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SMR.705 - 20

COLLEGE ON SOIL PHYSICS

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"Soil Structure Degradation"

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These are preliminary lecture notes, intended only for distribution to participants.

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SOIL STRUCTURE DEGRADATION

SOIL DEGRADATION may be defined as a decrease on soil quality, due to natural and man induced causes.

SOIL QUALITY has been defined as the ability of the soil to perform three critical functions as a:

- Medium for plant growth
- Regulator of the water regimes in hydrological units.
- Environmental filter.

This ability depends both on the inherent attributes (physical, chemical and biological properties) of the soil, and on its interaction with natural and applied inputs.

Soil degradation may be caused by unfavourable alterations of soil's physical, chemical and biological properties and processes.

PHYSICAL PROCESSES OF SOIL DEGRADATION lead to changes in the soil's mechanical, hydrological and rheological properties which have a negative effect on PLANT PRODUCTIVITY AND ENVIRONMENTAL QUALITY.

Changes in soil structural variables:

- FORM (arrangement of soil particles and voids)
- STABILITY (ability to retain FORM when exposed to different stresses)
- RESILIENCE (ability of a soil to recover its form through natural processes)

are the main effects of SOIL PHYSICAL DEGRADATION

They are manifested through problems of:

- SEALING AND CRUSTING
- COMPACTION
- IMPEDED DRAINAGE AND POOR AERATION
- HIGH RUNOFF AND ACCELERATER WATER AND WIND EROSION

The effects of such problems on crop production may be partially masked, up to some limit, through improved technological inputs, generally with increases in environmental problems and costs of production.

Aeration, infiltration, water storage, drainage, and hence runoff and water erosion depend largely on SOIL PORE DISTRIBUTION while **mechanical resistance** is governed by SOIL STRENGTH.

SOI STRENGTH can be defined as the capacity of the soil to withstand forces without failure due to rupture, fragmentation, or flow. It is due to the bonding cohesion among soil particles and the angle of internal friction, and can be an indicator of mechanical [illegible]

The degradation of soil structure is ranked as one of the most serious land degradation problems, because the other physical, chemical and biological characteristics are so interrelated to it, that they are usually also affected. It is generally the consequence of a non appropiate land use and management.

A widespread decline of soil structure has ocurred in many soils around the World, when they are intensivelly farmed specially if this farming relies heavily on mechanized operations. This decline is generally much more accelerated in tropical and subtropical regions, because of the particular interactions of soil and climate characteristics with soil management in those regions.

The decline in vegetation cover and organic matter in the surface soil may result in a collapse of soil structure, causing SURFACE SEALING, which drastically reduces water infiltration into the soil; and SURFACE CRUSTING, which in some cases may limit seedling emergence

SOIL COMPACTION is the process of decreasing the porosity and pore sizes, with denser packing of particles, generally due to "COMPRESION" by heavy traffic load (farm machinery), which is sometimes accompanied of soil "DEFORMATION" by tillage tools (specially when tillage is done under non appropiate (too wett) moisture conditions, causing discontinuities in the pore system. In terms of water fluxes, pore continuity is more important than its % in volume.
Natural processes (rainfall, wetting and drying, sedimentation), or trampling by animals may also contribute to soil compaction.

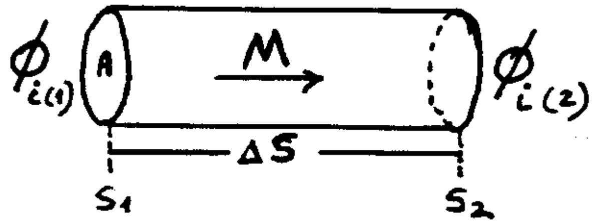
MEASUREMENTS OF SOIL STRUCTURE and its rate of change or degradation is complex because of its dynamic quality, and because different natural characteristic are of importance depending on soils, climatic conditions, and cropping systems. But the identification of the limitting factors, and the estimation of the fragility of different soils to structural degradation are necessary to determine if changes in management are necessary.

For that, we need reliable data on the dominant soils, along with models of their dynamics, to be used to predict risks derived of their use and potential productivity; and to select the most appropriate management.

Water, which is often the main limiting factor for crop production, is also the main individual factor, directly or indirectly responsible of the soil physical degradation processes. Besides, most of the limitations and effects of soil physical degradation in relation to productivity, are more or less associated to the continuity in the supply of available water to the crop under particular climatic conditions.

The field techniques and methodology to predict the physical soil behaviour must be based on direct and simple measurements based on clear physical relations, and have to take into consideration the dynamic nature of the soil physical properties, specially the ones related to soil structure. Moreover, the quantification of such properties must be aware of the dynamic action of root growth.

GENERAL FLOW EQUATION



$$\varphi_i = -A t K_i \frac{\Delta \phi_i}{\Delta S}$$

$$J_i = \varphi_i / A t$$

J_i : FLOW DENSITY

K_i : CONDUCTIVITY OF THE MATERIAL M FOR THE FLUID i

$$\Delta \phi_i = \phi_{i(2)} - \phi_{i(1)}$$

It applies to flow of heat, electricity, vapor, liquids . .

WATER FLOW IN SOILS

M : SOIL $\quad i$: WATER

$$J_{H_2O} = \frac{V}{At}\left(\frac{m^3}{m^2 sec} = \frac{m}{sec}\right) = -K_{H_2O}\left(\frac{m}{sec}\right) \cdot \frac{\Delta \Psi_H}{\Delta S}\left(\frac{m}{m}\right)$$

Ψ_H : HYDRAULIC POTENTIAL $= \Psi_P$ (PRESSURE POTENTIAL) $+ \Psi_Z$ (GRAVITATIONAL POTENTIAL) $\quad \frac{\Delta \Psi_H}{\Delta S}$: HYDRAULIC GRADIENT

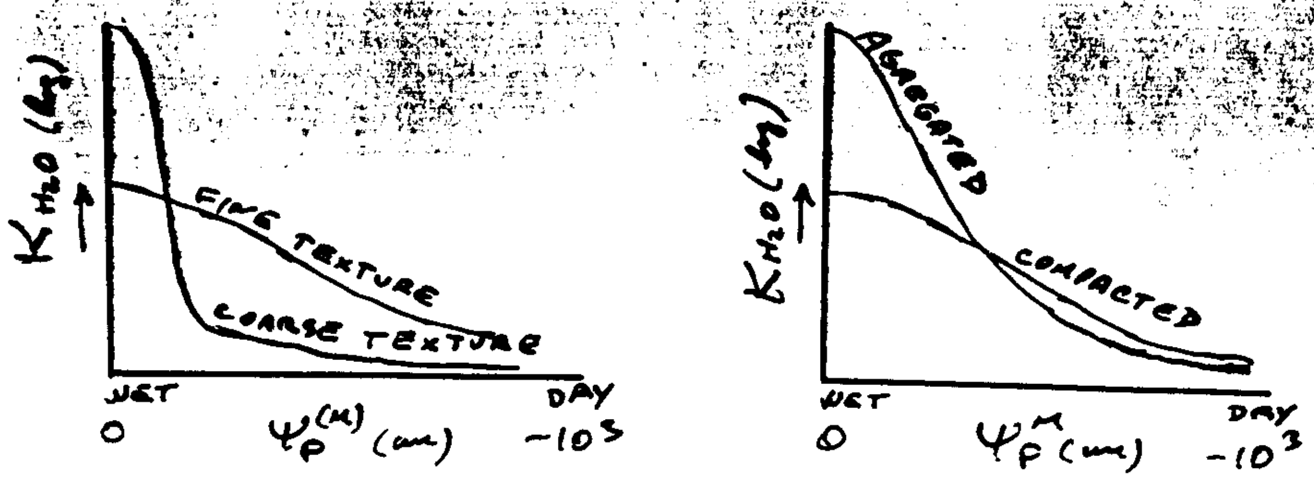
$$K_{H_2O} \text{ (HYDRAULIC CONDUCTIVITY)} = \frac{k \cdot \rho \cdot g}{\eta}$$

k : CHARACTERISTIC OF THE POROUS MEDIA

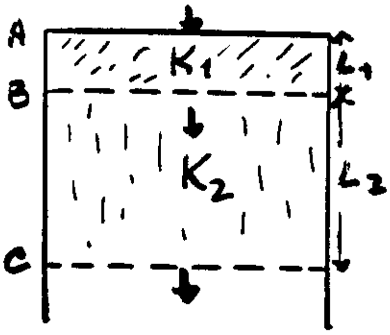
ρ (density) and η (viscosity) : CHARACTERISTIC OF THE FLUID

g : GRAVITY

EFFECTS OF TEXTURE AND COMPACTION ON SOIL HYDRAULIC PROPERTIES AT DIFFERENT MOISTURE CONTENTS



HYDRAULIC CONDUCTIVITY OF LAYERED SOILS



Q : Volume of water percolated through ABC in time t

A : Soil section area accross the direction of flow.

t : time to percolate Q.

$$K_{AC} = K_S = -Q/Ati_S \qquad i_S = (H_C - H_A)/(L_1+L_2)$$

$$K_{AB} = K_1 = -Q/Ati_1 \qquad i_1 = (H_B - H_A)/L_1$$

$$K_{BC} = K_2 = -Q/Ati_2 \qquad i_2 = (H_C - H_B)/L_2$$

H : Hidraulic potential in head (l) units.   C : Reference level

$$H_C = 0 \,;\; H_A = L_1+L_2 \,;\; H_C - H_A = -(L_1+L_2) \,;\; H_B - H_A = H_B - (L_1+L_2)$$

$$H_C - H_B = -H_B \qquad K_S i_S = K_1 i_1 = K_2 i_2$$

$$K_S \cdot \frac{-(L_1+L_2)}{(L_1+L_2)} = K_1 \frac{((H_B - (L_1+L_2))}{L_1} \quad (1)$$

$$K_S \cdot \frac{-(L_1+L_2)}{(L_1+L_2)} = \frac{K_2\,(-H_B)}{L_2} \qquad H_B = \frac{K_S L_2}{K_2} \quad (2)$$

(2) in (1)
$$-K_S = \frac{K_1\,((KL_2/K_2) - (L_1+L_2))}{L_1}$$

$$K_S L_1 = K_1\,(L_1+L_2) - (K_S K_1 L_2/K_2)$$

$$K_S = \frac{K_1 K_2\,(L_1+L_2)}{K_2 L_1 + K_1 L_2} = \frac{L_1+L_2}{(L_1/K_1)+(L_2/K_2)}$$

FOR n LAYERS:

$$K_{(1 \dots n)} = \frac{L_1 + L_2 + \dots L_n}{(L_1/K_1) + (L_2/K_2) + \dots (L_n/K_n)}$$

EXAMPLE: $L_1 = 0{,}5$ m ; $K_1 = 0{,}01$ m/hour
$L_2 = 10$ m ; $K_2 = 5{,}00$ m/hour

$$K_{S\,(L_1+L_2)} = \frac{0{,}5+10}{(0{,}5/0{,}01)+(10/1)} = \frac{10.5}{50+10} = 0{,}175 \text{ m/hour}$$

$$K_{S\,(\text{WEIGHTED MEAN})} = \underline{(0{,}01 \times 0{,}5) + (10 \times 5)} = 4{,}76 \text{ m/hour}$$

RAINFALL INFILTRATION

INFILTRATION is the process of water entry to the soil through its upper surface by downward flow. Water may reach the soil surface by flooding the surface, by sprinkling or as rain. The relation between the rate of water supply to the soil surface and the rate of infiltration through it determines the distribution of such water between runoff and storage in the root zone.

VERTICAL INFILTRATION **into an initially dry (unsaturated) soil occurs under the influence of a combination of suction and gravity gradients. The resulting infiltration rate (units of length/time) is a consequence of both the hydraulic conductivity and the hydraulic gradients in the soil surface zone, but it is also affected by the conditions in lower parts of the soil profile.**

The influence of the suction (M) gradient decreases with time until it becomes negligible in the upper part of the soil profile, leaving the constant gravitational gradient as the only force moving the water downward. Therefore, in a uniform soil, without sealing and after prolonged ponding, the flux of water tends to approach the hydraulic conductivity. As a consequence, the infiltration rate under atmospheric pressure (also called "infiltrability" generally decreases from an initially high value in a dry soil, to a much lower constant value termed [illegible] -time rate or steady-state

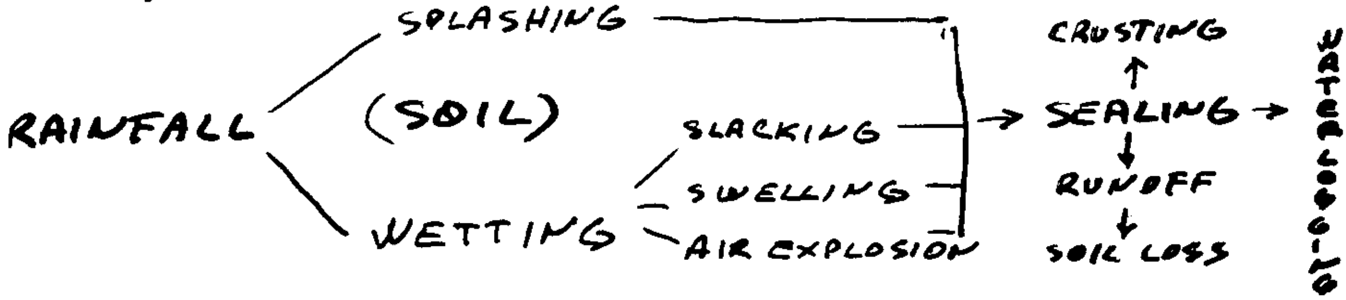
The decrease of infiltration rate of a soil with time is not only due to the decrease of the hydraulic gradient (the suction component), but also to other factors like structural deterioration and SEALING of the soil surface, swelling of clays, entrapment and compression of soil air, etc. These factors are generally more important when the supply of water is through natural RAINFALL.

The decrease in the infiltration rate with time during a rainstorm may be attributed to: - A decrease in the vertical hydraulic gradient with wetting of the soil profile
- SURFACE SEALING by raindrop impact.

The formed seal acts as a bottleneck, and because of its high hydraulic resistance, this causes infiltration into the underlying soil to occur at a suction which generally results in unsaturated flow conditions. As the hydraulic conductivity of the seal decreases, the matric potential, and as a consequence the suction gradient accross the seal, increases, which partially offsets the decreased conductivity on the surface seal. The effect of the SEAL on the infiltration of water in the soil is a decrease on the initial and final infiltration rates, and on the length of time necessary to reach the final or steady infiltration rate.

The rate of formation of a seal and its water transmission properties are determined by physical, mechanical and [illegible] conditions.

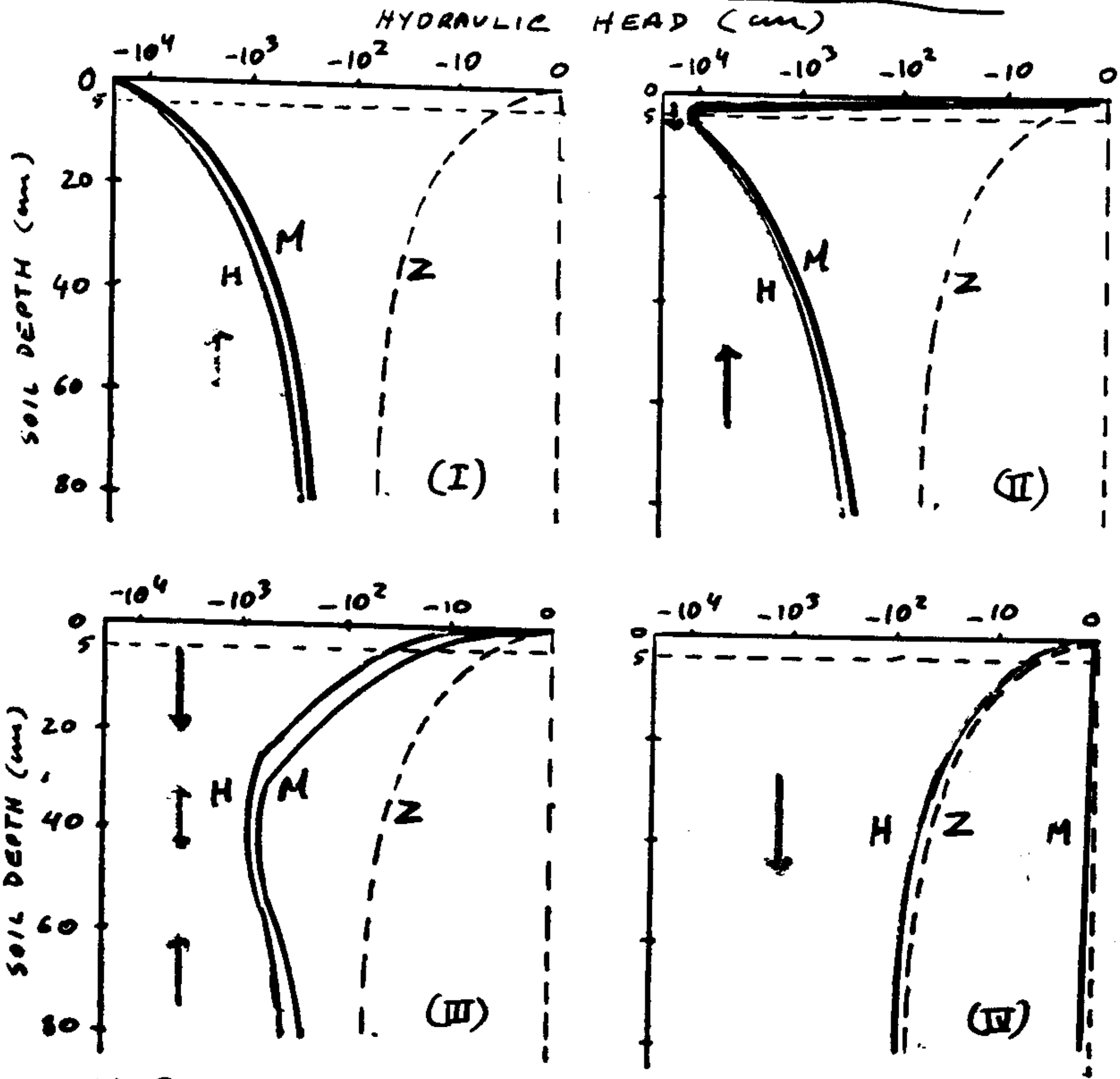
Some important factors and processes leading to sealing, and the derived effects (Bergsma and Kamphorst, 1986) are:



Besides the raindrop's beating action, the percolation of rainfall water, decreasing the electrolyte concentration of the surface soil solution contributes to the dispersion of clay particles which block the pores and decrease even further the saturated hydraulic conductivity of the upper soil layer.

The final infiltration rate in a surface sealed soil will depend not only on the hydraulic properties of the seal, but also on the ones of the soil layer below it, which remains <u>unsaturated</u>, and it will be lower when such layer has coarser pores. Although the final IR decreases with increasing aggregate size of the tilled layer under the seal, because its macropores keep a matric potential with lower K the total intake of water in plowed soils generally exceeds that on finely cultivated or unplowed natural soils because the time and rainfall energy required to form a continuous seal increases with increasing roughness of the surface. This will depend on the structural stability and size of the surface clods, which will determine the evolution of K_s under natural rainfall.

ORIGINALLY DRY (NO SEALING EFFECTS)



H, P, M, Z : HYDRAULIC, PRESSURE, MATRIC, GRAVITATIONAL POTENTIALS EXPRESSED IN HEAD (ℓ) UNITS z : DEPTH

I : CUMULATIVE INFILTRATION IR : INFILTRATION RATE (IR)

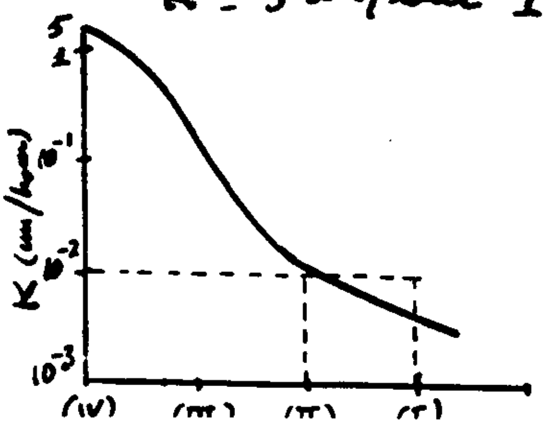
$\Delta H = \Delta P + \Delta Z = \Delta M + \Delta Z$ $IR = -K \cdot (\Delta H / \Delta z)$ $\Delta z = 5cm$ (0-5cm)

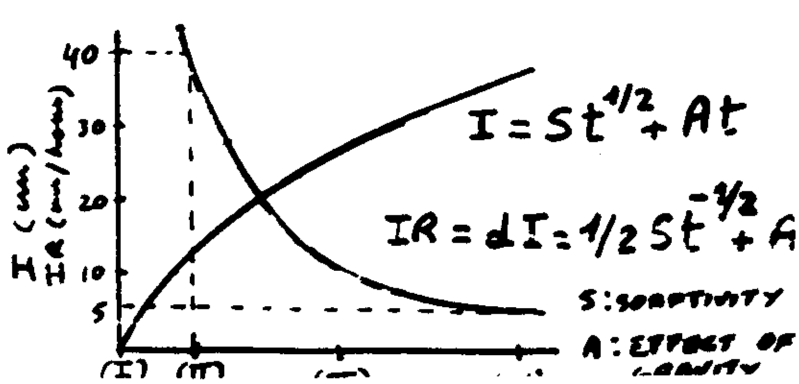
(II): $\Delta M = -2\times10^4 - 0 = -2\times10^4 cm$; $\Delta Z = -5-0 = -5cm$; $\Delta H \approx -2\times10^4 cm$

$K = 10^{-2} cm/hour$ $I = -10^{-2} \cdot (-2\times10^{-4}/5) = 40 cm/hour$

(IV): $\Delta M \simeq 0$; $\Delta Z = -5-0 = -5cm$; $\Delta H \simeq -5 cm$

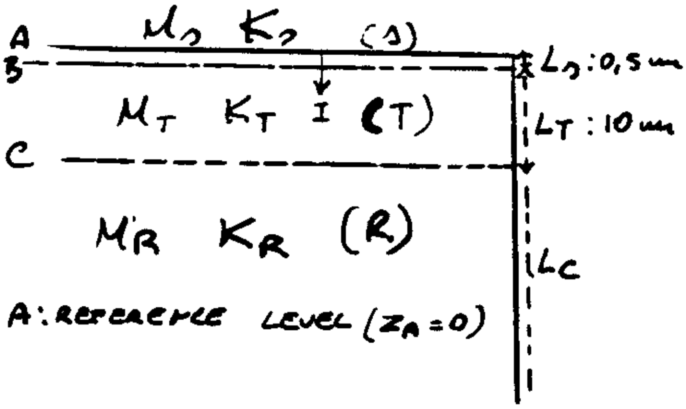
$K = 5 cm/hour$ $I = -5 \cdot (-5/5) = 5 cm/hour$

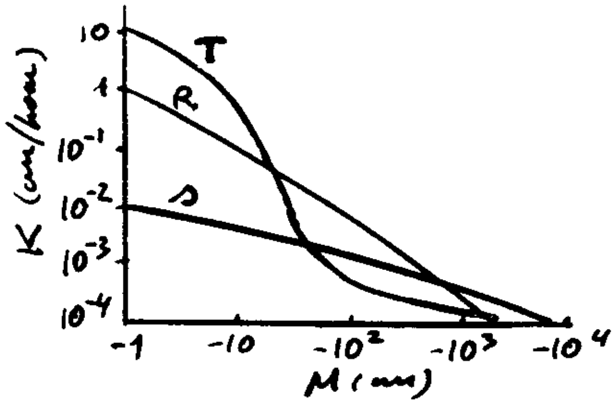




WATER INFILTRATION IN A SOIL WITH A SEAL ON TOP OF A TILLED LAYER

S: SEAL T: TILLED LAYER R: CONSOLIDATED SOIL





S: SATURATED WITH WATER (NO FLOODING)

I: INFILTRATION RATE

$$I_S = -K_S i_S \; ; \; i_S = (H_{B(T)} - H_A)/L_S \; ; \; H_{B(T)} = M_{B(T)} + Z_B = M_{B(T)} - L_S$$

$$i_S = (M_{B(T)} - L_S)/L_S \qquad H_A = M_A + Z_A = 0 + 0 = 0$$

$$(1) \quad I_S = -K_{S\,(M=0)} \cdot (M_{B(T)} - L_S)/L_S = (L_S - M_{B(T)})/R_S$$

(R_S = HYDRAULIC RESISTANCE $= L_S/K_S$

$$I_T = -K_{T\,(M_{B(T)})} \cdot i_T \; ; \; i_T = (H_C - H_{B(S)})/L_T \; ; \; H_C = M_{C(R)} - Z_C$$

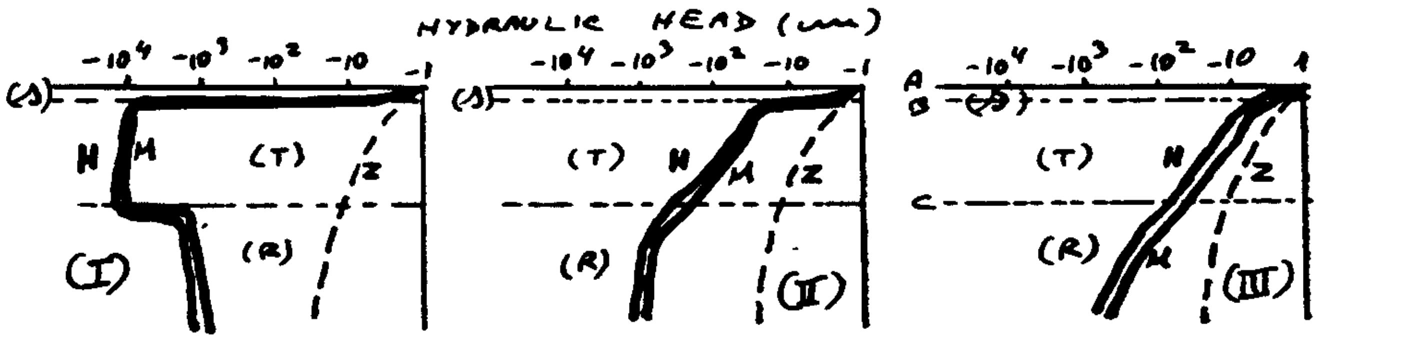
$$H_{B(S)} = M_{B(S)} + Z_B = 0 + Z_B = Z_B \; ; \quad Z_C = -(L_T + L_S)$$

$$Z_B = -L_S$$

$$i_T = (M_{C(R)} - L_T - L_S + L_S)/L_T = (M_{C(R)} - L_T)/L_T$$

$$(2) \quad I_T = -K_{T\,(M_{B(T)})} \cdot (M_{C(R)} - L_T)/L_T$$

I WILL BE THE MINIMUM VALUE OF (1) AND (2)



(I)

$K_S = 10^{-2}$; $M_{B(T)} = -10^4$

$K_{T(M_{B(T)})} = 10^{-5}$; $M_{C(R)} = -10^3$

$$I_S = \frac{-10^{-2} \cdot (-10^4 - 0{,}5)}{0{,}5} = 2 \times 10^2$$

$$I_T = \frac{-10^{-4}(-10^3 - 10)}{10} = 10^{-2}$$

$$I_{(I)} = 10^{-2} \text{ cm/hour}$$

(II)

$K_S = 10^{-2}$; $M_{B(T)} = -50$

$K_{T(M_{B(T)})} = 10^{-2}$; $M_{C(R)} = -10^2$

$$I_S = \frac{-10^{-2}(-50 - 0{,}5)}{0{,}5} = 1$$

$$I_T = \frac{-10^{-2}(-100 - 10)}{10} = 0{,}1$$

$$I_{(II)} = 0{,}1 \text{ cm/hour}$$

(III)

$K_S = 10^{-2}$; $M_{B(T)} = -5$

$K_{T(M_{B(T)})} = 1$; $M_{C(R)} = -50$

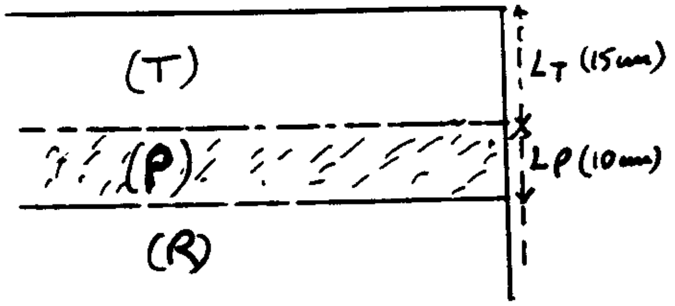
$$I_S = \frac{-10^{-2}(-5 - 0{,}5)}{0{,}5} = 0{,}11$$

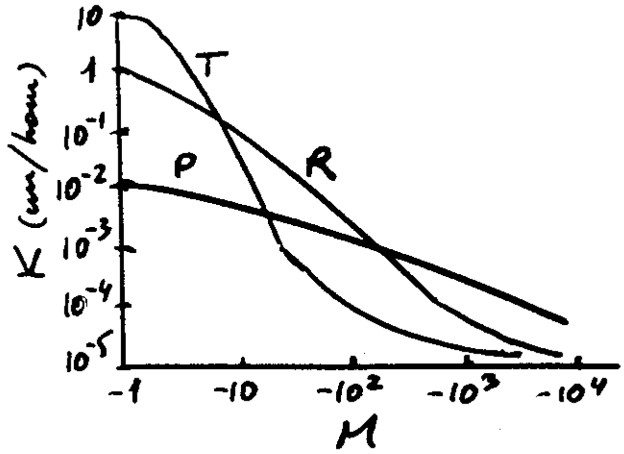
$$I_T = \frac{-1(-50 - 10)}{10} = 6$$

$$I_{(III)} = 0{,}11 \text{ cm/hour}$$

WATER INFILTRATION IN A TILLED SOIL WITH A SHALLOW COMPACTED PAN. (NO SEALING)

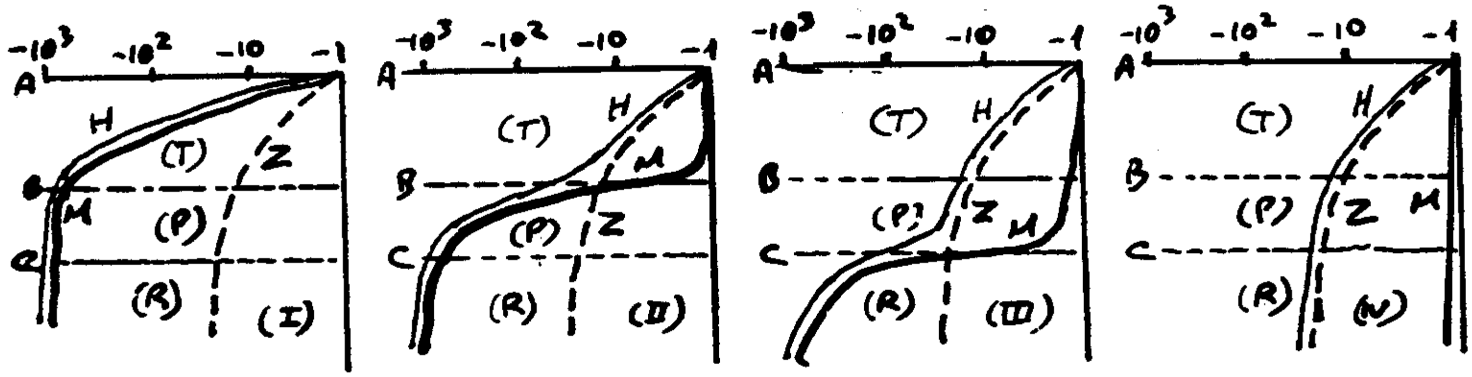
T : TILLED LAYER P : COMPACTED PAN R : CONSOLIDATED SOIL





A : REFERENCE LEVEL ($z_A = 0$)

HYDRAULIC HEAD (cm)



(I) $h_A = 0$; $h_B = -10^3$; $h_C = -10^3$; $K_T = 1$ cm/hour

$$I_T = -K_T (h_B - h_A - L_T)/L_T = -1(-10^3 - 15)/15 = 70 \text{ cm/hour}$$

$$I_{(I)} = 70 \text{ cm/hour}$$

(II) $h_A = 0$; $h_B = -1$; $h_C = -10^3$; $K_T = 10$; $K_P = 10^{-3}$

$$I_T = -10(-1-15)/15 = 10 \text{ cm/hour} \; ; \; I_P = -10^{-3}(-10^3 + 1 - 10)/10 = 0{,}1 \text{ cm/hour}$$

$$I_{(II)} = 0{,}1 \text{ cm/hour}$$

(III) $h_A = 0$; $h_B = 0$; $h_C = -1$; $K_T = 10$ cm/hour ; $K_P = 10^{-2}$ cm/hour

$$I_{(III)} = K_S = (L_T + L_P) \Big/ \left(\frac{L_T}{K_T} + \frac{L_P}{K_P} \right) = 25/(1{,}5 + 10^3) = 0{,}025 \text{ cm/h}$$

$$I_{(III)} = 0{,}025 \text{ cm/hour}$$

(IV) $h_A = 0$; $h_B = 0$; $h_C = 0$; $K_T = 10$; $K_P = 10^{-2}$; $K_R = 1$

$$I_{(IV)} = K_S = \frac{L_T + L_P + L_R}{L_T/K_T + L_P/K_P + L_R/K_R} = \frac{15 + 10 + 10}{1{,}5 + 10^3 + 10} = 0{,}03 \text{ cm/h}$$

$I_{(IV)} = 0{,}03$ cm/h

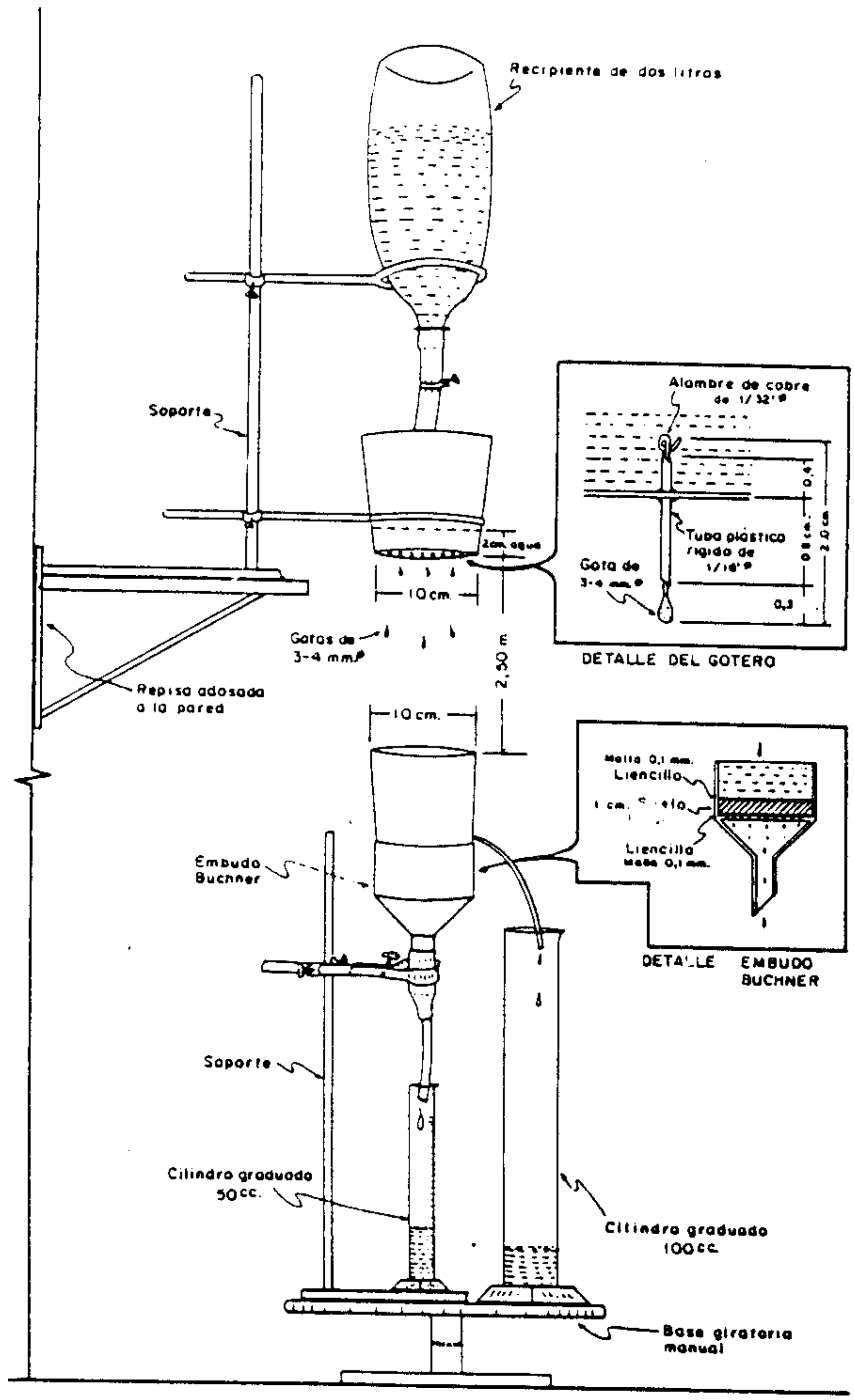


Figura 10a. Simulador de lluvia para ser utilizado en el laboratorio.

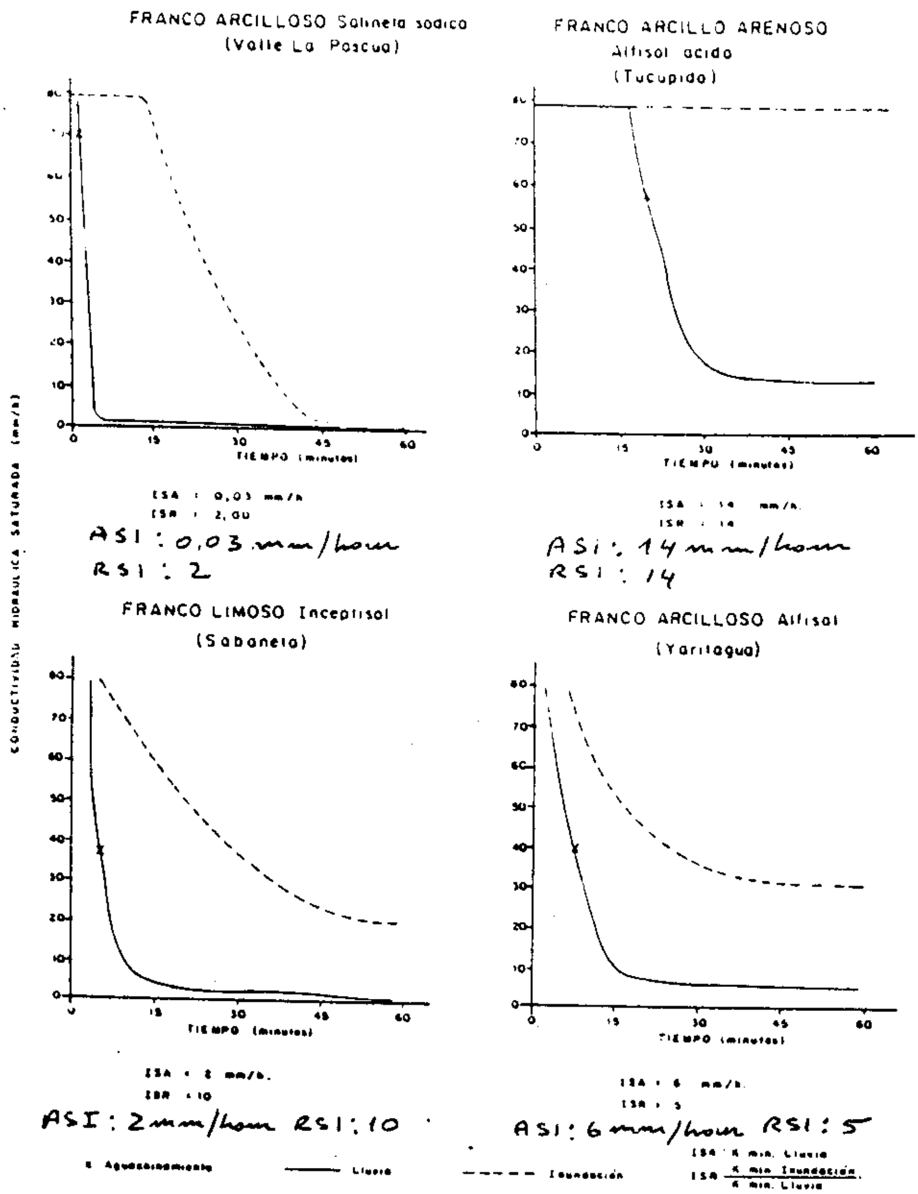


Figura 10b Evolución de la conductividad hidráulica con sello y sin sello superficial.

ASI : ABSOLUTE SEALING INDEX = MINIMUM K UNDER RAINDROP IMPACT ———

RSI : RELATIVE SEALING INDEX = $\frac{\text{MINIMUM K UNDER FLOODING}}{\text{ASI}}$

– – – – – – K UNDER FLOODING (NO RAINDROP IMPACT)

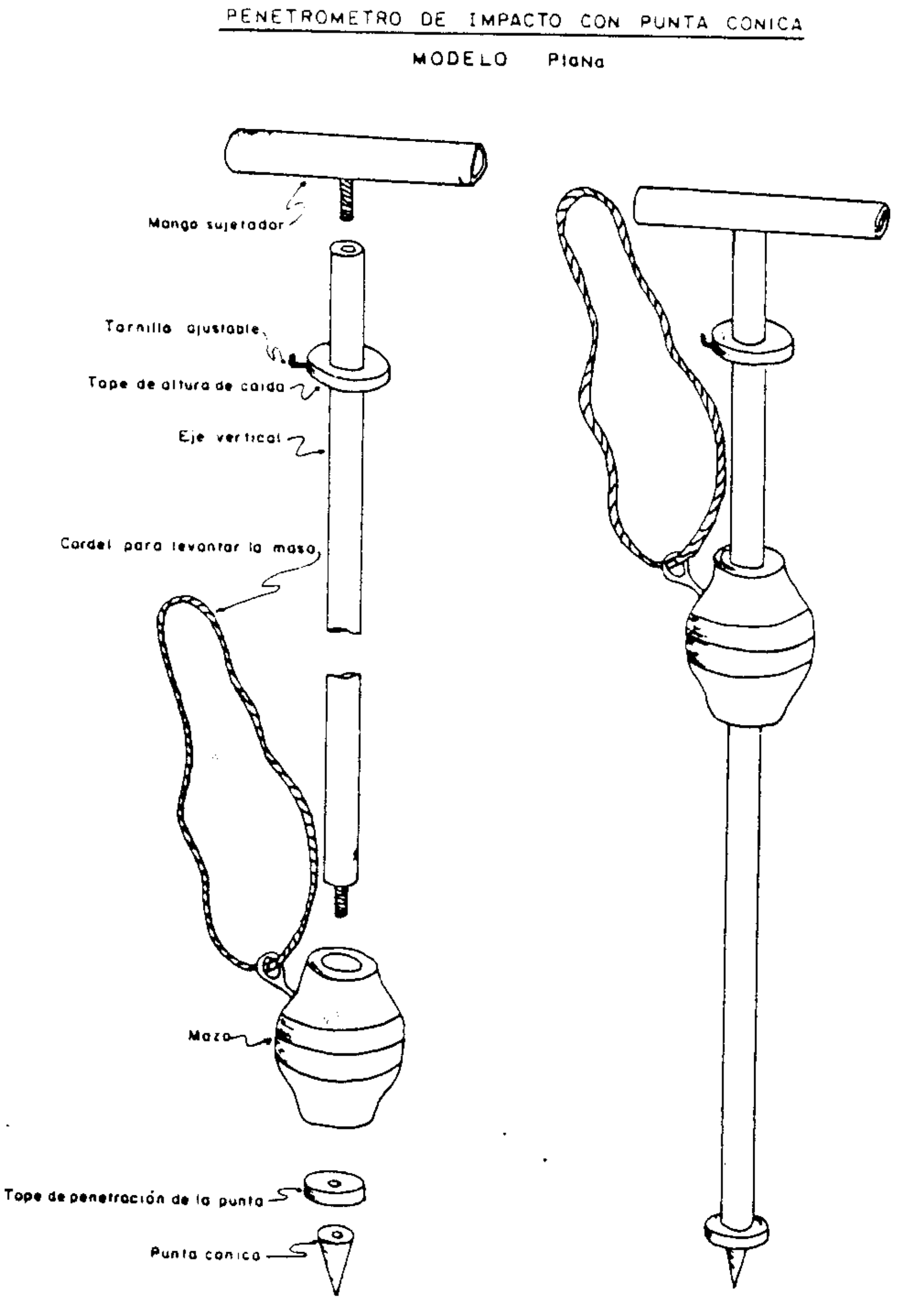


Figura 1. Equipo para evaluar resistencia a la penetración (penetrómetro de impacto con punta cónica).

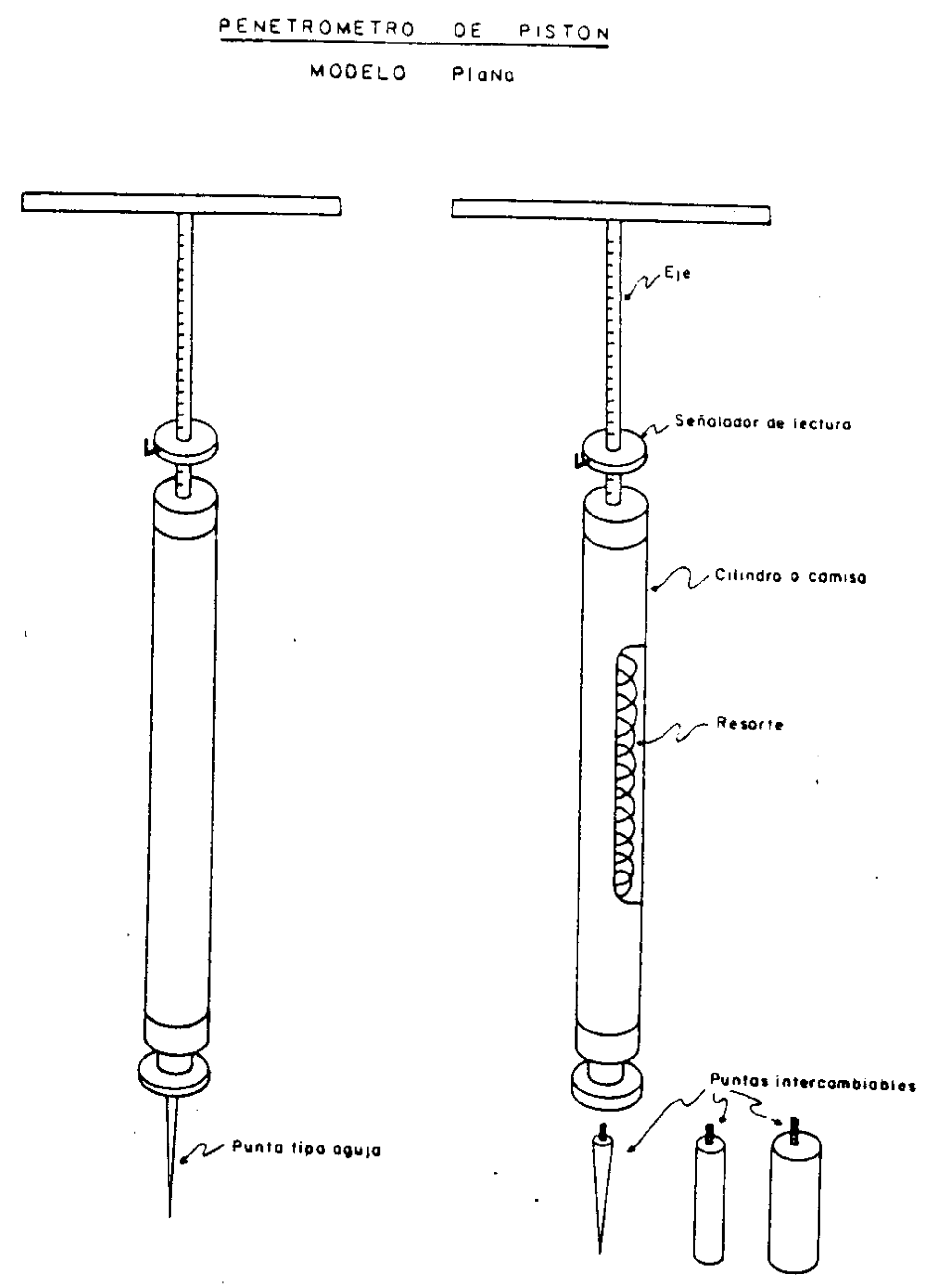


Figura 3. Penetrómetro de resorte con puntas intercambiables.

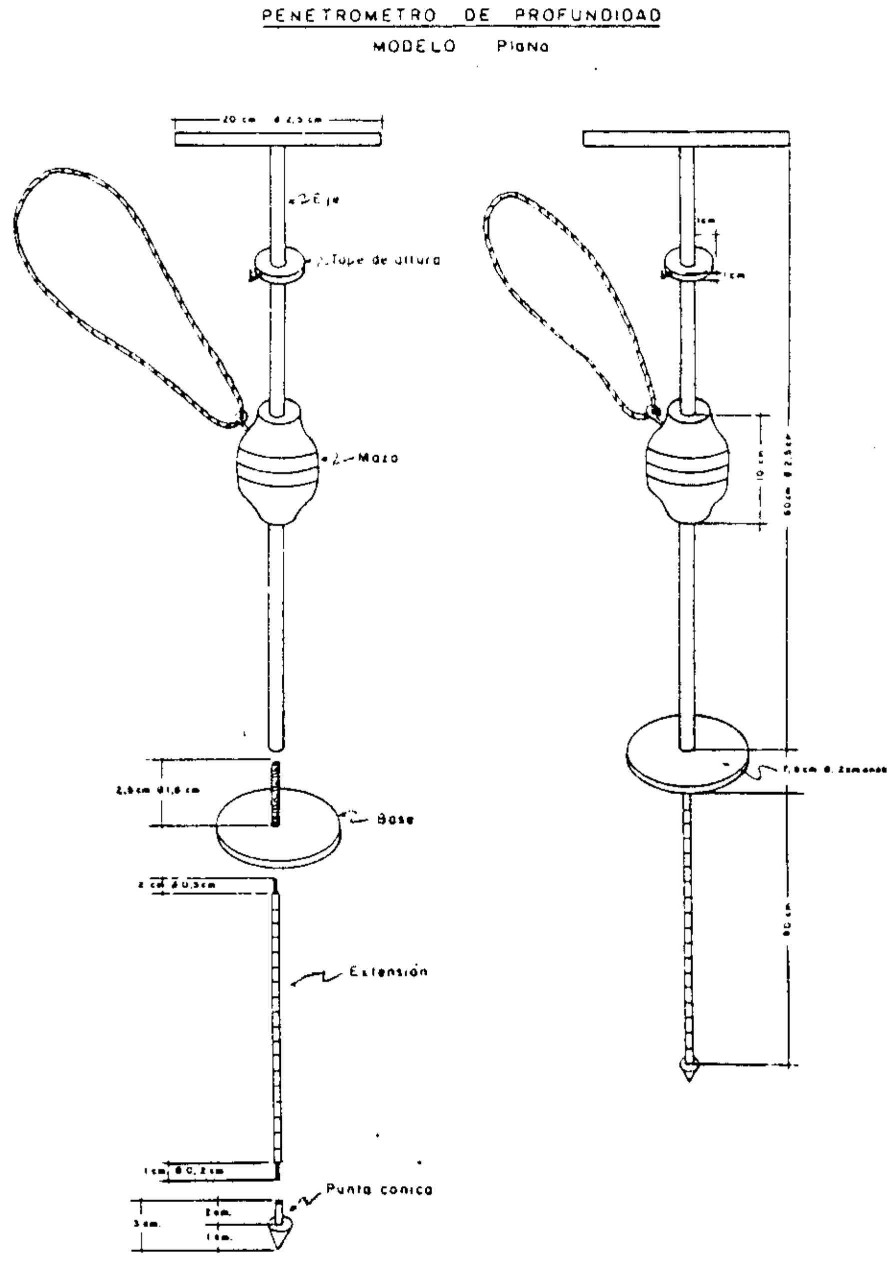


Figura 2. Equipo para evaluar resistencia a la penetración (penetrómetro de profundidad).

$$R\,(KPa) = \frac{M^2\,(gm) \cdot h\,(cm) \cdot n}{20\,(M+m)(gm) \cdot S\,(cm^2) \cdot z\,(cm)}$$

R : Resistence to penetration. S : Area of the cone base
M : Mass of falling weight z : Depth of penetration.
h : High " "
n : Number
m : mass of the equipment

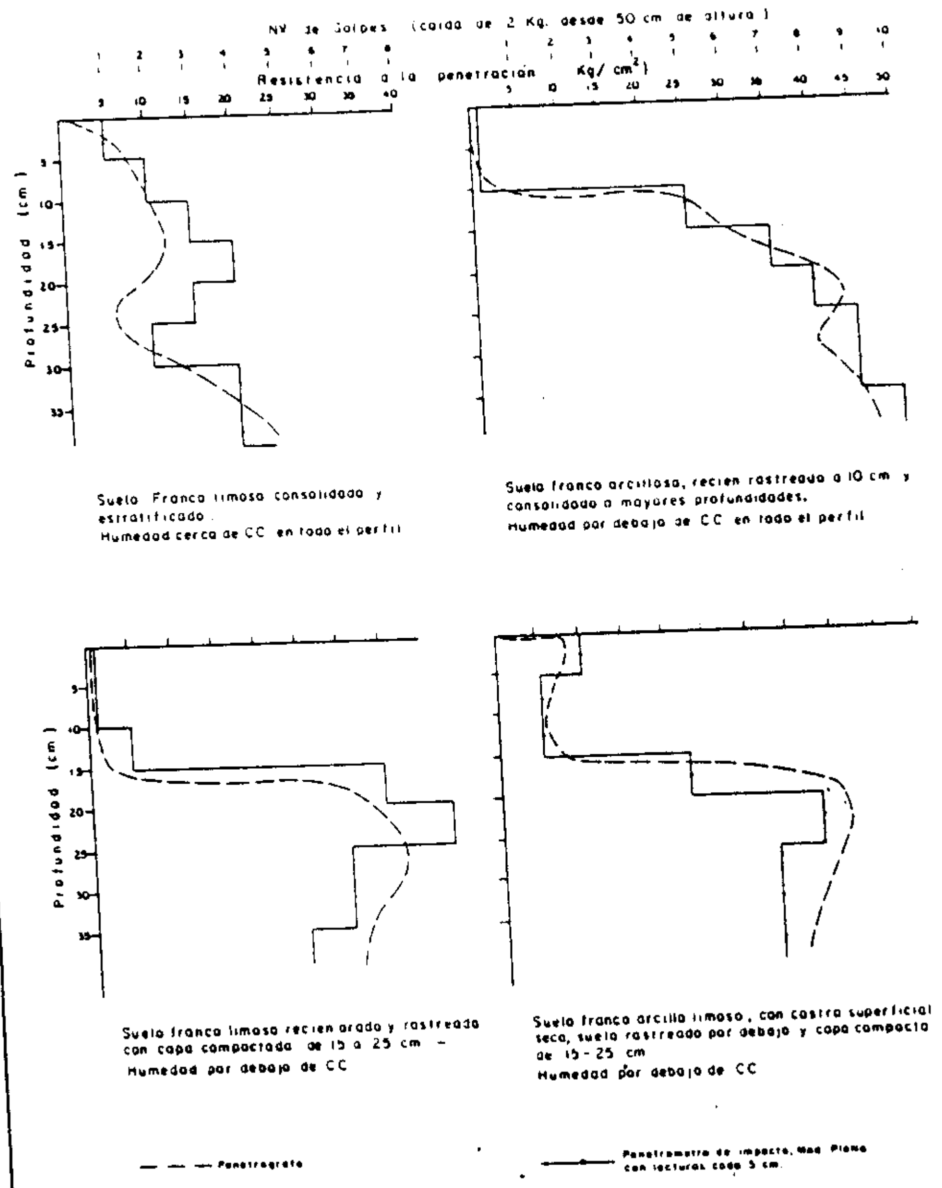


Figura 5. Valores de resistencia a la penetración obtenida con un equipo comercial y con el penetrómetro de profundidad diseñado.

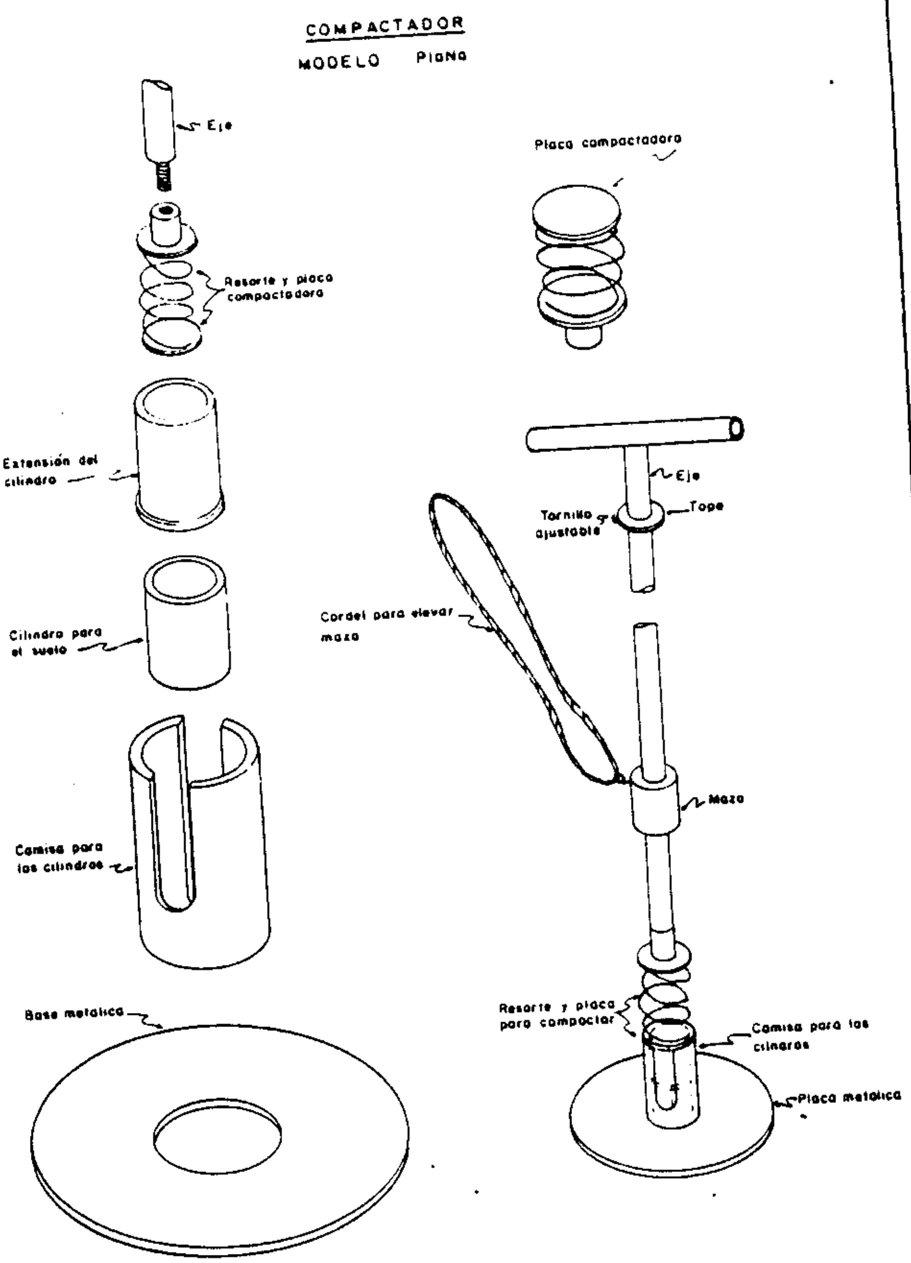


Figura 7. Equipo de compactación de muestras disturbadas de suelos.

$$E\ (KPa) = \frac{M(gm) \cdot h\ (cm) \cdot n \cdot N}{10\ \text{Volume of cilinder}\ (cm^3)}$$

E: Applied energy when a weight M falls N times from an altitude h and the soil is compacted in n layers (one by one)

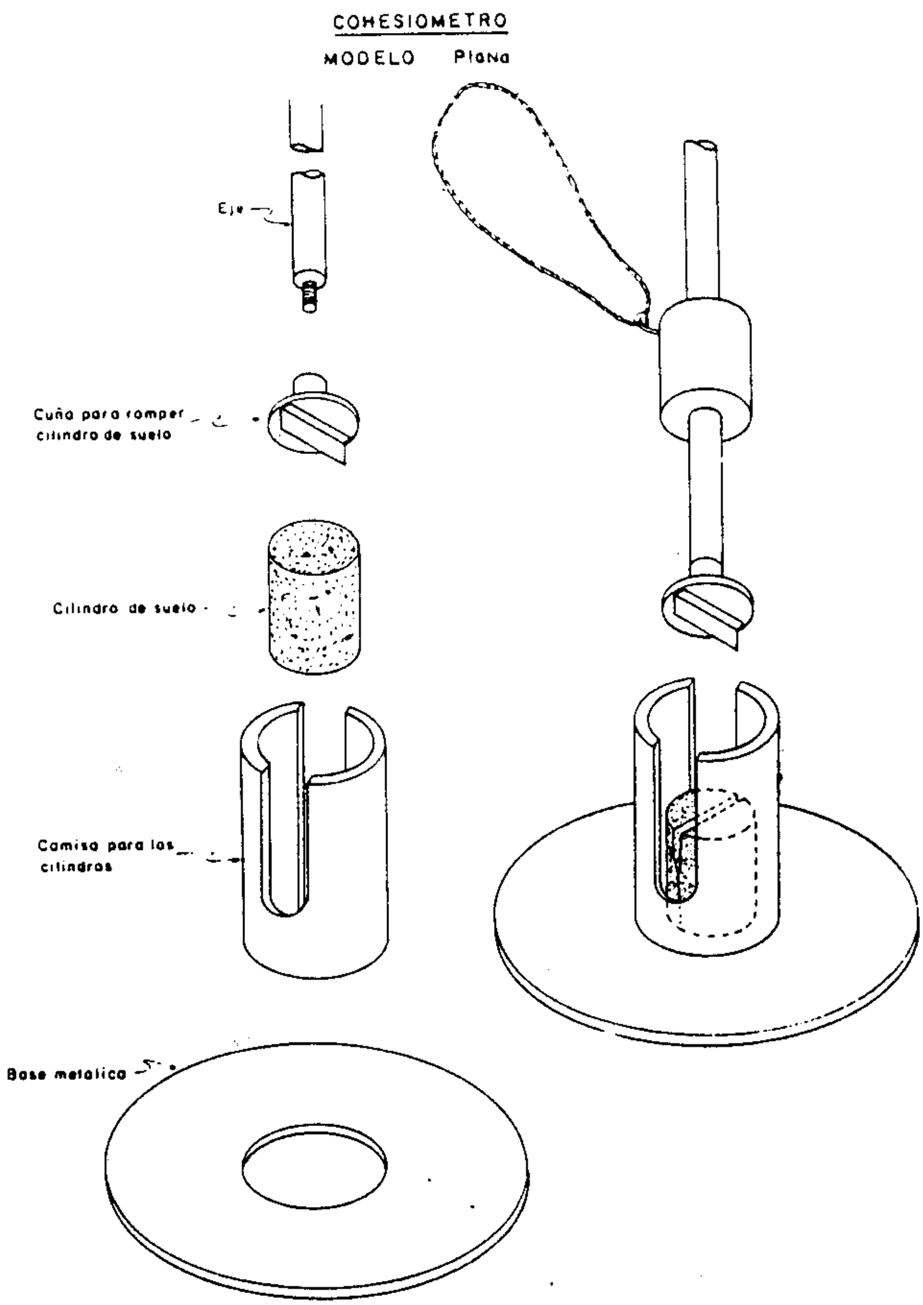


Figura 9. Equipo para medir cohesión en seco en muestras de suelo disturbadas o no disturbadas.