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

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COLLEGE ON SOIL PHYSICS

15 April - 3 May 1985

COLLOQUIUM ON ENERGY FLUX AT THE SOIL ATMOSPHERE INTERFACE

6 - 10 May 1985

TENSIOMETER

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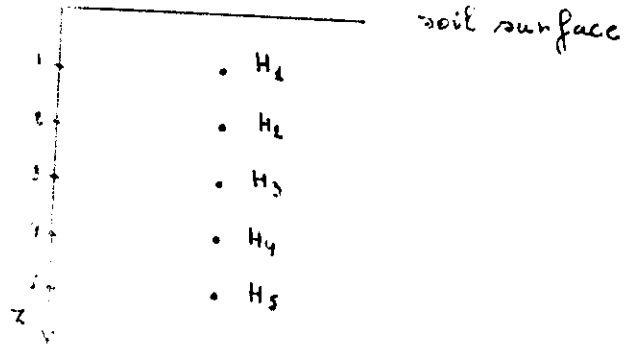
TENSIOMETER

Dr. ir. R. Hartmann

Hydraulic Head Profile

$$H = h + z$$

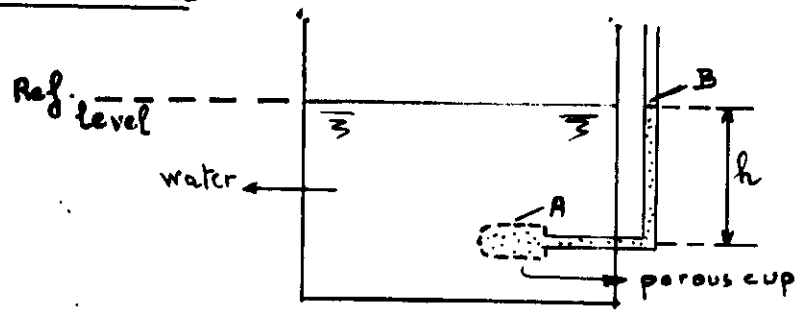


How to measure "h" ?

with "tensiometer"

TENSIOMETER

① Saturated



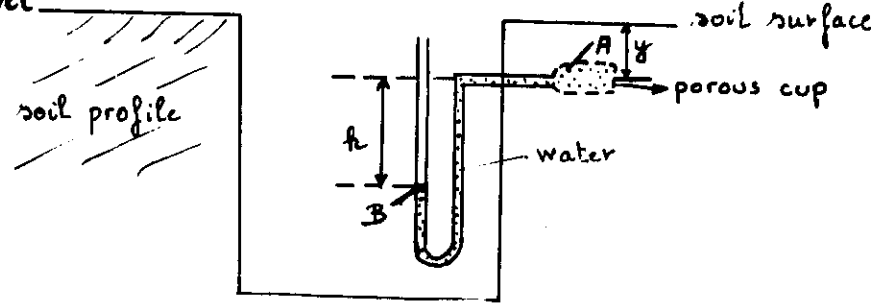
$$\Psi_{t_A} = \Psi_{m_A}^{=0} + \Psi_{o_A}^{=0} + \Psi_{g_A}^{=-h} + \Psi_{p_A}$$

$$\Psi_{p_A} = P_A = \frac{\pi r^2 h \rho g}{\pi r^2} \rightarrow h$$

(equilibrium)

$$\Psi_{t_B} = \Psi_{m_B=0} + \Psi_{o_B=0} + \Psi_{g_B=0} + \Psi_{p_D=0} \rightarrow \Sigma = 0$$

② Unsaturated

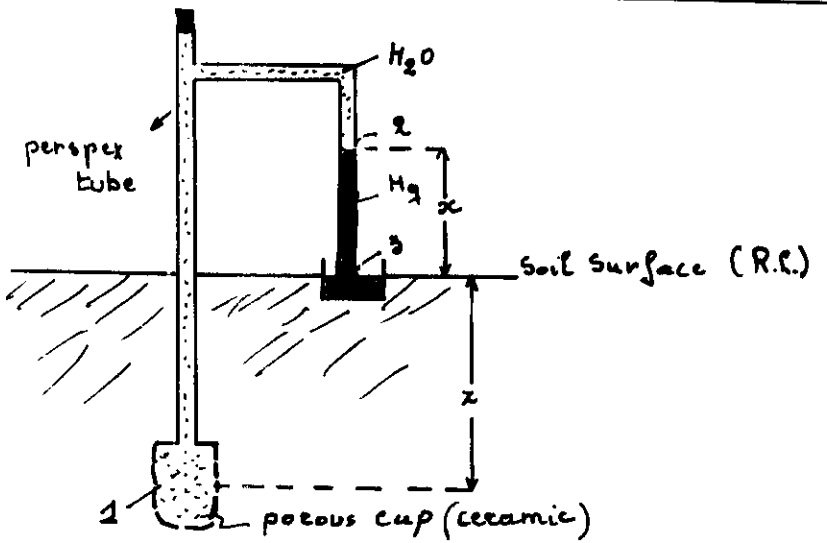


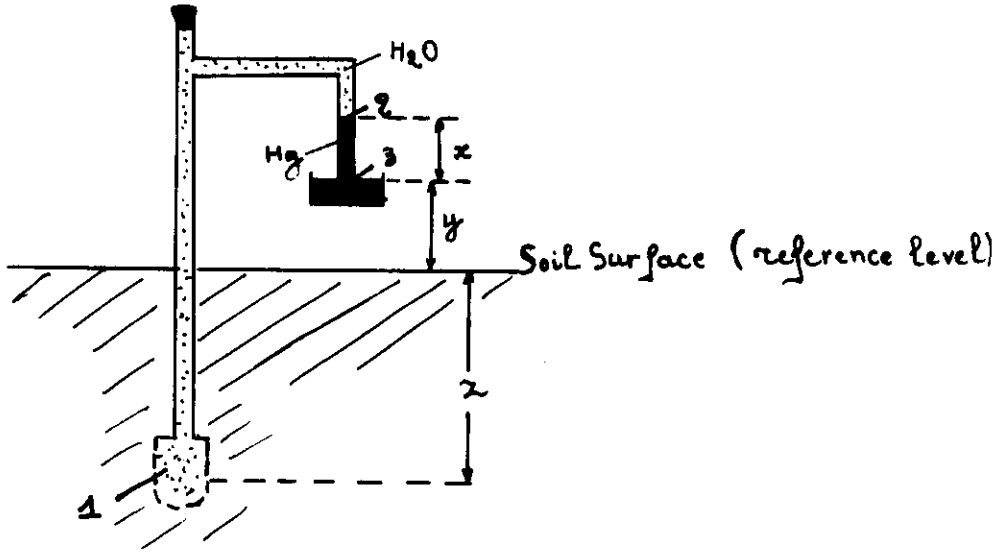
$$\Psi_{t_A} = \Psi_{m_A} + \Psi_{o_A}^{=0} + \Psi_{g_A}^{=-y} + \Psi_{p_A}^{=0}$$

$$\Psi_{t_B} = \Psi_{m_B}^{=0} + \Psi_{o_D}^{=0} + \Psi_{g_D}^{=-(h+y)} + \Psi_{p_B}^{=0}$$

$$\Psi_{m_A} - y = -h - y \rightarrow \boxed{\Psi_{m_A} = -h}$$

Determination of matric potential with tensiometer





Hydrostatic law for liquids in equilibrium

$$z + P/\rho g = \text{cst}$$

- z: gravitational head
- $P/\rho g$: pressure head (soil water)

water

$$z_1 + P_1/\rho_\omega g = z_2 + P_2/\rho_\omega g$$

$$-z + P_1/\rho_\omega g = x + P_2/\rho_\omega g$$

Hg

$$z_2 + P_2/\rho_{Hg} g = z_3^{=0} + P_3^{=0}/\rho_{Hg} g$$

$$P_2 = -x\rho_{Hg} g \quad (2)$$

$$P_1 = P_2 + x\rho_\omega g + z\rho_\omega g \quad (1)$$

(2) in (1)

$$P_1 = -x\rho_{Hg} g + x\rho_\omega g + z\rho_\omega g$$

per unit weight $\frac{P_1}{\rho_\omega g} = -13{,}6x + x + z = \boxed{-12{,}6x + z = h_1}$

water

$$z_1 + \frac{P_1}{\rho_\omega g} = z_2 + \frac{P_2}{\rho_\omega g}$$

$$-z + \frac{P_1}{\rho_\omega g} = x + y + \frac{P_2}{\rho_\omega g}$$

Hg

$$z_2 + \frac{P_2}{\rho_{Hg} g} = z_3 + \frac{P_3^{=0}}{\rho_{Hg} g}$$

$$x + y + \frac{P_2}{\rho_{Hg} g} = y$$

$$P_1 = P_2 + z\rho_\omega g + x\rho_\omega g + y\rho_\omega g \quad (1)$$

$$P_2 = -x\rho_{Hg} g \quad (2)$$

(2) in (1) $\rightarrow$ $P_1 = -x\rho_{Hg} g + x\rho_\omega g + z\rho_\omega g + y\rho_\omega g$

$$\frac{P_1}{\rho_\omega g} = h_1 = -13{,}6x + x + z + y$$

or $\boxed{h_1 = -12{,}6x + y + z}$

SOIL WATER PRESSURE HEAD → h

$$h = -12.6x + y + z$$

HYDRAULIC HEAD → H

$$H = h + z = -12.6x + y + z + (-z)$$

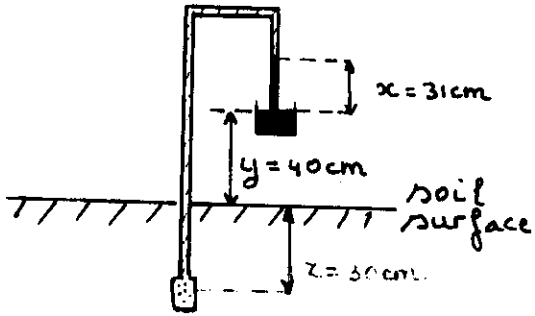
$$H = -12.6x + y$$

Example

x = 31 cm of Hg

y = 40 cm

z = 30 cm



$h = (-12,6 \cdot 31 + 40 + 30)\,cm = -320,6\ cm\ H_2O \approx -0,32\ atm$

$H = (-12,6 \cdot 31 + 40)\,cm = -350,6\ cm\ H_2O \approx -0,34\ atm$

Characteristics of tensiometer

- cup conductance (K')

$$K' = \frac{\Delta V}{\Delta t\ \Delta h} \quad (cm^3 \cdot min^{-1} \cdot atm^{-1})$$

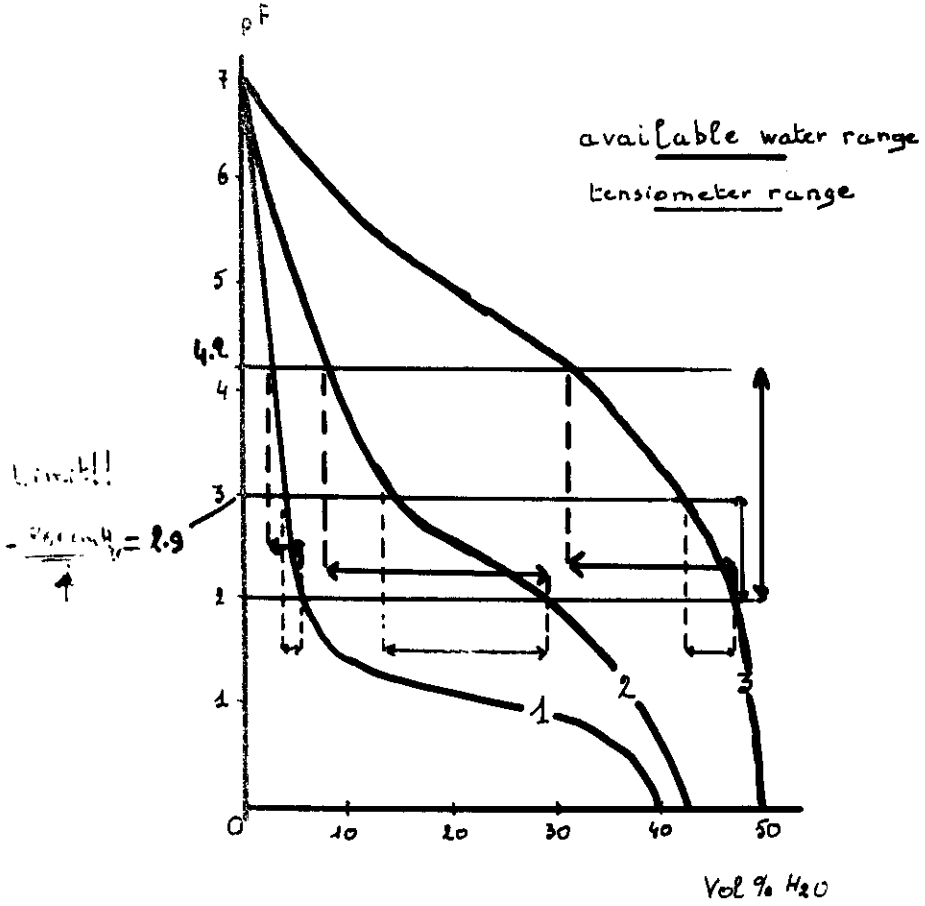
- sensitivity of the manometer (S)

$$S = \frac{\Delta h}{\Delta V} \quad (atm \cdot cm^{-3})$$

- response time (T_R)

$$T_R = \frac{1}{K' S} \quad (min)$$

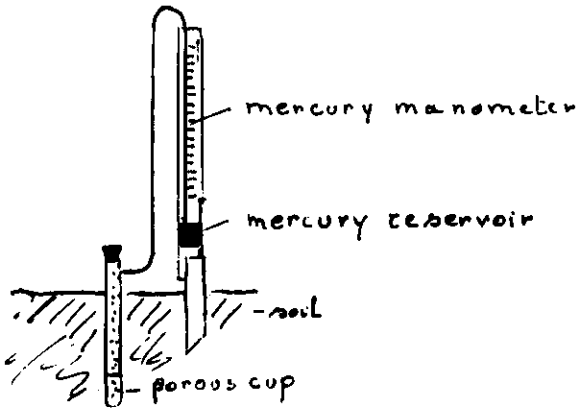
Practices & Limitations of Tensiometer



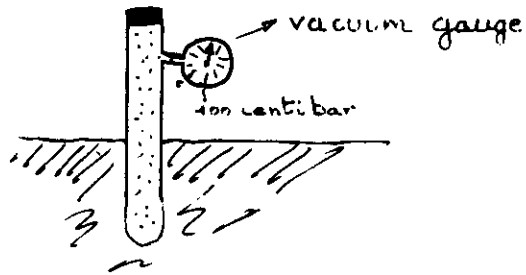
①	Sand	75%	of	available	moisture range
②	Loam	75%	"	"	"
③	Clay	30%	"	"	"

READINGS

1. Mercury manometer

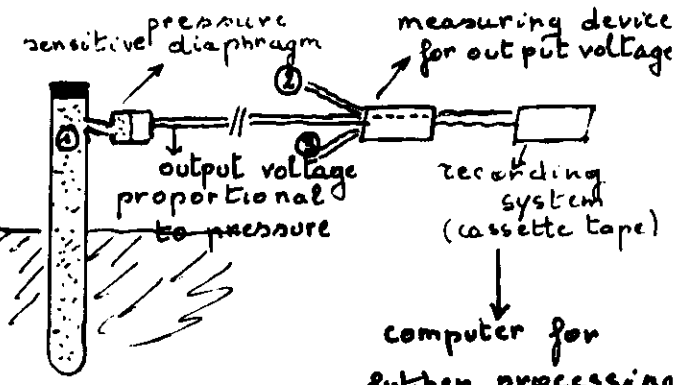


2. Vacuum gauge



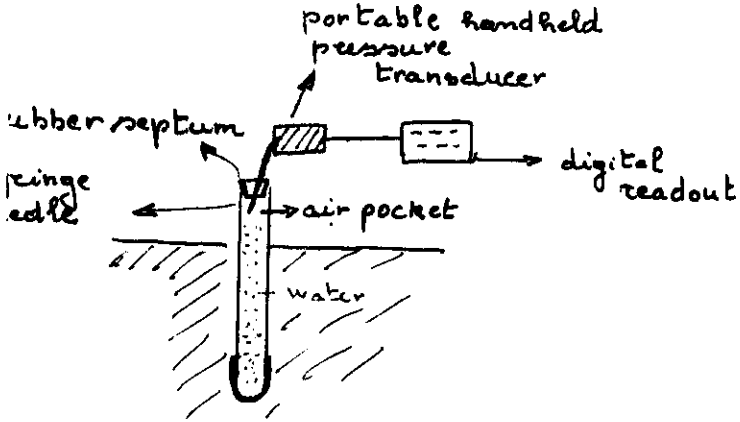
3. Pressure transducer

(3.1)



suitable for research application!

Expensive, and impossible to use where tensiometers are spaced far apart as in irrigated fields



advantages (for large field experiments)

- tensiometers without gauges are
  - less costly
  - easy to replace
  - easy to cover and protect (→ sunshine)
- possible to read many tensiometers in a short time
- only one (expensive) transducer is used
- readings independent on the vertical distance between transducer and tensiometer

GENERAL REMARKS

1. Preparation

- Leak control
- Complete saturation of porous cup
  - use deaerated water
  - fill-up by suction

2. Installation

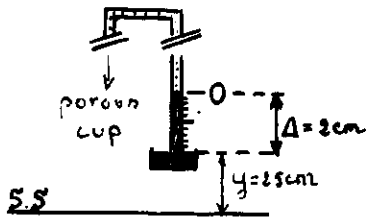
- avoid contact of porous cup with fatty element (fingers!)
- make hole with appropriate auger
- install tensiometer
- fill-up the tube if necessary with soil mud to obtain good contact between soil - cup
- connect capillary tube to mercury reservoir
- adjust the mercury level until it corresponds with the zero of the scale
- eventually zero adjusting

(4) if h=0 at z=0

$-13{,}6\,x + y + z = h$

$y = +13{,}6\,x$

x or $\Delta = \frac{y}{13{,}6}$ } zero setting!



for $y = 25\,cm$

$\Delta = 2\,cm \rightarrow H = -13{,}6\,x$

Readings

(y+z)

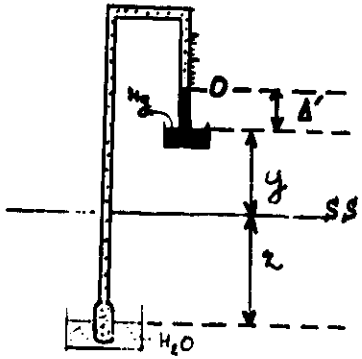
$h = -12,6x + y + z$

for $h = 0$ $\quad y + z = 12,6x$ or $12,6\,\Delta'$

or $\Delta' = \frac{y+z}{12,6}$ ↓ zero setting!

$h = -12,6x$

Readings



Direct reading of H or h on the scale

$H = -12,6x$ $\qquad$ $h = -12,6x$

instead of reading the rise of mercury in cm use a scale graduated in 12,6 cm

$x = 8cm$ $\quad H = -100cm$ $\quad h = -100cm$

$x = 4cm$ $\quad H = -50cm$ $\quad h = -50cm$

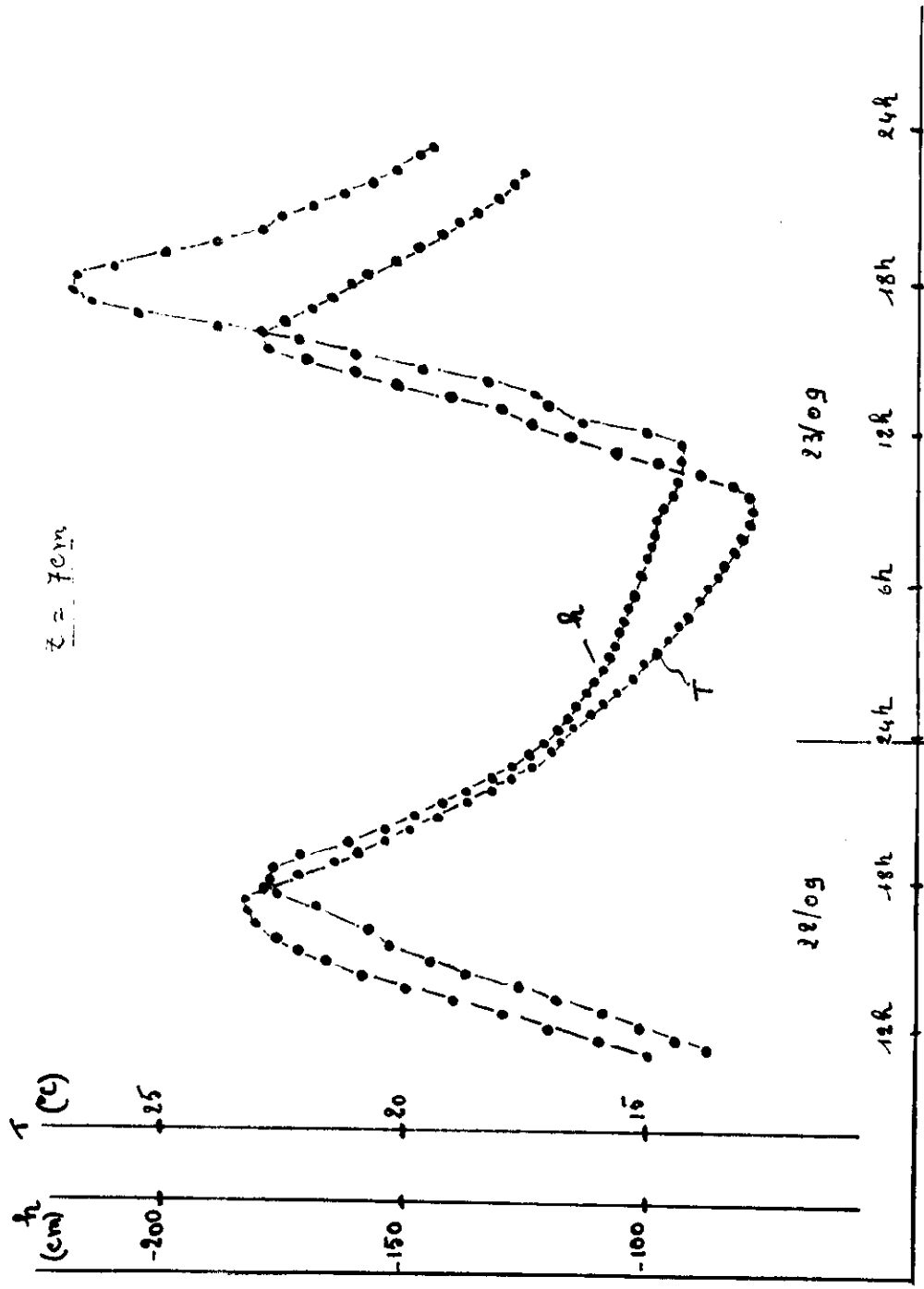
etc ...

3. Readings
- time (early morning)
- intensity (daily)

4. Control
- air bubbles
- leaks

5. Protection
- direct solar radiation
- carbonic (rabbits, ...)

6. Accuracy of measurement
- length of porous cup : $\frac{l\,cm}{2}$
- scale : 0,1 cm
- change of mercury level in reservoir



Application of tensiometer measurements

1. Determination of direction of waterflow at different levels in soil profile.

2. Flux control at a certain depth
   - capillary rise
   - drainage

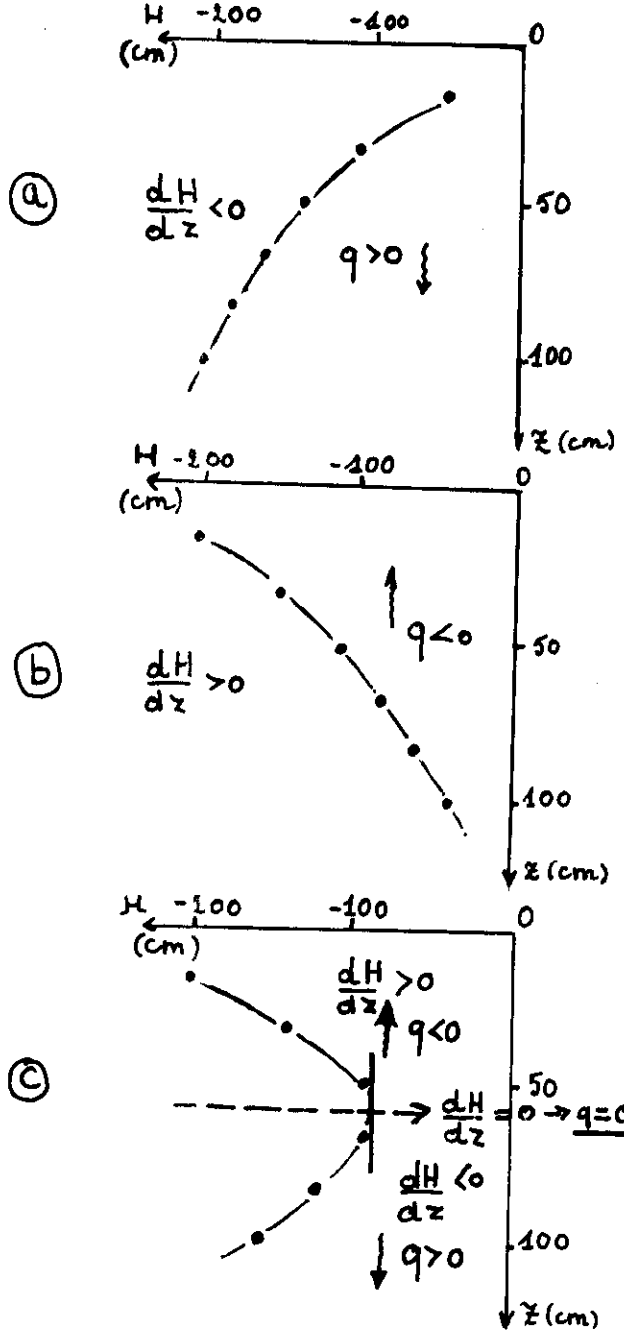
3. Determination of pF-curve

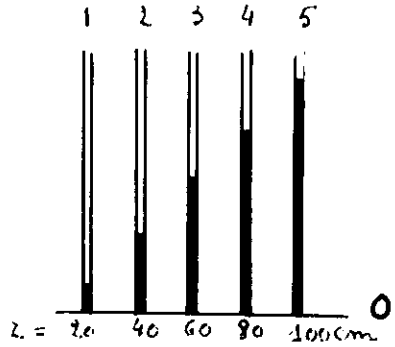
4. Scheduling irrigation

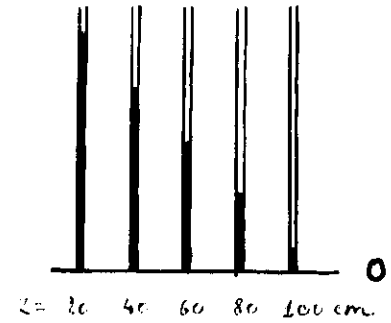
   depth of wetting

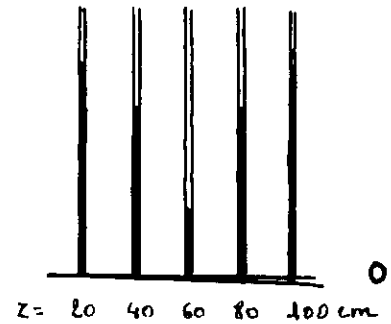
① Determination of the direction of the water flow

② Flux control at depth z $\quad q = -K(\theta)\frac{dH}{dz}$

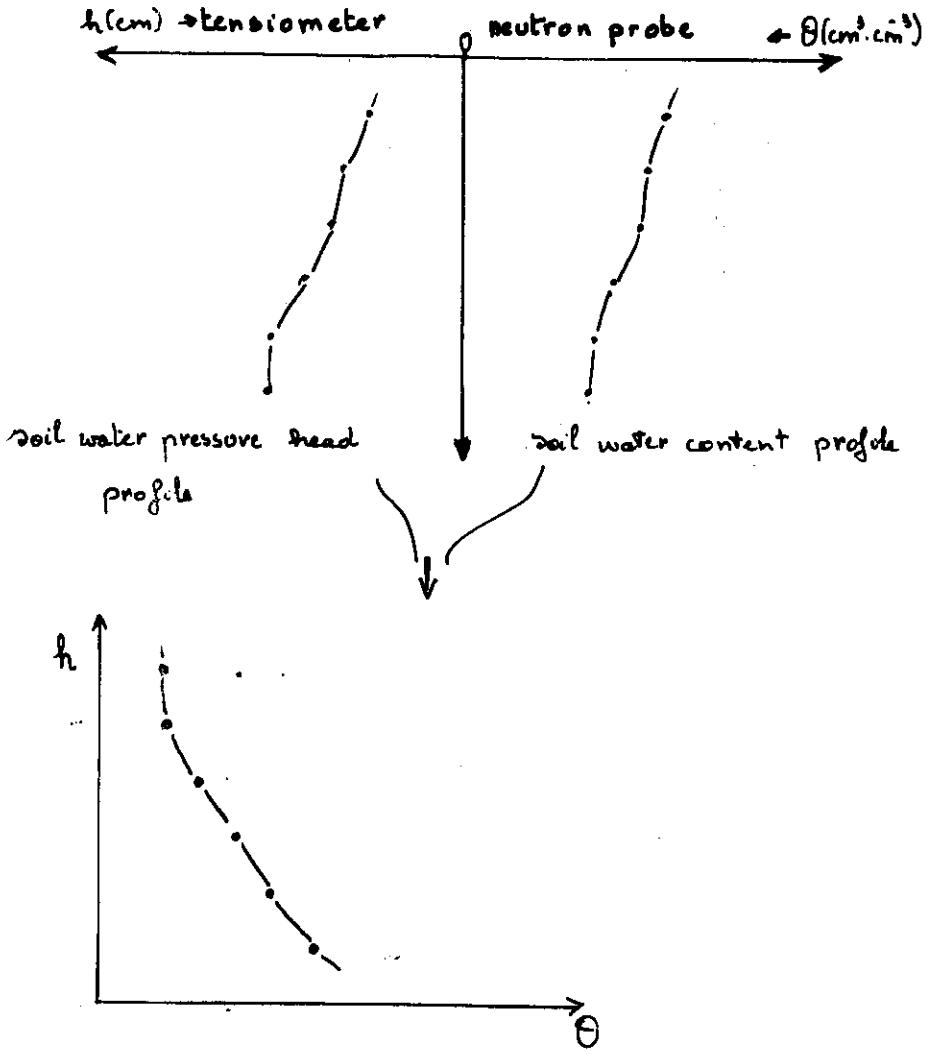






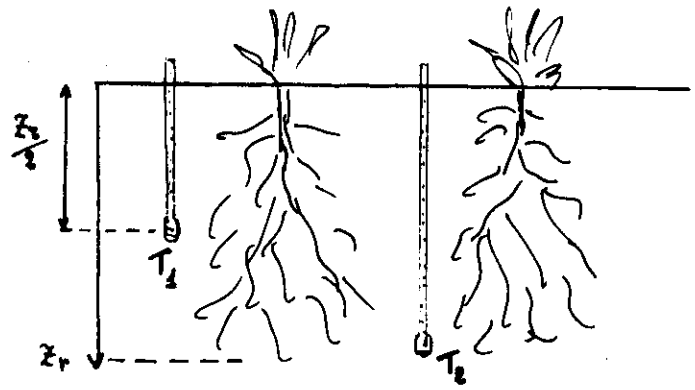


③ Determination of the soil moisture characteristic curve or pF-curve

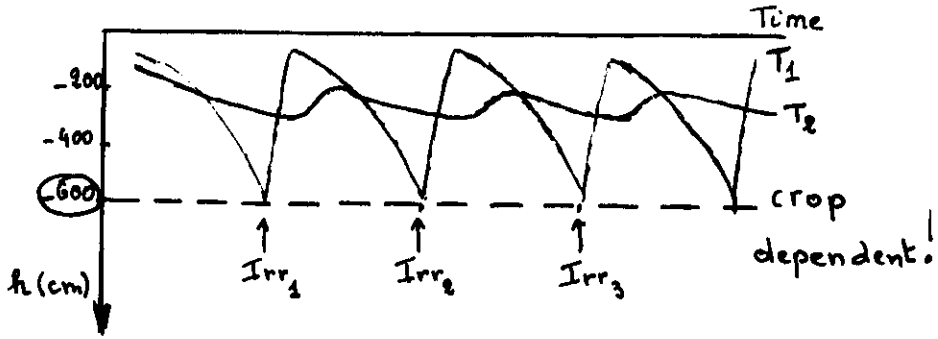


④ Scheduling irrigation

- Depth of installation



- Time of irrigation
  - When (T_1)
  - How Long (T_2)



Matric potential at which water should be applied for maximum yields of various crops

CROP	MATRIC POTENTIAL (cm)
Vegetative crops	
Cauliflower	-150
Cabbage	-600 to -700
Carrots, peas	-300 to -500
Lettuce	-400 to -600
Root crops	
Sugar beet	-400 to -600
Potatoes	-300 to -500
Carrots	-550 to -650
Fruit crops	
Lemon	-400
Avocado	-500
Tomatoes	-800 to -1500
Bananas	-300 to -1500

How to use the tensiometer

- **do not irrigate** when readings are in the **0 - 100 mbar** range
- **optimal plant growth** when readings are in the **-100 to -250 mbar** range
- **do not delay irrigation** when readings are in the **-700 to -800 mbar** range