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9. Autorizado por

Nelson de Jesus Parada
Director

10. Setor *DME* Código

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12. Autoria *Luiz Carlos Baldicero Molion*
Juan José Verdesio Bentancurt

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LAND-USE AND AGROSYSTEM MANAGEMENT IN HUMID TROPICS*

by

L.C.B. Molion and J.J.V. Bentancurt

Instituto de Pesquisas Espaciais - INPE

Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq

12200 - São José dos Campos, SP, Brazil

ABSTRACT

This work is a study of the interaction of climatological parameters with different land use systems in the humid tropics. The climate of humid tropical regions is characterized as a function of large scale parameters and the differences of the energy and water balances terms over different cover types are discussed. It is shown that humid forests have a higher net radiation flux when compared to different cover types and, therefore, have more energy available to vaporize water. Consequently, the changeover from forest to other land uses modifies the regional climate. An attempt is made to identify techniques wich would attenuate the land use effects on the climate of tropical regions.

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LAND-USE AND AGROSYSTEM MANAGEMENT IN HUMID TROPICS

1. Introduction

The climate of a region on the Earth's surface depends on several factors of large and regional scales, called *climatic controls*, the most important being:

a) Large scale climatic controls:

- The solar constant, i.e., the shortwave radiative energy arriving from the sun at the "top" of the atmosphere per unit area, per unit time; the orbital parameters and the gaseous and particulate components of the earth's atmosphere, altogether, determine the latitudinal distribution of the solar energy over the planet's surface. This is, by far, the most important source of energy sustaining life and the variety of physical phenomena occuring in the earth-atmosphere system;
- The distribution of continents and oceans, with their contrasting albedos;
- The general circulation of the atmosphere, which can be regarded as a consequence of the two factors above.

b) Regional scale climatic controls:

- The general circulation of the atmosphere, acting on this scale;
- The local topography;
- The nature of surface cover;
- The hydrologic cycle and
- The influence of ocean currents on coastal regions.

1.1 - Large Scale Characteristics of Humid Tropics

The large scale climatic controls are responsible for the general features of the energy and water vapor latitudinal distribution.

Figure 1, extracted from Sellers (1965), shows the average annual latitudinal distribution of evaporation (E), precipitation (r) and total runoff (Δf). As it can be seen, generally speaking, the humid tropics, are the region comprised roughly between 12^oN to 10^oS, where precipitation exceeds evaporation, with the excess of water — the total runoff — being transported to higher latitudes. Accordingly, figure 2, also taken from Sellers (1965), shows that the same latitudinal belt, with a positive radiation balance (Rg), provides most of the sensible heat which is transported poleward by the general circulation of the atmosphere (Δc),and by the ocean currents (Δf) to make up for the negative radiation balance at those latitudes. The sensible heat, carried by the general circulation, about 75% - 80% of the total heat transported poleward (Δc + Δf), is provided to the atmosphere through the latent heat excess, that is the difference between annual precipitation and annual evaporation. The large scale climatological characteristics of the humid tropics are, therefore, a positive radiation balance, an excess of precipitation over evaporation and a divergence of sensible heat flux.

Another interesting way of defining such a region is using water balance as a climatic index; Budyko (1974) defines a ratio Rg/Lr, which he calls the radiational index of dryness. Physically, it represents the ratio of the net amount of radiative energy available for evaporation from a wet surface to the amount of heat required to evaporate the mean annual precipitation. It is much greater than 1.0 in desert regions, where $Rg \gg Lr$, and it is less than 1.0 in humid regions, where $Rg < Lr$. Budiko also suggests that there is an optimum value of Rg/Lr near 1.0 at which, for a given Rg, productivity will be a maximum. For the latitudinal belt between 12^oN - 10^oS, using the annual average values for Rg = 105 Kcal/year and r = 1800 mm/year, taken from Sellers (1965), one obtains Rg/Lr, approximately equal to 1.0, meaning that in this belt, according to Budyko's

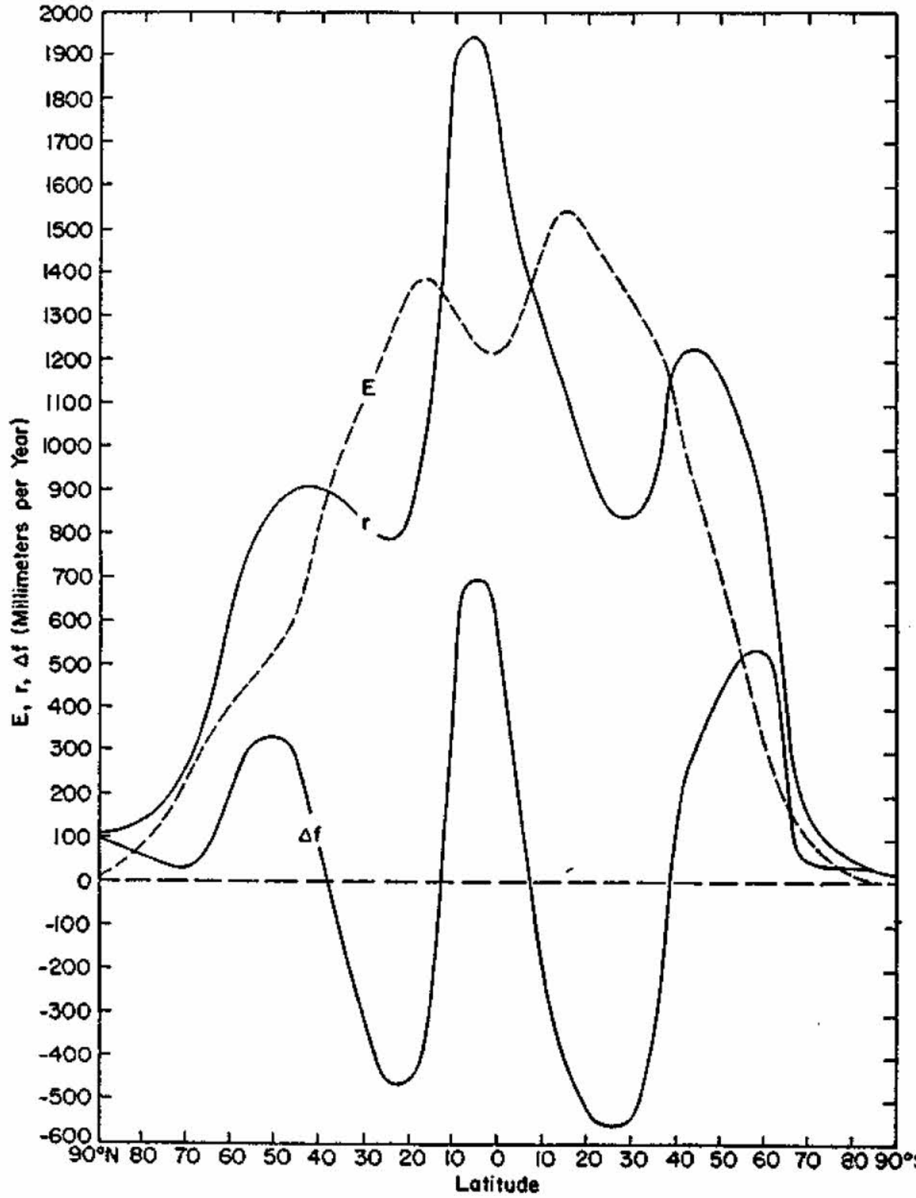

Figure 1 - The average annual latitudinal distribution of evaporation (E), precipitation (r), and total runoff (Δf = r-E).(Source:Sellers,1965).

suggestion, productivity should be maximum. However, within these boundaries, one finds regions which can be classified as semi-arid using the same criterium. This occurs due to the interaction of the regional scale climatic controls, being the general circulation of the atmosphere the most important one. The belt 12ºN - 10ºS covers an area of approximately 98 x 10^6 km^2,of which 76 x $10^6 km^2$ are oceans and 22 x 10^6 km^2 (22 percent) are land areas. About 50% of these land areas is covered with humid forest: the Central and South America, the Central Africa and the "Maritime Continent" (Indonesia, Malaysia, Philippines, New Guine,etc.) humid forests. The largest of these is the Amazonas forest, which covers an area of about 7 percent of the belt and about 30 percent of the land area within the belt. The general climatic characteristics of the "Maritime Continent" and Central America are determined by the general circulation of the atmosphere and the surrounding oceans. The Congo and Amazonas regions, however, have a certain degree of continentality and there, perhaps, local controls may have a marked influence on the regional climate. Consequently, it is in these regions that a large-scale anthropogenic action in changing surface cover may affect the climate profoundly. It is generally accepted that the changeover from forest to crop or pasture fields locally alters the heat balance. In this process, the albedo generally increases and less solar energy is absorbed in the submedium, reducing the energy available for heating the overlying air column and for convection. Exposure and cultivation of the soil greatly modify its heat conductivity and capacity, changing the heat flux into and out of the ground and producing greater temperature extremes at the surface; low level wind profile and turbulence change drastically, due to decreased surface aerodynamic roughness, yielding higher wind speeds at ground level. This, together with exposing the ground to high rainfall intensities, promotes soil erosion. On the other hand, evapotranspiration is reduced. There are a number of reasons: drainage of fields prior to cultivation,rapid runoff, bare soil for considerable periods of the year and shallower root system of a field crop compared to trees (Landsberg, 1974). Forest covered ground, therefore, evaporates more than any other land-use type (Geiger, 1971).

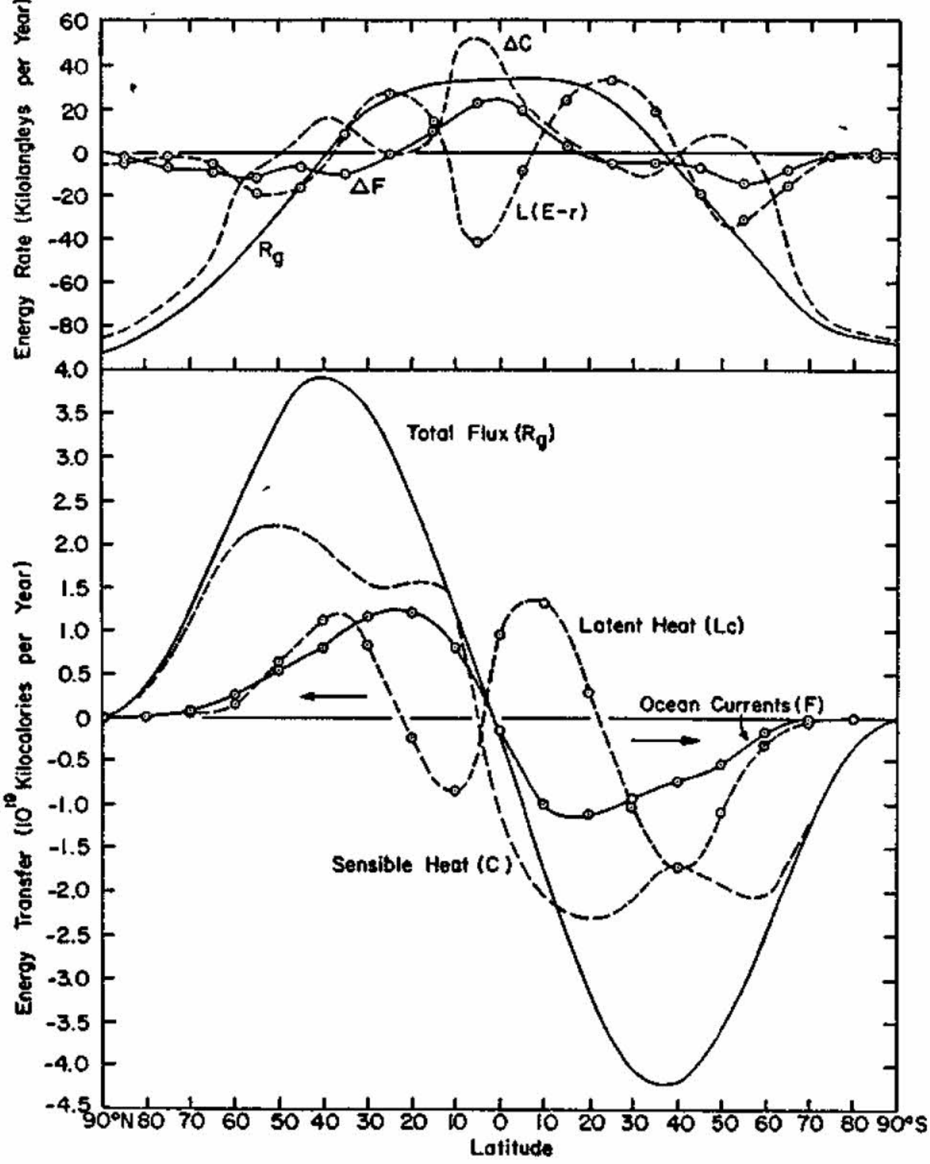

Figure 2 — The average annual latitudinal distribution of the components of the energy balance of the earth-atmosphere system in kly year^{-1}(top) and of the components of the poleward energy flux in 10^{19} kcal year^{-1} (bottom). (Source: Sellers, 1965).

The effects of surface changes may also influence the climate in a larger scale. Newell (1971) expressed his concern in this regard: "Most of the contribution to the latent heat term comes from South America, Africa and the *"Maritime Continent"* ... What will happen to the large scale atmospheric general circulation, if tropical forests are removed over Brazil and Indonesia — and perhaps over Central Africa?"

With increasing world's population, one might expect that the humid tropics with no shortage of solar energy and of water will be urged to be transformed in food producers. An attempt is made here to analyse the interaction of the meteorological parameters and forms of land use for these regions, possibly pointing out the suitable land use systems which lead to the smallest climatic changes. It is also attempted to identify the meteorological information and research to improve agrosystems management in these areas.

1.2 - Land Use Systems in The Humid Tropics

Beforehand one should exclude the methods still in practice in developing tropical countries, namely the large scale land transformation by slash and burn and the subsequent use of techniques, which have proved their effectiveness in temperate latitudes.

Paradoxally, the only technique of land use, which has succeded in the humid tropics, is the one used by the indigenous tribal communites, although nowadays it would not be able to supply the food demand. The method consists of clearing a few hectares of forests and establishing the cultures. When the land loses its fertility a few years later, the plot is abandoned and the natives move to another place, where the process is repeated. In the fallow plot, the forest takes about 30 years to grow back; it reaches a secondary climax because the changes to which it was submitted were not profound. The natives had cleared the space leaving the larger trees and had worked the land using primitive tools which do not compact the soil. There is a lesson to be learned from this primitive settlers: exploitation of small areas and a large fallow period of 30 to 50 years depending on the soil needs.

The National Center for Scientific Research of France is carrying an experiment in the French Guyana with the objective of studying the behavior of the tropical forest. The scientists have already verified that its capacity of regeneration is very weak and its equilibrium is very delicate. The frequently prevailing idea is that a soil, having a certain level of fertility, retains it naturally through the period of its utilization and development. This is far from true and, even with cultivation in a rainy climate, the replacement of natural vegetation by cultivated vegatation accompanied by the necessary working of the soil, the contribution of organic matter, mineral improvements, fertilizer harvesting, crops etc., changes a number of processes in the evolution of soil. Unfortunately, there are inumerous examples, in tropical regions, where the changes of natural conditions, caused by new land use patterns have led to soil deterioration and local climatic changes which have been detrimental to agriculture.

2 - The Energy and Water Balances in the Humid Tropics

As it was seen, the large scale climatic controls give the general characteristics of the humid tropics. In the regional scale, it seems appropriate to discuss the interaction of land use and meteorological parameters in view of the energy and the water balances for the active surface. However, only recently, the tropics have been object of such studies and there are not many results available. Thus, most of the following discussion will be based on scientific knowledge, acquired from studies accomplished for other latitudes.

2.1 - The Energy Balance

Baumgartner (1967) studied the differential evaporation fluxes from forest and three other types of land use based on the flux components of the energy balance equation. Following his procedure, one can write the radiation balance equation as:

$$Rn = SW\downarrow + DSW\downarrow - RSW\uparrow + LW\downarrow - LW\uparrow - RLW\uparrow \qquad (2.1)$$

where

- Rn = net radiation or radiation balance
- SW↓ = direct solar radiation
- DSW↓ = diffuse solar radiation
- RSW↑ = reflected solar radiation by the surface
- LW↓ = thermal atmospheric radiation or counterradiation
- LW↑ = thermal radiation emitted by the surface
- RLW↑ = reflected thermal radiaton by the surface.

The terms SW↓ and LW↓ are not influenced by the surface cover and DSW↓ only slightly, through backscattering; RLW↑, in general, is neglected, because most of the natural surfaces absorb thermal radiation nearly as a black body. Accordingly, the only pertinent variations with regard to the latent heat flux are those associated with the reflected solar radiation (RSW↑) and the thermal surface emission (LW↑).

Equation (2.1), then, can be rewritten as

$$Rn = ASW\downarrow - LW \qquad (2.2)$$

where

$ASW\downarrow = GSW\downarrow\,(1-a)$ = absorbed solar radiation at the active surface
$GSW\downarrow$ = direct plus diffuse radiation
LW = net thermal radiation
a = surface albedo

The average values for incident solar radiation and counterradiation were taken as $GSW\downarrow = 200\ wm^{-2}$ and $LW\downarrow = 400\ wm^{-2}$ (Molion, 1976). The albedo and emissivity values are quoted in Sellers (1965). The forest canopy was assumed to be at the mean annual temperature of the equatorial belt, $T = 298^{o}$ K (Sellers, 1965) and the arable land, grassland and bare soil were 2^{o}, 5^{o} and 10^{o}, respectively above that.

The following table was constructed for four land use types. E is simply Rn expressed in mm $year^{-1}$ and can be considered as the equivalent water vapor losses.

TABLE 2.1

RADIATION FLUXES AT THE ACTIVE SURFACE

FLUXES and PARAMETERS	FOREST	ARABLE LAND	GRASS LAND	BARE SOIL
(1-a)	0.90	0.80	0.75	0.70
$ASW\downarrow\ wm^{-2}$	180	160	150	140
ε	0.97	0.96	0.95	0.93
T ^{o}K	298	300	303	308
$LW\uparrow\ wm^{-2}$	430	437	450	470
LW wm^{-2}	30	37	50	70
Rn wm^{-2}	150	123	100	70
E mm yr^{-1}	1800	1476	1200	840

If all the net radiation were used to evaporate water, tropical forests would have an evaporation more than twice as high as bare soils.

The net radiation is the radiative energy available to be partitioned among the other forms of energy:

$$Rn = H + LE + S + F \tag{2.3}$$

where

H = sensible heat flux to the atmosphere

LE = latent heat flux to the atmosphere

S = heat conduction into the soil

F = energy flux used in photosynthesis

The last term of equation (2.3) is usually disregarded under the argument that it is,in average, about 0.5% of the incoming solar radiation, not exceeding 1.0% of it. Considering the mean annual balance, the term S is usually not of interest, since its net value tends toward zero. However, on seasonal or daily basis, this term is of relative importance.

Table 2.2, adapted from Baumgartner (1967), shows the soil heat flux (S*=S/Rn) and the net radiation at the ground (Rno) under different cover types, in percentage of the net radiation at the active surface. for a typical sunny day.

TABLE 2.2

SOIL HEAT FLUX(S*) AND NET RADIATION AT THE GROUND(Rno) UNDER DIFFERENT COVER TYPES

FLUXES	BARE SOIL	SHORT GRASS	GRAIN	TALL GRASS	SPRUCE FOREST
Rno	100	50	20	9	7
S*	23	15	10	5	4
Rno - S*	77	40	10	4	3

Both, the net radiation at the soil surface (Rno) and the soil heat flux decrease with increasing canopy mass. The quantity (Rno-S*) reveals that the maximum energy for the latent heat flux at the ground surface is for the bare soil. Thus, the latent heat term for evaporation of soil moisture may be about two-thirds of Rn for the bare soil and only about 3 percent of Rn for the forest soil. In table 2.2 it is apparent that the net radiation, converted within the canopy,increases with increasing canopy mass, being zero percent for the bare soil and 93 percent for the spruce forest. Read (1977) estimated 57 percent of net radiation absorption in a tropical forest, in Panama. Geiger (1971) quotes several authors who measured solar radiation at ground level under tropical rainforests; the figures range from 0.5 to 1.0 percent of the total radiation incident at the top of the canopy, exceeding 1.0 percent for short periods but never more than 5.0 percent. Therefore, the forest has more energy available for vaporization by means of transpiration and interception evaporation but less for direct evaporation of soil moisture.

On the daily basis and long term average, S tends to zero. Therefore, equation (2.3) may be rewritten as

$$\overline{Rn} = \overline{H} + \overline{LE} \qquad (2.4)$$

where the overbar indicates mean values.

The partitioning of the available energy between H and LE depends primarily on the soil moisture. In nature, it seems that the process of evaporation has priority; thus, a wet surface would release more letent heat than sensible heat, the reverse occurring with surfaces under water stress. Baumgartner (1967) suggest that, for saturated surfaces, one may use values for H/Rn of the order of 0.3 to 0.4, with a tendency of surfaces, with the higher net radiation values and turbulent exchange conditions towards 0.4 and, with lower values, towards 0.2. Here, it was found more appropriate to use the concept of Bowen Ratio, $B^* = \overline{H}/\overline{LE}$, whereby equation (2.4) is modified as follows:

$$\overline{Rn} = \overline{LE}\ (1 + B^*)$$

and the latent heat

$$\overline{LE} = \overline{Rn}/(1 + B^*) \qquad (2.5)$$

Tentative values for B* are given in Table 2.3, assuming soil saturation for all four cover types, and, as before, E is the equivalent vapor losses in mm $year^{-1}$

TABLE 2.3

ENERGY FLUXES AT THE ACTIVE SURFACE

FLUXES and PARAMETERS	FOREST	ARABLE LAND	GRASS LAND	BARE SOIL
Rn wm^{-2}	150	123	100	70
B*	0.35	0.40	0.45	0.50
H wm^{-2}	39	35	31	23
LE wm^{-2}	111	88	69	47
E mm yr^{-1}	1332	1056	826	564

As it can be seen from Table 2.3 evaporation of forest can be more than two times higher than that of the bare soil.

In conclusion, it has been shown that evaporation differences among cover types, with no lack of water, can be quantitatively explained in terms of energy considerations alone; that forests evaporate more water than any other cover type. Finally, the energy balance concept can be used to predict the effects on local climate of different land uses.

2.2 - The Hydrologic Balance

When studying the climate of a region, the hydrologic cycle cannot be disregarded since it is a climate forming factor. First of all, because the hydrologic cycle is not only a product of the climate itself, but also of the biological-geographical landscape. Second, it exerts an influence on climate, which cannot be reduced to the combined effects of the other climate forming factors, namely the interaction of the atmospheric moisture, precipitation and runoff. The hydrologic cycle is broken into two parts for the purposes of the present discussion: the surface and the aerological branches.

2.2.1 - The Surface Hydrologic Balance

Under natural conditions, disregarding irrigation and dew formation, the principle of continuity for water requires that, for a column of soil extending from the surface to a depth where the vertical moisture exchange is practically absent:

$$P = R + E + dm/dt \tag{2.6}$$

where

P	=	precipitation
E	=	evapotranspiration
R	=	total runoff
dm/dt	=	exchangeable soil moisture

On the annual basis, considering long term means, the exchangeable soil moisture tends towards zero and equation (2.6) is rewritten as follows:

$$\overline{P} = \overline{E} + \overline{R} \tag{2.7}$$

where the overbar indicates annual means.

2.2.2 - The Atmospheric Hydrologic Balance

For the atmospheric column, extending from the surface to the "top" of the atmosphere, the balance equation, for mass continuity, is

$$E + A = P + dw/dt \tag{2.8}$$

where A is the net import rate of water vapor into the air column and dw/dt is the storage of water vapor in the column. Again, when one takes long term means, dw/dt approaches zero and, therefore, equation (2.8) is written as follows:

$$\overline{E} + \overline{A} = \overline{P} \tag{2.9}$$

Comparing equations (2.7) and (2.9), one finds that, for a stable climate, the total runoff must balance the net import of water vapor for the atmospheric-soil column, that is:

$$\overline{R} = \overline{A} \tag{2.10}$$

2.2.3 - The Hydrologic Cycle Components and Land Use Systems

In the humid tropics, the replacement of natural forests by any other type of surface cover may affect any or all of the following processes:

1. Runoff
2. Evapotranspiration
3. Net import of water vapor
4. Precipitation
5. Exchangeable soil moisture.

1. Runoff

There are no conclusive results in the literature,regarding the possible increase of total water yield on the annual basis, when forests are replaced. However, it is accepted that forested areas present smaller flood peaks compared to other land uses. Pereira (1967) comments on an experiment in East Africa,where a tea plantation substituted the natural forest: "the overall result from 1700 acre valley of 800 acres of young tea plantation has been a twofold increase in stormflow at the lowest intensity class, rising to a fourfold increase at highest class." Snow (apud Molion, 1976) studied the effect on runoff of the replacement of tropical forest by primitive agricultural system in Panama canal zone. He observed that the total runoff, for the forested period and agriculture period, did not change significantly. However, flood peaks increased in the rainy season. The change of land use affected the monthly distribution of runoff but not the total runoff. As it was seen before, the mean annual runoff is equal to the net imported water vapor into a region, since this term is controlled by the general circulation of the atmosphere, it is unlikely that $\overline{R}$ may be influenced by local changes in land use. On the other hand, advanced agriculture and flood controling techniques may satisfactorily substitute the role of the tropical forest in regulating stormflows.

2. Evapotranspiration

The evapotranspiration of a surface is composed of three fluxes: transpiration by plants, soil moisture evaporation and evaporation of rainfall intercepted by the surface cover. Forest intercepts more rainfall than any other type of surface cover; this water evaporates immediately, never reaching the soil surface. Studying the water balance for a tropical forest site, in Panama, Read (1977) states that forest interception was 50% of the annual rainfall; two stand types in the Amazonas forest at San Carlos de Rio Negro, Venezuela (Heuveldop,1979), showed a surprisingly small average value of 13% for interception, especially because stem flow has not been included; Jackson (1971) estimated 5 to 20 percent interception in tropical forest in Tanzania.

Although these results differ considerably, one may conclude that replacing tropical forest by other cover types, more rainfall will be available at the ground surface for infiltration and especially for runoff, therefore, reducing evapotranspiration.

3. Net Import or Advection of Water Vapor

The advection of water vapor into a region is controlled by the general circulation of the atmosphere and, therefore, is not affected by land use changes. For a large tropical region, such as the Amazonas, for instance, large scale changes in natural vegetation may alter advection internally. Reduction of aerodynamic roughness of the surface may increase the wind close to the ground; this, in turn, would transport more water vapor upwind, changing its areal distribution.

4. Precipitation

There are two sources of moisture for precipitation: local evaporation and advected water vapor. Several studies realized in temperate latitudes (see Benton and Estoque, 1954; Rasmusson, 1968) concluded that about 90% of the total precipitation is attributed to advected moisture, even for areas of continental size. Therefore, changes of land use patterns in the tropics would not interfere with precipitation. This may be true for the *"Maritime Continent"* and for Central America. Molion (1976) and Lettau et al.(1979) have shown that local evapotranspiration is an important source of water vapor in Amazonas tropical forest,contributing to about 50 percent to precipitation. In view of this, changing forest cover to any other type of surface, reduces the local evapotranspiration and, consequently, the total precipitation.

5. Exchangeable Soil Moisture

The major factors that influence infiltration either directly or indirectly are: soil texture, soil depth, soil structure, soil porosity, antecedent soil moisture, presence of rock outcrops, amount of incorporated organic matter, presence of humus layer and litter, slope and shape of the land, smoothness of the terrain and microtopographic features, amount and type of vegetative ground cover, rainfall rate and duration.

A forest floor has high water absorption capacity,recharges more uniformly and releases water more slowly. Removing the forest protective canopy increases the availability of water at the soil surface by that percentage of rainfall, which was previously intercepted. If ordinary agricultural and grazing techniques are used, however, the soil will be compacted and this water will primarily increase the overland flow rather than infiltrate. Schubart (1977) made measurements of soil permeability in two different cover types, with the same soil characteristics, near Manaus, Amazonas: a primitive forest stand and a five years old pasture field. He found that the soil under forest cover, absorbed in the average 12.2 $cm^3/cm^2/min$ compared to 1.3 $cm^3/cm^2/min$ in the pasture field. Also, he observed that 5 to 10 cm of the superficial layer of the soil was already eroded, compared to the soil protected by large felled stems. It was seen, in a preceding section, that the availability of net radiation, for evaporating soil moisture directly, increases with decreasing surface cover. Even though the proper land use, together with land conservation techniques, may improve infiltration in relation to standard agricultural practices, the soil under cultivation will have a lower moisture retention time than that under forest. This may increase the hazards of water stress during relatively drier periods, and irrigation may be necessary.

2.3 - Concluding Remarks

One might ask now what would be the most suitable land use system for humid tropics, in the light of the preceding discussion? It appears that a balance among forest, natural or man-made, cultivated land and pasture fields (with perhaps a higher proportion of forests followed by cropland and, finally, by pastures) may be suitable land use for humid tropics. UNESCO (1970) presents three good reasons in this regard:

- Maintenance of local climatic and ecological conditions which appear, in particular, to depend upon the increase timberland in comparison with the total surface of the sector in view;

- Action on water balance in each drainage basin, though it is difficult at present to ascertain and calculate the precise effect, which the retention or disappearance of a timber area might have on this cycle;

- Protection of the soil against degradation under the action of atmospheric agents (water and wind erosion, violent thermal influences of the atmosphere on the soil).

However, the Amazonian experience with cattle raising in *"terra firme"*, where the soils are mainly sandy or lateritic types, may perhaps call for a balance between forest and crops only, especially under shade cultivation. Only a carefull research can provide arguments for the final choice and in the microscale basis, this will depend on the soil type and structure. Burgos (1979) idealized several ecosystems and microagrosystems for the humid tropics, with their respective energy and water balances (Fig. 3). There is an urgent need for establishing pilot projects with especial emphasis on the energy and water balances and sediment transport rate, so one can replace the sketchs of Fig. 3 by actual numbers. The present figures available in the literature, are mostly for temperate latitudes and for traditional land use techniques outside the tropics. With these results on hand, the task of choosing the appropriate land use system for a region in the humid tropics will become less difficult.

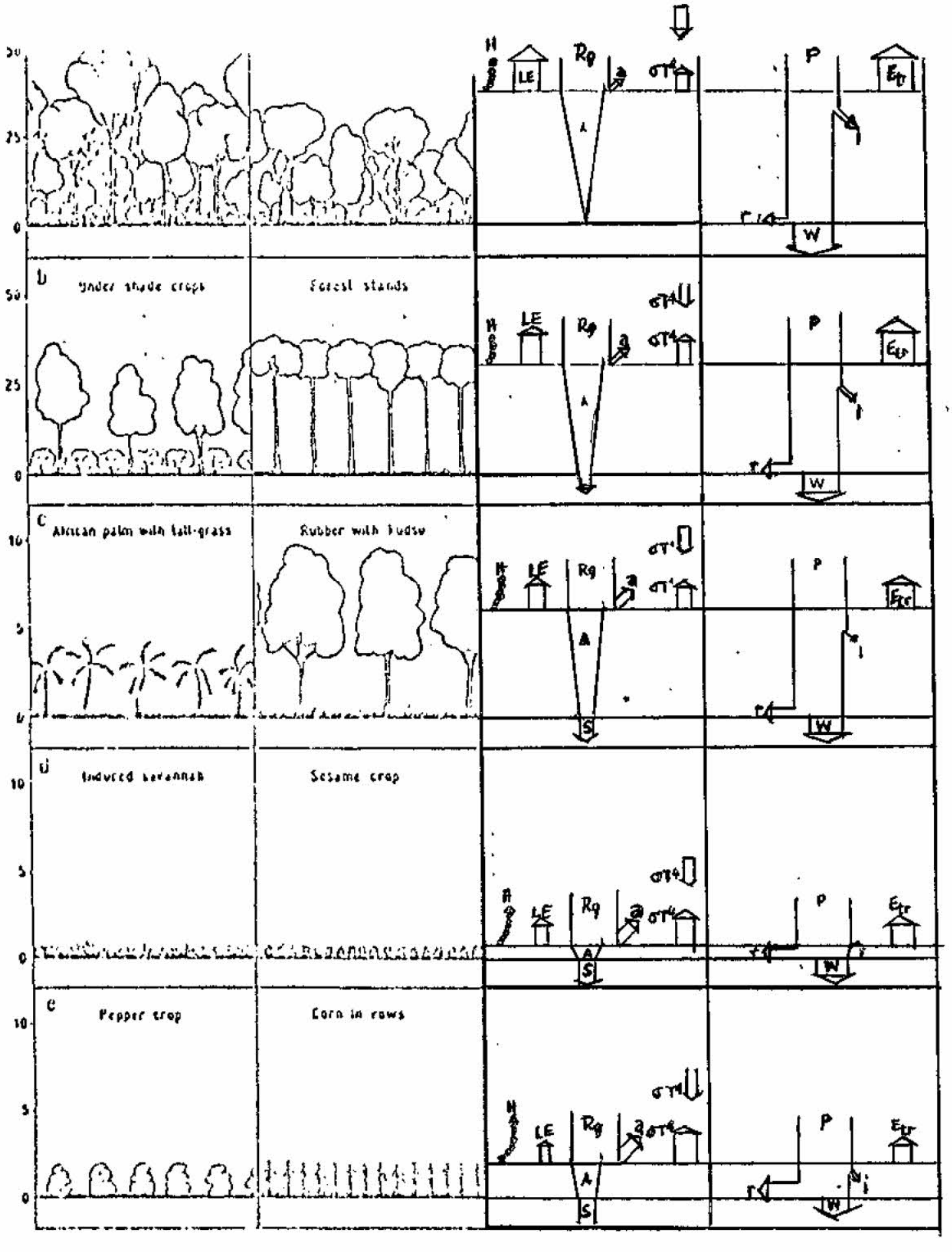

Fig. 3 - Ecosystems and microagrosystems in humid tropics forest. R, means incoming solar radiation; a, albedo; A, energy absorbed by vegetation cover; σT^4, thermal radiation; LE, latent heat; H, sensible heat; S, heat conduction into soil; P, precipitation; I, interception; r, runoff, E_{tr}, real evapotranspiration; W, soil moisture (Source; Burgos, 1979).

3 - Cultivation Under Shade

Most of the agricultural techniques were developed in regions where the available solar energy is, in average, lower than in the humid tropics. The cultivation under shade, for example, still an incipient technique, was restricted to a few crops of high commercial value such as cocoa. As stated before in the humid tropics cultivation under shade may be preferable to traditional open land cultivation or pasture fields.

Fitkau and Kling (1963) calculated that the Amazonas "*terra firme*" forest produces about 45 kg/ha of animal meat. A cattle head weighes, in average, about 450 kg; then,it would be necessary about 10 hectares to raise one single head. Santos et al. (1979) analised 12 cattle raising projects in the region of Paragominas, Northeastern Amazonas, and concluded that immediately after the deforestation and burning, the pastures supported one cattle head per hectare; after a few years, the yield decreased to 0.3 cattle head/ha, which shows good agreement with Fitkau and Klinge's (1963) calculation. On the other hand, cultivation of cocoa under shade produces about 1.5 ton/ha, which represents a gross income of US$ 5,000/ha. Considering Fitkau and Klinge figures, in terms of beef production, it would provide a gross of US$ 50/ha. Therefore, the cultivation of cocoa under shade is presently, more profitable, at the rate of 100 to one, compared to cattle production.

In the available literature, one finds that the following crops have been produced successfully, under shade:

1. *Cocoa* - This crop is suitable for fertile and well structured soils in the tropics, and naturally requires shade for its cultivation. There is already some experience acquired with this type of culture in many tropical countries (Trinidad, Brazil, Ghana, Nigeria, Costa Rica, etc.). Cocoa may be associated with banana, hevea, Brazil nuts and shaded crops such as beans.Although theoretically possible, these associations still lack accurate technical information regarding plant density, type and treatment of soils and meteorological conditions favorable to pest strike.

2. *Shaded Beans* - There is a variety of beans which are capable of growing under poor light conditions. These leguminous plants play an important role in fixing nitrogen, which improves soil nutritional conditions for other plants.

3. *Coffee* - There are species and hybrids of this plant that can produce under shade. The coffee under shade cultivation would help to protect the soil against erosion. In the past, the tropical deciduos forest of Southeastern Brazil were replaced by extensive open coffee plantations. This led to erosion and the suspended sediments concentration of Parana River reflects the present land use conditions.

4. *Palms* - This type of plant can be cultivated within the forest land, with selected species, gives better yields than most of the other types of monocultures. It accepts associations with trees and crops and produces heart of palm, oils,fruits and fibres.Some species, which develop well under shade, are "assaī" (Euterpe edulis and Euterpe oleracea), "pupunha" (Bactris gasipaes), "inajā" (Maximiliana sp). However, several other species, such as "babaçu" (Altaia speciosa and Orbignia martiana), "cohune" (Orbignia cohune), "dendê" (Elaeis guineensis) have better development with direct solar radiation, although, in nature, they are found within the forest. After deforestation in the humid tropics, it is very common the invasion of palms, especially the "dendê" and "babaçu".

There are inumerous tropical species which deserve more research on their nutritional and/or medicinal properties, such as different types of grass, shrubs and "guaranā" (Paulinia cupana).

Goddland et al. (1977) list several possible methods of utilization of the rainy tropical ecosystem, recommending the agrisilvicultural exploitation and rejecting the standard annual cycle monoculture of large extent. The worst type, they say, are rangelands.

Presently, the least expensive land use is the partial clearing of the forest and the introduction of the various species which grow under shade. This permits a rational land use for preservation of the ecosystem. However, it is still not well-known how much of the original forest may be cleared without perturbing the nutrient cycle. The main nutrients reservoir in the humid tropics is the biomass itself. If the biomass is destroyed, this reservoir vanishes. Golley et al. (1978) found in tropical forest in Panama that the inflow and outflow of nutrients are very small. Sioli (1969) studied the nitrogen and phosphorous cycles in the Negro River basin, in Amazonas. He concluded that the forest has an inflow of 6.2 kg/ha/year of nitrogen and 0.18 kg/ha/year of phosphorous through rainfall and an outflow of 4.8 and 0.1 kg/ha/year, respectively. The waters of Negro River have less nutrients than rainfall itself, indicating that the forest retains even these small imported amounts.

There is an urgent need to determine which plant species of commercial value are to be cultivated under poor light conditions; what are the water needs of such species, since these cultures compete with the protective forest for the available soil moisture; and which micrometeorological conditions favor the strike of pests in the agroecosystems.

4 - Flooding Agriculture

The tropical rivers flood plains ("varzeas") have the most suitable conditions for development of cultivation and grazing livestock. Meggers (1977) states that the more developed pre-columbian civilizations of the Amazonas region were the ones which exploited the "varzeas". The major problem is how to benefit from the high and low water stages annual cycle. The flooding brings natural fertilizers for the soil; when water lowers, there is an explosive plant mass production, with high levels of primary production per unit area. At this time, the aquatic animals have abundant supply of food. The lower water stage may be used for seasonal cropping and, as it happens in temperate latitudes, the production surplus may be stored for high water stage season.

There are several types of crops which can be raised in "varzeas" with high yields. Goodland et al. (1977) cite peanuts, ramie, chick-peas, jute, soybeans, cassava, tobacco, rice, sesame, "urena spp", cow-pea (vigna ungiculata) and maize. Different types of grass that exist naturally in the "varzeas" could be used for feeding livestock. An example of well succeeded rice cultivation with polders ("dikes") is the Jari project in Amapá, Northeastern Amazonas. They have two harvests per year with high yields.

The proteins can be produced by rational exploitation of native and exotic animals such as buffaloes, reptiles (alligator,turtles), fish and mammals (tapir, cow-fish and several types of rodent), using natural or captivity conditions.

Besides the rich fertile conditions, the "varzeas" have the advantage of being the stronger ecosystem than the "terra firme"; the soil erosion is less pronounced. Henceforth, the exploitation of humid tropics should begin with the "varzeas" rather than the "terra firme".

It is necessary to develop more research to gain better knowledge on high/low water stages, polders techniques and nutrients cycles; to search for other types of grass and to ameliorate the existent ones.

5 - Flooding Grazing Livestock

The problem of allocating land for a specific use is very complex. Although economic and social considerations are of the uttermost importance, long-term ecological factors can often be critical. Environmental factors such as climate, soil and topography are the best guides for the long-term use of land and, of those, a combination of rainfall and temperature often constitute the main factors which determine whether a region is to be used for livestock production and, if so, what type of livestock is to be practised.

In many parts of the world, population pressure and/or the increasing needs for cash and food crops have led to the development of extensive livestock industries in those areas which are least atractive to human settlement and least suited to crop production. Where livestock industries occur in areas of dense human population and high agricultural potential, they are usually of an intensive type (eg. feed-lotted or housed ruminants, intensive pig and poultry production) and the livestock is protected, to some extent, from natural environmental changes and, conversely, the environment is protected from it!

During the 1960's, the Brazilian government, aiming at the economical development of the Amazonas Region, offered fiscal incentives for implantation of cattle raising projects. Investors involved in this interprise were from Southern Brazil and, among them, multinational livestock corporations. The story is repeated again; instead of attempting to tame indigenous species, they brought into this new environment their domesticated livestock and cultural techniques of their homelands, which could be applied only to "terra firme" areas. This implied in the replacement of natural forests, with poor soils and adverse meteorological factors, by pasture fields.

Santos et al. (1979) studied 12 cattle raising projects in the region of Paragominas, state of Pará, located at Northeastern Amazonas. They analised the pasture management pratices and the physical conditions of the areas where the projects were installed, taking samples of soil, grasses and grass rooting systems. They also questioned the projects managers, regarding the deterioration of pasture fields. They found that, presently, pastures cannot support more than one cattle head per hectare; that the major part of these projects has the pastures in a fairly developed state of degradation caused by erosion, laterite formation and bush encroachment, especially the "juquira" bush. They concluded that the ultimate causes leading to failure are deforestation of improper areas, location of pastures in areas of climatic restriction (with considerable water stress), the use of inadequate techniques (such as deforestation, burning, grass aereal sowing), overgrazing and mismanagement of pastures. The "terra firme" areas in Amazonas, therefore, cannot be used for livestock production by traditional techniques without destroying the environment.

As mentioned before, the richest areas in nutrients are the "varzeas". Due to periodical floodings, the "varzeas" cannot maintain traditional cattle production. According to the natives and local tecnnicians, the best suited cattle species for the "varzeas" is the water buffalo. They state that these animals can adapt very well to the "varzeas" conditions. Quoting a native: "they live in the water; they are resistant to the "carapanã" flies and, when it is necessary, they dive and search for their own food". The water buffalo, however, has been used in several Asian countries as draft animals, and as meat or milk producers they may not be the most efficient species available. It is, therefore, necessary to measure the performance of the species with respect to both, their ecological adaptability and their economic suitability.

The theme on cattle production in humid tropics was brought about in view of the need to use, efficiently, the animal protein resources for the benefit of mankind, which has never been more urgent than nowadays. It is weel-known that, in many developing nations of Africa, Asia and Latin America, protein insufficiency is the most important single cause of child mortality. Because of the generally superior biological value of animal protein in relation to plant proteins, its shortage is of particular nutritional significance. It seems that the most suitable cattle species for humid climates is the water buffalo. It should not be forgotten, however, that humid tropics have a tremendous source of animal protein which is not normally exploited, namely the aquatic animals: fish, reptiles and mammals.

6 - Soil Erosion and Degradation

The soil is a part of the environment which results from the action of the atmosphere and the biogeocenoses on the lithosphere over a certain time. Its formation is the result of a series of processes of destruction or simplification, of rearrangements of varying complexity and, almost always, of reorganizations. These processes spring from the exchange and absorption of energy derived from solar radiation and from the action of atmospheric agents, mainly precipitation and wind, which control the humidity and aggregation of the soil. The coming into being of the soil leads to the development of plants, which allows that of animals at its expense and the development of the human being, the last element in the chain. Soil, thus, plays an essential part in all the ecosystems on the surface of the globe. In other words, soil is essential to life of man who, in respect to various activities, depends on the life of animals and plants which, in turn, can only grow thanks to the soil itself. To enable the soil to play its part in any ecosystem, it must be of sufficient thickness. This critical thickness varies according to ecological zones and is the result of two conflicting phenomena: deepening of the soil by the process of pedogenesis and its thining down by natural erosion. The first cannot continue indenfinitely. It is a consequence of climatic, biotic, edaphic and topographical conditions. It happens very slowly and it takes geological time steps, thousands, millions of years. It can also be stopped by "obstacles", such as the formation of a lateritic shell or even a calcareous crust, or by the presence of a seam in the rock itself, which is particularly resistant and roughly horizontal: quartz, aplite etc. The second, natural erosion, is slow when it is normal, and occurs chiefly under a dense cover of vegetation, which intercepts the raindrops and diminishes their kinetic energy, reduces and slows down the flow of water, increases percolation by maintaining good porosity and a stable structure in the upper horizons of the soil and may "strengthen" the mass of soil, through its varying depth by its strong roots.

Unfortunately, the putting of land under cultivation very often causes accelerated erosion. In 1956, the secondary forest at Adiopodoumé (Ivory Coast) lost 2.4 ton/ha of earth while nearby, in an area that had been cleared and cultivated with cassava, the loss of earth rose to 92.8 ton/ha. In 1957, these losses were respectively 0.03 ton/ha and 28.7 ton/ha. In 1955, at Sefa (Senegal) the erosion under dry forest was calculated at 0.02 ton/ha while land opened for cultivation with ground-nuts lost 14.9 ton/ha, (UNESCO, 1970).

Pereira (1973) comments on the Bermejo River (Argentina), which is a tributary of the Paraná River with a drainage area of only 4% of the Paraná River Basin. The land use described as *"mountain pasture with many goats"*, yet in a low rainfall zone, loses, in average 26.0 ton/ha of earth, per year. The first indications of human settlement are already showing up in the Amazonas River basin. Gibbs (1967) presents data of the first expedition in which were collected samples of suspended sediments in cross sections of the Amazonas River and of its major tributaries. The Negro River presented a sediment transport rate of 0.02 x 10^6 ton/day and the Madeira River 0.43 x 10^6 ton/day. Table 6.1 shows the data of a recent expedition, in 1976/77, reported by Meade et al. (1979). The sediment transport rate of the Negro River did not change but that of the Madeira River increased roughly 3 times. The Negro River basin is, presently, one of the areas which exhibits less anthropogenic influence whereas the Madeira River basin has been significantly exploited in the period between the two expeditions.

In humid tropics, the important meteorological parameters leading to erosion are the high rainfall intensities and wind speed, to a lesser extent. Winds in the humid tropics are, in average, weak compared to other latitudes. This is due to the fact that the equatorial belt is a zone of confluence of atmospheric currents, where most of the horizontal momentum is being converted into vertical momentum, mainly by the vertical eddies. Thus, wind is not a factor as significant as rainfall intensity. However, it is well documented that the process of replacing forest by any other type of land use, decreases the surface aerodynamic roughness, therefore, increasing the wind speed at low levels; wind, then, may become an important erosion factor in the tropics.

Rainfall is the most important agent of erosion. After the protective forest canopy is removed, the mechanical impact of raindrops tends to desaggregate the surface structural components (crumbs) into smaller particles which seal the pores and lower, even more, the infiltration rate of the soil, already compacted by agricultural use. Simultaneosly, the rainfall, which was previously intercepted by the canopy and immediately evaporated, reaches now the surface. The consequence is an increase of the overland flow and, therefore, of erosion.

Control of erosion and conservation of the soil depend on the use of two sets of methods: *a) mechanical* methods, which control the flow of water and therefore the erosion; *b) biological* methods, which give the soil greater resistance against the water action by bringing the vegetation and cultivation practice into play. Control of water flow is effected by modifying the topography and infiltration, by means of suitable methods of cultivation (type and direction of ploughing) or of structures designed to reduced its speed: terraces for retention and for diversion, bank and steps, seepage trenches with diverting culverts etc. It can also be effected by the special areal arrangement of the vegetation: cultivation in rotated strips, stop hedges and protective woods strips, grassing of banks etc.

Since man works the soil to produce plants, he also has biological means to control erosion. He can produce plants that effectively protect the soil against water action, plants that improve the qualities of the soil and give it greater resistance. In summary, the most effective way to conserve soil against erosion depends on the optimal land use and on the use of rational agricultural methods, with regard to their nature, intensity and time of execution.

TABLE 6.1

SUSPENDED - SEDIMENT TRANSPORT RATES OF THE AMAZONAS RIVER BASIN

	SEDIMENT TRANSPORT RATE (10^6 TON/DAY)	CONCENTRATION (mg/LITER)
Iquitos	1.7	400
S. Paulo de Olivença	1.7	275
S. Antônio do Içã	1.7	245
Coari	1.4	150
Manacapuru	2.2	200
Rio Negro	0.02	5
Rio Madeira	1.1	300
Óbidos	4.7	235

(Source: Meade et al., 1979)

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