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College of Soil Physics

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Soil salinization and sodification processes 4

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Soil Salinization and Sodification Processes

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Soil degradation and desertification , mainly by erosion, has affected more hilly sloping lands, but in valley bottoms where irrigation is being used for increasing productivity, salinisation and sodification have become a widespread form of soil degradation and desertification.

There are evidences that land degradation processes leading to desertification by salinisation in the whole World is getting worse, because of different or mixed causes varying from one place to the other.

SALT AFFECTED SOILS DEVELOPED UNDER NON IRRIGATED CONDITIONS

Sahel (Senegal, Africa)

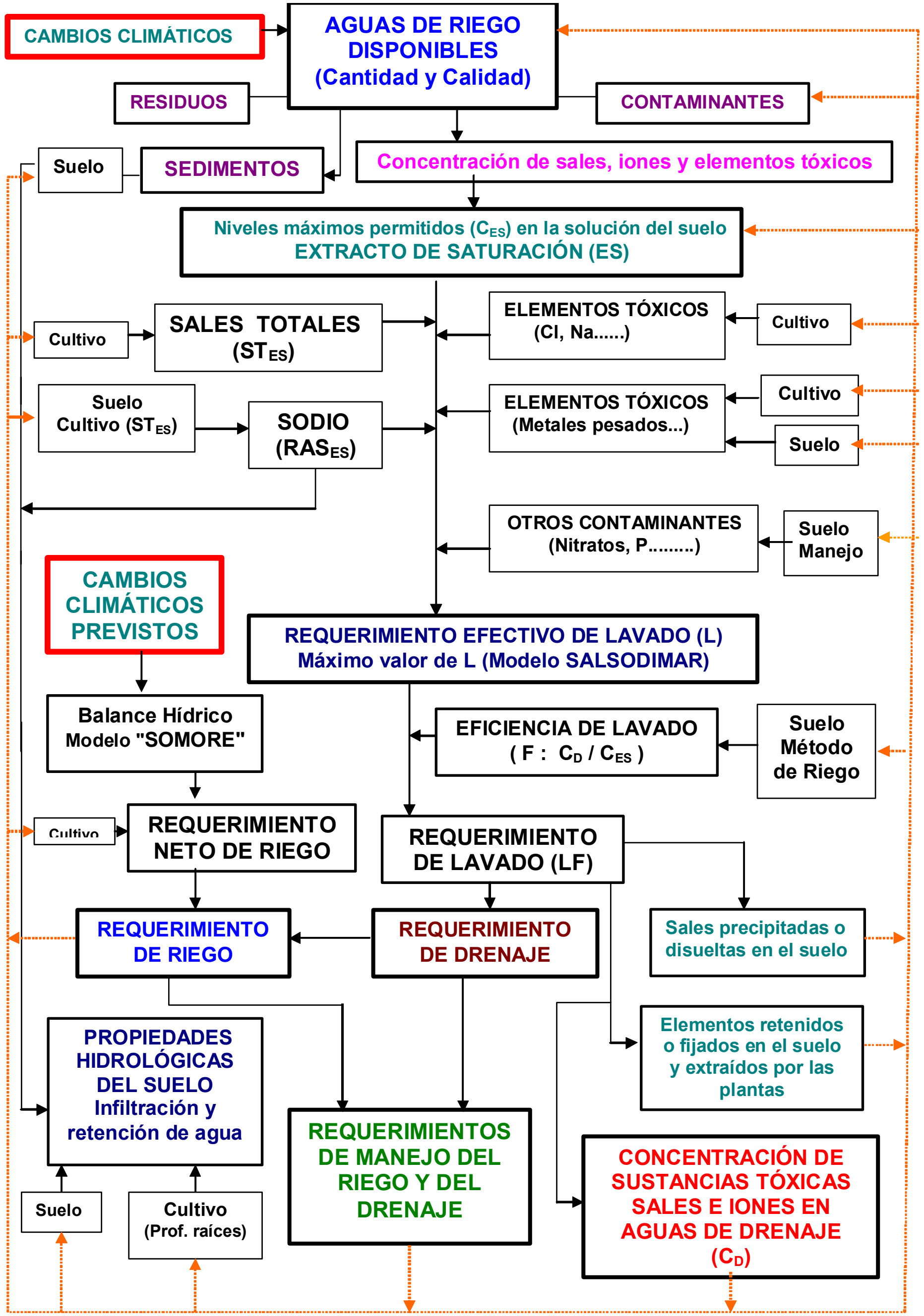


Figura 2.- Diagrama de flujo de un modelo conceptual de balance de sales y sustancias tóxicas en suelos bajo riego (RAS: Relación de Adsorción de Sodio) (Modelo SOMORE: Pla, 1997a; Modelo SALSODIMAR, Pla, 1996; 1997b). (········► Posibles alternativas para resolver limitaciones)

Irrigation causes drastic changes in the regime and balance of water and solutes in the soil profile, which may result in soil salinisation, one of the processes of soil degradation leading to land desertification.

The salinity problems are a consequence of salt accumulation in zones and depths where the soil moisture regime is characterized by strong losses of water by evaporation and transpiration, and by reduced leaching of the remaining salts.

The salt accumulation may conduce to a partial or complete loss of soil capacity to provide the required amounts of water to plants, changing fertile lands to deserts.

The problems of secondary salinisation are a consequence of non adequate water mangement by irrigation and drainage, under a particular set of conditions, including:

-Climate

-Crops

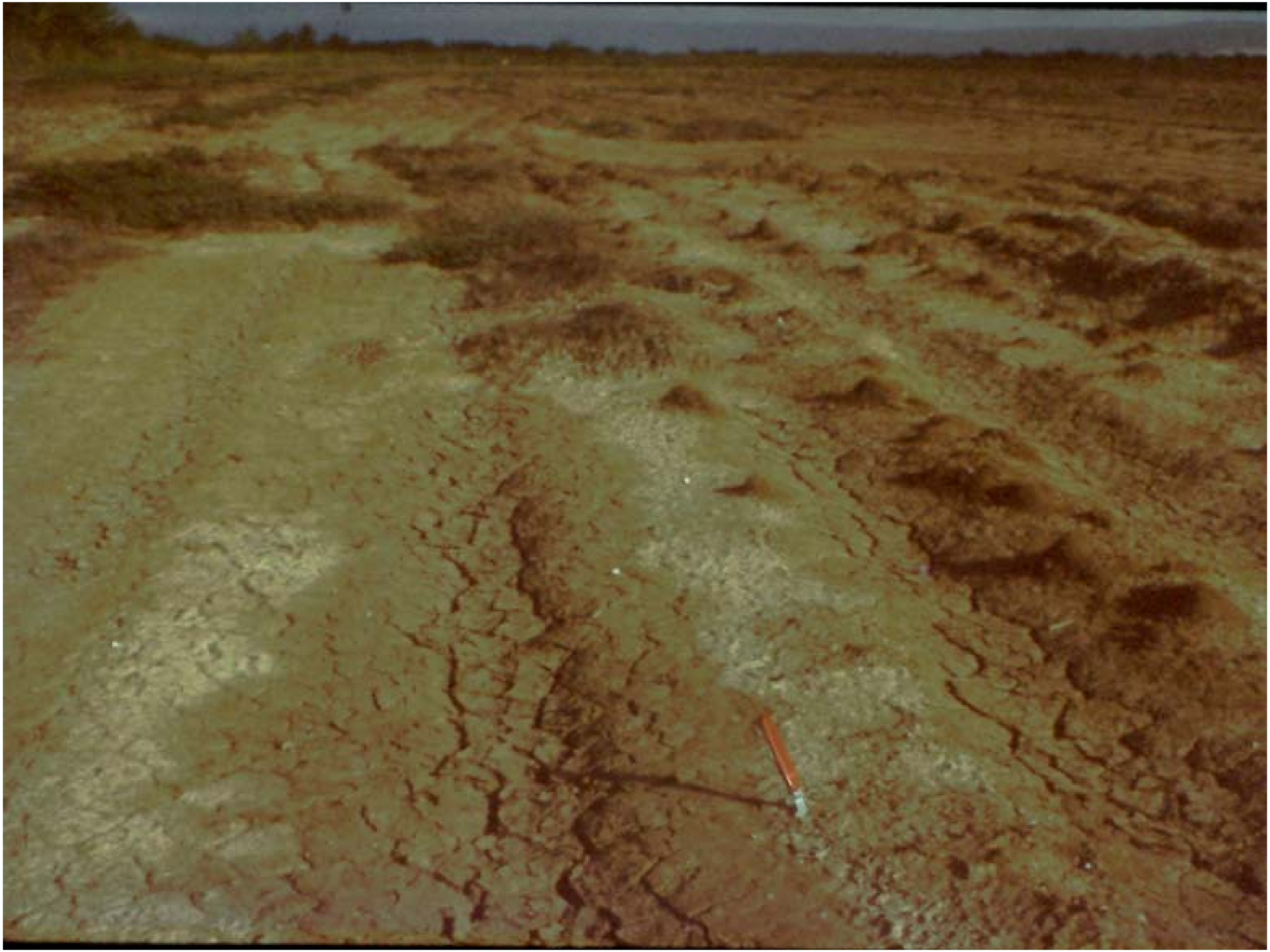
-Soils

-Fertilization

-Growndwater depth

-Water quality

-Irrigation system

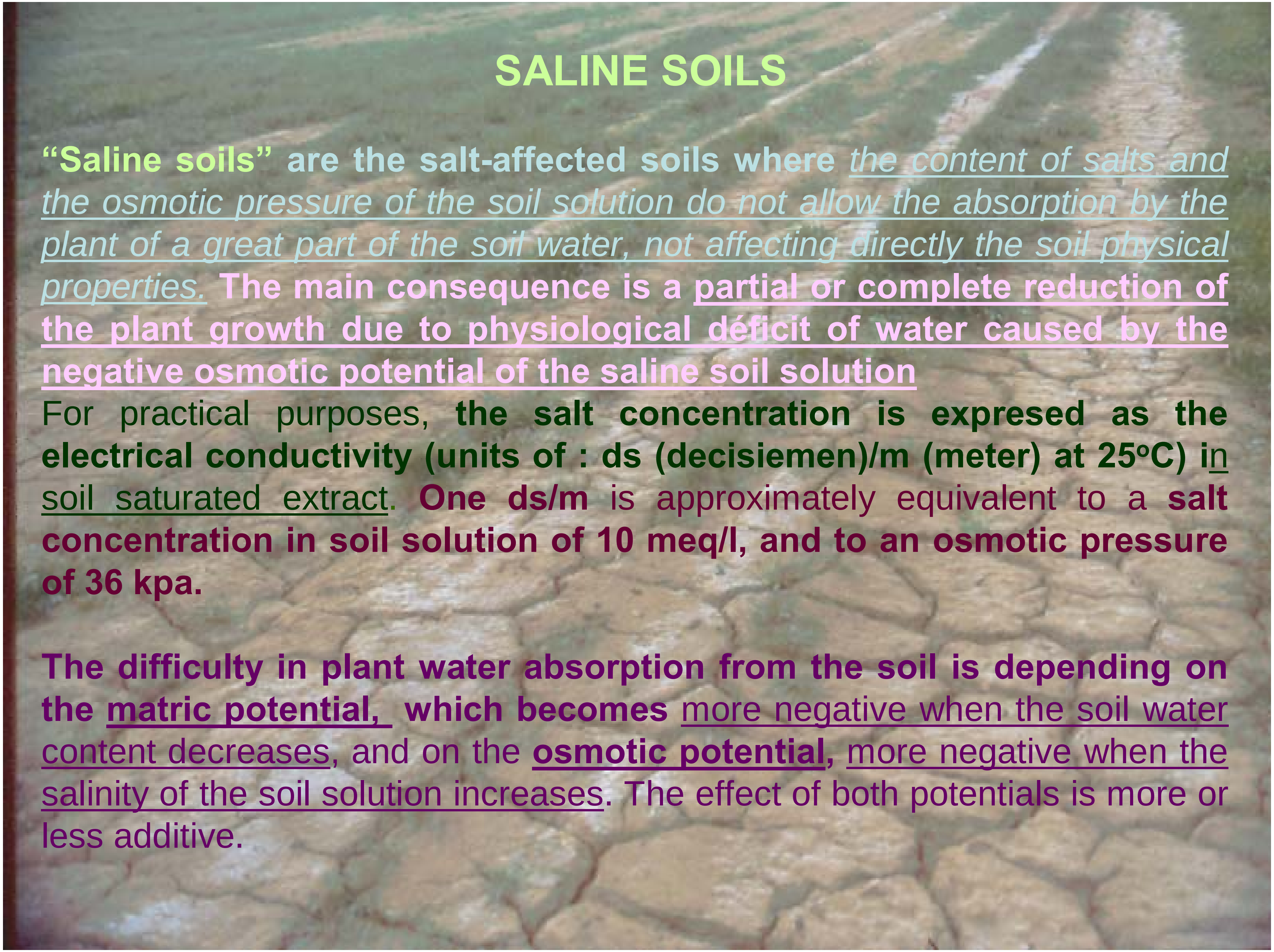


The **salt affected soils**, **depending on their main effects on soils and plants, may be clasified as:**

SALINE SOILS
SODIC SOILS

Tradicionally the **sodic soils have been called alcali soils, but** these only included the sodic soils with bicarbonates and carbonates of Na, and pH higher than 8.5-9.0, and often higher than 10.
There are other soils with properties of sodic soils with lower pH and Na levels lower than the so-called alcali soils.

Adicionally there are other specific types of salt-affected soils like the so-called “saline-acid” soils.



SALINE SOILS

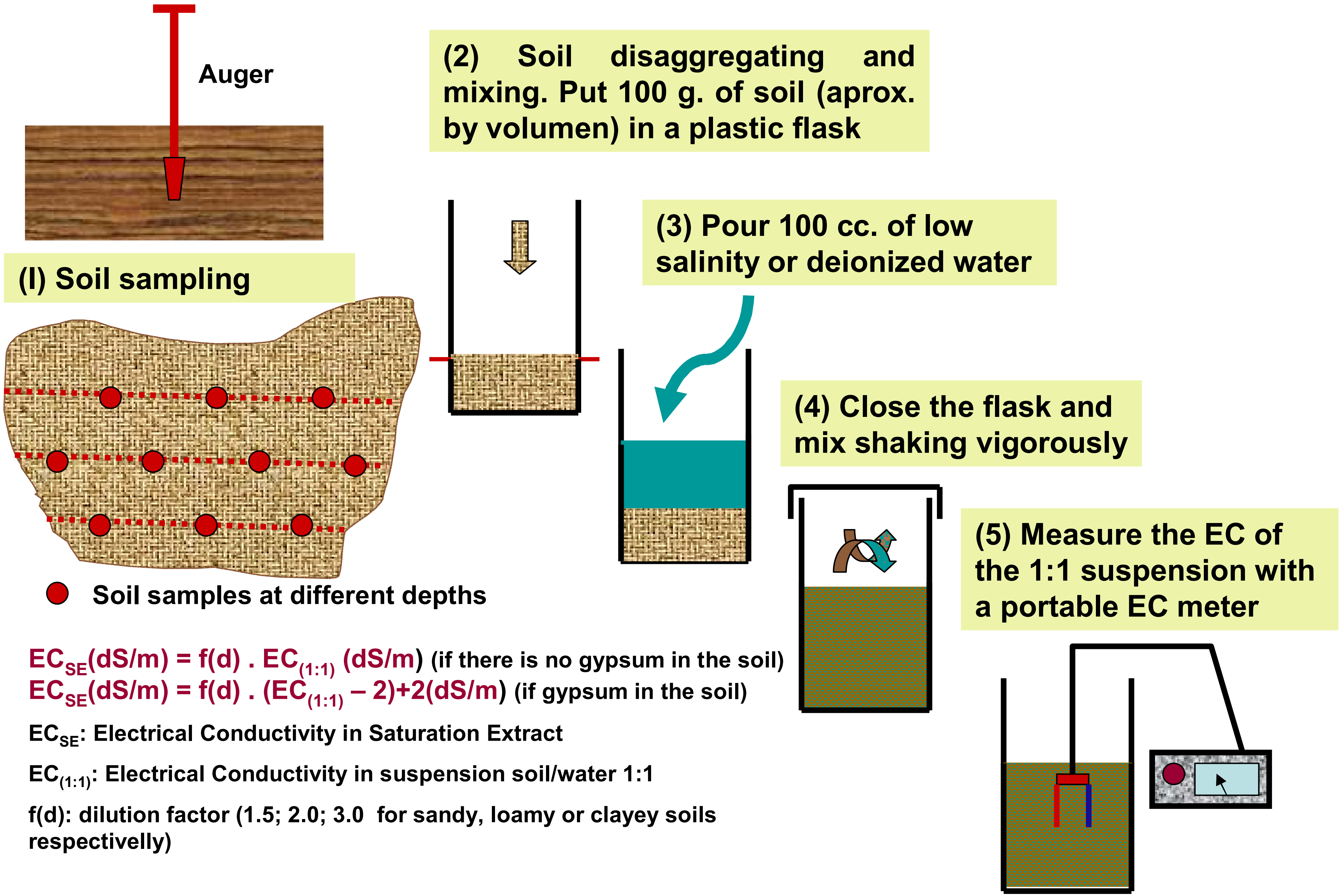
“Saline soils” are the salt-affected soils where *the content of salts and the osmotic pressure of the soil solution do not allow the absorption by the plant of a great part of the soil water, not affecting directly the soil physical properties.* **The main consequence is a partial or complete reduction of the plant growth due to physiological déficit of water caused by the negative osmotic potential of the saline soil solution**

For practical purposes, **the salt concentration is expresed as the electrical conductivity (units of : ds (decisiemen)/m (meter) at 25°C)** in soil saturated extract. **One ds/m** is approximately equivalent to a **salt concentration in soil solution of 10 meq/l, and to an osmotic pressure of 36 kpa.**

The difficulty in plant water absorption from the soil is depending on the matric potential, which becomes more negative when the soil water content decreases, and on the **osmotic potential**, more negative when the salinity of the soil solution increases. The effect of both potentials is more or less additive.

EVALUATION OF SOIL SALINITY IN THE FIELD

ELECTROMAGNETIC INDUCTION SENSORS



(I) Soil sampling

● Soil samples at different depths

(2) Soil disaggregating and mixing. Put 100 g. of soil (aprox. by volumen) in a plastic flask

(3) Pour 100 cc. of low salinity or deionized water

(4) Close the flask and mix shaking vigorously

(5) Measure the EC of the 1:1 suspension with a portable EC meter

$EC_{SE}(dS/m) = f(d) \,.\, EC_{(1:1)}\ (dS/m)$ (if there is no gypsum in the soil)

$EC_{SE}(dS/m) = f(d) \,.\, (EC_{(1:1)} - 2)+2(dS/m)$ (if gypsum in the soil)

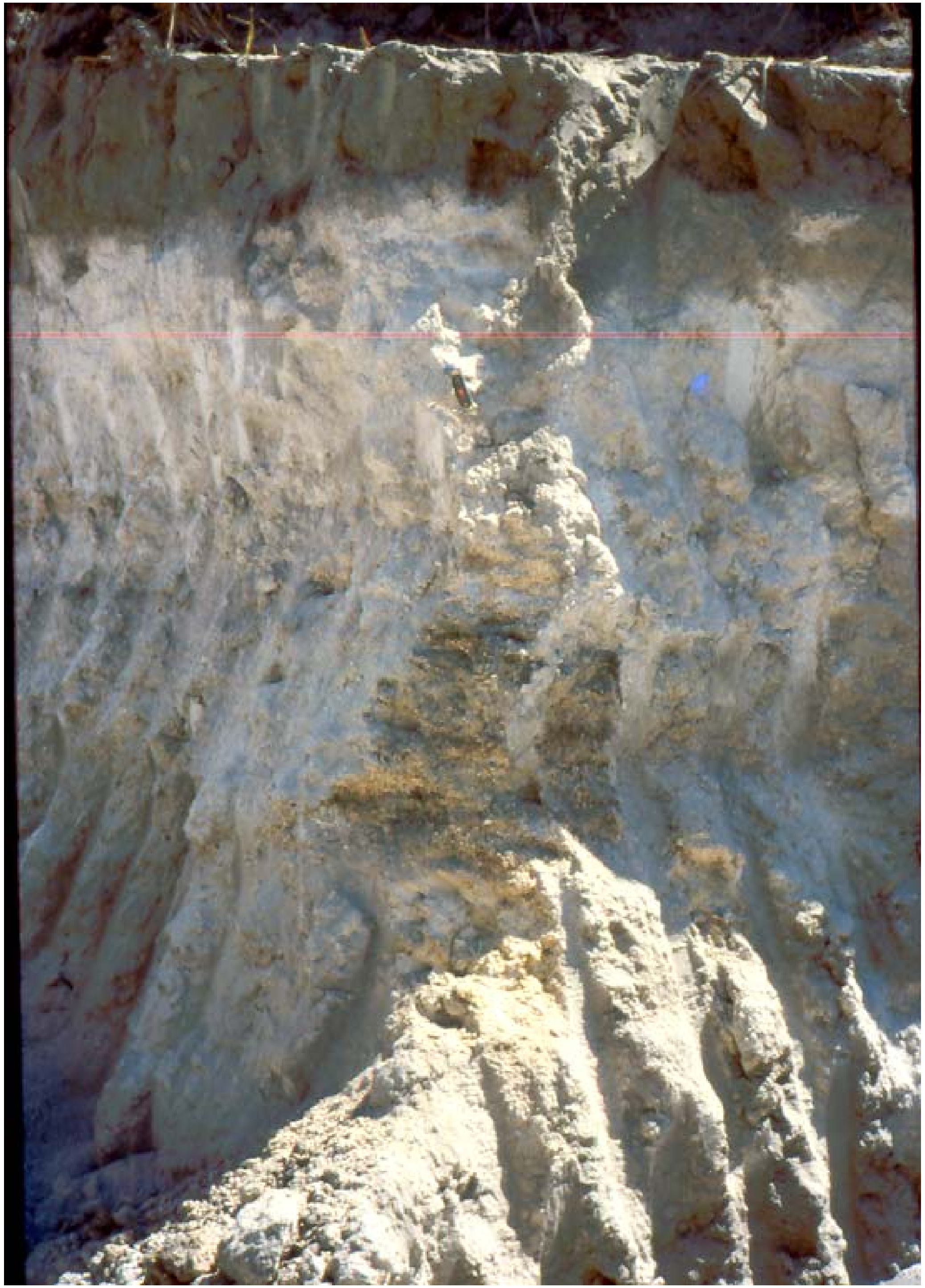
EC_{SE}: Electrical Conductivity in Saturation Extract

$EC_{(1:1)}$: Electrical Conductivity in suspension soil/water 1:1

f(d): dilution factor (1.5; 2.0; 3.0 for sandy, loamy or clayey soils respectivelly)

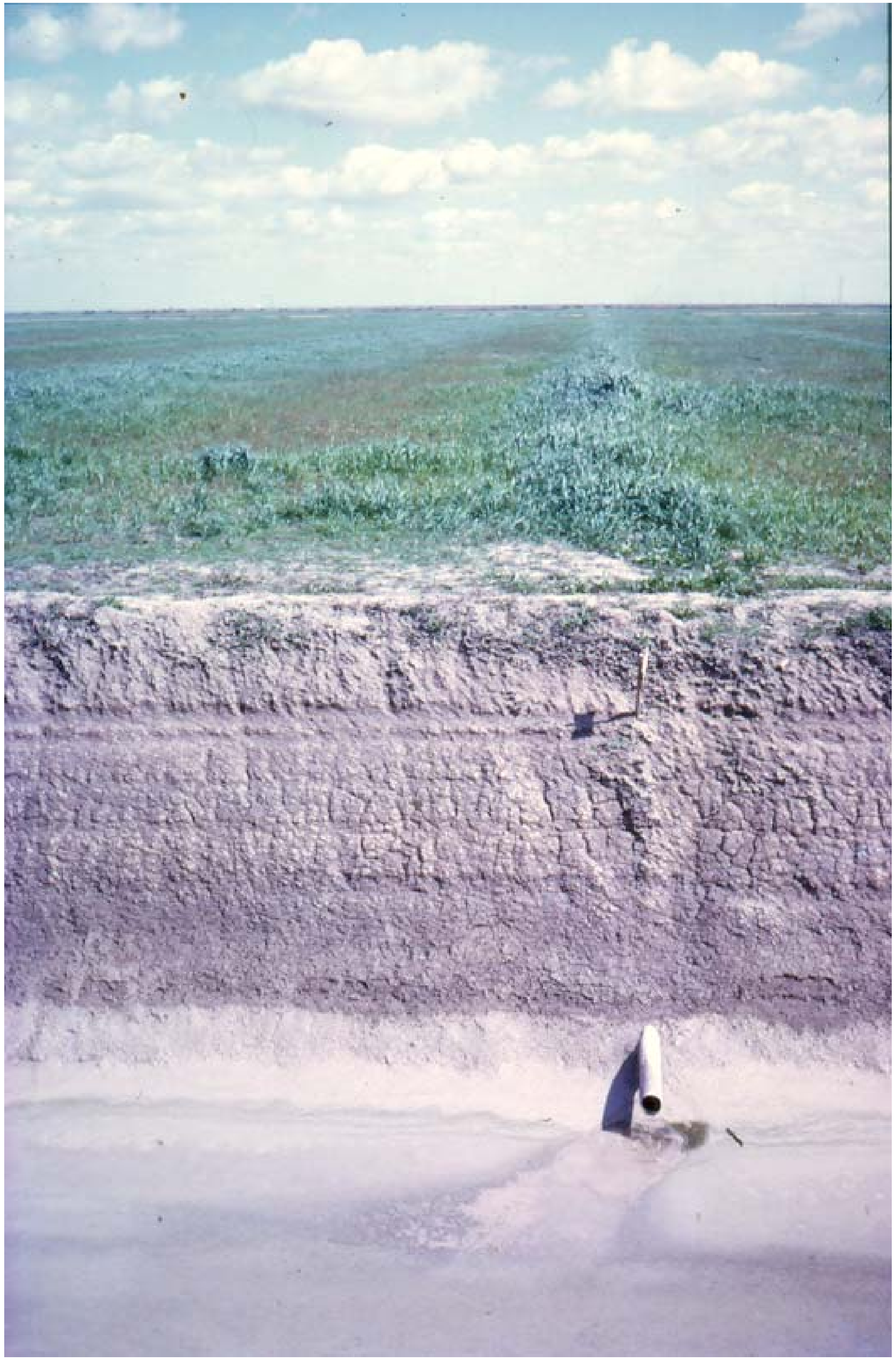
EVALUATION OF SOIL SALINITY "IN SITU"

SOILS WITH GYPSUM AND CARBONATES OF Ca and Mg of limited solubility



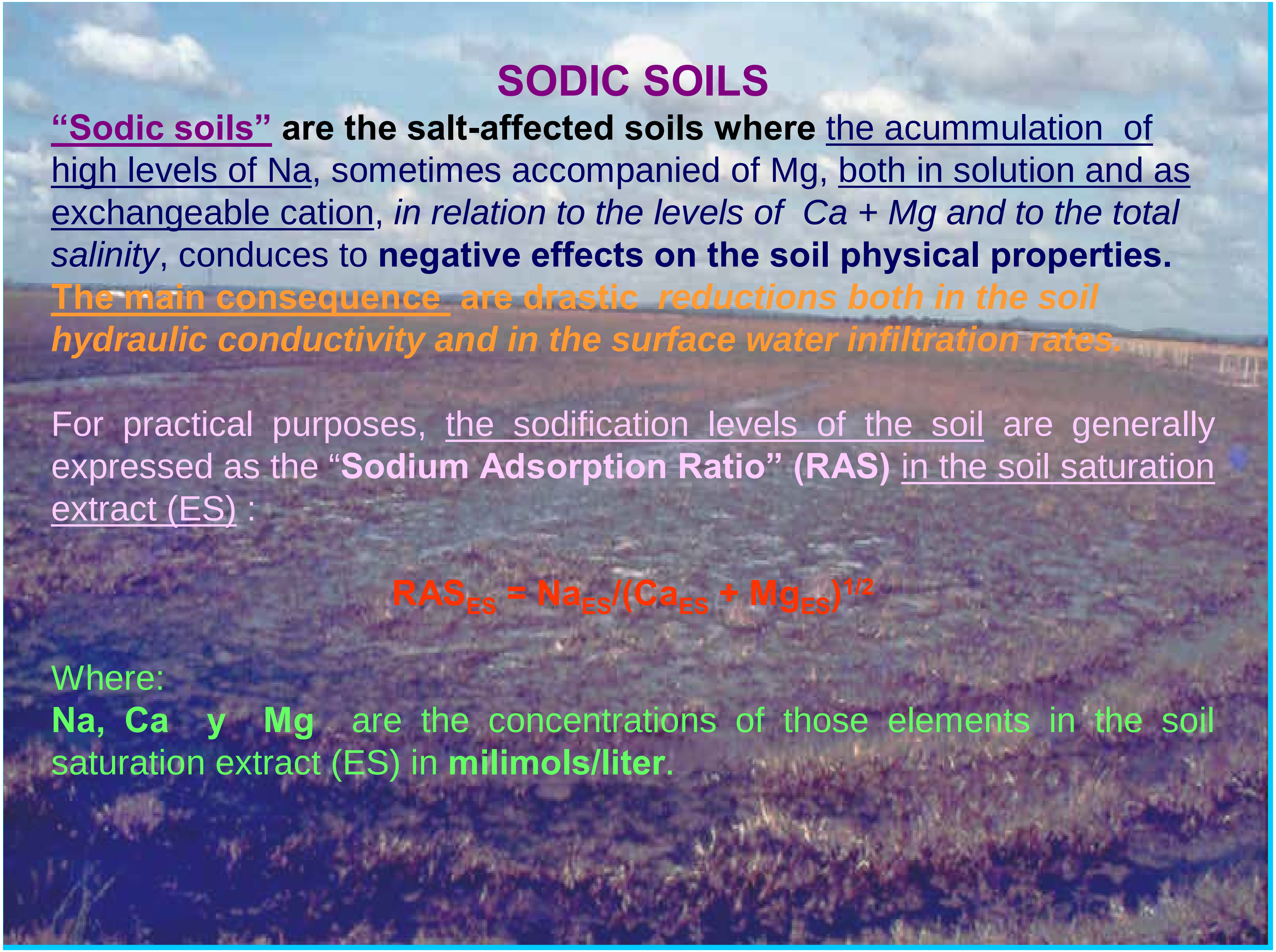
RECLAMATION OF SALINE SOILS


CATERPILLAR
CAT
D8H



VALUABLE CROPS IN SALINE SOILS


AVISA



SODIC SOILS

"Sodic soils" are the salt-affected soils where the acummulation of high levels of Na, sometimes accompanied of Mg, both in solution and as exchangeable cation, *in relation to the levels of Ca + Mg and to the total salinity*, conduces to **negative effects on the soil physical properties.** **The main consequence are drastic *reductions both in the soil hydraulic conductivity and in the surface water infiltration rates.***

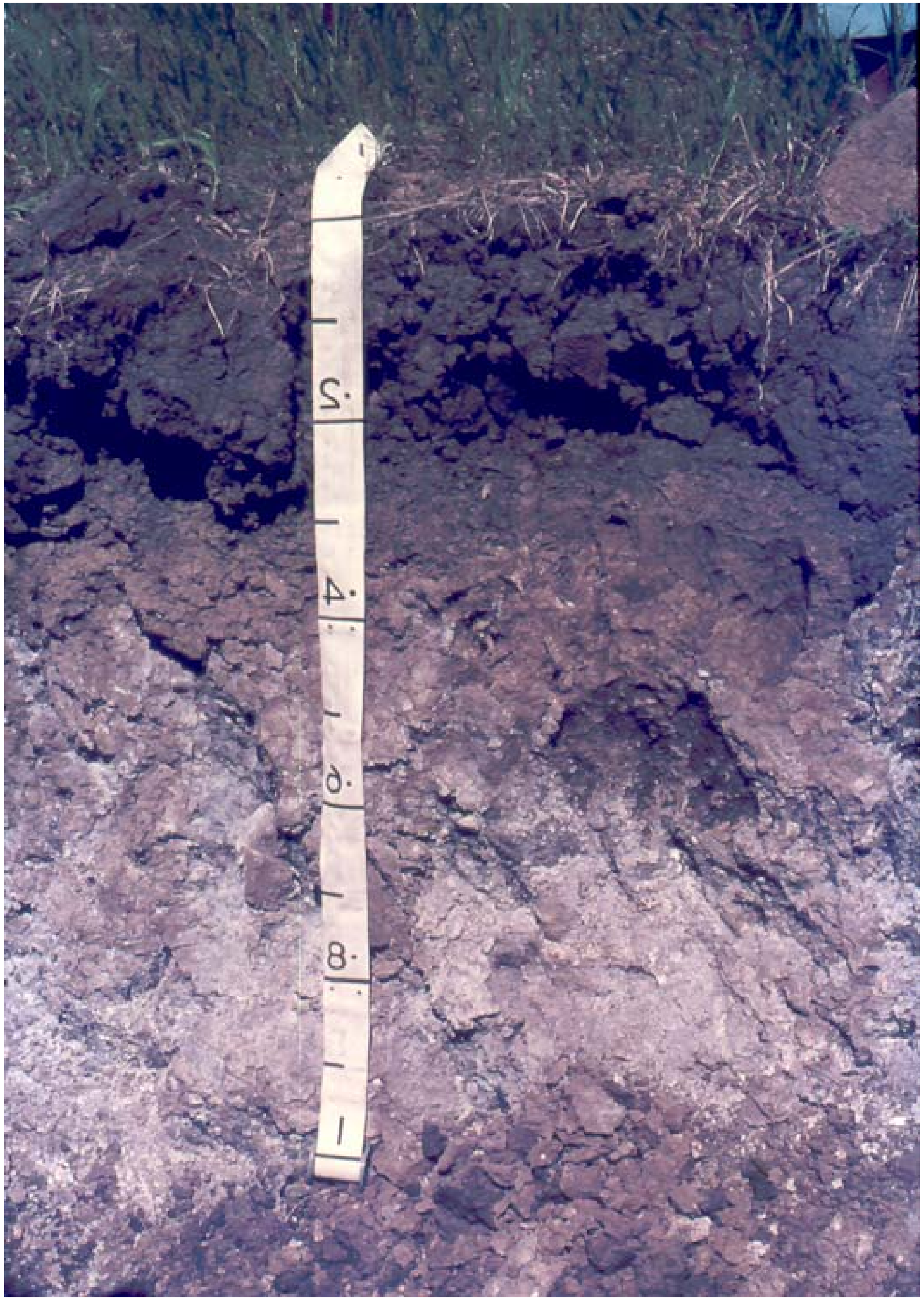
For practical purposes, the sodification levels of the soil are generally expressed as the "**Sodium Adsorption Ratio" (RAS)** in the soil saturation extract (ES) :

$$RAS_{ES} = Na_{ES}/(Ca_{ES} + Mg_{ES})^{1/2}$$

Where:

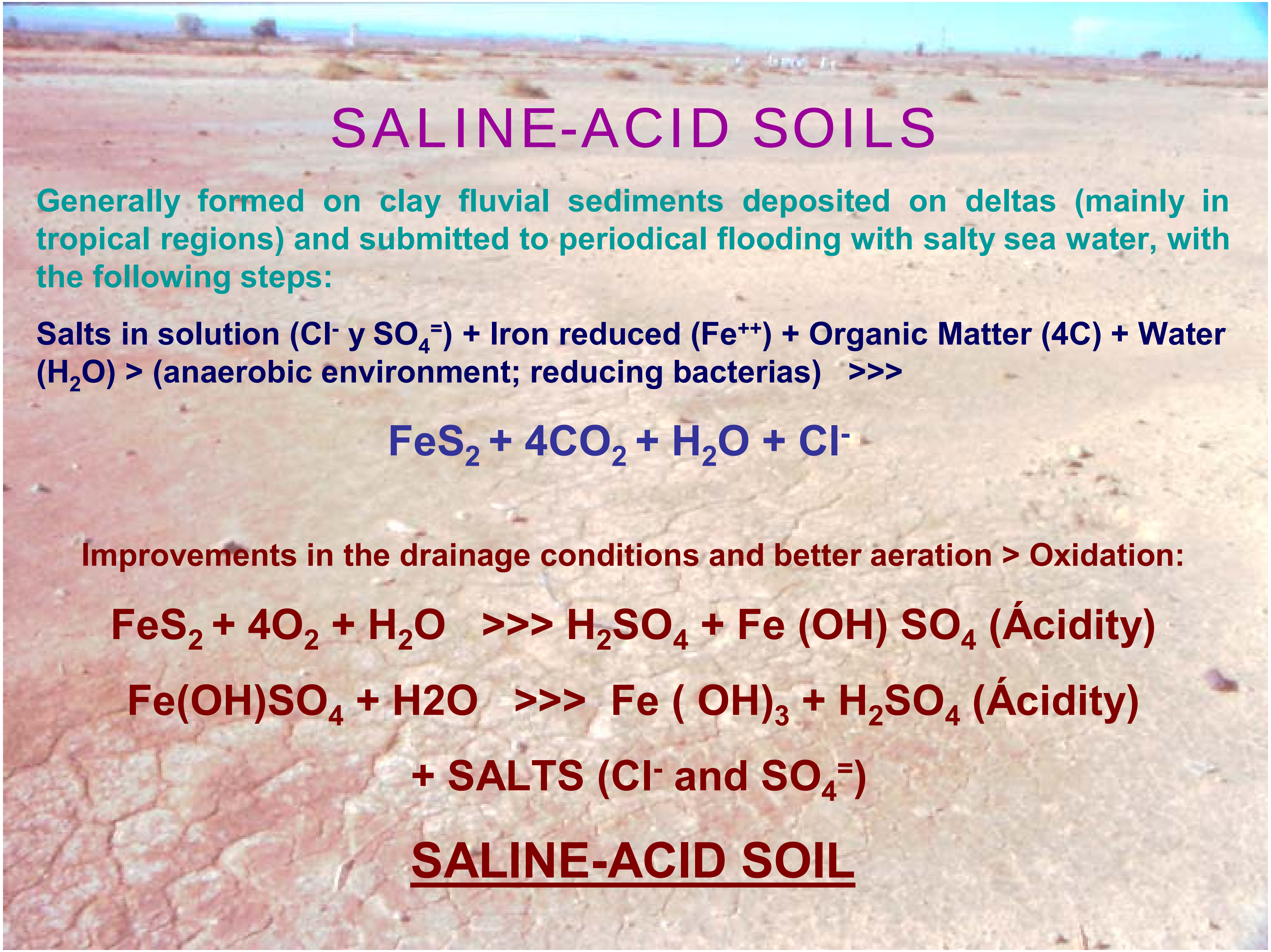
Na, Ca y Mg are the concentrations of those elements in the soil saturation extract (ES) in **milimols/liter**.

RECLAMATION OF SODIC SOILS


.2
.4
.6
.8
1


VERSATILE
950

NUTRIENT DEFFICIENCIES AND TOXICITIES ASSOCIATED TO SALINITY



SALINE-ACID SOILS

Generally formed on clay fluvial sediments deposited on deltas (mainly in tropical regions) and submitted to periodical flooding with salty sea water, with the following steps:

Salts in solution (Cl^- y $SO_4^=$) + Iron reduced (Fe^{++}) + Organic Matter (4C) + Water (H_2O) > (anaerobic environment; reducing bacterias) >>>

$$FeS_2 + 4CO_2 + H_2O + Cl^-$$

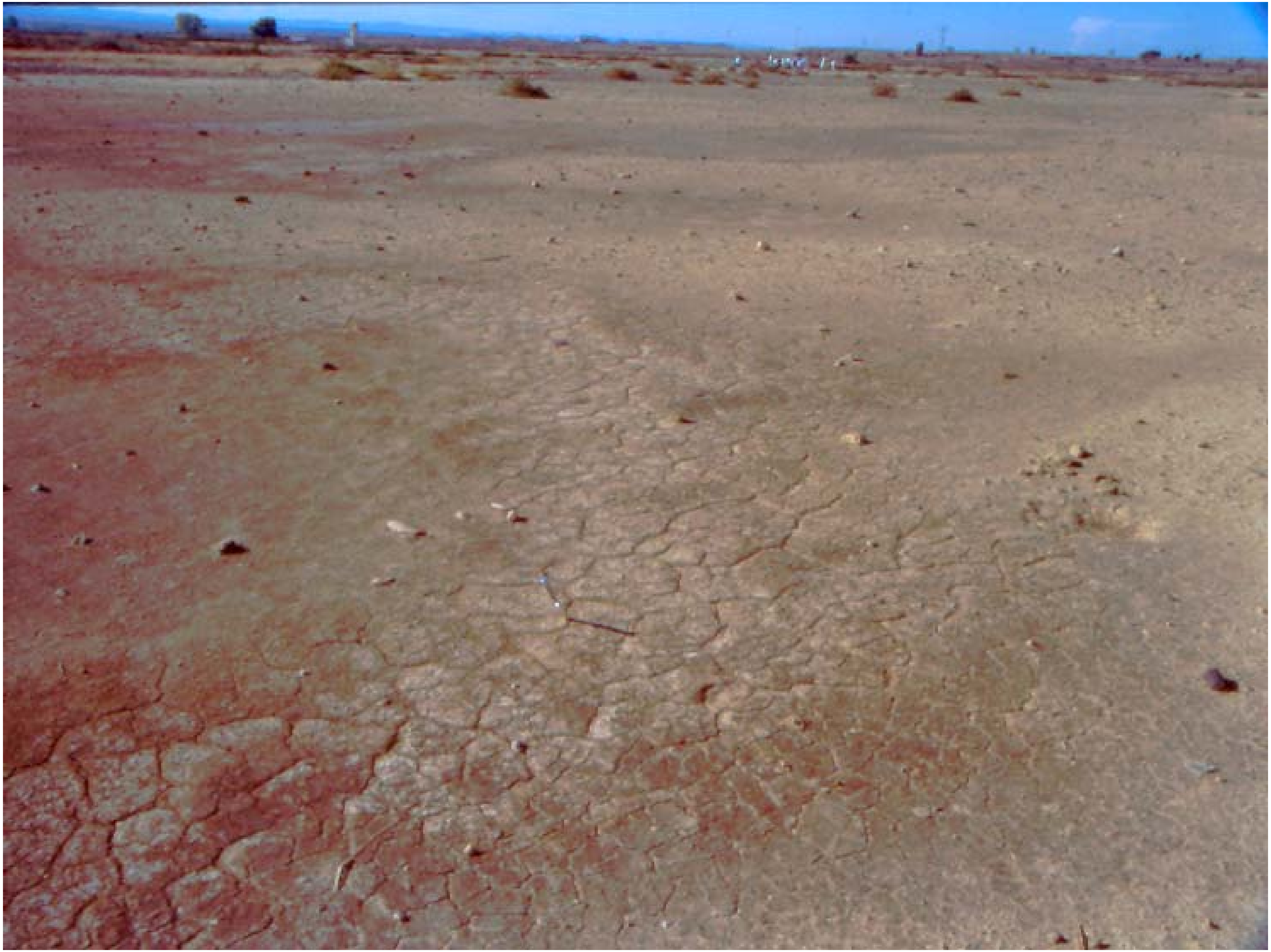
Improvements in the drainage conditions and better aeration > Oxidation:

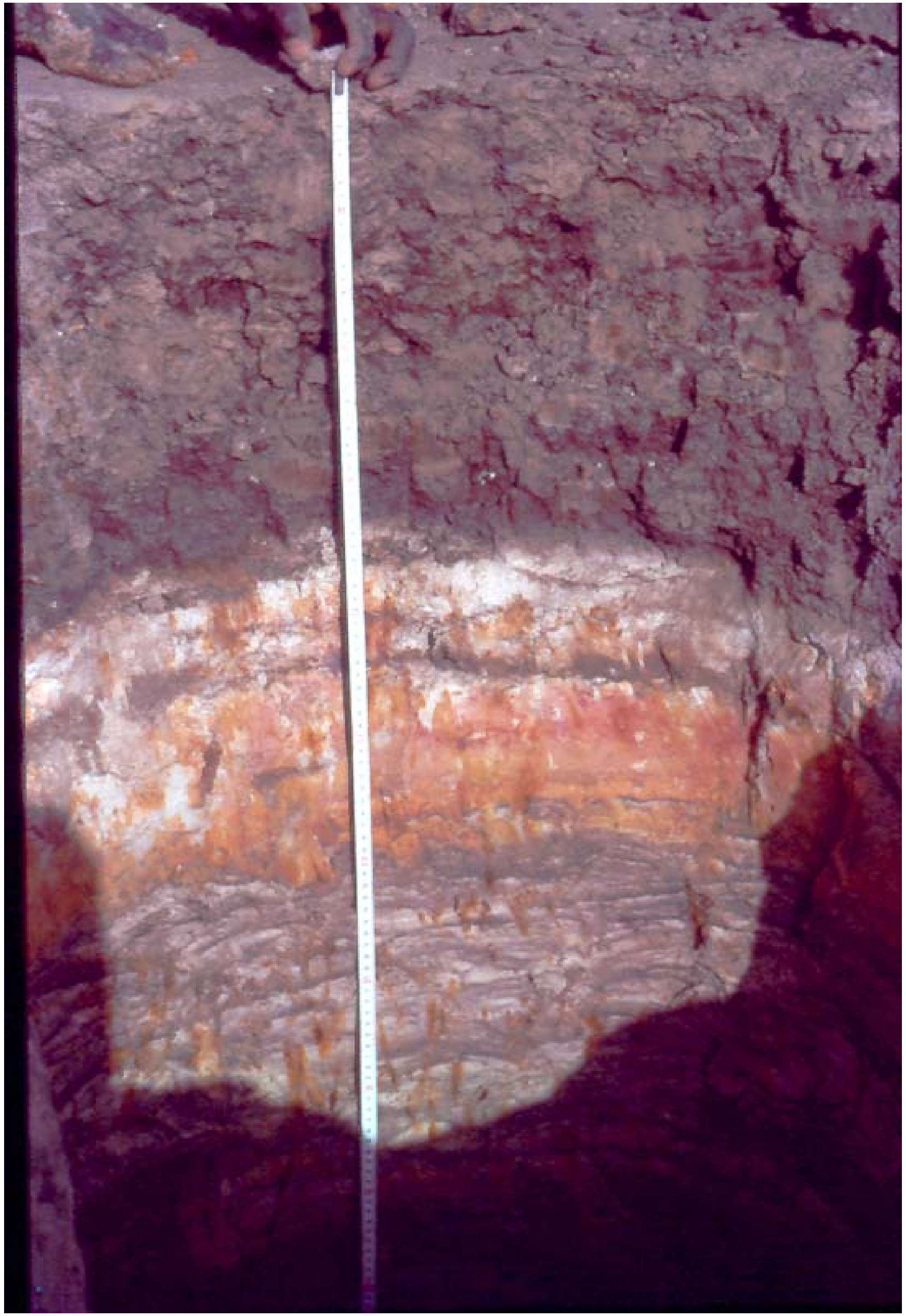
$$FeS_2 + 4O_2 + H_2O \quad >>> H_2SO_4 + Fe\,(OH)\,SO_4 \text{ (Ácidity)}$$

$$Fe(OH)SO_4 + H2O \quad >>> \; Fe\,(\,OH)_3 + H_2SO_4 \text{ (Ácidity)}$$

$$+ \text{ SALTS } (Cl^- \text{ and } SO_4^=)$$

<u>SALINE-ACID SOIL</u>





The reclamation of soils already affected by salinity cannot generally be justified by strictly economical reasons

It is more convenient to preestablish, using predictive indices and models, the best alternatives for the management of irrigation and drainage waters in order to prevent and to control salinization and sodification problems for each combination of climate, soil and available irrigation water

This is even more necessary when :

. there is a high competence for the use of the available high quality water

. the quality of the available water is poor

. it is required to reduce the volume of effluents of salinized or contaminated drainage water

Irrigation increases yields 100-400 %

World: 250 x 10^6 ha irrigated lands. 10% degraded by salinisation. 0,5 x 10^6 ha salinised yearly

World: 97,5% salt water; 2,5% fresh water

Cost of desalinisation (38 g/l > 0,5 g/l): 0,46 € /m^3 (2,1 in 1970)

Freshwater withdrawn:	Agriculture	Domestic	Industries
World	69%	10%	21%
W Europe	34%	15%	51%

(50% consumed by evapotranspiration in Agriculture)

(95% waste water in Industries)

(90% waste water in domestic use)

The quality of irrigation water is a relative term, and it is defined as the water characteristics determining its possibilities of being used for some specific purposes

In irrigation waters, the characteristics generally considered are the presence and content of:

- **CHEMICAL contaminants: Salts, certain ions and other contaminants in solution**
- **PHYSICAL contaminants: Sediments and temperature**
- **BIOLOGICAL contaminants: Pathogens**

The qualification of irrigation waters would be determined by their potential to cause problems, more or less reversible, leading to:

- Diminishing yields and quality of crops and their products
- Problems of contamination of crops, soils, groundwaters, and effluents
- Requirements of special practices, equipments and structures for the management of irrigation and drainage water, of soils and of crops

The qualification of waters in relation to potential problems of soil salinization and sodification is mainly based in the absolute and relative content of salts and certain ions

(HCO3-, Cl-, SO4=, NO3-, Ca++, Mg++, Na+, K+).

These contents are interpreted in relation to potential problems of **salinity** (limitations in the use of the soil water by plants), and of **sodicity** (deterioration of the soil physical properties) in relation to particular conditions of:

Soils
Climate
Crops
Limited available irrigation water
Difficulties in the management of irrigation and drainage

In the last decades there have been developed several systems for qualifying irrigation waters in relation to potential problems of salinization and sodification, including:

General schemes for average conditions, which cannot be applied to solve practical problems due to their qualitative nature and inability to be adjusted to specific situations

Empirical indices developed for very specific conditions of soils and crops in a specific area, which cannot be used or adapted to different conditions.

Among the general schemes the most known is the one proposed by the USSL-USDA (1954), which was developed for the predominant conditions in the SW of USA.

80 AGRICULTURE HANDBOOK 60, U. S. DEPT. OF AGRICULTURE

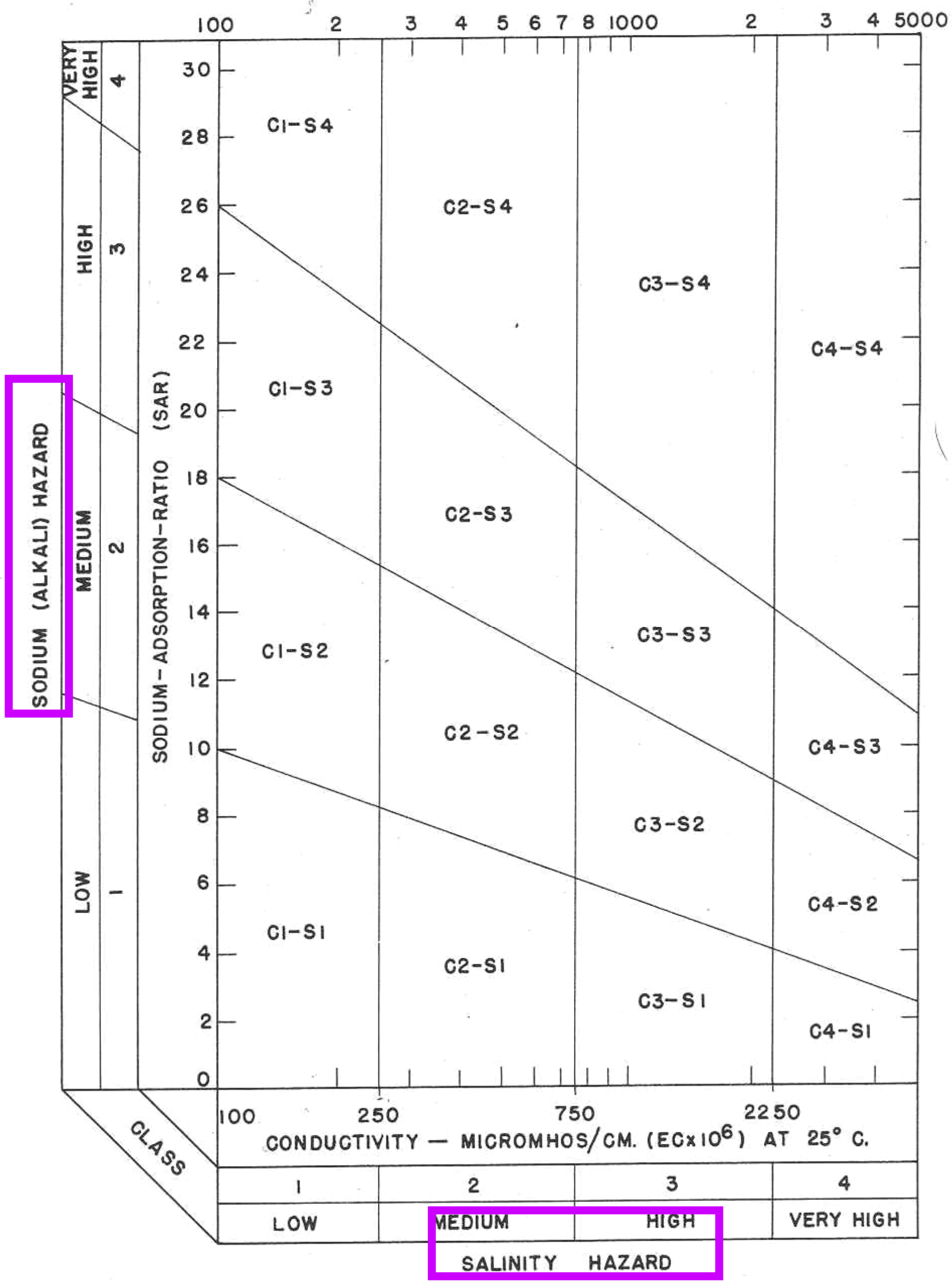
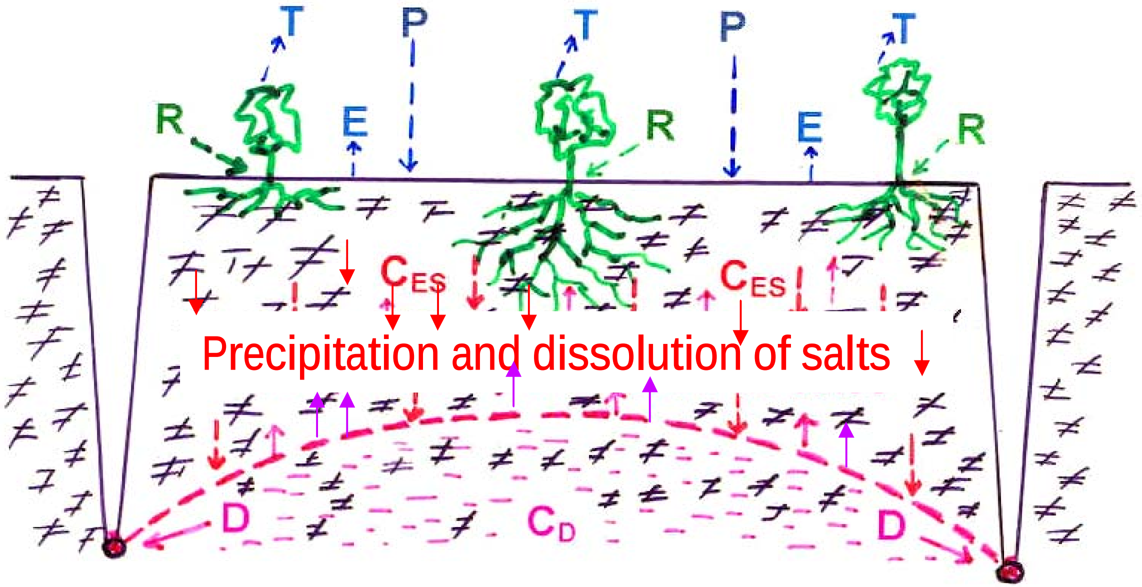


FIGURE 25.—Diagram for the classification of irrigation waters.

The accumulation of salts in the soil occurs when the input of them with the irrigation water, required to replace the water losses by evaporation and transpiration, exceeds the losses by precipitation, leaching and internal drainage

Besides, the salt concentration in the soil solution increases in between of those additions by irrigation water, when the soil moisture decreases due to the temporal losses of water by evaporation and transpiration

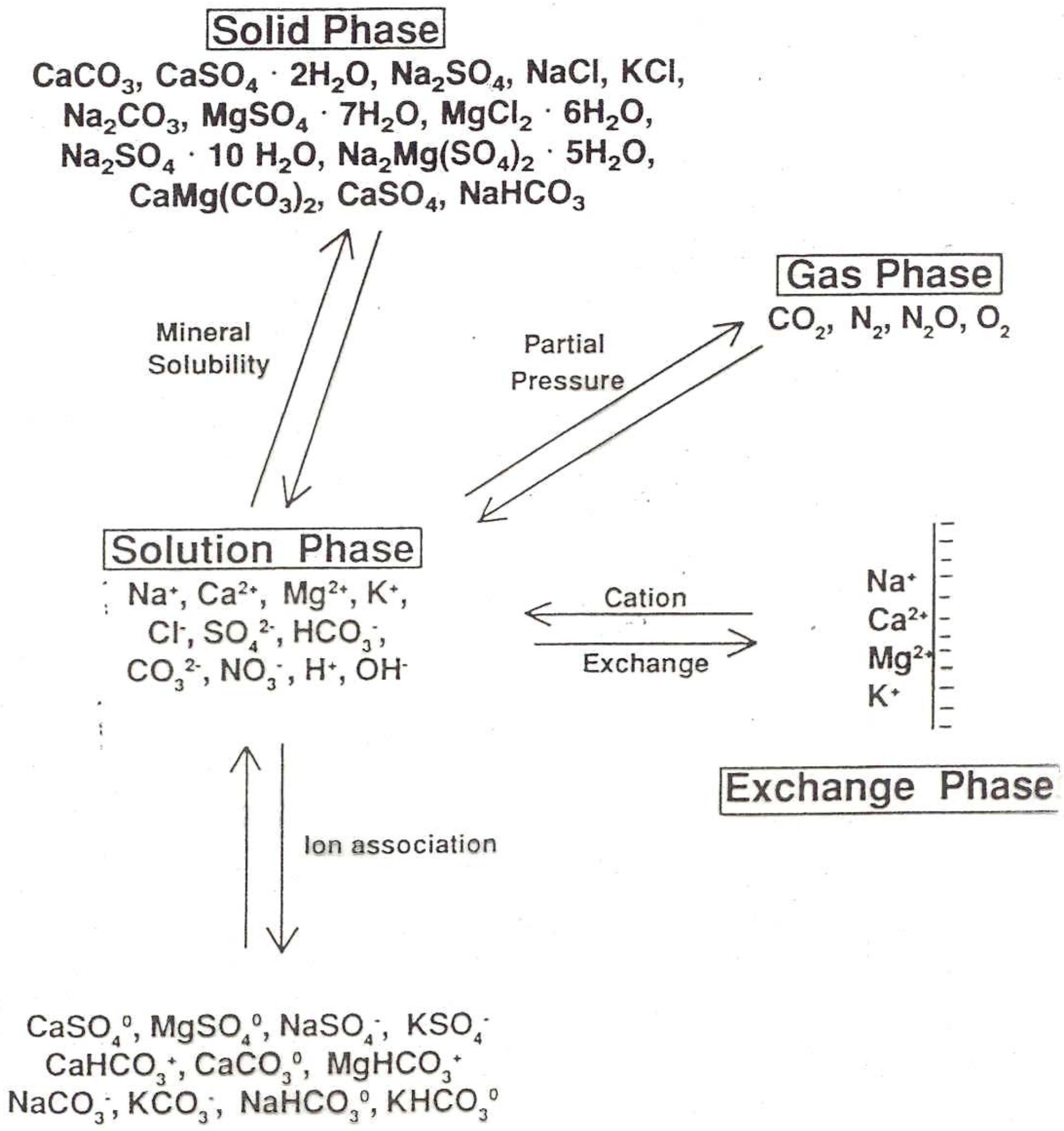


The levels and composition of salts in the soil will be determined by the:

Composition of salts in the applied irrigation water

Possibilities of the different salts to reach determinate concentrations before they precipitate in the soil

Additionally, the composition of cations in the soil exchange phase is determined by the composition and relative concentration of the different cations in soil solution



Solid Phase

$CaCO_3$, $CaSO_4 \cdot 2H_2O$, Na_2SO_4, NaCl, KCl,
Na_2CO_3, $MgSO_4 \cdot 7H_2O$, $MgCl_2 \cdot 6H_2O$,
$Na_2SO_4 \cdot 10\ H_2O$, $Na_2Mg(SO_4)_2 \cdot 5H_2O$,
$CaMg(CO_3)_2$, $CaSO_4$, $NaHCO_3$

Mineral Solubility

Gas Phase

CO_2, N_2, N_2O, O_2

Partial Pressure

Solution Phase

Na^+, Ca^{2+}, Mg^{2+}, K^+,
Cl^-, SO_4^{2-}, HCO_3^-,
CO_3^{2-}, NO_3^-, H^+, OH^-

Cation Exchange

Na^+
Ca^{2+}
Mg^{2+}
K^+

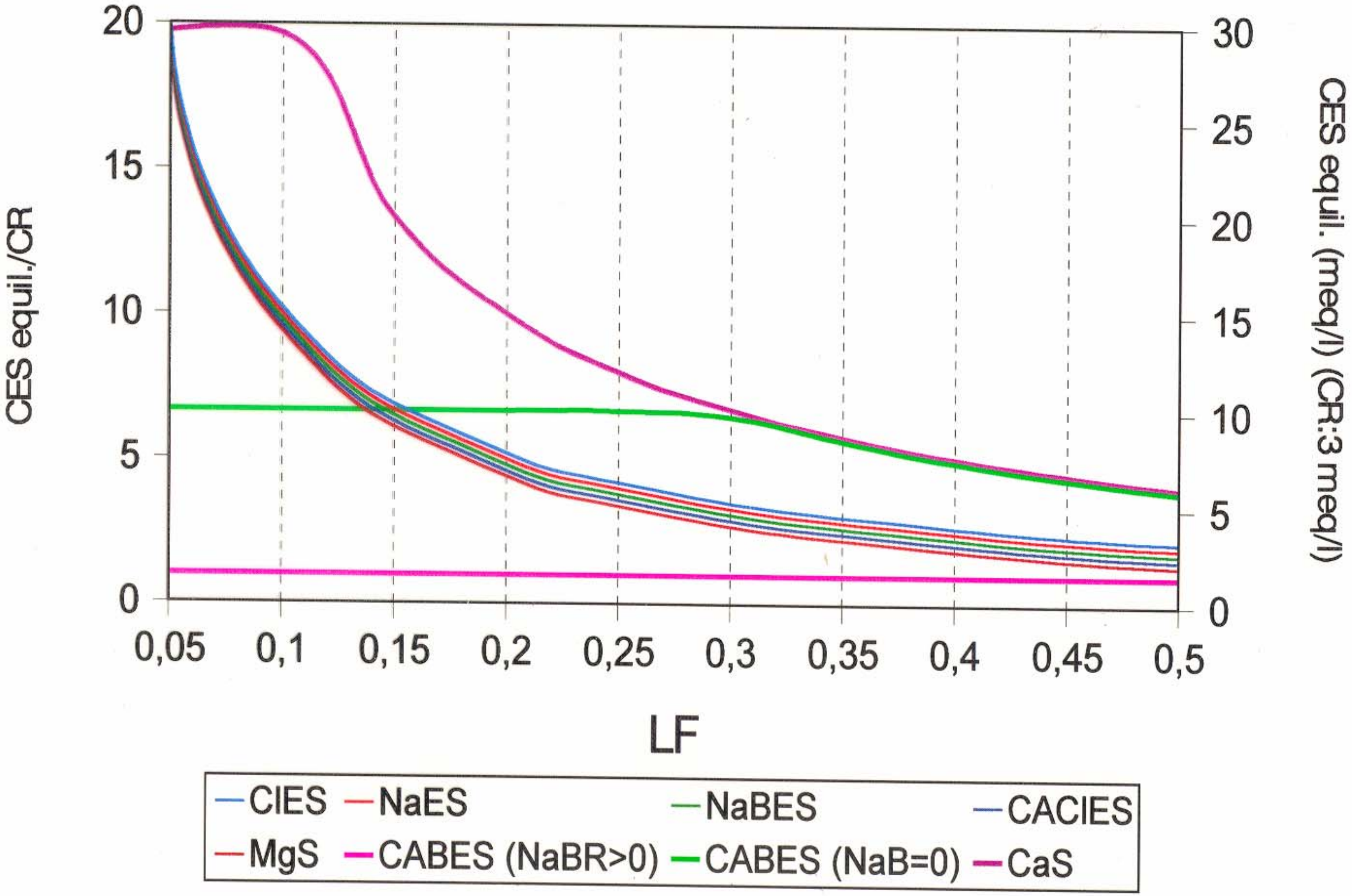
Exchange Phase

Ion association

$CaSO_4^0$, $MgSO_4^0$, $NaSO_4^-$, KSO_4^-
$CaHCO_3^+$, $CaCO_3^0$, $MgHCO_3^+$
$NaCO_3^-$, KCO_3^-, $NaHCO_3^0$, $KHCO_3^0$

Equilibrium concentrations (CES equil.) of salts and ions in the soil solution vs effective leaching fraction (LF)

CES/CR: CIES, NaES, NaBES, CaCIES, MgS, CABES (NaB>0); CES (CR=3meq/l): CABES (NaB=0), CaS



In the soil salinisation process, the changes that may happen in the composition of the soil solution derived of the precipitation of some salts of limited solubility, like bicarbonates (carbonates) of Ca and Mg, and Ca sulfates, are very important.

Conditions leading to such precipitation, like:

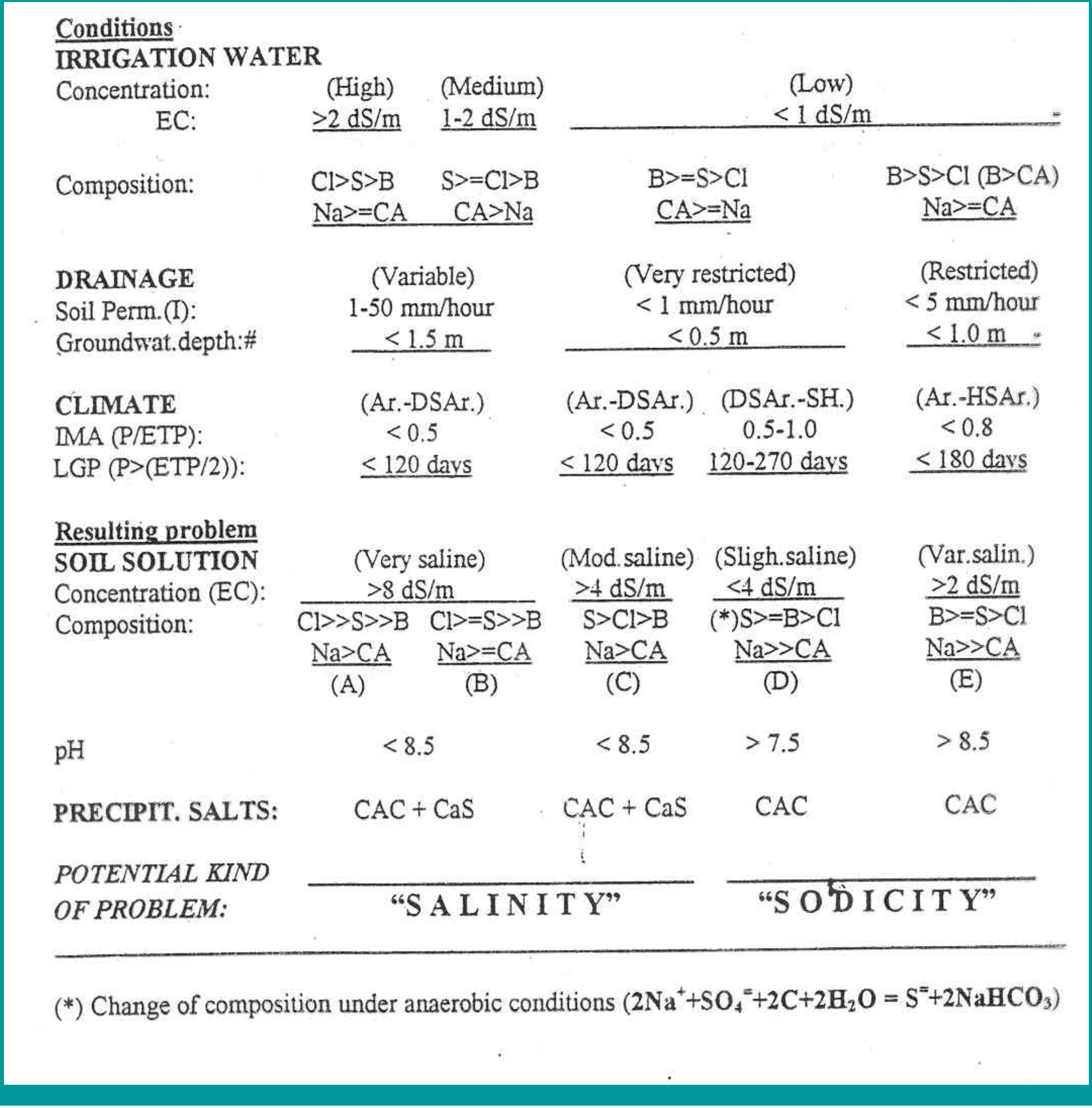
Predominion of bicarbonates among the anions in the irrigation water, specially with the relation:

$(HCO3-/(Ca++ + Mg++)>1$

Losses of CO2

Defficient drainage

would contribute to a relative enrichment of Na in the soil solution and at the same time in the exchange complex, and to a decrease in total salinity in the soil solution.



Conditions					
IRRIGATION WATER					
Concentration:	(High)	(Medium)	(Low)		
EC:	>2 dS/m	1-2 dS/m	< 1 dS/m		
Composition:	Cl>S>B Na>=CA	S>=Cl>B CA>Na	B>=S>Cl CA>=Na		B>S>Cl (B>CA) Na>=CA
DRAINAGE	(Variable)		(Very restricted)		(Restricted)
Soil Perm.(I):	1-50 mm/hour		< 1 mm/hour		< 5 mm/hour
Groundwat.depth:#	< 1.5 m		< 0.5 m		< 1.0 m
CLIMATE	(Ar.-DSAr.)		(Ar.-DSAr.)	(DSAr.-SH.)	(Ar.-HSAr.)
IMA (P/ETP):	< 0.5		< 0.5	0.5-1.0	< 0.8
LGP (P>(ETP/2)):	< 120 days		< 120 days	120-270 days	< 180 days
Resulting problem					
SOIL SOLUTION	(Very saline)		(Mod. saline)	(Sligh.saline)	(Var.salin.)
Concentration (EC):	>8 dS/m		>4 dS/m	<4 dS/m	>2 dS/m
Composition:	Cl>>S>>B Na>CA	Cl>=S>>B Na>=CA	S>Cl>B Na>CA	(*)S>=B>Cl Na>>CA	B>=S>Cl Na>>CA
	(A)	(B)	(C)	(D)	(E)
pH	< 8.5		< 8.5	> 7.5	> 8.5
PRECIPIT. SALTS:	CAC + CaS		CAC + CaS	CAC	CAC
POTENTIAL KIND OF PROBLEM:	"SALINITY"			"SODICITY"	

(*) Change of composition under anaerobic conditions $(2Na^{+}+SO_4^{=}+2C+2H_2O = S^{=}+2NaHCO_3)$

The plants do not take salts in the same proportion as they absorb soil water, and the losses of water by evaporation and transpiration leave the salts in solution behind.

Therefore, it is not possible to control salinity in irrigated soils without an adequate leaching of the salts and drainage of the leaching water, which requires a net flux of water below the soil root zone

This can be achieved applying an excess of irrigation water above the plant water requirements.

When the original soil, before being irrigated, contains an excessive amount of salts in soil solution, there would also be necessary to apply an excess of water for leaching them.

In any case, the amount of excess water to apply will depend on the content and kind of salts present in the irrigation water, on the original content of salts in the soil solution, on the climate, and on the crops.

The excess of water required to leach salts from the soil, to reclaim or to prevent salinization, may cause other environmental problems derived of the disposal and further use of that water.

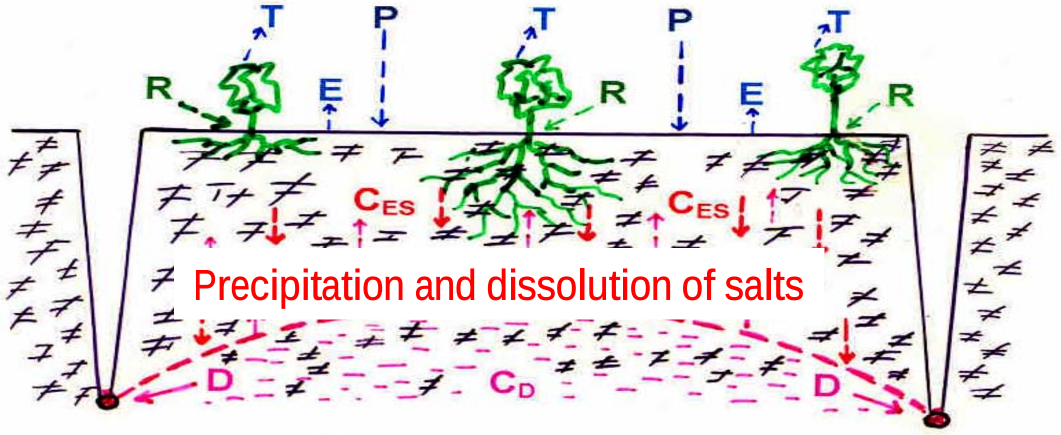
The problem is agravated because those leachates may contain not only natural salts, but also

-residues of fertilizers and pesticides - which are generally used in large amounts in intensive irrigated agriculture, and

-other polutants contained or derived from animal wastes and composted materials used as amendements, and from

-partially or non treated urban and industrial effluents used for irrigation

Precipitation and dissolution of salts



$H_R = (H_{ET} - H_P) + H_D$ $\quad$ $H_R\, C_R = H_D\, C_D$ $\quad$ $(C_{ET} = 0;\ C_P \approx 0)$

$H_D/H_R = C_R/C_D = L$ $\quad$ $C_D/C_{ES} = F\ \ (\leq 1)$

$C_D = C_{ES} \times F$ $\quad$ $C_R/(C_{ES} \times F) = L$

$$LF = C_R/C_{ES}$$

Potential precipitation of salts: $CaCO_3$, $MgCO_3$, $CaSO_4$

Potential dissolution of salts : " " "

If there is precipitation of Ca and Mg carbonates and of Ca sulfates :

$$LF_{ST} = (Na + Mg + CaCl)/(ST_{ES} - 40)$$

$$LF_{Na} = \frac{[(RAS_{ES}{}^2 \times (Mg + CaCl)^2) + (320\ Na^2)]}{80\ RAS_{ES}} - \frac{(Mg + CaCl)}{80}$$

$(Ca + Mg)\ C_p = B - 10\ LF$ $\quad$ $CaS_p = CaS - 30\ LF$

The fraction of irrigation water applied in excess of the crop water requirements, and that infiltrates and finally is lost as drainage water after percolation through the soil rooting zone, is called leaching fraction (L)

L: Leaching fraction
L = HD / HR = CR / CD

HD: Drainage water in depth

HR: Irrigation water in depth

CR: Salt concentration in the irrigation water

CD: Salt concentration in the drainage water

The calculation of L has been changing through the years (Pla, 1968: 1983: 1988: 1996, 1997) (Rhoades, 1968, 1984), (Pla & Dappo, 1977), (FAO, 1976, 1986), and its use has been extended to the control of soil sodicity. L, integrating in a unique figure the present and required balances of water, salts and sodium in the soil, may be used as a basis for the predictive indices and models for salinity and sodicity in irrigated soils.

Calculation of the leaching requirements and of the concentration and composition of salts in the resulting soil solution (Pla, 1997)

$$C_D \,/\, C_{ES} = F\ (\leq 1)$$

$$LF = C_R \,/\, C_{ES}$$

C_D: Salt concentration in drainage water

C_{ES} : Salt concentration in saturation extract

F: Leaching efficiency

C_R: Salt concentration in irrigation water

LF: Leaching requirement

L : Effective leaching requirement

Required information

- **Cations and anions more common in irrigation waters (meq /liter) :**

Ca^{++} **(Ca)**, Mg^{++} **(Mg)**, Na^{+} **(Na)**,
$CO_3^{=} + HCO_3^{-}$ **(B)**, $SO_4^{=}$ **(S)**, Cl^{-} **(Cl)**

- **Salts in irrigation water:**

$NaB = B - Ca - Mg$ *si* $NaB \geq 0$;
$MgB = B - Ca - NaB$ *si* $MgB \geq 0$;

$CaCl = Ca - B - S$ *si* $CaCl \geq 0$;
$CaS = Ca - B - CaCl$ *si* $CaS \geq 0$

- **Critical levels of total salts (STES), chlorides (ClES), sodium (NaES) and other toxic elements in the soil saturation extract (ES) for different crops.**

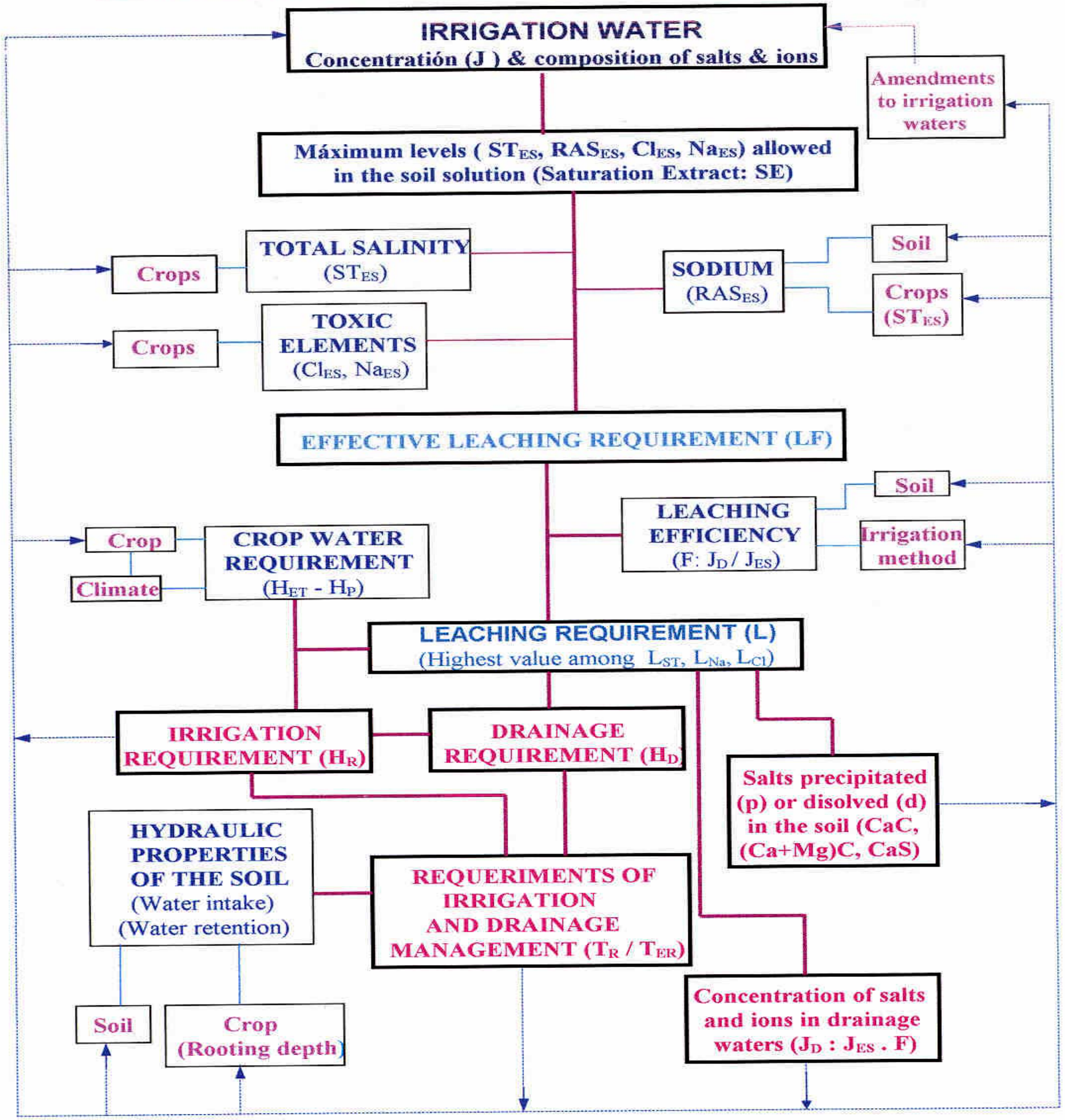
When the calculations show the possibility of precipitation of Ca carbonates and sulfates in the soil, the critical levels of STES may be increased by 20 meq/l.

Next figure shows the flow diagram which was the basis for the development of the **model SALSODIMAR** (Pla, 1996), which **integrates the influence of climate, crops, soils, groundwater depth and composition, irrigation water quality, and irrigation and drainage management** on the desertification by salinization, sodification and contamination of soils and groundwater.

It may be useful, among other things, ***to preview the best alternatives for the use and management of the available soils and waters****, preventing the process of desertification by secondary salinization.*

It has proved to be reasonably good ***to predict salinization problems*** *and* ***to deduce the best alternative practices for irrigation and drainage to prevent salinization and sodification*** *and other related environmental problems leading to desertification*

FLOW DIAGRAM OF THE SIMULATION MODEL **"SALSODIMAR"**



IRRIGATION WATER
Concentratión (J) & composition of salts & ions

Amendments to irrigation waters

Máximum levels (ST_{ES}, RAS_{ES}, Cl_{ES}, Na_{ES}) allowed in the soil solution (Saturation Extract: SE)

Crops

TOTAL SALINITY (ST_{ES})

SODIUM (RAS_{ES})

Soil

Crops (ST_{ES})

Crops

TOXIC ELEMENTS (Cl_{ES}, Na_{ES})

EFFECTIVE LEACHING REQUIREMENT (LF)

Soil

LEACHING EFFICIENCY (F: J_D / J_{ES})

Irrigation method

Crop

Climate

CROP WATER REQUIREMENT (H_{ET} - H_P)

LEACHING REQUIREMENT (L)
(Highest value among L_{ST}, L_{Na}, L_{Cl})

IRRIGATION REQUIREMENT (H_R)

DRAINAGE REQUIREMENT (H_D)

Salts precipitated (p) or disolved (d) in the soil (CaC, (Ca+Mg)C, CaS)

HYDRAULIC PROPERTIES OF THE SOIL
(Water intake)
(Water retention)

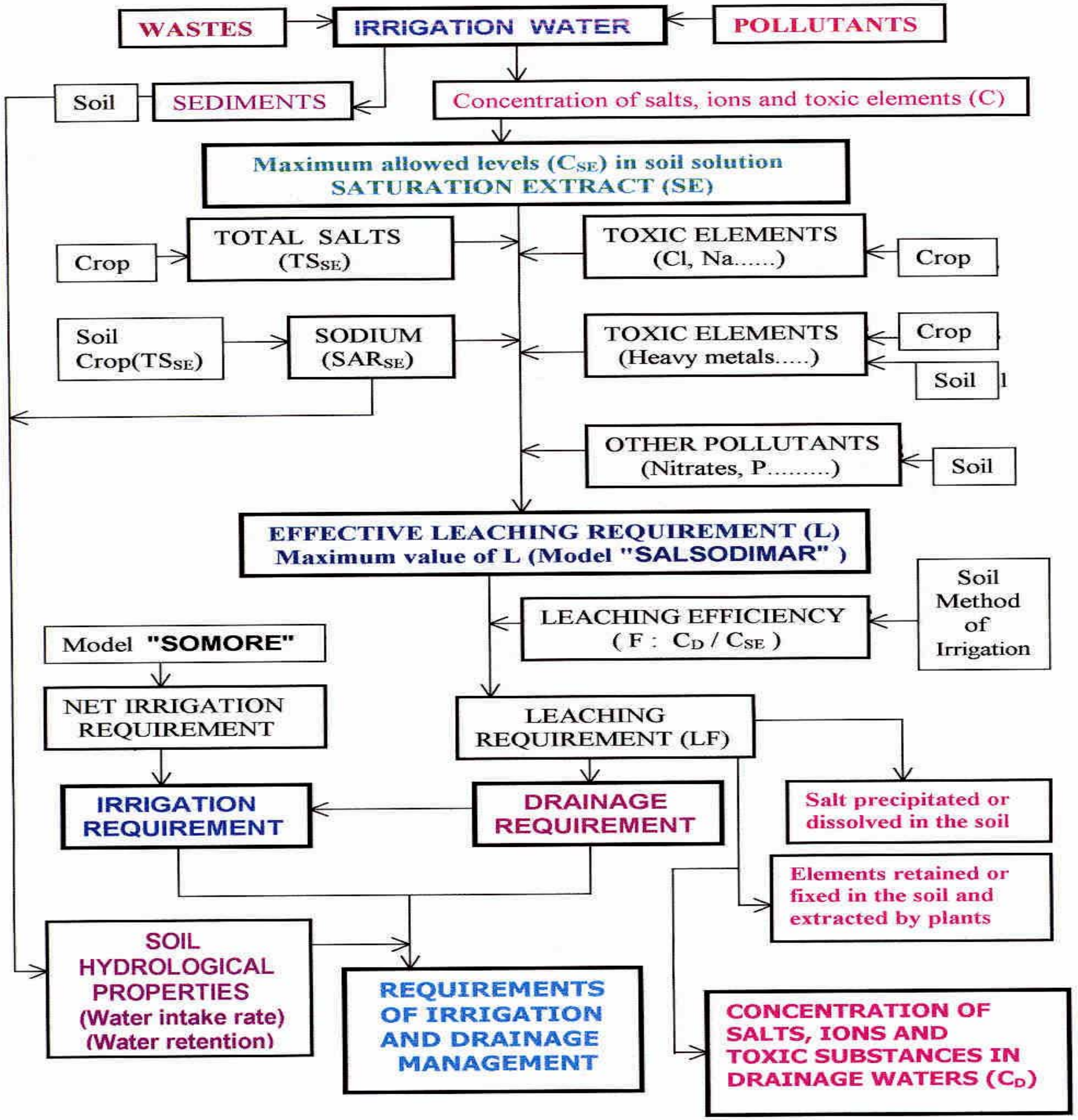
REQUERIMENTS OF IRRIGATION AND DRAINAGE MANAGEMENT (T_R / T_{ER})

Soil

Crop (Rooting depth)

Concentration of salts and ions in drainage waters (J_D : J_{ES} . F)

→ **Potential alternatives** (crops, waters, soils ...) **for limitations in** irrigation, drainage, salts ..



WASTES

IRRIGATION WATER

POLLUTANTS

Soil

SEDIMENTS

Concentration of salts, ions and toxic elements (C)

Maximum allowed levels (C_{SE}) in soil solution
SATURATION EXTRACT (SE)

Crop

TOTAL SALTS
(TS_{SE})

TOXIC ELEMENTS
(Cl, Na......)

Crop

Soil
Crop(TS_{SE})

SODIUM
(SAR_{SE})

TOXIC ELEMENTS
(Heavy metals.....)

Crop

Soil

OTHER POLLUTANTS
(Nitrates, P.........)

Soil

EFFECTIVE LEACHING REQUIREMENT (L)
Maximum value of L (Model "SALSODIMAR")

LEACHING EFFICIENCY
(F : C_D / C_{SE})

Soil
Method
of
Irrigation

Model "SOMORE"

NET IRRIGATION REQUIREMENT

LEACHING REQUIREMENT (LF)

IRRIGATION REQUIREMENT

DRAINAGE REQUIREMENT

Salt precipitated or dissolved in the soil

Elements retained or fixed in the soil and extracted by plants

SOIL HYDROLOGICAL PROPERTIES
(Water intake rate)
(Water retention)

REQUIREMENTS OF IRRIGATION AND DRAINAGE MANAGEMENT

CONCENTRATION OF SALTS, IONS AND TOXIC SUBSTANCES IN DRAINAGE WATERS (C_D)

Scheme 2. Flow diagram of a conceptual model of a balance of salts and toxic substances in irrigated soils (SAR: Sodium Adsorption Ratio) (Model "SOMORE": Pla, 1997a; Model "SALSODIMAR": Pla, 1997b)

Tolerance of different crops to total salinity (and to chlorides) in the soil saturation extract (STES and CIES)

TOLERANT CROPS (ST_{ES}: 80-160 meq/l)

Guayule
Cebada
Algodón
Remolacha azucarera
Pasto Bermuda
Trigo
Cártamo
Sorgo
Dátil
Olivo
Higuera

MODERATELLY TOLERANT CROPS (ST_{ES}: 40-80 meq/l)

Soja
Tomate
Espinaca
Girasol
Pepino
Melón
Alfalfa
Caña de azúcar
Maíz
Arroz
Patata
Viña

MODERATELLY SENSIBLE CROPS (ST_{ES}: 20-40 meq/l)

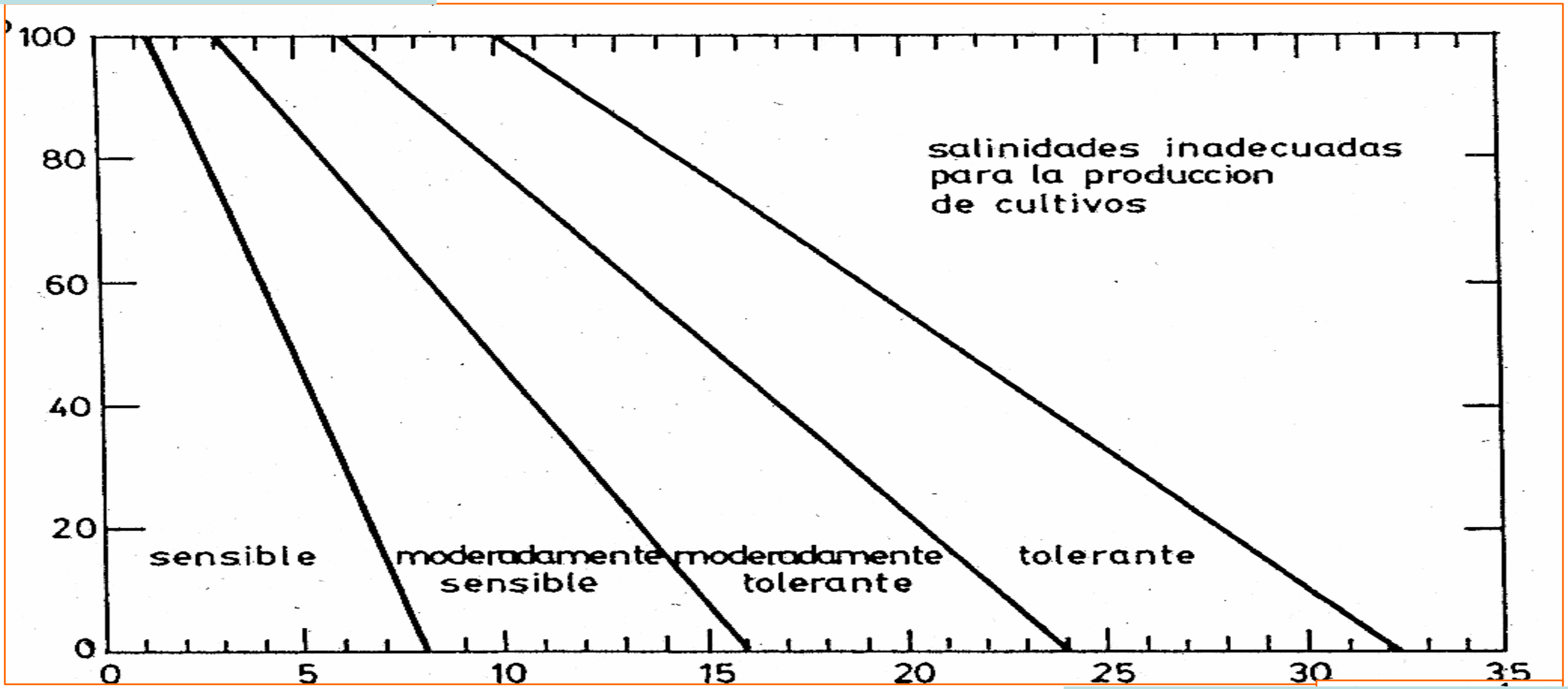
Cebolla
Pimiento
Lechuga
Col
Cacahuete
Zanahoria (Cl < 10 meq/l)

SENSIBLE CROPS (máx. ST_{es}: < 20 meq/l)

Ciruelo
Limonero
Naranjo (Cl < 20 meq/l)
Judía (Cl < 10 meq/l)
Manzano
Peral
Aguacate (Cl < 12 meq/l)
Melocotonero
Berenjena
Fresal (Cl < 10 meq/l)

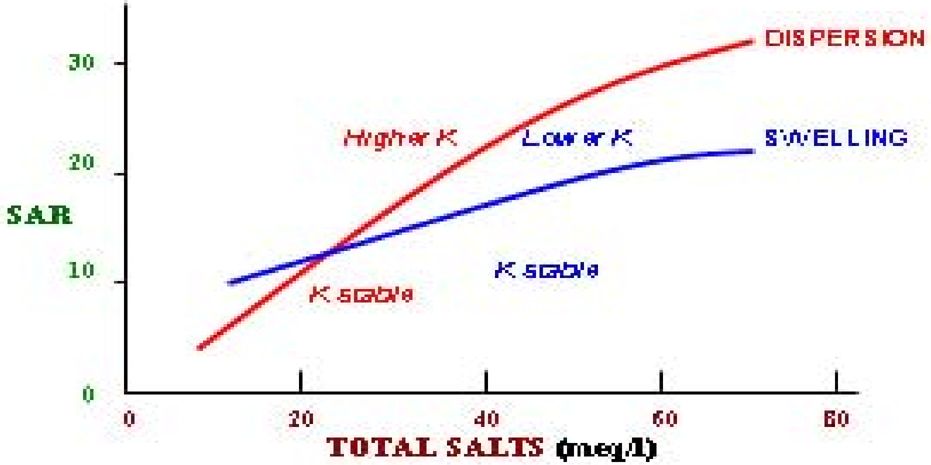
Crop salt tolerance

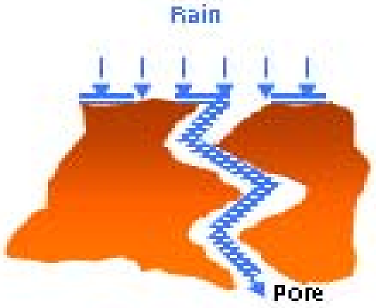
Relative yield Y%



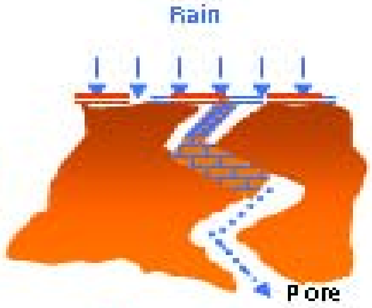
Electrical conductivity
dS/m

EFFECTS OF SODIUM (SAR) AND TOTAL SALTS IN SOIL SOLUTION ON THE SATURATED HYDRAULIC CONDUCTIVITY (K) OF THE SOIL



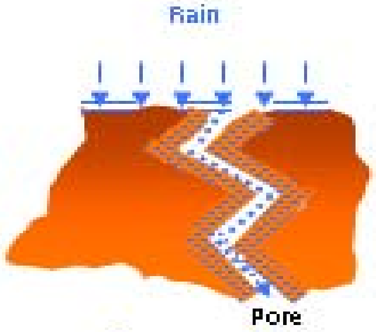


K stable



Lower K

DISPERSION
Clogging of pores
(Irreversible)



Lower K

SWELLING
Blocking of pores
(Reversible)

REQUIREMENTS OF IRRIGATION AND DRAINAGE MANAGEMENT

Departing from and adequate evaluation of the leaching requirements, taking into consideration the previewed salt precipitation or dissolution in the soil profile, and the possibilities of sodification besides salinization it is possible a more precise calculation of the irrigation and drainage requirements: $L = LF / F$

$$H_R = (H_{ET} - H_P) / (1 - L)$$

$$H_D = (L\,(H_{ET} - H_P)) / (1 - L)$$

$$T_R / T_{ER} = (H_{ET} - H_P) / (720\ I\ (1-L))$$

$$T_{ER} \leq T_{ER}\ (\text{máx.})$$

$$T_{ER}\ (\text{máx.}) = (15 \times DA \times P \times CC) / (H_{ET} - H_P)$$

Irrigation requirements (HR) and drainage requirements (HD) in mm/month, mm/day…., in order to satisfy the crop water requirements and to control at the same time the levels of salts, chlorides, sodium …. in the soil solution and drainage waters under the pre selected critical levels

Requirements for the irrigation management (TR /TER) in order to be able to fill the irrigation and drainage requirements (HR, HD), derived from the relation between the duration of irrigation (TR: time in hours or days required for the infiltration in the soil of the irrigation water) and the maximum interval in hours or days among irrigations (TER) for each soil (P, DA, CC and I).

The requirements for irrigation and drainage management are the basis for precising the best possible alternatives for irrigation and drainage management.

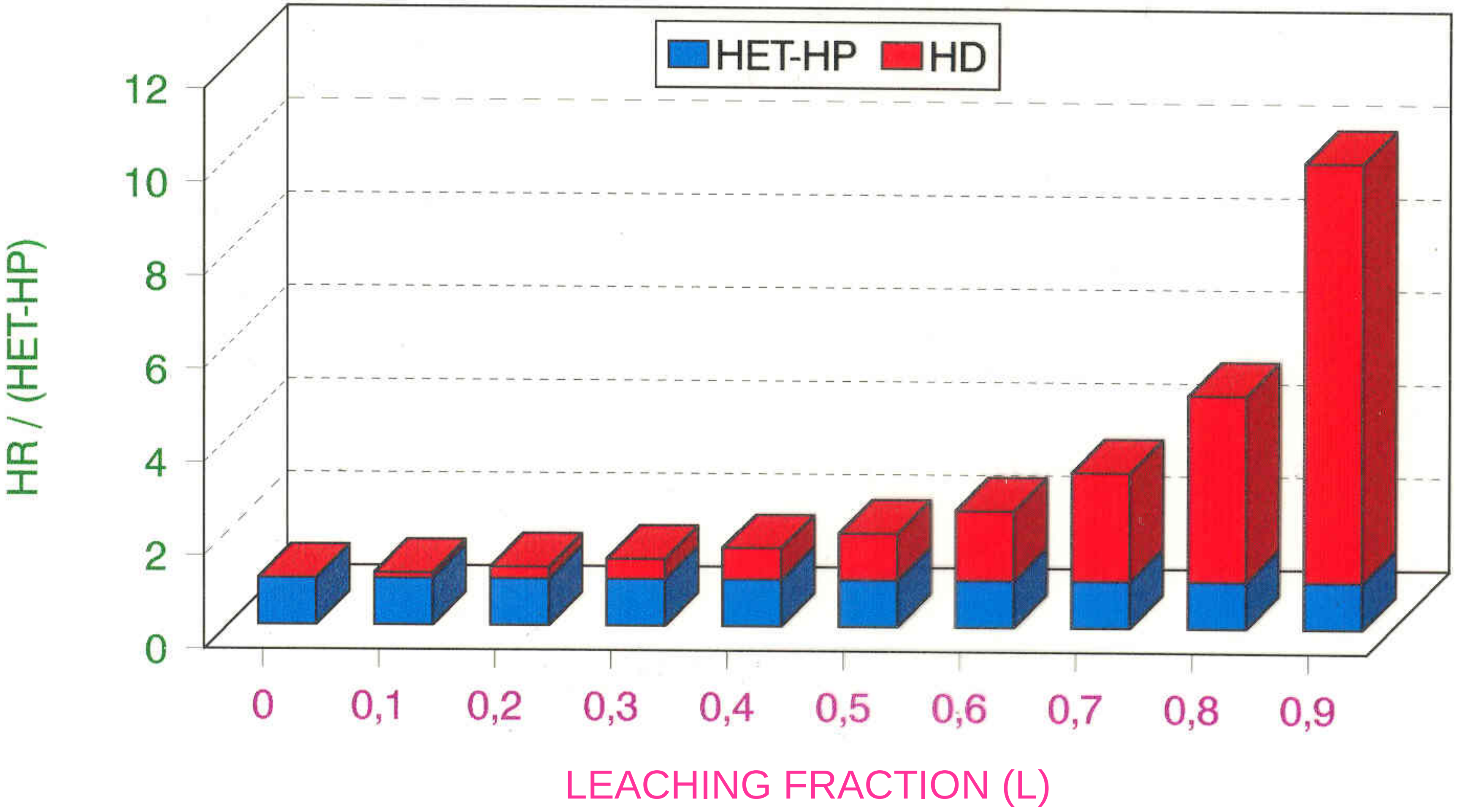
The final selection of a determinate alternative will depend on practical, economical and environmental limitations, such as

-availability and cost of the irrigation water,
-soil hydrological properties,
-groundwater depth,
-natural drainage capacity and requirements of artificial drainage,
-costs of the irrigation system,
-limitations in the volume and salinity of the effluent drainage waters, etc.

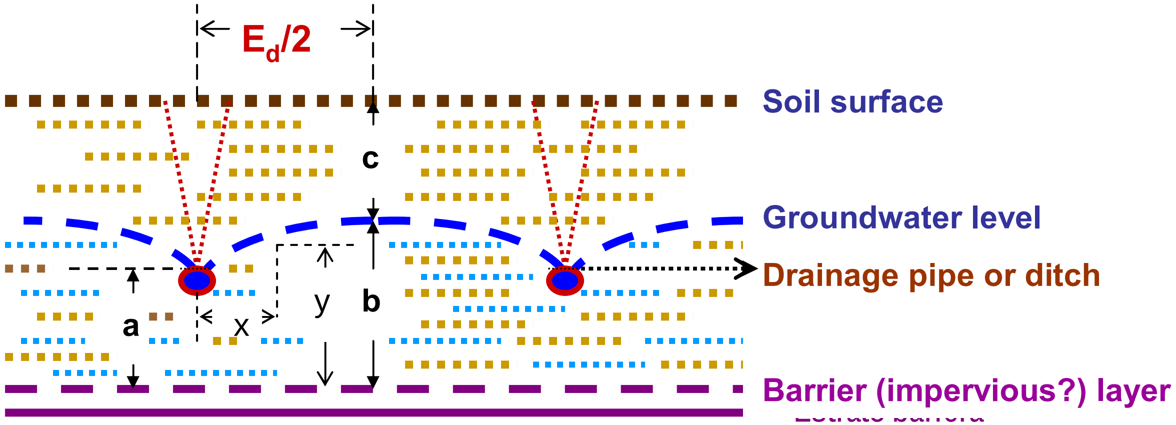
Irrigation water requirements (HR) in relation to the net irrigation water requirements (HET-HP) for different leaching fractions (L)

(HET: evapo-transpiration; HP: effective rainfall; HD: drainage requirements)

(HET: evapo-transpiración; HP: precipitación efectiva; HD: requerimiento de drenaje)



DONNAN DRAINAGE FORMULA



E_d : Distance between the drainage lines (m)

a: Vertical distance from the depth of the drainage line to the barrier layer

b: Vertical distance from the groundwater level at the middle point between the drainage lines to the barrier layer

c: Minimum depth of the groundwater level (m)

If c+b (depth of the barrier layer) > 3m, we take c+b = 3m

$$E_d = (4K\,(b^2 - a^2)/h_d)^{1/2}$$

K: Saturated hydraulic conductivity (m/day)

h_D: Water depth to be drained (m/day)

$Q_x = (c)\,(E_d/2 - x)$. When $x = 0$: $Q_x = Q/2$ y $c = Q/E_d$
$Q_x = Q / E_d\,(E_d/2 - x)$
$i = dy/dx$; $A = (y)$ (1 m section); $Q = A\,i\,K$
$Q_x = Q / E_d\,(E_d/2 - x) = K \,.\, y \,.\, dy/dx \,.\, 1m$
$Q/2KE_d.1m\int(E_d - 2x)dx = \int y\,dy$

Integrating between the límits: $x = E_d/2$; $x = 0$; $y = b$; $y = a$

$$Q / 2K.E_d.1m\,(E_d x - x^2)\Big|_{0}^{E_d/2} = y^2/2\Big|_{a}^{b}$$

$(Q / 2K.E_d.1m).(E_d^2/2 - E_d^2/4) = (b^2 - a^2)/2$; $Q\,E_d/4K = b^2 - a^2$
$E_d = 4K\,(b^2 - a^2) / Q$
$h_d = Q / E_d$; $Q = h_d \,.\, E_d$; $E_d^2 = 4K\,(b^2 - a^2) / h_d$

$$E_d = (4K\,(b^2 - a^2)/h_d)^{1/2}$$

Q: Volume in m^3/day discharged from a drainage line per m of líne
K: Saturated hydraulic conductivity (m/day); i: hydraulic gradient
A: Area of the section (m^2) through which the water flows to the drainage line (y.1m)
h_d: Water depth (m/day) to be drained = $m^3/(m^2.day)$

It is assumed:

-That all the flux in the drainage line is due to the water removal from a soil section 1 m thick extending to a distance of $E_d/2$ at each side of the drainage line. -That the horizontal flux Q_x, at any distance x, is proportional to the distance from the middle point between the drainage lines, where the flux is cero.
- That when x=0, the flux towards the drainage is ½ of the total flux in the drainage line (Q/2). Therefore,Q_x, at any point perpendicular to the drainage line will be: $Q_x = (c)\,(E_d/2 - x)$

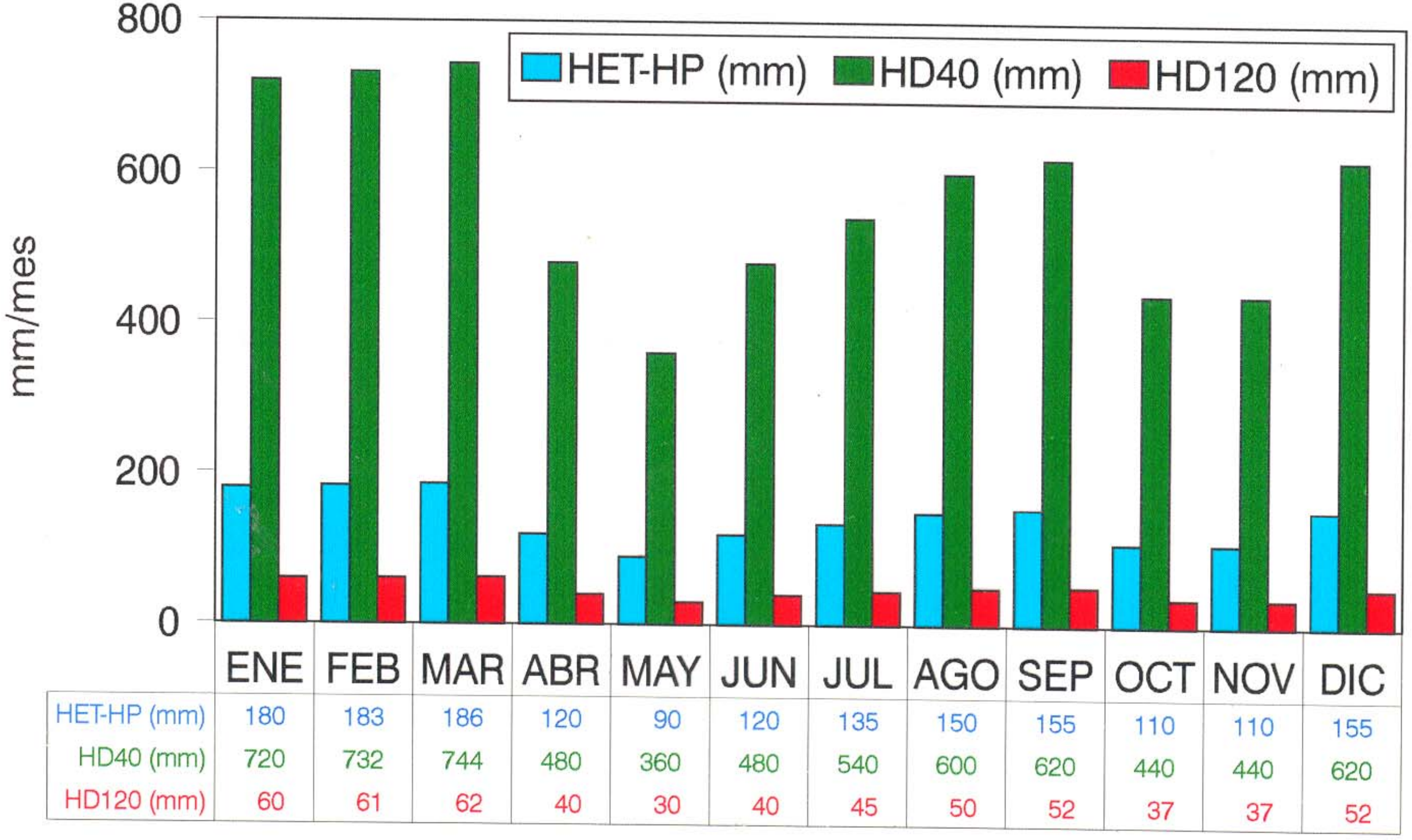
	meq/litro									
	Na	**Ca**	**Mg**	**Cl**	**S**	**B**	**NaB**	**MgB**	**CaCl**	**CaS**
I	11,5	5,6	3,9	9,7	4,5	6,7	0	1,1	0	0
II	2,1	9,0	3,1	1,4	10,3	2,3	0	0	0	6,7
III	2,0	1,0	1,0	1,0	0,5	2,5	0,5	1,0	0	0
III(E)	2,0	1,5	1,0	1,0	1,0	2,5	0	1,0	0	0

(III(E) es el agua III más una enmienda de yeso de 0,5 meq/litro o 43 g/m^3)

Cuadro 2. Concentración y composición iónica de las sales presentes en aguas de riego seleccionadas

Figura 6. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para cultivos sensibles (STES: 40 meq/l) (HD40) y tolerantes (STES: 120 meq/l) (HD120) en un clima árido tropical

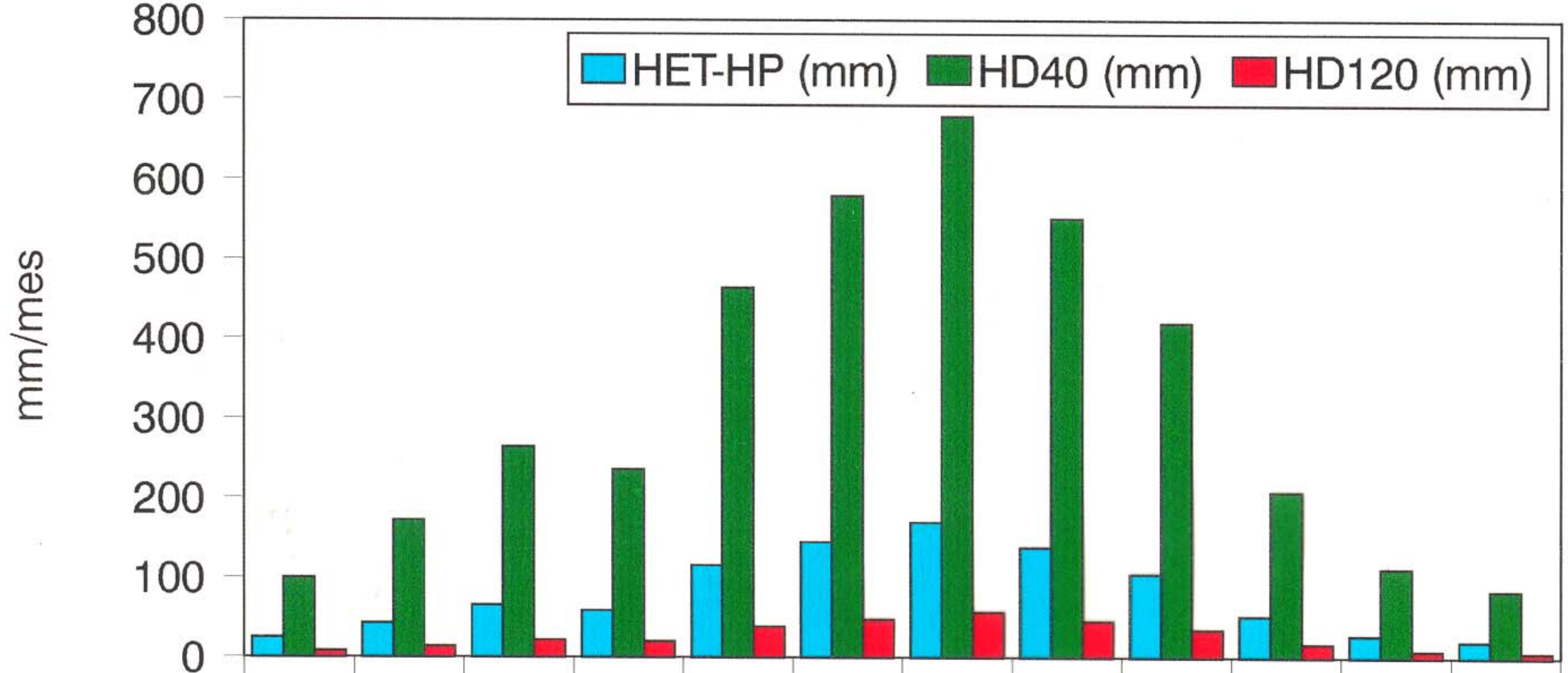
AGUA I (LFST40 = 0,48; LFST120 = 0,13; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	180	183	186	120	90	120	135	150	155	110	110	155
HD40 (mm)	720	732	744	480	360	480	540	600	620	440	440	620
HD120 (mm)	60	61	62	40	30	40	45	50	52	37	37	52

Figura 6. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para cultivos sensibles (STES: 40 meq/l) (HD40) y tolerantes (STES: 120 meq/l) (HD120) en un clima mediterráneo semiárido

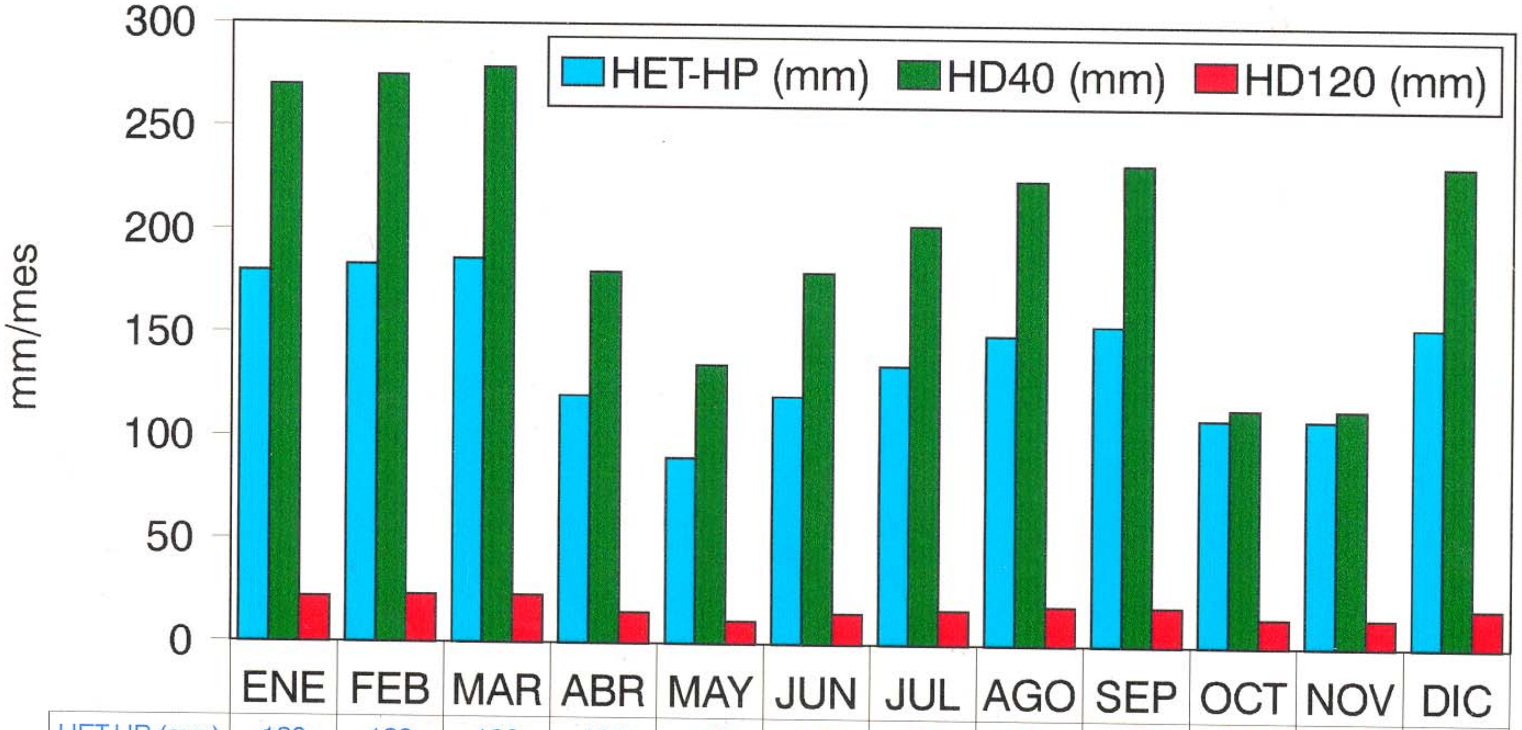
AGUA I (LFST40 = 0,48; LFST120 = 0,13; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	25	43	66	59	116	145	170	138	105	52	28	21
HD40 (mm)	100	172	264	236	464	580	680	552	420	208	112	84
HD120 (mm)	8	14	22	20	39	48	57	46	35	17	9	7

Figura 7. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para cultivos sensibles (STES: 40 meq/l) (HD40) y tolerantes (STES: 120 meq/l) (HD120) en un clima árido tropical

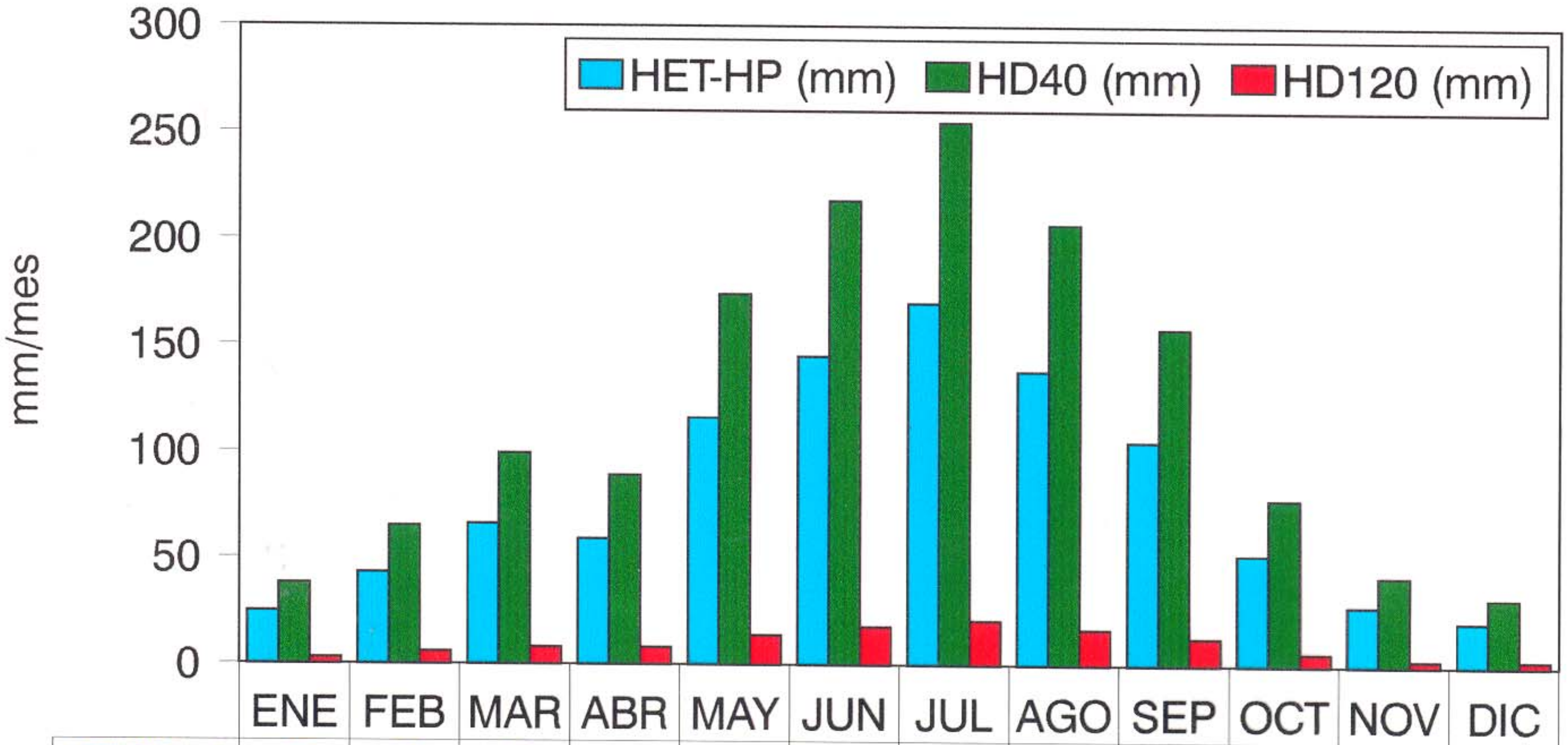
AGUA II (LFST40 = 0,36; LFST120 = 0,07; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	180	183	186	120	90	120	135	150	155	110	110	155
HD40 (mm)	270	275	279	180	135	180	203	225	233	115	115	233
HD120 (mm)	22	23	23	15	11	15	17	19	19	14	14	19

Figura 7. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para cultivos sensibles (STES: 40 meq/l) (HD40) y tolerantes (STES: 120 meq/l) (HD120) en un clima mediterráneo semiárido

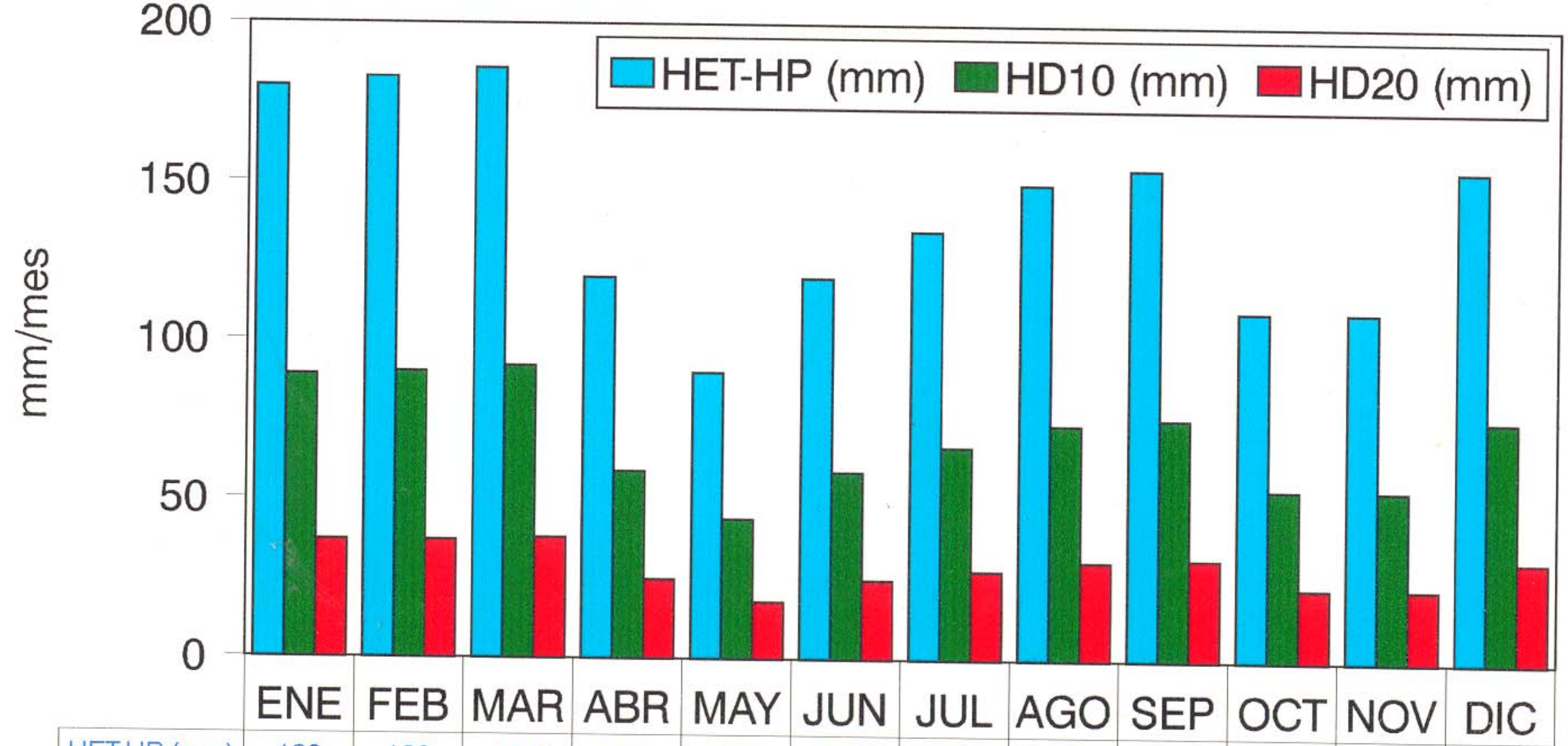
AGUA II (LFST40 = 0,36; LFST120 = 0,07; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	25	43	66	59	116	145	170	138	105	52	28	21
HD40 (mm)	38	65	99	89	174	218	255	207	158	78	42	32
HD120 (mm)	3	6	8	8	14	18	21	17	13	6	3	3

Figura 8. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para valores límites de RASES: 10 (HD10) y de RASES: 20 (HD20) en clima árido tropical

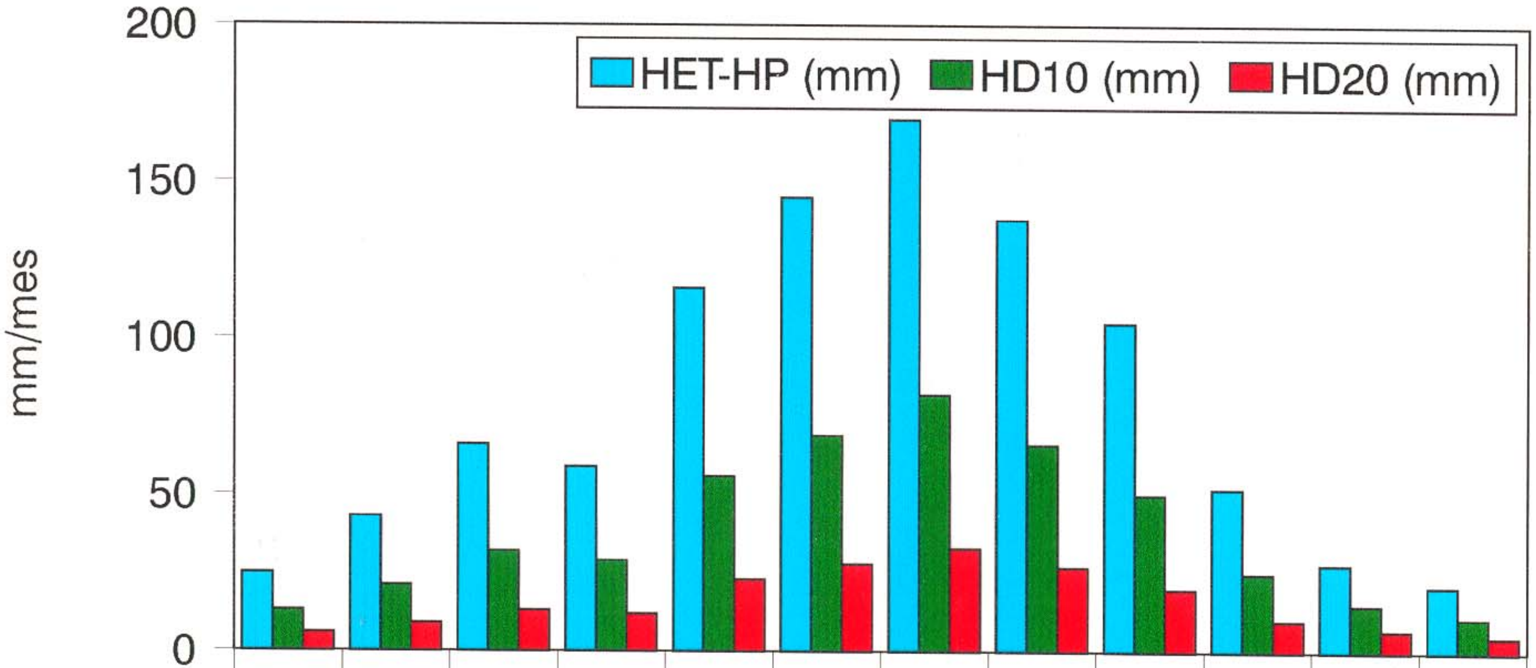
AGUA III (LFNa10 = 0,20; LFNa20 = 0,10; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	180	183	186	120	90	120	135	150	155	110	110	155
HD10 (mm)	89	90	92	59	44	59	67	74	76	54	54	76
HD20 (mm)	37	37	38	25	18	25	28	31	32	23	23	32

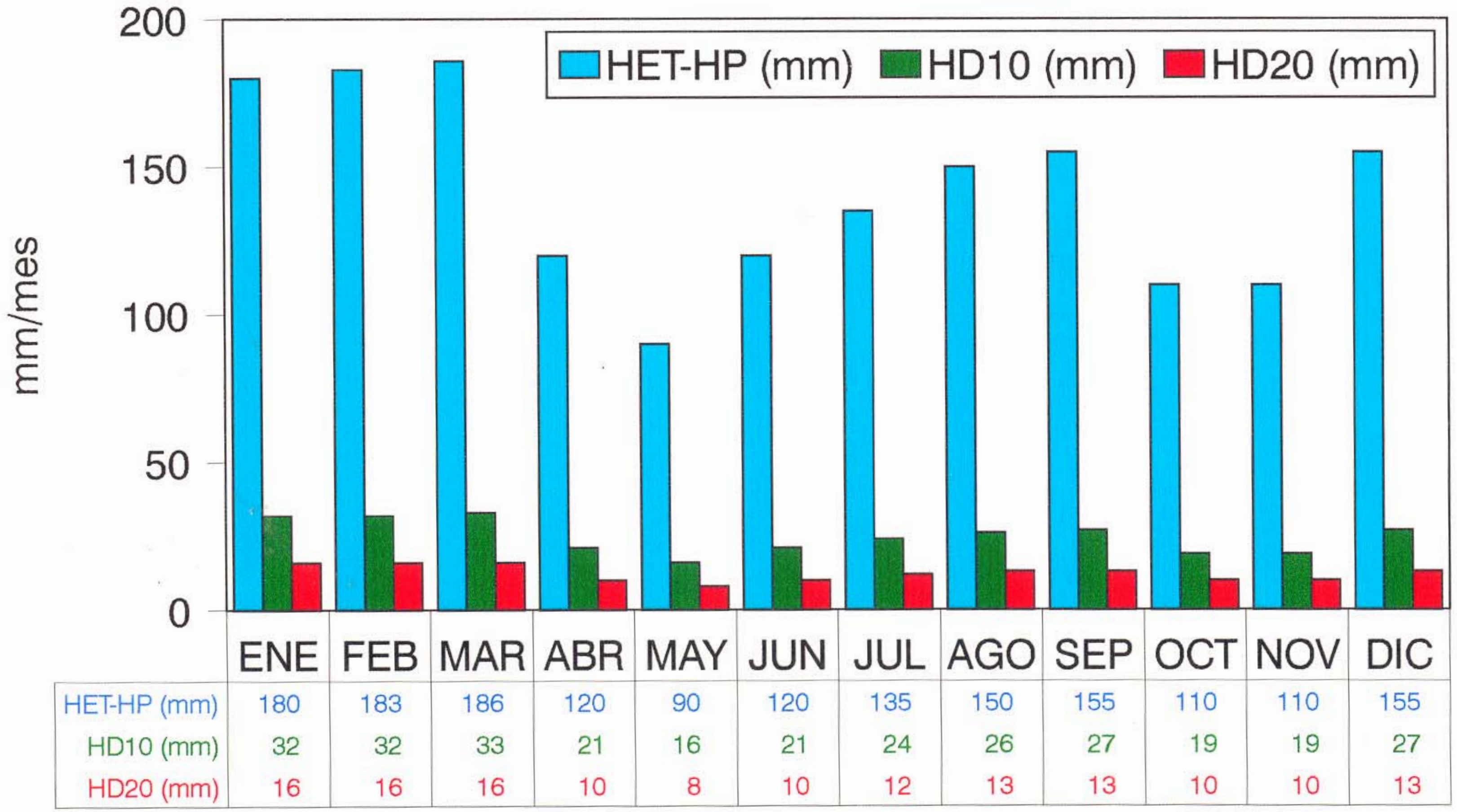
Figura 8. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para valores límites de RASES: 10 (HD10) y de RASES: 20 (HD20) en clima mediterráneo semiárido

AGUA III (LFNa10 = 0,20; LFNa20 = 0,10; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	25	43	66	59	116	145	170	138	105	52	28	21
HD10 (mm)	13	21	32	29	56	69	82	66	50	25	15	11
HD20 (mm)	6	9	13	12	23	28	33	27	20	10	7	5

Figura 9. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para valores límites de RASES: 10 (HD10) y de RASES: 20 (HD20) en clima árido tropical

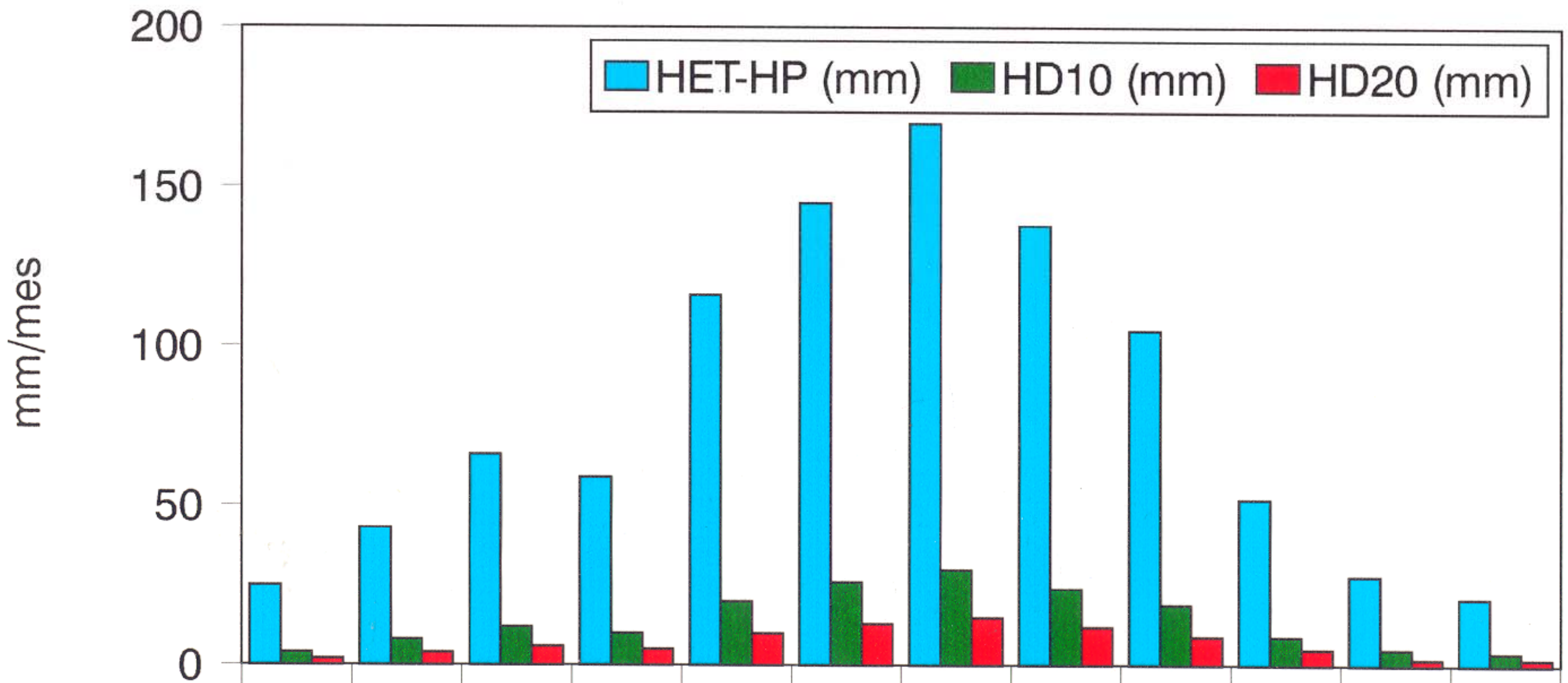


AGUA III(E) (LFNa10 = 0,09; LFNa20 = 0,05; F = 0,6)

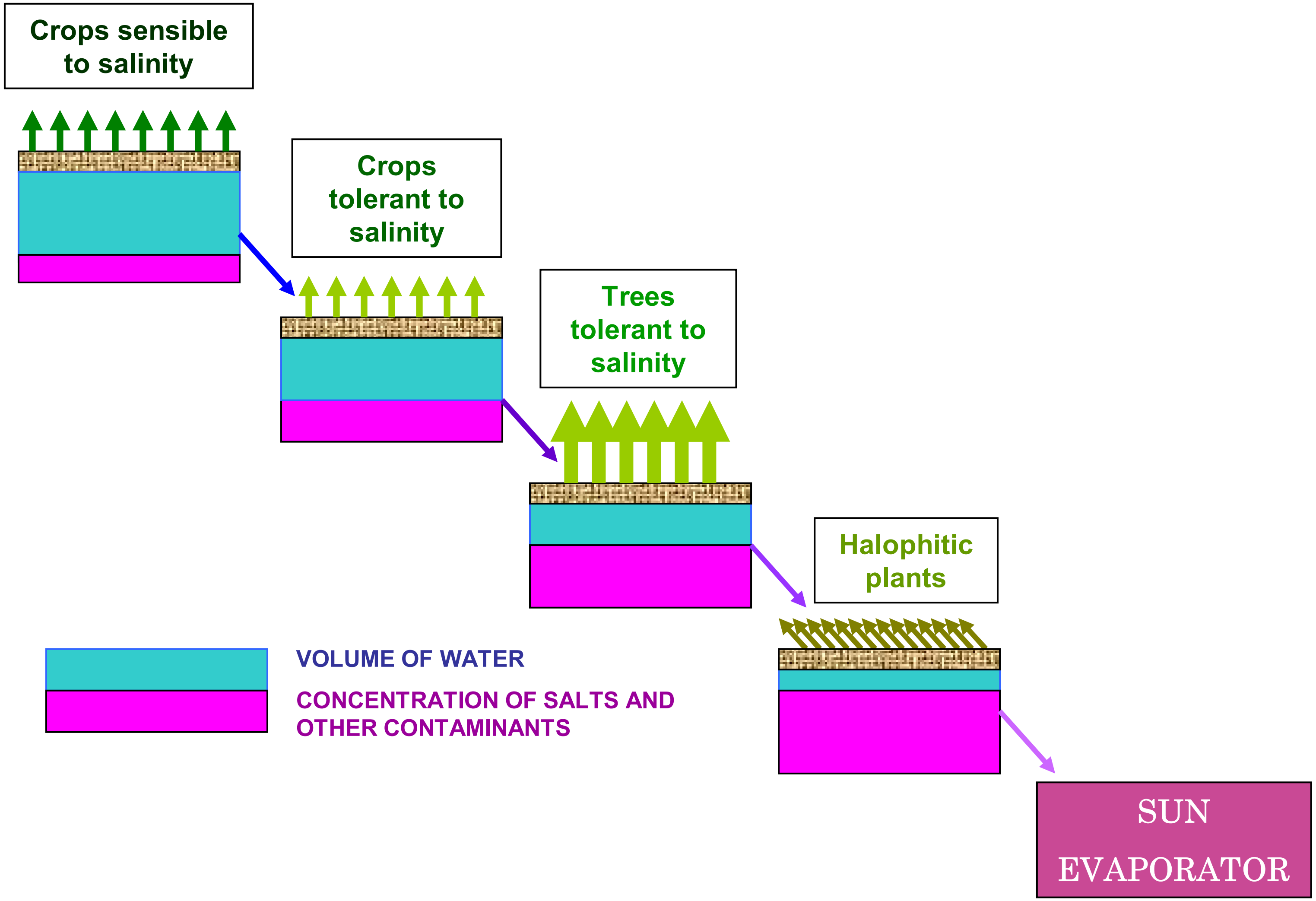
	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	180	183	186	120	90	120	135	150	155	110	110	155
HD10 (mm)	32	32	33	21	16	21	24	26	27	19	19	27
HD20 (mm)	16	16	16	10	8	10	12	13	13	10	10	13

Figura 9. Requerimientos de riego (HR = HET-P+HD) y de drenaje (HD) para valores límites de RASES: 10 (HD10) y de RASES: 20 (HD20) en clima mediterráneo semiárido

AGUA III(E) (LFNa10 = 0,09; LFNa20 = 0,05; F = 0,6)



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
HET-HP (mm)	25	43	66	59	116	145	170	138	105	52	28	21
HD10 (mm)	4	8	12	10	20	26	30	24	19	9	5	4
HD20 (mm)	2	4	6	5	10	13	15	12	9	5	2	2



Crops sensible to salinity

Crops tolerant to salinity

Trees tolerant to salinity

Halophitic plants

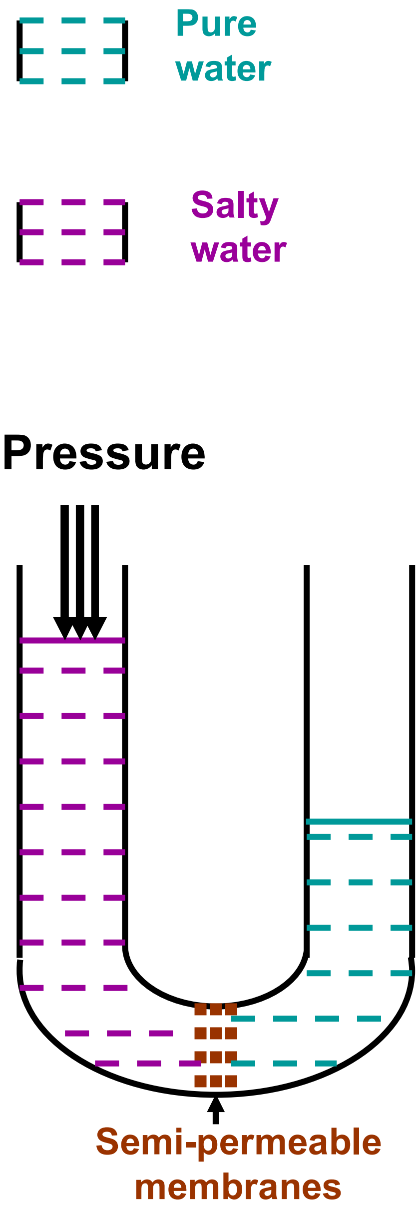
SUN EVAPORATOR

VOLUME OF WATER

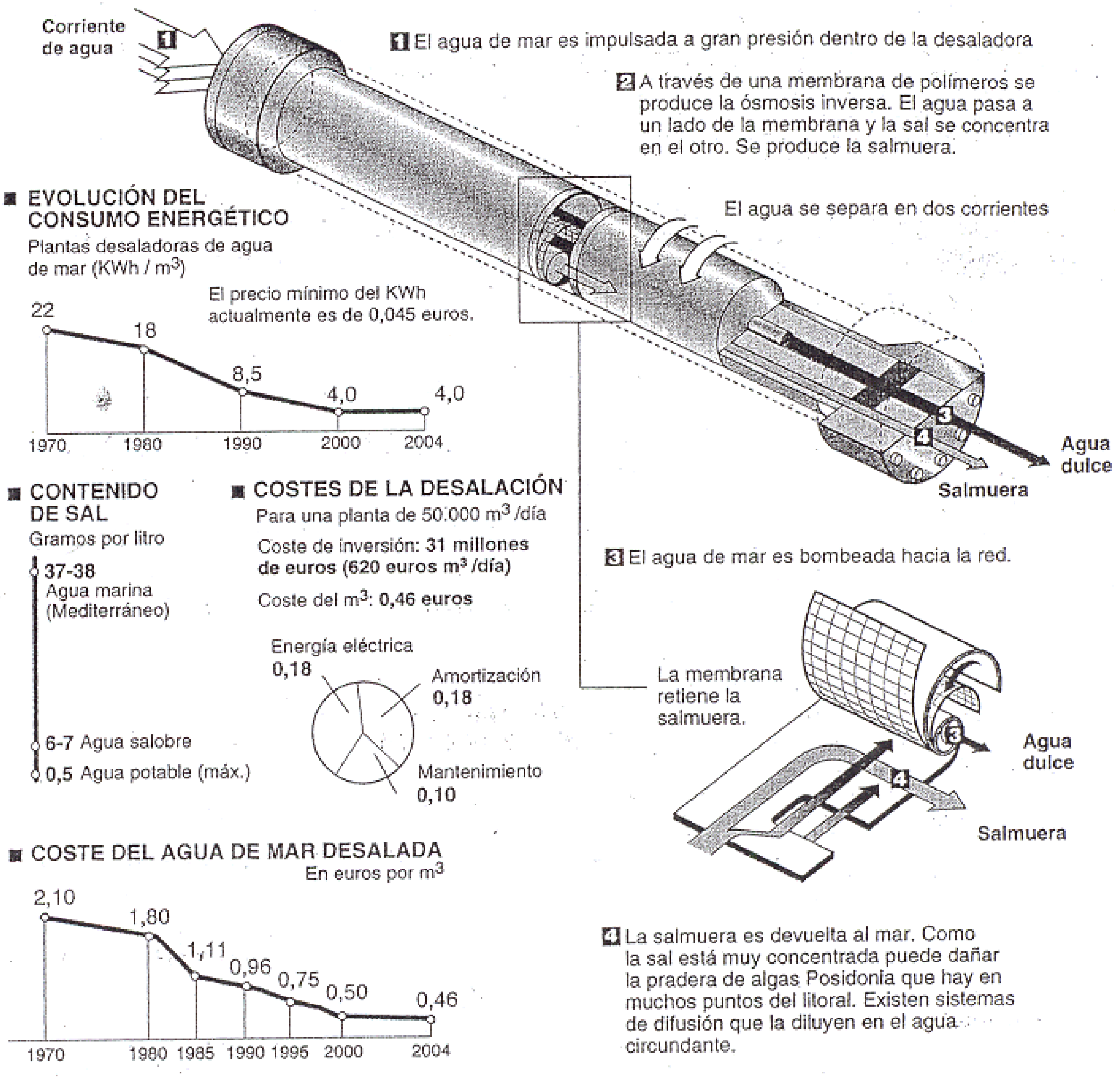
CONCENTRATION OF SALTS AND OTHER CONTAMINANTS

REUTILIZATION AND DISPOSAL OF DRAINAGE WATERS OF INCREASING SALINITY AND CONTAMINATION

DESALINISATION OF SEA WATER



PROCESS OF DESALINISATION OF SEA WATER BY INVERSE OSMOSIS



1 El agua de mar es impulsada a gran presión dentro de la desaladora

2 A través de una membrana de polímeros se produce la ósmosis inversa. El agua pasa a un lado de la membrana y la sal se concentra en el otro. Se produce la salmuera.

El agua se separa en dos corrientes

3 El agua de mar es bombeada hacia la red.

La membrana retiene la salmuera.

4 La salmuera es devuelta al mar. Como la sal está muy concentrada puede dañar la pradera de algas Posidonia que hay en muchos puntos del litoral. Existen sistemas de difusión que la diluyen en el agua circundante.

EVOLUCIÓN DEL CONSUMO ENERGÉTICO

Plantas desaladoras de agua de mar (KWh / m^3)

El precio mínimo del KWh actualmente es de 0,045 euros.

1970	1980	1990	2000	2004
22	18	8,5	4,0	4,0

CONTENIDO DE SAL

Gramos por litro

37-38 Agua marina (Mediterráneo)

6-7 Agua salobre

0,5 Agua potable (máx.)

COSTES DE LA DESALACIÓN

Para una planta de 50.000 m^3 /día

Coste de inversión: **31 millones de euros (620 euros m^3 /día)**

Coste del m^3: **0,46 euros**

Energía eléctrica **0,18**

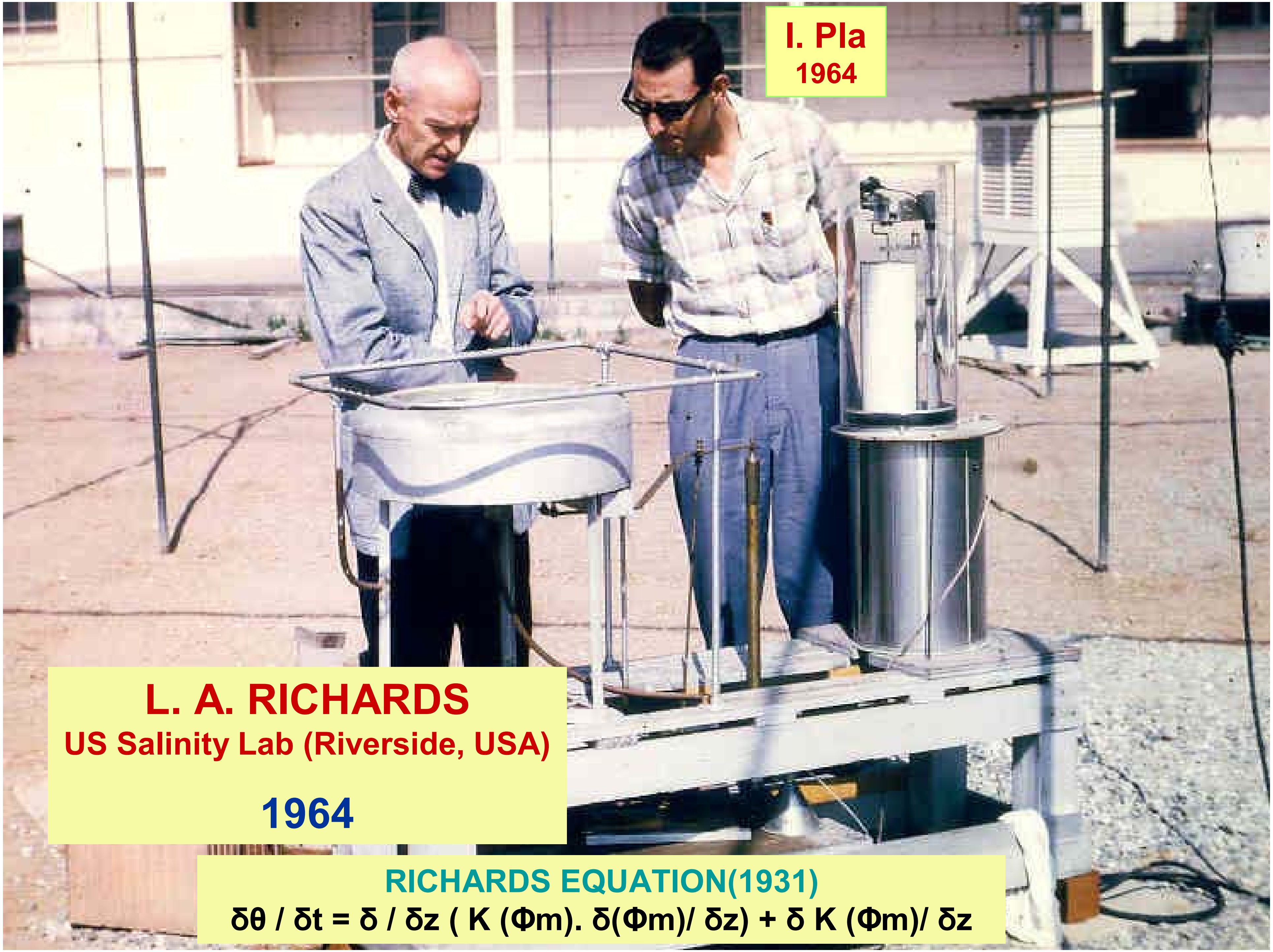
Amortización **0,18**

Mantenimiento **0,10**

COSTE DEL AGUA DE MAR DESALADA

En euros por m^3

1970	1980	1985	1990	1995	2000	2004
2,10	1,80	1,11	0,96	0,75	0,50	0,46



I. Pla
1964

L. A. RICHARDS

US Salinity Lab (Riverside, USA)

1964

RICHARDS EQUATION(1931)

$$\delta\theta / \delta t = \delta / \delta z \; (K (\Phi m). \delta(\Phi m) / \delta z) + \delta K (\Phi m) / \delta z$$

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