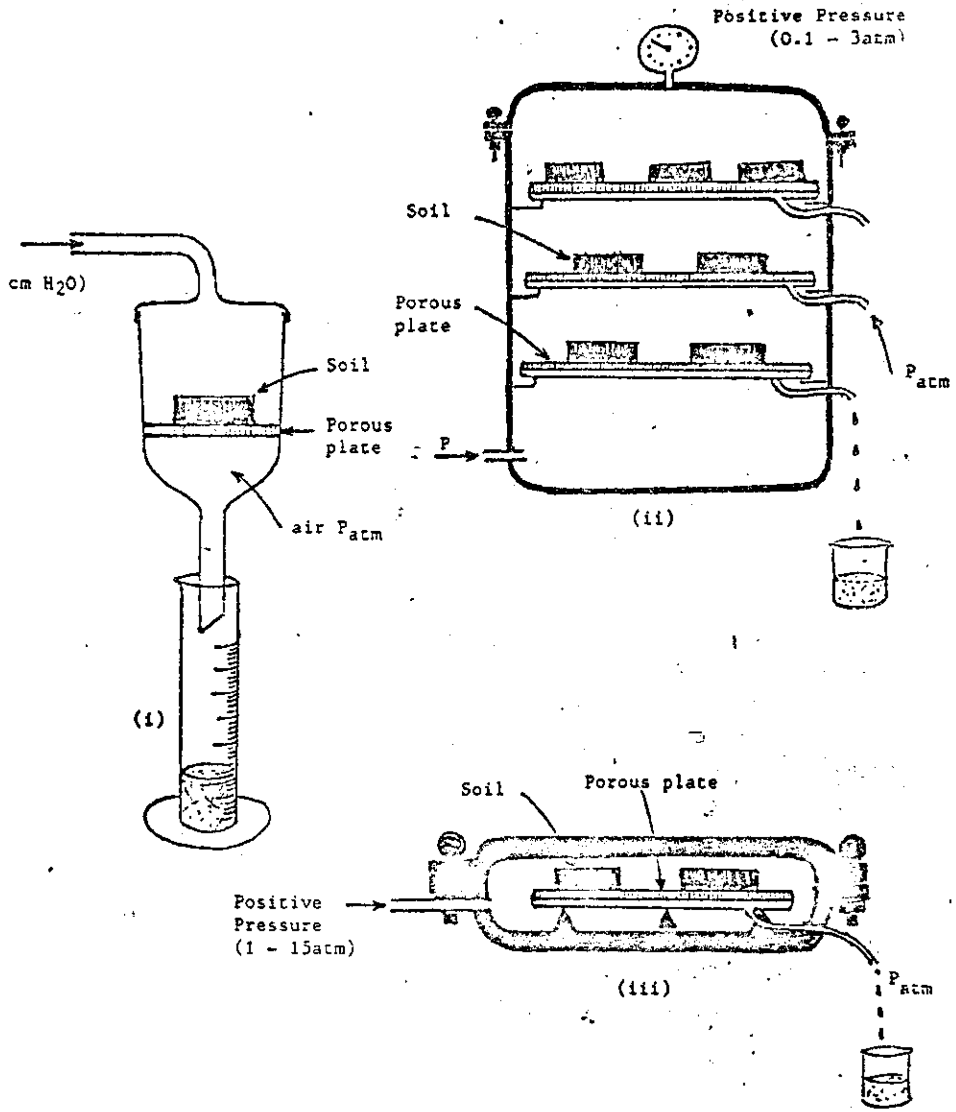
- POROUS PLATES UNDER SUCTION



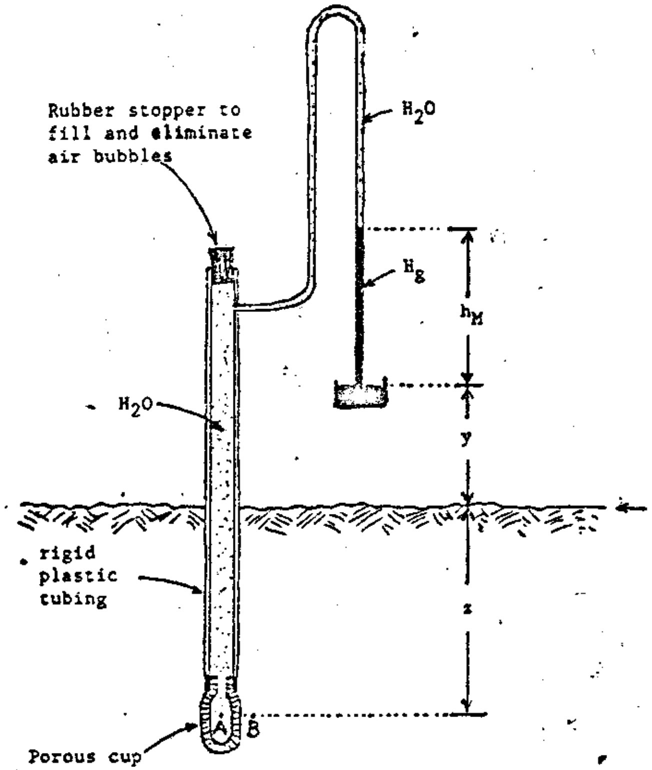
SOIL-WATER CHARACTERISTICS OR SOIL-WATER RETENTION CURVES



POROUS PLATES UNDER PRESSURE



TENSIOMETER



$$h_A = -12.6\, h_M + y + z$$

MEASUREMENT OF WATER FLUXES

- steady-state

$$q = -K(\theta)\frac{\partial H}{\partial x}$$

- Transient-state

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial x} \qquad \text{CONTINUITY}$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K\frac{\partial H}{\partial x}\right]$$

$$\int_0^L \frac{\partial \theta}{\partial t} = K\frac{\partial H}{\partial x} = q$$

MEASUREMENT OF $\partial\theta/\partial t$ AT DIFFERENT TIMES AND POSITIONS IS OF EXTREME IMPORTANCE. WE NEED NON-DESTRUCTIVE SAMPLING $\Longrightarrow$

NUCLEAR METHODS

NUCLEAR METHODS

3.1. USE OF TRACERS

3.2 GAMMA-RADIATION ATTENUATION

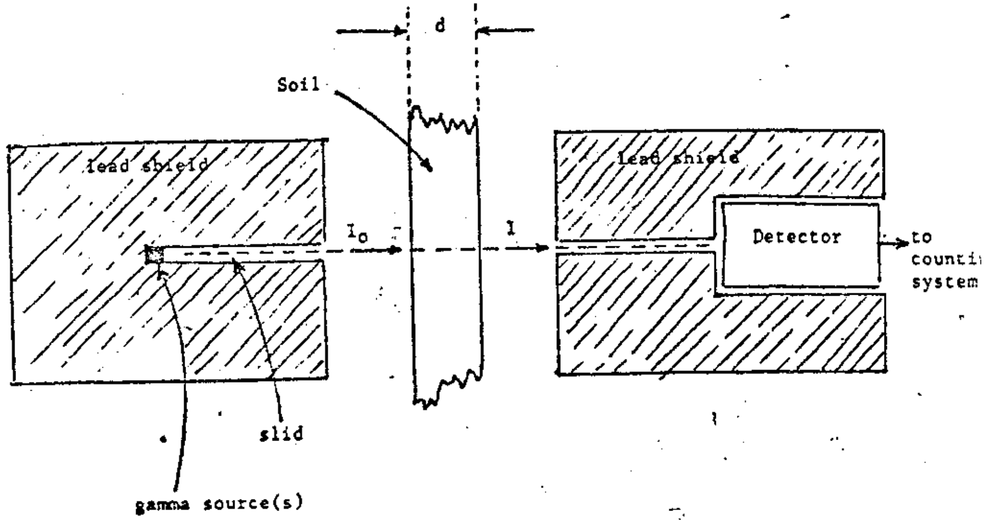
3.3 GAMMA-RADIATION SCATTERING

3.4. NEUTRON MODERATION

^{3}H $\quad \underbrace{^{2}H/^{1}H \quad ^{18}O/^{16}O}_{\text{NATURAL AND ARTIFICIAL}}$

^{36}Cl, ...

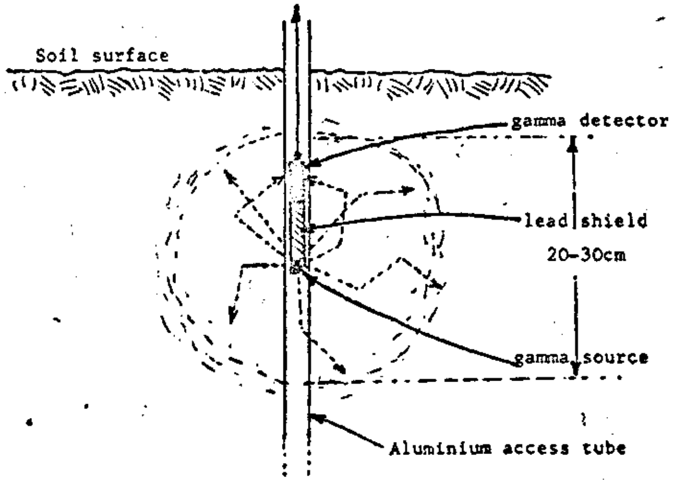
GAMMA ATTENUATION



$$I = I_o \, e^{-d(\mu_s BD_d + \mu_w \theta)}$$

LABORATORY

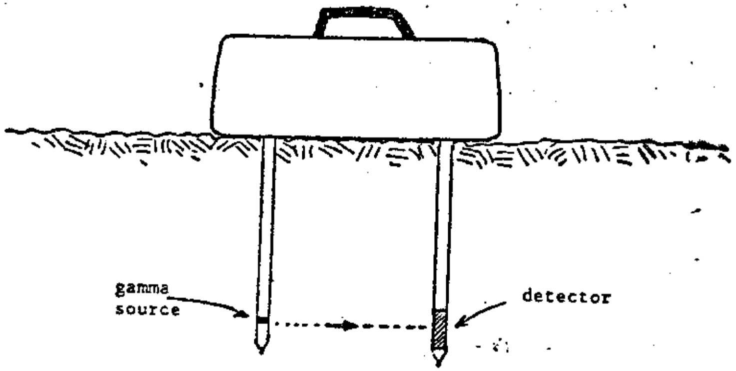
BACKSCATTERING



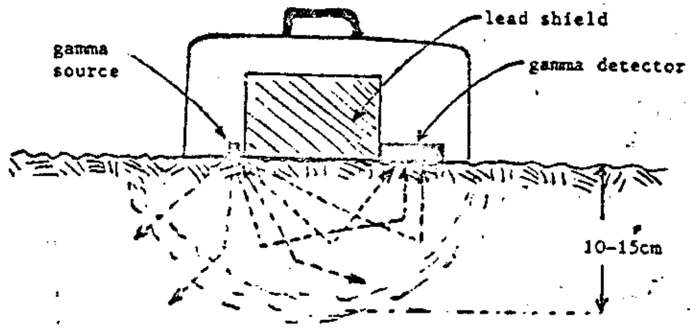
DEPTH FIELD PROBE

FIELD PROBES

a) ATTENUATION



b) SCATTERING



NEUTRON MOISTURE METER

NEUTRON SOURCES:

Ex: Am-Be

Am is an α emmitter

$$^{4}_{2}\alpha + ^{9}_{4}Be \rightarrow \left[^{13}_{6}C\right] \rightarrow ^{12}_{6}C + \underbrace{^{1}_{0}n}_{\text{FAST NEUTRON}}$$

INTERACTION OF NEUTRONS WITH MATTER:

i) elastic collision
ii) absorbtion
iii) desintegration

NEUTRON THERMALIZATION
or MODERATION
or SLOWING-DOWN

$$E_{fast} \longrightarrow E_{thermal}$$

NEUTRON ENERGIES

HIGH ENERGY	$E > 10$ MeV
FAST	$10\text{ MeV} > E > 10\text{ KeV}$
INTERMEDIATE	$10\text{ KeV} > E > 100\text{ eV}$
SLOW	$100\text{ eV} > E > 0.05\text{ eV}$
EPITHERMAL	$E \cong 1$ eV
THERMAL	$E = 0.025$ eV

NEUTRON SLOWING DOWN

ELEMENT	AVERAGE N° OF COLLISIONS REQUIRED FOR THERMALIZATION OF 2 MeV NEUTRONS
H	18.2
Li	69.3
B	104.5
C	115.4
O	152
Al	251
Si	262
Ca	371
U	2169

SLOW NEUTRON DETECTORS

1. BORON TRI-FLUORIDE: SIMILAR TO A GM TUBE WITH SOME BF_3 GAS

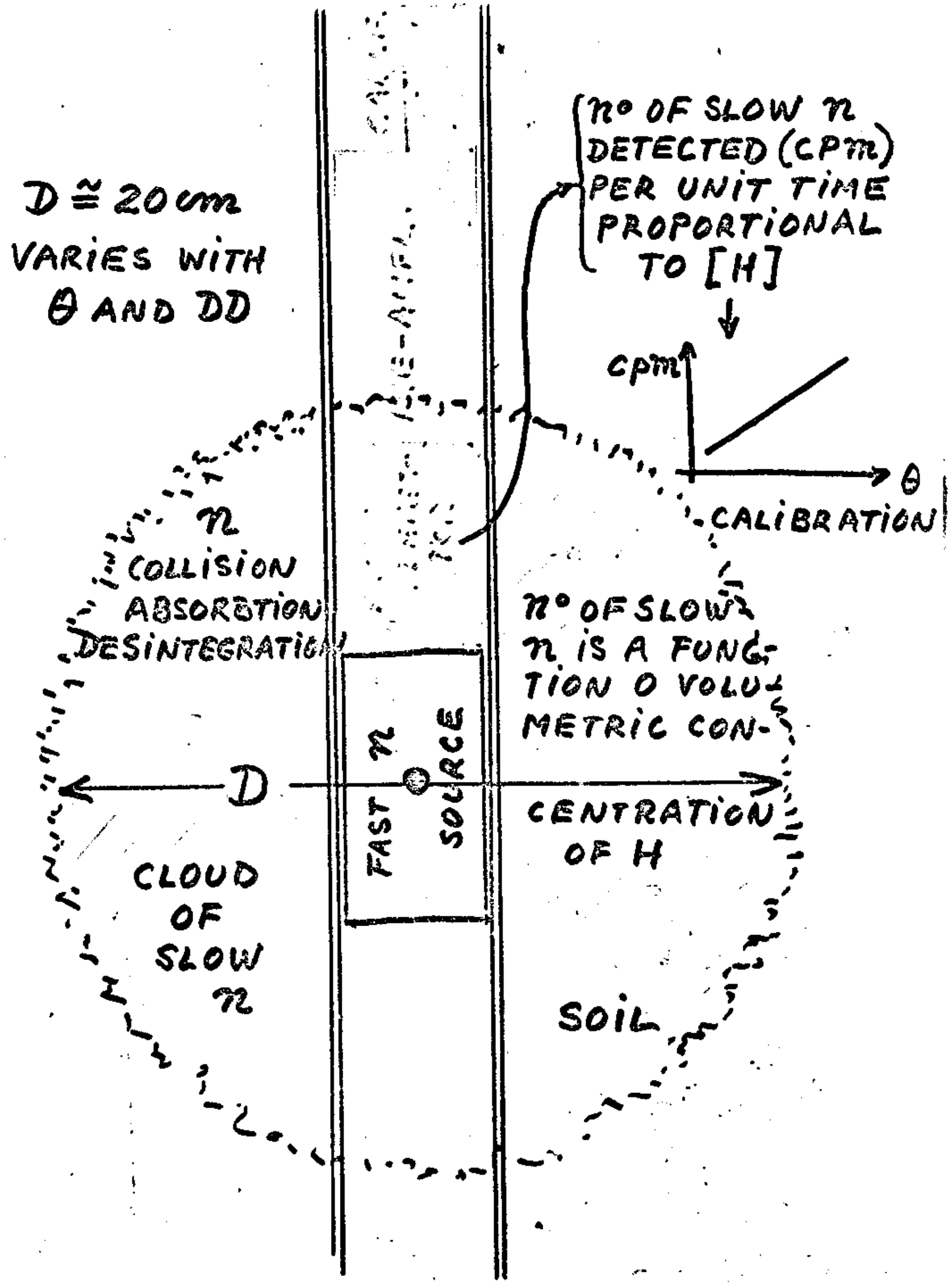
$$ {}^{10}_{5}B + {}^{1}_{0}n \longrightarrow {}^{7}_{3}Li + {}^{4}_{2}\alpha \qquad (n,\alpha) $$

2. HELIUM-3 DETECTORS

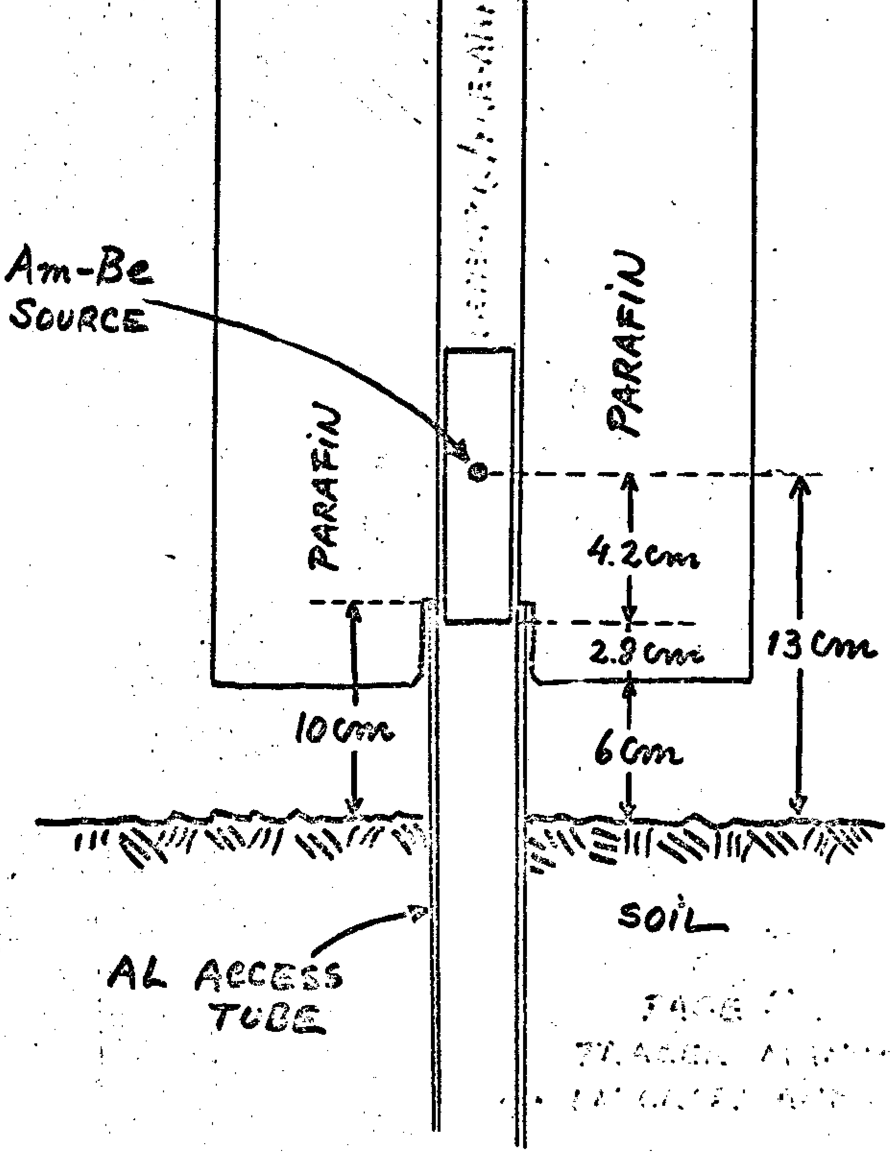
$$ {}^{3}_{2}He + {}^{1}_{0}n \longrightarrow {}^{3}_{1}H + {}^{1}_{1}p $$

3. SCINTILLATION DETECTORS
   SOLID CRYSTAL OF EUROPIUM ACTIVATED WITH ^{6}Li

$$ {}^{6}_{3}Li + {}^{1}_{0}n \longrightarrow {}^{4}_{2}\alpha + {}^{3}_{1}H \qquad (n,\alpha) $$

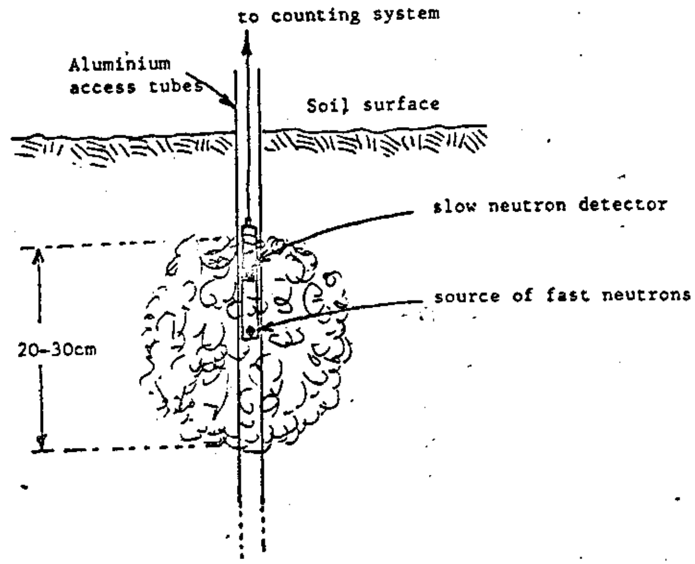


TROXLER DEPTH MOISTURE PROBE.

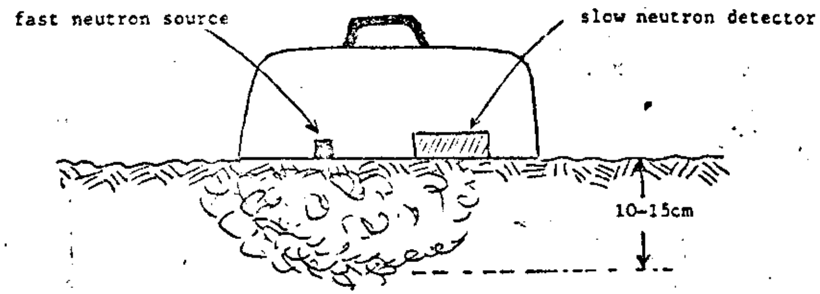


NEUTRON PROBES

a) DEPTH

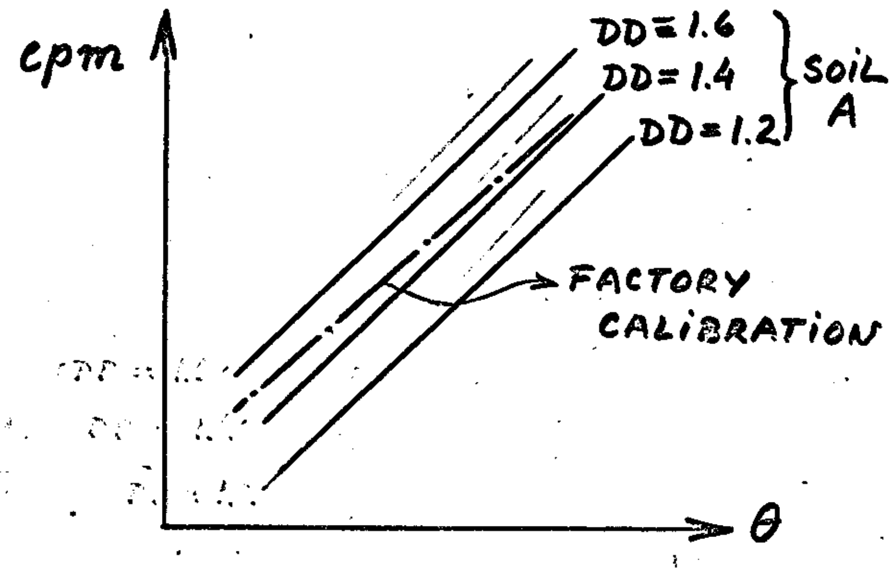


b) SURFACE



CALIBRATION

MANUAL PAGES
192
211
⋮
222



ALL LINEAR FOR USEFUL RANGE

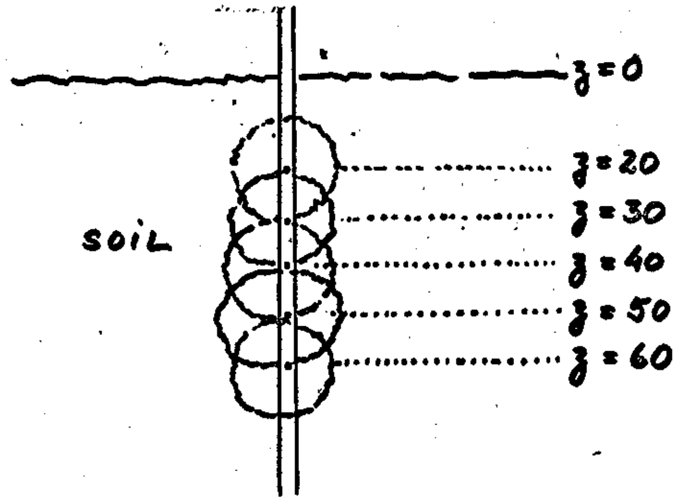
$$cpm = a\theta + b$$

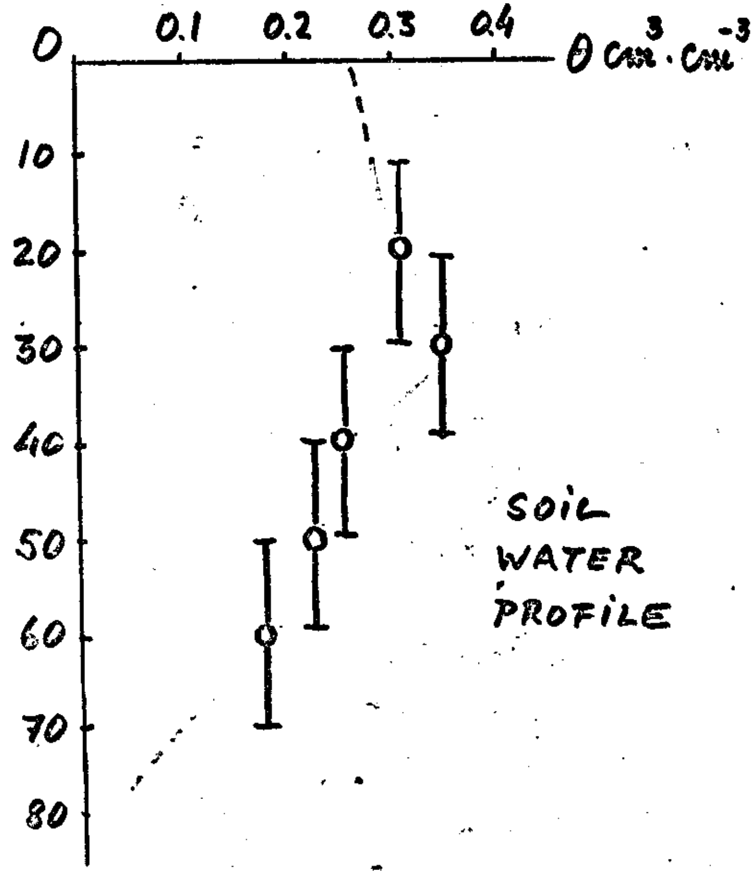
a AND b ARE FED TO THE MICROPROCESSOR

- TO AVOID ELECTRONIC DRIFTS:

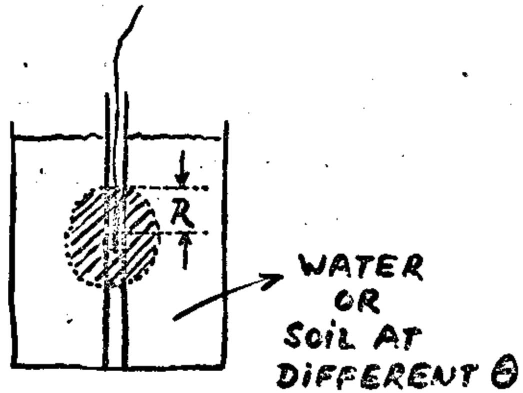
COUNT RATIO: $CR = \dfrac{\text{CPM SOIL}}{\text{CPM STANDARD}}$

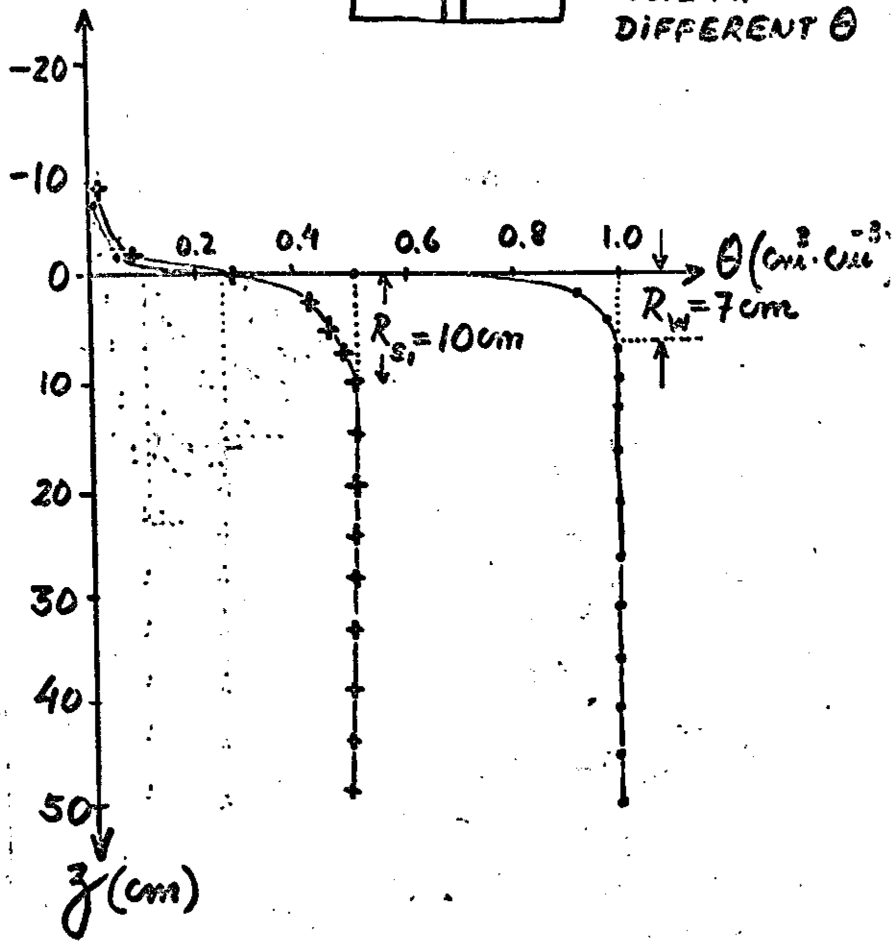
$$CR = a'\theta + b'$$





SPATIAL RESOLUTION OF NEUTRON PROBE





DATA ANALYSIS

WE HAVE MEASUREMENTS OF θ AS A FUNCTION OF TIME AND DEPTH WITH 6 REPS.

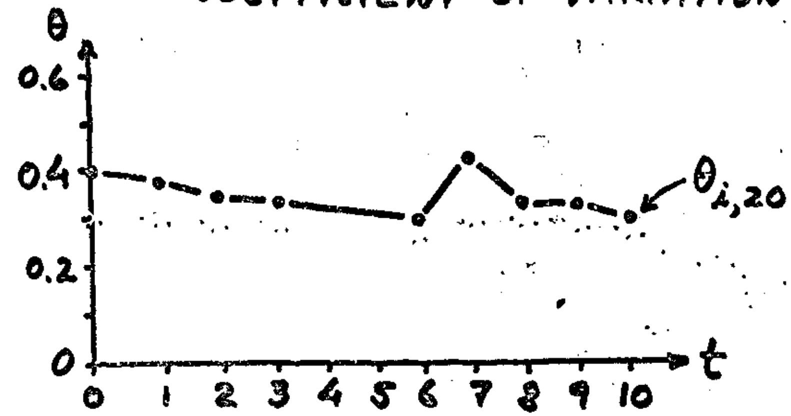
$$\theta_{i,z} \begin{cases} i = \text{time (days)} \\ z = \text{depth (cm)} \end{cases}$$

$i = 0$	31/05/83	$z = 0$	soil surface
$i = 1$	1/06/83	$z = 10$	10 cm below surf.
$i = 2$	2/06/83	$z = 20$	⋮
⋮	⋮	⋮	

$\theta_{3,30} = ?$ ______

1. AVERAGE HOLDING i AND z CONSTANT
   - STANDARD DEVIATION
   - COEFFICIENT OF VARIATION

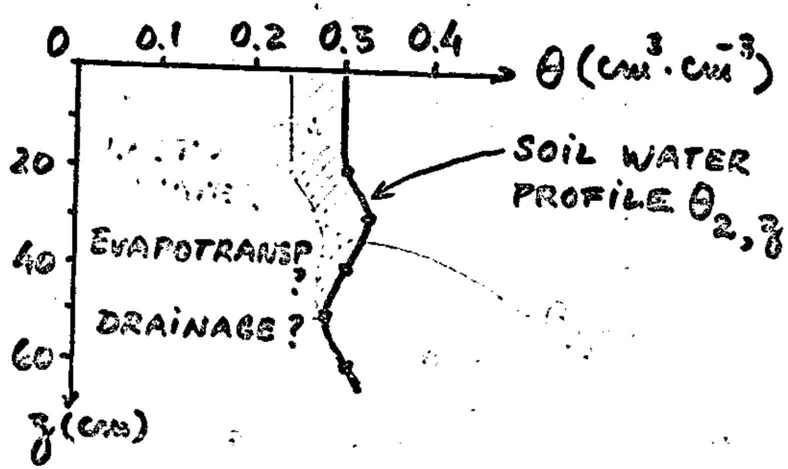
2.



$\left[\dfrac{\partial\theta}{\partial t}\right]_z$ = RATE AT WHICH θ OF A GIVEN DEPTH CHANGES WITH TIME

$$\left[\frac{\partial\theta}{\partial t}\right]_z \approx \frac{\theta_{i,z} - \theta_{i+1,z}}{t_{i+1} - t_i} \cdot \begin{cases} - & \text{WATER LOSS} \\ + & \text{WATER GAIN} \end{cases}$$

3.

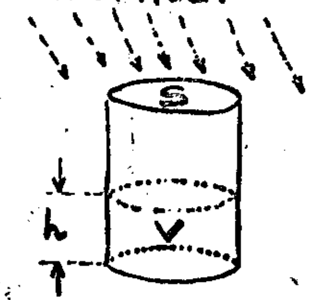


I IRRIGATION ⟶ mm, inches, ...
R RAINFALL ⟶ mm
ET EVAPOTRANSPIRATION ⟶ mm/day
D DRAINAGE ⟶ mm

WATER BALANCE: $R + I - ET - D = \Delta\text{STORAGE}$

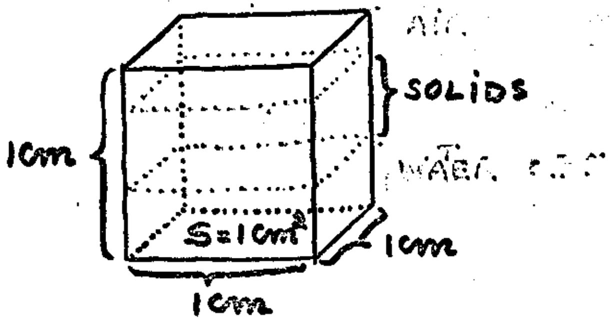
$$\theta\,(cm^3 \cdot cm^{-3}) \xrightarrow{?} mm$$

RAINFALL:



$$\frac{V}{S} = h \qquad 1\,mm = \frac{1\,\ell}{m^2}$$

ASSUME $\theta = 0.35\ cm^3 \cdot cm^{-3}$



$$h = \frac{0.35\ cm^3}{1\ cm^2} = 0.35\ cm = 3.5\ mm$$

$$\boxed{h \equiv \theta}$$

z (cm)	θ (cm³·cm⁻³)	h (cm)
0–1	0.35	0.35
1–2	0.33	0.33
2–3	0.30	0.30
3–4	0.31	0.31
4–5	0.29	0.29
5–6	0.30	0.30
6–7	0.28	0.28
7–8	0.28	0.28
8–9	0.27	0.27
9–10	0.25	0.25
⋮	⋮	⋮

$\Sigma h \longrightarrow$ WATER STORAGE $= S$

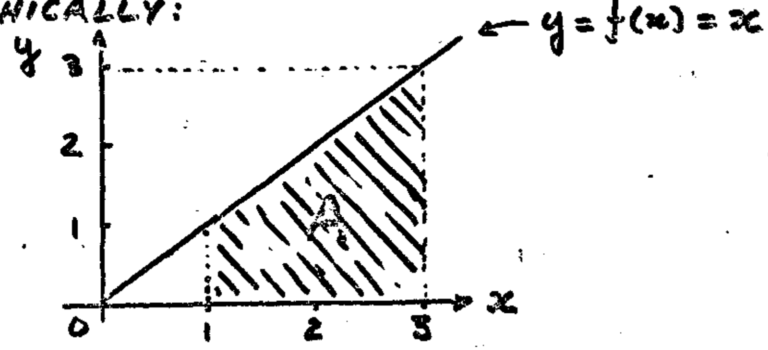
$$S_{i,L} = \int_{z_1}^{z_2} \theta \, dz \quad \text{where } L = z_2 - z_1$$

$$y = \int x \, dx \longrightarrow y = \frac{x^2}{2} + C$$

$$y = \int_1^3 x \, dx = \left[\frac{x^2}{2} + C\right]_1^3 = \left[\frac{3^2}{2} + C\right] - \left[\frac{1^2}{2} + C\right] =$$

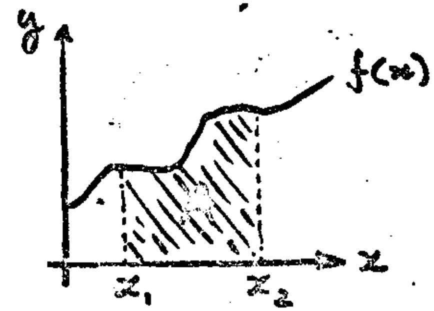
$$= 4.5 + C - 0.5 - C = 4$$

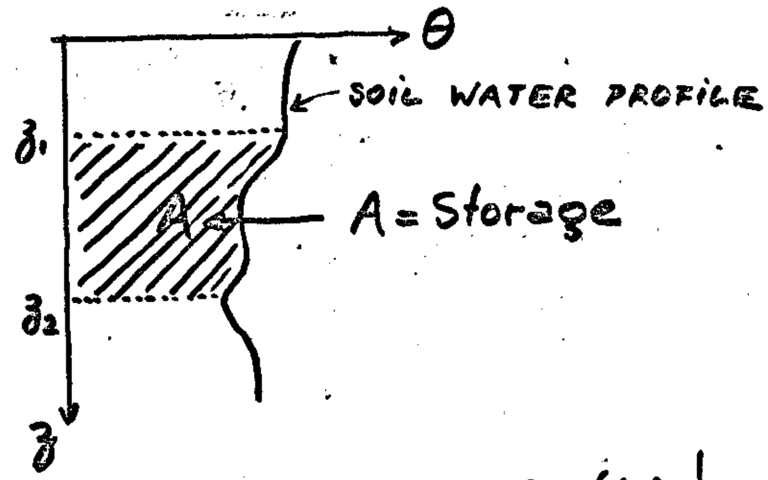
GRAPHICALLY:



$$A = \frac{1+3}{2} \cdot 2 = 4$$

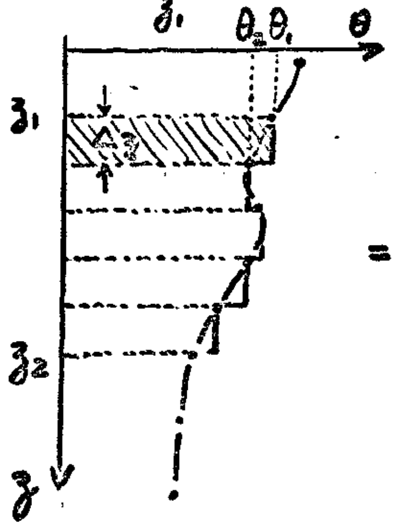
$$y = \int_{x_1}^{x_2} f(x) \, dx = A$$





BUT WE DO NOT HAVE $\theta = f(z)$!

$$S_{i,L} = \int_{z_1}^{z_2} \theta \, dz \cong \sum_{n=1}^{i} \theta \, \Delta z =$$



$$= \theta_1 \Delta z + \theta_2 \Delta z + \cdots + \theta_5 \Delta z =$$

$$= \Delta z (\theta_1 + \theta_2 + \cdots + \theta_5) =$$

$$= \underbrace{5 \times \Delta z}_{(z_2 - z_1) = L} \underbrace{\frac{(\theta_1 + \theta_2 + \cdots + \theta_5)}{5}}_{\text{AVERAGE OF } \theta \text{ BETWEEN } z_1 \text{ and } z_2}$$

$$S_{i,L} = \bar{\theta}(z_2 - z_1) = \bar{\theta} \cdot L$$

EXAMPLE:

z	$\theta_{4,z}$	$\theta_{7,z}$
15	0.401	0.320
30	0.396	0.328
45	0.389	0.361
60	0.392	0.385
75	0.376	0.373
	$\bar{\theta}$: 0.391	$\bar{\theta}$: 0.353

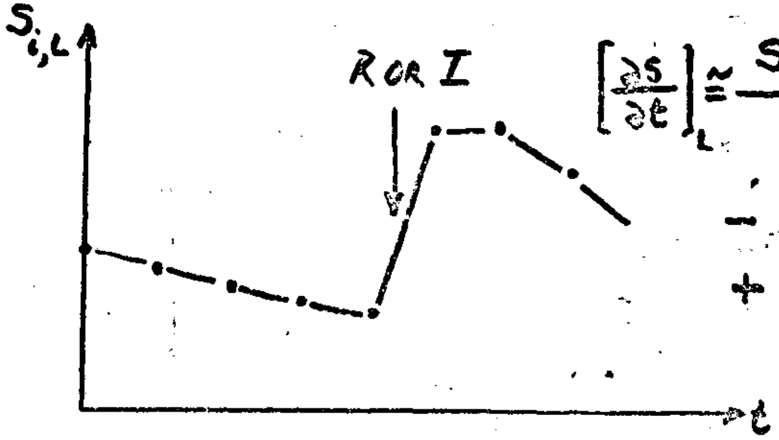
$S_{4,75} = 0.391 \times 75 = 29.3\,cm = 293\,mm$

$S_{7,75} = 0.353 \times 75 = 26.5\,cm = 265\,mm$

$\Delta S = S_{4,75} - S_{7,75} = 28\,mm$

RATE OF LOSS $= \dfrac{\Delta S}{3} = 9.3\,mm \cdot day^{-1}$

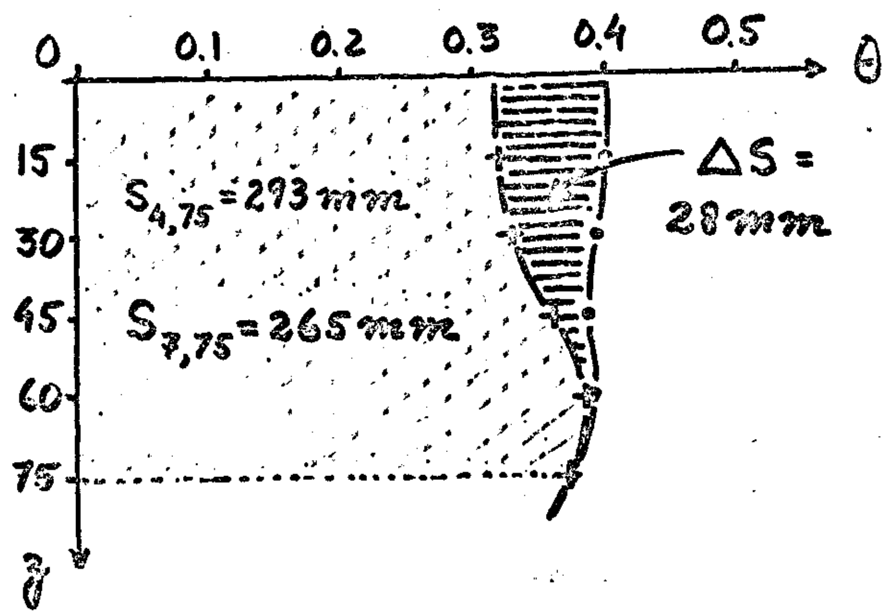
4.



$$\left[\frac{\partial S}{\partial t}\right]_L \simeq \frac{S_{i,L} - S_{i+1,L}}{t_{i+1} - t_i}$$

− WATER LOSS

+ WATER GAIN



If your rooting depth is L you can define a $S(F.C.)_L$ at field capacity and a $S(P.W.P.)_L$ at permanent wilting point, so that:

$S(F.C.)_L - S(P.W.P.)_L = $ IRRIGATION