The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1867-65

College of Soil Physics

22 October - 9 November, 2007

Hydrological approach to soil and water conservation 8

Ildefonso Pla Sentis
University of Lleida
Spain

SOIL DEGRADATION PROCESSES

by

Ildefonso Pla Sentís

Dept. of Soils and Environmental Sciences

University of Lleida

Av. Alcalde Rovira Roure 191

E-25198 Lleida (Spain)

ipla@macs.udl.cat

SOILS and WATER are the most important resources for ensuring sustainability of food production

Poor soil and water management may cause severe land and soil degradation

Unfavourable alterations of the soil physical, chemical and biological properties have a negative effect on plant productivity and environmental quality

SOIL DEGRADATION has been defined as a decrease in the soil ability to accomplish its functions as:

-***Basis for plant growth***

-***Regulator of the water regime***

-***Environmental filter***

due to natural or anthropogenic causes

Soil and land degradation directly affects food supplies, diminishing crop yields and increasing risks of production

In addition to effects on crop productivity and production risks, soil degradation also affects negativelly hydrographic catchments, and the water supply to the population and for irrigation and production of hydroelectric power

Natural desasters by floodings, landslides, sedimentation…. affecting with growing incidence mostly the developing countries are also rooted in soil degradation

The problems of soil and water degradation and derived effects are increasing troughout the World, partially due:

-to a lack of appropriate identificación and evaluation of the degradation processes and of the relations cause-effects of soil degradation for each specific situation,

and

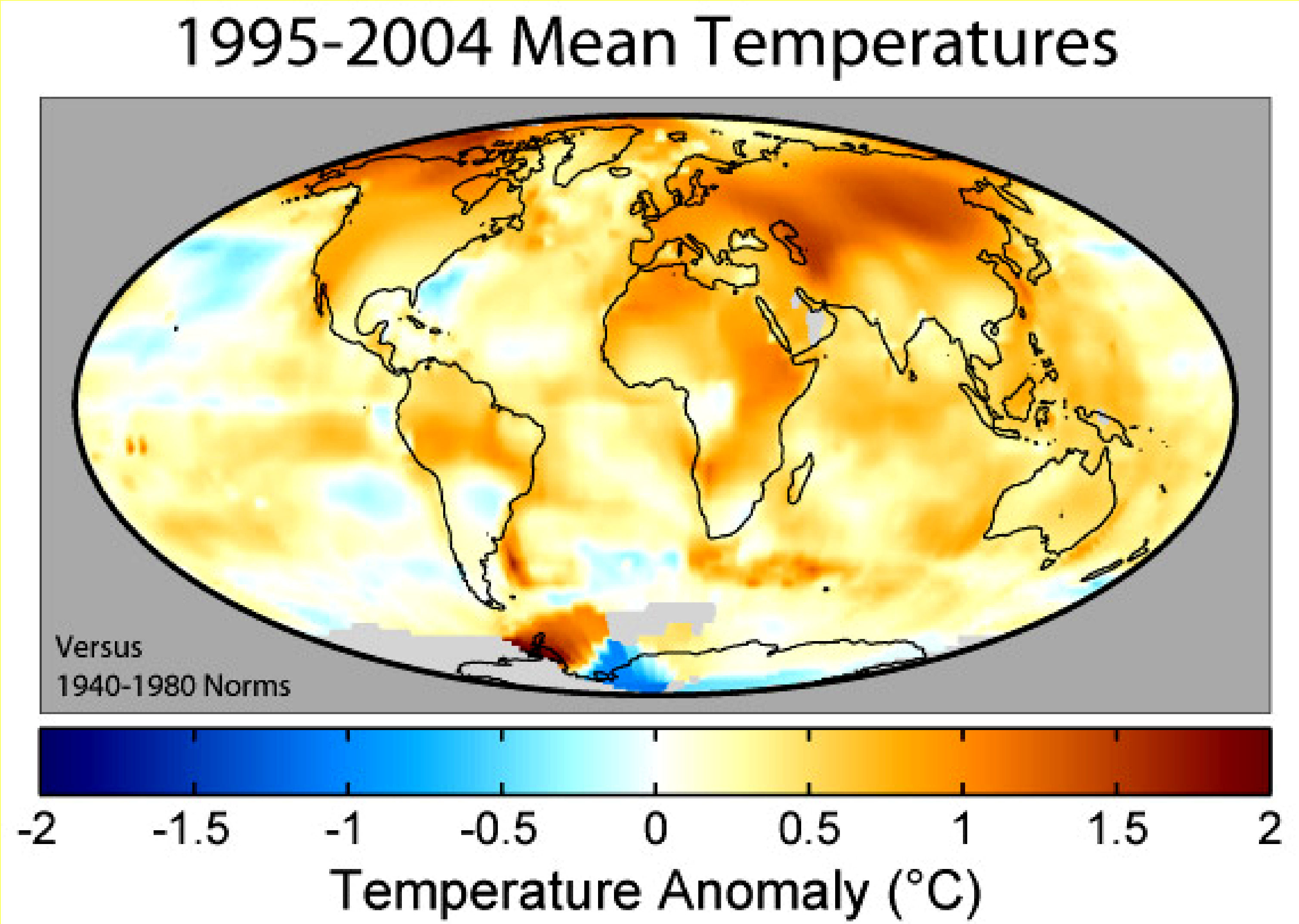
-the generalized use of empirical approaches to select and apply soil and water conservation practices

In some occasions, the wrong selection or application of soil and water conservation practices and structures may increase land degradation processes and derived environmental impacts

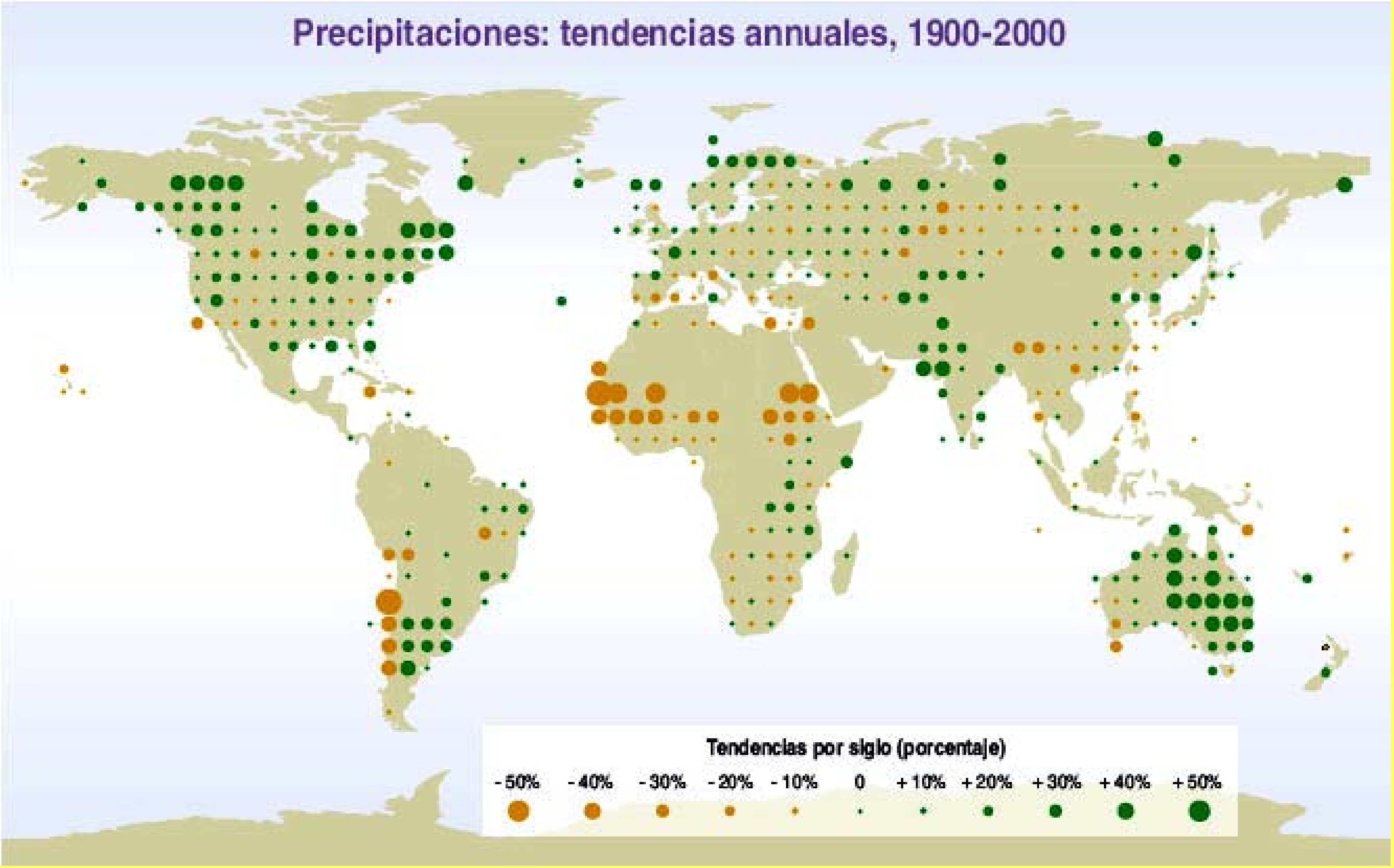
Economic and social problems,

connected to population pressure, market changes and prices, and technical needs,

may produce drastic and sudden changes in land use and management, which may increase the potential hazard of land degradation and side efects



1995-2004 Mean Temperatures
Versus
1940-1980 Norms
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Temperature Anomaly (°C)

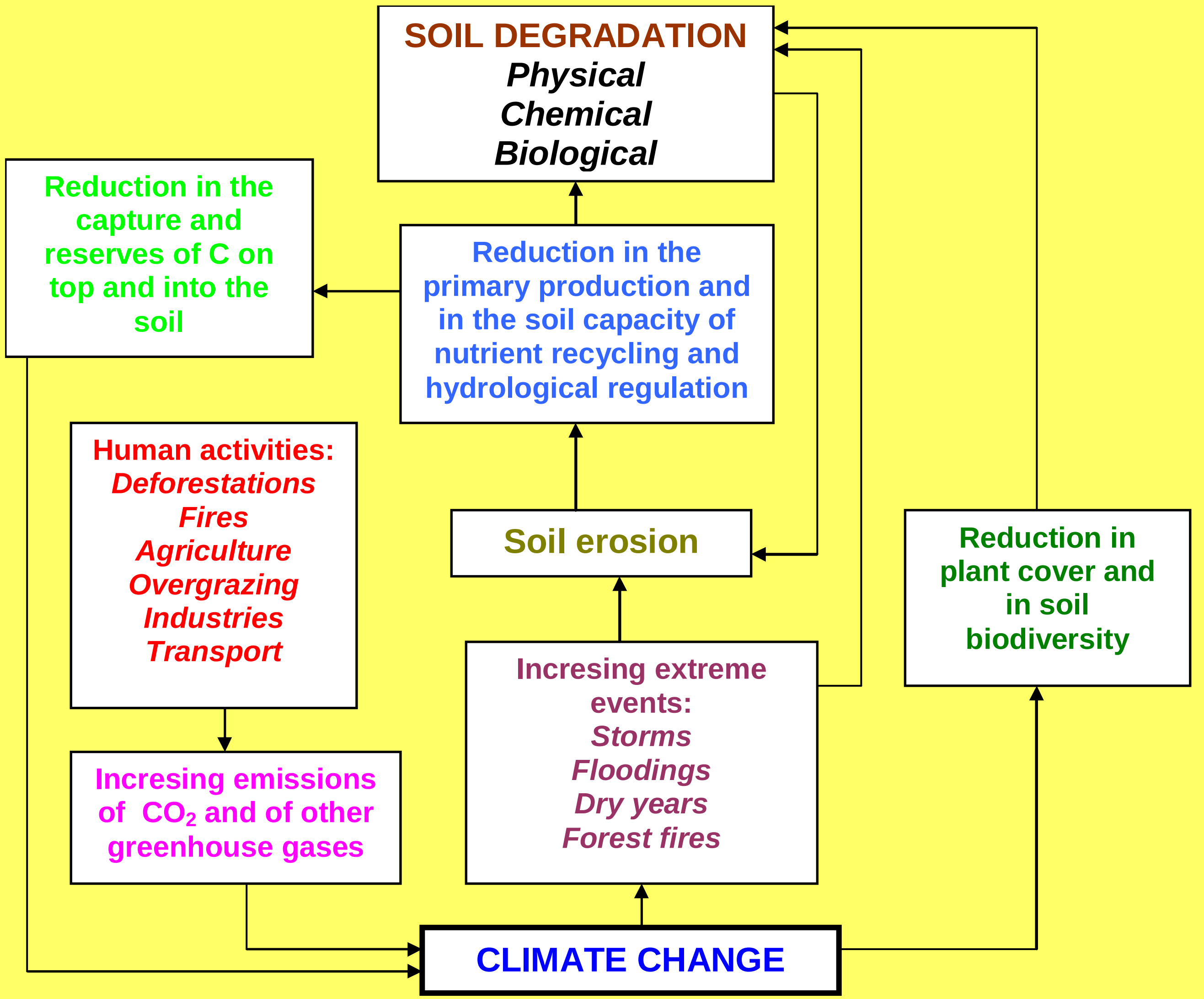

Precipitaciones: tendencias annuales, 1900-2000
Tendencias por siglo (porcentaje)
- 50%
- 40%
- 30%
- 20%
- 10%
0
+ 10%
+ 20%
+ 30%
+ 40%
+ 50%

GLOBAL CLIMATIC CHANGES may contribute:

-to accelerate some land and soil degradation processes and their effects in some regions of the World,

but in any case,

-land use changes, including deforestations and other human activities leading to soil degradation processes may affect more the processes and effects of land degradation than the previewed global climatic changes, or may increase the influence of these changes



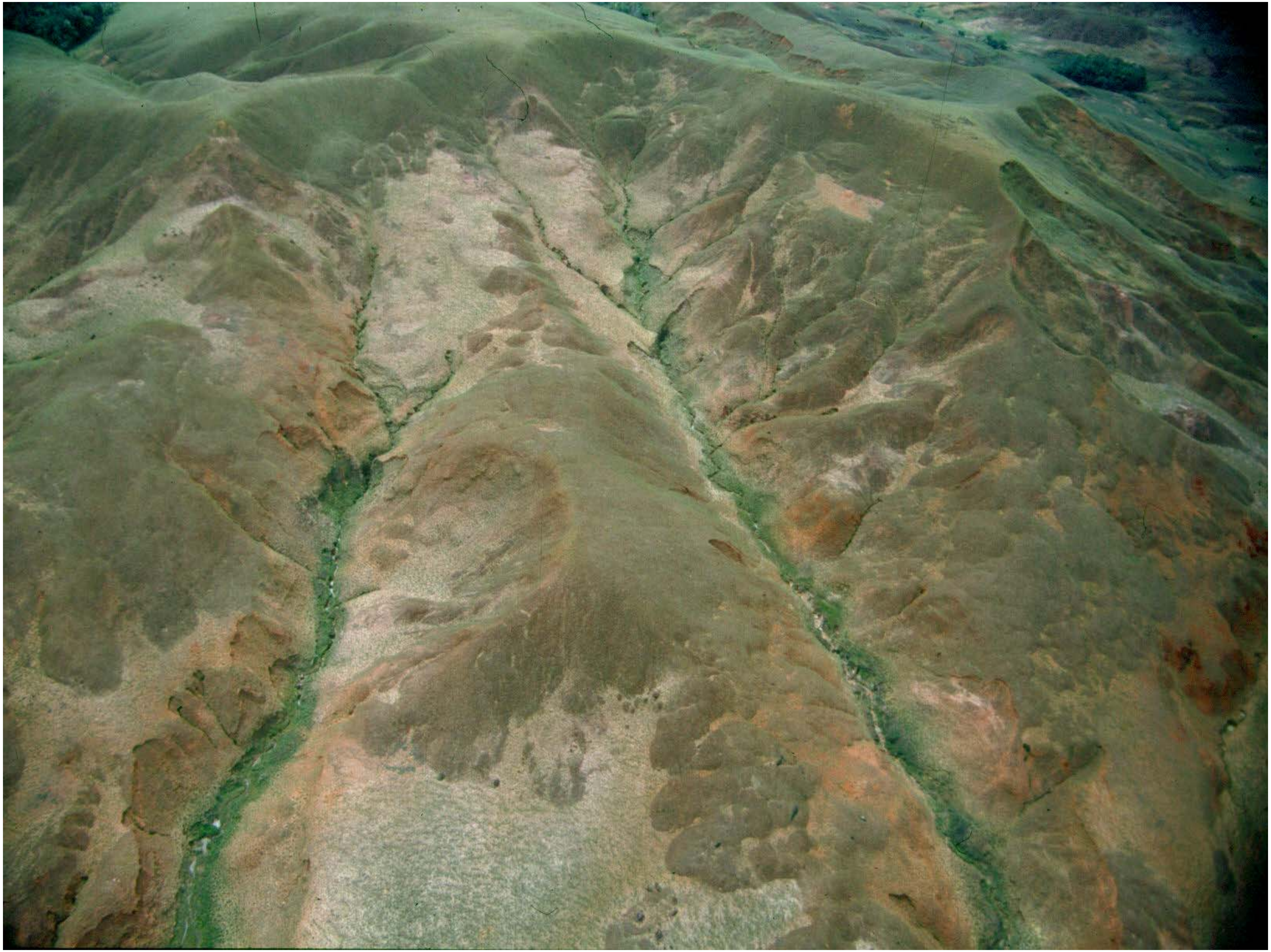
Relations between soil degradation and climate change.

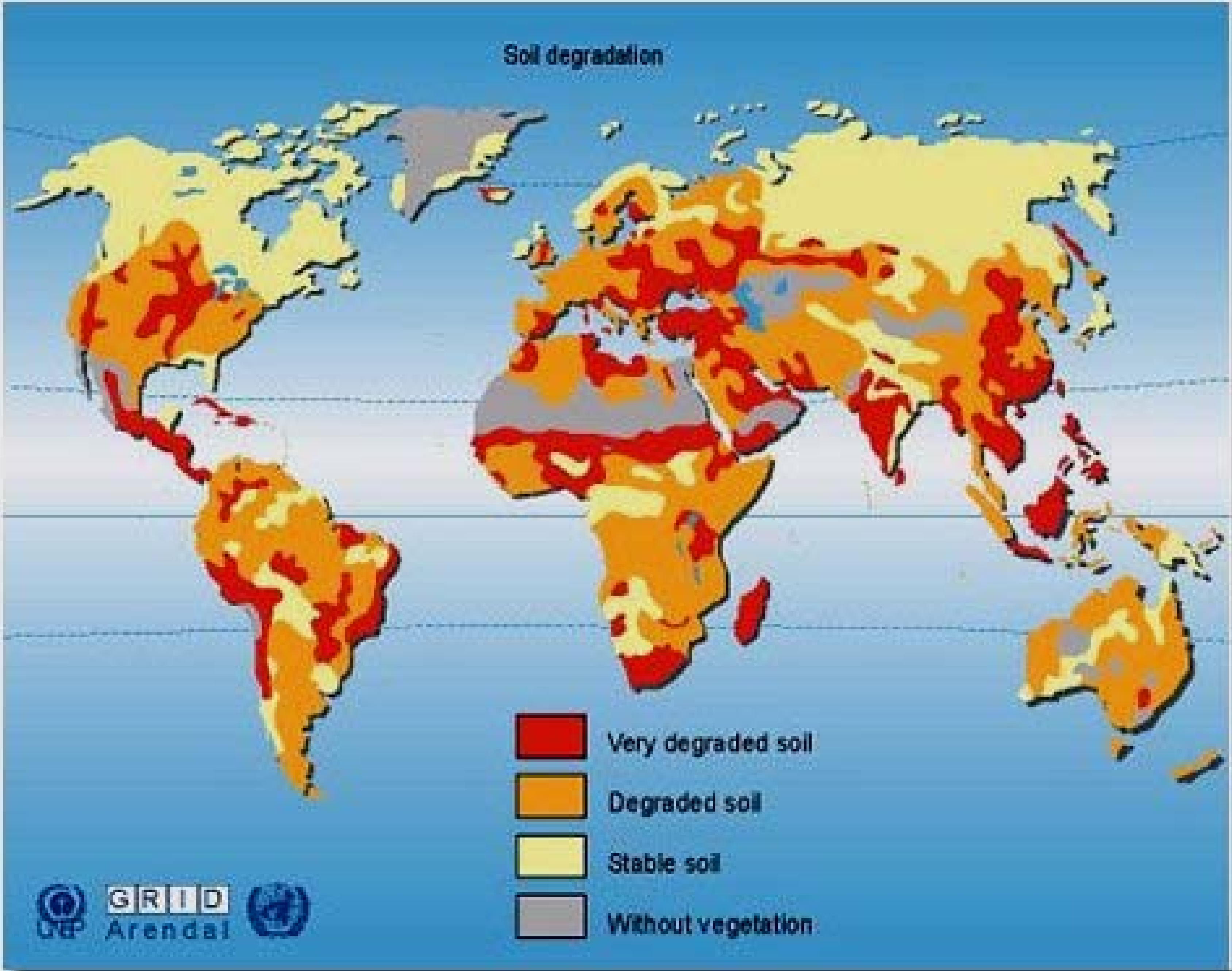
The main World environmental problem is the <u>degradation of the soil and water resources</u>, mostly associated to the growing <u>agricultural, urban and industrial developments.</u>

<u>Soils</u> play a very important role in the <u>hydrological cycle.</u>

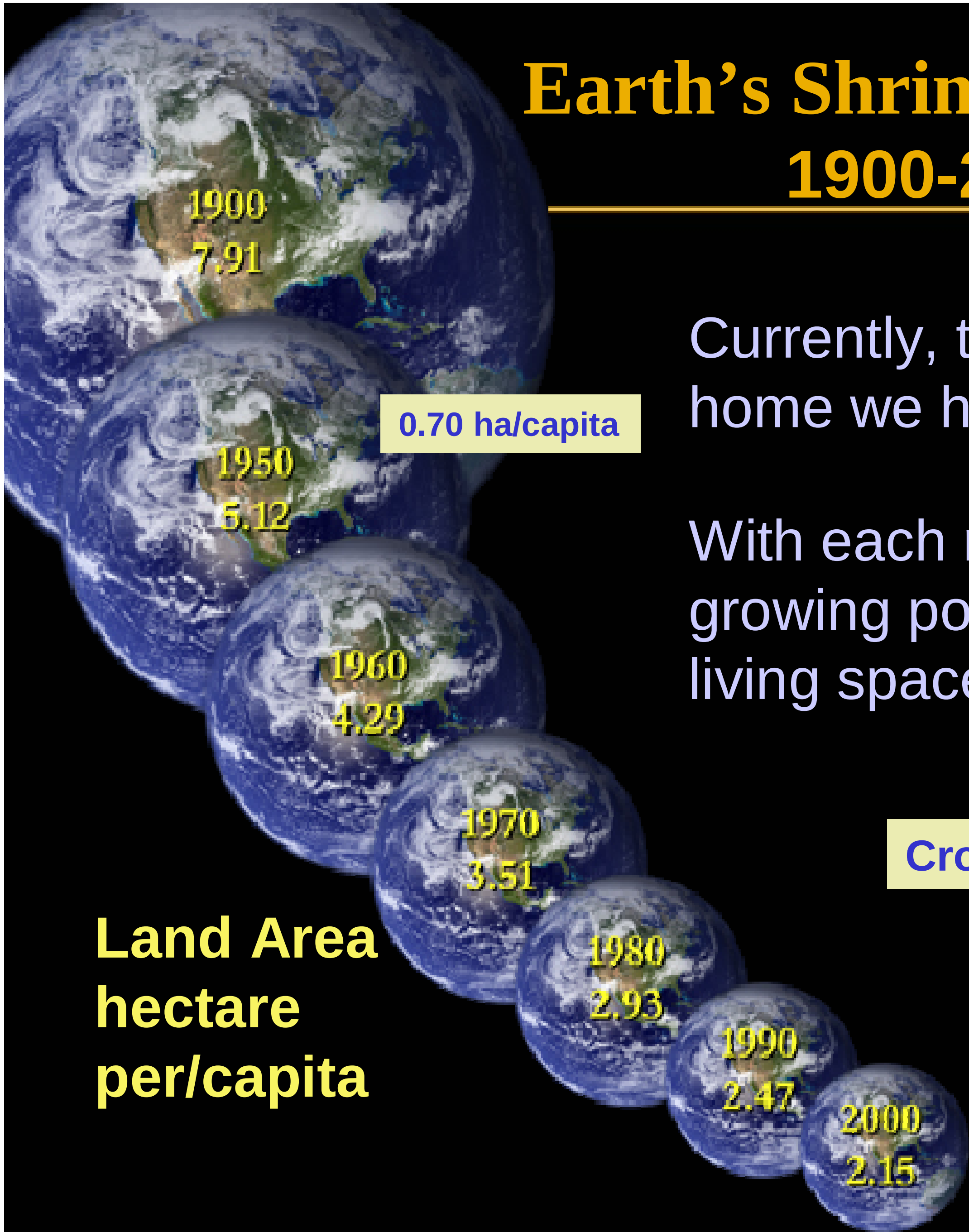
Continuing <u>shrinkage of quality water supplies</u> for different uses (human consumption, irrigation, etc) points out the importance of <u>water conservation</u> besides <u>soil conservation</u>.

An <u>integrated approach</u> in the conservation of soil and water is further justified by the close relationship between <u>soil and water quantity and quality.</u>




Soil degradation
Very degraded soil
Degraded soil
Stable soil
Without vegetation
GRID
Arendal

Earth's Shrinking Biosphere
1900-2000 AD



0.70 ha/capita

Currently, the Earth is the only home we have.

With each new person added to our growing population, the amount of our living space decreases.

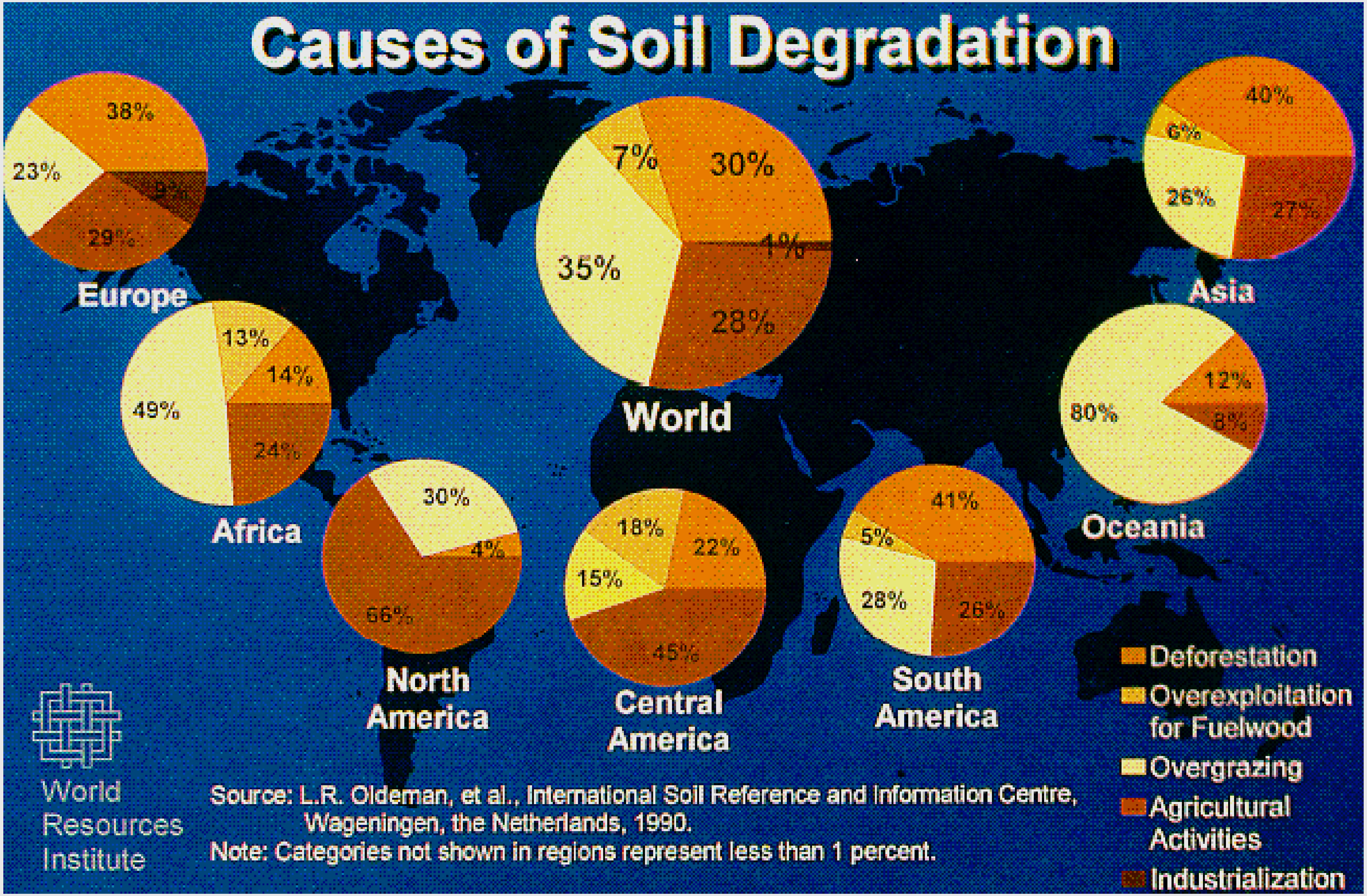
Land Area hectare per/capita

Cropland Area (hectare per/capita)

China: 0.15 ha/capita

0.25 ha/capita

India: 0.12 ha/capita


Causes of Soil Degradation
38%
23%
29%
Europe
7%
30%
35%
1%
28%
World
40%
6%
26%
27%
Asia
13%
14%
49%
24%
Africa
12%
80%
8%
Oceania
30%
4%
56%
North America
18%
22%
15%
45%
Central America
41%
5%
28%
26%
South America
Deforestation
Overexploitation for Fuelwood
Overgrazing
Agricultural Activities
Industrialization
World Resources Institute
Source: L.R. Oldeman, et al., International Soil Reference and Information Centre, Wageningen, the Netherlands, 1990.
Note: Categories not shown in regions represent less than 1 percent.

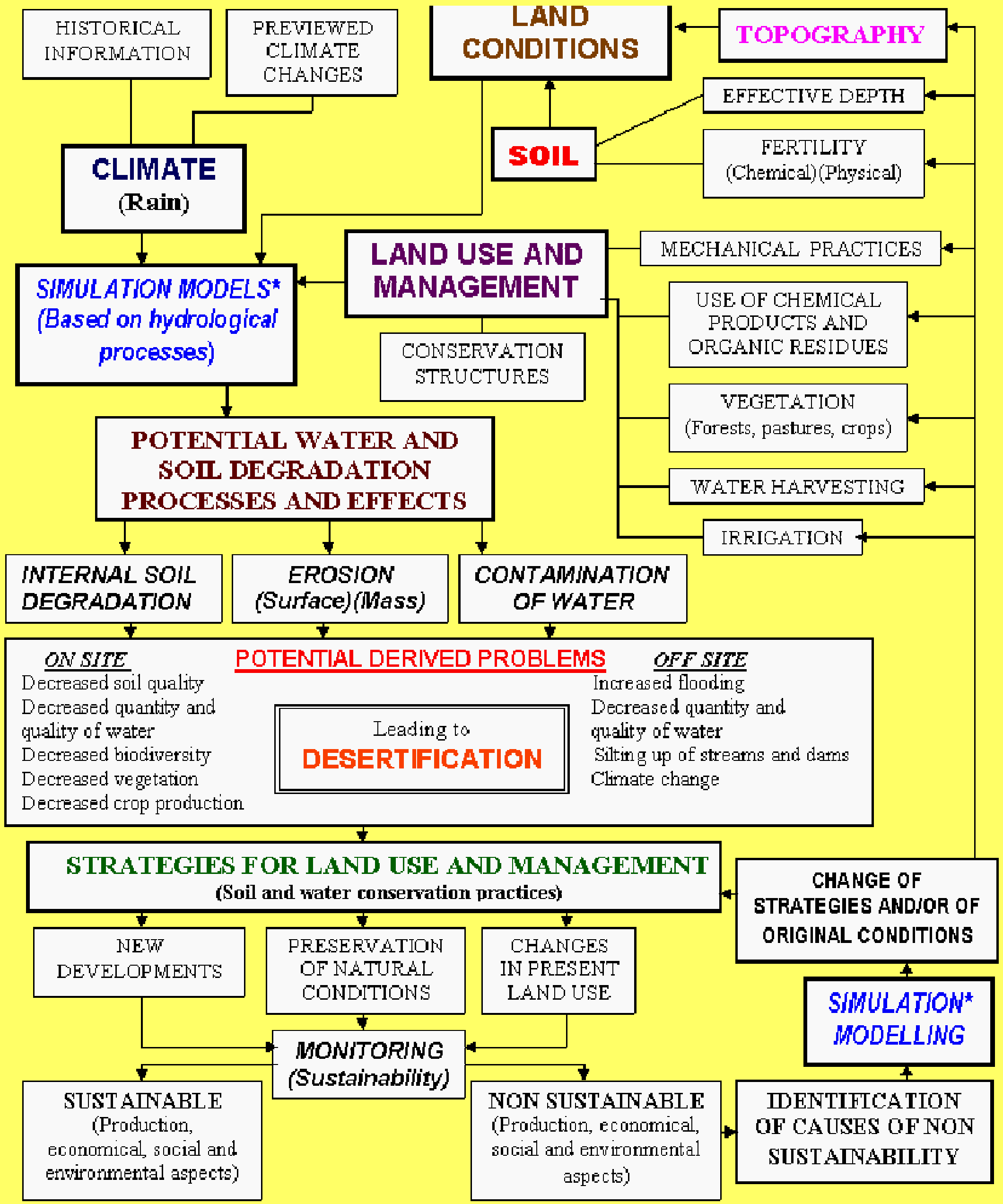


Figure 3. Integrated framework, mainly based on hydrological processes, for evaluating potential soil and land degradation and desertification, as a basis for a rational land use planning under Mediterranean climate (Pla, 2006).

The soil moisture regime, determined by the changes in soil water content with time, is the main single factor conditioning plant growth and crop production.

That will be mainly conditioned by soil properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater, and the limitations to root growth under the particular rainfall characteristics.

These conditions may be modified through soil and plant management practices, including tillage, irrigation, drainage, date of sowing, etc.

Hydrological processes determine the <u>transport of water soluble materials and pollutants</u> occurring naturally or human derived.

Naturally occurring constituents within the soil are <u>mobilized and transported</u> as a result of the infiltration and flow of rainfall and irrigation water.

Pollutants are partially <u>retained, released and transformed in the soil</u> before reaching groundwater.

Therefore, <u>the quality of water resources</u> may be greatly influenced by soil hydrological processes.

The main factor attempting against the <u>sustentability of agricultural production</u> is soil and land degradation.

Also of growing importance are the <u>offsite effects of land degradation</u> on increased risks of catastrophic floodings, sedimentations, landslides, etc, and on global climate changes.

Although land degradation is affected by <u>soil and climate characteristics</u>, it is mainly due to <u>unnappropiate use and management of the natural resources soil and water</u>, generally imposed by social and economic pressures.

The inadequate management of soils and water may lead:

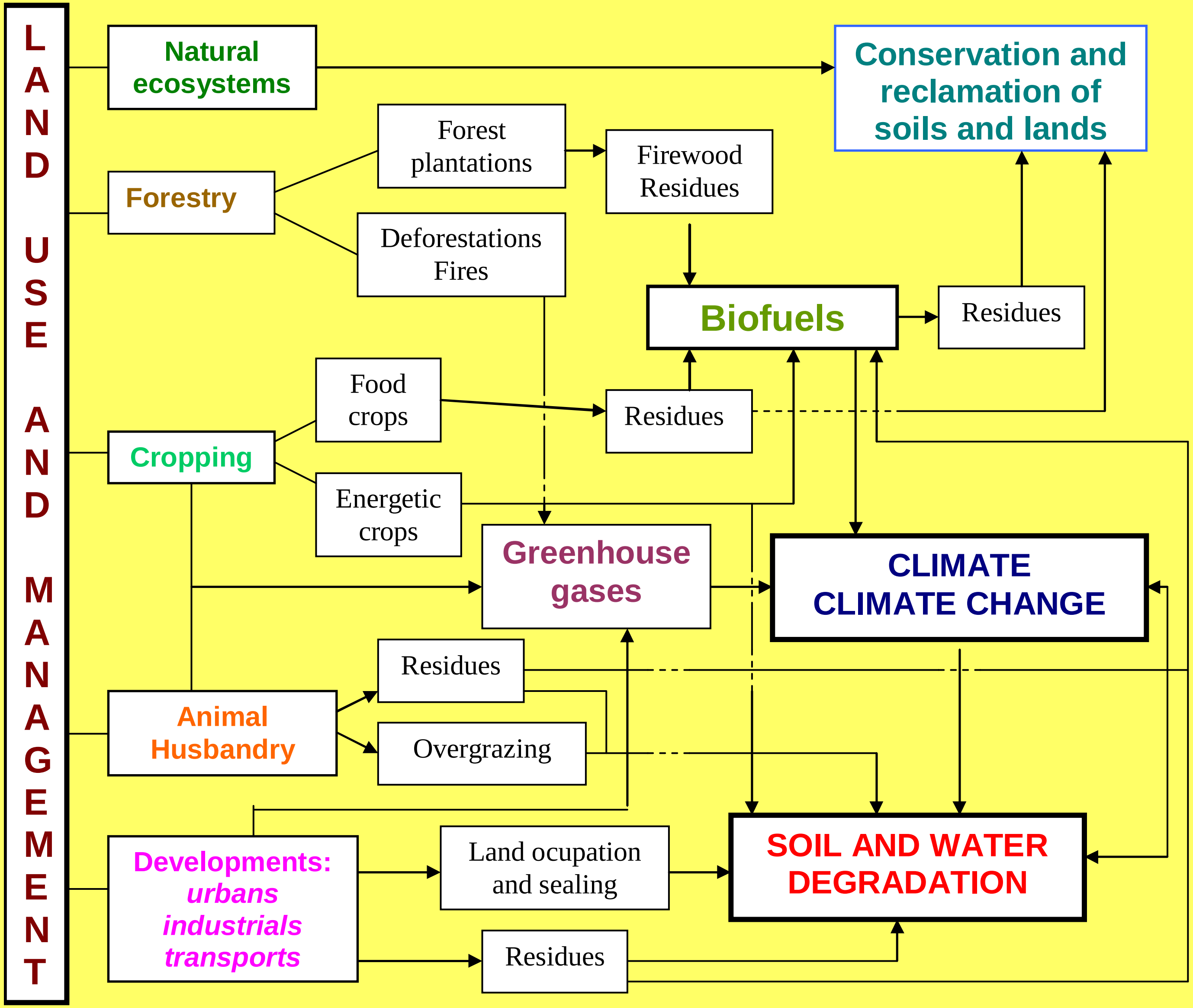
-to a loss of water and energy,

and

-to soil degradation by

sealing,
compaction,
erosion,
salinization …..,

which generally result in negative environmental effects



Relations among the land use and management and climate with the soil degradation and conservation

The main objective of the research on SOIL PHYSICS in relation to agriculture and environment must be:

-to generate basic knowledge on the complex soil-water system

and

-to apply such knowledge to reach higher levels of crop production in a sustainable way

without negative environmental effects

For that,

scientific research, <u>fundamental in concepcion but practical in its results</u>,

is required

to develop or to adapt soil management practices to the specific requirements of the rainfed or irrigated agriculture in regions with different climates, soils and socio-economic conditions,

without causing degradation of the resources soil and water

One of the main problems of this research is:

-to find ways to study specific processes in a complex system of interdependent phenomena,

and

-how to integrate the results of those studies for a better understanding of the functioning of the system as a whole.

Such understanding is essential to be able to generalise the particular experiences obtained under specific conditions to different soils and climate conditions

The process of soil degradation generally starts with the degradation of the soil structure, specially the functional attributes of the soil pores to transmit and to retain water, and to facilitate the root growth.

The damage of such attributes is manifested trough inter-related problems of:

-***surface sealing,***

-***soil compaction,***

-***limited root development,***

-***restricted drainage,***

-***more frequent droughts,***

-***excessive runoff,***

-***accelerated soil erosion.***

Water, that is often the main limiting factor of plant growth, is also the main factor directly or indirectly responsible for soil and land degradation processes.

The processes of <u>soil and water degradation</u> are closely linked through unfavorable alterations in the hydrological processes determining the <u>soil water balance and the soil water regime.</u>

They are also conditioned by the <u>climatic conditions</u> and by the <u>use and management of the soil and water resources.</u>

Although the close interaction between the conservation of the soil and water resources is increasingly being accepted, still in most of the cases they are evaluated separately, and consequently the <u>prediction and prevention of the effects</u> derived from their degradation are <u>inadequate in many situations.</u>

The processes of soil degradation caused by soil-climate-management interactions, generally result on unfavorable and some times drastic changes in the soil hydrological processes.

The main soil and water degradation processes include soil water erosion (surface and mass movements), soil sealing and crusting, soil compaction, soil and water salinization and sodificaction, and soil and water pollution.

In addition to the negative effects on plant growth and on productivity and crop production risks, catastrophic floodings, sedimentations and landslides are also rooted on accelerated land degradation.

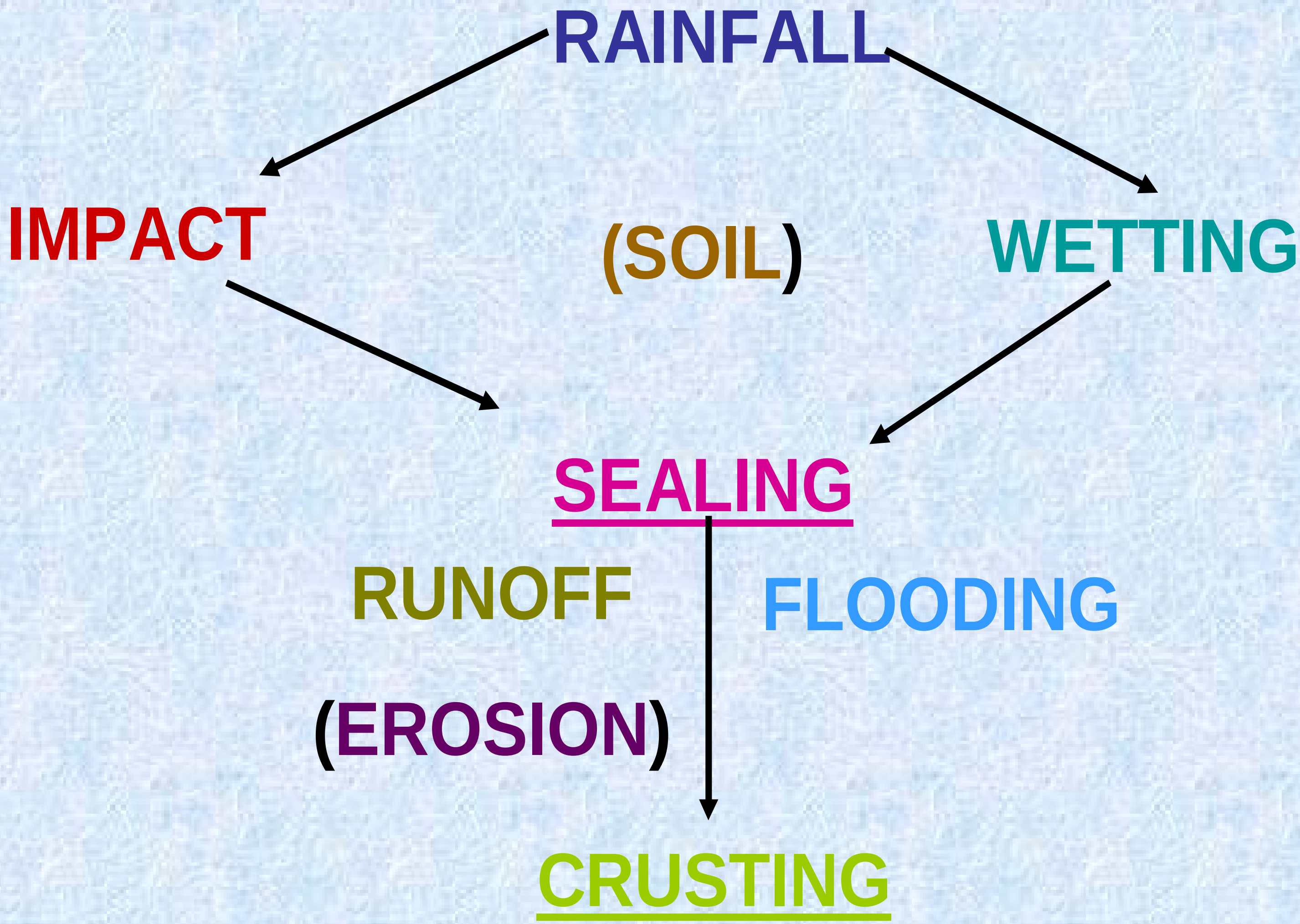

EPS 47

Unprotected soil surface is exposed to the direct <u>impact of raindrops</u>, causing disruption of soil aggregates and <u>sealing effects</u>.

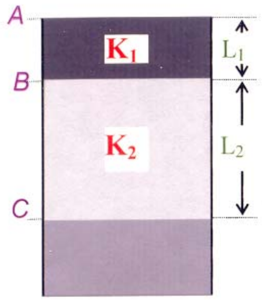
Sealing effects make reference to <u>sharp decreases in water infiltration rates.</u>

When sealing effects decrease infiltration and cause runoff, it is necessary <u>to distinguish the rainfall data from the amount of water that really enters the soil</u> and contribute to the available soil moisture and internal drainage.

This is very important both in <u>agronomy and hydrology.</u>


RAINFALL
IMPACT
(SOIL)
WETTING
SEALING
RUNOFF
FLOODING
(EROSION)
CRUSTING

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

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

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

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

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

$$K_S i_S = K_1\ i_1 = K_2\ i_2 = - Q / A\ t$$

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

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

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

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

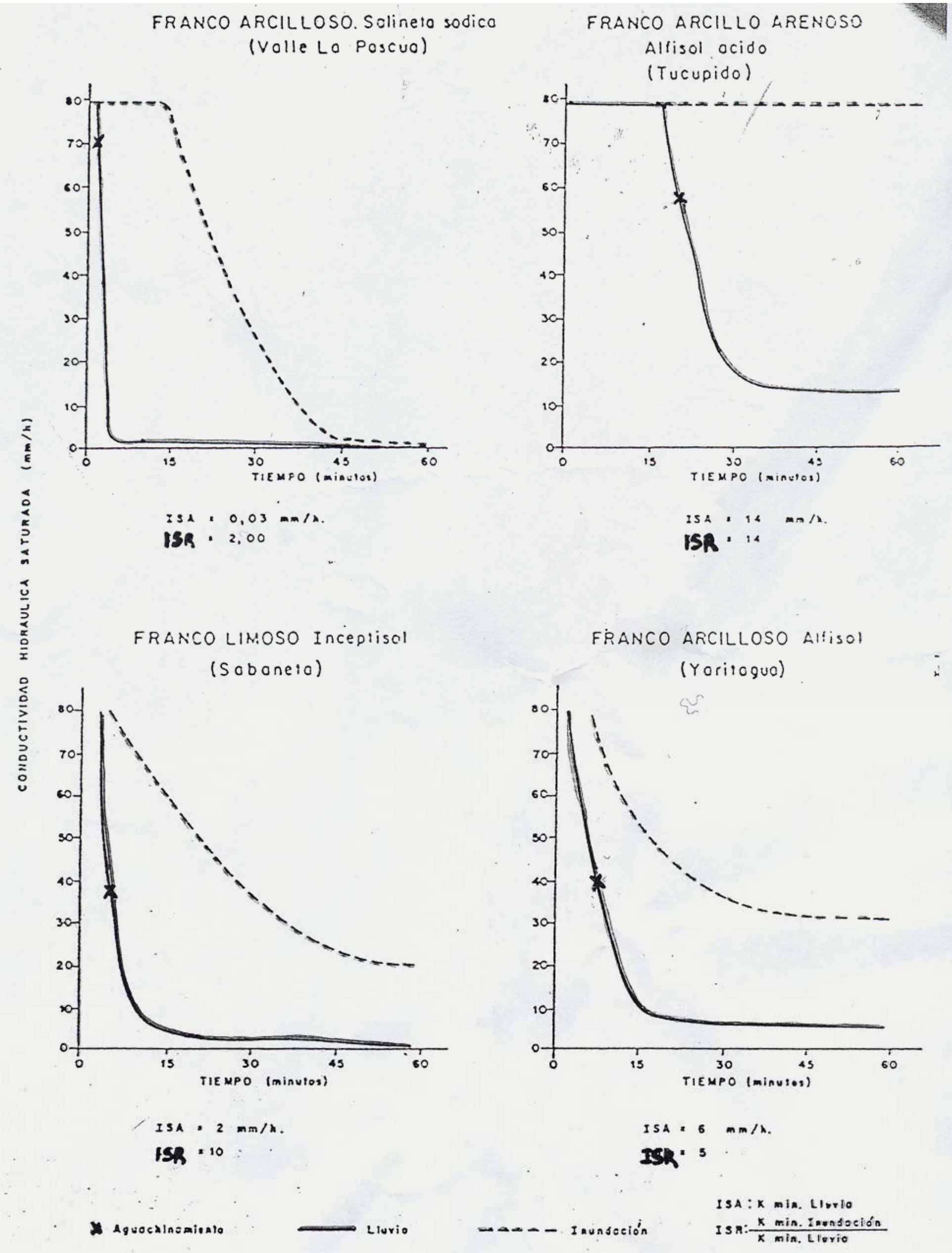
$$K_S = (L_1 + L_2)\ /\ ((L_1/K_1) + (L_2/K_2))$$

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

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) = ((0,01x0,05)+(10x5))/(0,5+10) = **4,76 cm/hour**



ico 5. Evaluación de la Conductividad Hidraulica con y sin sello superficial y cálculo del ISA ISR.

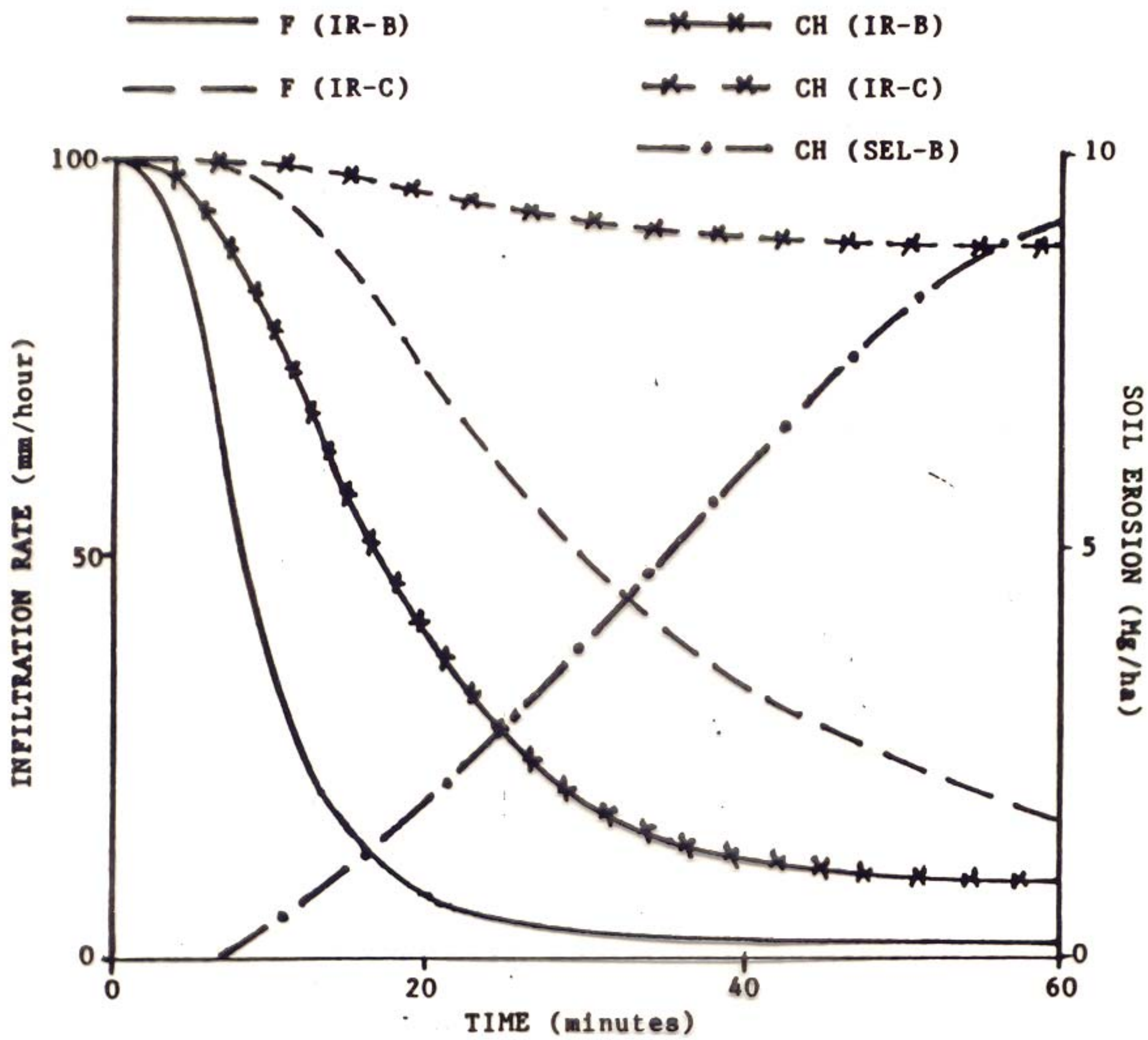
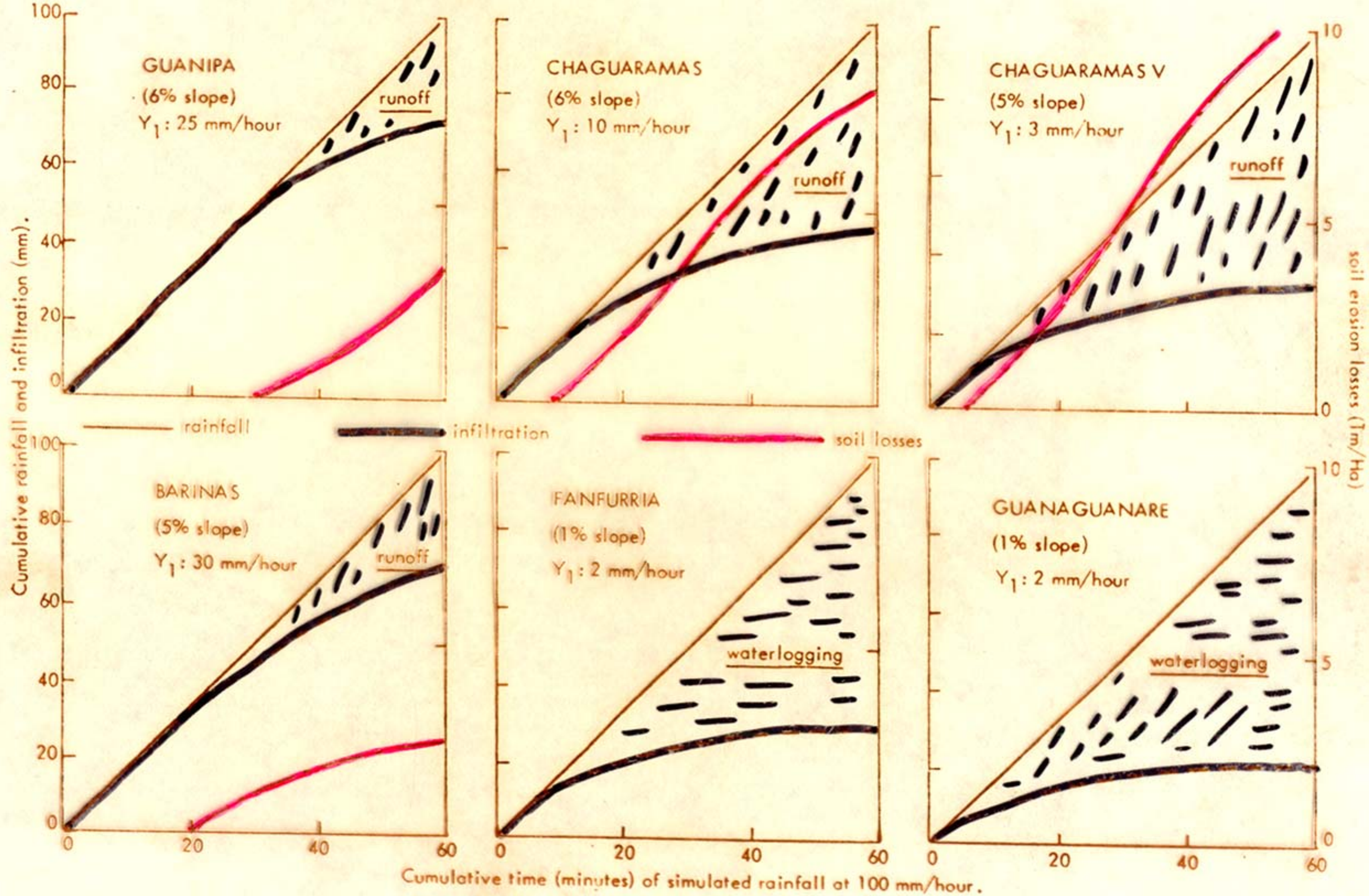


Fig. 2. Water infiltration rates (IR) and soil erosion losses (SEL) under simulated rainfall at 100mm. hour^{-1}, in an initially air dry tilled soil, bare (B) or completely covered (C) by crop residues. (CH: Chaguaramas soil; F: Fanfurria soil).

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).



SOIL COMPACTION ***or increase in:***

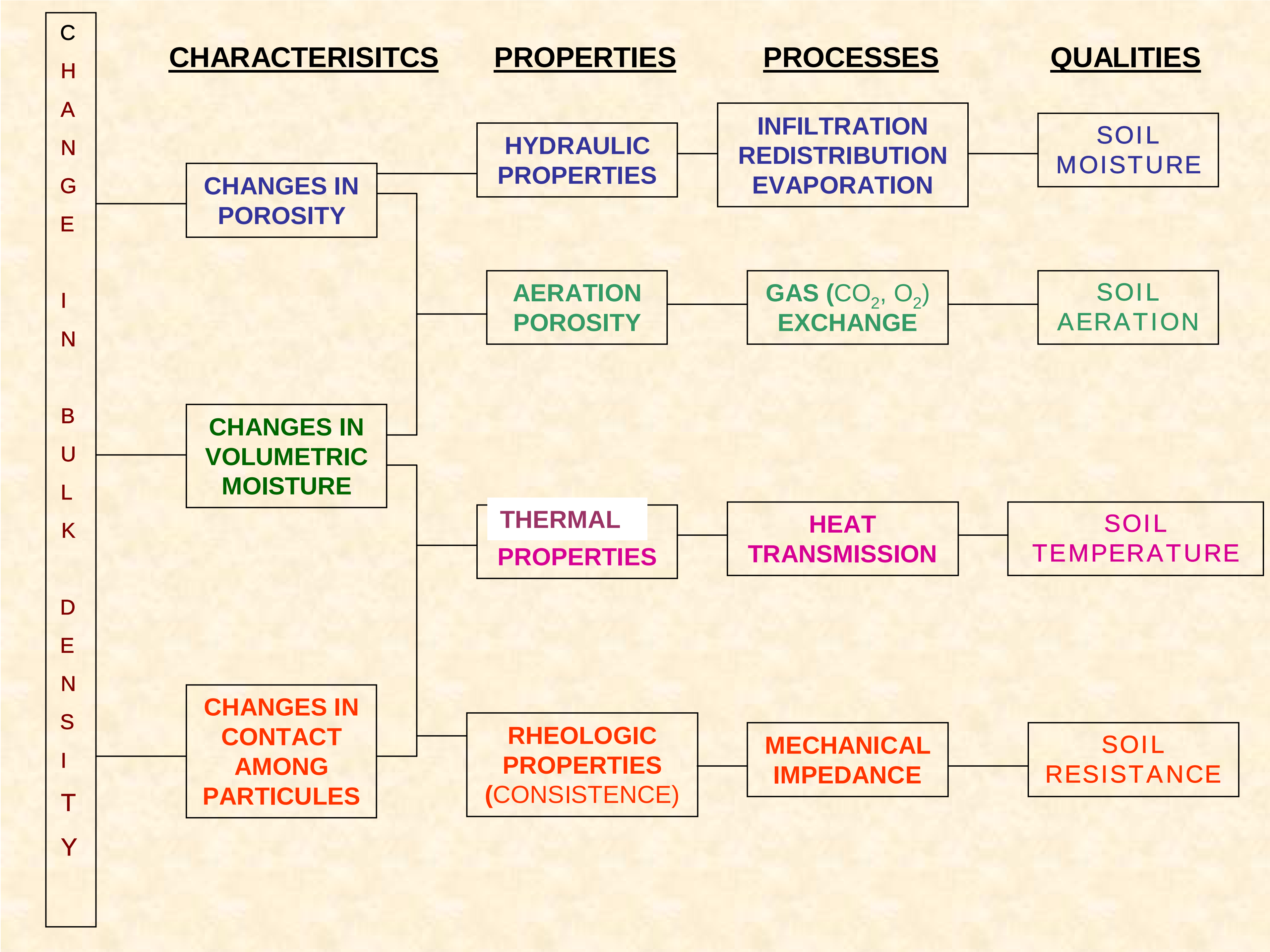
-Bulk Density = Dry Soil Mass/Soil Volume (Soil Volume = Vol. of solids + Vol. of pores)

(Compaction with Compresion and / or Deformation of pores)

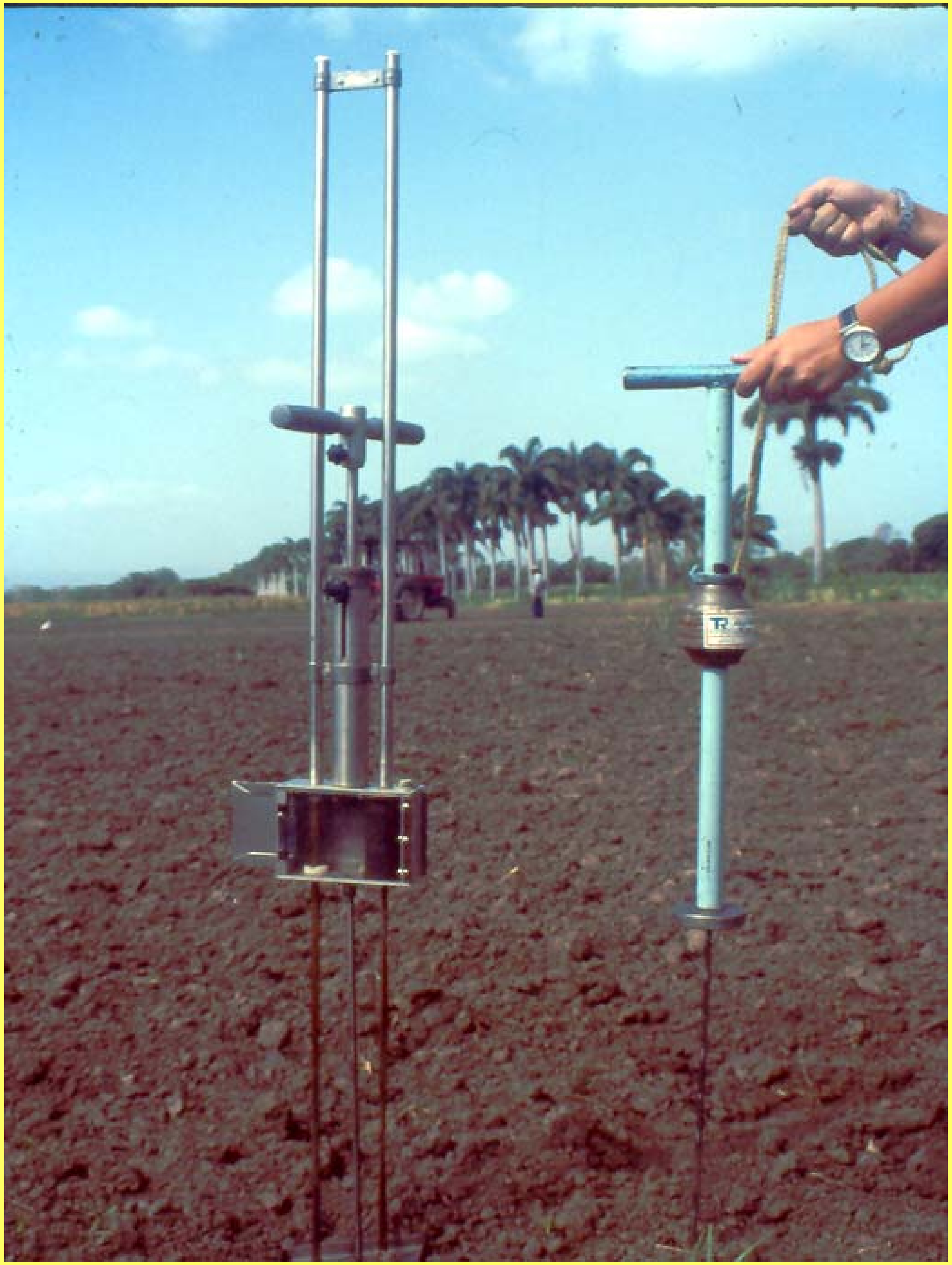
It is mainly associated to agricultural mechanization and to a decrease in organic matter and in aggregate stability,

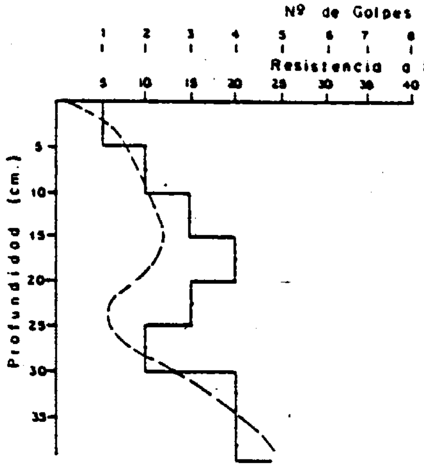
Soil compaction directly affects crop growth, and increases risks of crop production, mainly derived of reductions in water and nutrient absorption by roots, due to reduced aeration and reduced root growth

Indirectly, by decreasing soil permeability, soil compaction may affect risks of crop production and erosion, by increasing water runoff in sloping land, or by enhancing waterlogging in flat lands

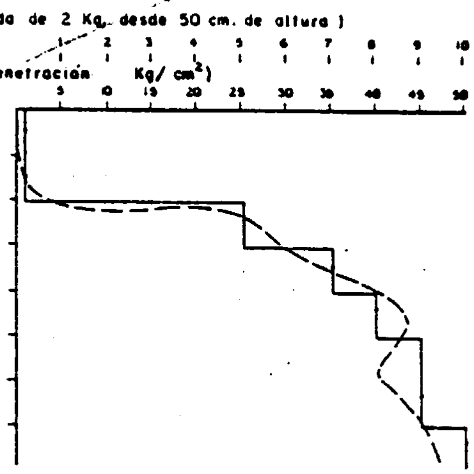


CHANGE IN BULKDENSITY
CHARACTERISITCS
PROPERTIES
PROCESSES
QUALITIES
CHANGES IN POROSITY
HYDRAULIC PROPERTIES
INFILTRATION REDISTRIBUTION EVAPORATION
SOIL MOISTURE
AERATION POROSITY
GAS (CO_2, O_2) EXCHANGE
SOIL AERATION
CHANGES IN VOLUMETRIC MOISTURE
THERMAL PROPERTIES
HEAT TRANSMISSION
SOIL TEMPERATURE
CHANGES IN CONTACT AMONG PARTICULES
RHEOLOGIC PROPERTIES (CONSISTENCE)
MECHANICAL IMPEDANCE
SOIL RESISTANCE

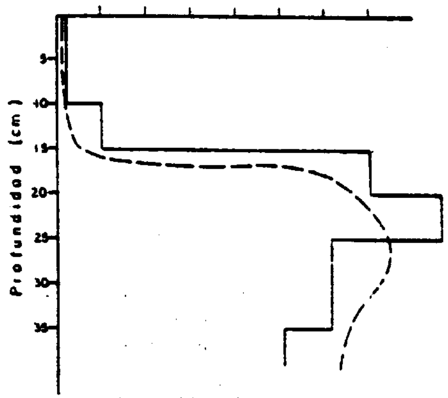




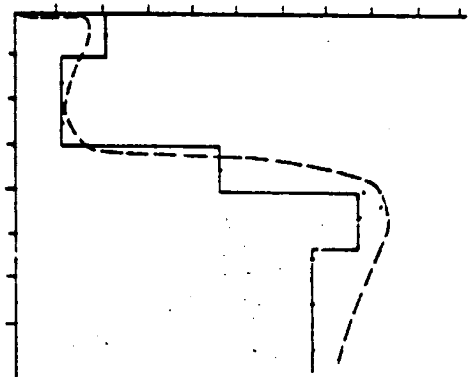
Suelo Franco limoso consolidado y estratificado.
Humedad cerca de CC. en todo el perfil



Suelo franco arcilloso, recien rastreado a 10 cm y consolidado a mayores profundidades.
Humedad por debajo de CC. en todo el perfil



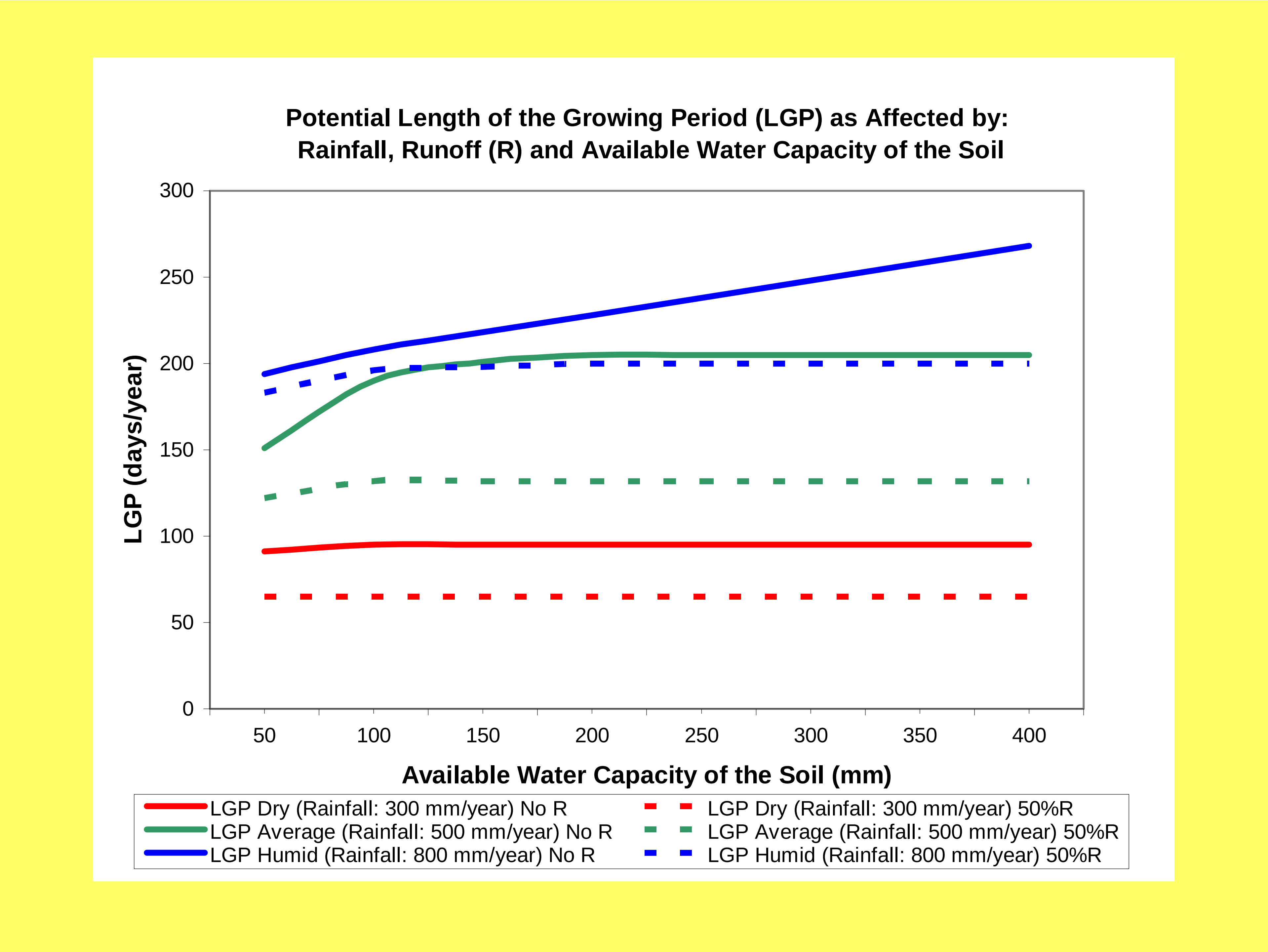
Suelo franco limoso recien arado y rastreado con capa compactada de 15 a 25 cm –
Humedad por debajo de CC.



Suelo franco arcillo limoso, con costra superficial seca, suelo rastreado por debajo y capa compacta de 15 - 25 cm.
Humedad por debajo de CC.

— — — Penetrógrafo

——— Penetrometro de impacto, Mod. Pinto con lecturas cada 5 cm.



Potential Length of the Growing Period (LGP) as Affected by:
Rainfall, Runoff (R) and Available Water Capacity of the Soil
LGP (days/year)
0
50
100
150
200
250
300
50
100
150
200
250
300
350
400
Available Water Capacity of the Soil (mm)
LGP Dry (Rainfall: 300 mm/year) No R
LGP Average (Rainfall: 500 mm/year) No R
LGP Humid (Rainfall: 800 mm/year) No R
LGP Dry (Rainfall: 300 mm/year) 50%R
LGP Average (Rainfall: 500 mm/year) 50%R
LGP Humid (Rainfall: 800 mm/year) 50%R

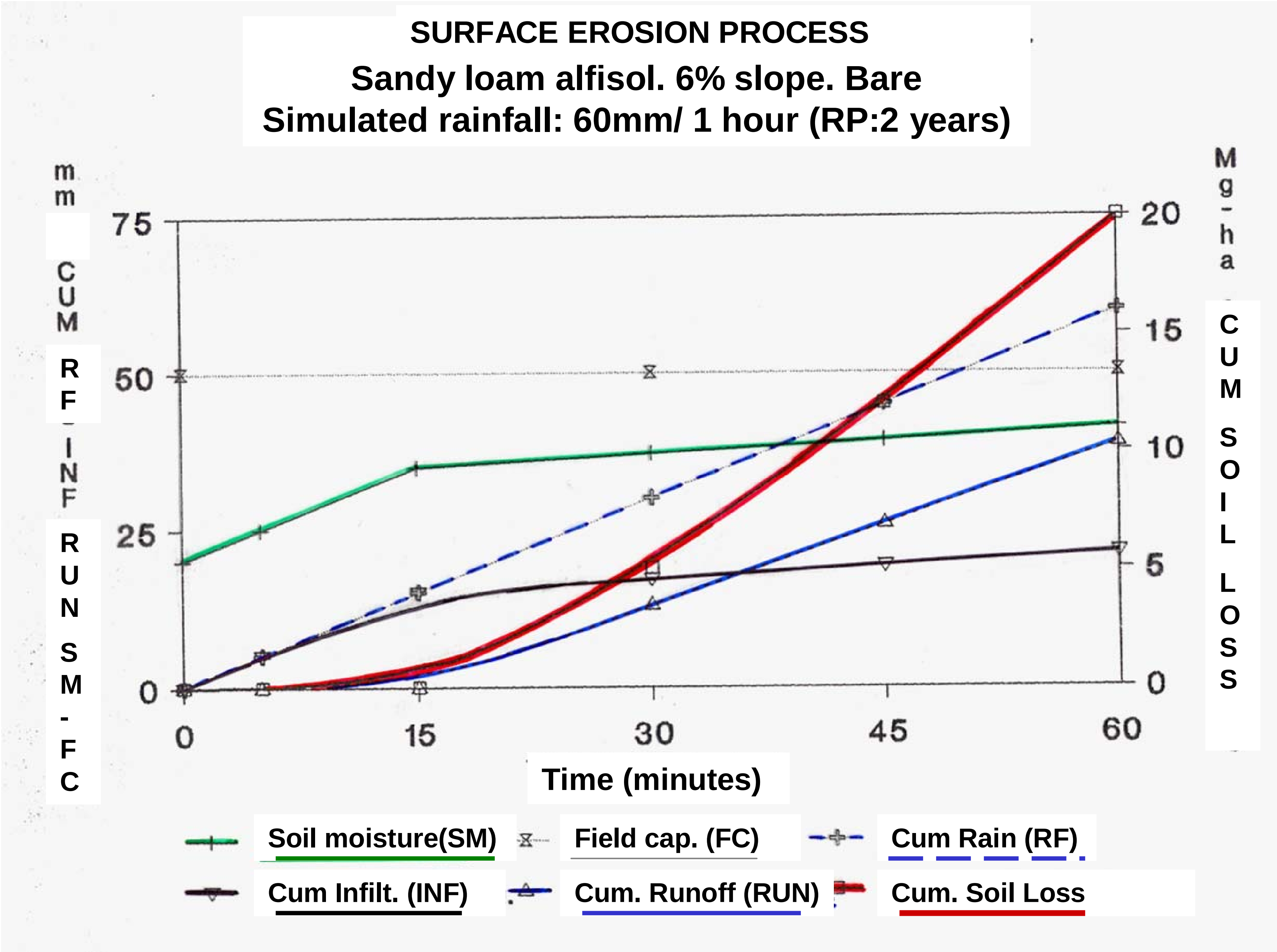
It may be seen that <u>as the sealing effect increases (increasing % runoff), the influence of the rooting depth (AWC) on the LGP decreases</u>,

It is clear that the <u>runoff and effective soil water capacity components of the water balance</u>, both highly affected by soil degradation processes, <u>cannot be neglected</u> in the evaluation and prediction of the effects of those processes on <u>water conservation and potential plant growth and crop production</u>.

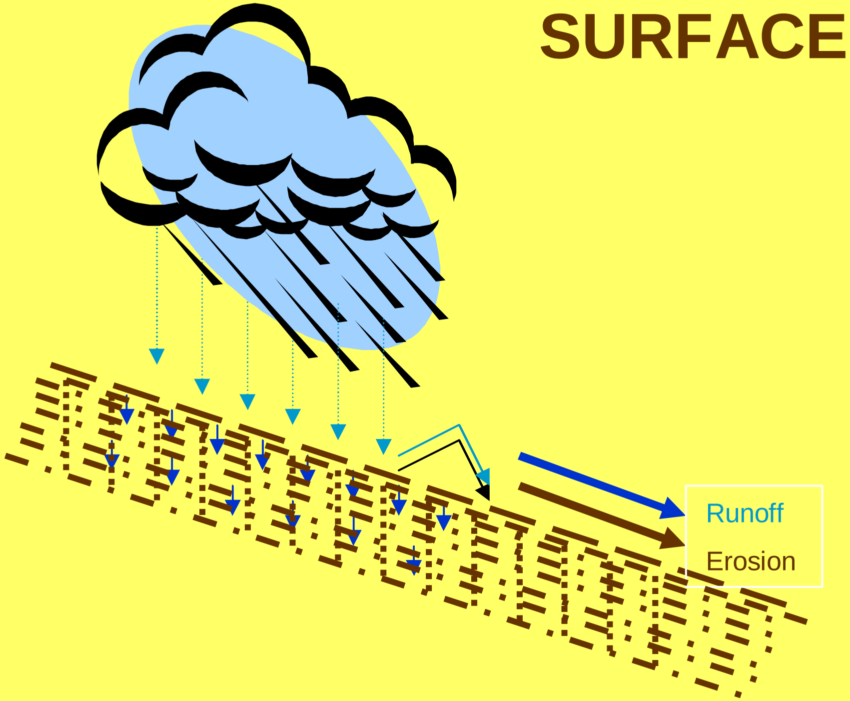
Among the different land degradation processes, soil water erosion is the major threat to the conservation of soil and water resources.

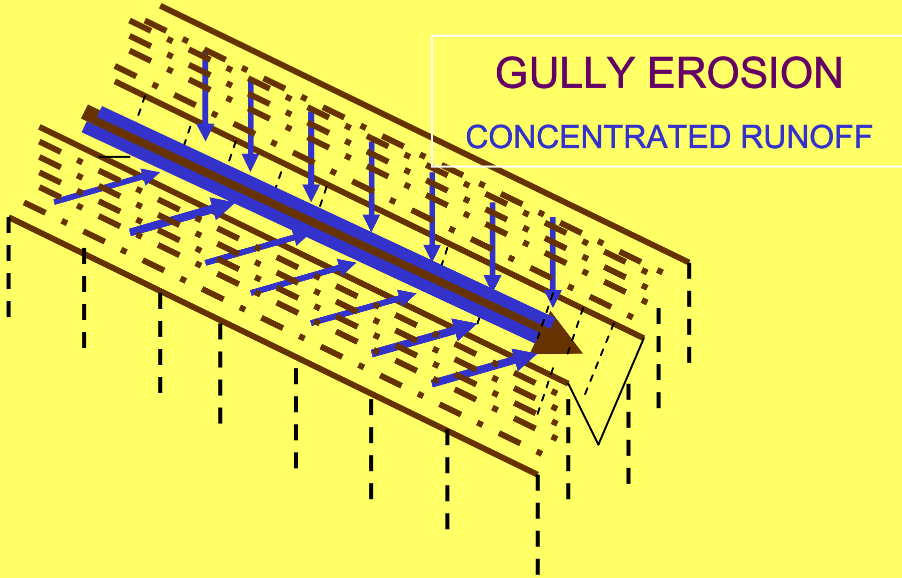
The processes of soil erosion, caused by the interactions of soil, rainfall, slope, vegetation and management, generally result on, or there are caused by unfavorable changes in the soil water balance and in the soil moisture regime, and in the possibilities of root development and activity.

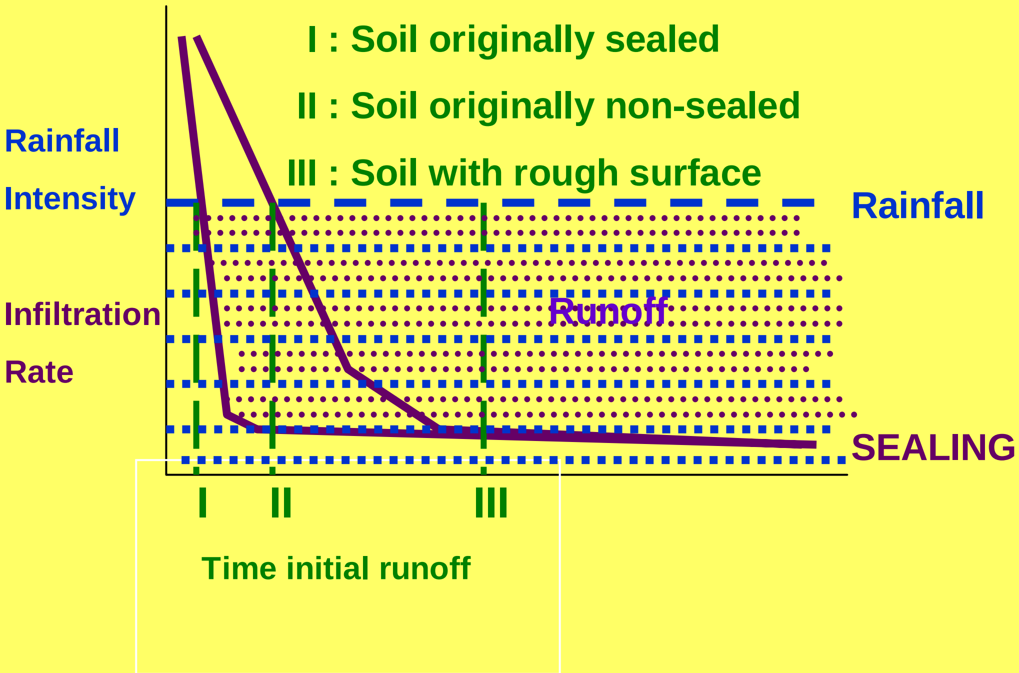
Soil erosion processes have direct negative effects on plant growth and crop production, and offsite effects on increased risks of catastrophic floods, sedimentation, landslides, etc.

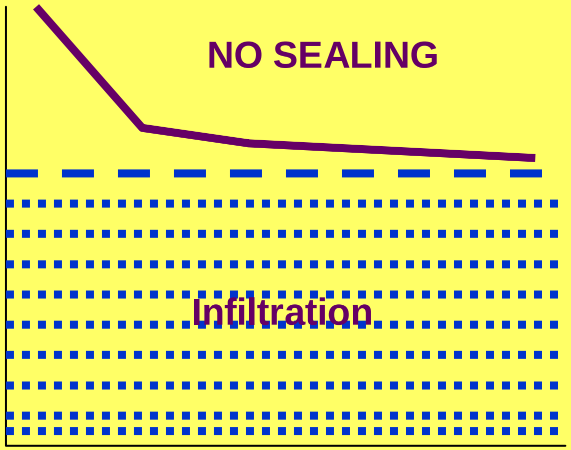

SURFACE EROSION PROCESS
Sandy loam alfisol. 6% slope. Bare
Simulated rainfall: 60mm/ 1 hour (RP:2 years)
mm
CUM RF - INF RUN SM - FC
Mg - ha CUM SOIL LOSS
75
50
25
0
20
15
10
5
0
0
15
30
45
60
Time (minutes)
Soil moisture(SM)
Field cap. (FC)
Cum Rain (RF)
Cum Infilt. (INF)
Cum. Runoff (RUN)
Cum. Soil Loss

SURFACE EROSION









Besides <u>surface erosion</u> in gentle to moderate slopes, <u>mass movements and landslide erosion</u> are common in more steep slopes.

In <u>surface erosion</u>, the soil particles detached by rainfall or running water, are transported by surface flowing water (surface runoff).

<u>Mass movements</u> are the gravitational movements of soil material without the aid of running water.

The <u>hydrological processes</u> leading to surface or landslide erosion <u>are different</u>, and therefore, soil conservation practices very appropriate for <u>controlling surface erosion processes may increase erosion danger by mass movements</u> under specific combinations of climate, soil and slope.

Landslides : Deforestation and intensive agricultural use

(Guatemala)

Mass or landslide erosion generally affects soils with exceptional resistance to surface erosion due to excellent structural and hydraulic properties of the surface soil.

Mass movements are generally initiated during and after concentrated and continuous precipitation events, and are associated with prolonged wet periods as a result of persistent antecedent rainfall, in soils with infiltration rates higher than internal drainage, which causes periodic saturation of the overlying soil.

In deeper unconsolidated sedimentary or volcanic materials or in deeply weathered rocks, with decreasing permeability with depth, the accumulation of internal drainage water below the surface soil cover may lead with time to potential conditions for larger and deeper mass movements.

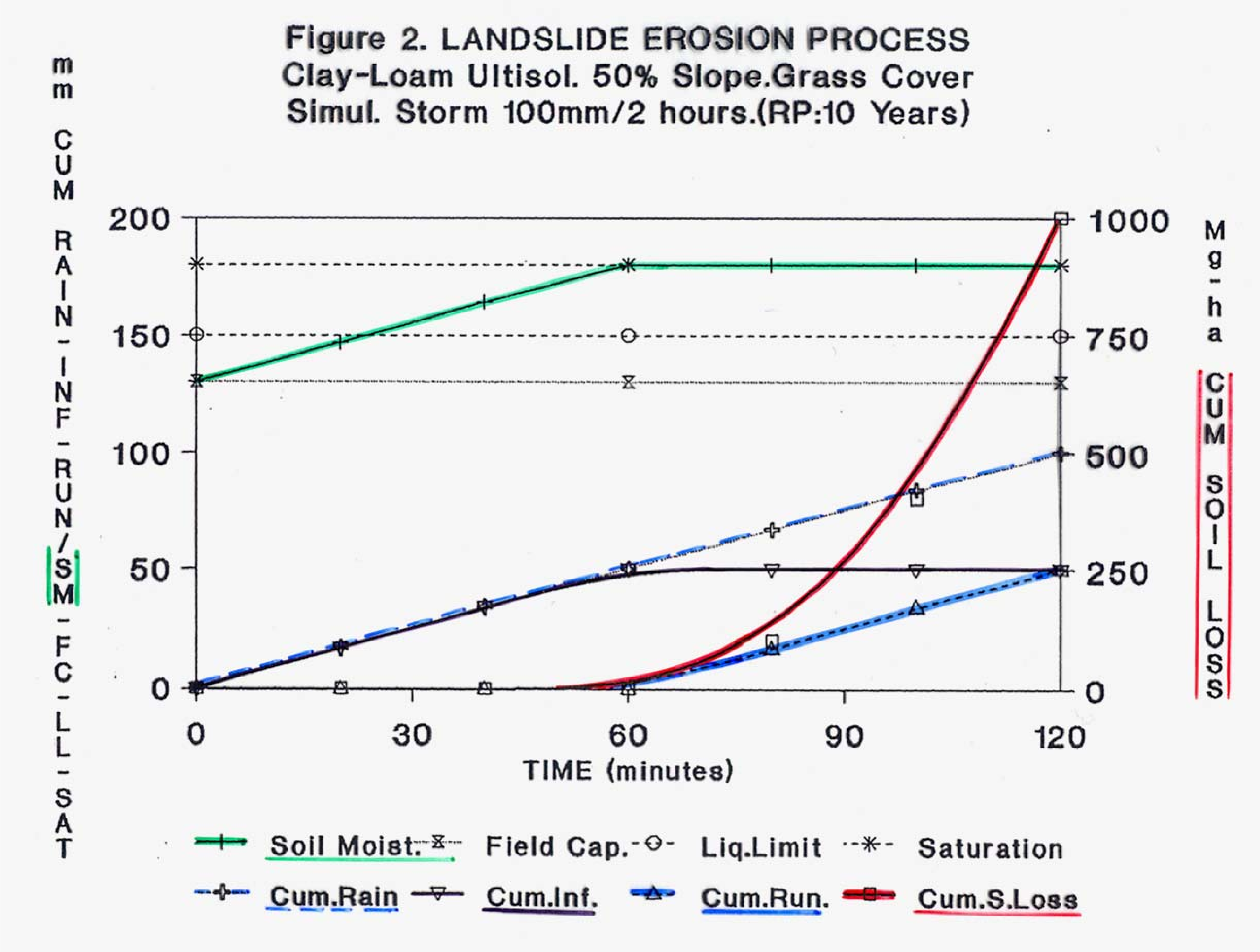


Figure 2. LANDSLIDE EROSION PROCESS
Clay-Loam Ultisol. 50% Slope.Grass Cover
Simul. Storm 100mm/2 hours.(RP:10 Years)
mm CUM RAIN-INF-RUN/SM-FC-LL-SAT
Mg-ha CUM SOIL LOSS
200
150
100
50
0
1000
750
500
250
0
0
30
60
90
120
TIME (minutes)
Soil Moist.
Field Cap.
Liq.Limit
Saturation
Cum.Rain
Cum.Inf.
Cum.Run.
Cum.S.Loss

LANDSLIDES

(MASS EROSION)

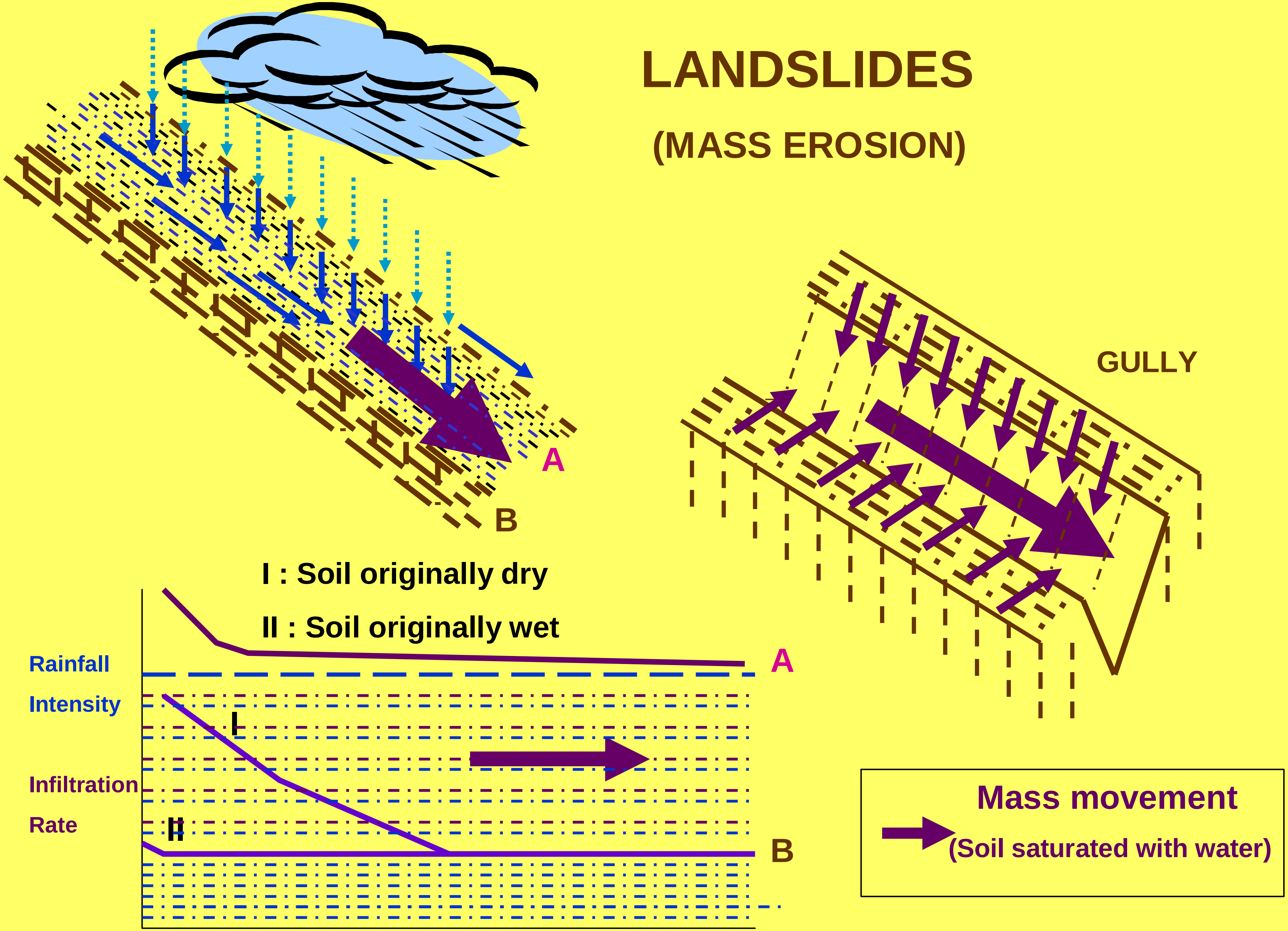
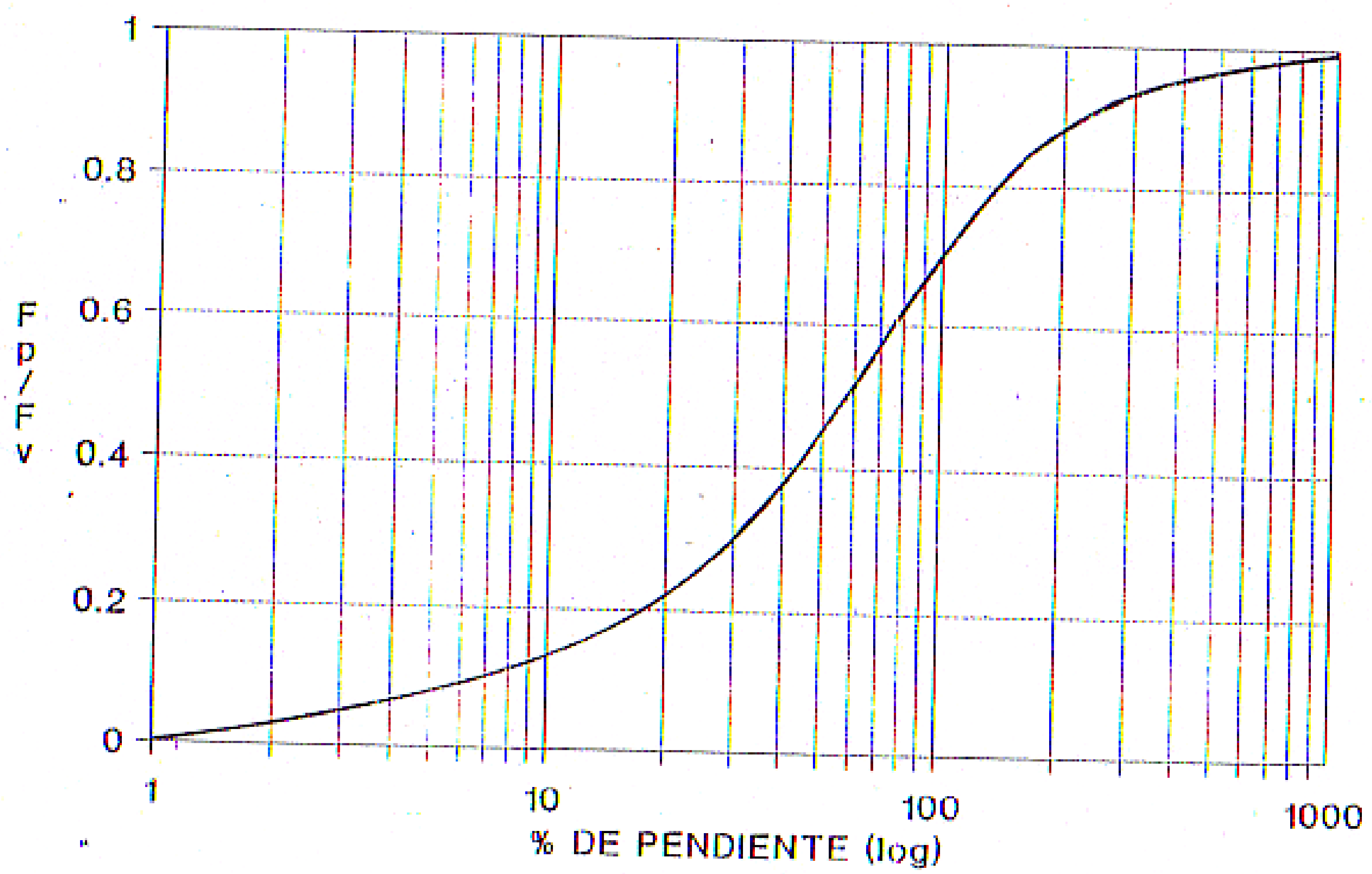
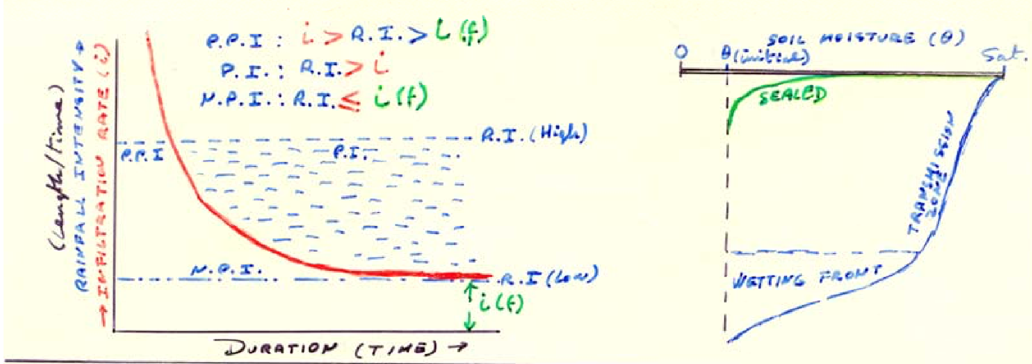
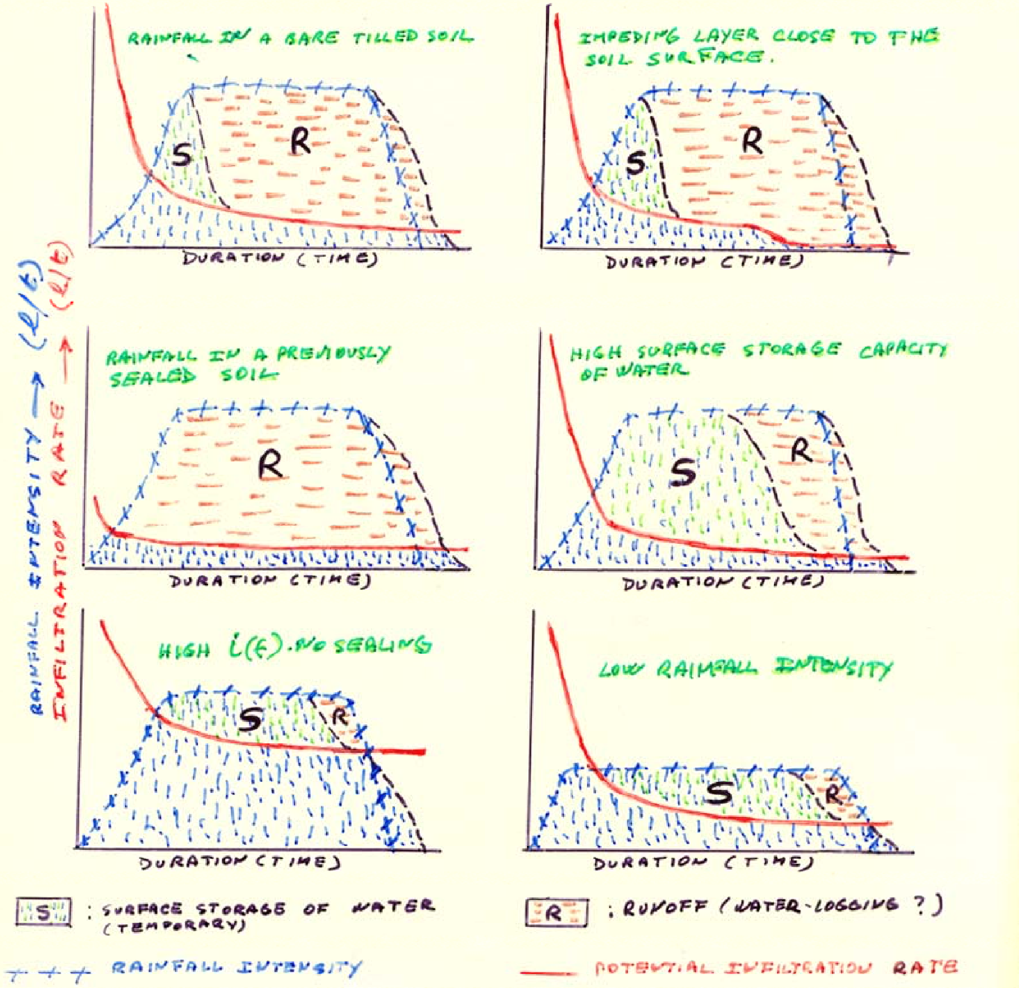


Figura 3. FUERZA DE DESLIZAMIENTO(Fp)en relacion a fuerza vertical(Fv=Masa de suelo x g) VS GRADO DE PENDIENTE





INFILTRATION AND RUNOFF (OR WATERLOGGING) DURING A RAINSTORM



BIOFUELS AND SOIL DEGRADATION

Biofuels are all kind of fuels, solids, liquids or gases, derived from biomass.

Their use in substitution of fosil fuels has been proposed as an alternative to moderate the global climate change derived of the accumulation of greenhouse gases in the atmosphere.

Because the accelerated and great increase in the production of energy crops may lead to the incorporation of new lands to cropping and to changes in use of the presently cropped lands, with effects on the resources soil and water, it is indispensable to consider this new situation

among the more important factors which can contribute in the near decades, in a positive or negative direction, to the processes of soil degradation and land desertification.

Ecologicamente Orientado

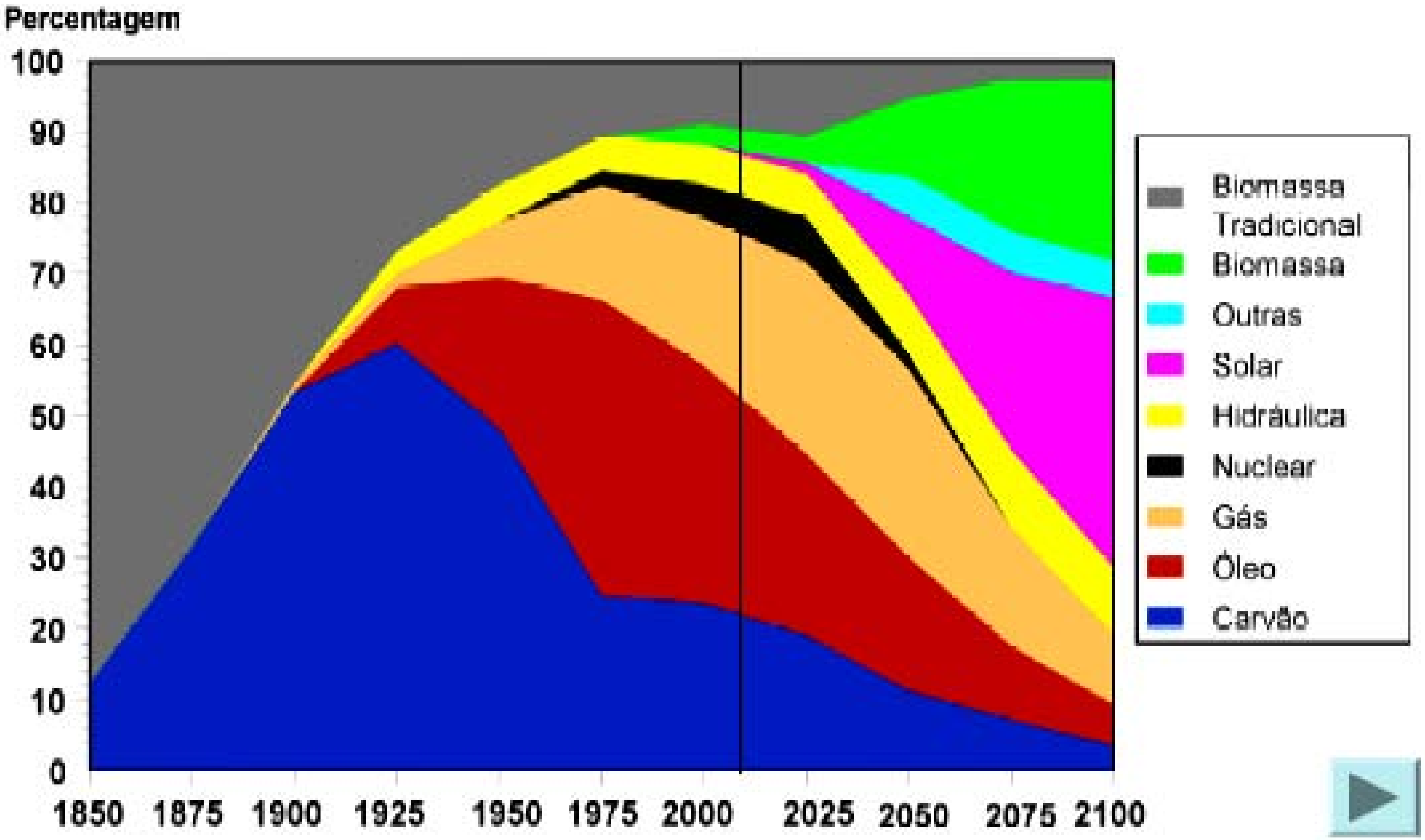


Figure 1. World Fuel Ethanol Production, 1975–2005

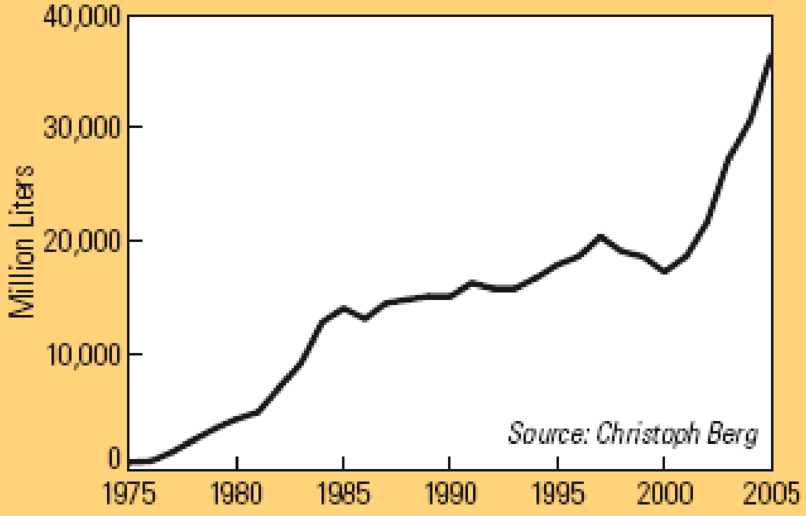


Figure 2. World Biodiesel Production, 1975–2005

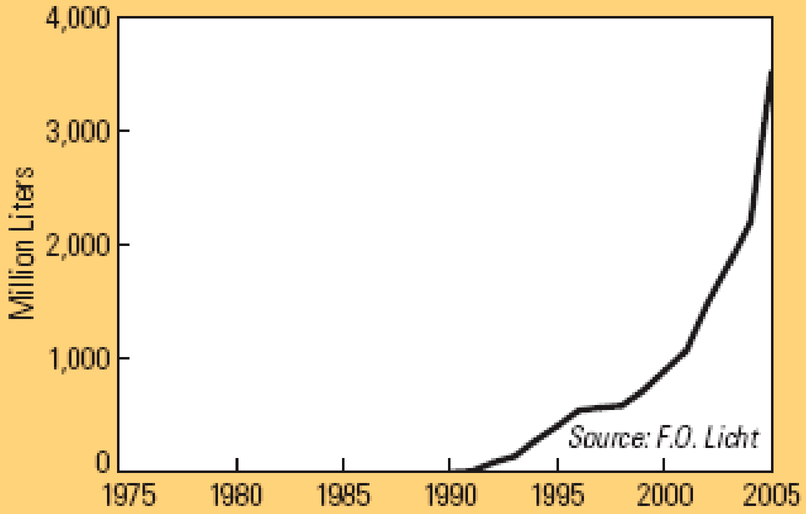
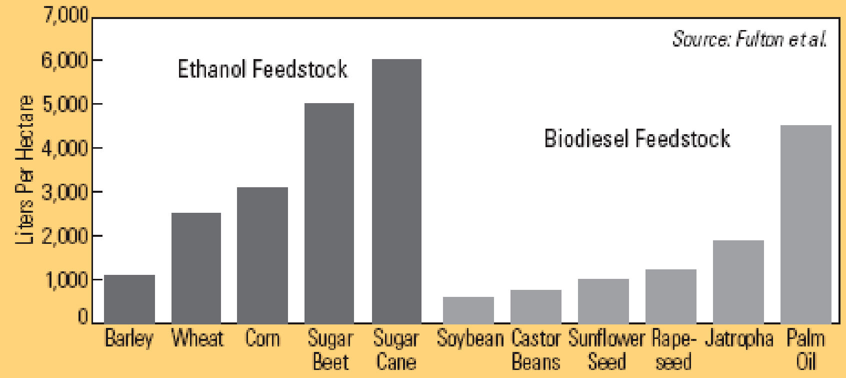


Figure 4. Biofuel Yields of Selected Ethanol and Biodiesel Feedstock

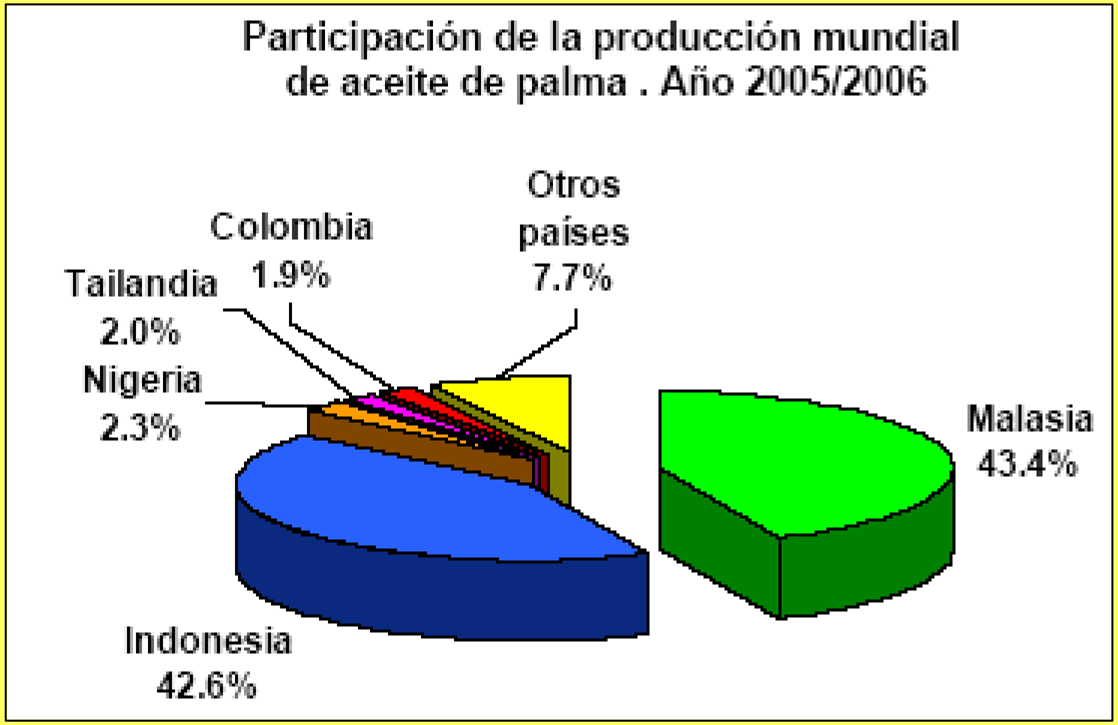


Sugar Cane

(Bioethanol)(6000 l/ha)

Oil Palm

(Biodiesel)
(5000 l/ha)

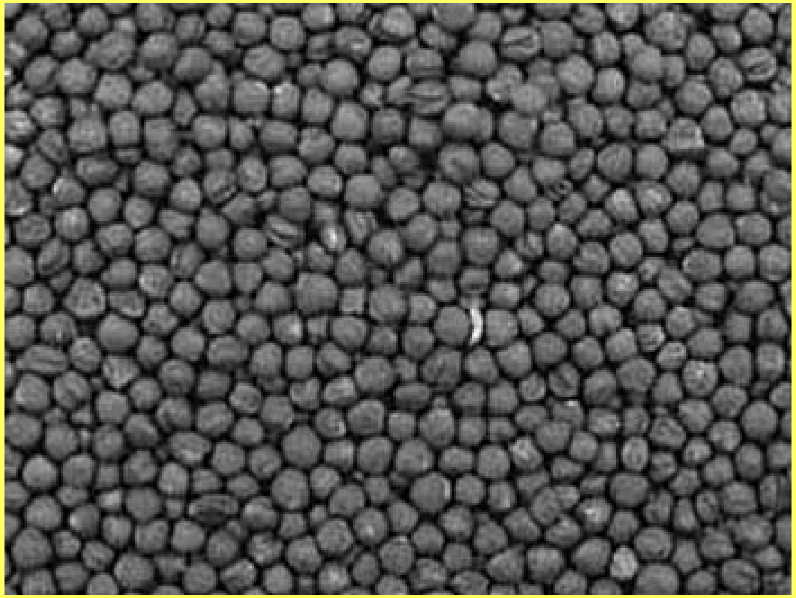


Sunflower Seed

(Biodiesel)(1200 l/ha)

Soybean

(Biodiesel)(700 l/ha)



Rapeseed

(Biodiesel)

(1500 l/ha)

Corn

(Bioethanol)
(3000 l/ha)

Sugar Beet

(Biodiesel)(5000 l/ha)

Wheat

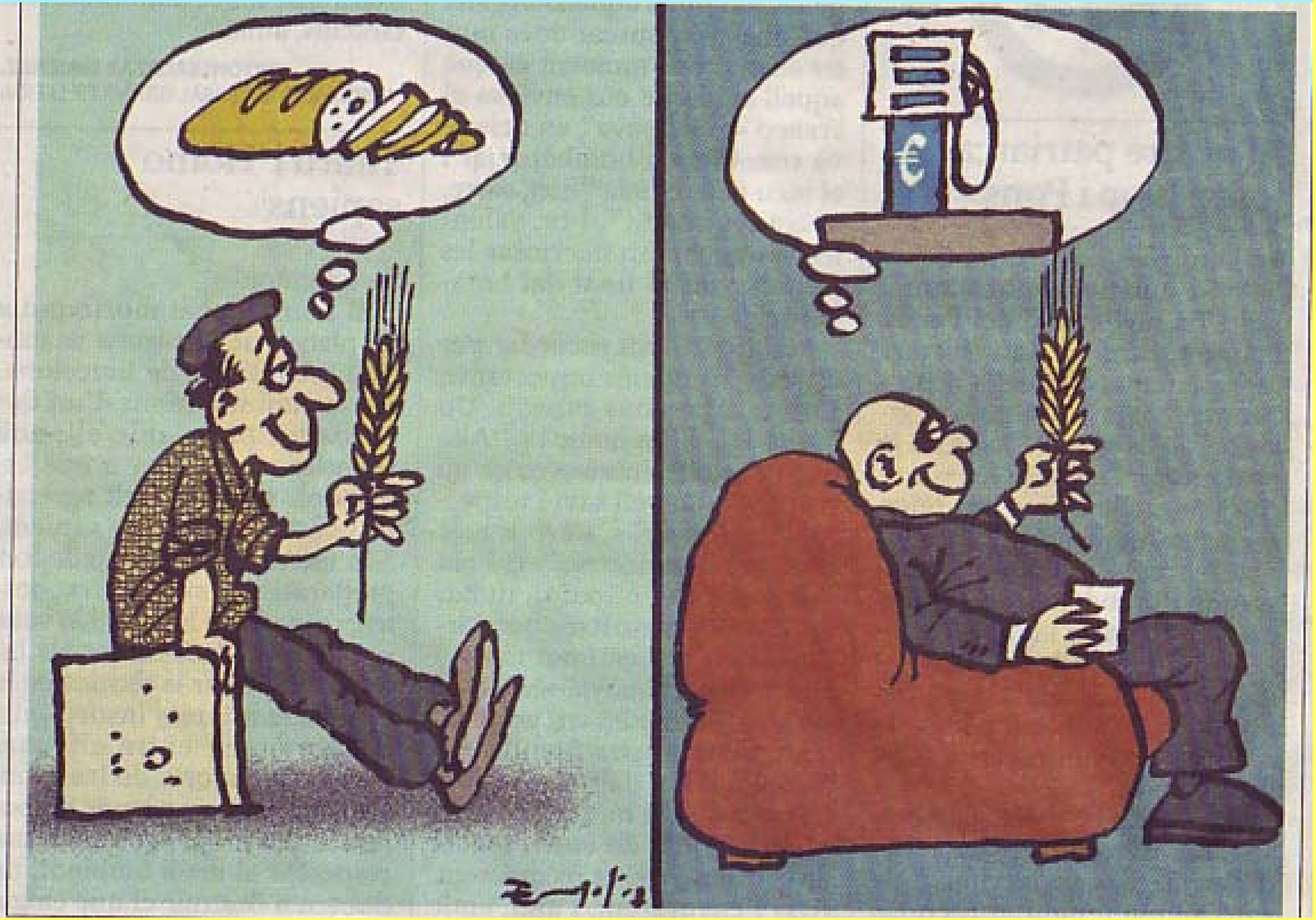
(Bioethanol)(2500 l/ha)

Barley

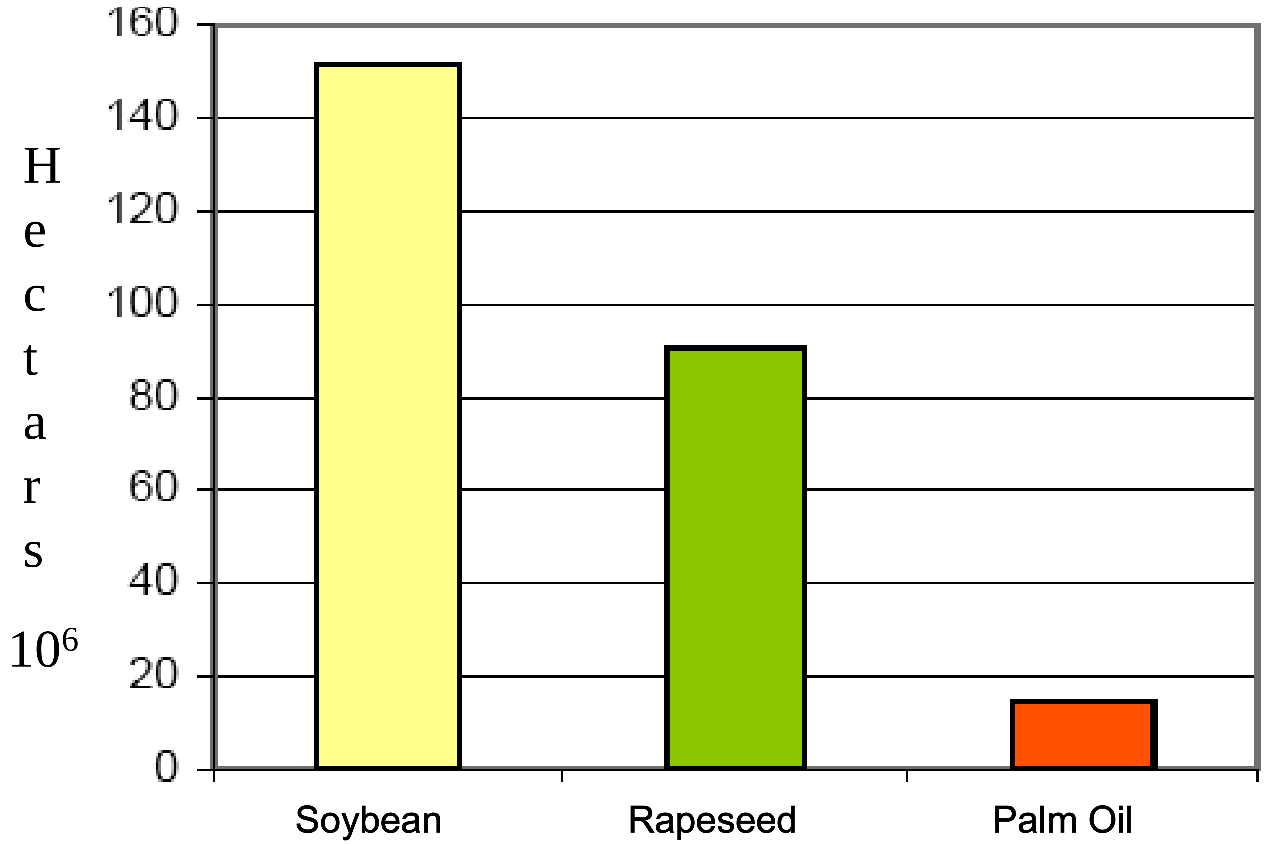
(Bioethanol)(1000 l/ha)

EFECTOS DE LA COMPETENCIA DE USO DE CEREALES PARA ALIMENTOS O BIOCOMBUSTIBLES

A los alemanes les preocupa el incremento del precio de la cerveza por el aumento del precio de la cebada



Requirements of newly cropped ha to produce biodiesel



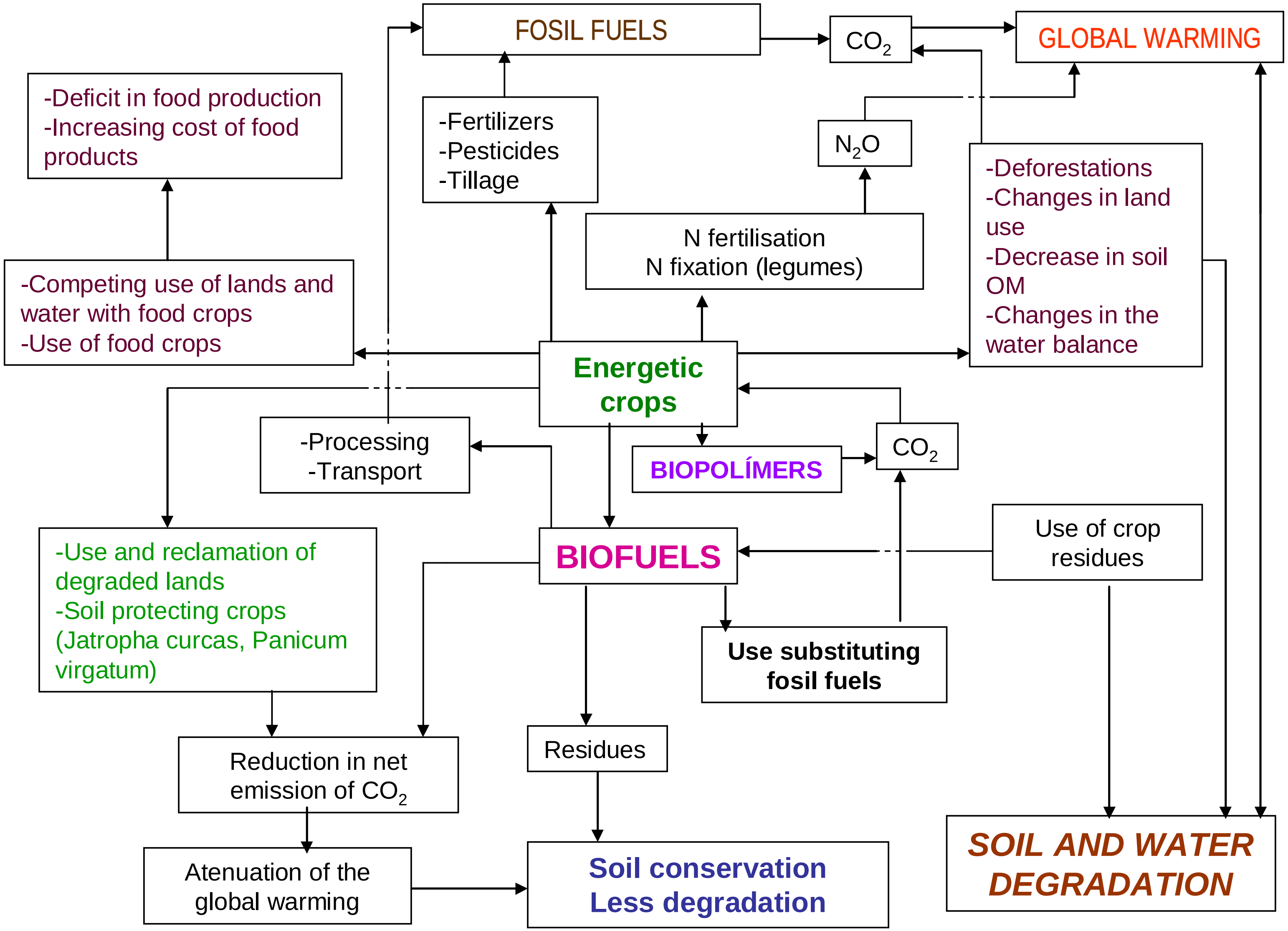
To substitute 5% of the biodiesel consumed worldwide there would be required 55 million metric tones of vegetal oil

Jatropha curcas (Euforbiacea)

(Biodiesel) (2000 l/ha)


Switch Grass **(Panicum virgatum)**

(Bioethanol)



Potential effects of biofuel production on soil and water degradation and global warming

FINAL RECOMMENDATIONS

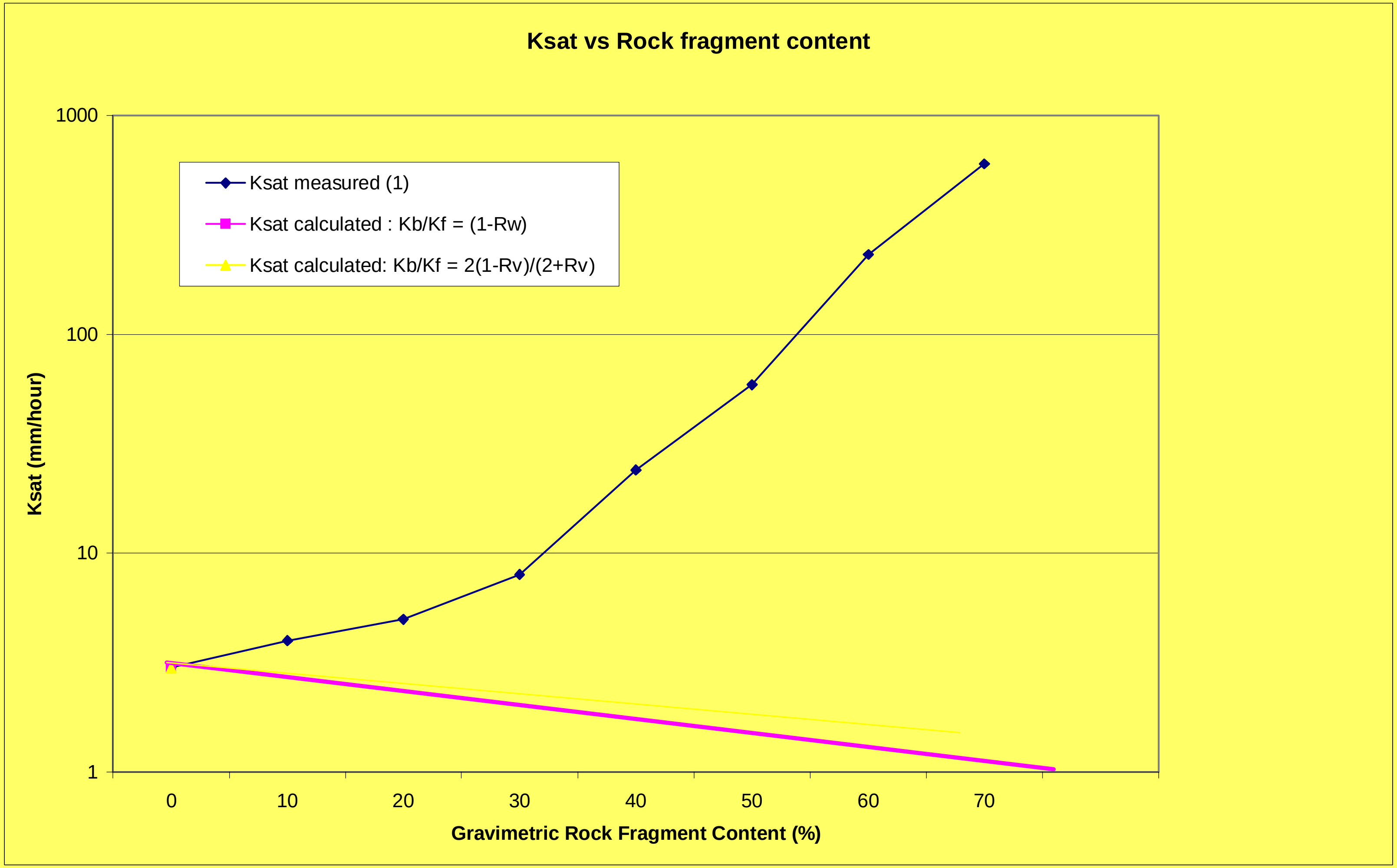
-Before starting any evaluation or research related to soil physics, independly of their nature, you have to consider its direct, indirect or even remote relation with the functions of soil as regulator of the environment and as a source of goods and services

-When selecting, adapting or developing methodologies for evaluation of the soil physical and hydrological properties, more than the precision of the available equipment you have to consider the possibilities to get the information with the approximation you require for any particular purpose, corresponding to the behavior of the soil under field conditions

-Avoid the use of pedotransfer functions or models with empirical approaches, unless the correlations in which they are based have a physical meaning, and have been developed or tested with appropriate local field information

-Take into consideration that most of the soil physical properties important for environmental or crop production purposes, are closely associated to other chemical and biological soil properties. Therefore, any evaluation of such physical properties have to take into consideration such interrelation, or have to be made as a part of an interdisciplinary team covering those aspects,

-Be aware that any careful direct observation and measurement, even if they are made with very simple and not very precise equipment but with a good physical basis, could be much more useful and exact than any detailed theoretical deduction based on very precise laboratory measurements on non appropriate isolated soil samples



Ksat vs Rock fragment content
1000
100
10
1
Ksat measured (1)
Ksat calculated : Kb/Kf = (1-Rw)
Ksat calculated: Kb/Kf = 2(1-Rv)/(2+Rv)
Ksat (mm/hour)
0
10
20
30
40
50
60
70
Gravimetric Rock Fragment Content (%)