

Agroforestry, water and soil fertility management in african tropical mountains

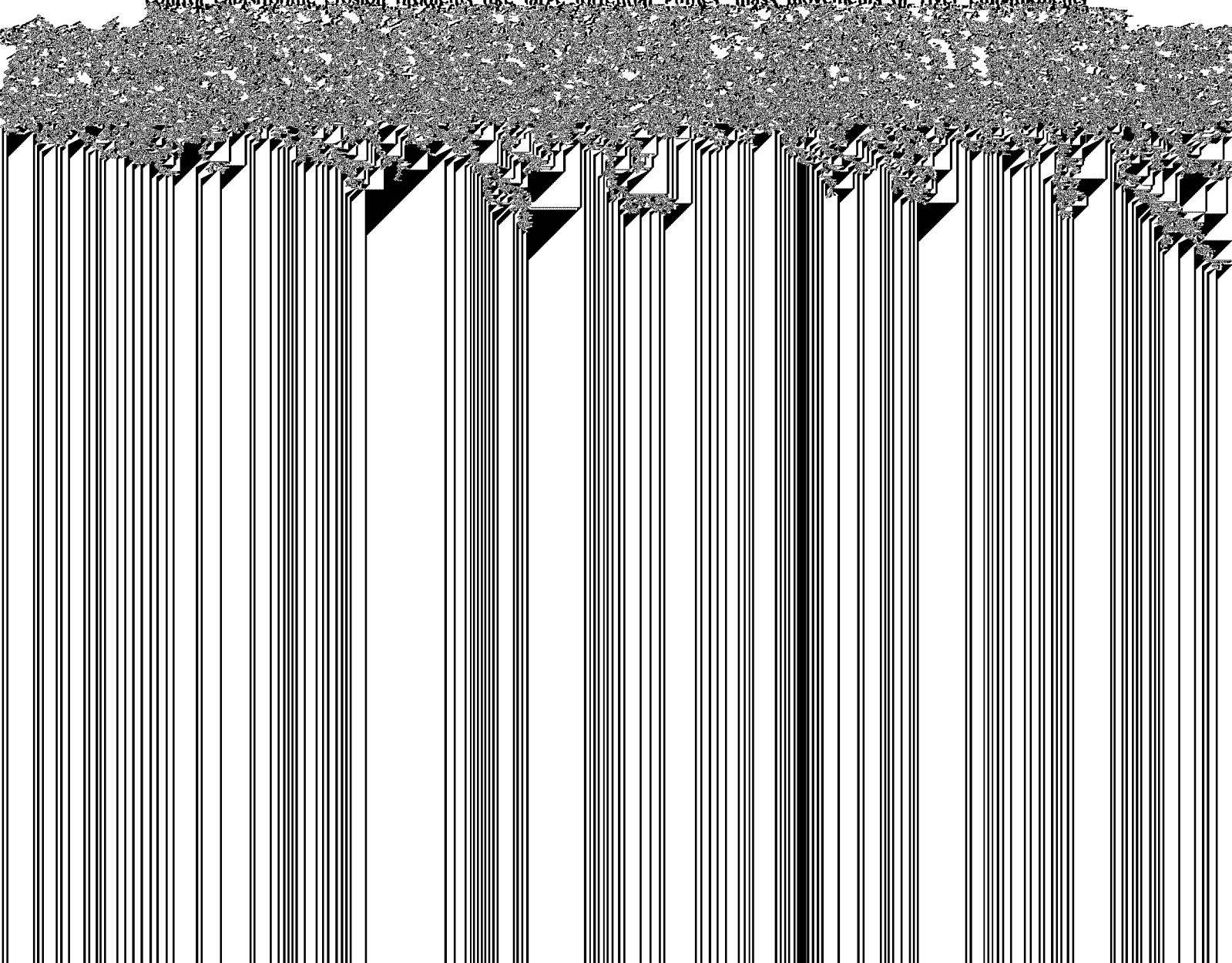
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Summary of a proposed keynote to the International workshop on: "SOIL EROSION PROCESSES ON STEEP LANDS" May 16 -21, 1993, Merida, Venezuela.

Although African plains are quite desartic (5 to 40 people/km²), tropical mountains are often overcrowd because the climate in altitude is more rainy, healthy and the mountains give some protection against military, religious and administrative pressures. With the improvement of medical aid, the population density between 1000 and 2500 m of altitude attein exceptionnel values (150 à 1000 inhabitants in the mountains of Rwanda, Burundi, Cameroun, Kenya, Ethiopia, etc.) that leads to delicate problems of soil protection against runoff and various types of erosion on steep cultivated slopes (sometimes more than 80% slopes).

The first care is to diagnose the diversity of the erosion processes and the factors modifying their intensity. It is usefull to distinguish manifestations of beginning erosion on productive soils that farmers can control with improved farming systems : organic matter and soil fertility degradation, sheet and rill erosion and dry creeping by cultural practices. Only the state departments have enough equipments and technicians to control catastrophic erosion nroblems like large torrential gullies, mass movements or river embankments



Now agroforestry gives an excellent opportunity to reduce runoff and erosion risks, to produce useful organic matter and return a lot of assimilable nutrients : highest densities of rural populations are living in "multistory gardens", the most complex agroforestry association.

Thanks to agroforestry, grassed embankment, living hedges of leguminous, cisterns, breeding in cattlesheds and complementary mineral fertilization it is technically possible to intensify significantly the production in the mountains without degrading the environment... until certain limits : soil fertility restoration has a price and many socio-economical problems have to be solved like land propriety, rural products price, roads to the market, etc. Erosion is not only a technical problem, but also a sign of an unbalanced society.

1 - DIAGNOSTIC OF THE ACTUAL SITUATION

1.1 - New strategy for a new situation

As long as population are spread on the mountains (10 to 40 inhabitants / km²), erosion problems are not serious and soil degradation problems are solved by long fallowing or by migration and new land clearing.

But from 1930, Rwanda and Burundi population concentrated on certain hillslopes got problems of starvation and soil protection. Then colonial administration imposed perennial crops (cassava, coffee) and antierosive structures (infiltration ditches protected by grassed lines, mulching for coffee plantation, step terraces for tea plantations). That strategy imposed by the foreign power to protect the soils, was badly accepted by the farmers because it requires much labour for installation (100 to 350 labour days) and maintenance of structures (20 to 100 days) without increasing the yields. "Why so much labour to preserve these poor soils for giving us so poor production ?". After 1962 and the independence, these structures were abandoned but erosion and soil degradation increased seriously.

Today the problems are different ! The population double each 15 to 20 years and exceed already 150 to 800 inhabitants per km². Two third of cropped grounds are acid, exhausted but quite continuously cultivated because it does not remain any ground in reserve for fallowing. Pressure is so hard on the land that slopes as steep as 80 % are cleared, overgrazed or tilled and scoured after 2 years of extensive farming. The average land area for a family will be less than 0,5 hectares in a few years. There is no more place for stocking on improved pasture (0,4 ha of *Pennisetum* to feed a cow giving manure for soil fertilization and milk for the family health).

Time is over to preserve the land : there is no more land reserve ! Soil productivity is already so low (400 to 800 kg/ha of beans, corn or sorghum, 1 to 3 tons/ha of sweet potatoes or cassava) : why to spend so much labour to protect it without significative production increase ? But industry does not exist and rural products business are not enough developed to give work and income to rural populations in excess. The new objective is now clear : manage water, biomass and nutrients and restore soil fertility to double the production each 20 years, to improve the farmers life level without degrading the rural environment. But fertilizer availability and low farmer income are problems to solve in order to attain this objective.

TABLE 1 - Diversity of Erosion Processes, Causes, Factors and Consequences.

Process	Causes	Factors	Consequences
Soil degradation	<ul style="list-style-type: none"> - Mineralization of organic matter - Salinization, motorization, etc... 	<ul style="list-style-type: none"> - Temperature - Humidity - Litter turn over 	<p>decrease :</p> <ul style="list-style-type: none"> ↓ OM Content decrease ↓ Water + nutrient storage capacity ↓ Porosity, infiltration <p>increase :</p> <ul style="list-style-type: none"> ↑ of runoff and Erosion risk
Sheet Erosion	Splash = <ul style="list-style-type: none"> - setting - shearing - projection 	<ul style="list-style-type: none"> - Vegetal cover 1000 - Slope 200 - Soil 30 - Structure A.E 10 	Sealing crust + Setting Runoff <ul style="list-style-type: none"> - Selective Erosion - Scouring
Dry mechanical <i>Creep</i>	Tillage practices	<ul style="list-style-type: none"> - Frequences - Intensity - Slope steepness - Soil fiability 	<ul style="list-style-type: none"> - Scouring - Humiferous - Horizon
Gully Erosion	Runoff energy $E = \frac{M.V^2}{2}$	<ul style="list-style-type: none"> - Runoff - volume = f {surface, rain, intensity - Speed = f (slope, roughness) - Resistance of the soil × vegetation - A.E structures : weir, etc. 	<ul style="list-style-type: none"> - Deep gullies - Imbattance of slopes - Alluvial fans
Mass mouvements (Sliding) on hillslopes	Gravity > Cohesion of the soil	<ul style="list-style-type: none"> - Cover weight {soil+water+vegetation - Humectation of sliding plane - Slope + drainage 	<ul style="list-style-type: none"> - Hillslope scouring - Mud slides.

CONCLUSIONS :

- 1 - Diversity of forms, causes, factors and means for fighting erosion.
- 2 - Temporal and spatial variability of erosion intensity.
- 3 - Great importance of the soil surface state.

processes (sliding and mass movement by ex.) when we try to decrease others (ex : sheet erosion and runoff) - (see table 1). In humid areas it is sometimes better to accept a certain amount of runoff than to increase the drainage, mass movement and nutrients leaching risks.

In the mountains, rainfall energy is lower than in the tropical plains (Roose, 1980) so that sheet erosion is not the most important risk : runoff energy is increasing with slope steepness when the flow is concentrated in rills and gullies. "Dry mechanical creep" by tillage practices pushing the soil down the hillslope (about 7 to 10 t/ha for one plowing) and rills are processes very efficient in the mountains to scour the humiferous topsoil, chiefly when the soil is bare and finely prepared for the seedbed. When slopes are steeper than 40-60 %, mass movements are to be feared during very rainy seasons or when rivers or roads cut the soil cover, chiefly on schist or clay stones, marl, gneiss and rock with micabeds or on convexe slopes of granit covered with a thin layer of permeable volcanic ashes.

Only the state departments have enough equipments and technicians to control catastrophic erosion problems like large torrential gullies, mass movements or river embankments degradation. But, with a minimum of technical framing, farmers communities can improve farming systems (better seedbed preparation, rough conservation tillage, tied ridging, organic matter, litter and weeds management, fertilization, rotation, hedges, mixed cropping with leguminous cover), cover the soil during the dangerous stormy period, increase the soil surface rugosity and macroporosity, reduce slope length and steepness (by hedges, grassed embankments) and reduce runoff and erosion risks on the hillslopes. These managements on the slopes influence the river stability too : prolongation of the concentration time of the flow in the river, reduction of the peak flow which is at the origin of the largest sediment transport in the torrential rivers.

1.3 - Sheet and rill erosion measurements on hillslopes of Rwanda and Burundi

The data (see table 2) were observed on very steep slopes (27 to 55 %) of the ISAR center of Rubona (Ndayizigiye, 1988-90), the PASI station of Butare (König, 1991) in Rwanda, the ISABU stations (Duchaufour and Bizimana, 1992) and of IRAZ station of Mashitsi (Rishirumuhirwa, 1992). Soils are very desaturated ferrallitic soils (ultisoils), acid and very resistant to the aggressivity of the rainfall.

From these datas, we may remember :

- the rainfall erosivity index (Wischmeier, 1960) ($Rusa = Ham \times 0,20$ to $0,25$) is important, but rainfalls in the mountains are less energetic than in other western african plains ($Rusa = Ham \times 0,5$) ;
- the risks of runoff and erosion are very high under bare plots (300 to 700 t/ha/year) but they are not increasing regularly on the steepest slopes (less sealing crust but more stones on very steep slopes) ;
- traditional associated cropping systems reduce seriously these risks of erosion (20 to 150 t/ha/year) but not enough if the tolerance is 1 to 12 t/ha/year according to soil depth ;
- 200 trees planted in between the crops are not enough efficient ;
- a first solution to stop erosion is to plant living hedges of grass and leguminous bushes (*Leucaena* or better on acid soils, *Calliandra*) each 10 meters and a big ridge covered by sweet potatoes or leguminous forage each 5 meters to stop the runoff energy ;

TABLE 2 : Erosion (t/ha/year) and runoff (% of the annual rainfall) on some runoff plots of Rwanda and Burundi.

After data of ISAR (Roose, 1988 ; Ndayizigiye, 1992-93), of PASI (König, 1991), of IRAZ (Rishirumwhirwa, 1992), and ISABU (Guizol, 1989 ; Duchaufour, Bizimana *et al.*, 1992).

Vegetal cover and management	Erosion t/ha/year	Runoff KRAM % of annual rainfall
Bare soil, cultivated along the slope	300 to 700	10 to 40 %
<i>Traditional crops</i>		
Cassava and sweet potatoes Maize + beans or peas and sorghum	20 to 150 (300)	10 to 37 %
<i>Agroforestry</i>		
- Trad. crops + 200 trees/ha	30 to 50 (Max. = 111)	5 to 7 %
- Id. + trees + living hedges each 10 m :		
. first year	7 to 16	10 to 15 %
. 4 th year (3 to 8 kg/m/year)	1 to 3	1 to 3 %
- Id. + trees + l.h. + covered ridges each 5 m.	1 to 4	0,1 to 2 %
<i>Permanent crops</i>		
- Banana :		
- open, residues exported (10 t/ha/year)	20 to 60	5 to 10 % (45)
- dense, mulch spraid or on lines	1 to 5	1 to 2 %
- Coffee plantation (or Cassava) + mulch (20 t/ha/year)	0,1 to 1	0,1 to 10 %
- Pine forest (5 to 10 t/ha/year of litter) or old fallow, grassland not degraded	0,1 to 1	1 to 10 %

() : Maximal value observed.

- a still more efficient solution is to cover the soil with a mulch of litter (under banana tree, coffee or cassava plantation) or with leguminous living carpet ;
- the problem of litter production can be solved by living hedges, trees, and banana or forage plantations ;

An other solution consist in reforestation with adapted *Pinus* (very good soil protection by litter) or other forest species growing above a dense soil cover decreasing runoff and erosion to acceptable level.

1.4 - Efficiency of antierosive structures (fig. 1 and 2)

Figure 2 from Duchaufour and Bizimana shows that many biological antierosive systems are efficient to decrease sufficiently erosion risks even on fragile sandy ferrallitic topsoil of the mountains : they associated a source of litter production (*Banana*, *Pinus* or *Grevillea* trees) and a mode of management of litter and weeds (spraid on the topsoil).

Bench terracing is also very efficient but it asks 800 to 1200 labour days/ha and soil fertility restoration (10 t/ha/2 years of manure and 3 t/ha/2 years of CO_3Ca + 300 kg/ha/year of NPK). Infiltration ditches, graded channel and stone bunds are less efficient and ask 200 to 350 labour days for building and 20 to 50 labour days for maintenance. Semi permeable stone bunds which are so efficient in West Africa does not seem to be on steep slopes : the flow running through the stones seems to concentrate erosion on steep slopes below the bunds (rills).

The most efficient farming system is a combination of little pieces of ground cultivated on the contour between embankments protected by grasses and living hedges alternating with a large ridge permanently covered. Living hedges, Banana plantation and *Grevillea robusta* trees produce a large volume of biomass available for mulching or forage : the system is efficient and profitable if associated with breeding in cattlesheds producing manure to be composted with crops residues, ashes and family residues (up to 5 m³/family). So it is not the structure which is the most efficient antierosive system, but the complete farming systems integrating agroforestry and water and fertilizer management well adapted to local human and ecological conditions.

1.5 - Conclusions : the USLE factors

Although slumping, creeping and runoff energies are probably more efficient to develop erosion on 20 to 60 % hillslopes, the USLE model of Wischmeier and Smith (1978) has been applied to analyse the runoff plots data concerning sheet and rill erosion (1 to 700 t/ha/year).

The Rainfall erosivity index (Rusa) has been calculated for annual average of 1400 to 2000 mm of rainfall. RUSA is variable from year to year and place to place between 270 to 700 in Rwanda (Ryumugabe et Berding, 1992) and between 240 to 950 in Burundi (Guizol, 1989 ; Duchaufour *et al.*, 1992). But generally, the rainfall energy per millimeter of rain is less important on the mountains of Rwanda, Burundi and Cameroon (R/H averages on 5 years vary from 0,25 to 0,30 ± 0,05) than on the plains of Western Africa (R/H = 0,50 ± 0,05) (Roose, 1980).

FIG. 1 - RELATIVE EFFICIENCY OF SOIL CONSERVATION PRACTICES IN BURUNDI (Duchaufour, Bizimana, *et al.*, 1992)

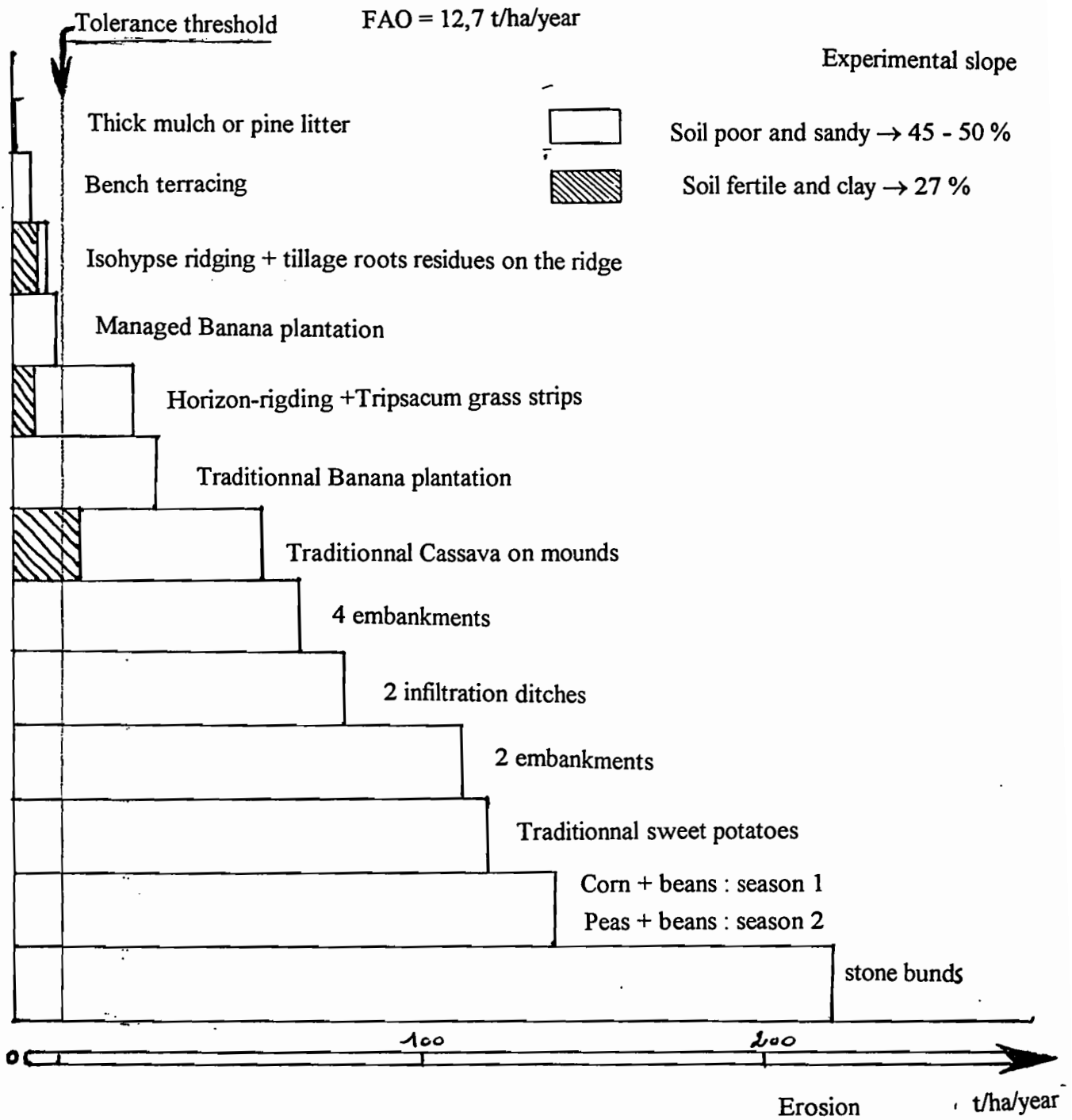
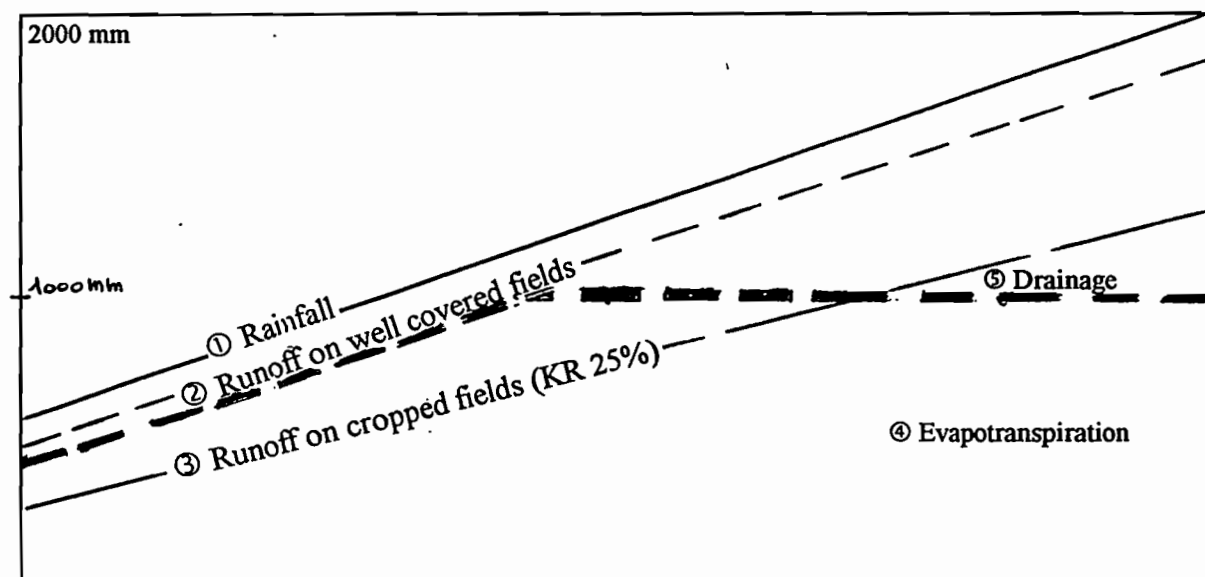


FIGURE 3 - Effect of runoff on drainage and river peak flow



- (1) Rainfall increase from 800 up 2000 mm.
- (2) Runoff on forested or well covered fields = $\pm 5\%$.
- (3) Runoff on cropped fields increases from 200 to 400 mm.
- (4) Evapotranspiration turns around 1000-1200 mm but decreases in arid condition.
- (5) Drainage is rapidly decreasing in semi-arid conditions.

In humid subequatorial conditions, after clearing the forest, when cropping the runoff increases and the deep drainage decreases. For farmers there is few changes in ETR and biomass production. But the river peak flow increases degrading the river beds embankments : the low flow will be lower.

In semi-arid areas, if runoff increases, drainage disappears and ETR + biomass production decrease. The river peak flow increases and the river bed is degraded : the flow becomes discontinue during the dry season.

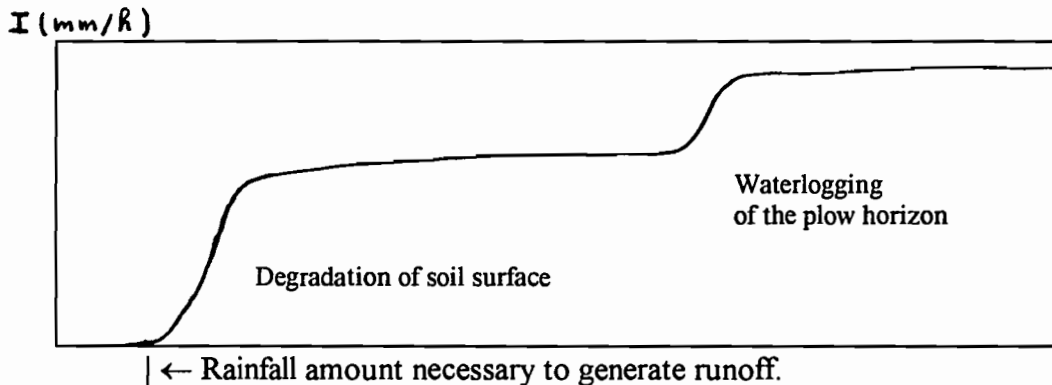
So, if we try to fight erosion and runoff, farmers of semi-arid regions will be much more interested (because biomass will increase) than these of very humid areas (rare biomass increase, but increase of leaching risks).

That type of functioning happens if a sealing crust is developing on the soil surface when soils are rich in silt and poor in organic matters. **Soil conservation** must destroy the structural crust by rough tillage, organic matter management on/in the topsoil and plant or litter to cover the topsoil.

b) - Runoff is developing when the storage capacity of the topsoil is filled up.

Each profile is able to store a water lamina in the rugosity of the soil surface and in its porus. When the soil is compacted, stony or limited by an impermeable layer, the rainfall fills up the poral space and then overflows whatever the rainfall intensity is.

FIGURE 4b - RUNOFF SOURCE : WATERLOGGING OF THE SOIL



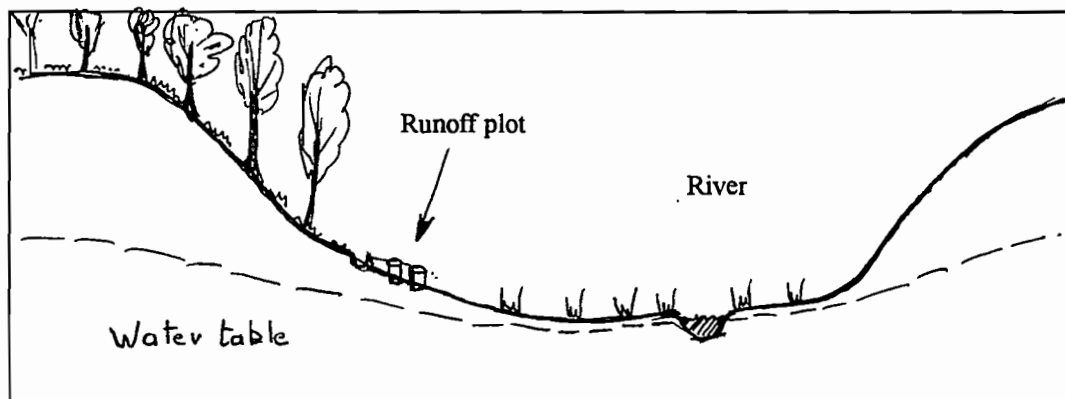
In this case, the soil drainage need to be improved (subsoiling) : covering the soil with mulch will not change the erosion risk.

c) - Partial area contribution

In a watershed, only certain areas give runoff :

- the river surface all the year long... but it gives a very limited flow during the dry season,
- the river and the waterlogged part of the valley during the rainy season,
- the hilltop when soils are superficial and rocky (low water holding capacity),
- the whole watershed sometimes when the soil moisture is over the water holding capacity, or if the soil surface is degraded.

FIGURE 4 c - RUNOFF SOURCE : PARTIAL AREA CONTRIBUTION



On a field also, seldom the runoff comes from the whole surface... but only from a waterlogged small area, a compacted area by overgrazing or by the tractor wheels, or a thin horizon above the rocks.

Traditionally soils conservationists have built more terraces on more steep slopes but it is not evident that there is more runoff on steep slopes : many experimental data confirm that in some cases, there is less runoff on steep slopes ! Before soil conservation management on a watershed, it is necessary to diagnose the runoff origin : where does it begin ? At what season ? In relation with what rainstorm type and what cultural practices ? Where in the toposequence ? Is it continue on the toposequence or discontinue ?

On mountains and steep hillslopes, runoff is less related to sealing crust than to compacted areas (house, paddock, roads, paths), rocky superficial soils of the hilltop or springs in the colluvial bottom area.

2.1.3 - Four modes of water management in relation to the "soil climate".

If we travel through Western Africa from the Sahel to the Subequatorial area, it is possible to observe four modes of water management in relation to rainfall and soil permeability.

2.1.3.1 - Antierosive structures

On the mountains, it will be necessary to select the antierosive management system, the structures and the cultural practices in relation with the running water management.

a) - On arid mountains the only area where one can cultivate, is the valley managed to capt and store the runoff from the bare hillslopes. But on tropical mountains if there is one dry season, it could be interesting to capt runoff from various impluvium (the roofs, the roads or the rocky hilltops), to store this water in cisterns for the family, the cattle and for complementary irrigation of multistory gardens.

b) - In semi-arid tropical countries, even if the rainfall amount is important (1000 mm in 8 months) it happen 2-3 weeks of drought reducing considerably the yield security : in that situation tied ridging or mulching would be able to improve the infiltration, the water holding capacity of the soil and the crop production.

c) - In semi-humid conditions where certain months are very rainy (> 300 mm) and the soils not enough permeable, it could be secure (chiefly for tuber root cropping) to organize the drainage of overland flow in diversion ditches or oblique ridging and grassed waterways. Diversion terraces was the system proposed by Bennet in the USA in 1939.

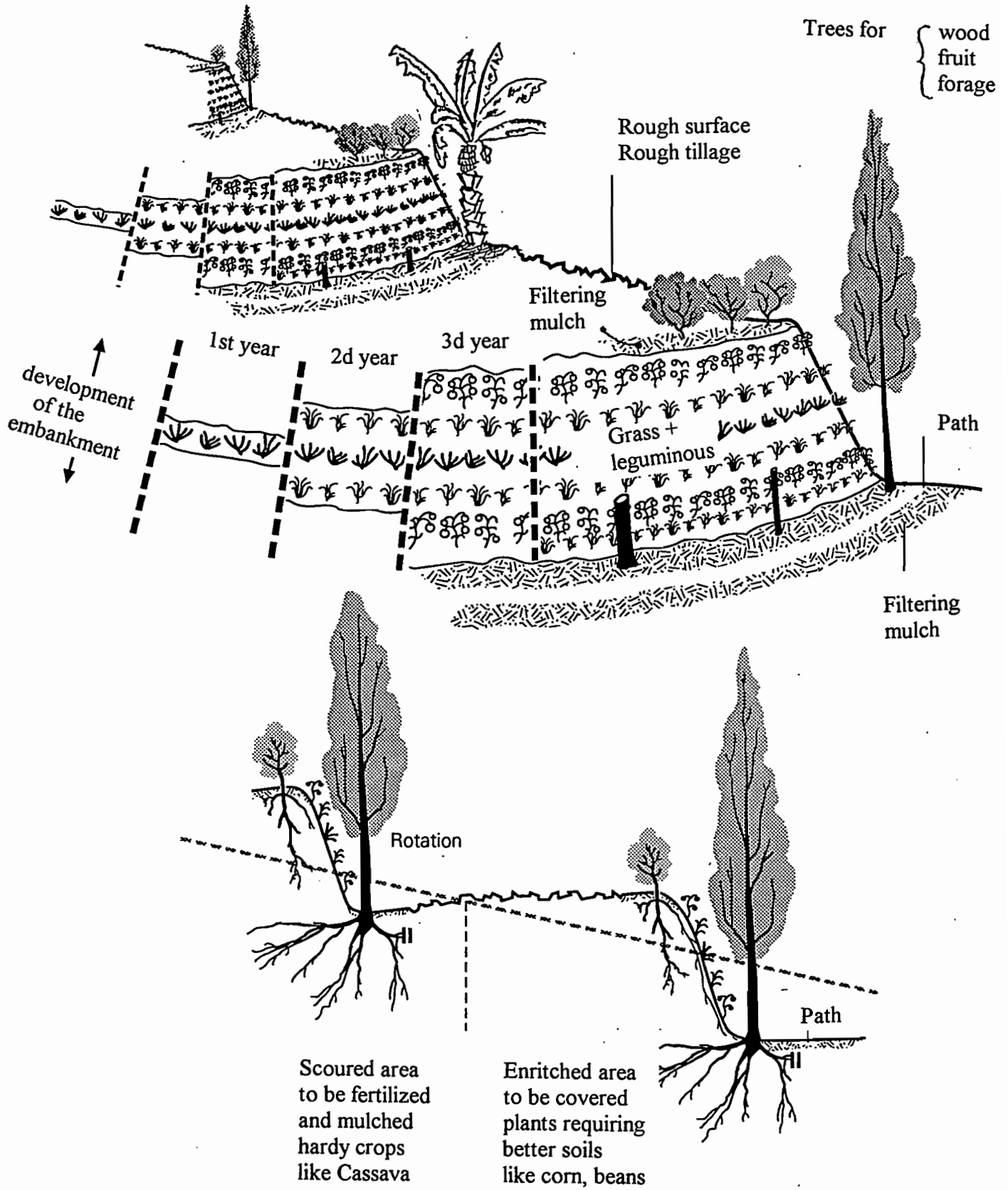
TABLE 3 - Antierosive structures and cultural practices in relation with running water management

Management type	Antierosive structure	Cultural practices
Runoff farming in arid and semi-arid area	- Impluvium, cistern - Soil dykes on wadies - Discontinued terraces	- Deep plowing, pitting - Microcatchment
Total infiltration in semi-arid (less 400 m) or sub-tropical areas on highly permeable soils	- Infiltration ditch - Bench terracing	- Rough plowing - Tied-ridging - Mulching
Water diversion in humid areas on slow permeable soils	- Graded channel - Ditches, terraces with lateral drainage	- Oblique ridging - Ridging paralelly to the slope
Runoff energy dissipation in all climates on permeable soils on slopes < 60 %	- Stone bunds or walls - Grass lines, buffer strips - Grassed embankment - Hedges - Step terraces	- Agroforestry - Rough tillage - Crops alternating with meadows - Mulching

d) - But it seems there is another system less dangerous than to concentrate runoff in graded channel, which is to spray the sheet runoff flow in order to maintain very low the velocity of this laminar flow (25 cm/sec. along Hjulström) under the velocity threshold where it cannot remove the soil nor dig rills/gullies. To maintain sheet runoff it is necessary to get short slopes (hedges each 5 to 10 meters with covered ridge each 5 meters to stop the runoff energy), permeable microdam structures and rough soil surface (cloddy or ridged soil, weeds, or leguminous high density of plants and plant cover associated with mulch or crop residues on the surface) (see fig. 5).

e) - If the soil is superficial on steep slopes (> 40 %), the weathering rocks less permeable, the risks of slumping are too high to build bench terraces and dig ditches : grassed embankments, trees lines or living hedges can help to build progressive terraces and limit the dry creep by cultivation practices. Step terraces (dH \approx 0,5 to 1 meter and 0,5 m wide) cutted in grass fallow are very efficient for tea plantations but also for peas, beans, sorghum and corn association on very steep

FIGURE 5 - Protected embankment development to dissipate runoff energy



2.2 - The biomass management

In Rwanda and Burundi, farmers are generally too poor to buy mineral fertilizers to intensify the productivity. Traditionally they dispose only of the biomass produced on their own fields or fallows but also along the roads, on common forest and grassland, etc... to maintain or restore the soil productivity.

In classic soil conservation, channels, ditches and terraces do not increase the biomass production. In the GCES approach one devotes one's whole attention to increase the biomass production, to return quickly the nutrients and to use judiciously the organic matter in order to maintain the soil productivity.

2.2.1 - How to increase the biomass production ?

In the tropical countries there is a relation between the organic matter returned to the soil and the soil productivity. In the great lakes area of central Africa, the litter production varies between 8 to 15 t/ha/year under the moist evergreen forest and 2 to 8 t/ha/year in the Tanzanian savannah but in savannah, bush fire and grazing decrease significantly the organic matter deposit on the soil surface. After clearing and burning the natural greencover, the organic matter content of the topsoil will decrease of 40 % in 4 to 10 years depending on the management of crops residues :

- sorghum and maize can give 2 to 5 t/ha/6 months of residues actually used to feed the cattle or to mulch the coffee plantation ;
- soja, peanuts and beans produce 0,5 to 2 t/ha of forage ;
- manioc and sweet potatoes produce 0,5 to 2 t/ha in 1 to 2 years of biomass to feed pigs or to mulch coffee ;
- banana plantation (5 x 3 m) is able to produce 3,3 t/ha of stipes and 2-6 t/ha of leaves used as forage or as mulch ;
- short fallows between cropping and weeds under cropping produce at least 0,5 to 2 t/ha/year.

Agroforestry can increase significantly the biomass production of the cropped fields. One or two hundred trees (like *Grevillea robusta*, *Cedrella serrata*, *Poliscias fulva*) planted around or in the field can produce enough wood for the fuel family needs but also 1 to 4 tonnes/ha/year of leaves and small branches appreciated for mulching. Hedges of *Calliandra calothyrsus*, *Leucaena leucocephala* or *diversifolia*, or *Cassia spectabilis* can produce in that area up to 3 to 9 t/ha/year of leaves (excellent forage) and 2 to 7 t/ha/year of little branches for the fire if they are planted at 5 to 10 meters of distance. (König, 1992 ; Ndayizigiye, 1992 ; see fig. 6. ; Balasubramanian and Sekayange, 1992). So the litter produced by hedges and trees can be superior to this of a forest and we must add crops residues growing between bushes and trees.

2.2.2 - How much nutrients agroforestry can return to the soil ?

Bushes selected for hedges are leguminous fixing nitrogen if soil conditions are not too poor in phosphorous and the pH not too low.

(keeping animals in sheds on thick litter, + water from cistern under the roof, + forage from the leguminous hedges). But with the demographic pressure, the farming surface will decrease to less than 0,4 hectares in years 2000... and cattle must stay on mountainous or savannahs grassland. For little farmers only goats and porks will remain to give a good manure composed with all the farm residues.

b) - Compost : it is a very long time (6 to 18 months) and labour consuming way to produce a good organic manure but the restitution rate to the soil are as low (30-40 %) as for the manure and it does not produce any meat ! However composting is a valuable practice for poor farmers without cattle (50 % in Rwanda) and for people getting large quantities of industrial organic residues (coffee envelopes, drenches of brewery, cities residues, etc.) But the major obstacle is the amount of labour to produce and transport the compost. The only efficient compost pit are digged under cattlesheds, protected by trees (to maintain shadow and humidity and to recover nutrients in drainage solution) and collect manure, ashes, used waters, family and crops residues ; manure and compost are a good basis to begin gardening that allow the rural development (ex. in Haïti).

c) - Weeds and residues ploughing in. There are many traditional systems to use weeds for mulching or composting : it allows a very fast turn over (1 to 3 months) maintaining a certain level of organic matter in the topsoil. But now farmers are using that biomass for cattle feeding because fallows are disappearing. It is also important to remember that these rough residues ploughed in large quantities, will fix the nitrogen microorganisms and create a nitrogen starvation in the topsoil. That burried organic matter will have very little effect on the soil erodibility (max. 5 % difference) (see the nomograph of Wischmeier and Smith, 1978).

d) - Mulching. Thick mulching (7 cm \approx 20 t/ha) is a very efficient method to reduce evapotranspiration, weeds growth, runoff and erosion and to maintain soil moisture during the dry season. Mulching is also a short way to turn over all the biomass and nutrients : first K, Ca, Mg, C by leaching, later N, P, C by mineralization and humification through meso- and micro-fauna. Mulched above the soil, the organic residues litter disappears 30 % later than plowed in and the risk of nitrogen starvation in the topsoil is less important. Agronomists think it is necessary to plow organic residues in the soil, but in the forests nobody plows the litter in the soil, because mesofauna is able to turn the organic matter into the soil profile ! In normal cultivated soil where worms are living, mesofauna can do it too ! Under coffee and banana plantation, mulching has protected and nourish the soil... but the problem is to produce enough vegetal mulch to cover all the cropped fields. A thin mulch (2 to 6 t/ha) spraid at the beginning of the rainy season on the prepared seedbed, cut down the splash and maintain a good mesofauna activity and a good infiltration capacity for a long time. Even if mulch covers only 50 % of the soil surface it can reduce erosion risks of 80 % and brings fresh organic matter to improve the soil surface structure.

2.3 - The soil nutrient management

2.3.1 - Effect of organic and mineral fertilization

At the figure 6 are compared the effect of 3 types of living hedges on erosion, runoff biomass production and yield during 4 years on a 27 % slope, 5 x 20 m runoff plots on acid



6 - Progressive correction of mineral deficiencies giving directly to plants assimilable nutrients they need, each at their rythm, and hiding complementary fertilization in the organic manure to avoid their washing by drainage or runoff waters and their insolubilization by free iron or aluminium.

2.3.3 - Maintenance of soil fertility in acid permeable soils.

Once soil erosion jugulated, and soil fertility restored, it remains to insure feeding of plants cultivated (local setting) at their rythm (fractionized doses), in relation with the level of production (N 40 to 160 kg/ha ; P 30 to 100 ; K 20 to 100 ; micronutrients, etc...) and in relation to the periodic leaching risks (liming after the most rainy periods). Pratically, it is necessary to manage at the optimum organic residues disponible and to add complementary minerals necessary to feed the plants and to balance losses by exportation, erosion, lixiviation, denitrification or insolubilisation, etc...

Rutunga (1991) observes on the poor soils that liming (2-3 t/ha) must be renewed each 3 years and manure (10 t/ha) each 2 years. On moderately rich soils, liming is not usefull but well organic and mineral fertilization. On rich volcanic soils, light mineral fertilization has not been proved to increase the yield significantly. Each plant has its own needs :

TABLE 4 - Fertilizers needs of each crops in Rwanda (Rutunga, 1991)

	N	P	K	
Beans Soja	34 20-40	25-50 40-50	34 30-50	In relation to decreases lime + inoculum + pH ≈5
Peas Peanut	34 30	34 30	34 0	+ inoculum + lime
Sorghum Maïze Wheat	60 78 88	60 42 42	17 42 42	if altitude + lime + manure
Irrigated Rice	60 100	30 60	30 60	- for 2 tons of paddy - for 6 tons of paddy
Irish potatoes Cassava Gardening	51 100 30-50	100 50 30-70	200 100 100-200	+ lime + manure if altitude or 35 t/ha of manure

3 - PERSPECTIVE : SOIL FERTILITY MANAGEMENT IN RELATION TO POPULATION PRESSURE

Agriculture intensification is needed when the population density increases but asks more labour and more inputs. So farming system changes are accepted by farmers only under the socio-economic and demographic pressures.

In the figure 7, it is shown there is no strict linear relation between erosion and demographic density : there are "crisis thresholds" depending on initial soil fertility and climate. Four periods are characterized by a density of inhabitants, a fertilization modus, a type of breeding, a cultivated land surface and soil, water and nutrients management systems. These situations have been observed in different countries of Africa, Asia and Latin America. The evolution goes from shifting cultivation to intense agroforestry ; but it appears difficult to pass over stages without corresponding demographic or socio-economic pressure.

4 - CONCLUSION

In tropical mountains, erosion risks (300 to 700 t/ha/year) and soil productivity degradation are increasing with slope steepness and population density (150 to 800 inhabitants/km²).

They are farming systems maintaining erosion to a tolerable level : mulching under coffee, banana, cassava plantations, contour ridging, greencover on the soil, reforestation with species giving a good litter. Bench terracing (1000 labour days), progressive terracing (100 labours days) and other antierosive structures are less efficient than biologic systems and more time and space consuming.

Agroforestry (by ex. 200 trees + leguminous hedges each 5 to 10 meters) allows to control erosion losses (1-3 t/ha/year), to produce mulch and forage (2 to 10 t/ha/year) and to recover nutrients (N 60-20, P 10-20, K20-40, Ca+Mg 20+40, etc...) for an acceptable labour supplement (10 to 30 days each year). This biomass must be valorized by breeding.

However, despite a dressing of 10 t/ha/year of dry dung and 6 to 8 t/ha of mulch, the crops yield was maintained quite low (400-800 kg/ha of beans, maize and sorghum, 3-8 t/ha of cassava). To take up the challenge to double the production before the population has doubled it is necessary to propose soil and water conservation (by hedges and cisterns), organic fertilization (mulch, greencover and farm manure improved) and above mineral fertilization (NPK 40 to 100 kg/ha/year and liming 2-3 t/ha/year).

