Agroforestry,water and soil fertility management in african tropical mountains

by **Dr. Eric ROOSE**

SOIL SCIENTIST OF ORSTOM
CHAIRMAN OF THE FRANCOPHONE EROSION NETWORK
B.P.5045 F 34032 MONTPELLIER FRANCE

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Although African plains are quite desertic (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 problems like large torrential gullies, mass movements or river embankments degradation.

Measurements on runoff plots have shown that sheet and rill erosion on slopes from 25 to 80% varies between 300 to700 t/ha/year with rainfall erosivity, soils and farming systems. Ferrallitic soils are very resistant to splash (K = 0.01 to O.2O) and traditional farming systems reduce considerably the losses. (C = 0.8 to 0.3). The runoff is generally less important (10 to 30%) on steep slopes than on slight glacis of the sahelian areas (30 to 70%). It is possible to jugulate erosion with a natural or leguminous fallow, a Pine plantation (litter), by mulching on coffea, banana or cassava plantation. The problem is to produce enough biomass : that is the first goal of agro forestry.

Traditional soil conservation strategies are very efficient in an economical context, but are now often overstepped with the demographic pressure changes. Modern "equipment " strategies (RTM, DRS, CES) who tried to impose mechanical approach to manage excess water by graded channels or bench terraces, are relatively inefficient and badly accepted by the farmers, because these methods require much labour for building and maintaining without increasing the productivity.

A new strategy (GCES = land-husbandry) is proposed to answerto the two main problems of poor farmers : how to increase rapidly the soil and labour productivity ? Thesolution elements are to be found in the efficient management of water, biomass and soil fertility restoration.

For water management, it is suggested to capt rainfall and runoff in cisterns to irrigate a garden and to keep caddle in sheds. On slopes, excess runoff energy can be dissipated on soil surface rugosity (ridging or mulching) and on grassed embankment with living hedges producing forage, green-manure and mulch.

For soil fertility restoration, erosion and leaching losses must be stopped by green production intensification (2-d goal of agroforestry) soil macroporosity must be rebuild by deep tillage and stabilised by organic matter, calcium carbonate or gypsum, and deep rooting crops (leguminous or sorghum) ; finally the soil must be "revitalised " by a local minimum dressing of manure,N-P-Kcomplement and excess acidity neutralisation (carbonate and phosphate crushed rocks).

Living hedges can reduce erosion risks by 99% ,produce energy wood and 3 to 8 kg of forage by linear meter and return to the soil as much as 80 to 120 kg of N, 2 to 3 kg of P, 30 to 60 kg of K and Ca , 10 to 20 kg of Mg. Thanks to agroforestry , water and nutrients management,it seems possible to intensify the agriculture production in the mountains without degrading the environment,until certain limits and with the help of the governments. Soil fertility restoration has a price !!!

Key words : GCES, soil fertility restoration, agroforestry, tropical mountains, Africa, water management.

AGROFORESTRY, WATER AND SOIL FERTILITY MANAGEMENT TO FIGHT EROSION IN AFRICAN TROPICAL MOUNTAINS

INTRODUCTION

Although many African plains are low populated (5 to 40 people/km²), tropical mountains are often overcrowd for various reasons : the climate is more rainy, the production more diversified, the volcanic soils are more productive, the cool climate is more healty (less tropical diseases) and the topographic conditions of the mountains gave some protection against military, religious and administrative pressures. With the improvement of medical aids, the population density between 1000 and 2500 meters of altitude (above there are new diseases problems) attein exceptionel values (150 to 800 inhabitants/km² in the tropical mountains of Rwanda, Burundi, Tanzania, Cameroon, Kenya and Ethiopia) that lead to delicate problems of soil protection against rainfall, runoff and various types of erosion on steep cultivated slopes (up to 60-80 %). (Hurni *et al.*, 1990).

The quick diagnostic of the problems shows that there are numerous erosion processes active in the mountains and it is usefull to distinguish two domains of antierosive activities. The first domain concern manifestations of "beginning erosion on productive soils" that farmers can control with improved farming systems : farmers of the hillslopes want to protect their fields against soil fertility degradation by organic matter mineralization, sheet and rill erosion and a forgotten process that could be called "dry creep under tillage practices".

The second domain concerns more the state technical departments looking to protect roads villages, bridges, lakes, harbours and rivers against siltation, floods, gullies, mass movements and all kinds of catastrophic erosion. Only the state departments can have enough equipments and specialist to control catastrophic problems. (Roose *et al.*, 1988).

In this paper, we will limit the objective to simple solutions that farmers with poor economic power can apply and improve progressively themselve with agroforestry systems.

Taking into account ten years data of runoff plots on 20 to 60 % slopes on various acid ferrallitic soils (oxisoils, ultisoils) of research programs of ISABU and IRAZ in Burundi, ISAR and PASI in Rwanda, we propose a new strategy that try to solve the urgent problem of farmers : how to intensify the productivity of fields and labour without soil fertility degradation ?

We suggest that traditionnal soil conservation approach alone is not acceptable by autosubsistant poor farmers. But the best way to increase rural development and fight against rainfall and runoff energy on hillslopes is to improve simultaneously the management of water, biomass and plant nutrient.

Now agroforestry gives an excellent opportunity to reduce runoff and erosion risks, to produce usefull 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 spraid 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 yieds. "Why so much labour to preserve these poor soils for giving us so poor production ?". After 1962 and the independance, these structures were abandonned 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 P*ennisetum* 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 attein this objective.

A new strategy (land husbandry or GCES) was proposed in 1987 at the workshops of Niamey, Puerto Rico and Medea, in 1988 in Rwanda, Burkina Faso, Cameroon and in 1990 in Burundi and Haïti. Whose objective is the rural development by the simultaneous management of water, biomass and soil fertility. First, the GCES approach tries to answer the urgent problems of the farmers : how to improve the security and the productivity of the ground and the labour by intensive agro-sylvo-pastoral systems. How ? By improving water management (infiltration capacity, runoff storage for complementary irrigation) and fertilization (biomass management, accelerated turn-over, liming, organic and mineral fertilization localised around plants cropped and ajusted to plants needs). Looking for quick green cover of the soil surface, runoff and erosion risks will decrease indirectly.

Fighting erosion remains essential for sustainable agriculture development but will no more be presented as the "main flag" but as one of many technical packages (like improved seeds, rotation, adapted fertilization, herbicides and pesticides, etc) that permit fast agriculture intensification. Priority will be given to best land management and then to deep soils fertility restoration, runoff and spring water harvesting, storage of composted organic residues and fertilizer that could help to develop intensive agriculture (orchard with market gardening). Marginal lands (superficial or rocky soils on more 60 % slopes) must be farm only under permanent green cover (grazing, orchard or forest). This strategy changes deeply the habits of classic soil conservationists which used to spend heavy investments on badlands management to reduce sediment transportation by the rivers.

This strategy asks time to change the habits and can be realized by stages :

1 - Dialogue between farmers and technicians doing two inquiries to evaluate risks (when, where, how begin runoff and erosion) and the farmers feelings on the way to control erosion risks (farming systems). It is also a good time to evaluate the research data.

2 - Demonstration and experimentation on the farmers fields to evaluate efficiency, feasability and profitability of various proposed antierosive systems. Evaluation by farmers and by experts of the technical and socio-economical aspects of the solutions proposed.

3 - Planification and extension from the individual farmer fields to the hillslope, to the village territory, or to the little watershed used by a rural community.

If we think that farmer's participation since the beginning of the project is essential for the success of soil conservation, it is necessary to enter in the farmers mentality who asks a visible, immediate and profitable respons of their own land to soil and water conservation practices. The challenge of the next years is to double the production and the net income with a package of technologies without increasing the environment degradation risks.

1.2 - Soil degradation and erosion processes are numerous (tabl. 1)

Each processus has its own source of energy, various factors modifying ther efficiency during the seasons and in the space along the toposequence, so that it is not possible to adapt universal solutions. Each hillslope requires a diagnostic of ecological and socio-economical conditions of soil and vegetation degradation if we want to avoid reinforcement of certain

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

Process	Causes	Factors	Consequences
Soil degradation	- Mineralization of organic matter - Salinization, motorization, etc...	- Temperature - Humidity - Litter turn over	decrease : ↓ OM Content decrease ↓ Water + nutrient storage capacity ↓ Porosity, infiltration increase : ↑ of runoff and Erosion risk
Sheet Erosion	Splash = - setting - shearing - projection	- Vegetal cover 1000 - Slope 200 - Soil 30 - Structure A.E 10	Sealing crust + Setting Runoff - Selective Erosion - Scouring
Dry mechanical Creep	Tillage practices	- Frequences - Intensity - Slope steepness - Soil fiability	- Scouring - Humiferous - Horizon
Gully Erosion	Runoff energy $E = \frac{M.V2}{2}$	- Runoff - volume = f {surface, rain, intensity - Speed = f (slope, roughness) - Resistance of the soil × vegetation - A.E structures : weir, etc.	- Deep gullies - Imbattance of slopes - Alluvial fans
Mass mouvements (Sliding) on hillslopes	Gravity > Cohesion of the soil	- Cover weight {soil+water+vegetation - Humectation of sliding plane - Slope + drainage	- 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 whith 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 x 0,20 to 0,25) is important, but rainfalls in the mountains are less energetic than in other western african plains (Rusa = Ham x 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 steepste 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 %
Traditional crops		
Cassava and sweet potatoes Maïze + beans or peas and sorghum	20 to 150 (300)	10 to 37 %
Agroforestry		
- 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 %
Permanent crops		
- 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 reafforestation 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 avaiblable 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 m^3/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

Althrough 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 $\pm$ 0,05) than on the plains of Western Africa (R/H = 0,50 $\pm$ 0,05) (Roose, 1980).

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

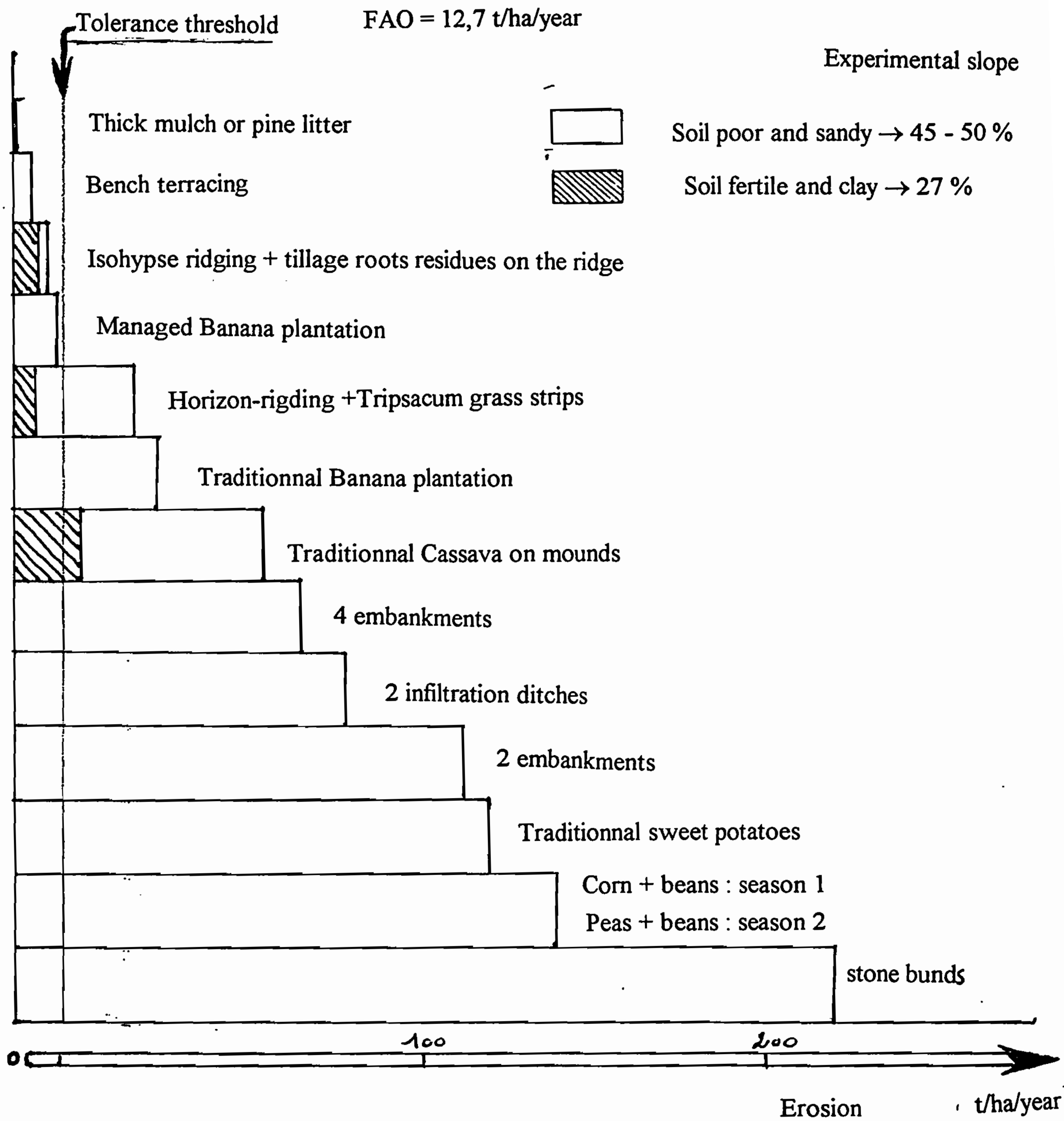
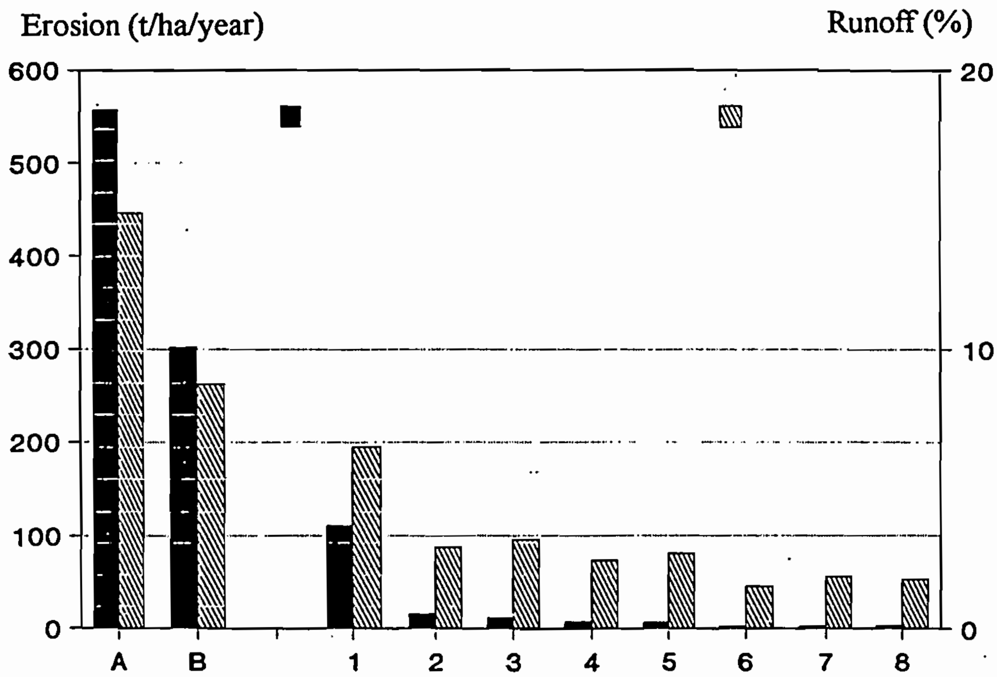


FIGURE 2 - Erosion (t/ha/year) and Runoff (%) on PASI runoff plots of Butare (Rwanda) : average 1987-1990. After König, 1992.



A : International reference : bare fallow cultivated
B : Local reference : Cassava on mounds

1 : Grevilla 200 trees/ha

2, 3, 4, 7 : GR + *Calliandra* hedge

5 + 8 : GR + *Leucaena* hedge

6 : GR + *Setaria* hedge

The erodibility (K) of ferrallitic soils is generally low to very low : they are well resistant to splash because they are well structured, (Roose, Sarrailh, 1991) rich in clay, in iron and stony on very steep slopes. After Guizol *et al.* (1989), the erodibility of ferri- and ferral-soils of Burundi varies much from very low (K = 0,015) to low values (K = 0,15). (Variability 1 to 10).

The cover factor (C) of traditionnal cropping systems is very variable (C = 0,6 to 0,1 and even 0,01 if mulching). Generally mixed cropping cover very well the soil surface after some months but the difference between crops depend on the number of rainy months when the soil cover is not complete : on these very steep slopes, even a moderate runoff (KR = 10 to 25 %) provokes dangerous rill erosion and topsoil scouring if the farmers do not intervene to restore quickly the soil surface rugosity. (Variability 1 to 100).

But the slope factor is one the most important (SL from 1 to 11) because the hillslopes are often convexe, long and steep and there are interactions between slopes, soils and cropping systems. The soil toposequence is also very important : if the soil cover of the hilltop, is thin, rocky, exhausted, the water storage capacity will be limited and the runoff beginning on the top will produce rill and gully erosion on the best grounds situated at the bottom of the hills.

The cultural practices factor (P) could be less important because the efficiency of the surface rugosity on the runoff decreases with the slope steepness.

In conclusion, in the mountains it is very important to reduce runnoff volume (by covering the soil as long a possible), to break runoff energy (by rough tillage, ridging, hedges, mulch) and to intensify the evapotranspiration (by agroforestry, leguminous and mixed cropping) to avoid rill, gully and mass movement.

2 - ELEMENTS OF SOLUTION

We have seen (table 2) that it is technically possible to stop erosion ;

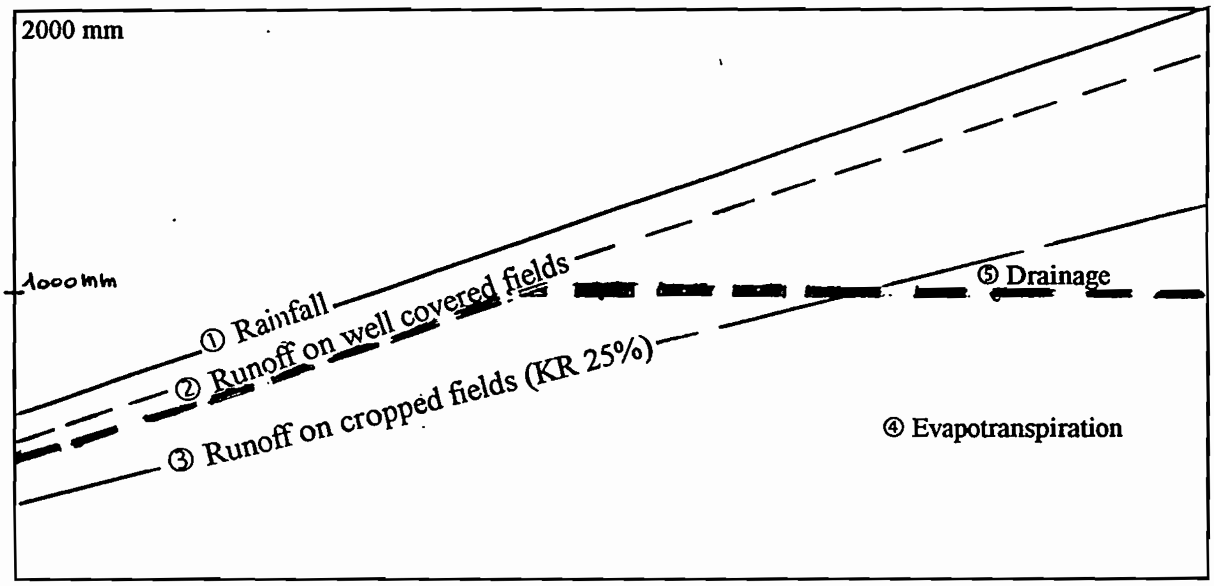
- by planting a forest with a good litter (Pine),
- by planting orchards, coffee or tea plantations with thick or thin mulching on stripes,
- by long fallowing or short fallow + leguminous forage crop,
- by mulching, living green cover, etc.,
- and by terracing (bench terracing or progressive terracing with hedges) ;

... Now we want to develop the GCES strategy, to show how to integrate water management, agroforestry and soil fertility to answer the socio-economic aspect of the problem (improve rapidly the land and labour productivity).

2.1 - The water management

Forest clearing, cultural practices and antierosive structures considerably modify the hydric functionning of hillslopes and rivers. In this section we will analyse the evolution of the water-balance in relation with the increasing runoff coefficient, the origines of the runoff and the four modes of water management before to discuss the antierosive structures and the cultural practices proposed for Rwanda and Burundi.

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 = ± 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).

2.1.1 - Water-balance and the impact of the runoff on the drainage and the vegetal production.

On the figure 3, are presented two water-balance exemples : (the one in case of low runoff risk under perennial vegetation (KR = 1 to 5 %), the second in case of cropping with medium risk of runoff (KR = 20 %). (Roose *et al.*, 1992).

. Curve 1 shows the annual rainfall amount increasing from 800 mm in the semi-arid savannah of Rwanda to 2000 mm in the humid area of the "Crest Zaïre-Nil".

. Curves 2 and 3 show that runoff is a lost of water for the plots and the crops, so that usefull water amount is inferior to the rainfall measured above the canopy. Curve 2 concerns the runoff on naturel protected places and curve 3 on extensive cropped fields.

. Curves 4 delimites two areas : under the line is the amount of plant evapotranspiration (RET during dry season = rains - runoff + drying up of the soil profile : during the rainy season RET ≈ potential evapotranspiration) and above the line, an area of drainage residual under the root zone to watertable and baseflow of rivers.

. In humid tropics, increasing runoff will reduce significantly the drainage risks and then the lowest water level of springs and watertables. But in the river, the concentration time will decrease and the peak flow will increase so that the river embankments will be degraded and the sediment transport will increase.

On the other hand, in semi-arid areas, the drainage is reduced so that if runoff increases after cropping, **R**eal **E**vapo**T**ranspiration (RET) will be reduced significantly ... and also the biomass production.

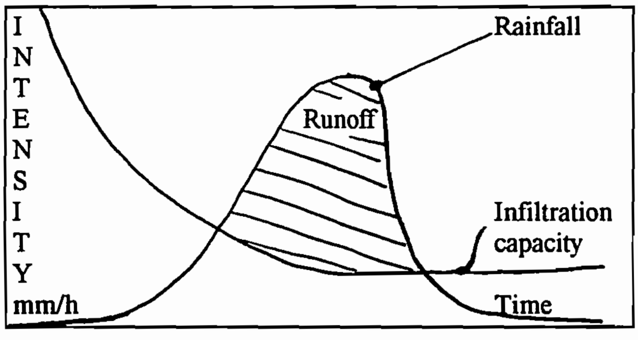
Therefore, the impact of the fight against runoff (and erosion) on crops yield can be very important in semi-arid areas but less evident in humid tropics. That is one of the reasons of the lack of benefical effect of soil and water conservation practices on the humid hillslopes of Rwanda ; the acidity, the aluminium toxicity and the chemical soil poverty are other reasons.

2.1.2 - The runoff origin and the soil and water conservation.

Runoff is explained by three different origins :

a) - Runoff is developping when the rainfall intensity becomes bigger than the infiltration capacity of the topsoil.

FIGURE 4a- RUNOFF SOURCES : INFILTRATION CAPACITY



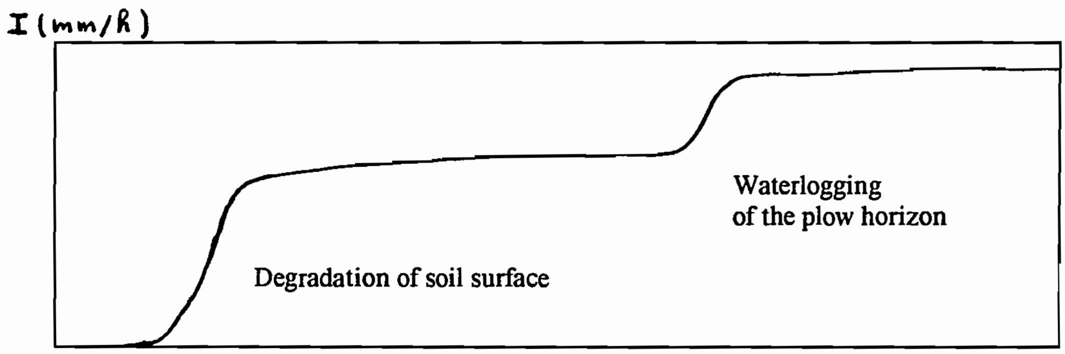
During the storm event, the soil infiltration capacity decreases because the succion decreases and the structure of the topsoil becomes degraded. (sealing crust).

That type of functionning happen if a sealing crust is developping 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 developping 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 wathever the rainfall intensity is.

FIGURE 4b - RUNOFF SOURCE : WATERLOGGING OF THE SOIL



| ← Rainfall amount necessary to generate runoff.

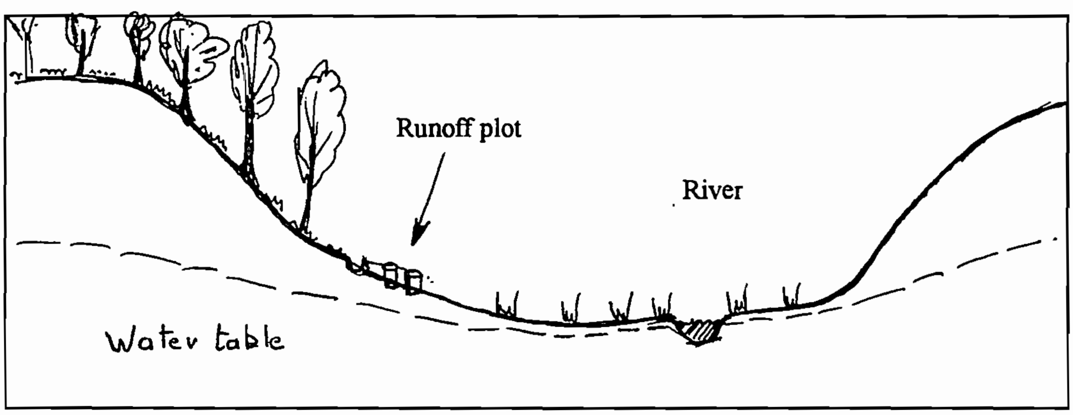
In this case, the soil drainage need to be improved (subsoiling) : covering the soil with mulch will not change the erosion risk.

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 of by the tractor wheels, or a thin horizon above the rocks.

Traditionnally 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.

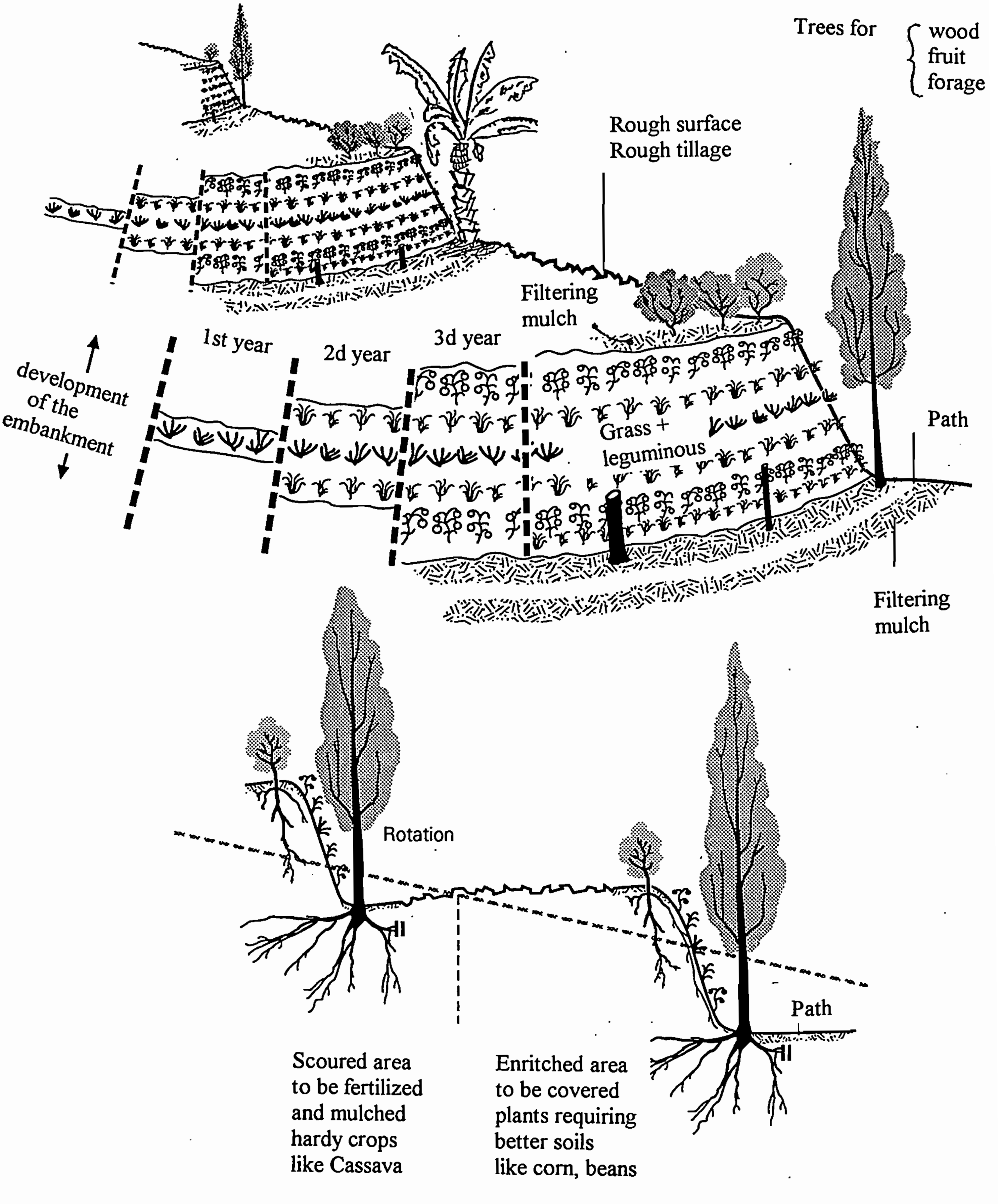
TABLE 3 - Antierosive structures and cultural practices in relation with running water management

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 ≈ 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



slopes (> 60 %) : these narrow terraces cut very well the velocity and the energy of the runoff when it overflows on the grassed embankment.

2.1.3.2 - Cultural practices

Cultural practices modify the soil surface infiltration capacity, its rugosity, its cover, the water storage and the concentration of the runoff flow : often they are more efficient than antierosive structures to reduce runoff volume and energy.

On the mountains, if we advice simple evolutive permeable structures to stabilize the hillslopes, we suggest in the other hand very complex farming systems, mixed cropping under multistory gardens where are maximised positive interactions between increasing biomass production, weeds, litter and crops residues management, protection of agregates and mesofauna activities increasing soil infiltration capacity, and reduced conservation tillage.

Rough tillage is often necessary if the soil has been compacted : it increases temporarily the infiltration capacity and disperses the runoff energy, it improves the water storage, helps to burry crops residues and to fight against weeds. Unfortunately, tillage reduces the cohesion of the ground, increases its erodibility by runoff water (principally when it produces a fine seedbed) and increases the risks of rills scouring the topsoil.

Earthing up and ridging allow to amass locally fertile ground for big tuber growth : but if not tied, they are dangerous practices in the mountains because they increase the slope steepness and concentrate the runoff in jets at the origin of rills and gullies.

Ridging parallel to the slope increases the superficial drainage and provoques rills. But if the slopes steepness exceed 30 %, short ridges well covered by mixed cropping (like in Cameroon) or successively parallel and perpendicular to the slope (like in Perou) can reduce major risks of gully and slumping. To avoid cumulative runoff energy, a large ridge (h > 40 cm) completely covered by a perennial grass, leguminous or crops (sweet potatoes) can be build each 5 meters. This ridging technique could be associated with living hedges (each 10 meters) to limit the width of the field on superficial soils (see table 2).

Oblique tied ridging with 1 % slope to a managed waterway is a good compromise to store 10-20 mm of rainfall and to drain excess rainstorm out of the tilled soil surface. Traditionnal farming systems in the mountains reduced the tillage practices : they produced much less than modern tillage but preserve much longer the soil fertility (less erosion risks).

Never forget that under forest where the soil fertility is restored, nobody plows the soil surface to burry the organic matter : mesofauna (worms and termites, ants etc.) dig tunnels and are able to restore good physical properties. If tillage increases erosion problems in the steep slopes, an increasing attention is needed to create new cultural practices that consume less energy and protect better the soil infiltration capacity.

2.2 - The biomass management

In Rwanda and Burundi, farmers are generally too poor to buy mineral fertilizers to intensify the productivity. Traditionnally they dispose only of the biomass produced on their own fields or fallows but also along the roads, on cummon 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 judisciously 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 maïze 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.

König on a very poor acid (pH ≈ 4) ferrallitic soil, showed that a well adapted *Calliandra* hedge, cutted 3 times a year, has brought 105 kg/ha of N, 10.3 kg of P and 21.8 kg of K for 9.7 t/ha/year of leaves (at 25 % H2O).

Ndayizigiye (1992, unpublished) got on a poor acid ferrallitic soil of the Rubona station (30 km far from the preceeding) a litter production of 4,8 to 6,4 t/ha/year of dry matter representing a dressing of 132 to 164 kg of nitrogen, 12 to 20 kg of phosphorus, 22 to 36 kg of potassium for hedges of *Leucaena leucocephala* and *Calliandra callothyrsus* at 5 meters spacing.

Balasubramanian and Sekayange (1992) in semi-arid savannah of Rwanda have measured a return of 3 to 4 t/ha/year of organic matter to the soil, 72 to 119 kg/ha of nitrogen, 1,4 to 3,2 kg of phosphorus, 30 to 60 kg/ha of potassium, 47 to 94 kg/ha of Ca and 8 to 18 kg/ha of magnesium after 4 years of plantation and the yield of biomass was not decreasing. This annual contribution of nutrients was similar to this of 10 tons of farm manure.

We have no reference about the nutrients deposit of leaves from the 200 trees planted on the field : their content in NPK could be very different from that of leguminous bushes selected for hedges ! But it is an evidence that agroforestry can bring a large contribution to the organic matter and nutrients balance of the soils by two ways : drastic reduction of soil losses (fig. 2) and leaching and quick turn over of nutrients capted in the atmosphere (N) or in the solutions of the soil deep horizons.

2.2.3 - Biomass valorization

The biomass produced by weeds and fallow (0,5 to 2 t/ha/year), by crops residues (2 to 10 t/ha/year), by agroforestry (6 to 20 t/ha/year) may be used for different purposes and knows different treatments before to be restituted to the topsoil after many months (1 to 18).

a) - Valorization of the biomass by breeding : it takes 3 to 6 months before the manure maturity. It is a well appreciated way by the farmers because extensive animal stocking is often the only possibility for farmers to accumulate a capital and to realize a hoard of money in a few months. But the organic and nutrient restitution to the soil is low (30 to 40 % of the biomass). Of course the organic matter of the manure has better qualities (C/N straw = 60 % ; C/N manure = 20 % ; C/N soil = 10 %) and it brings also the microflore essential to mobilise the mineral stock of the soil and to do it assimilable for plants. The nutrients dressing by a ton of manure (25 % of moisture) are variable : for exemplar 4 kg of N, 15 kg of phosphorus, 12 kg of potassium, 19 kg of magnesium and 25 kg of calcium (Rutunga, 1991). With 20 tons of that manure it is possible to improve the organic status of the soil and also to feed most of the crops. Note the very bad restitution of nitrogen because in Africa there is very few manure fermented with enough litter to fix nitrogen from liquid dejecta, but only dry dung exposed to the sun light, crunched under the cow sabots.

In Rwanda, if there is no more communal grassland (or industrial food residues), a family produces rarely more than five tons of manure mixed with crops and family residues. That is just enough to maintain the productivity of 0,2 to 0,3 hectares. Remaining field continue to support soil degradation and poor crops of cassava or sweet potatoes tolerant to poor soil acidity. One of the GCES objective is to improve manure quality and quantity by improving the breeding system (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 montainous 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 enveloppes, dreches of drewery, 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 ≈ 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 desaturated ferrallitic soil on granit in the Rubona station (Ndayizigiye, 1993). On this trial, many conclusions are already clear :

Biomass : *Calliandra* hedges each 7 meters give twice as much biomass as *Leucaena*. The mixed *Calliandra* (bush) + *Setaria* (grass) is better during the 2 first years but *Setaria* disappears after 2-3 years.
The production of cutted biomass (3 times a year) was increasing each year and spraid on the seedbed as a ligh mulch covering 80 % of the soil for *Calliandra* and only 40 % for *Leucaena*. But 15 days after, it remains only little branches : little leaves were digested by the soil.

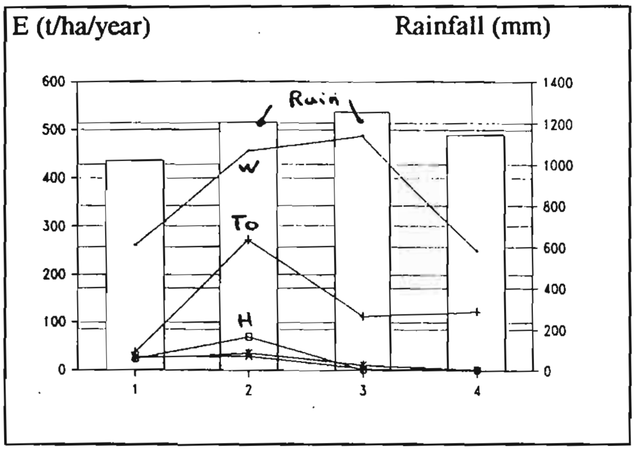
Runoff : except during the first month after plantation, the soil surface is quite well covered by traditionnal cropping system and there are a lot of cultivation practices (2 manual hoeings and 2 weedings for each season) inproving the infiltration capacity, so that 2 years after plantation the yearly average runoff (KRAM %) is very low : 12 % for the bare fallow, 8-10 % for traditionnal cropping, 1-2,5 % for cropped + hedges (each 7 m).
The runoff appears chiefly during some heavy and long storms during the second rainy season under sorghum on very wet soil.
The maximal runoff coefficient (KR max. %) decreases from 48-68 % under bare and cropped plots to 19-35 % on hedged cropped fields. So hedges (+ mulch coming from them) reduce significantly the losses by runoff for the fields and the risks of gully on hillslopes and peak flood in the valley.

Soil losses : in relation to rainfall aggressivity and soil degradation, sheet and rill erosion decreased from 250-450 t/ha/year on the bare cultivated fallow, to 80-120 t/ha/year on the regional standard of cropping and to 1-2 t/ha/year on the cropped and hedged plots 2-3 years after hedges plantation.
It is not to be forgotten that cropped field received 10 t/ha/year of manure and even 20 t on the 3th year : even so much manure is not sufficient to reduce erosion under tolerated erosion rate (1 to 12 t/ha/year).
It is encouraging to note that erosion and runoff are increasing from year to year on bare fallow and even on traditionnal cropped fields with manure, but decreasing with the hedged fields.
So with hedges each 5 to 10 meters runoff and erosion risks are reduced to acceptable very low level. But what is the influence of these risks limitation on the crops yields ?

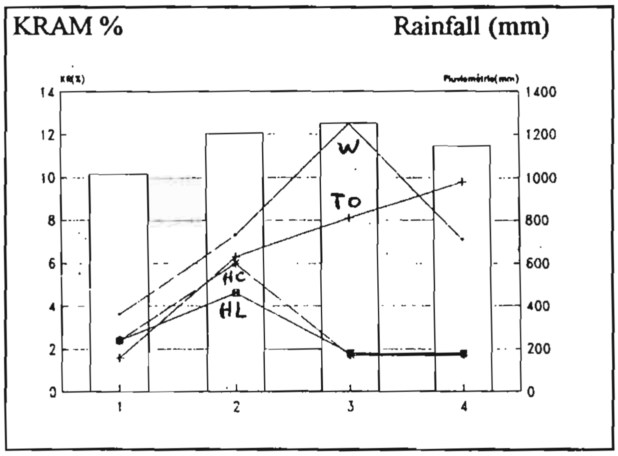
Crops yields :
- The first season, the first year with similar erosion, yields were not significatively different (580 to 922 kg/ha) with or without hedges : so the experimental field is homogenous.
- The second year, yields have decreased of 10 to 30 % depending on the importance of erosion, in spite of 10 t/ha of manure.
- At the 3d year, with 30 t/ha of manure, yields increased from 32 % on the local standart to 53-68 % in hedged fields.
At the 4th year, after 2,5 t/ha of $CaCO_3$, 10 t/ha of manure and N_{51}- P_{51}- K_{51}, yields increased up to 2032 kg/ha for the standart to 2132-2318 kg/ha for hedged fields, in spite of the place used by the hedges (15 %).
- In the second season, yields of sorghum remained very low (420 to 640 kg/ha) except after improved pH and NPK fertilization, where it grows up to 1320 kg on the standart and 1400-1544 kg on the hedged plots.

FIGURE 6 - Influence of living hedges of *Leucaena leucocephala* and *Calliandra calothyrsus* (1 meter wide each 7 meters) on average runoff (KRAM %), erosion (t/ha/year), biomass production (kg/100m/year) and yield of 2 seasons of cropping at the ISAR station of Rubona (Rwanda) on a 27 % slope on a acid desaturated ferrallitic soil. After Ndayizigiye (1993).

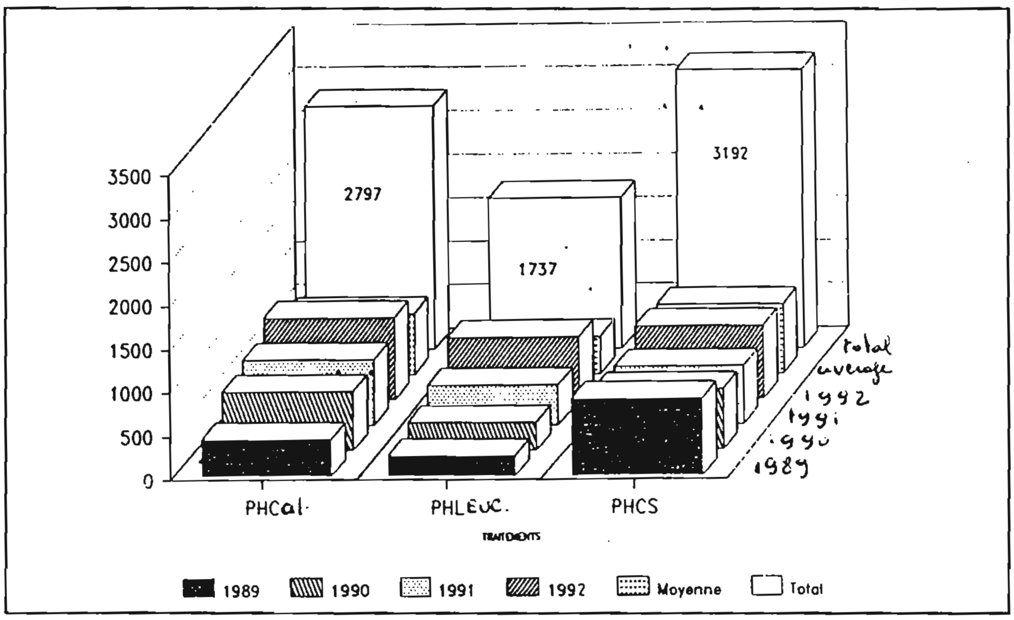
Erosion in relation to annual rainfall

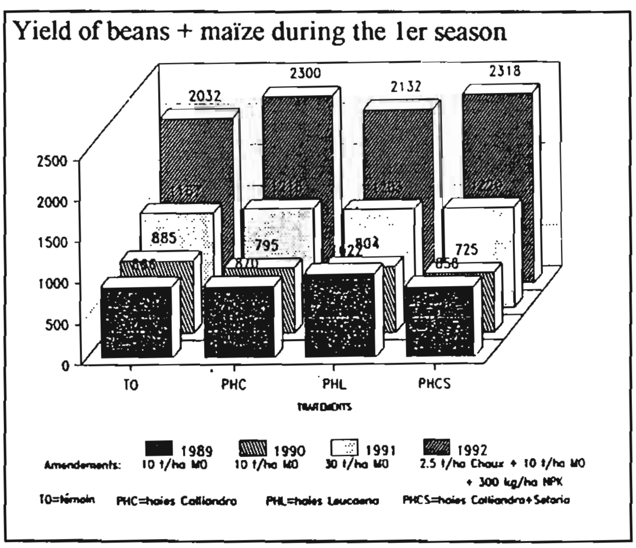


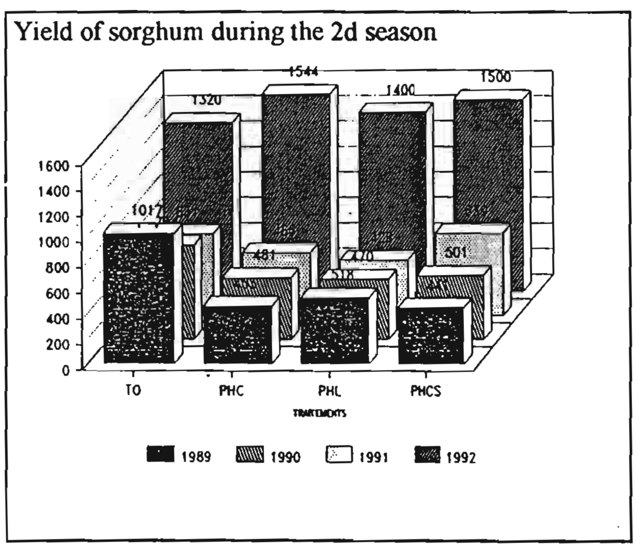
Runoff (KRAM = % annual rainfall)



Biomass production by hedges (kg per 100 meters)







W = bare standard of WISCHMEIER
TO = cultivated standard
HC = hedges of *Calliandra*
HL = hedges of *Leucaena*
HCS = hedges of *Calliandra* + *Setaria*

So, it seems that if erosion and runoff increased, the yields are decreasing. Ten tons of manure and 6 tons of leguminous mulch have not improved the production of maïze, beans or sorghum. Thirty tons of manure and 6 tons of mulch increased significantly the yield of the first season but very few that of sorghum on the second yield.

So, on these acid very poor ferrallitic soils, it was not possible to increase significantly the soil productivity in spite the efficient water and soil conservation management and a dressing of ten tons of manure : organic fertilization of that poor soil deficient in Ca, N and P is not sufficient because plants, animals and manure are also deficient (in P). With complementary mineral fertilization improving a bit the manure, the acidity (up to pH = 5 to stop aluminium toxicity) and the content of assimilable N, P, it was possible to multiply the crop yield by 2 or 3 and valorize the complementary labour required to maintain the soil conservation management structure (hedges). It is important to note that fertilization is better valorized on managed plots than on the reference fields, probably because runoff and erosion are jugulated. Till now farmers are more interested by hedges as a source of forage (at the limit of their fields) than as a soil conservation practice.

2.3.2 - Soil fertility restoration

Outside the volcanous area of Rwanda, most of the ferrallitic soils of Rwanda and Burundi are very acid, with sometimes aluminium toxicity, which is a sign of a strong drainage and heavy risks of leaching, still increased if runoff is suppressed without biomass production intensification. Soil conservation alone is no more acceptable by farmers because it does not valorize their labour : it is necessary to manage at the same time soil conservation, water-storage and soil fertility restoration to produce significantly better yields.

Soil fertility restoration consist in six steps to do, to arrive quickly (1 or 2 years) to an interesting production level. A degraded soil is generally scoured, compacted, unstable, sterile, acid and/or N+P+K deficient and knows generally intense runoff.

To restore the productivity of the soil, we need to correct these deficiencies :

1 - Control of runoff and erosion : adapted sustainable farming system and efficient simple antierosive productive structure.

2 - Deep subsoiling to reorganise a deep drainage and a deep rooting.

3 - Stabilization of the macroporosity and the structure by ploughing in organic residues (or $CaCO_3$ or gypsum) and by cropping a plant developping much rooth biomass (greencover, leguminous, sorghum, Pennisetum, etc.).

4 - Revivification of the "death soil" by dressing of 10 to 20 t/ha of mature manure or compost to mixt locally to the topsoil.

5 - Liming (1 to 5 t/ha/3 years) to increase the pH up to 5 where aluminium and manganese toxicity disappear.

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.

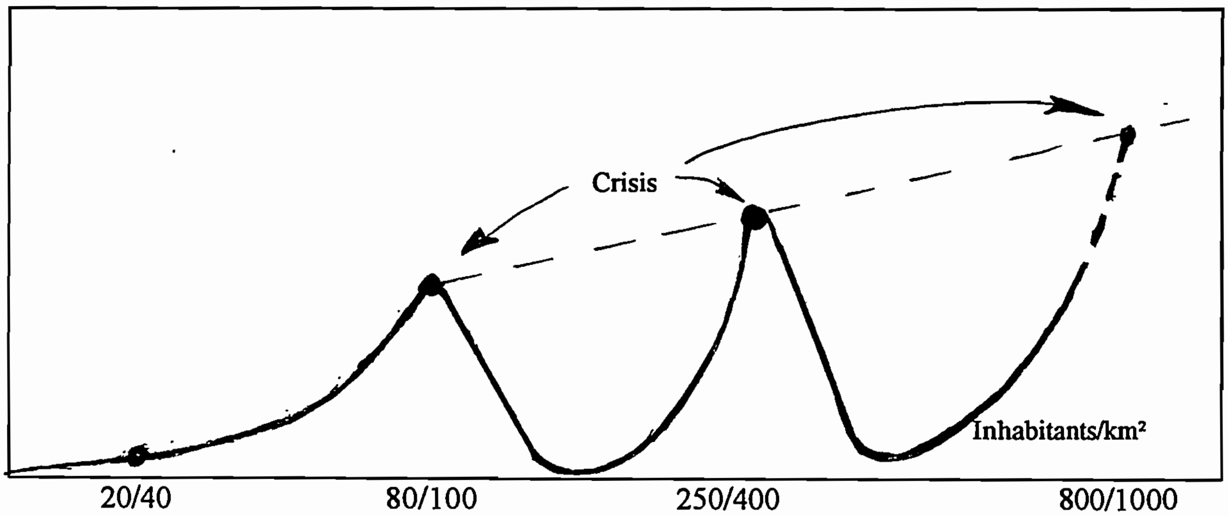
Once soil erosion jugulated, and soil fertility restored, it remains to insure feeding of plants cultivated (local setting) at their rythm (fractionized doses), in relation with the level of production (N 40 to 160 kg/ha ; P 30 to 100 ; K 20 to 100 ; micronutrients, etc...) and in relation to the periodic 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

FIGURE 7 - Soil fertility management in relation to population pressure



Shifting cultivation	Unbalanced intensification	Intensification by labour + organic manure	Intensification by labour + organic M. + NPK Ca
Fertilization by ashes and long fallow	- shorter fallows - weeds and residues plowed in - very few dry dung	- very short fallow - leguminous fallow - crop residues → animals - dry dung	- agroforestry - compost, mulch - farm manure - liming + NPK
Breeding - quite missing - moving of stockes - chicken + goats only	- extensive grazing - KRAAL for the night - dry dung 600 kg/cow/year -some cows	- crop residues + short extensive grazing - 1/2 day stalling - dry dung + compost ≈ 1500 kg/cow/year - rare cows + goats	- crop residues + very short grazing + forage - permanent stalling - farm manure x compost 5 to 10 t/year/family - no cow + pigs + goats
Forestry - burning	- cutting x burning	beginning of agroforestry	- intensive gardening in multistory gardens
Land surface 1 + 20 ha	1 + 5 ha	1 + 3 ha	< 1 to 0,5 ha + external ressources
Agriculture - Cassava - Root crops	- cereals + beans + Cassava	- Cassava + cereals + beans - rice	Cassava + beans

3 - PERSPECTIVE : SOIL FERILITY 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 whith 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, maïze and sorghum, 3-8 t/ha of cassava). To take up the challenge to double the production before the population has doubbled 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/3years).

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