

## Chapter 11. Agroforestry, mineral fertilization and land husbandry in Rwanda

### ATTAINING FOOD SELF-SUFFICIENCY IN A HEAVILY POPULATED TROPICAL MOUNTAIN REGION

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#### **The situation**

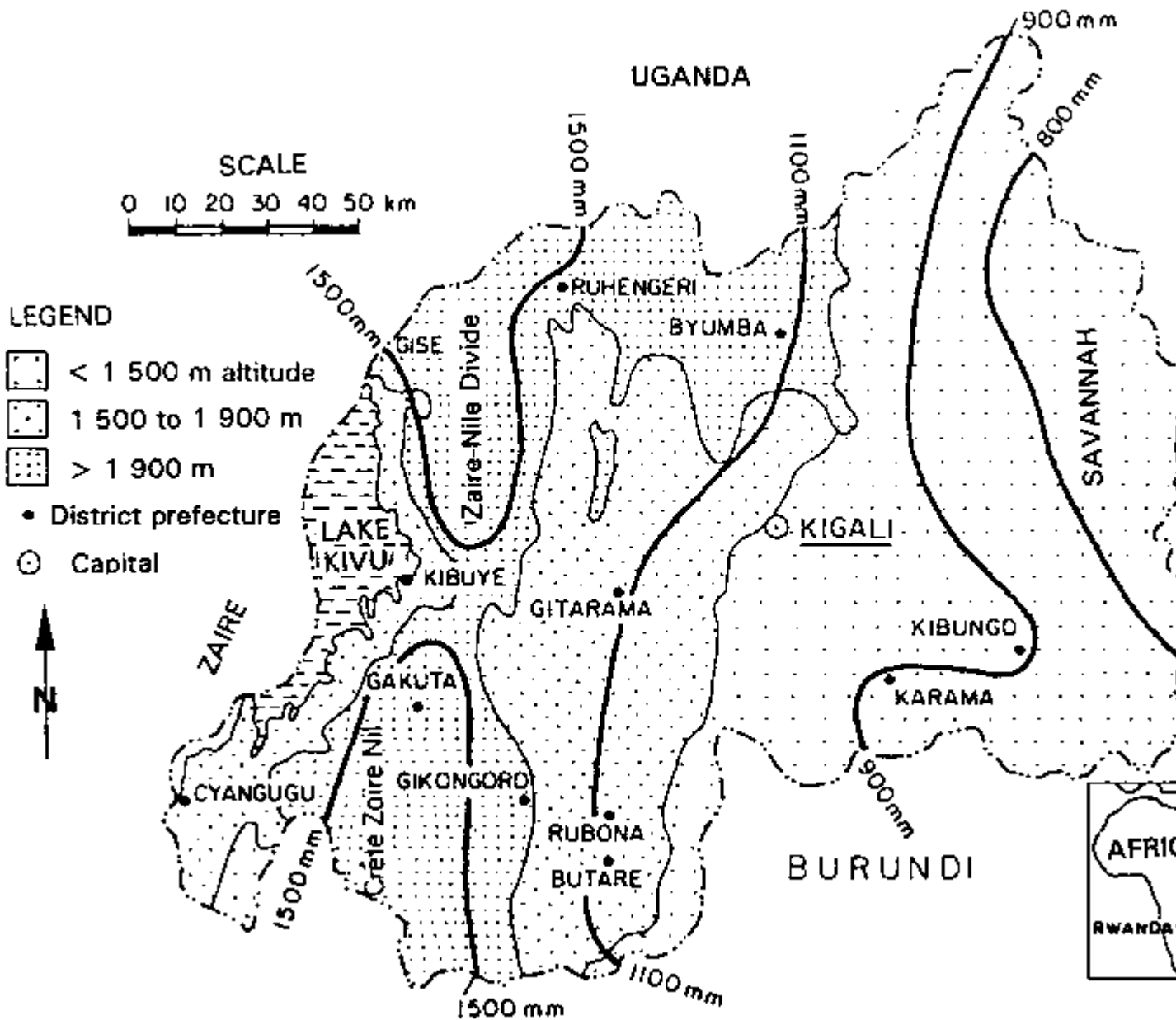
Rwanda is a small (26000 km<sup>2</sup>) mountainous (900 to 4200 m altitude) land-locked country in Central Africa, more than 1000 km from the Indian Ocean and 2000 km from the Atlantic.

A country with a thousand hills, Rwanda has a very wide variety of landscapes. There are six major bioclimatic zones, divided according to geological bedrock, landform, population density, crops, and especially rainfall, which increases with altitude (Delepierre 1982; Gasana 1990) (see Figure 70).

The country has recently undergone massive demographic growth: its population was estimated at 1 million at the beginning of the century, 2.6 million at Independence in 1962, 8 million in 1992, and will exceed 10 million towards the year 2000. The growth rate is one of the highest in the world - 3.7%, meaning that the population doubles every 17 years. Economic growth can no longer keep up with population growth, and the farming population has fallen below the poverty threshold. As the country has virtually no more land reserves, the average size of holdings is shrinking dangerously; it is now under 0.8 ha, and more than 25% of families have to subsist on less than 0.4 ha.

Three communities inhabit this high, tropical landscape: artisans (5%), farmers (85%) and herders (10%). The farmers - the largest group - cultivate the slopes of mid-altitude hills, while the herders occupy the hilltops during the rainy season and the lowlands during the dry season. As a result of population pressure, agriculture rapidly took over all arable land, so that the large cattle herds were forced into the eastern savannahs or the highlands (the Zaire-Nile Divide and volcanoes). Moreover, 50% of farming households today have some sheep or goats, and 30% have one or two cows. When farms are only 0.4 ha it is no longer possible to expand animal husbandry and forage crops: fallow periods have almost disappeared, and grazing is limited to roadsides and private or communal thickets. The trend is inexorably toward keeping small animals (goats, pigs, chickens) more or less permanently penned. This raises the problem of fertilizing land that was hitherto manured with cattle dung, for the reduced availability of dung means that it is no longer possible to maintain fertility on more than 30% of the land. More organic manure (from pens), more mineral supplements, and mulching will thus be needed.

**FIGURE 70** Agro-environmental zones of Rwanda showing altitude (< 1500, < 1900 and > 1900 m) and rainfall (< 900, < 1500 and > 1500 mm) (cf. Delepierre 1982)



The main problem for this agricultural country (more than 90% of the population earns its living from agriculture) with scant mineral or commercial resources is that of ensuring food and wood self-sufficiency for a very large population (from 150 to over 800 per km<sup>2</sup>), without degrading this landscape of large elongated hills.

Since erosion risks vary greatly in Rwanda, the volcanic zone (one-third of the country), the areas surrounding Lake Kivu, and the Zaire-Nile Divide (where risks of landslides are greater, the steeper the slope, the more abundant the rainfall [up to 2000 mm] and the more frequent the earthquakes) have been left aside, and the results confined to those obtained on the central uplands (in the Butaré region) and in the low-lying savannah zone of the east (Karama).

## Analysis of local conditions

The two zones selected vary considerably in terms of erosion risks.

- **The low-lying plains** (900 to 1500 m altitude), covered in shrub savannah, receive 800 to 1000 mm/yr of rain over two rainy seasons. This area is less rugged (slopes of less than 15%), less well-watered, and less densely populated than the rest of the country as a result of malaria and various tropical ailments, and consequently less exposed to the risk of erosion. Most of the eastern part of this area is presently given over to extensive livestock production, even though the soil is often quite fertile. The ferralitic or ferruginous soils here are less acid and less desaturated than elsewhere, but water runs off more easily (a result of the formation of slaking crusts) and crops suffer each year from rainfall irregularity and stress. Managing surface water is probably the main problem for agricultural development in the area, while losses through erosion and drainage are moderate.
- **The central plateau** (1500 to 2000 m altitude) receives between 1200 and 1500 mm of rain, spread over ten months. Rainfall erosivity is significant (250 to 500  $R_{USA}$  units), and the very dense farming population (250 to 800 per km<sup>2</sup>) has to cultivate every piece of land, including slopes of over 40% on the sides of convex hills.

During the first season (September to December), the rain is fine and only one quarter as forceful as in West Africa. It falls on dry, well-drained, and manually well-tilled soil, and does not cause much damage. However, in the second season (February to June) there are several larger, heavy storms (60 to 100 mm/day). If they fall on moist soil, on steeply sloping slopes or soil fine-tilled for sowing, the water forms rills, which then scour the full depth of the tilled soil down the whole length of the plot. All this soil easily blocks the erosion control ditches, which overflow, so that the runoff accumulated in them then cuts gullies which will wreck erosion control measures all the way down to the foot of the hill.

The topsoil horizon is quickly scoured, not only by rill erosion but also by dry mechanical erosion following multiple tillage procedures: deep-ploughing the land twice (to dig in weeds) and hoeing twice in each cropping season causes 30 to 60 tonnes of earth to move down the slope as far as the next obstacle, so that banks rise by 15 to 30 cm per year.

At this rate, the soil cover on the hilltops is soon stripped, uncovering alterites and blocks of rock. Much less water is now absorbed and retained, which means that during periods of heavy rainfall, large amounts of water gush down from the degraded hilltops, gullying the slopes, changing the flow rate of rivers, increasing peak flows, attacking river banks, and washing away the gravel from river beds. The delicate balance in these mountains is disrupted by uncontrolled clearing, overgrazing, growing crops that provide little cover on very steep slopes, and the removal of stones that protect river beds for building.

Ferralitic soils are generally very desaturated, acidic, (frequent pH of 5 - 4), deficient in P and N. and poor in bases. They seem on the whole very permeable, except where they have been compacted (tracks, cattle trails, paths to dwellings) or pounded by rain. They retain little water (1 mm of available water per centimetre of soil) or nutrients (1 to 5 meq/100 g of fine soil), so that it is important to maintain an adequate level of organic matter. They are often rejuvenated by erosion, with a layer of rubble or ferruginous gravel at a depth of between 30 and 100 cm. Soil erodibility ranges from low to medium on schist, and Wischmeier's K factor is generally under 0.20 (Roose and Sarrailh 1989, Ndayizigiyé 1993).

TABLE 40

**Erosion (t/ha/yr) and runoff (% of annual rainfall) on small plots ( 5 × 20 m) on steeply sloping (25-60%) ferralitic soils in Rwanda and Burundi**

Plant cover	Treatment	E t/ha/yr	Runoff Kaar %
Bare soil	tilled parallel with the slope	300 to 550	10 to 40%
Manioc or potato, maize/bean or peasorghum, as companion crops	traditional hoe tillage	50 to 150 (300)	10 to 37%
Crops + idem + 200 trees/ha	litter 50 kg/tree/yr	30 to 50 (111)	5 to 7 %
Idem + trees + hedges every 5 to 10 m	biomass	year 1: 7 to 16	10 to 15%
	3 to 6 kg/m <sup>2</sup> /yr	year 4: 1 to 3	1 to 3%
Idem + trees + hedges	± covered ridges every 5 m	1 to 4	0.1 to 2%
Banana plantation	open, mulch removed (10 t/ha/yr) or	20 to 60	5 to 10% (45)
	complete, mulch spread out or in lines	1 to 5	0 to 2%
Coffee plantation or manioc	thick mulch (20 t/ha/yr)	0 to 1	0.1 to 10%
<i>Pinus</i> forest, pasture, old fallow	(5-15 t/yr of litter)	0 to 1	1 to 10%

( ) = maximum levels recorded

Except for the two planting periods the countryside is green, for annual rainfall is good if irregularly distributed. Erosion risk would therefore be moderate if the cultivated slopes were not so steep (Berding 1992). Two country-wide surveys indicated that 50% of the cultivated land is on slopes exceeding 18%, 20% on slopes exceeding 40%, 5 to 6% on slopes exceeding 65% (the limit for terracing), and 1% on slopes exceeding 84%.

Erosion risks are aggravated locally by two phenomena.

- **Land tenure problems.** The concern for equality in inheritance means that each heir receives an equal share of each section of land, which means in turn splitting the original plot into as many vertical strips as there are heirs. The result is that on densely populated hills (those farmed for a long time) very long, narrow plots are put under crops at the same time, which seriously increases the risk that sheet erosion will scour the soil right to the bottom of the slope. Once such scouring starts, it happens again each year in the same spots, because it is difficult to prevent runoff from flowing toward the lowest points in a field. The land is quickly ruined. Land tenure laws should be changed.

- **Landslides.** If erosion control on a hill calls for digging total absorption ditches on slopes of over 40% or on shallow soils on a sliding alterite (schist, gneiss, micaceous rock or volcanic ash on granite domes), the slope is thrown out of balance. If a long series of storms waterlogs the soil cover

(and especially if this is compounded by earthquakes), it can start sliding from one of these ditches, and continue down to the river, which can then be temporarily blocked by this mass of earth.

Experiments show how urgent it is to combine all available erosion control techniques in order to stabilize sloping land while also substantially increasing its productivity (see Table 40).

There are about 250 reliable measurements of annual erosion on plots of 100 m<sup>2</sup> (20 m in length) fairly similar to farmers' fields, on steep slopes (25 to 60%, except for the IRAZ banana plantations, where S = 8%), on ferralitic soils that have been somewhat rejuvenated or received colluvial deposits and are very desaturated and acid, but also very resistant to rainfall aggressiveness ( $K < 0.2$  to 0.1). The results of these experiments indicate that:

- the risks of sheet and then rill erosion are very high on bare soil, varying from 300 to 550 t/ha/yr, depending much more on rainstorms than on slope; it would take only 5 to 10 years to remove the whole topsoil horizon (20 cm) at this rate;
- the risks of runoff ( $K_{aar} = 10$  to 40%) can be serious on such steep slopes when they are poorly covered (as with degraded soil);
- traditional farming methods and intercropping do considerably lessen risks ( $C = 0.2$  to 0.5), but not enough, since the tolerance threshold is no more than 1 to 12 t/ha/yr depending on soil depth;
- trees dotted among the crops do little to improve soil conservation;
- hedges of grass or bushes every 10 metres, plus large ridges covered with pulses or sweet potatoes every 5 metres, do constitute a valid preliminary solution;
- mulching (tested under banana, coffee or cassava) is a second solution which is immediately effective even on steep slopes;
- reforestation with pines (needle litter being very effective) or other species allowing an understorey quickly reduces runoff and erosion to acceptable levels (Roose, Ndayizigiyé and Sekayange 1992).

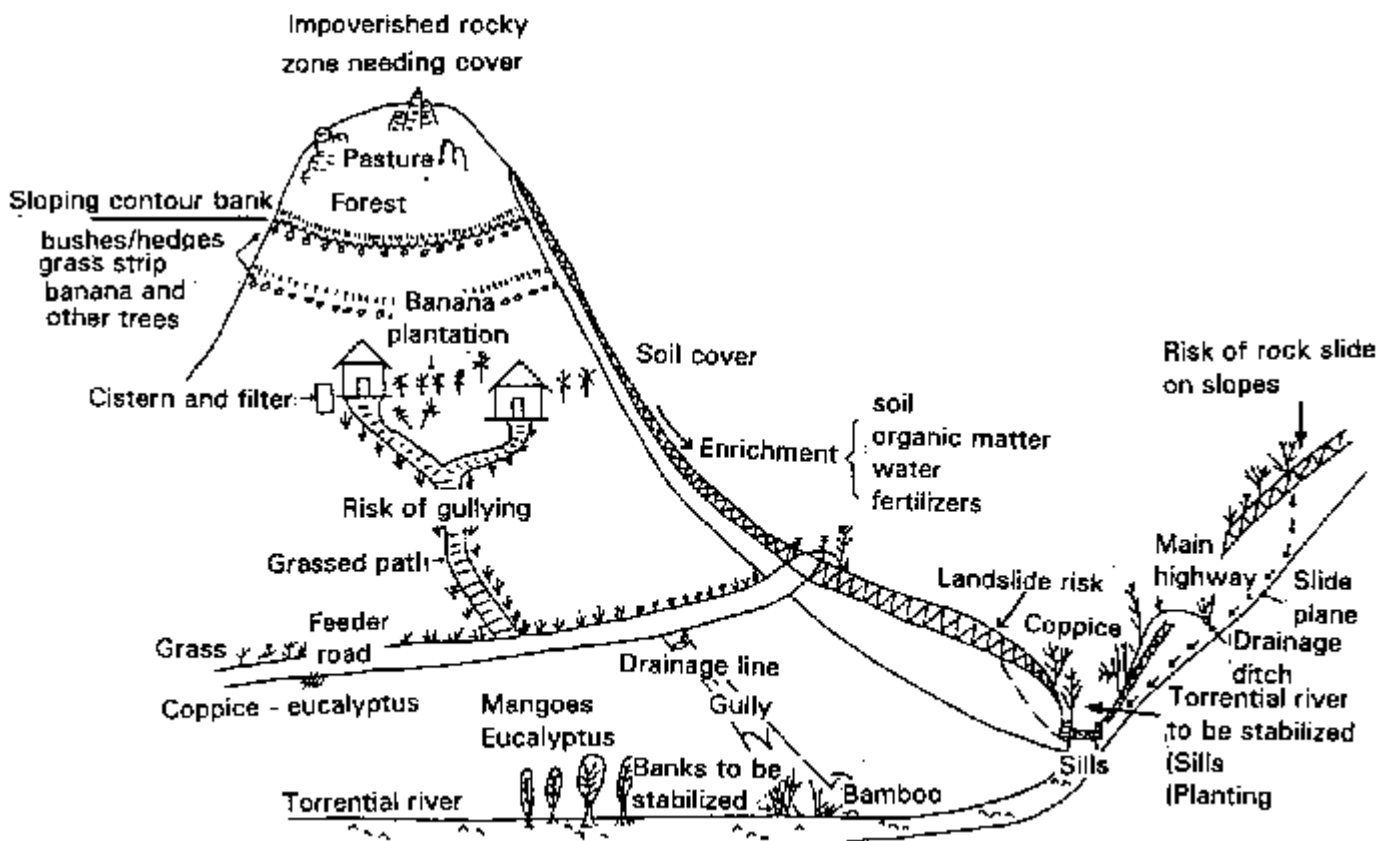
Blind ditches and bench terraces cannot be studied effectively on these small plots (5 m wide). On land managed under erosion control projects, it has been seen that these methods can increase risks of gullying and landslides where the soil cover is thin or the slope too steep (> 40%)

Farming methods - not just erosion control structures - play the major role in stabilizing slopes.

**In conclusion**, these verdant landscapes can give an impression of stability to busy experts who are used to the gullied, bare land of semi-arid regions. In reality, however, the soil is very poor, very steep slopes of 60 to 100% are cultivated out of necessity as land is short, rain is excessive at some periods and scant at others, and the cover provided by crops on the most degraded land is too light to protect the soil from the various erosive processes in the Rwandan hills (see Figure 71).

**FIGURE 71 Six processes leading to rural environmental degradation (cf. Roose 1992a, b)**  
**Quartzite/schist hill**

1. Soil degradation:
    - organic matter
    - fertility
 → Infiltration
  2. Sheet and rill erosion
  3. Dry mechanical erosion: creep
  4. Gulying (tracks)
  5. Landslides
  6. Shifting of torrent channels
- } scouring of topsoil  
 } farmers' responsibility  
 } serious accidents downstream (mud flows, flooding)  
 } State responsibility



## Traditional techniques

The crops are planted in dispersed fashion around the habitat in direct relation to soil fertilization. When a young family sets up home on a levelled platform cut into the hill, it plants its banana plantation around it, and this will receive most of the available nutrients (domestic waste, crop residues, ash, peelings and latrine waste). Companion food crops are grown between the bananas: maize, beans, cush-cush, potato and herbs. A small field of maize intercropped with beans receives a little manure/compost, and broadcast-sown sorghum is grown in the second season.

The only plots not eroded are those that are mulched and under coffee trees: in order to avoid the penalties conscientiously imposed by Ministry of Agriculture field staff, coffee plots (100 to 200 m<sup>2</sup>) are copiously mulched with cassava and sorghum stalks, various types of grass pulled up from the banks, and banana leaves. The remaining land (two-thirds) receives no manure or fertilizer, and inevitably degrades under such frugal crops as cassava and sweet potato.

Weeds are carefully pulled up, either - depending on need and season - to feed stabled animals, or to cover furrows and reduce erosion, or to be piled up in large heaps, covered with earth and immediately planted with sweet potato cuttings. In any case, vegetation is very quickly recycled.

Plots are sometimes scattered several kilometres away from dwellings (rented fields). Despite the many disadvantages (time spent travelling back and forth, difficulty in guarding and manuring plots), scattered fields do allow farmers to cope with climate-related risks (localized storms and hail, damage from animals and disease). Young technocrats dream of dwellings concentrated in villages and consolidation of landholdings so as to promote intensive, modern, mechanized farming. This is a serious mistake in a country with no alternative way to feed a very large rural population forced off the land (no industry, no international waterway, no trade). Furthermore, the land is too steep to risk the introduction of tractors (little likelihood of cost effectiveness, and risks of compaction), and an element that now enriches the land (domestic waste) would become a pollutant hard to control within a village.

Present farming techniques take a great deal of work, which is often performed by groups of neighbours using two rudimentary implements, the machete (sometimes curved like a sickle) and a long-handled hoe. Following a short fallow (from a few months to one or two years), the soil surface is cleared of infesting weeds and then deep-ploughed to turn in the weeds (30 cm and more). Stolons and other persistent roots are dried in heaps, and composted or burnt. A month later the plot is fine-tilled for drill sowing (maize) or broadcast sowing (second-season sorghum); an intercrop may be sown after the first hoeing to fill empty seed holes and cover the whole area.

All tillage is manual, using hoes. Animal traction is difficult on steep slopes and is never even considered, for there is no tradition of draught animals. There is no mechanization (far too expensive at such a distance from the sea), which means that there is little compaction of deep horizons, and drainage seems normal. Deep drainage would be needed only in the vicinity of springs.

Ridging or larger mounding is confined to tuber crops and digging in weeds. On the other hand, crops are usually grown on raised beds or large mounds in the valleys and marshlands in order to ensure good drainage.

Apart from spreading manure on fields near dwellings, soil fertility is maintained by intercropping, rotation, digging in weeds, and a short fallow. However, there is an erosion control technique traditionally used on steep slopes, especially for growing peas on schist and in the highlands in the north and on the Zaire-Nile Divide (Nyamulinda 1989). It consists of micro-step terraces 1 metre wide, cut into the slope, preserving the root systems of clumps of grass. This allows space for a double row of maize/beans or peas. The risers (0.5 to 1 m high) are kept firmly in place by the root networks. The main concern with these narrow terraces is to keep the cultivated beds within the topsoil horizon, for the wider the terrace the more the soil structure is disturbed and the more the sterile deeper horizons are exposed (Roose et al. 1992). The traditional technique is to turn half a bed on to the one below in the second year - thereby mechanically shifting the surface layer of soil right along the slope. Trials on erosion plots have shown that with an improved version of this method (placing beds strictly along the contour and using the grass from the risers) all erosion can be stopped and rainwater better managed, even on schist soils on 60% slopes.

Lastly, there is a local technique of managing runoff on tracks, which consists of digging a pit in the upper slope, in which runoff and its load of sediment are directed. When it is half-full of sediment, a clump of banana trees is planted in it, to benefit from the additional water and nutrients. When the first pit is almost full, another is dug lower down (= Rudumburi).

In conclusion, traditional methods allowed maintenance of the stability of the landscape and a modest production level. Now that the population has become too numerous to keep enough land under fallow, something has to be done to keep the soil in place, but also to bring about a rapid increase in soil productivity for both food and fuelwood crops).

### **Suggestions for managing surface water**

#### ADAPTATION TO EACH CLIMATIC REGION

**In semi-arid regions** (especially the eastern savannah), placing land under cultivation brings a major increase in runoff and a reduction in evapotranspiration, and thus in the production of biomass. Runoff control measures (improvements in infiltration and localized storage) can therefore have a considerable impact on yields of crops that suffer as much from drought as from mineral deficiency. Farmers will quickly become interested in runoff management techniques.

**In humid regions** ( $R > 1000$  mm), clearing land and putting it under cultivation bring an increase in the risks of runoff, in peak flows of rivers, and therefore in the risk of erosion of banks. There is a consequent reduction in drainage, the leaching of fertilizers, and the dry season flow of springs and rivers. Runoff (and erosion) control will thus have relatively little effect on crop yields, unless there are periods of drought during vulnerable phases in the growth cycle. This is one reason why erosion control has had little impact on yields in the humid hills of Rwanda, the other causes being the chemical poverty and acidity of the soil.

**In conclusion**, if runoff is reduced by farming techniques and/or suitable erosion control structures, plant production must be intensified to avoid increased risk of nutrient leaching by drainage water and landslides on steep slopes: hence the attraction of intercropping, fertilization and agroforestry.

#### WATER MANAGEMENT STRUCTURES SUITABLE FOR RWANDA

Four approaches to surface water management can be identified, depending on climate and soil permeability, with corresponding erosion control structures and farming techniques (Roose, Ndayizingiyé and Sekayange 1992). Here only the most appropriate are described.

**Cisterns of drinking water** collecting 10 to 50 m<sup>3</sup> of clean water from roofs considerably alleviate the work of carrying water, improve hygiene, and allow for a few penned animals, the production of manure and a very intensive multi-storey garden around dwellings.

**Cisterns or pools collecting runoff water** (100 to 500 m<sup>3</sup>) on tracks or rocky or overgrazed slopes allow livestock watering and supplementary irrigation of short-season vegetable and fruit crops (see Haiti).

**Total absorption ditches** encourage infiltration of runoff water on slopes of less than 20%, on deep, permeable soil. Unfortunately, they require a lot of work (200 to 350 days to dig, plus 20 to 50 days per year for upkeep), and hardly improve crop yields at all (which is why farmers abandon them). Their main attraction is in the gradual transformation of the landscape into very gently sloping terraces. Diversion ditches are unadvisable for mountainous regions, as gulying is bound to set in at their outlets.

**Stop-wash lines** or semi-pervious microdams (lines of grass, stones, hedges, grassed banks) do not stop runoff, but do slow down water, dissipate its energy, and spread it into sheets, thereby encouraging sedimentation. A bank quickly forms (20 to 30 cm/yr), with a gradual terrace which can then be transformed into two horizontal terraces, one enriched (reserved for intensive cropping), and the other poorer (frugal crops such as cassava and sweet potatoes), so that fertility must be gradually restored (see Figure 72). The demand for labour is more occasional (50 days to build, plus 10 days per year for upkeep), as are fertilizer requirements.

**Horizontal or bench terraces** allow all water (rain + runoff between terraces) to be absorbed, and make the most of manure inputs. Clearly, however, bench terracing requires a huge investment in terms of labour (500 to 1000 days/ha to build) and inputs (10 t/ha of manure, 1 to 5 t/ha of lime, plus the fertilizer for each crop) before the natural fertility of the soil is restored. This method should be chosen only if there are both inputs and the markets and practicable roads to capitalize on surplus production. There must be no risk of landslides.

**Micro-step terraces** (cultivated width about 1 metre) on permanent grassed risers (maximum 50 to 100 cm) require much less work and stabilize steep slopes very well under manual intercropping, since the crop roots remain in the original topsoil.

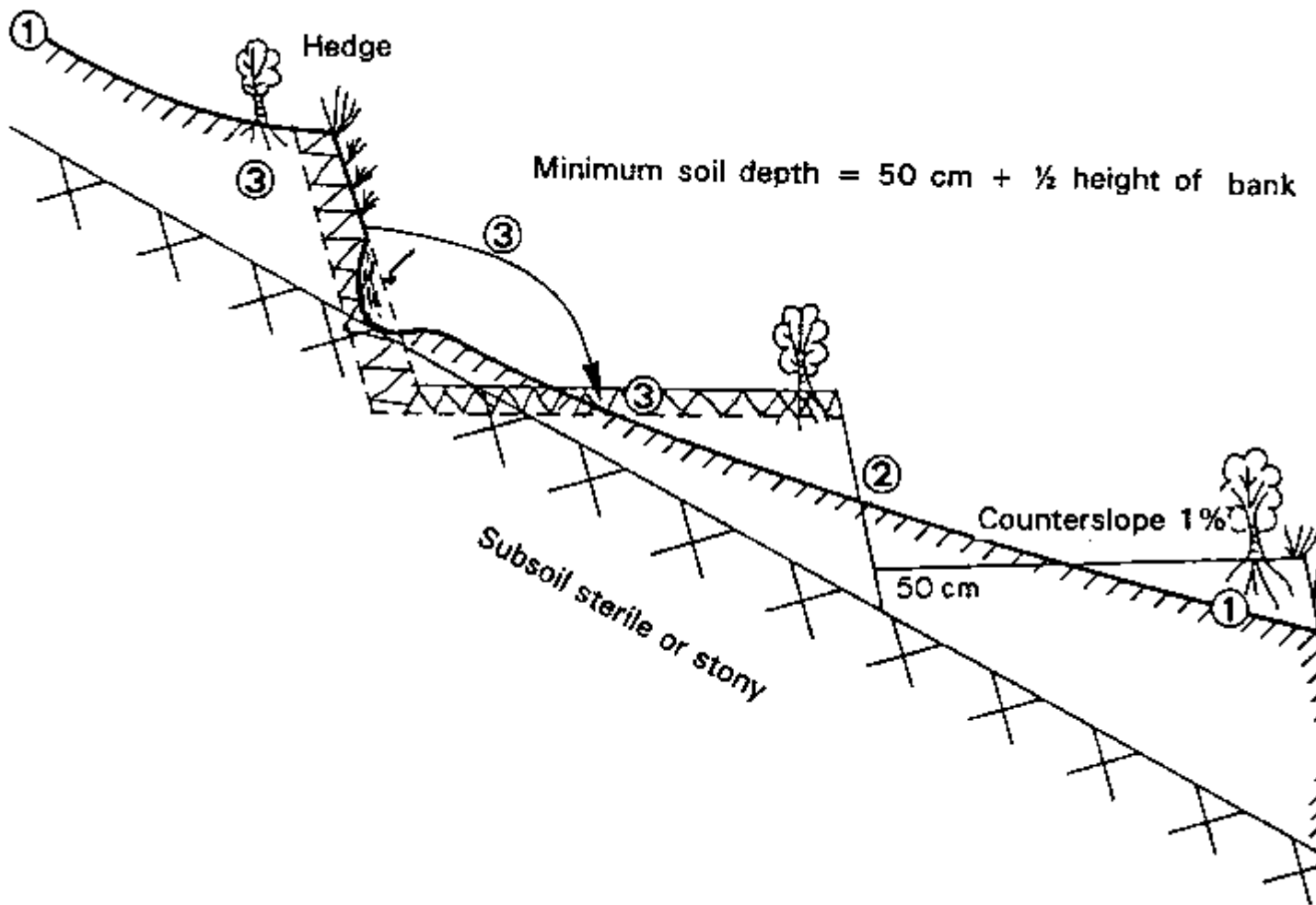
#### THE MOST SUITABLE TILLAGE TECHNIQUES

Tillage techniques that modify the state of the soil surface, roughness, plant cover, the activity of mesofauna and/or infiltration capacity are often very effective in reducing the volume of runoff and dissipating its energy.

**Flat tillage with large clods is essential on soils that are too compacted.** It temporarily increases infiltration, improves water storage and helps to dig in crop residues and combat weeds. Unfortunately, it inhibits earthworm activity, reduces soil cohesion, and increases erodibility by runoff water, especially if seeds are sown on a bed of very fine aggregates.

**Mounding and ridging**, parallel with the slope, gather together good topsoil so that large tubers can be grown, but these practices are dangerous on steep slopes since they concentrate runoff into trickles that can dig rills and gullies, and detach gravel and other stones that protect the soil from rainsplash.

**FIGURE 72 Development of gradual terraces into horizontal terraces: a CIGAND project proposal**



(1) At present the hills hold many gradual terraces which are too wide between banks which are too steep or even undermined at their base. After 5 to 7 years, the lower part of the terrace has filled out with fine soil, while the upper part is scoured and tends to become sterile: intervention is required.

(2) Fine the line in the terrace where sterile subsoil or rock appears at about 1.3 m (50 cm + 1/2 the height of the bank), plant a new line of grasses, and build a bank at a 40% slope, covered with grass + fodder legumes.

(3) To prevent the terrace above from becoming sterile after levelling work, the wall of the uphill bank can be knocked down one last time to correct its slope, and a good layer of topsoil spread on the terrace above.

**Tied ridging** perpendicular to the slope improves water storage under small rainstorms, but can lead to gullying or landslides under heavy storms. Only **large ridges (H = width ≥ 40 cm) permanently protected by creeping plants** (e.g. sweet potato or forage pulses) and at intervals of under 5 metres, can break the force of runoff on slopes. Combined with hedges, they can quickly stabilize steep slopes (20 to 60%).

## Suggestions for managing soil fertility

### BIOMASS MANAGEMENT

In Rwanda, most farmers are too poor to buy enough mineral fertilizer to boost the productivity of all their land. Traditionally their only means of maintaining or restoring soil productivity is the biomass produced on their fields and on fallow areas, roadsides, communal forests, etc. Application of SPR and SWC methods (ditches) does not increase biomass production, and also reduces the productive area. Land husbandry, on the other hand, attaches great importance to improving biomass production and to careful management of organic matter so as to restore the essential nutrients to the soil as quickly as possible.

In the tropical African rain forest 8 to 15 t/ha of litter are returned to the soil each year. Under savannah 2 to 8 t/ha of leaves are returned to the soil, unless they are destroyed by fire or livestock! After clearing (burning off natural vegetation and putting the land under crops), the amount of organic matter in the topsoil horizons falls by 40 % in four to ten years, depending on how organic residues are managed - manure, compost, direct turning in, or mulching.

Under crops there is a fair amount of available biomass:

- maize and sorghum can leave 2 to 5 t/ha/6 months of residues, at present used for feeding stock or mulching the coffee plantation;
- soybeans, groundnuts and beans produce 0.5 to 2 t/ha of good-quality fodder;
- cassava and sweet potatoes provide 0.5 to 2 t/ha of biomass which can be used for feeding pigs or mulching the coffee;
- a banana plantation (3 × 5 m density) can produce 3.3 t/ha of stems and 2 to 6 t/ha of leaves which can be used as mulch or fodder;
- short fallow periods (a few months between two cropping cycles) and weeds provide 0.5 to 2 t/ha/yr of green matter.

### AGROFORESTRY

This method can considerably boost biomass production on cultivated fields. Two hundred trees (*Grevillea robusta*, *Cedrella serrata*, *Polyscias fulva*, etc.) planted in or around fields can produce enough firewood for the whole family, plus 1 to 4 t/ha/yr of leaves and twigs very useful for mulching.

Planted every 5 to 10 metres, hedges of *Calliandra calothyrsus*, *Leucaena leucocephala* or *diversifolia*, or *Cassia spectabilis*, can provide 3 to 9 t/ha/yr of leaves (excellent fodder) and 2 to 7 t/ha/yr of firewood; in other words, more biomass may be produced on a cultivated field from crop residues, trees and hedges, than under primary or secondary forest. However, it is important to make sure that enough of it is restored to the soil.

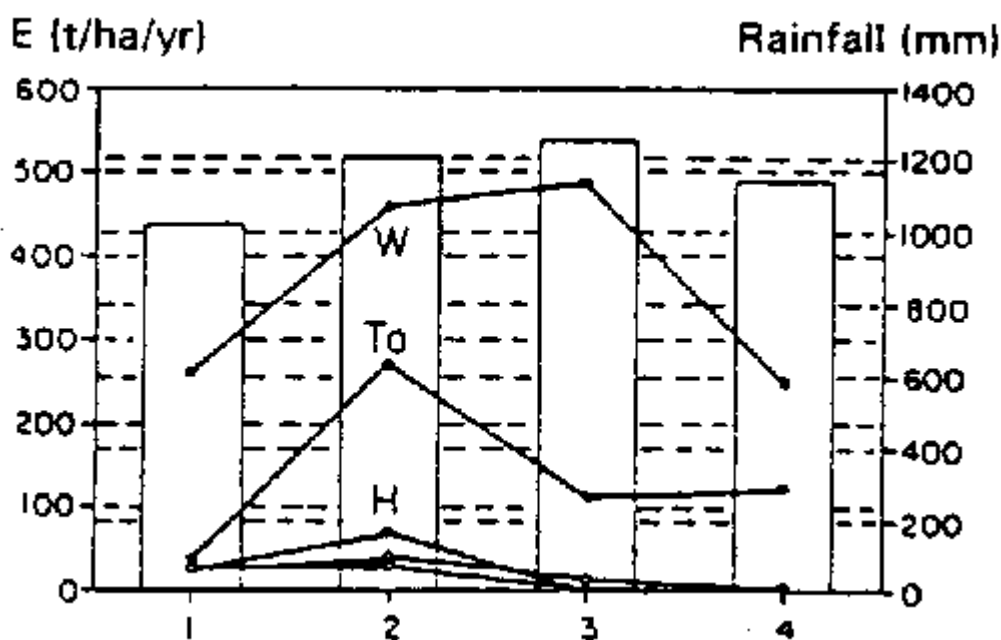
### BIOLOGICAL UPTAKE OF NUTRIENTS THROUGH AGROFORESTRY

If the soil is neither too acid nor too deficient in phosphorus, the shrubs chosen for hedges can fix nitrogen from the air. Depending on author and site (Balasubramanian and Sekayange (1992) in the eastern savannah, König (1992) and Ndayizigiyé (1992) around Butaré on the central plateau), cutting the hedges three times can bring up to the soil surface: 75 to 130 kg/ha/yr of nitrogen, 2 to 20 kg of phosphorus, 20 to 60 kg of potassium, and similar amounts of calcium and magnesium, depending on the richness of the soil in these elements an input of minerals close to that from 10 tonnes of farm manure. Apart from the litter provided by 200 trees per hectare, it is clear that agroforestry can make a considerable contribution to the organic and mineral balance of the soil in two ways: by significantly reducing nutrient loss through erosion and drainage, but also by extracting nitrogen from the air and through the uptake of nutrients carried by drainage beyond the reach of the roots of annual crops.

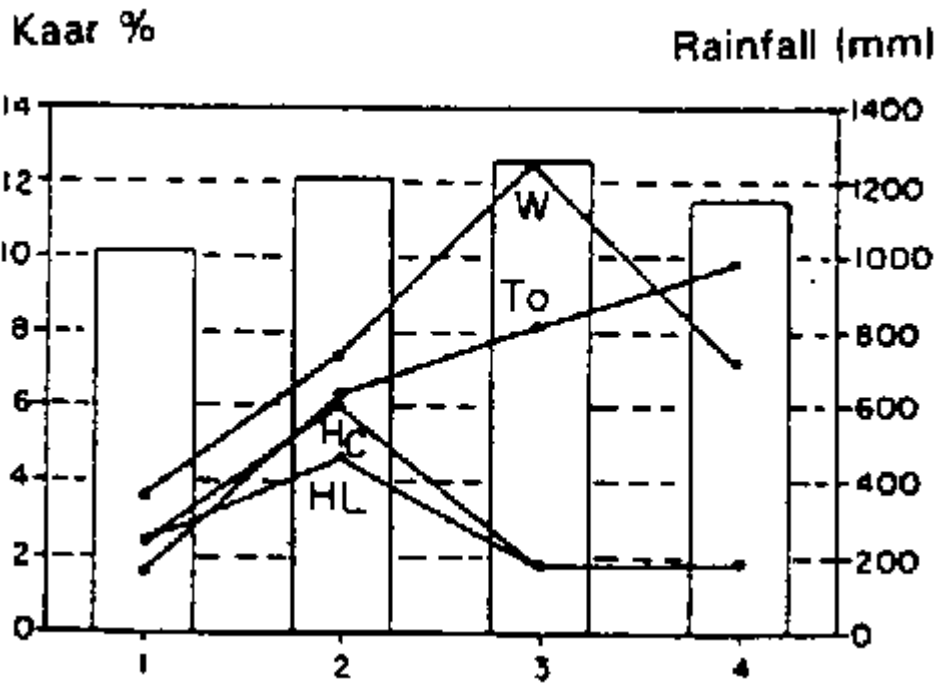
**FIGURE 73**

**Effect of hedges of *Leucaena leucocephala* and *Calliandra calothyrsus* (1 m thick every 7 m) on average annual runoff (Kaar %), erosion (t/ha/yr), hedge biomass production (kg/100m/yr) and harvests of two cropping seasons at the ISAR station at Rubona in Rwanda on a 27% slope and on acid ferralitic soil (cf. Ndayizigiyé 1993)**

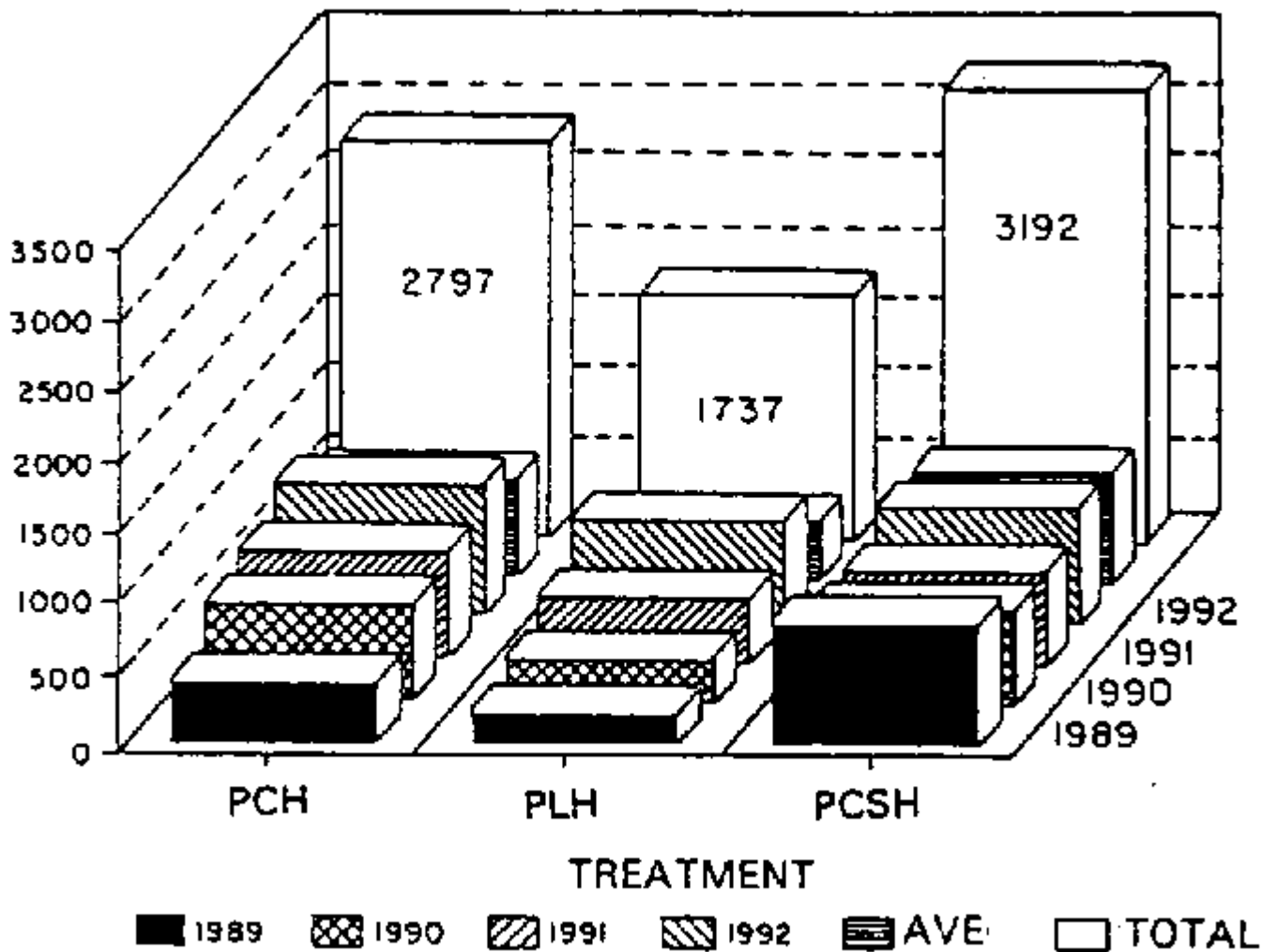
**Erosion as a function of annual rainfall**



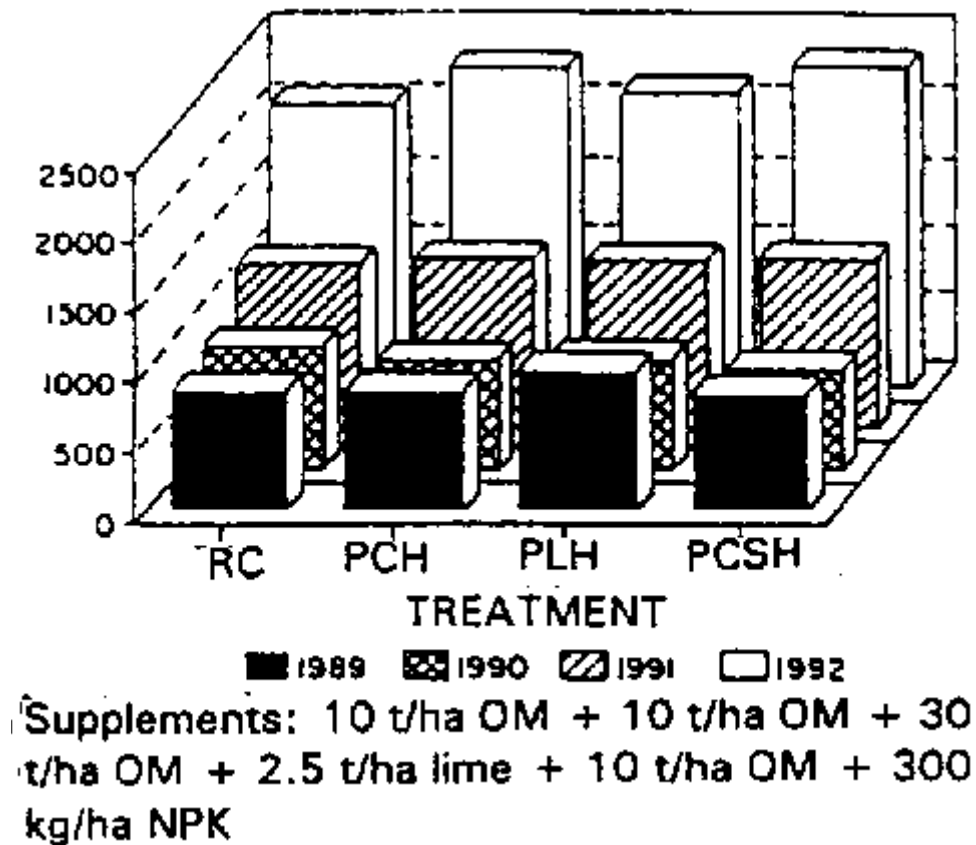
**Runoff (Kaar = % of annual rainfall)**



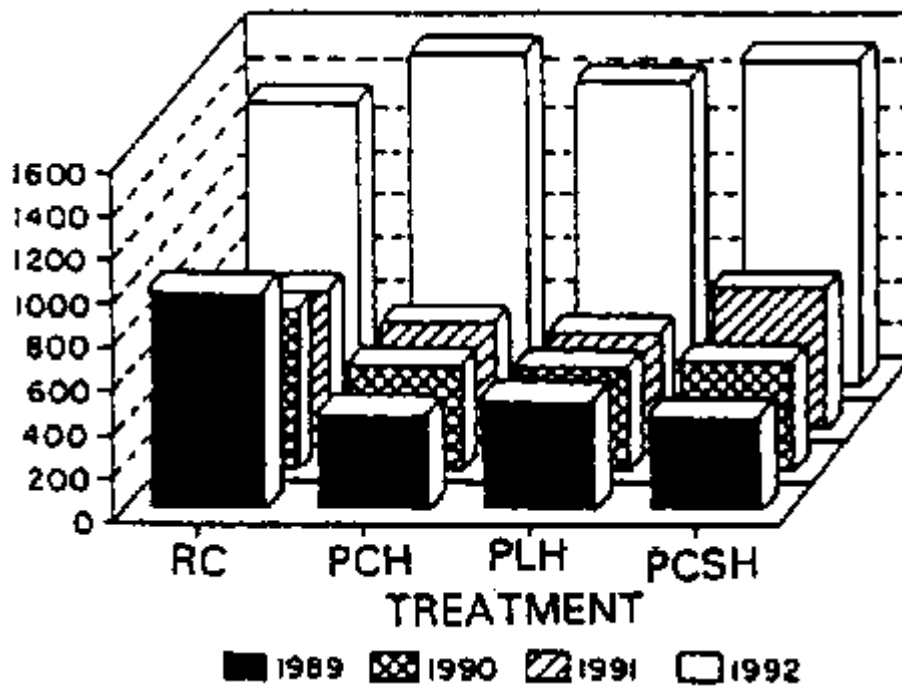
Hedge biomass production (kg per 100 m of hedge)



Bean and maize harvest (kg/ha) in the 1st season



Sorghum grain harvest (kg/ha) in the 2nd season



W = Wischmeier's standard bare plot  
 CH = *Calliandra* hedge

P = production  
 LH = *Leucaena* hedge  
 RC = Regional control plot  
 CSH = *Calliandra* + *Setaria* hedge

TABLE 41  
**Requirements of NPK, lime and manure for each crop on the acid ferralitic soils of Rwanda**  
 (cf. Rutunga 1992)

Crops	N	P	K	Lime, manure, inoculant
Bean	34	25-30	34	depending on cryptogamic diseases
Soybean	20-40	40-50	30-50	+ inoculant + lime if pH < 5
Pea	34	34	34	+ inoculant + lime + manure
Groundnut	30	30	0	
Sorghum	60	60	17	at altitude + manure (+ lime)
Maize	78	42	42	
Wheat	88	42	42	
Irrigated rice	60	30	30	for two tonnes of paddy
	100	60	60	for six tonnes of paddy
Potato	50	100	200	+ lime + manure if at altitude
Manioc	100	50	100	
Horticultural crops	30-50	30-70	100-200	or 35 tonnes of manure

#### APPLICATIONS OF ORGANIC MATTER AND MINERAL SUPPLEMENTS

Figure 73 compares the effects of three types of hedge, always at intervals of 7 metres, on erosion (t/ha/yr), average annual runoff (Kaar %), biomass production from hedges, and cereal production.

**Biomass.** *Calliandra* hedges give twice as much biomass as *Leucaena* (4 to 8 t/ha/yr). Prunings spread on the ground three times a year cover 80% of the surface with *Calliandra* and 40% with *Leucaena*. However, after two weeks all the small leaves have gone, digested by soil microflora, leaving only the twigs - which children can collect as firewood. Perhaps other shrubs should be investigated for intercropping.

**Runoff.** Apart from the first month after planting, the soil is so well-covered that after two years runoff is negligible: 12% on bare soil, 8 to 10% under traditionally grown crops, 1 to 2.5% under crops with hedges every 7 metres. Runoff is serious only in the case of the long rainstorms of the second season under sorghum on a waterlogged soil. -Maximum daily runoff reaches 68% on bare fallow, 20 to 35% under crops.

**Soil loss.** Sheet and rill erosion decreases from 450 t/ha/yr on bare fallow to 80 to 120 t/ha/yr under traditionally grown crops, and 1 to 2 t/ha/yr under crops two to three years after planting hedges. It should be noted that the crops received 10 t/ha/yr of farm manure (and even 90 t/ha in the third year), although even such a high input of manure was not enough to bring erosion down to acceptable levels. However, while erosion tends to increase from year to year under traditional

methods, it decreases on plots protected by hedges proportionate to the slope of the land (from 27 to 15%).

**Impact on crop production.** In the first year harvests were much the same, indicating that the plots were similar at the outset. In the second year, despite 10 t/ha of manure, yields fell from 10 to 30%. In the third year, following an application of 30 t/ha of manure, yields climbed from 32 to 53 or 68% in the fields with hedges. It was only in the fourth year, when 2.5 t/ha of  $\text{CaCO}_3$ , 10 tonnes of manure and  $\text{N}_{51}$ ,  $\text{P}_{51}$ ,  $\text{K}_{51}$  were applied that yields increased markedly from 500 to over 2000 kg/ha of cereals and up to 2318 kg/ha between the hedges, despite the space taken up by these hedges (15%). Second-season sorghum production remained poor (420 to 640 kg/ha) except after liming and supplementary mineral applications (up to 1544 kg on the plots with hedges).

In this trial on acid ferralitic soil, it seems that even if erosion and runoff are brought under control, yields still continue to fall. Ten tonnes of manure plus six tonnes of pulse mulch were not capable of increasing yields of cereals and beans, because the plants, the soil, the animals and the organic manure are deficient in the same elements (especially P and N). However, yields tripled and the erosion control measures paid off after the pH was corrected (2.5 t/ha/3 yrs of lime was enough to eliminate aluminium toxicity), and supplementary minerals applied (60 units of NPK were enough for the cereals).

So far it seems that farmers are becoming steadily more interested in hedges, but more as sources of dry-season fodder and boundary markers than as erosion control measures. They have not fully grasped all that is involved in the hedge system, particularly the need to cut back roots and branches to limit competition with crops.

## RESTORING SOIL FERTILITY

Outside the volcanic zones, desaturated ferralitic soils are very acid, often exhibit aluminium toxicity, and have excellent drainage, which means that there is a high risk that fertilizer will be leached out in drainage water, especially if runoff is suppressed without intensifying cropping. In such circumstances, farmers will reject soil conservation as leading to no increased return for their work. It is vital that soil conservation, water storage and fertility restoration be introduced simultaneously if there is to be any significant improvement in yields.

The following six rules must be followed if soil fertility is to be restored in one or two years:

- control of runoff and erosion;
- deep subsoiling in order to reorganize rooting;
- stabilization of macroporosity by digging in organic matter (or lime) and by a crop with a vigorous rooting system;
- correction of the pH (pH 5);
- revitalization of the soil through applications of manure or compost (3 to 10 t/ha/2 yrs);
- correction of the main soil deficiencies, or at least provision of the essential crop nutrients.

## MAINTENANCE MANURING

As was seen in the Rubona trial (Figure 73), once erosion has been brought under control and the physical, biological and chemical fertility of the soil restored to an acceptable level, plants still have to be fed (localized manuring) as and when needed (staggered doses), depending on crop production goals (N = 40 to 160 kg/ha/yr + P = 30 to 100 kg/ha/yr + K = 20 to 100 kg/ha/yr) and the risk of periodic leaching. In practice, organic residues have to be better managed and the mineral supplements vital to the crops added, as ferralitic soil can store very few nutrients and little water.

Rutunga (1992) has noted that on Rwanda's poor land, liming (2 to 5 t/ha) should be done every three years, and organic manure applied every three crop cycles. On soil of average richness, liming makes little or no difference, but mineral and organic manuring does. As for rich volcanic soil, weak doses of NPK have so far produced only slight improvements in yields.

#### **CONCLUSIONS ON LAND HUSBANDRY IN RWANDA (Plate 32)**

In the heavily populated tropical mountains of Central Africa, the risks of erosion (300 to 700 t/ha/yr) and degradation of soil fertility increase with slope and population density (150 to 800 per km<sup>2</sup>) (Figure 74).

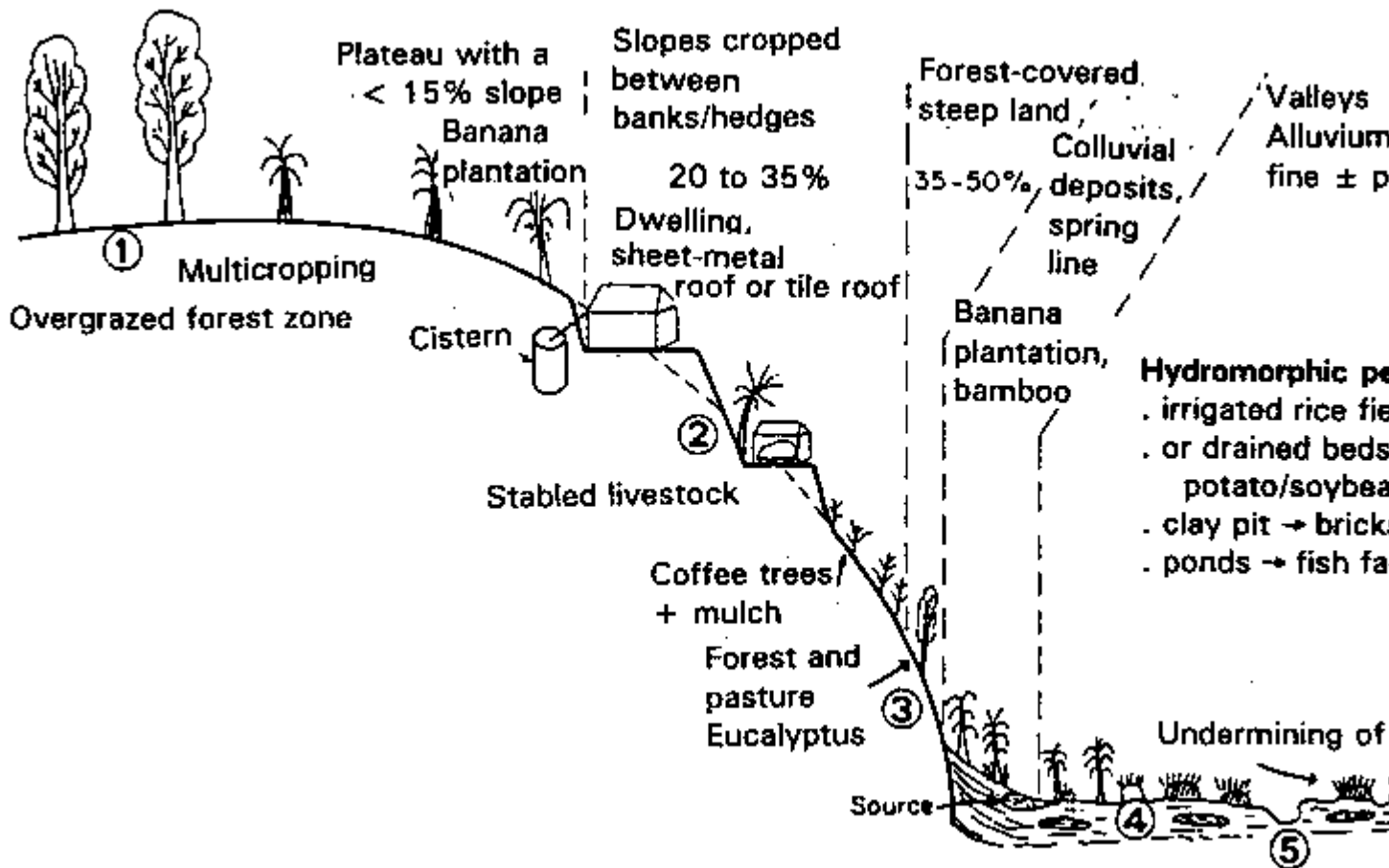
Some production systems can keep erosion at an acceptable level: mulching under coffee, banana or cassava, large contour ridges with permanent plant cover, green manure covering the soil surface, reforestation with species that provide good litter. Radical or gradual terracing (1000 and 100 days' labour respectively) and other erosion control structures are less effective than biological systems (grassed banks, hedges, etc.) and require more upkeep and space.

Agroforestry (e.g. 200 trees per hectare plus hedges every 5 to 10 m) can control erosion (1 to 3 t/ha/yr), produce fodder and mulch (4 to 10 t/ha/yr) and take up nutrients from deep in the soil (N 20 to 100, P 10 to 20, K 2 to 40, Ca + Mg 20 to 40, etc.), with a reasonable amount of work (10 to 30 days per year). Animal husbandry can enhance the benefit of this biomass, since dung is one of the keys to fertilizing ferralitic soil, which is like a sieve.

However, despite applications of 10 t/ha/yr of dried corral-dung and 4 to 8 t/ha of pulse mulch, land productivity has remained very low (400 to 800 kg of beans, maize and sorghum, 3 to 8 t/ha of cassava). If the challenge of doubling production before the population doubles (17 years) is to be met, it is vital to propose a technological package comprising management of both water and soil: cisterns, hedges, organic fertilization (mulching, green manure and improved farm manure) with a mineral supplement (40 to 100 kg/ha/yr of NPK, and 2 to 5 t/ha/3 yrs of lime). SWC is not enough.

It may be noted that the densest populations in the world live in "multi-storey gardens" where the positive interaction between animal husbandry, crops and trees is carried to the furthest extreme. In Africa, much remains to be done before achieving the intensity of production found in the gardens of Asia.

#### **FIGURE 74 Erosion risk and suggested improvements for the granito-gneissic hills of Rwanda**



### Ferralitic acid soil

- permeable
- heavy leaching
- P-N-K-Ca-Mg deficiency
- good resistance to erosion

- (1) Rainsplash and rills ( $\rho$ ) scouring of topsoil
- (2) Rainsplash, rills ( $\rho$ ) gullies, compaction of tracks
- (3) Undermining of banks by river, gullies and mass sliding
- (4) Deposits with very irregular texture: gravel-sand, clay-peat - drainage necessary
- (5) Torrential river with very varied flows and solid loads

### Problems

- How to feed a very dense population living on very poor soil
- How to evacuate excess water from very steep cultivated slopes
- How to improve management of bottom lands

### Attempted improvements

- 1 Drain bottom lands, introduce streambed cultivation: very difficult when only part of the basin is being treated.

2 Slopes: stabilize ground with hedges every 10 m and 200 trees/ha.

- (p) production of fodder, firewood, mulch;
- (p) stabilize the ground against sliding (roots), runoff/mulch;
- (p) trees bring organic matter and nutrients to the surface;
- (p) grassed banks, and hedges.

3 Absolutely necessary on these poor, acid soils: biomass management + mineral applications:

- (p) manure/compost pits + lime and  $P_2O_5$  + ash to raise the pH to  $> 5$ ;
- (p) staggered spot application of a mineral supplement for plants.

4 Transform banks into fodder belts stabilized by legume hedges + grasses and tillage detritus (roots, twigs, stones).

5 Improvement of tracks: generalized grassing, and drainage to cisterns or sedimentation pits planted with bananas.

6 Need to organize the marketing of agricultural products (tracks, etc.) and inputs.

## **CHAPTER 11: RWANDA**

Bitoki O., Kaboneka S. and Duchaufour H. 1990. *L'agroforesterie. Du fourrage, rnaïs pour quel objectif ?* Sém. Agrostologie, Bujumbura, ISABU. 18 p.

Duchaufour H. 1991. Bilan de dix ans de recherches en parcelles et bassin versant au Burundi. *Bull. Réseau Erosion 11*: 36-37.

Eggle A. 1985. La conservation des sols à l'aide des méthodes agroforestières: le cas du Rwanda. *Bull. Rech. Agron. Gembloux 20(3 + 4)*: 561-587.

Kang B.T., Wilson G.F. and Lawson T.L. 1984. *Alley cropping: a stable alternative to shifting cultivation*. IITA, Ibadan, 22 p.

Moeyersons J. 1990. Les glissements de terrain au Rwanda occidental. *Cah. ORSTOM Pédol.* 25(1): 131 + 150.

Ndayizigiye F. 1990. Aperçu sur les pratiques de conservation des sols et de gestion de l'eau au Rwanda. *Bull. Réseau Erosion 10*: 87-97.

Ndayizigiye F. 1991. Aménagement des collines sur le plateau central du Rwanda. *Bull. Réseau Erosion 11*: 173-184

Neumann I. 1983. Use of trees in smallholder agriculture in tropical highlands. In: *Environmentally-sound Agriculture*. Lockerretz W. (ed.). Praeger, New York. pp. 351-374.

Neumann I. 1983. La promotion des cultures associées au projet. *Etude et Experiences n° 4*. PAP, Nyabisindu, Rwanda. 75 p.

- Neumann I. and Pietrowicz P. 1985. L'agroforesterie à Nyabisindu. *Etude et Expériences* n° 9 PAP. Nyabisindu, Rwanda.
- Ngarambe V. 1990. Les techniques culturales et l'aménagement de terroir au Burundi. *Bull. Réseau Erosion* 11: 195-204.
- Nyamulinda V. 1991. Erosion de versants sous culture et transports solides dans les bassins des hautes terres de Ruhengeri au Rwanda. *Bull. Réseau Erosion* 11: 38-63.
- Nyamulinda V. and Ngiruwonsanga V. 1992. Lutte antiérosive et stratégies paysannes dans les montagnes du Rwanda. *Bull. Réseau Erosion* 12: 71-82.
- PAP. 1984. L'érosion et la lutte contre l'érosion. *Fiche techn.* n° 1, PAP, Nyabisindu, 36 p.
- PAP. 1985. L'arbre et la hale dans l'exploitation paysanne. *Fiche technique* n° 3, PAP, Nyabisindu.
- PAP. 1987. Agroforesterie à Nyabisindu. *Fiche technique* n° 9. PAP, Nyabisindu.
- PAP. 1990. Essais de valorisation des talus dans le système des terrasses progressives. *Fiche technique* n° 10. PAP, Nyabisindu.
- Roose E., Ndayizigiye F., Nyamulinda V. and Byiringiro E. 1988. La gestion conservatoire de l'eau et de la fertilité des sols G. CES: une nouvelle stratégie de lutte antiérosive pour le Rwanda. *Bull. Agric. Rwanda* 21(4): 264-277.
- Sabatier J. 1986. *Lutte antiérosive et développement sur la bordure orientale du Plateau Central du Rwanda*. Sémin. CIRAD-DSA, Montpellier.
- Tassin J. 1992. Agroforesterie, Conservation des sols et réalités paysannes. *Bull. Réseau Erosion* 12: 191-193.
- Yamoah C. F., Agboola A. A. and Mulongoy K., 1986. Nutrient contribution and maize performance in alley cropping systems. *Agroforestry systems* 4: 247-254.

