The Abdus Salam International Centre for Theoretical Physics

2444-21

College on Soil Physics - 30th Anniversary (1983-2013)

25 February - 1 March, 2013

Infiltration under different soil condition

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COLLEGE ON SOIL PHYSICS 2013

(30TH Aniversary)

ICTP, Trieste (Italy)

INFILTRATION
UNDER DIFERENT SOIL CONDITIONS

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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.

The knowledge of the <u>infiltration process</u> as it is affected by the soil's dynamic properties and by the supply of water is very important for an efficient soil and water management and conservation, especially when the water supply is through RAINFALL

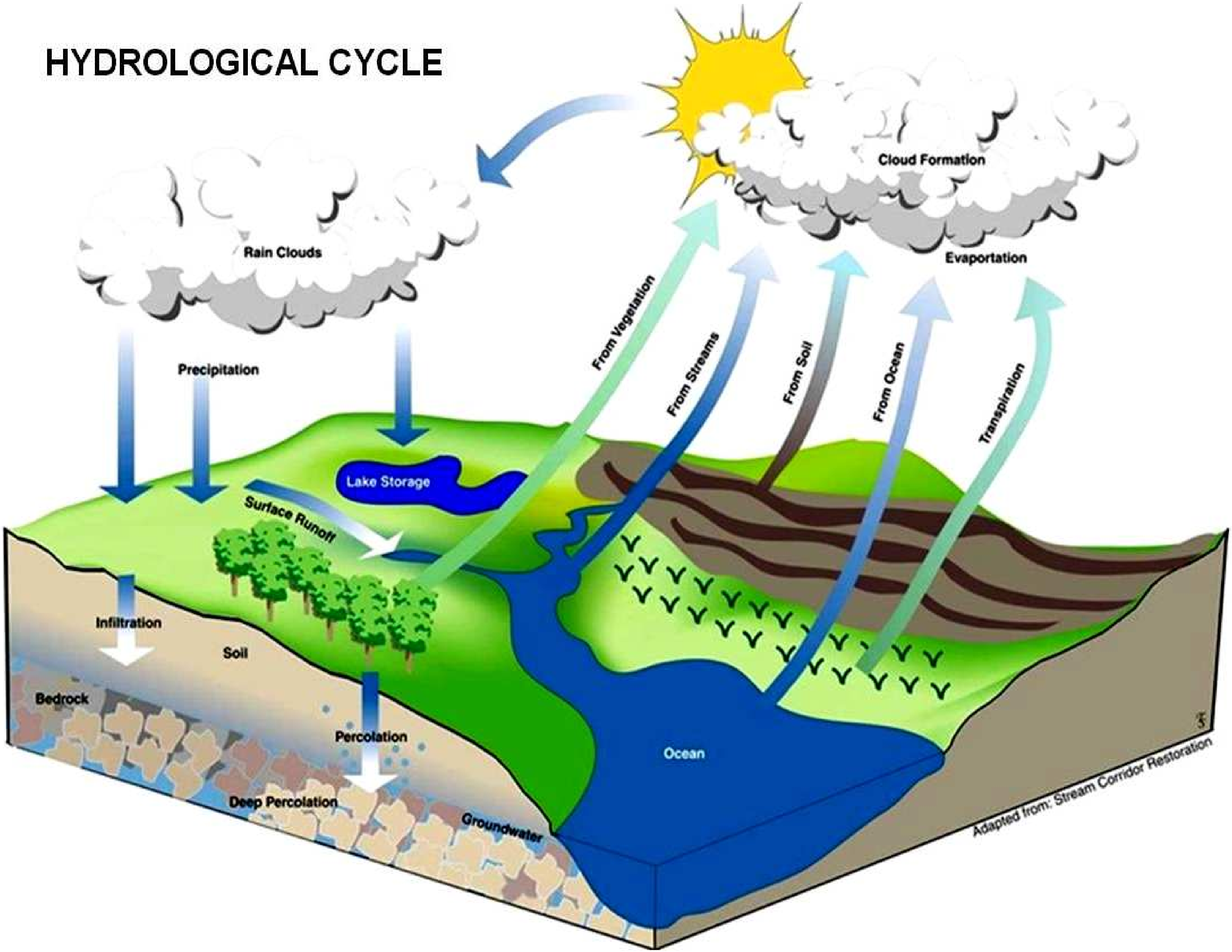
Soil infiltrability, together with rainfall characteristics, is the most important hydrological parameter for the evaluation and diagnosis of the soil water balance and soil moisture regime.

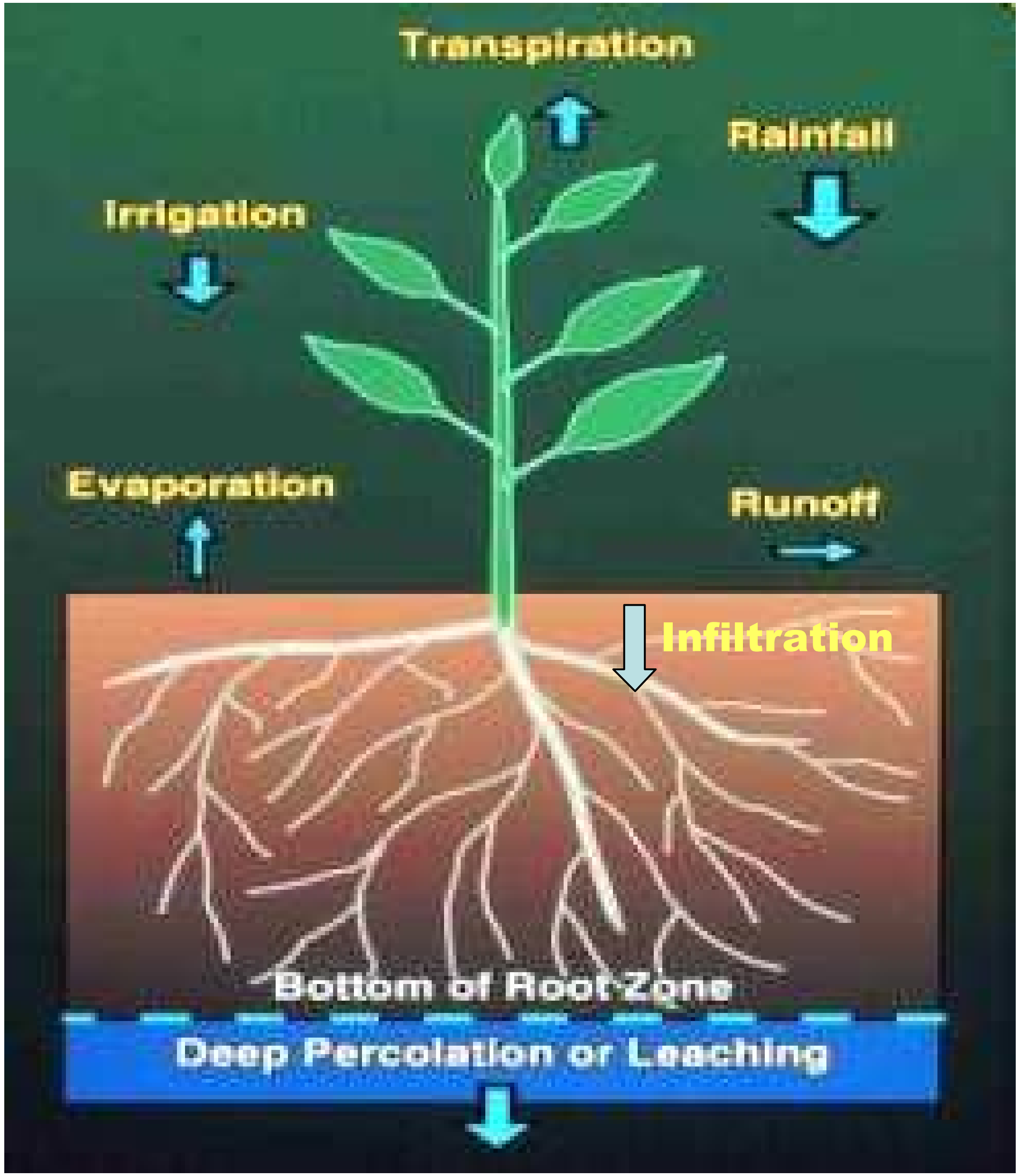
Those balances and regimes are the main regulating factors of the:

-on site water supply to plants and other soil organisms and of

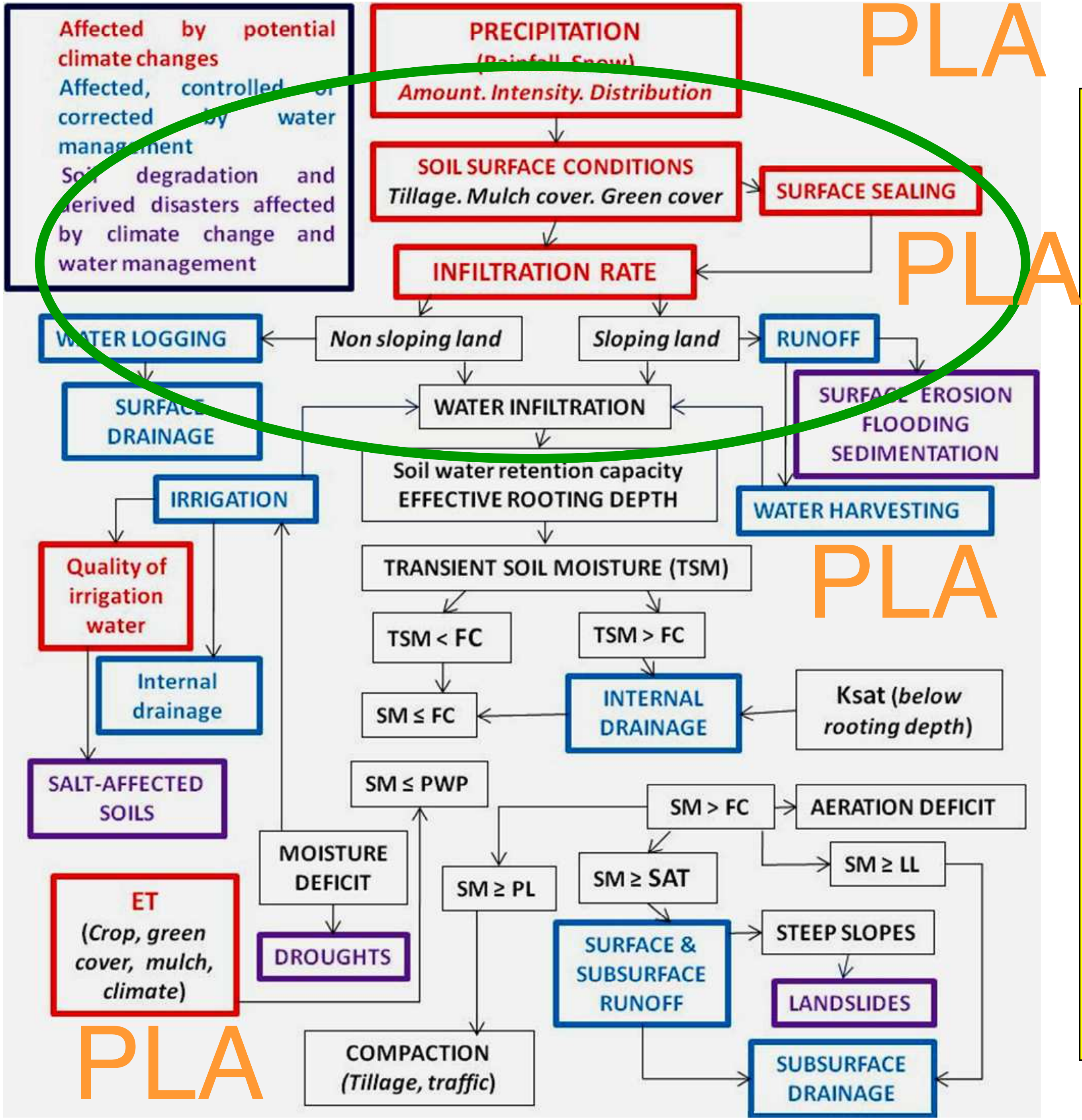
-other important processes like runoff, surface and mass erosion, drainage, etc, affecting sedimentation, flooding, soil and water pollution, water supply for different purposes (population, agriculture, industries, hydroelectricity), etc.

HYDROLOGICAL CYCLE





Transpiration
Rainfall
Irrigation
Evaporation
Runoff
Infiltration
Bottom of Root Zone
Deep Percolation or Leaching



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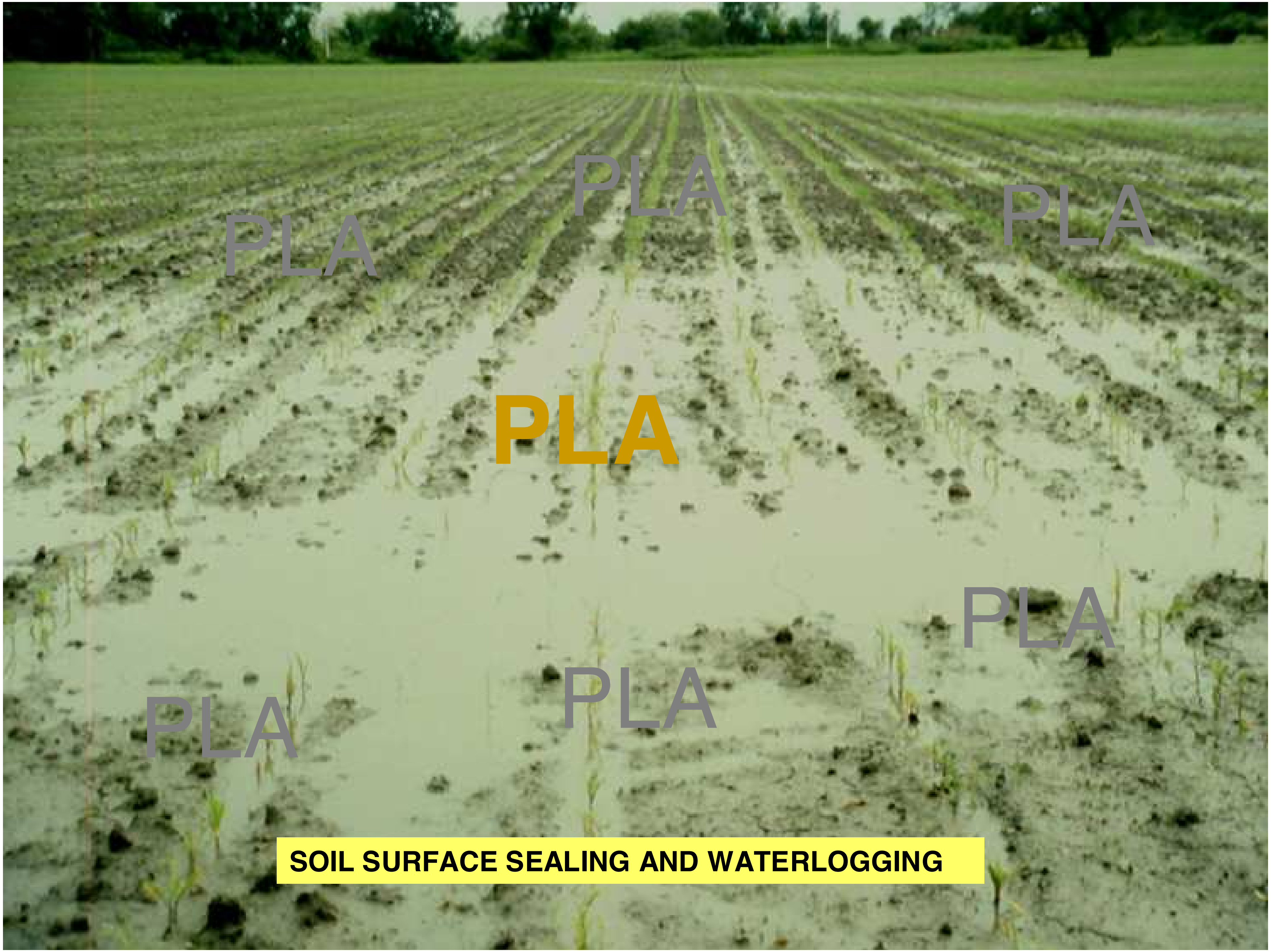
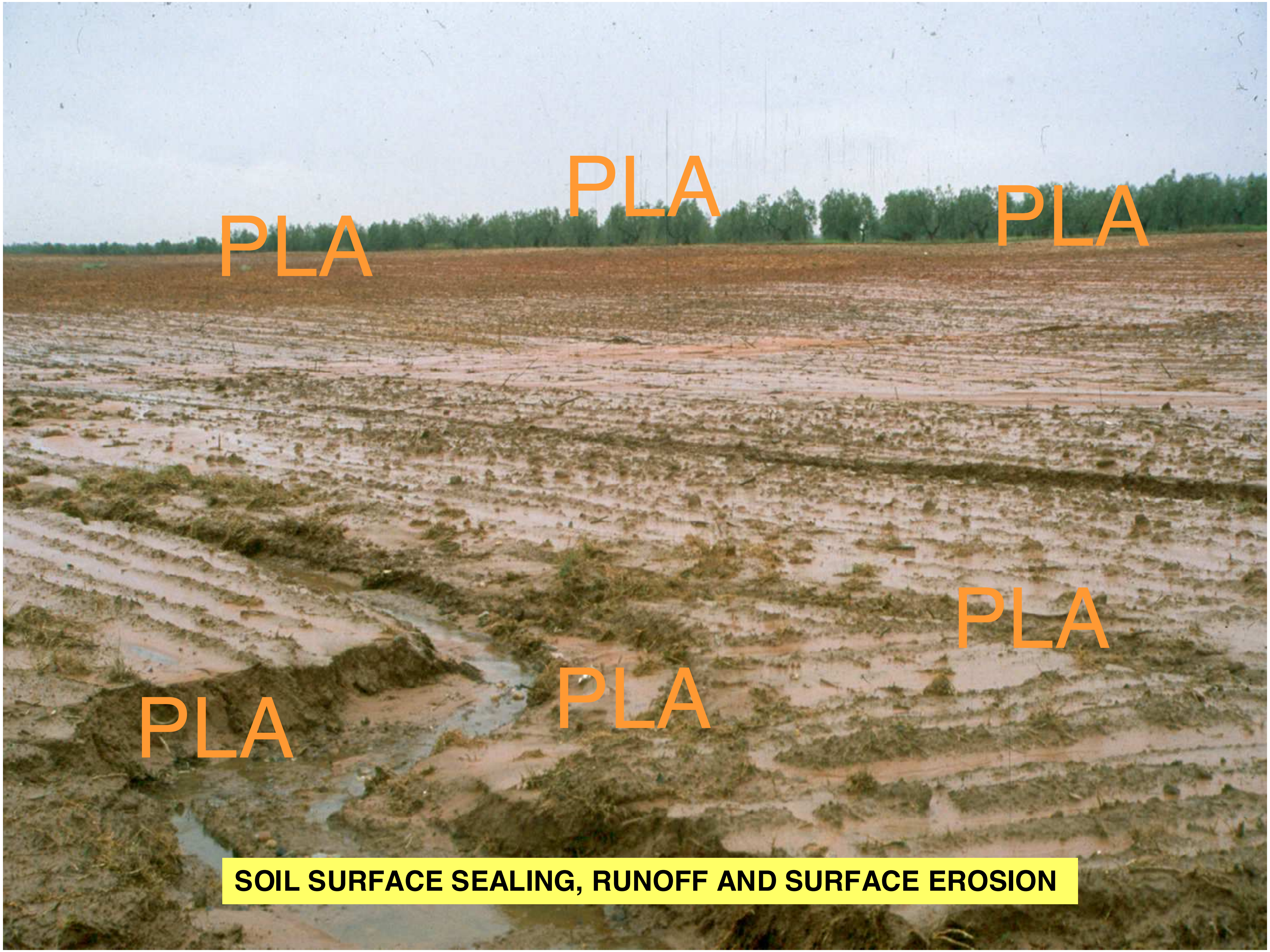
Flow diagram showing the critical influence of

soil water infiltration

on the soil water balance and soil water regime, and their effects on soil hydrological processes responsible of plant water supply, soil salinization, soil erosion (surface and mass erosion), and other soil degradation processes, under different climate conditions and land management practices (model SOMORE: Pla, 1997, 2000, 2006) (SM: Soil moisture at root depth; FC: Field capacity; PWP: Permanent wilting point; ET: Evapo-transpiration)



SOIL SURFACE SEALING AND WATERLOGGING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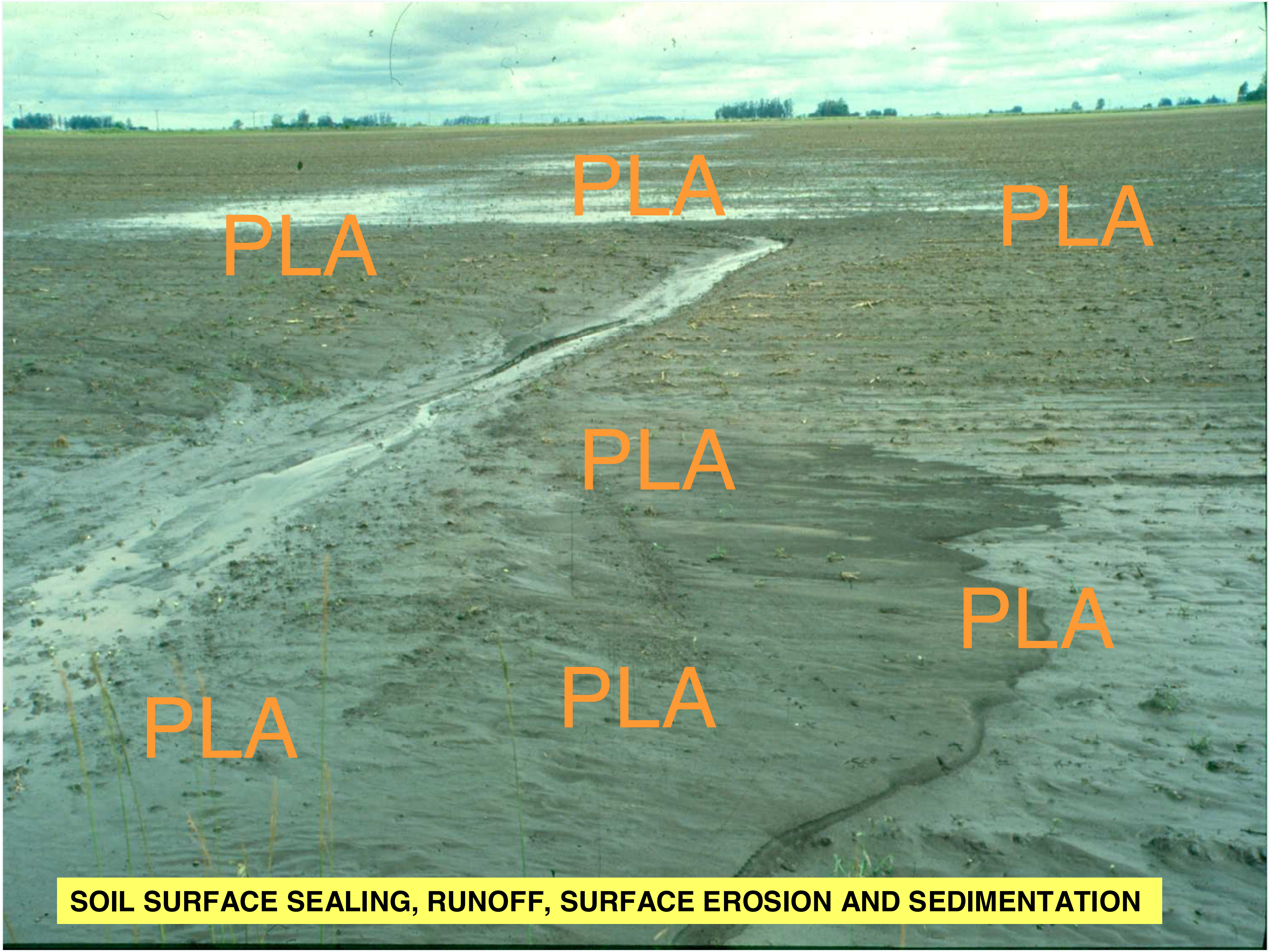
SOIL SURFACE SEALING, RUNOFF AND SURFACE EROSION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SOIL SURFACE SEALING, RUNOFF, SURFACE EROSION AND SEDIMENTATION


PLA
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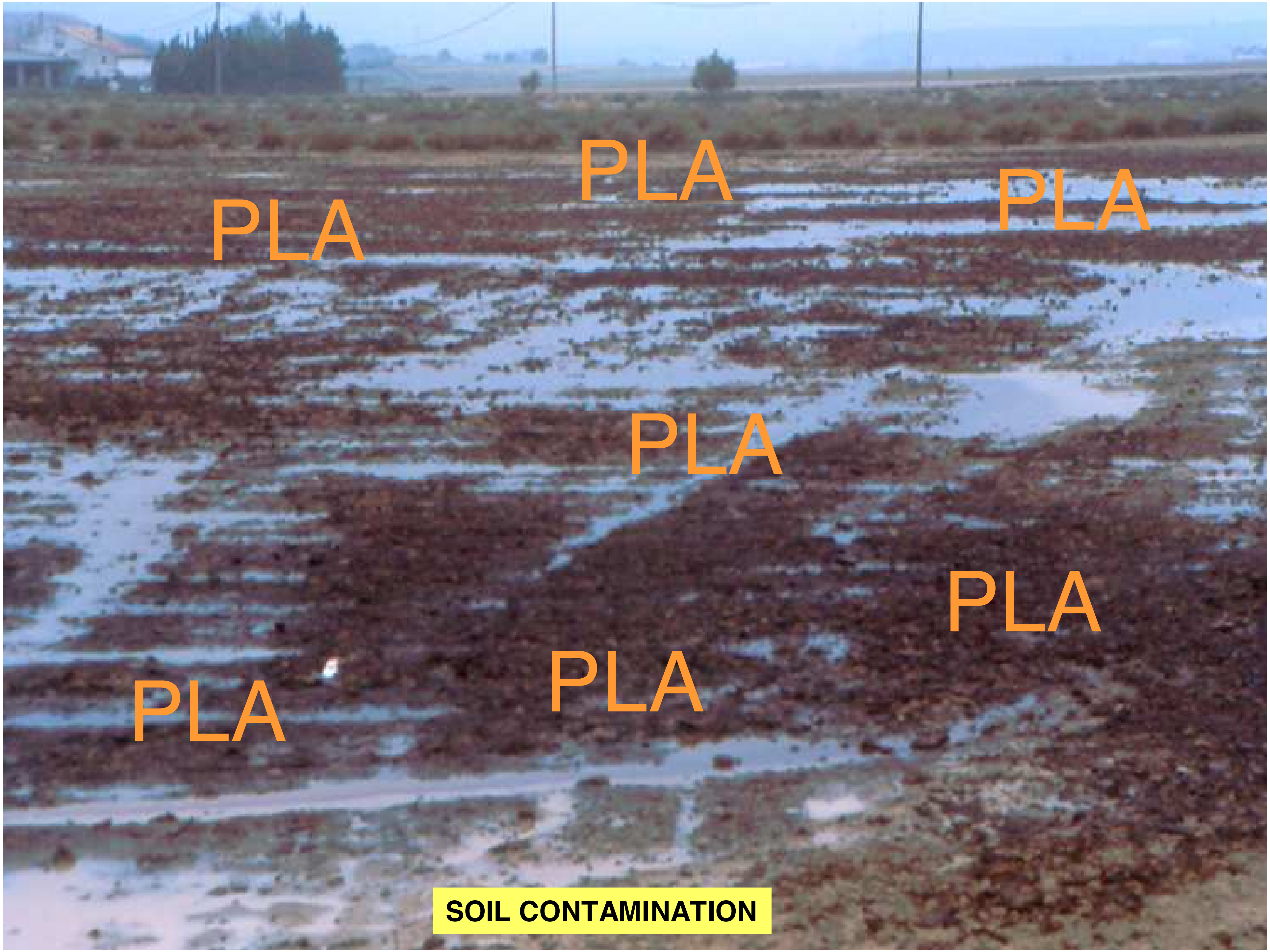
LANDSLIDE (MASS EROSION)

SOIL SALINIZATION UNDER IRRIGATION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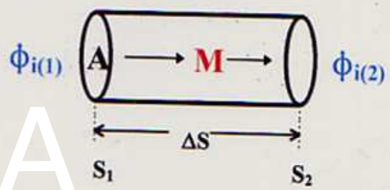
SOIL CONTAMINATION

VERTICAL INFILTRATION into an initially dry (unsaturated) soil ocurs under the influence of a combination of matric (suction) and *gravity gradients*.

The resulting infiltration rate (units of velocity: 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

FLOW OF WATER IN A POROUS MATERIAL (SOL)



General flow equation:

$$Q_i = - A\ t\ K_i\ (\Delta\phi_i / \Delta S)$$

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

$J_i = Q_i / A\ t$ **: Flow density**

K_i **: Conductivity of the material M for fluid "i"**

i : Heat (Fourier´s law); i : Electricity (Ohm´s law); i : Gas (Fick´s law)

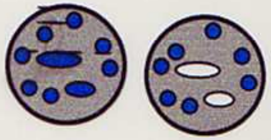
i : Water **(Darcy´s law)**

$$\boxed{J_{H2O}\ (V/At : m^3/m^2\ sec = m/sec) = -K_{H2O}\ (m/sec).\Delta\Psi_H / \Delta S\ (m/m)}$$

Ψ_H : Hydraulic potential; $\Delta\Psi_H/\Delta S$: Hydraulic gradient in the flow direction; K_{H2O} : Hydraulic Conductivity

$$\boxed{K_{H2O} = (\mathcal{K} \cdot \rho_{H2O} \cdot g) / \eta_{H2O}}$$

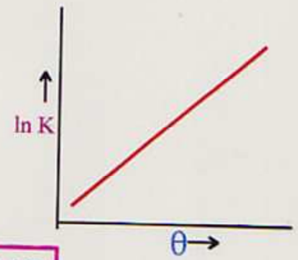
$\mathcal{K}$: Intrinsic permeability of the soil; ρ_{H2O} : Water density
g : Gravity; η_{H2O} : Water viscosity; θ : Volumetric moisture



I II

$\theta_I > \theta_{II}$
$K_I > K_{II}$

$\mathcal{K}_I > \mathcal{K}_{II}$
$\eta_I < \eta_{II}$



$$\boxed{K(\theta) = K(sat)^{\exp(a\theta)}}$$

Non-saturated horizontal flow: $J_{H2O} = q = - K(\theta) \cdot \delta M / \delta x$

$$\boxed{q = - K(\theta) \cdot (\delta M / \delta\theta) \cdot (\delta\theta / \delta x) = - D(\theta) \cdot \delta\theta / \delta x}$$

M : Matric potential; D(θ) : Diffusivity

The influence of the <u>matric (suction) gradient</u> decreases with time until it becomes negligible in the upper part of the soil profile, leaving the constant <u>gravitational gradient</u> as the only force moving the water downward

Therefore, in a uniform soil without sealing and after prolonged pondding, the <u>flux of water tends to approach the saturated hydraulic conductivity</u>

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 final infiltration rate or steady state infiltrability.

The cumulative infiltration, which is a term used for the time integral of infiltration rate, has a curvilinear time dependence slope up to a constant value

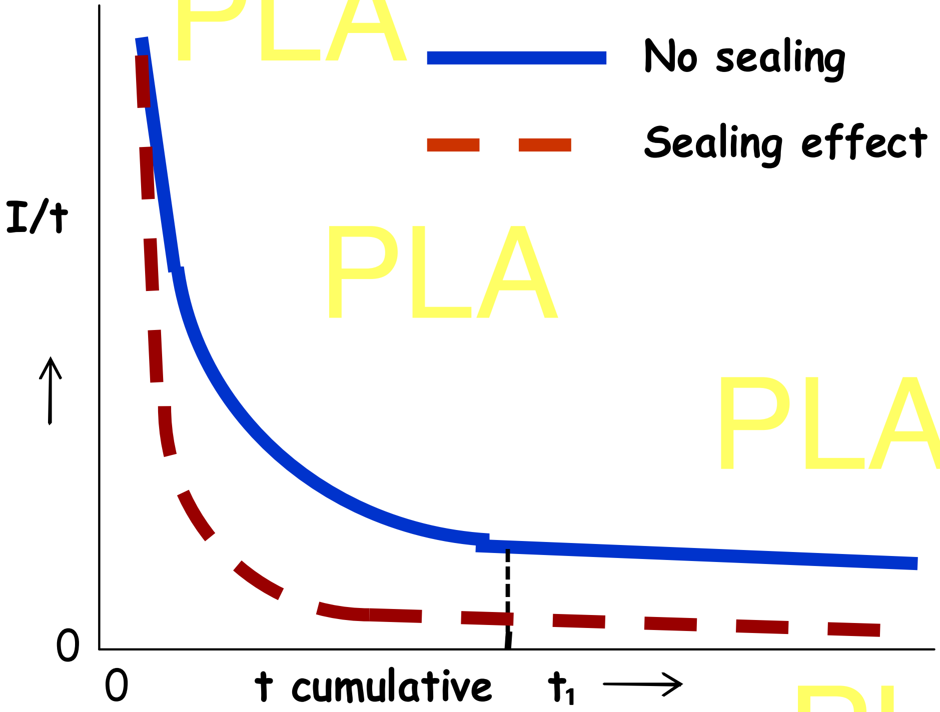
The <u>decrease of infiltration rate of a soil with time</u> is not only due to the decrease of the hydraulic gradient (the matric or suction component), but also to other factors like:

- **Structural deterioration and sealing of the soil surface**

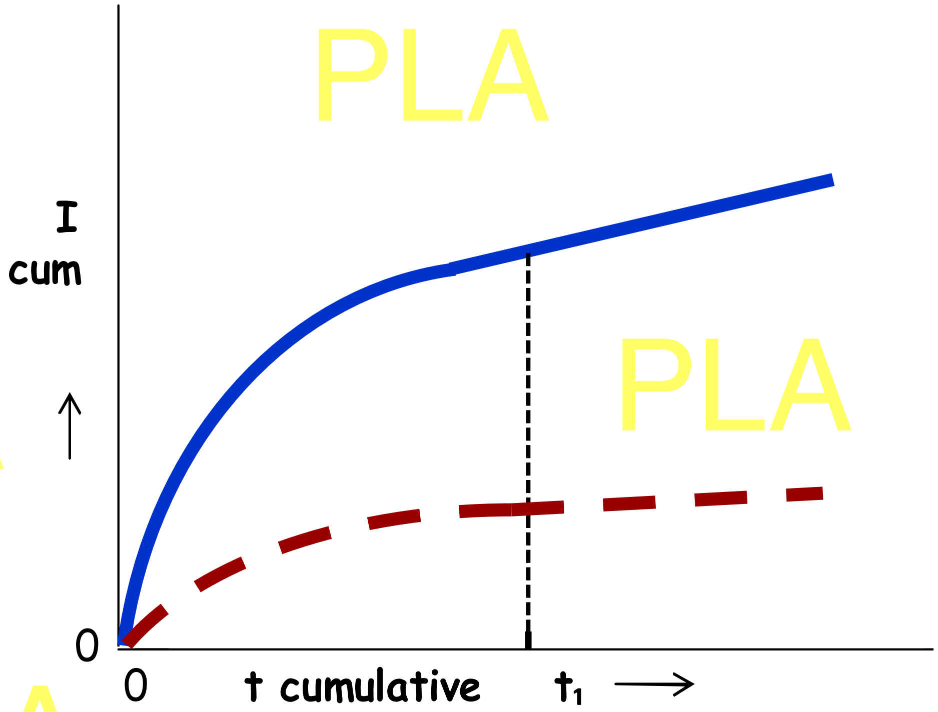
- **Swelling of clays**

- **Entrapment and compression of soil air…**

These factors are generally more important when the supply of water is through natural rainfall



Instantaneus infiltration rate (I/t)
t: time ; t_1 : Time to reach I/t constant



I cum : cumulative infiltration; t : time;
t_1 : time to reach dI/dt constant

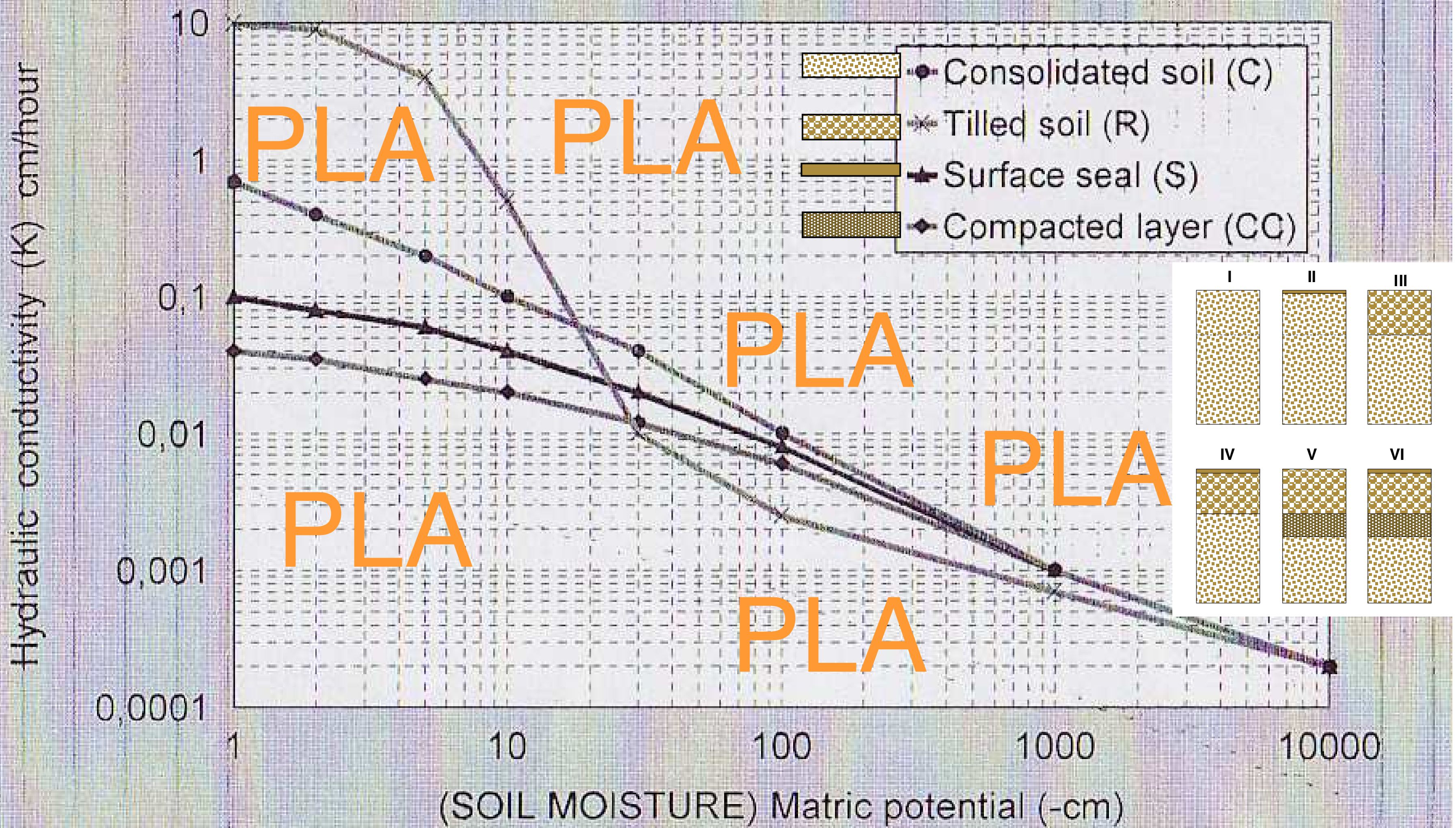
Factors Affecting Infiltration Rate

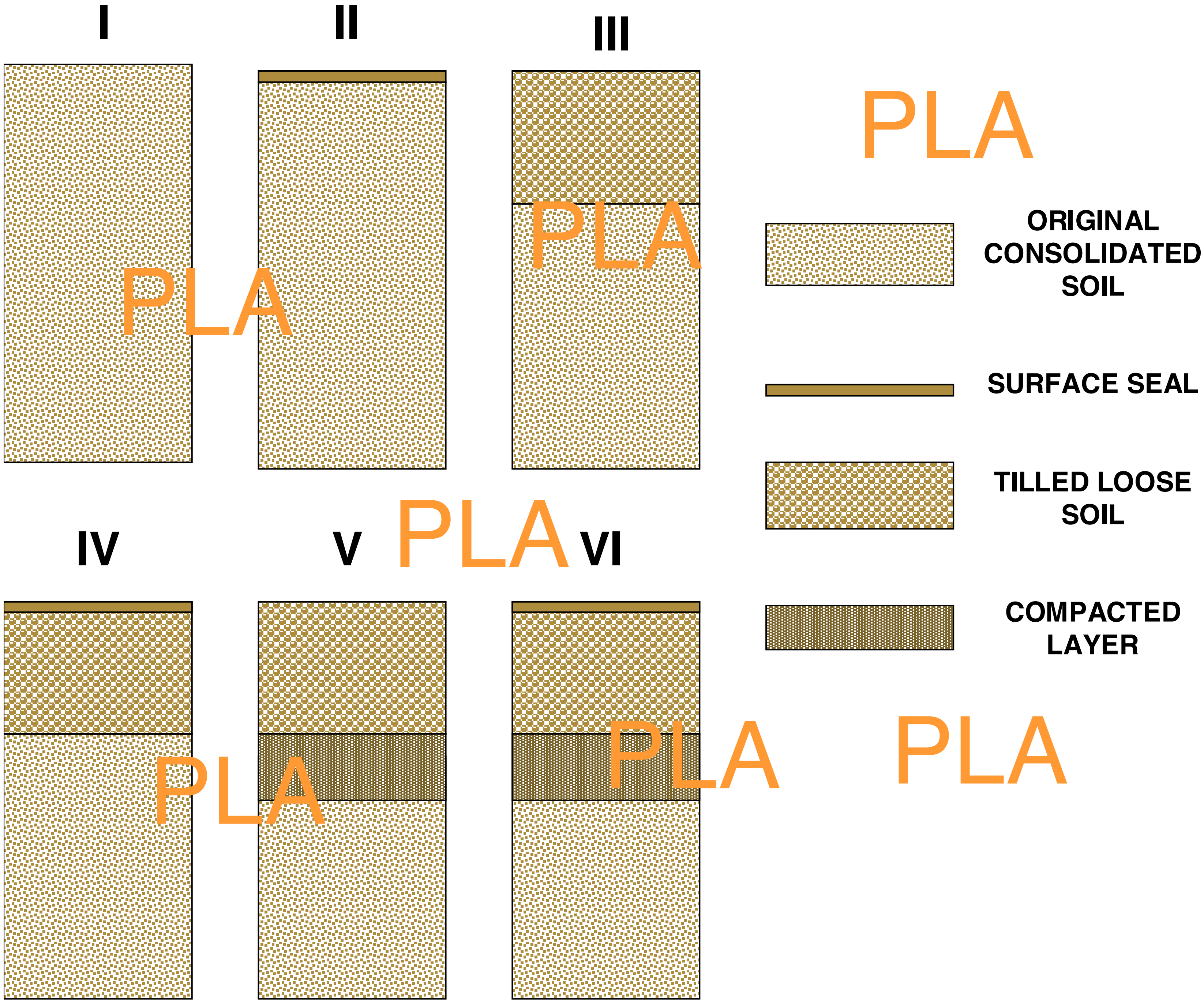
- **INFILTRATION RATE**
  - **Hydraulic Conductivity**
    - **Fluid properties**
      - Density
      - Viscosity
    - **Porous medium properties**
      - Moisture Content
      - Pore size, shape distribution, continuity
      - Surface conditions
  - **Gradient of potential**
    - **Pressure gradient**
      - Hydrostatic head at the soil surface
      - Pressure and moisture content at wetting front
    - **Gravitational gradient**
      - Depth to the wetting front

THE FOLLOWING SLIDES SHOW ONE EXAMPLE OF HOW THE DIFFERENT LAYERS IN A SOIL PROFILE, NATURAL OR CREATED BY MANAGMENT OR CLIMATE FACTORS, MAY AFFECT THE PROCESS OF WATER INFILTRATION IN AN INITIALLY DRY SOIL

HYDRAULIC CONDUCTIVITY CHANGES WITH SOIL MOISTURE

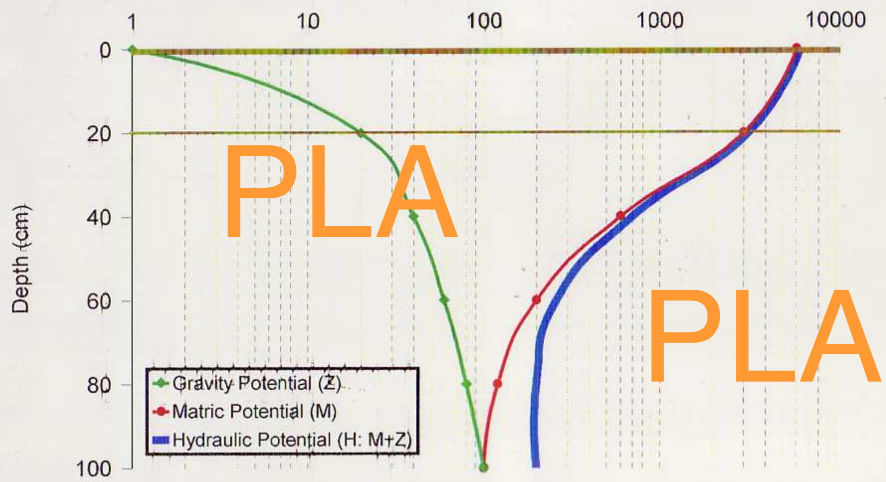
log K (cm/hour) vs log matric potential (cm)




I
II
III
IV
V
VI
ORIGINAL CONSOLIDATED SOIL
SURFACE SEAL
TILLED LOOSE SOIL
COMPACTED LAYER

SOIL WATER INFILTRATION

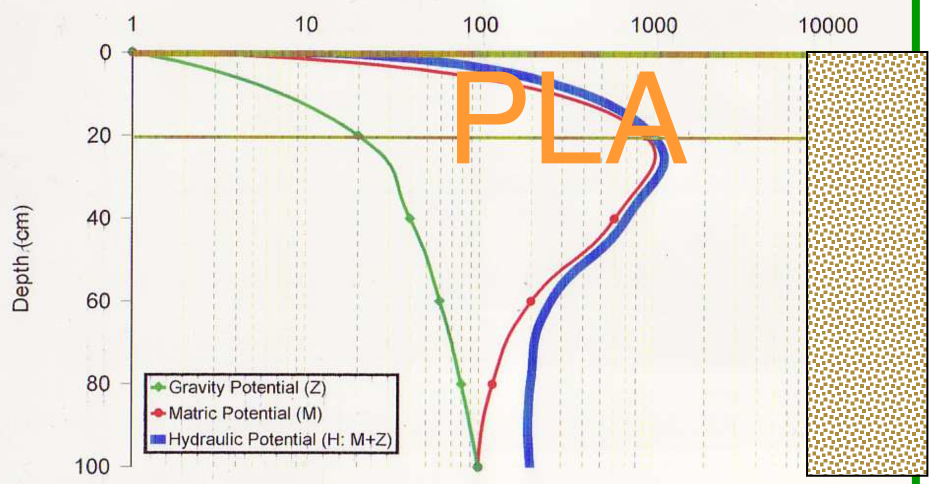
Soil uniform consolidated without surface sealing



Initial situation (I)

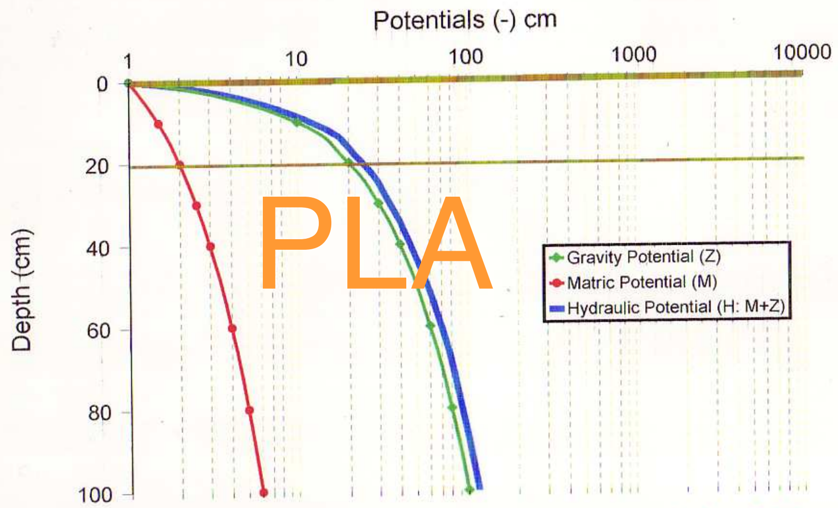
SOIL WATER INFILTRATION

Soil uniform consolidated without surface sealing



Inf.= - Kc(0-20cm).(ΔH/20cm) = - 0,05 cm/h . (-1000cm/20cm) = 2.5 cm/h (II)

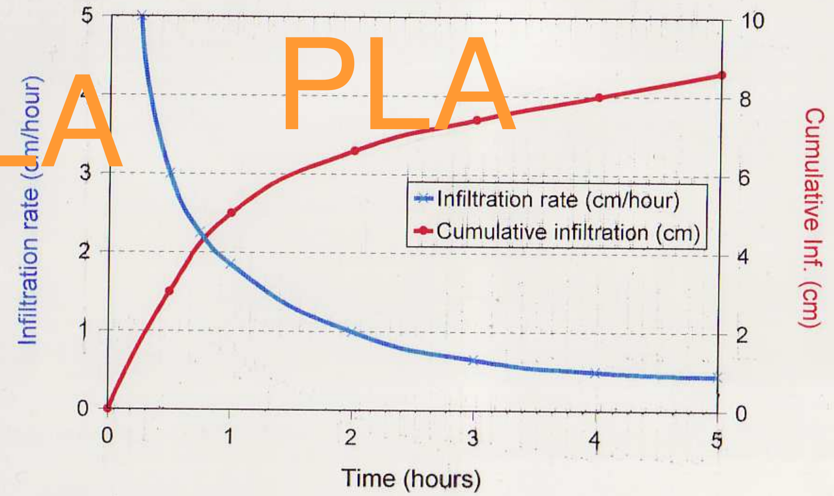
Soil uniform consolidated without surface sealing



Inf.= - Kc(0-20cm).(ΔH/20cm) = - 0,6 cm/h . (-20cm/20cm) = 0,6 cm/h (III)

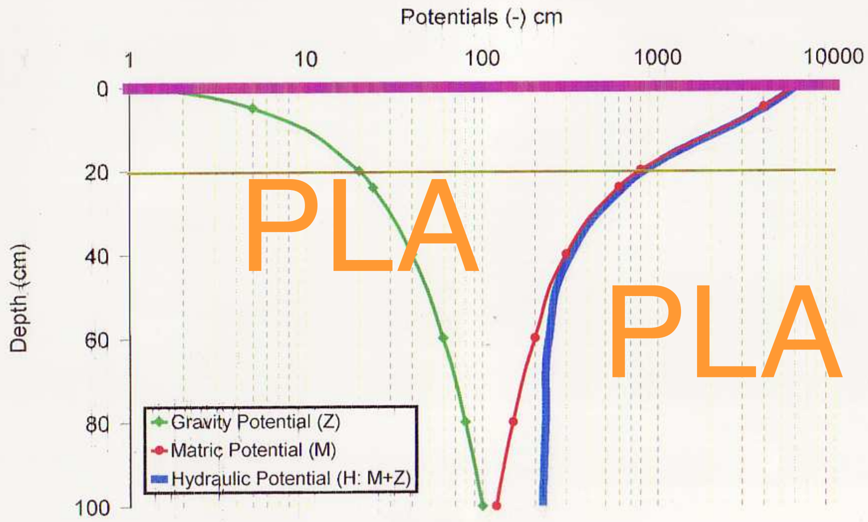
SOIL UNIFORM CONSOLIDATED WITHOUT SURFACE SEALING

Infiltration rates (cm/hour) and cumulative infiltration (cm) vs time



SOIL WATER INFILTRATION

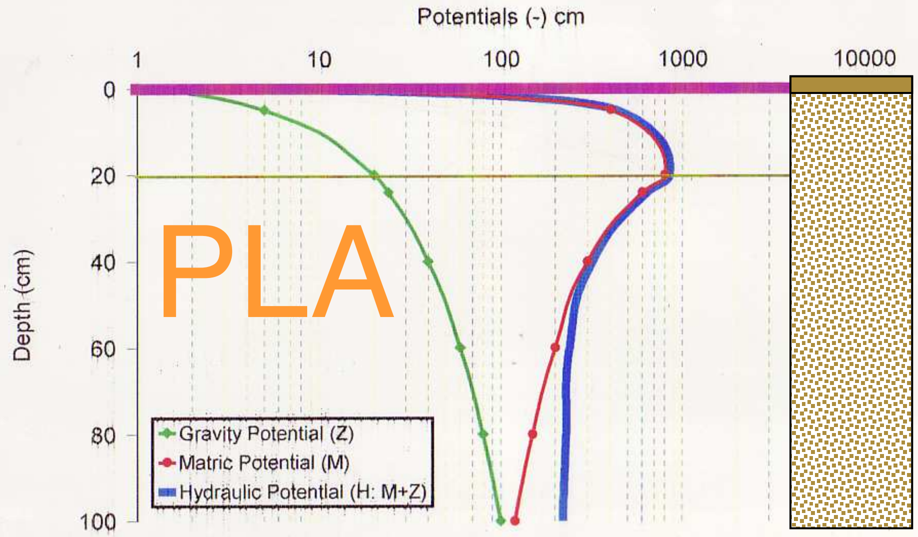
Soil uniform consolidated with surface sealing (0-0,5cm)



Initial situation (I)

SOIL WATER INFILTRATION

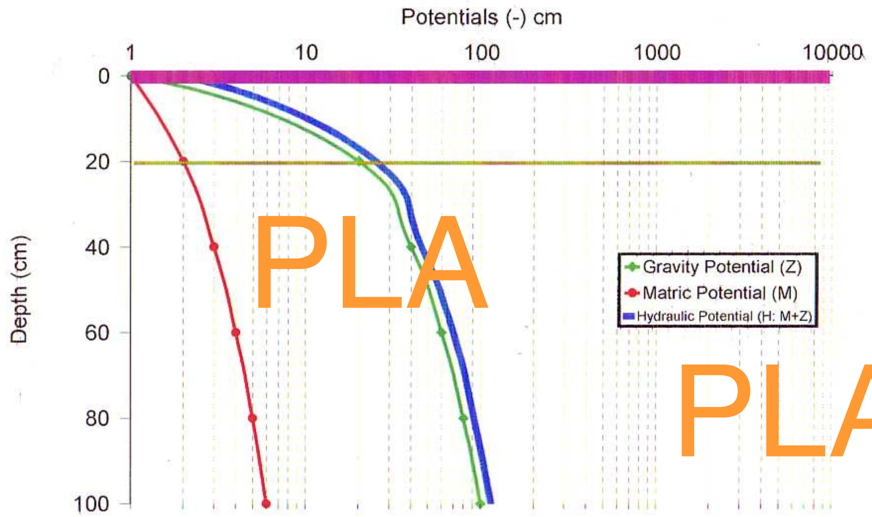
Soil uniform consolidated with surface sealing (0-0,5cm)



<Inf. = - Ks (sat.) . (Δ H/0,5cm) = - 0,1cm/h . (-200cm/0,5cm) = 40cm/h ? (NO)>

Inf. = - Kc (0-20cm). (Δ H/20cm) = - 0,003cm/h . (- 800cm/20cm) = 0,12 cm/h (II)

Soil uniform consolidated with surface sealing (0-0,5 cm)

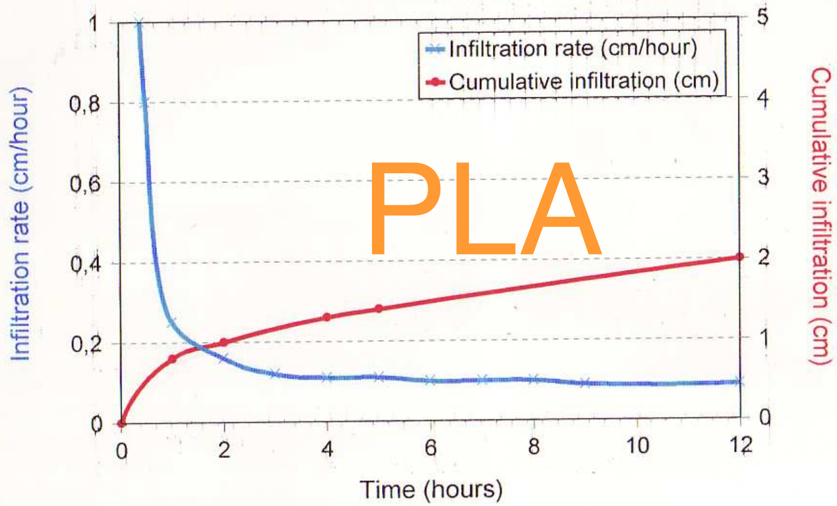


<Inf.= -Kc (sat)(0-20cm).(ΔH/20cm) = -0,5 cm/h . (-20cm/20cm) = 0,5 cm/h ?(NO)>

Inf. = - Ks (sat) . (Δ H/0,5cm) = - 0,1 cm/h . (-0,5cm/0,5cm) = 0,1 cm/h (III)

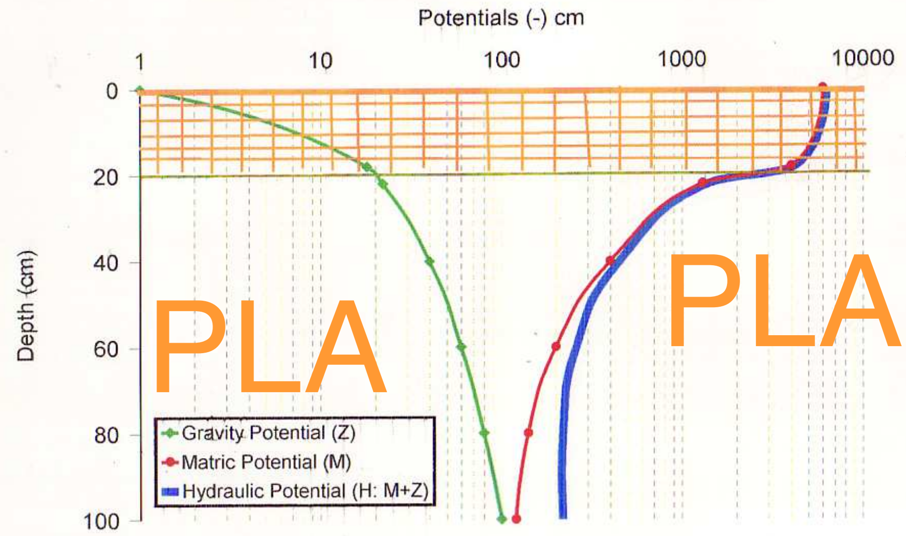
SOIL UNIFORM CONSOLIDATED WITH SURFACE SEALING

Infiltration rates (cm/hour) and cumulative infiltration (cm) vs time



SOIL WATER INFILTRATION

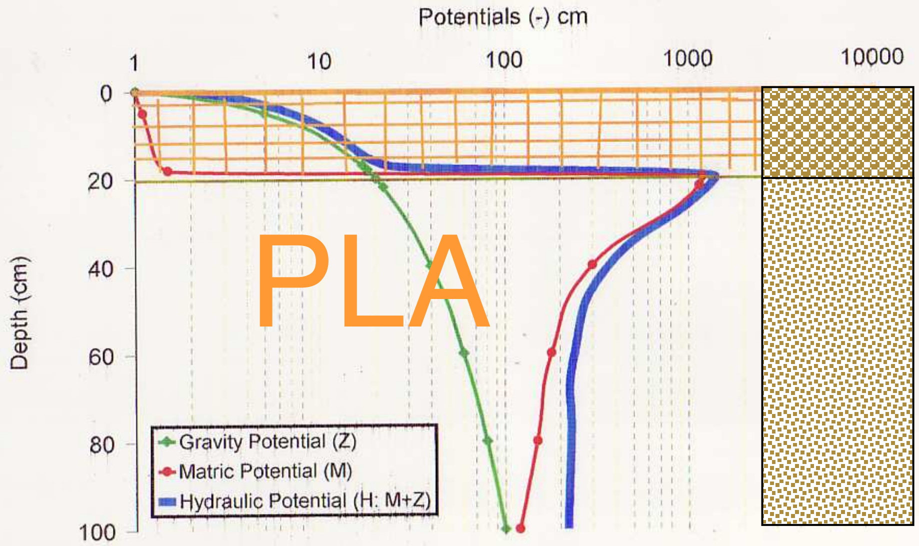
Tilled soil (0-20cm) without surface sealing



Initial situation (I)

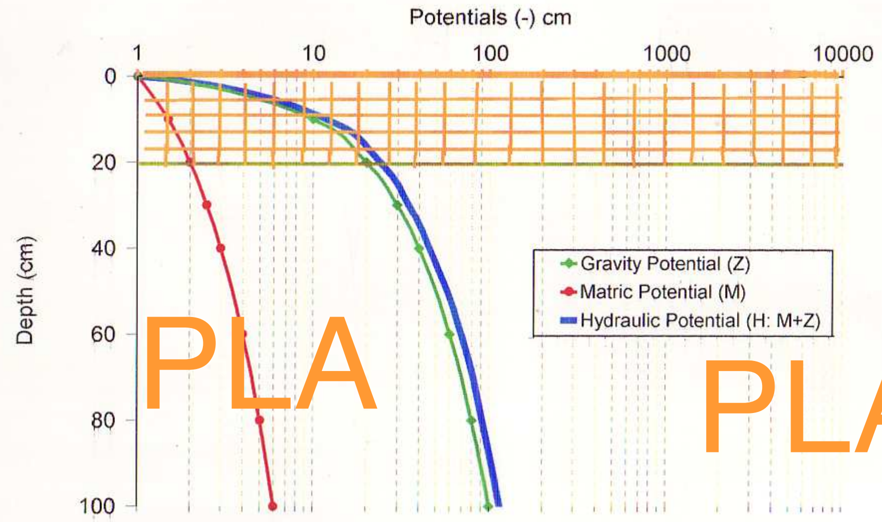
SOIL WATER INFILTRATION

Tilled soil (0-20cm) without surface sealing



Inf. = - Kr (0-20cm). (ΔH/20cm) = - 1cm/h . (- 1400cm/20cm) = 70 cm/h (II)

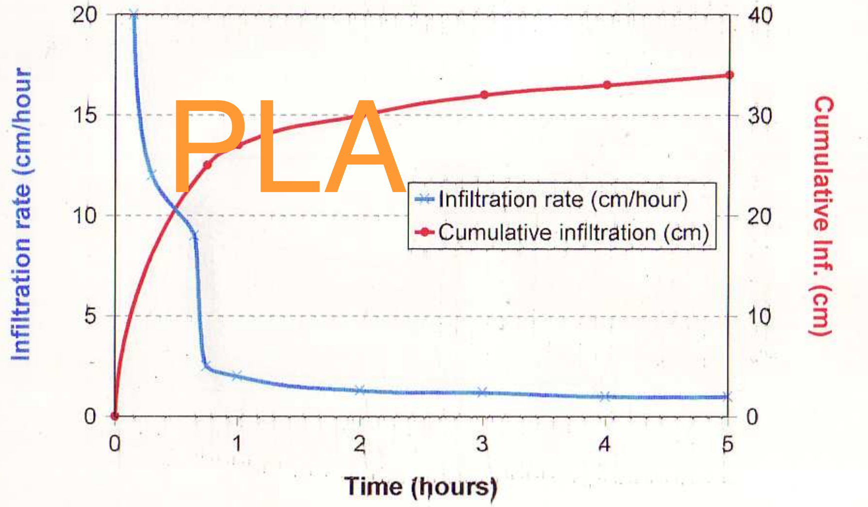
Tilled soil (0-20cm) without surface sealing



<Inf.= -Kr (0-20cm).(ΔH/20cm) = -10cm/h . (-20cm/20cm) = 10 cm/h ?(NO)>
Inf.= - Kc(sat.).(ΔH/ΔZ) = - 0,6 cm/h . (-1) = 0,6 cm/h (III)

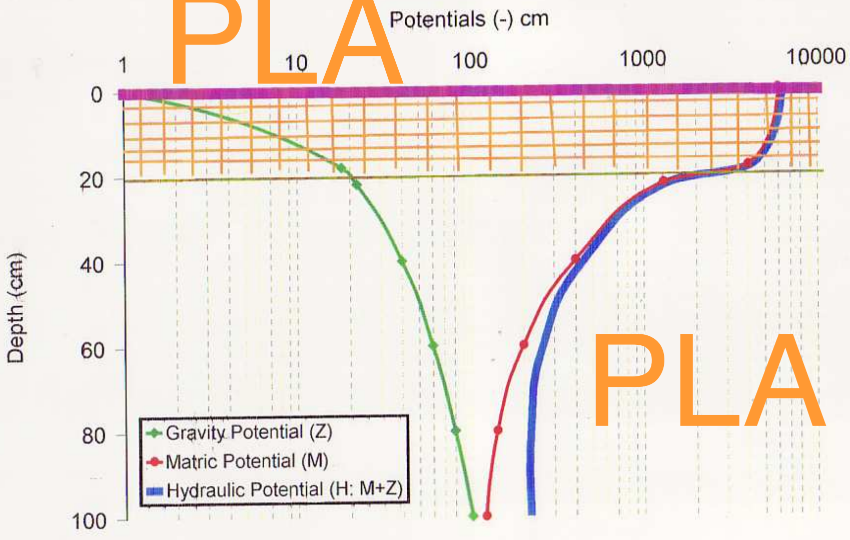
TILLED SOIL (0-20cm) WITHOUT SURFACE SEALING

Infiltration rates (cm/hour) and cumulative infiltration (cm) vs time



SOIL WATER INFILTRATION

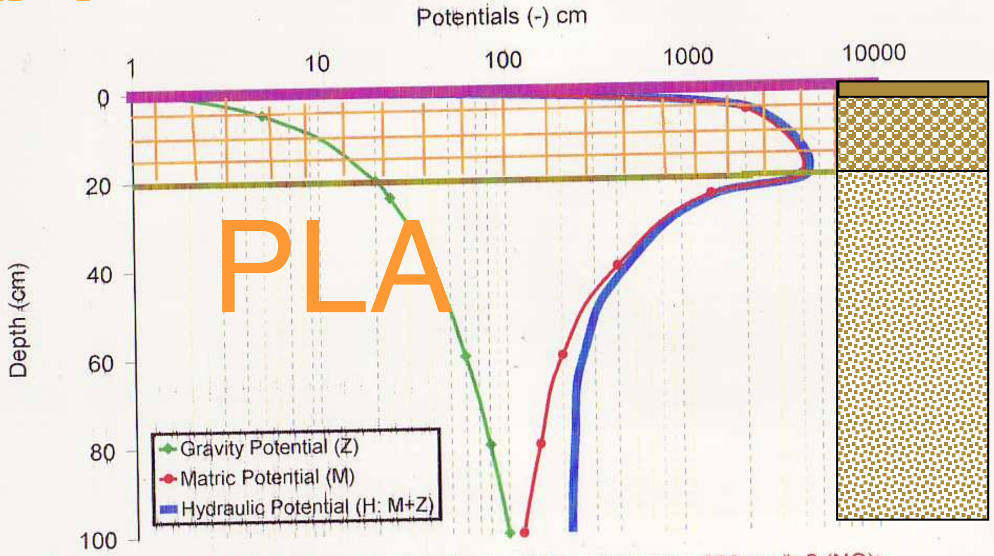
Tilled soil (0-20cm) with surface sealing



Initial situation (I)

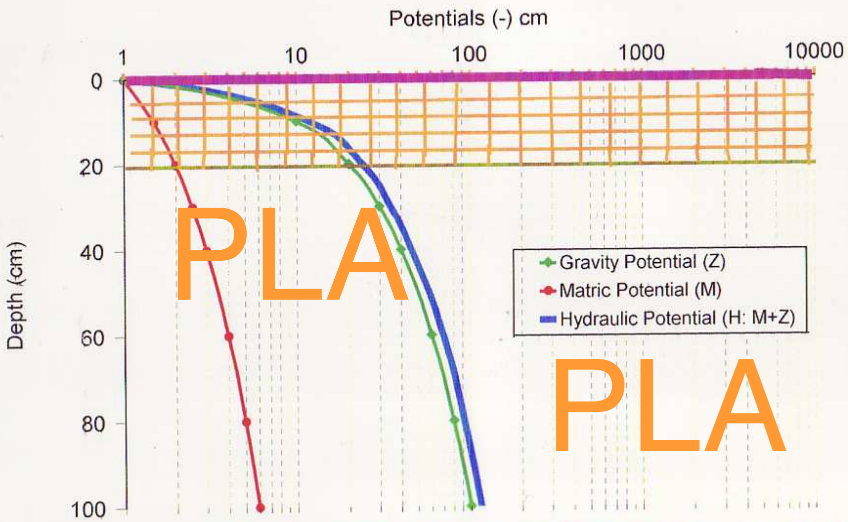
SOIL WATER INFILTRATION

Tilled soil (0-20cm) with surface sealing



<Inf.= -Ks (sat.) . (Δ H/0,5cm) = -0,1 cm/h . (- 1000cm/0,5cm) = 200 cm/h ? (NO)>
Inf. = - Kr (0-20cm). (Δ H/20cm) = - 0,001cm/h . (- 1400cm/20cm) = 0,07 cm/h (II)

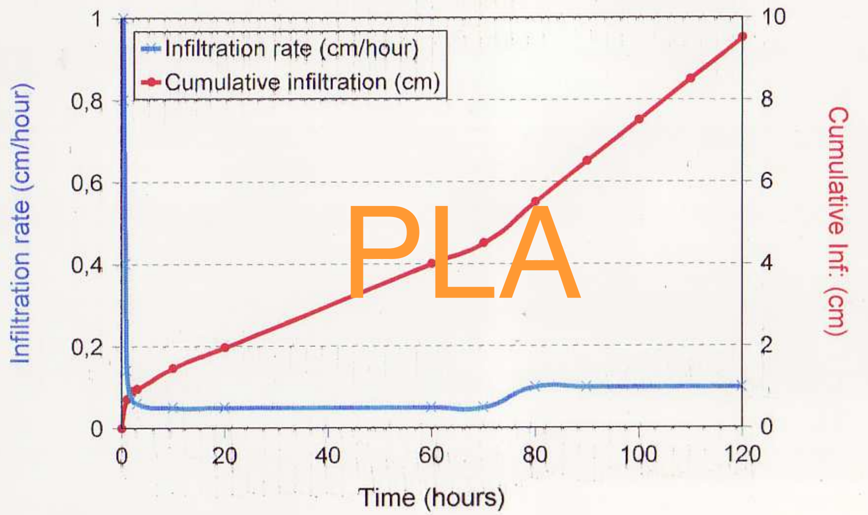
Tilled soil (0-20cm) with surface sealing



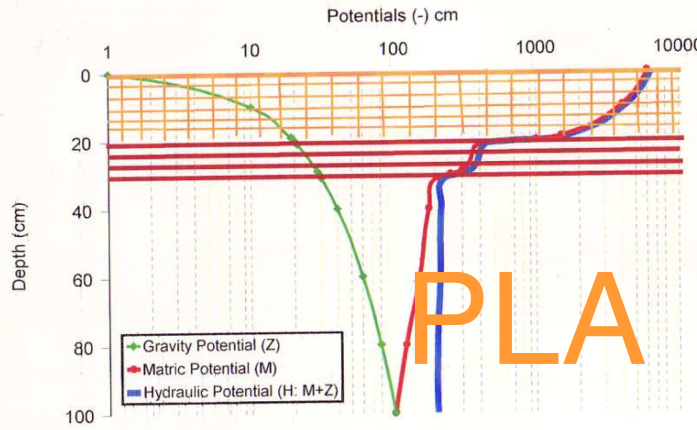
<Inf.= -Kr(0-20cm).(ΔH/ΔZ) = -10cm/h . (-20cm/20cm)=10 cm/h ?(NO)> / <Inf.= -Kc(sat).(ΔH/ΔZ) = - 0,6 cm/h.(-1) = 0,6 cm/h ?(NO)>/ Inf.= -Ks(sat) . (-0,5cm/0,5cm)= - 0,1 cm/h . (-1) = 0,1 cm/h (III)

TILLED SOIL (0-20cm) WITH SURFACE SEALING

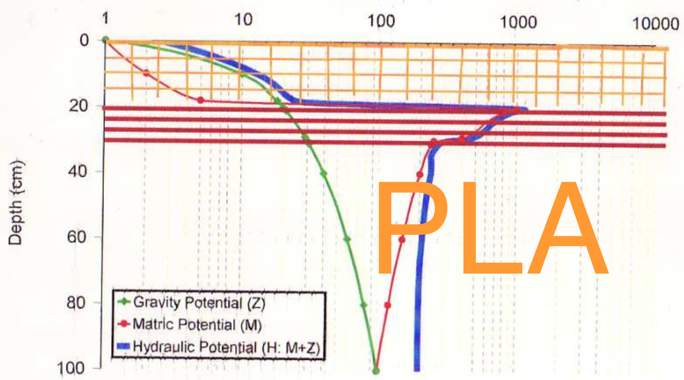
Infiltration rates (cm/hour) and cumulative infiltration (cm) vs time



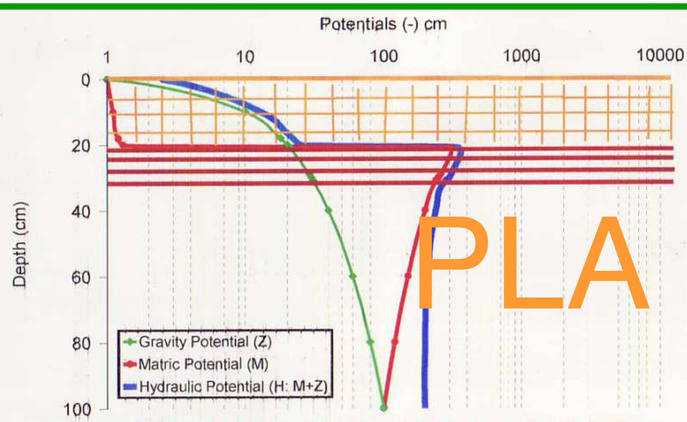
Tilled soil (0-20cm), with compacted layer (20-30cm) without surface sealing



Initial situation (I)



Inf. = - Kr (0-20cm). (Δ H / 20cm) = - 1cm/h . (- 1000cm / 20cm) = 50 cm/h (IIa)

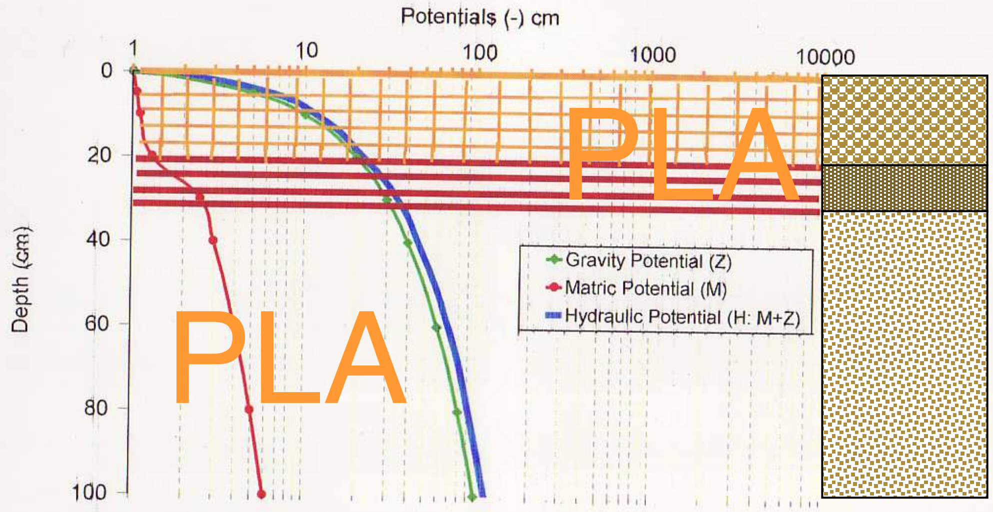


<Inf. = - Kr (0-20cm). (ΔH/20cm) = - 10cm/h . (- 20cm/20cm) = 10 cm/h ?(NO)>

Inf. = - Kcc (20-30cm) . (ΔH cm/10cm) = - 0,002 . (- 100cm/10cm) = 0,02 cm/h (IIb)

SOIL WATER INFILTRATION

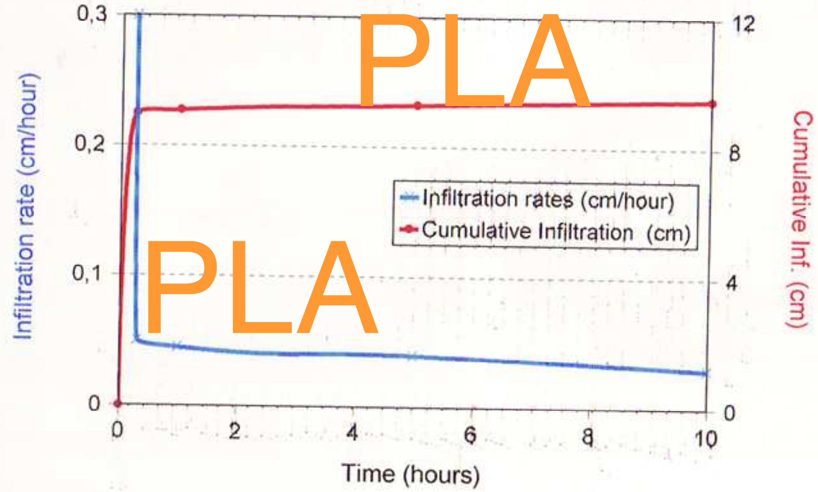
Tilled soil (0-20cm), with a compacted layer (20-30cm), without surface sealing



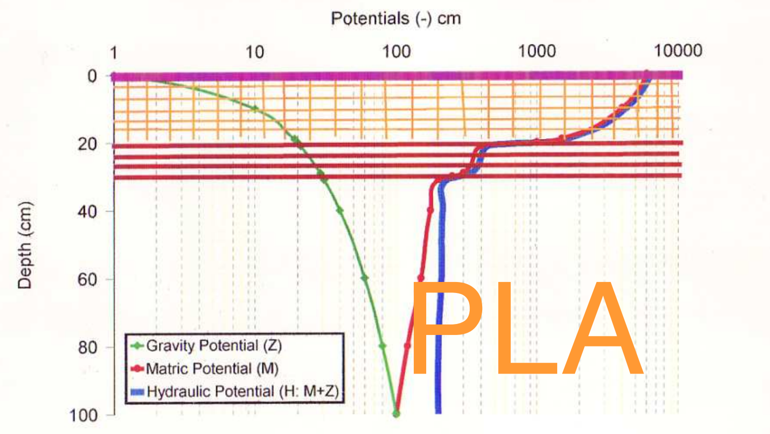
Inf.= - Kcc (sat.) . (Δ H / 10cm) = - 0,04cm/h . (-10cm / 10cm) = 0,04 cm/h (III)

TILLED SOIL (0-20cm) WITH A COMPACTED LAYER (20-30cm) WITHOUT SURFACE SEALING

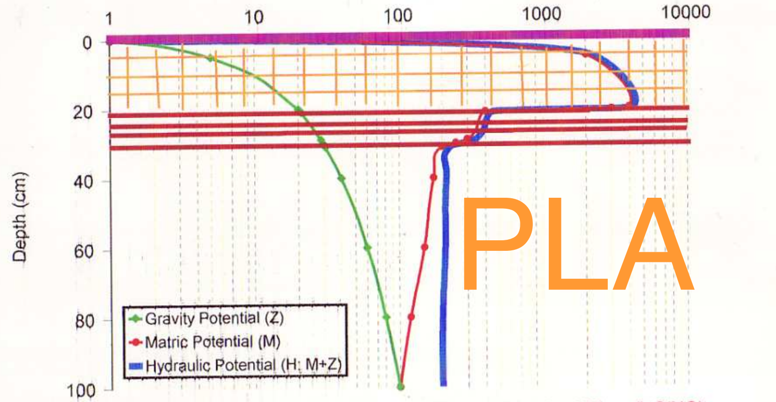
Infiltration rates (cm/hour) and cumulative infiltration(cm) vs time



Tilled soil (0-20cm), with compacted layer (20-30cm) and surface sealing

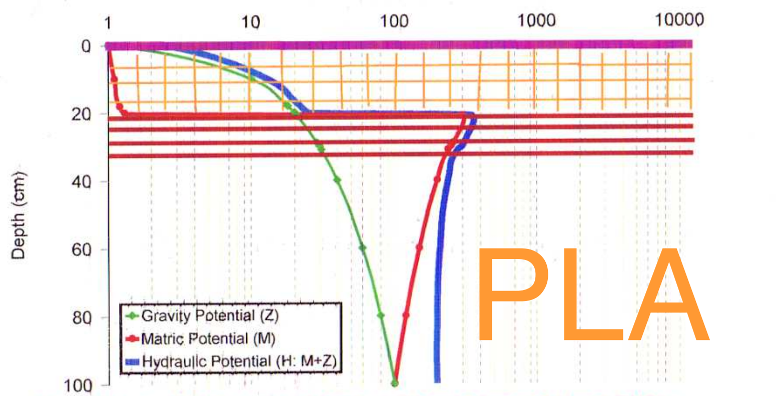


Initial situation (I)



<Inf.= - Ks (sat.) . (ΔH / 0,5cm) = - 0,1 cm/h . (- 1000cm / 0,5cm) = 200 cm/h ?(NO)>

Inf. = - Kr (0-20cm) . (ΔH / 20cm) = - 0,001cm/h . (- 1400cm / 20cm) = 0,07 cm/h (IIa)

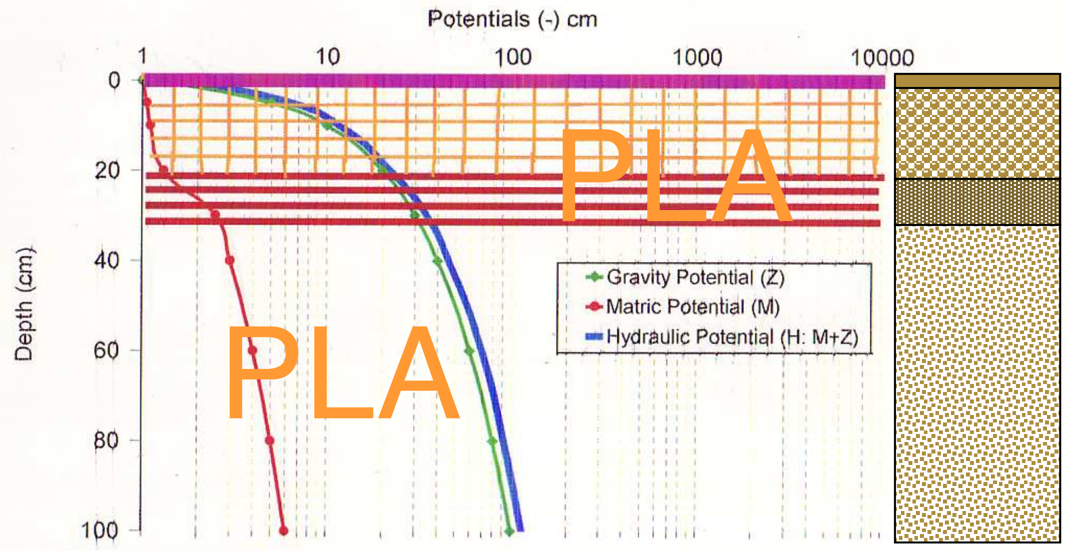


<Inf. = - Ks(sat) . (ΔH / 0,5cm) = - 0,1cm/h . (- 0,5cm / 0,5cm) = 0,1 cm/h ?(NO)>

Inf. = - Kcc(20-30cm).(ΔH cm/10cm) = - 0,002cm/h . (-100cm / 10cm) = 0,02 cm/h (IIb)

SOIL WATER INFILTRATION

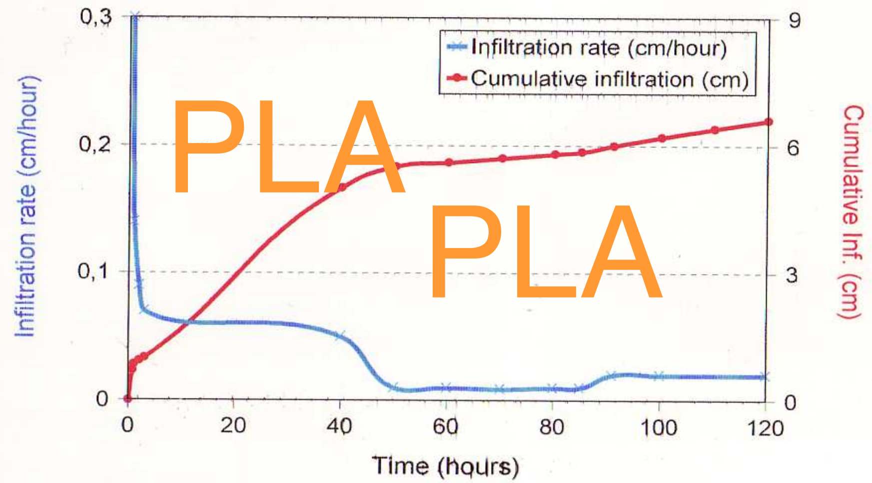
Tilled soil (0-20cm), with compacted layer (20-30cm) and surface sealing



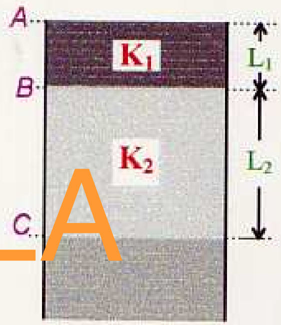
Inf.= - Kcc (sat.).(ΔH / 10cm) = - 0,04cm/h . (-10cm / 10cm) = 0,04 cm/h (III)

TILLED SOIL (0-20cm) WITH COMPACTED LAYER (20-30cm) AND SURFACE SEALING

Infiltration rates (cm/hour) and cumulative infiltration (cm) vs time



HYDRAULIC CONDUCTIVITY OF LAYERED SOILS



Q : VOLUME OF WATER PERCOLATED TROUGH *ABC* IN TIME **t**

A : SOIL SECTION AREA ACCROSS THE DIRECTION OF FLOW

t : TIME TO PERCOLATE **Q**

H : HYDRAULIC POTENTIAL IN HEAD UNITS

C : REFERENCE LEVEL

$K_{AC} = K_S = -Q / A\,t\,i_S$ $\quad i_S = (H_C - H_A) / (L_1 + L_2)$

$K_{AB} = K_1 = -Q / A\,t\,i_1$ $\quad i_1 = (H_B - H_A) / L_1$

$K_{BC} = K_2 = -Q / A\,t\,i_2$ $\quad i_2 = (H_C - H_B) / L_2$

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

$$K_2 L_S = K_1\, i_1 = K_2\, i_2 = -Q / A\,t$$

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

$K_S \,.\, (-(L_1+L_2)/(L_1+L_2)) = K_2 \,.\, (-H_B/L_2)\ ;\ \ H_B = (K_S L_2)/K_2$

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

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

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

For **n** layers: $\boxed{K_{(1....n)} = (L_1+L_2+....\ L_n) / ((L_1/K_1)+(L_2/K_2)+...\ (L_n/K_n))}$

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

$K_S\ (L_1 + L_2) = (0{,}5+10) / ((0{,}5/0{,}01)+(10/5)) = 10{,}5/(50+2) =$ **0,20 cm/hour**

K_S (Weighted Mean) $= ((0{,}01\text{x}0{,}05)+(10\text{x}5))/(0{,}5+10) =$ **4,76 cm/hour**

Numerous empirical and theoretically based expressions have been developed to describe the time dependence of the infiltration rate and of the total (cumulative) quantity of water infiltrated in the soil.

The Philips solution to the general flow equation:

$$\partial \Theta / \partial t = \partial D(\Theta) / \partial z \, . \, \partial \Theta / \partial z + K(\Psi_M)$$

where: $D(\Theta) = K(\Psi_M) \, . \, \partial \Psi_M / \partial \Theta$

for downward vertical flow leads to (assuming flooding conditions):

$$I \text{ (cumulative infiltration)} = St^{1/2} + At$$

$$I \text{ (infiltration rate)} = dI = \tfrac{1}{2} St^{-1/2} + A$$

Where:

S (sorptivity) embodies the influence of the soil-water relations (matric suction and conductivity) in the wetting process

A represents the effect of gravity

S and A depend on Θ (volumetric soil moisture) and on the soil surface conditions

Therefore the direct measurement of water infiltration rates or its indirect deduction from other soil characteristics or properties has become indispensable for the evaluation and modelling of the previously mentioned processes.

Indirect deductions from other soil characteristics measured under laboratory conditions in the same soils, or in other soils, through the so called “pedo-transfer” functions, have demonstrated to be of limited value in most of the cases.

Direct “in situ” field evaluations have to be preferred in any case.

EFFECT OF THE STONES ON THE INFILTRATION RATE OF WATER IN THE SOIL

(Pedotransfer functions)

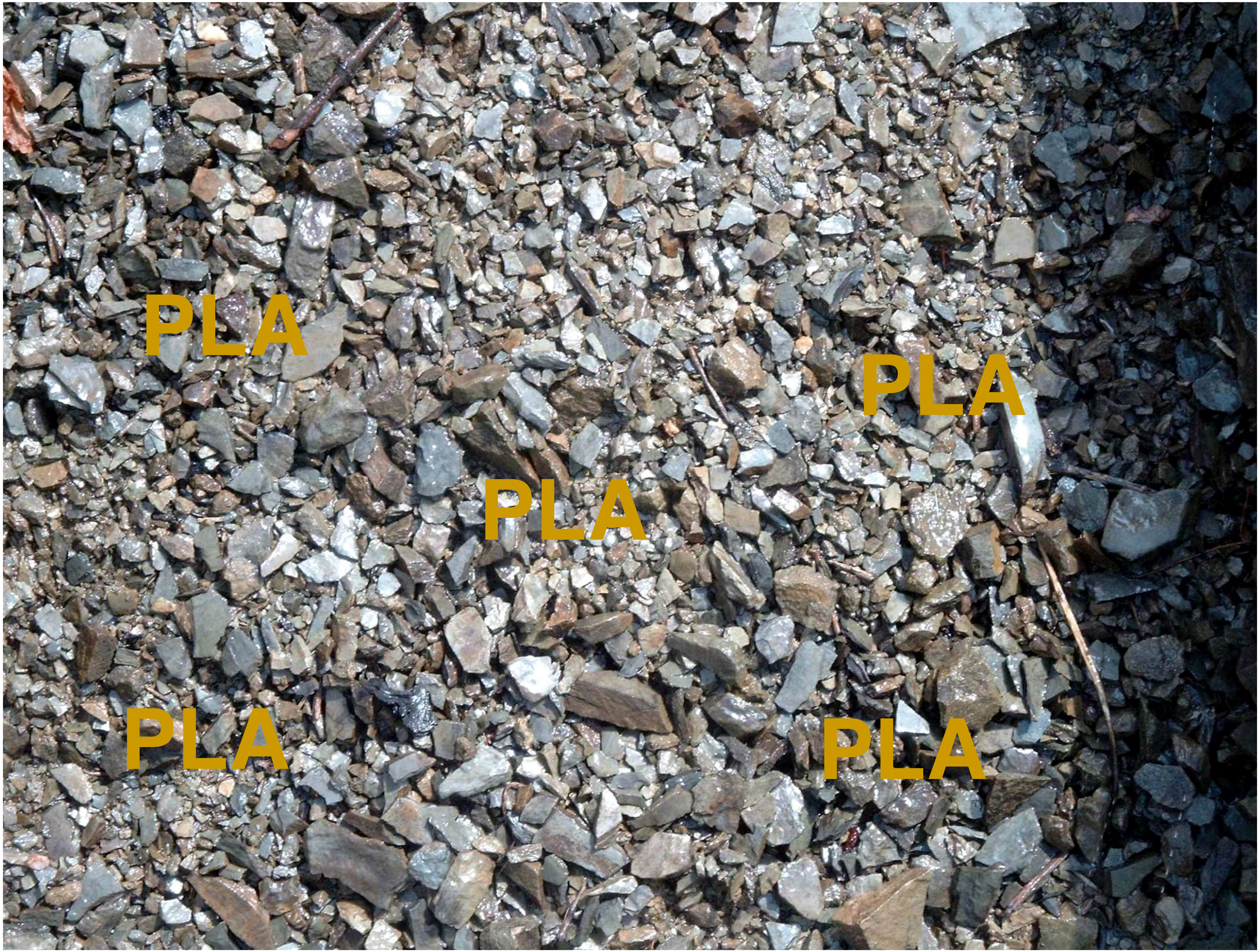
(1) Ks / Ksf = 2 (1- Vp) / (2+Vp) (1979)
(2) Ks / Ksf = 1 – Vp (1984)
(3) Ks / Ksf = (1- Mp) / ((1- Mp(1-(3a / 2)) (1994)

Ks : Saturated hydraulic conductivity of the soil with stones
Ksf : “ “ “ “ without “
Vp : Volume fraction of the soil ocuppied by stones
Mp : Mass fraction of the stones in the soil
a = Bulk density of the soil with stones
Mp / Vp = Density of the stones

EXAMPLE: Mp : 0,60 (60%)
(REAL VALUES)
REAL MEASURED VALUES
Ks (230 mm/hora) / Ksf (64 mm/hora) = 3,75

USING THREE DIFFERENT PROPOSED PEDOTRANSFER FUNCTIONS:
(1) Ks/Ksf = 0,20; (2) Ks/Ksf = 0,54; (3) Ks/Ksf = 0,40

EXAMPLE OF ERRORS USING PEDOTRANSFER FUNCTIONS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Infiltration rate is one of the most important factors playing a role in many agronomic, engineering and environmental activities.

Therefore, many field and laboratory methods have been developed over time to estimate this parameter.

Unfortunately, these methods often result in very dissimilar infiltration values since the parameter not only depends on soil texture and structure, but is very sensitive to sample size and location, sample collection procedures, flow geometry, and various soil physical-hydrological characteristics which may be altered by the soil disturbance imposed by the measurement technique.

Infiltrometers:

They are instruments to measure the velocity of infiltration ("infiltration rate") of water into the soil. Most of them are based on an artificial application of water in enclosed sample areas of surface soil.

There are two general types of infiltrometers:

1) **Ponding or Flooding type, measuring the velocity of infiltration of water flooding the soil under a small positive or negative hydraulic head. The most common are the double or single ring infiltrometers, and the disk and well permeameters.**

2) **Rainfall simulators, measuring the infiltration rate of the soil by the difference between the water applied as artificial rainfall and the runoff.**

In some cases, the final infiltration rate, supposed to be close to the saturated hydraulic conductivity (Ksat), is estimated using undisturbed soil cores (5-10 cm diameter) carefully removed from the field, measuring in the laboratory Ksat using a constant head method

Another way to have a general average value of the infiltration capacity of the soil is by rainfall-runoff hydrograph analysis in a watershed.

Ring infiltrometers (double or single):

In this method, a ring of 20-50 cm diameter is partially introduced in the soil (10-20 cm deep), and a constant or variable head of flooding water is maintained inside the ring. If a double ring system is used, an outer ring (with a diameter about 10-20 cm larger than the inner ring) is also introduced in the soil. The rings are generally made of resistant metal or plastic materials, but in some ocasions they may be substituted by rings made with the same surrounding soil, stabilized with a plastic sheet.

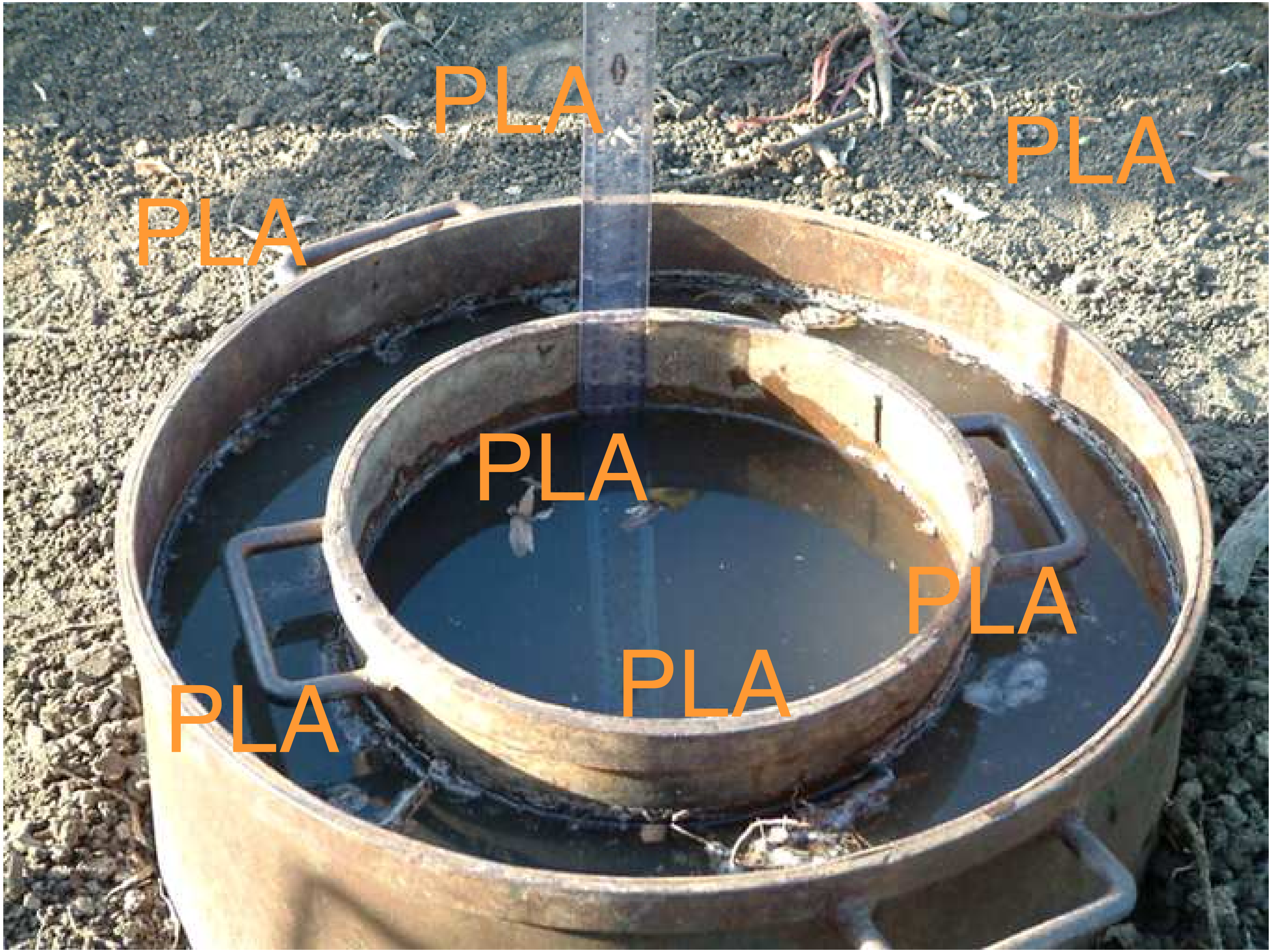
To keep a constant head we may use a supply of water trough a Mariotte flask. With variable head, the head of water is allowed to decrease with time as the flooding water infiltrates in the soil.

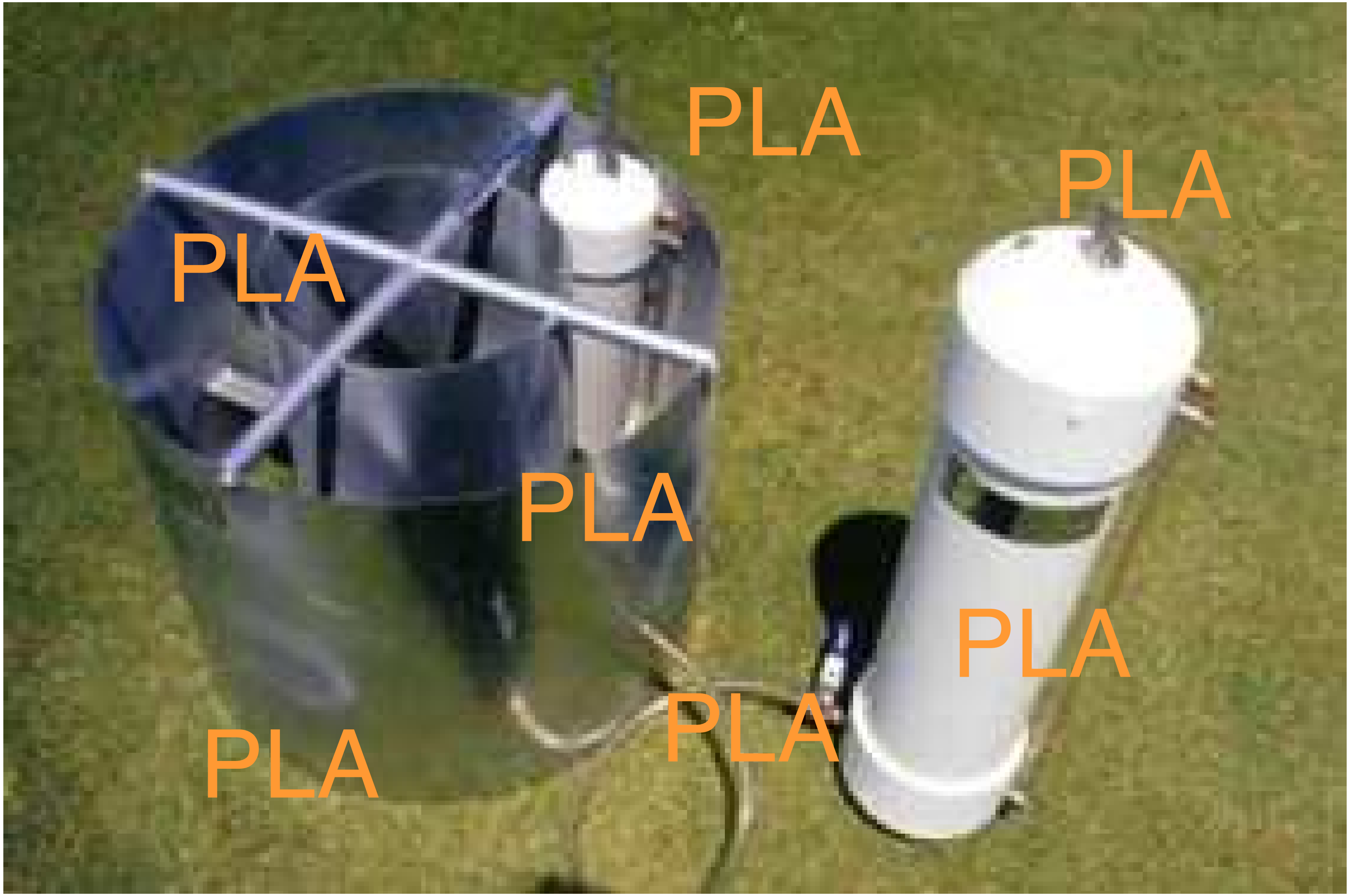
There is measured the amount of water infiltrating in the soil per unit area and unit time, until reaching constant values. These values may correspond aproximatelly to the saturated hydraulic conductivity of the soil.

The double ring system is used for assuring that the flux of water in the inner ring, where the measurements are made, remains mostly vertical. This is specially important when the soil is initially dry, and before the constant value of infiltration velocity is reached.

DOUBLE RING INFILTRATION
MEASUREMENT WITHOUT CYLINDERS

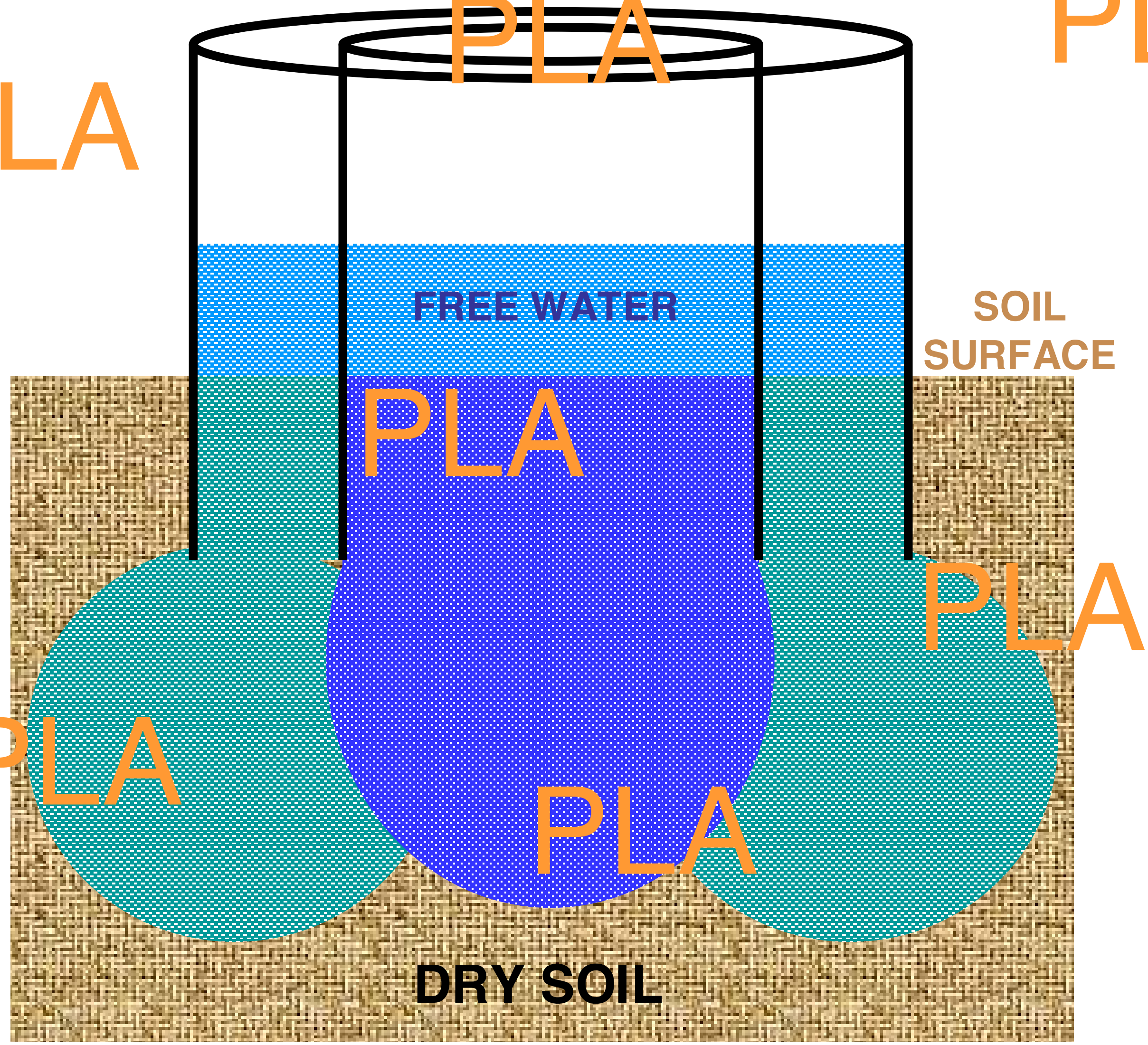
DOUBLE RING INFILTROMETERS USING TWO RUGGED STRONG METAL CYLINDERS





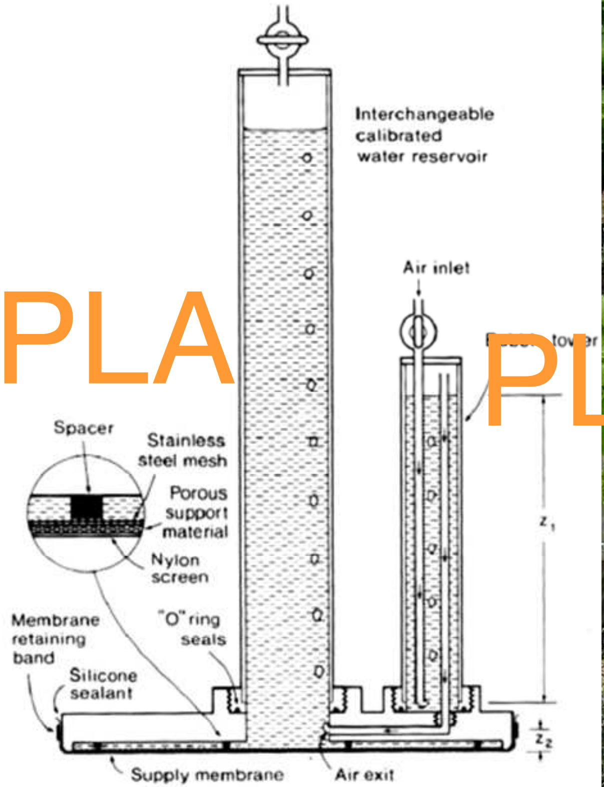
DOUBLE RING INFILTROMETER WITH A MARIOTTE BOTTLE SYSTEM TO KEEP A CONSTANT HEAD

FLUX OF WATER IN THE INNER ( ) AND OUTER ( )RING



Disk infiltrometers consist of a circular porous plate or membrane which is placed on the soil surface. Water is supplied to the plate using a Mariotte bottle arrangement and the rate of water entry into the soil can be measured on a graduated cylinder. Generally a ring is attached to the disk infiltrometer to allow ponded infiltration measurements.

With this infiltrometers (also called tension infiltrometers) water can be supplied to the plate under tension, permitting to measure unsaturated hydraulic conductivity of the soil at low tensions. In this case, water is allowed to infiltrate soil at a rate, which is slower than when water is ponded on the soil surface



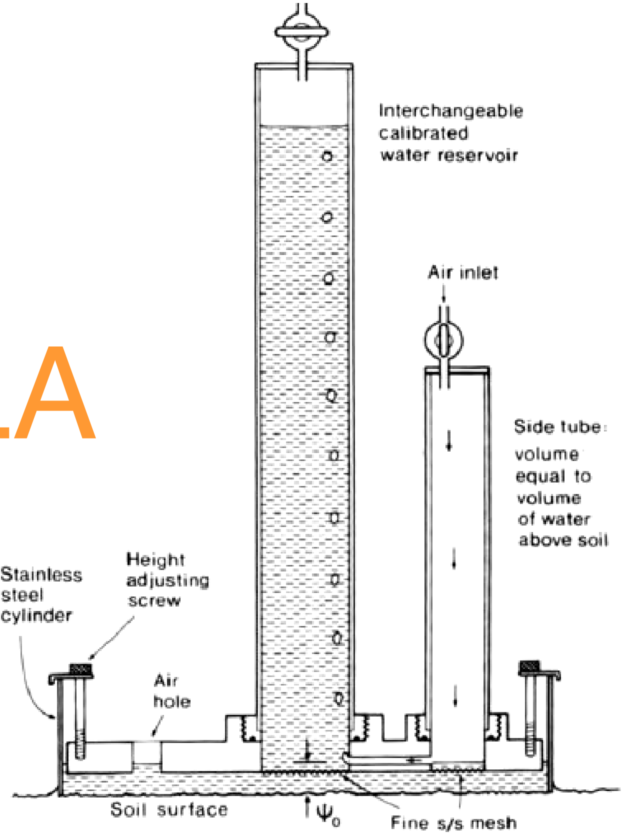
Unsaturated Hydraulic Conductivity (K(h)

$$Q^* = 2\pi a + 4$$

$$a = \alpha r / 2$$

$$K(h) = Ks^{\exp(\alpha h)} \text{ (G)}$$

DISK INFILTROMETER



Saturated Hydraulic Conductivity (Ks)

Q^* : Dimensionless flux

r: Radius of the disk (cm)

α: Parameter in the Gardner hydraulic conductivity equation (G) (1/cm)

K(h): Hydraulic Conductivity (cm/hour) at tension h(cm)

RAIN INFILTRATION

The decrease of 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 action

The high energy load of the raindrops is responsible for surface sealing on bare soil.

The potential for seal development depends considerably on the particle size distribution

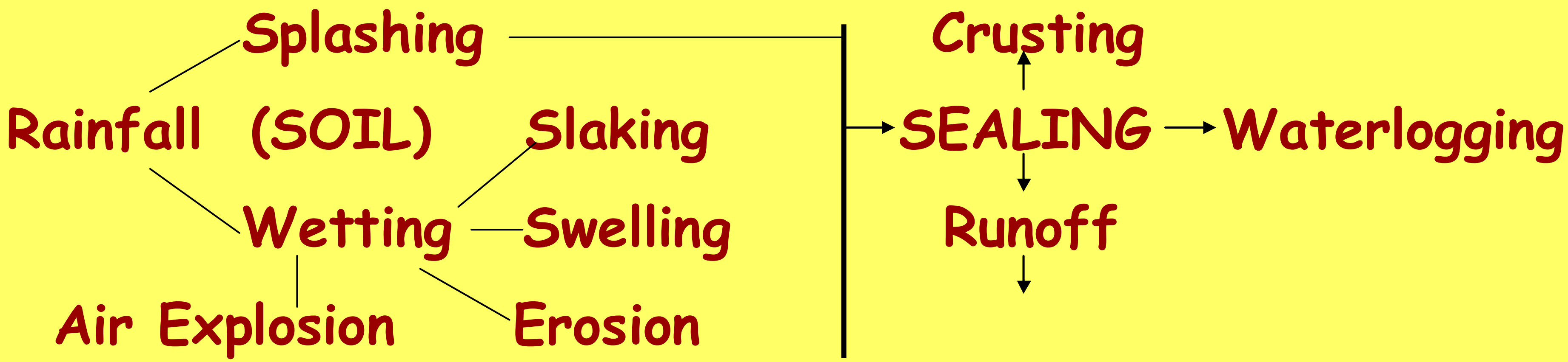
RAINWATER DROP IMPACT

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 matric potential (suction) which generally results in unsaturated flow conditions

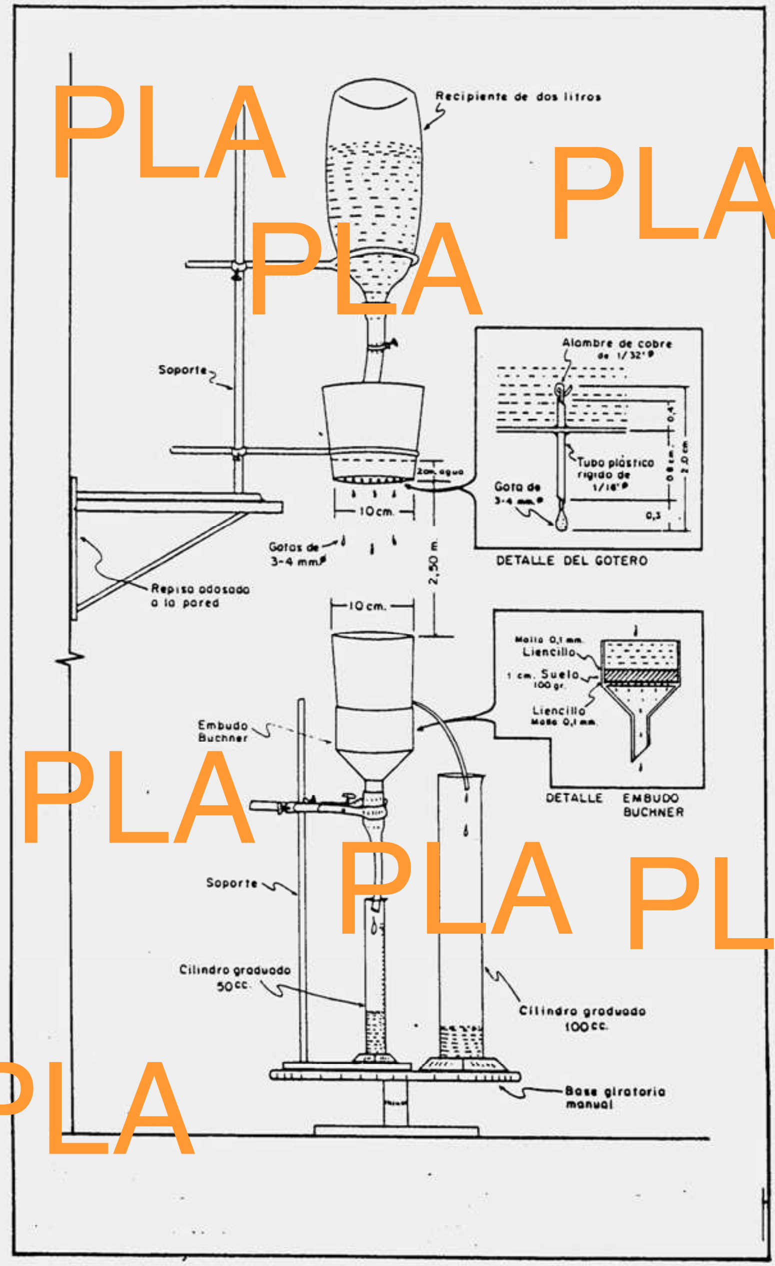
As the hydraulic conductivity of the seal decreases, the matric potential, and as a consequence the (suction) gradient across the seal increases, which partially ofsets he decreased conductivity of the surface seal

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 climate factors



Besides the raindrops beating action, the percolation of rainfall water, decreasing the electrolite concentration of the surface soil solution contributes to the dispersion of clays which block the pores and decrease even further the saturated hydraulic conductivity of the upper soil layer



A SIMPLE LABORATORY EQUIPMENT FOR MEASURING THE SEALING SUSCEPTIBILITY OF SURFACE SOILS ("SEALING INDEX") CONSISTING OF A RAINFALL SIMULATOR AND A DEVICE FOR MEASURING THE PERCOLATION OF WATER THROUGH A LAYER OF SOIL AGGREGATES WITH OR WITHOUT RAINDROP IMPACT AND PROTECTIVE COVER

PLA 1975

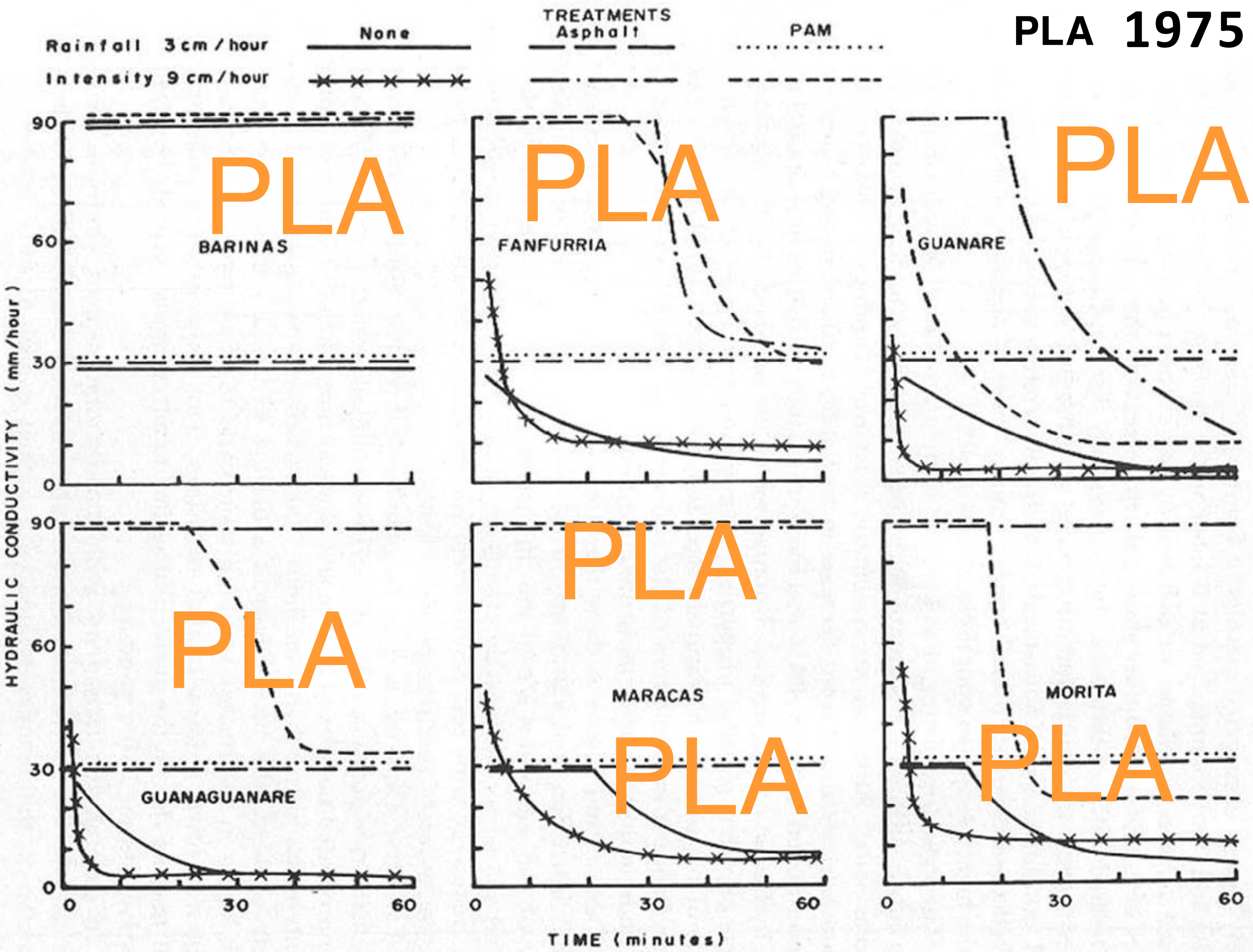
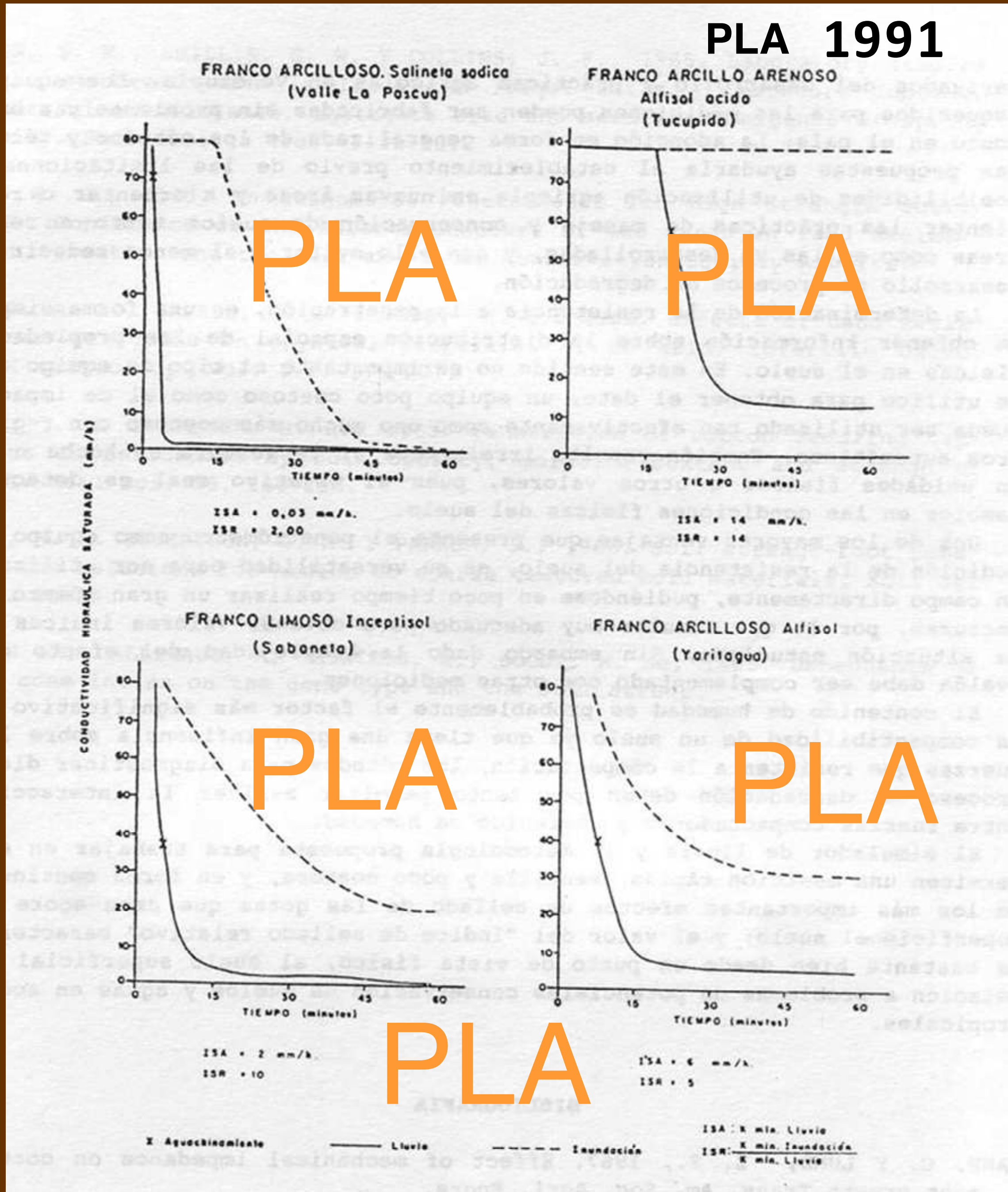
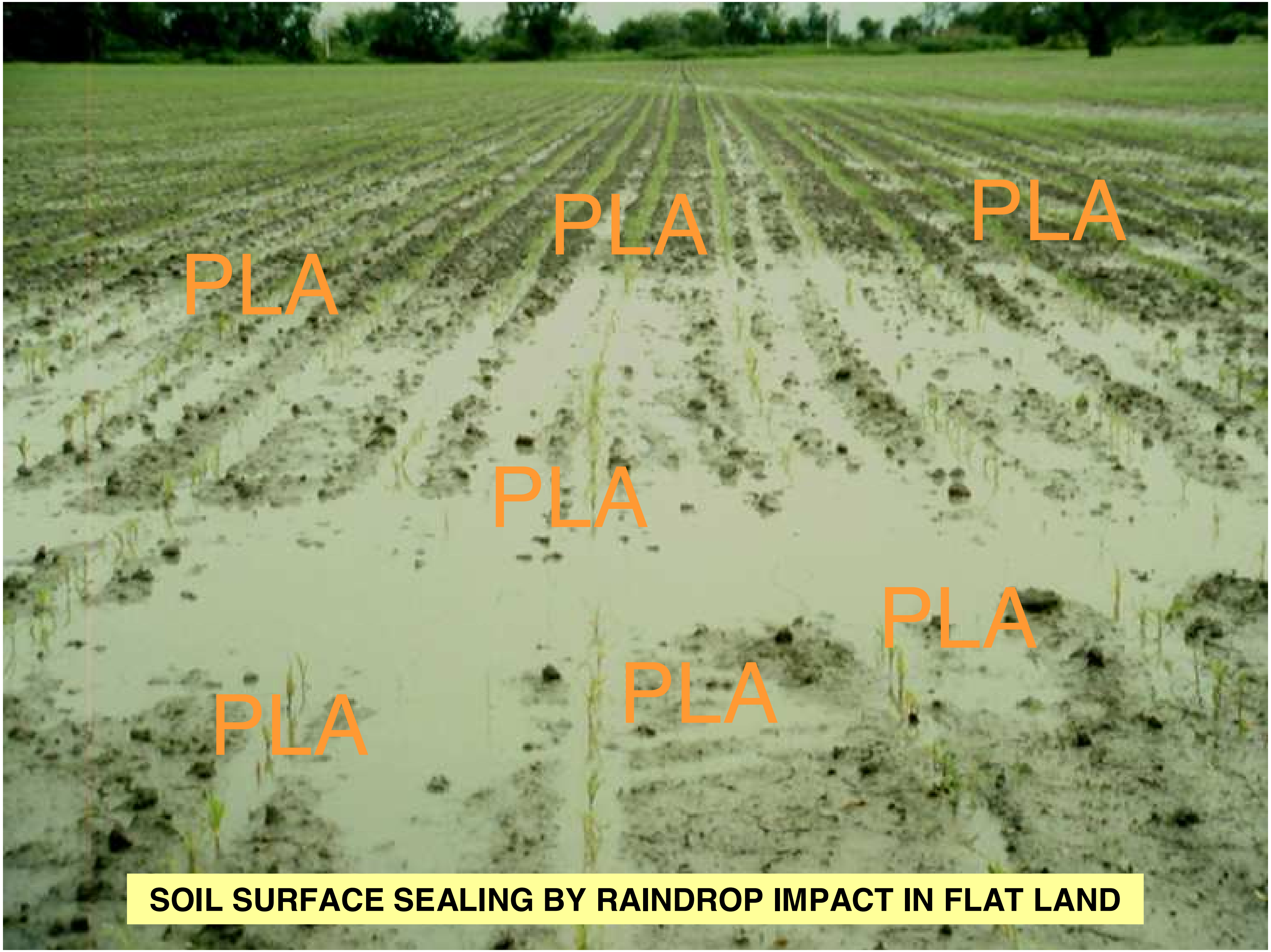


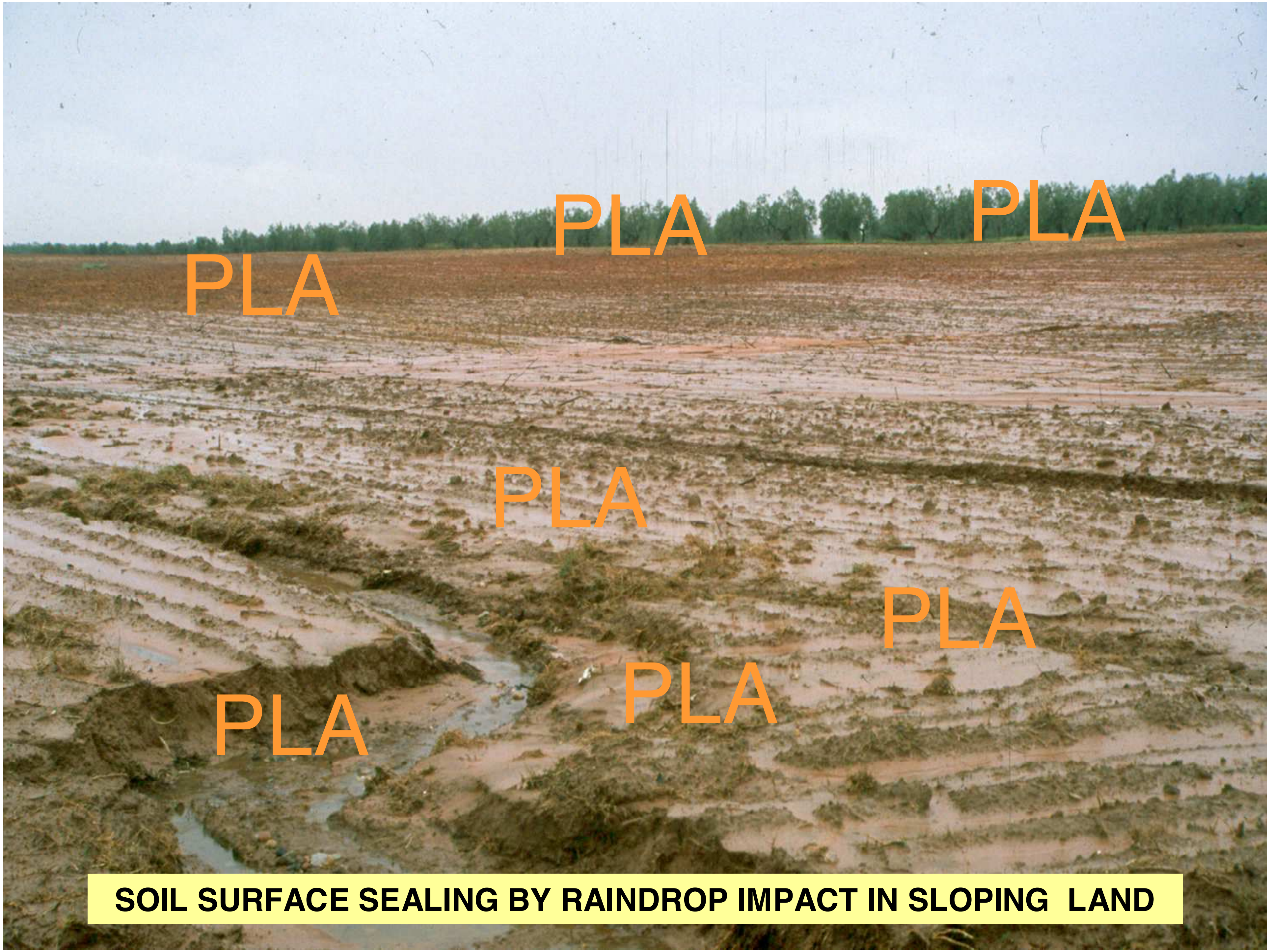
Figure 4. Changes in hydraulic conductivity with time in a layer of soil aggregates approximately 1.5 cm thick and 2 to 4 mm in diameter receiving a simulated rainfall with intensities of 3 and 9 cm/hour, as affected by a previous treatment with soil conditioners. The times were taken after the soil was saturated with water.



PLA 1991
FRANCO ARCILLOSO. Salineta sodica
(Valle La Pascua)
ISA = 0,03 mm/h.
ISR = 2,00
FRANCO ARCILLO ARENOSO
Alfisol acido
(Tucupido)
ISA = 14 mm/h.
ISR = 14
FRANCO LIMOSO Inceptisol
(Sabaneta)
ISA = 2 mm/h.
ISR = 10
FRANCO ARCILLOSO Alfisol
(Yaritagua)
ISA = 6 mm/h.
ISR = 5
CONDUCTIVIDAD HIDRAULICA SATURADA (mm/h)
TIEMPO (minutos)
X Aguachinamiento
Lluvia
Inundación
ISA: K min. Lluvia
ISR: K min. Inundación / K min. Lluvia

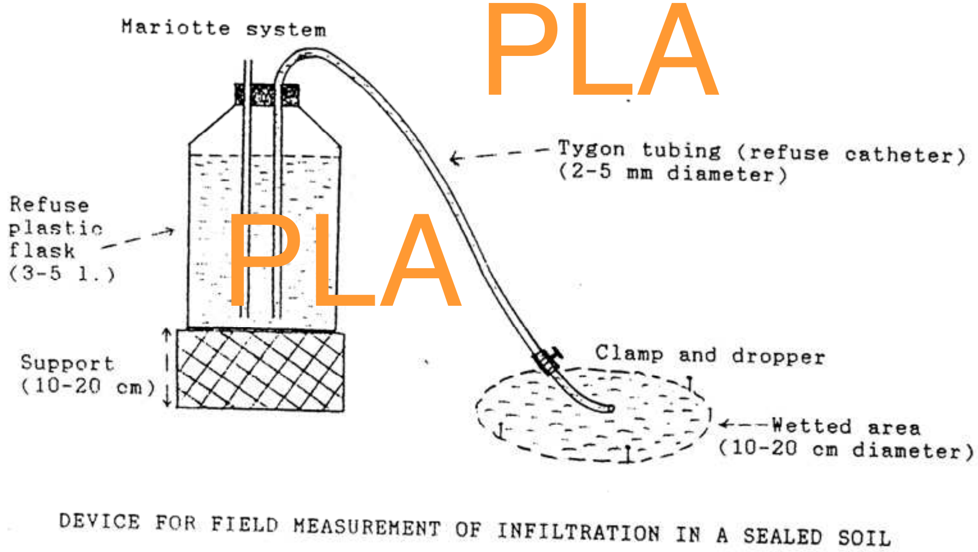


SOIL SURFACE SEALING BY RAINDROP IMPACT IN FLAT LAND



SOIL SURFACE SEALING BY RAINDROP IMPACT IN SLOPING LAND

Dropping method to measure water infiltration rate in a sealed soil



$$\text{I (mm/hour)} = \frac{\text{10 Q (cm}^3\text{ / hour)}}{\text{A (cm}^2\text{)}}$$

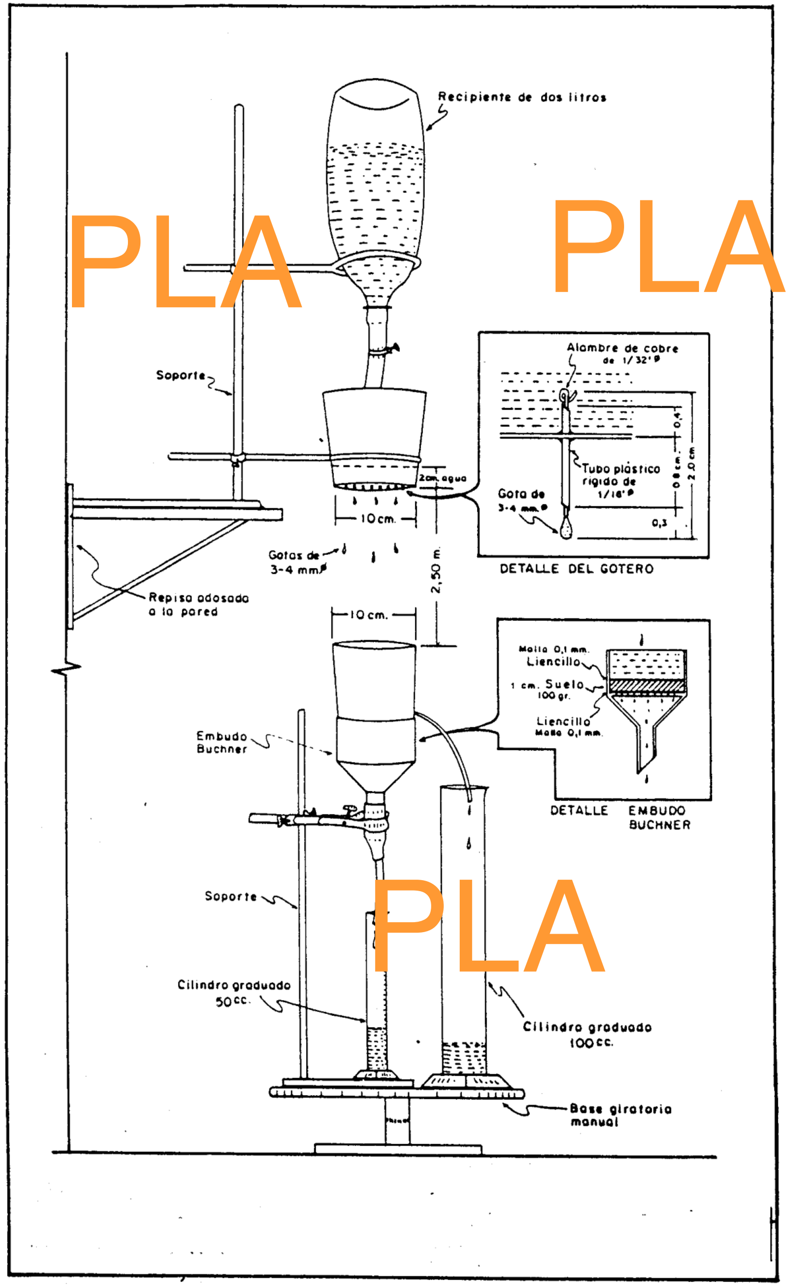
I: Infiltration rate
Q: Flow rate of water in the dropper
A: Wetted area in the soil surface at equilibrium

Rainfall simulation has been used as a practical tool for evaluating the interaction of falling water drops on the soil surface, to measure both stability of soil aggregates to drop impact and water infiltration rates. In both cases it is tried to simulate the effects of natural rainfall, which usually occurs at very different, variable and erratic rates and intensities.

One of the main arguments against the use of rainfall simulators is the difficulty to reproduce the size, final velocity and kinetic energy of the drops in natural rainfall.

In spite of this, with the use of rainfall simulators it is possible to obtain very good information, which if it is properly interpreted in relation to each particular condition (land and crop management, rainfall characteristics, measurement conditions, etc.) may be used as one of the parameters for deducing and modelling soil water balance and soil moisture regime under different land use and management and variable climate conditions.

Due to the possibility for a better control of the intensity of simulated rainfall and of the size of water drops, and the possibility to make more repeated measurements under very variable soil and land conditions, both in the laboratory and specially in the field, the better results have been obtained with small size 500-1000 cm2, easily dismantled, drop former simulators, than with larger, nozzle, or more sophisticated equipments

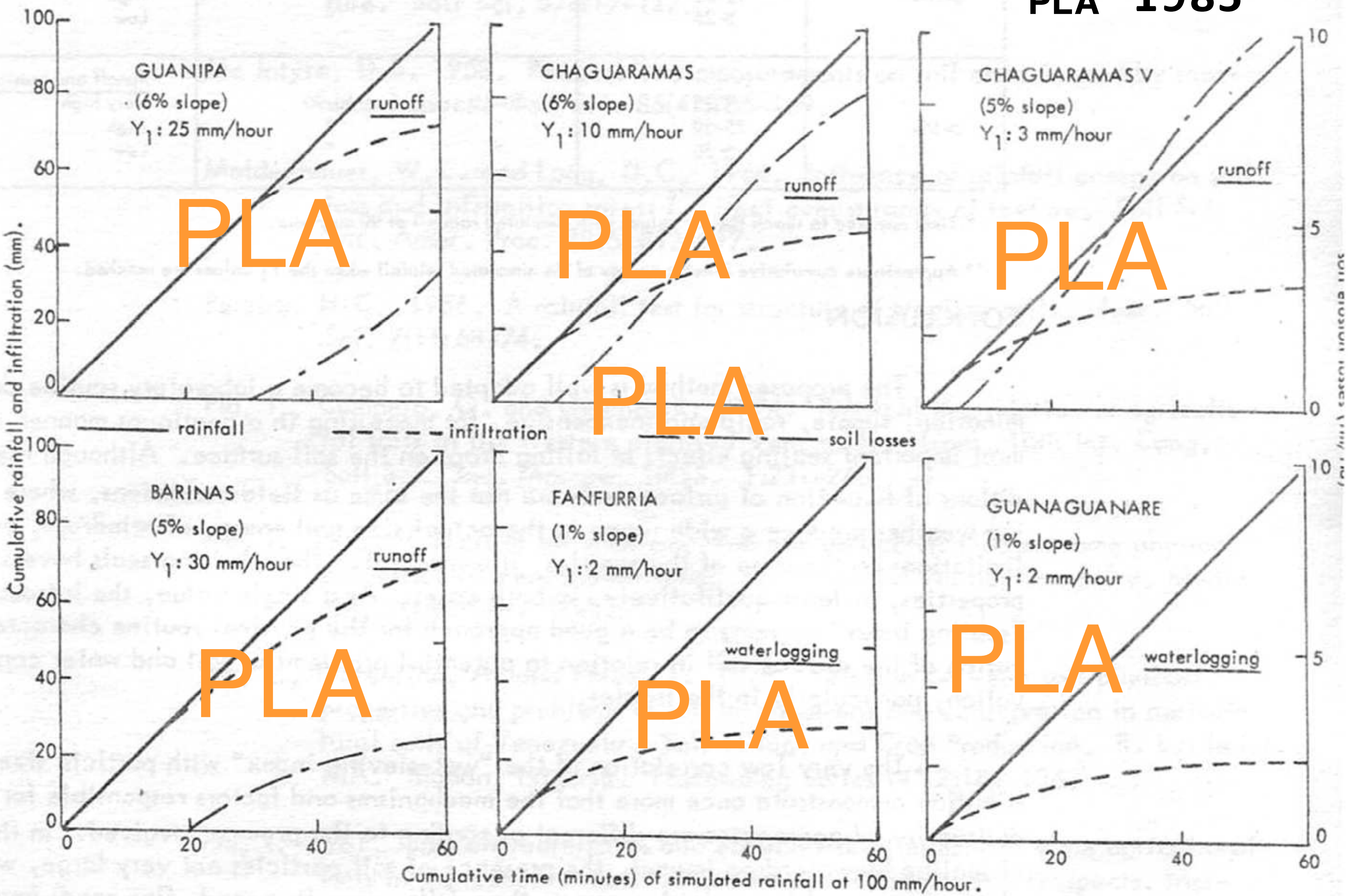


RAINFALL SIMULATORS TO BE USED UNDER LABORATORY OR GREENHOUSE CONDITIONS

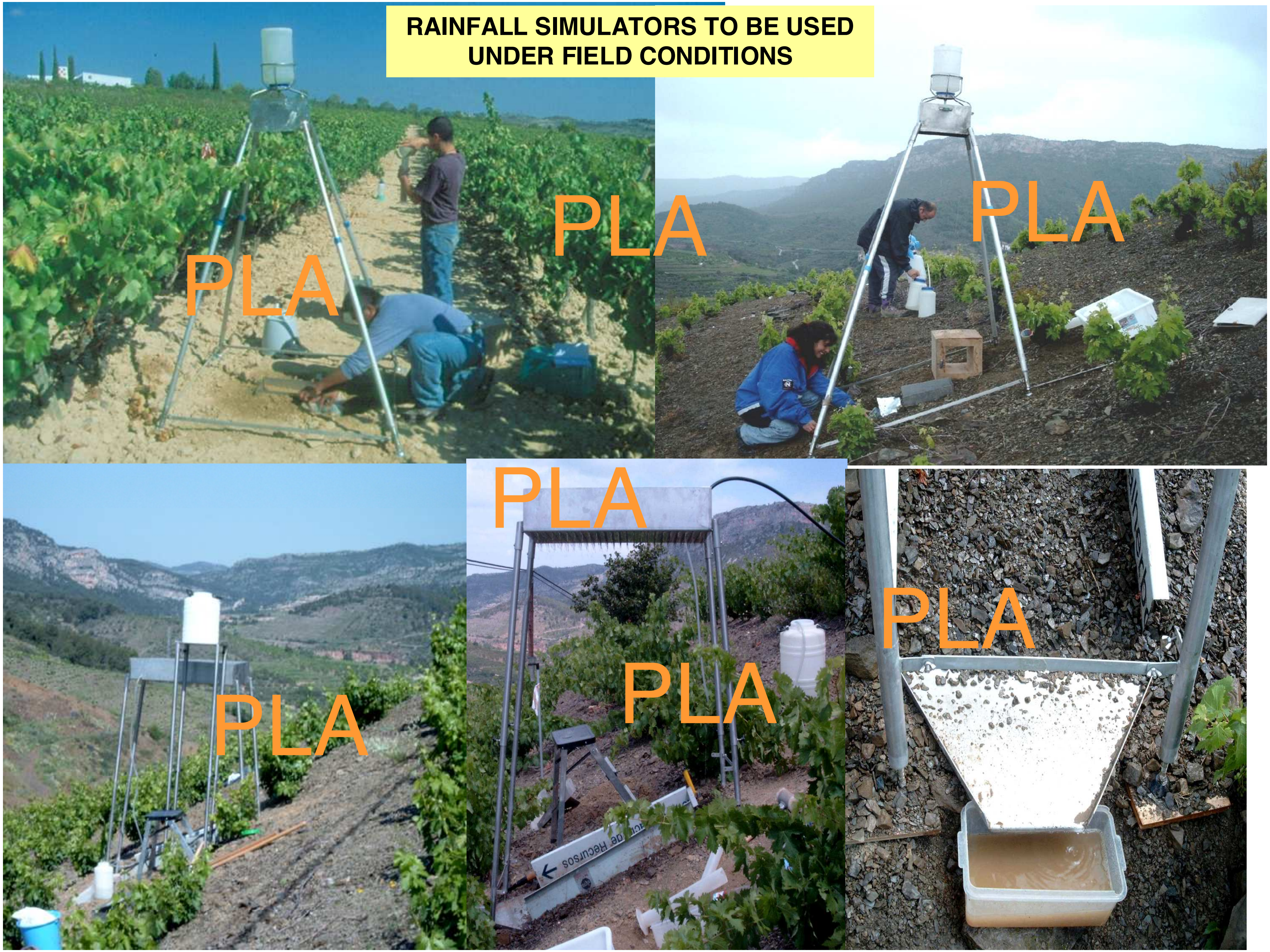
RAINFALL SIMULATOR TO BE USED UNDER FIELD CONDITIONS

FIGURE 5.- Cumulative infiltration and soil erosion losses of simulated rainfall (100 mm/hour) tests under field conditions in six agricultural soils (see table 1) with different "sealing indexes" (Y_1).

PLA 1985



RAINFALL SIMULATORS TO BE USED UNDER FIELD CONDITIONS



Recent results obtained in comparing different methods to measure infiltration rate, using single ring infiltrometers, rainfall simulators, and disc permeameters of different sizes, and soil cores, in soils with very contrasting surface and profile characteristics and conditions, including stony soils and very sloping lands.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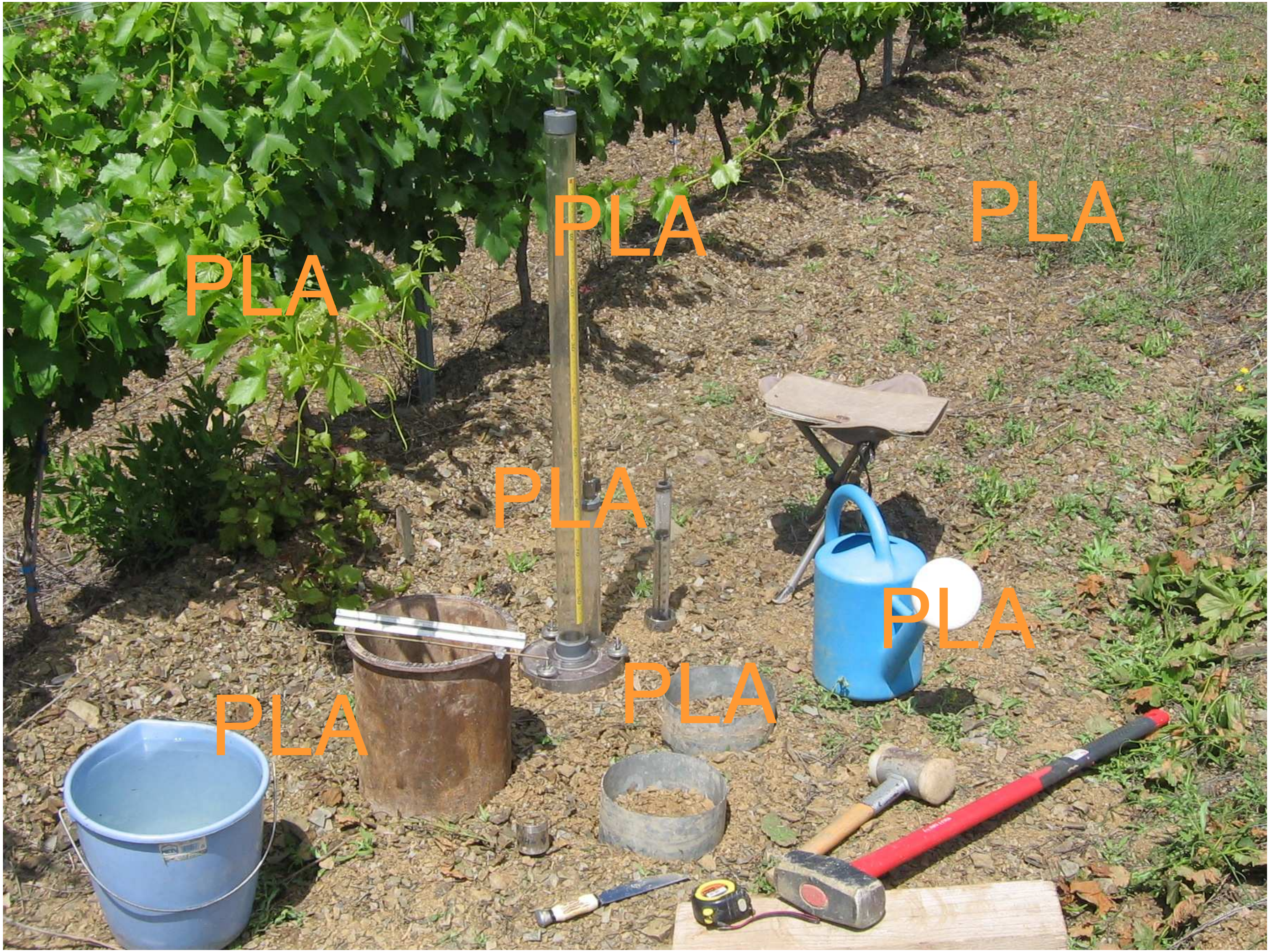


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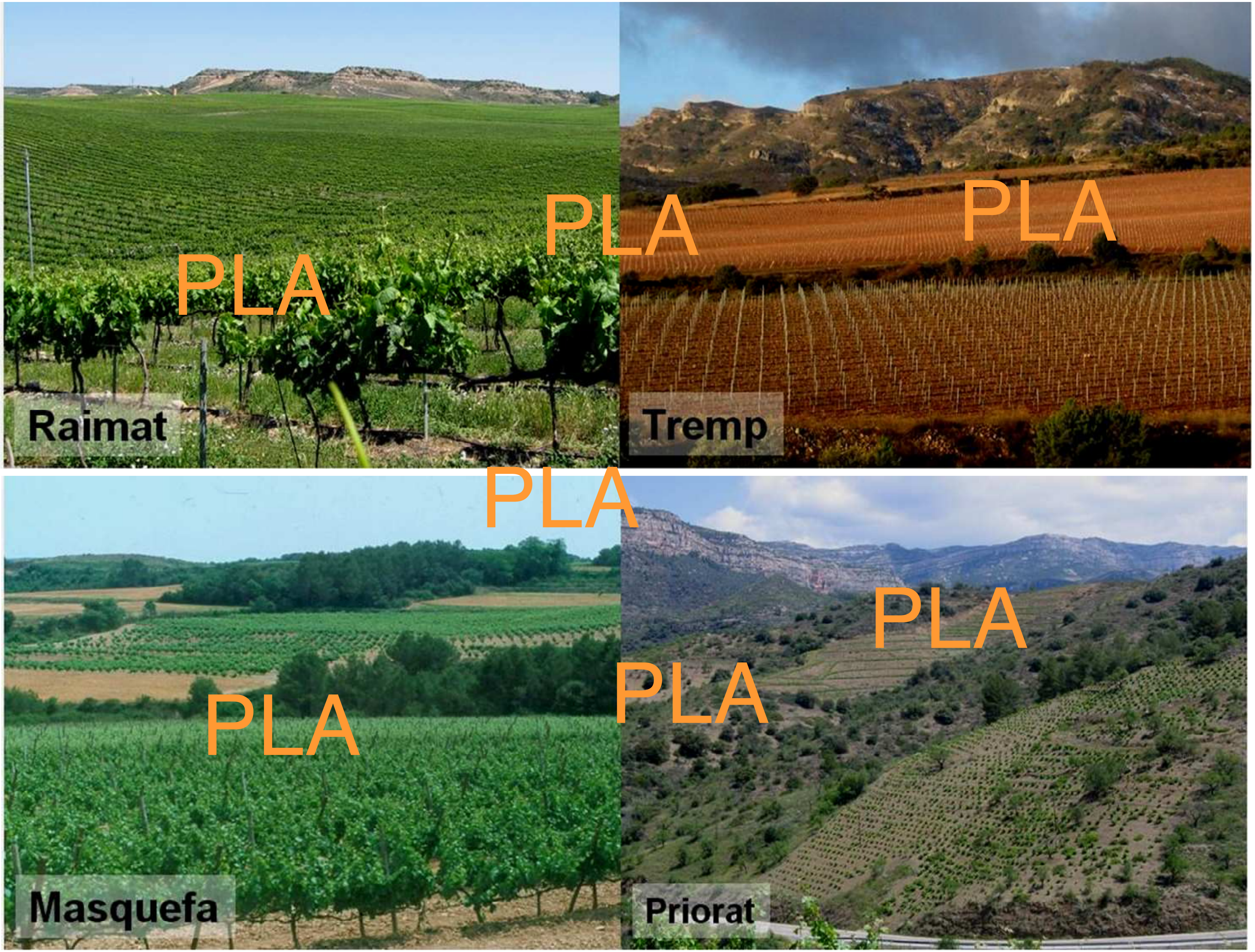
Raimat
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Tremp
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Masquefa
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Priorat

Table 1. Particle size distribution of surface soil (weight %)

Areas		Fracion < 2 mm			Fraction %	
		Sand %	Silt %	Clay %	> 2 mm	< 2 mm
Tremp	Mean (8)	48	36	17	60 (1)	40
(Dryland)	Standard E	2	1	1	6	6
Priorat	Mean (8)	52	27	21	62 (2)	39
(Dryland)	Standard E	7	4	5	8	8
Masquefa	Mean (8)	31	48	21	19 (1)	81
(Dryland)	Standard E	1	1	0	4	4
Raimat	Mean (8)	24	53	23	19	81
(Irrigated)	Standard E	1	0.4	1	4	4

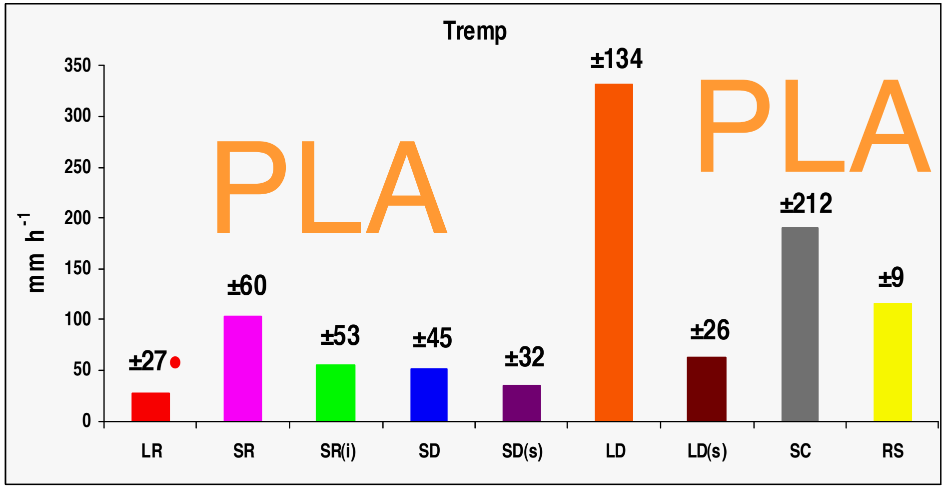
(1): Cobblestones (Rounded); (2): Slate pieces (Flat)

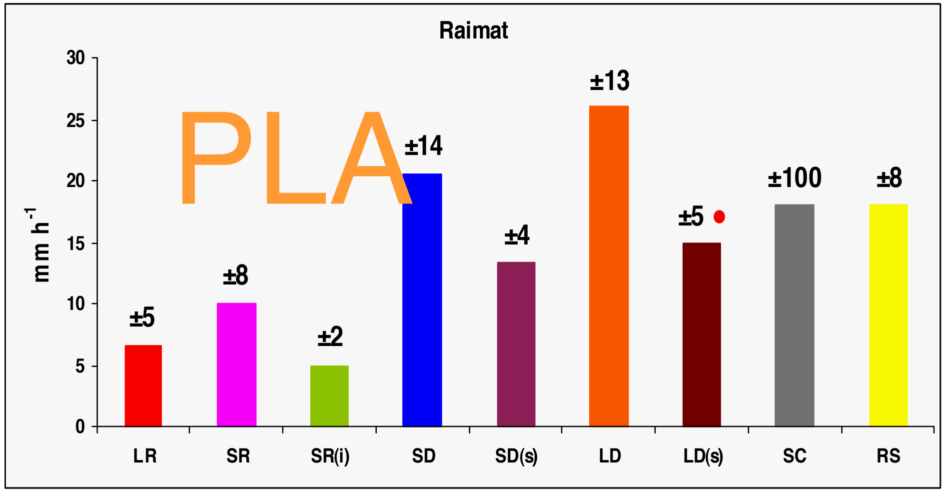
Table 2. Some properties of surface soils

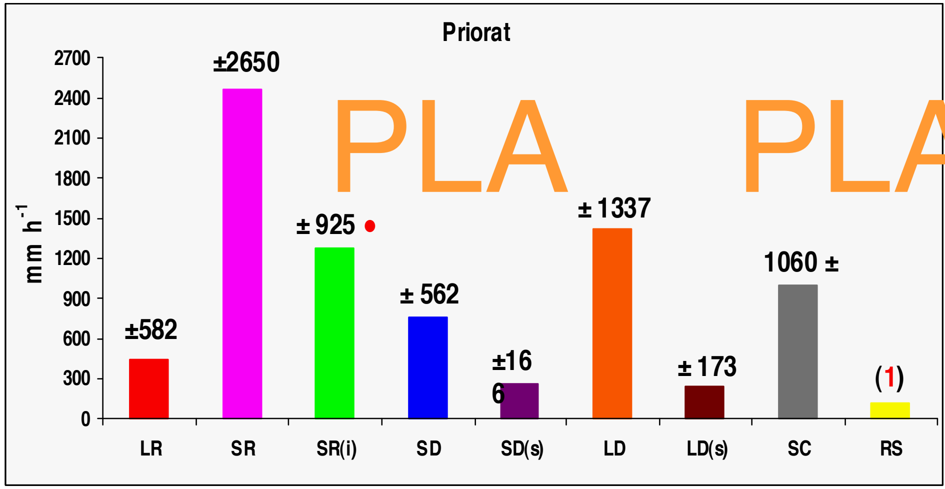
Areas		pH (1)	EC dS m^{-1} (2)	OM %
Tremp	Mean (8)	8.34	0.30	1.95
(Dryland)	Standard E	0.08	0.03	0.11
Priorat	Mean (8)	7.81	0.38	0.74
(Dryland)	Standard E	0.13	0.04	0.06
Masquefa	Mean (8)	8.30	0.56	1.12
(Dryland)	Standard E	0.13	0.21	0.15
Raimat	Mean (8)	7.88	2.33	3.05
(Irrigated)	Standard E	0.13	0.69	0.40

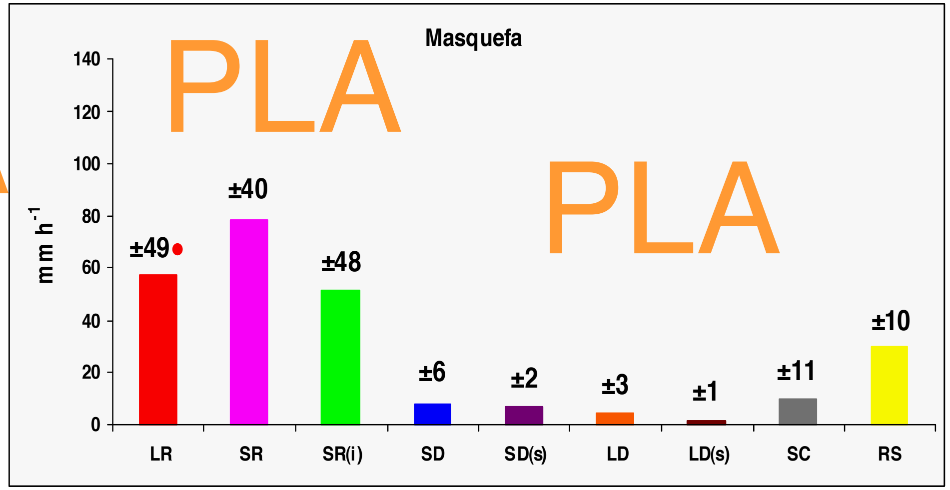
(1): 1(soil):2.5 (water); (2): 1(soil): 1 (water)

Final infiltration rates









LR: Large diameter single ring (30 cm Ø); SR: Small diameter single ring (20 cm Ø); SR(i): Small diameter single ring with drop impact (20 cm Ø); LD: Large diameter disc (4.5 cm-20cm Ø) ; LD(s): Large diameter disc with sand cover (4.5 cm - 20cm Ø); SD: Small diameter disk (4.5 - 7 cm Ø); SD(s): Small diameter disc with sand cover (4.5 cm – 7 cm Ø); SC: Small diameter core (5 cm Ø by 5 cm high) saturated hydraulic conductivity; RS: Rainfall simulator (30 cm long by 20 cm wide) ; ● : Standard error of the mean; (1): > 120 mm h^{-1} (Lymited by simulated rainfall intensity).

VARIABILITY OF INFILTRATION RATES MEASURED WITH THE DIFFERENT METHODS IN DIFFERENT SOILS

CONCLUSIONS

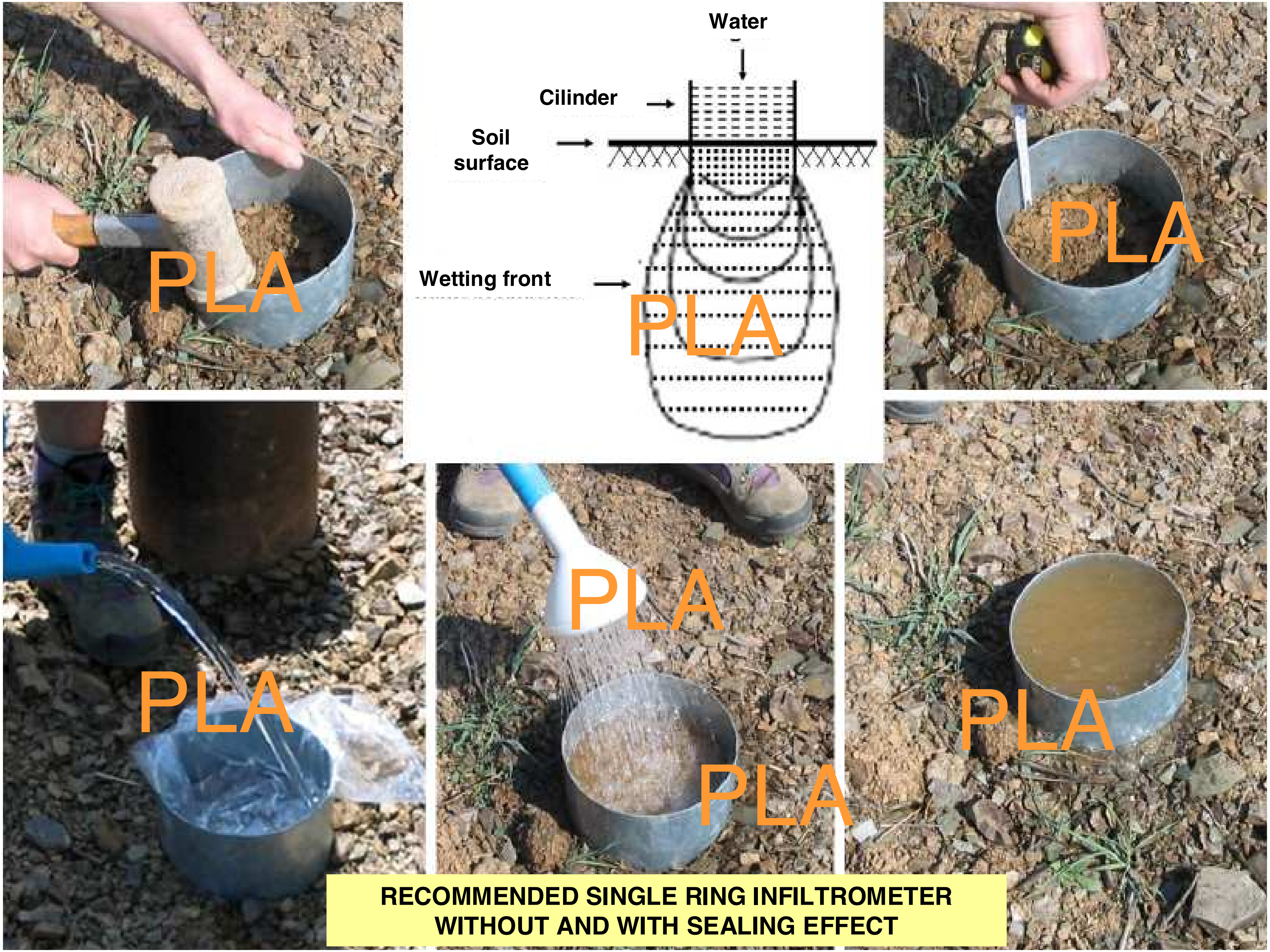
In flat or gently sloping lands, taking into consideration the difficulties of measurements under field conditions, and the requirements of repeated measurements (due to the variability on soil hydrological properties), among the tested methods there would be recommended the one using the small (20 cm diameter) single ring infiltrometer, with and without drop impact. With this method, a fixed depth of water (5-8 cm) is allowed to infiltrate in previously wetted soil, and repeating the process until reaching constant time.

The disk infiltrometers were the ones giving more unreliable results under field conditions, in flat or sloping lands, specially on stony soils. In general the results are significantly affected by the manipulation of the equipment and the soil under the disk, specially when a sand layer is used in soils with irregular or stony surface. They may be used only in soils with very smooth and uniform surface, with no significant differences between the small (cheaper) and the large disk.

The rainfall simulators give the best and more reliable results under steeper sloping conditions. There have to be preferred simple and small (covering at least 500 cm2), which may be easily moved and used for repeated measurements without requirements of large volumes of water.

As a general conclusion there that there are not methods universally applicable to any soil and land condition, and that in many cases the results are significantly influenced by the way we use a particular method or instrument, and by the alterations in the soil conditions by the land management, but also due to the manipulation of the surface soil before and during the measurement.

Due to the commonly found high variability, natural or induced by land management, of the soil surface and subsurface hydrological properties, and to the limitations imposed by the requirements of water for the measurements, there is proposed a simple and handy method, which do not use high volumes of water, adaptable to very different soil and land conditions, and that allow many repeated measurements with acceptable accuracy for most of the purposes.



**RECOMMENDED SINGLE RING INFILTROMETER
WITHOUT AND WITH SEALING EFFECT**