DIVERSITY OF TRADITIONAL AND MODERN STRATEGY FOR SOIL AND WATER CONSERVATION. ECOLOGICAL AND ETHNICAL IMPACT IN SUDANO-SAHELIAN AREAS OF WESTERN AFRICA.

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SUMMARY

Soil conservation systems are various in relation with ecological and socio-economic conditions. Generally, traditional strategies were well adapted but are today obsolete because the population has grown very fast. Current strategy of rural equipment has also failed by lack of farmers consensus. Therefore the author proposes a strategy of rural development (water and soil fertility management) which is founded on needs, traditions and economic possibilities of farmers.

In the second part, the author analyses the observed variability of soil conservation systems applied in the Sudano-Sahelian area of Western Africa. It is well known that this environment is fragile. Even if sheet erosion is relatively moderate (0,5 to 30 t/ha/year), the losses of nutrients and water by runoff (5 to 40% of annual rainfall) are intolerable on arable slopes of semi-arid areas. In relation with the variety of the environment (water economy and ethnies), the authors discerns four subareas where traditional strategies are different :

- the South Sudanian area (Rainfall > 1000 mm) : drainage farming.
Senoufos farmers cultivate on broad ridges for excess rainfall drainage.

- the North Sudanian area (R = 1000 to 700 mm) : rainfed farming
Miniankas farmers build protection earth bunds at the bottom of the hills but try to infiltrate all the rainfall in the field (tied ridging).

- the South Sahelian area (R = 700 to 400 mm) : runoff farming.
The Mossis of Yatenga try to capt all runoff water (cistern, pounding, stone bunds, Zai, mulching, hoeing out, etc...).

- the North Sahelian area (R < 400 mm) : valley farming.
Slopes are used for extensive stocking : management for intensive cropping are localized in the valley.

The soil conversation structures alone are not able to solve runoff problems in cultivated areas, but they are useful to develop more intensive agro-silvo-pastoral systems taking into account the management of biomass, nutrients and the soil surface status.

KEY WORDS : Sudano-Sahelian area - Soil and water conservation strategies - Variability of water economy - Diversity of conservation methods.

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1 - INTRODUCTION :

Erosion is a concept covering many processes varying very much in time and space; consequently soil conservation strategies must change from one area to another and also from people to people.

Geological erosion is generally slow (a few tons/km2/year) but some catastrophic phenomena can occur suddenly, like landslide taking down hillside, centennial forest and villages.

Accelerated erosion is developping in relation with human activities : overgrazing, clearing the forest, repeated fires, poor cultural practices, reduced fallow, unbalance of nutrients and soil organic matter will progressively lead to soil degradation, runoff and erosion.

But if poor management involves increasing erosion risks, people can progressively adapt its agro-silvo-pastoral systems to local ecological situations. Often rural communities are able to select soil and water conservation strategies for maintaining their environment.

In this paper we want to describe briefly traditional and modern soil conservation strategies, then to analyse the diversity of strategies developed by various societies of Sudano-Sahelian area in Western Africa and finally to suggest that it is necessary to take these into account if we want to increase the production with water and soil fertility conservation management.

2 - STRATEGIES OF SOIL CONSERVATION

Shifting cultivation has been practiced all around the world when the population pressure is low (20 to 40 inhabitants/km2 in relation to climate and soil fertility). After clearing the forest, crops are grown on ashes and the land is abandoned to fallow as soon as it does not give enough yield for the labour required. If the demographic pressure increases, the fallow duration decreases and the soil fertility is progressively degrading.

2-1 TRADITIONAL STRATEGIES

Facing these vegetation and soil degradation problems, successive generations developed various strategies of water economy and soil fertility management as a function of ecological and socio-economic conditions.

21.1 RIDGING, INTERCROPPING AND AGROFORESTRY

In volcanic areas of South Western Cameroun moist forests, the BAMILEKE have sucessfully maintained their environment despite high population density (150 to 300 inhabitants/km2). They have combined large ridges with intercropping covering the soil all the year round and with various agroforestry systems.

21.2 STONE LINES, STONE WALLS AND MANURING

In olden days, the DOGONS from MALI have taken refuge in the sandstone cliffs of Bandiagara to resist Muslim influence. For survival they have developed many kinds of soil and water conservation systems :

- stone lines along their little piece of land to capt sand during the dry period and runoff during the rains;
- stone walls after bringing earth from the sandy plains in order to build new soils on sandstone flag (runoff haversting);
- mulching and composting with familial waste, animal faeces and cropping residues.

21.3 BENCH TERRACING

When population is dense, land scarce and labour plentiful and cheap, bench terraces with irrigation or drainage are found numerous like around the Mediterranean sea, in Asia and Latin America.

21.4 BOCAGE, A CLOSE ASSOCIATION BETWEEN TREES, ANIMALS AND CROPS.

European areas have already met many erosion crises. The most famous happened in medieval times when the natural fallow had to be abandoned because of the demographic pressure. Manuring and plowing were introduced to restore faster the chemical and physical fertility of soils. Breeding was associated with cropping and the forestry systems; landscapes were divided with quickset hedges to separate groves, fields and meadows. This system could be today the best solution for Sudano-Sahelian area.

But these days the mechanization and industrialization of agriculture and the economic crisis call into question those types of management. A new erosion crisis is being developed and we need new strategies of water and soil fertility management.

2-2 MODERN STRATEGIES FOR RURAL EQUIPMENT

During the last century various modern soil conservation strategies have been developed.

22.1 MOUNTAINOUS LAND RESTORATION (R.T.M.)

Moutainous land restoration was developed in France after 1850, then in European moutains to protect fertile valleys roads and railway lines through the mountains. Forestry department bought degraded land in the moutains, restored vegetation and corrected torrential mountain streams with mechanical and biological methods. (Lilin, 1986)

22.2 SOIL AND WATER CONSERVATION (C.E.S.)

Soil and water conservation of cropped soils, have been organized in the USA since 1930. The quick extension of industrial row crops poorly covering the soil surface (like cotton, maize, tobacco, peanuts) provoked catastrophic wind and water erosion. In 1930, 20% of the USA arable land was declared degraded by erosion. Under Bennet's impulsion (1939), the Soil and Water Conservation Service was constituted in each county, with the objective of advising and helping farmers who ask for technical and financial assistance to protect their land. A central department achieved technical studies for the projects.

Two schools of soil conservation are still fighting today on the field :

- That of Bennet who observes that gullies induce spectacular soil losses in relation with the energy of runoff which is a function of its mass and the square of its velocity (Ec. runoff = 1/2 MV2).

The struggle against erosion try to reduce runoff velocity and its erosive energy (by graded terrasses, weirs, dams, grassed waterways, etc...) whithout reducing runoff volume on the field.

- That of Ellison and Wischmeier calls back to mind that runoff develops after topsoil structure degradation by raindrops kinetic energy. The struggle against erosion tries to improve the soil infiltration capacity of the field with farming techniques increasing the vegetation cover with a minimum of mechanical antierosive structures in the lanscape.

22.3 INTEGRAL PROTECTION AND SOIL RESTORATION (D.R.S.)

That strategy was developed in Algeria and around the Mediterranean sea in 1940-60 facing the dramatic problems of accelerated silting of reservoirs, degradation of bridges, roads and cropped or overgrazed hillsides. The main objective was to protect degraded land from clearing, cropping or overgrazing and to restore the soil infiltration capacity by planting trees considered the best way to improve soil fertility. Tremendous amounts of financial and mechanical means were used to intercept sheet runoff in the fields (various terrace systems, Monjauze's dykes, etc...) to forest degraded land and to structure areas for intensive agriculture (Plantie, 1961; Monjauze, 1964; Greco, 1978).

2-3 A STRATEGY FOR RURAL DEVELOPMENT (G.C.E.S.)

Since 1975-80, numerous critical papers from researchers, socio-economists and agronomist have established frequent failure of soil conservation projects looking more for rural equipment than for farmers' needs (Lovejoy, Napier, 1986). The premium to engineers was not completely beside the point of heavy equipment used for soil conservation.

In the USA, despite 50 years of remarkable work of the Soil Conservation Service, 25% of arable lands are still losing more than 12 t/Ha/year of soil, which is the tolerance admissible for deep soil erosion.

In Northern and Western Africa, farmers often prefer to abandon land managed by state technical services rather than maintain conservation structures whose objectives and ownership they are ignorant of (Heusch, 1986).

The reasons for failure are numerous (Marchal, 1979; Lefay, 1986; Reij et al, 1986) :

1) Selection of techniques poorly adapted to local soil, climate and society;

2) Poor planning or bad implimentation or lack of maintenance;

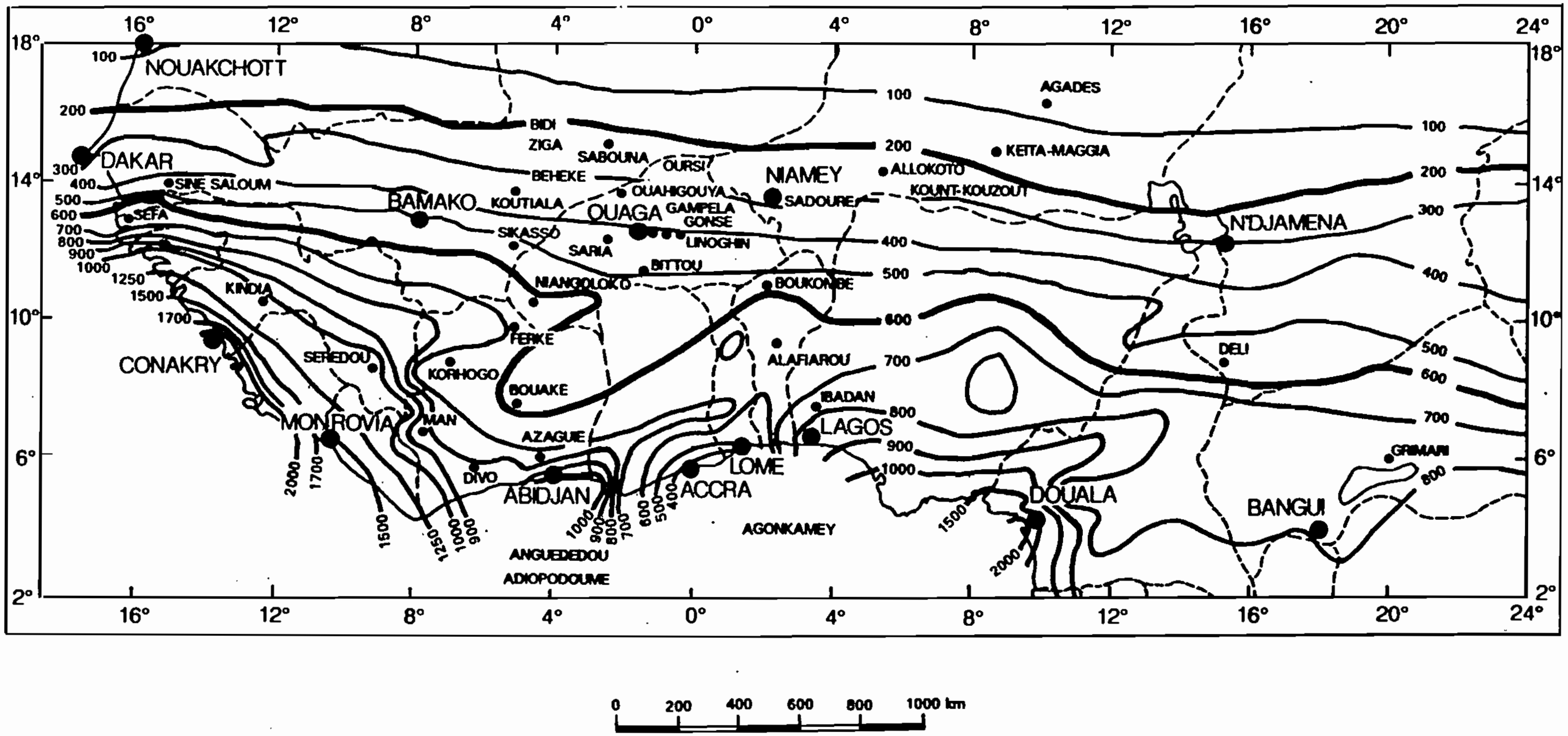
3) Lack of farmers participation and rejection of the project because of the loss of useful soil surface whitout compensing yield improvement between the structures;

4) Disorganization of the land for cultivation practices.

So it was urgent to develop a new strategy that we call WASOFMAN (water and soil fertility managment) (G.C.E.S.= Gestion conservatoire de l'eau et de la fertilité des sols). It takes better into account farmers and herders needs and proposes methods improving soil infiltration capacity, biomass

Fig 1 : Situation of runoff plots and research-development places.

SKETCH OF THE REPARTITION OF THE MEAN ANNUAL RAINFALL AGRESSIVITY INDEX (RUSA OF WISCHMEIER) IN WESTERN AND CENTRAL AFRICA.



After rainfall data of ORSTOM's hydrologic Department until 1975 (after ROOSE, 1980) production, vegetation cover and yield or net profit (Roose, 1987). The starting point is the way farmers feel about the problem of soil fertility degradation. It develops into three phases :

1) Preliminary dialogues between farmers, researchers and technical services. This phase begins with two inquiries in order to localise problems, to assess damages, their importance, their causes and the factors with which it will be possible to play to reduce runoff and soil degradation. It is the time of walking on the land to meet farmers on their fields, talk about their feeling on water managment, erosion and fertilizer problems, discover their traditional strategies to use economically available water, to maintain soil fertility and to keep herds.

2) During the second phase, when the researcher has got farmers' confidence, experiments have to take place in the farmers fields (not in research station) to quantify and compare faisability, efficiency, yield, runoff and erosion risks under various farming techniques and managment systems.

3) Then an overall management plan of the village land must be drawn after 3 to 5 years of dialogue in order to improve the use of the land, the structure of the landscape and to correct gullies, rivers and roads with simple methods easily controllable by the farmers. Nothing can be done whithout the farmers agreement, who have to learn to manage their environment.

After this brief survey of existing conservation strategies we need to look how the antierosive fight is traditionally organized in the Sudano-Sahelian area of Western Africa.

3 - THE DIVERSITY OF STRATEGIES IN SUDANO-SAHELIAN ZONE

There is a very big contrast between the broad ridge and furrow system of the Senoufos of Northern Ivory Coast and the direct planting system of the Mossy of Central Burkina Faso.

Over a 600 km distance we can observe an evolution of cultivation practices from the intensive time and labour consuming system to zerotillage. If the cultivation practices adapted by farmers over the centuries to ecological situations are so different, it is not surprising that the uniform soil conservation system (graded channel) terraces adapted to the Central Great Plains of the USA, has led to a serie of failures.

Before analysing this diversity of soil and water traditional strategies we need a quick description of the ecological conditions where various ethnical groups are living (see table 1).

3.1 THE SUDANO-SAHELIAN MEDIAS ARE FRAGILE AND DIVERSIFIED

Under this general appellation, we can distinguish four ecological areas : the Sahelian area (Rainfall from 150 to 400 mm/year), the Southern Sahelian area (R. from 400 to 700 mm), the Northern Sudanian area (R = 700 to 1000 mm) and the southern Sudanian area (R > 1000 mm/year). The annual rainfall amount is decreasing from 1200 to 150 mm, but over the last ten years (very dry) they have lost about 35%. The rainfall season continues for 3 to 6 months with very high intensity compared with the low infiltration capacity of sealed soil surface (Infiltration = 3 to 12 mm/hour). The daily rainfall events reach 50 to 75 mm each year, 90 to 120 mm once in ten years and 110 to 170 mm once in a century (Brunet-Moret, 1963). The erosivity index of the rainfall (Rusa) decreases from 600 to 100 when we

Area Rainfall Case Study	Sudanian > 1 000 mm Korhogo	North Sudanian 1000 to 700 Koutiala	South Sahelian 700 to 400 Ouahigouya	North Sahelian 400 to 150 Gorom Mare of Ours
References Rainfall R mean annual 1967-88 R max. month R day 1/1 1/10 1/100 I30 1/1 1/10 Rusa mean Drainage mm Density : hab./km^2	Camus, 1976 1350 - 250 318 76 - 119 - 169 75 - 108 mm/h 675 468 to 155 30 to 80	B. Moret, 1963 900 - 200 250 62 - 107 - 166 60 - 78 420 180 to 70 30 to 50 près de Koutiala	B. Moret, 1963 725 - 180 207 55 - 101 - 145 59 - 82 360 50 to 0 70 > 100	Chevallier et al, 1982 535 - 120 177 49 - 79 - 109 32 - 45 260 0 10 hab.
Soils on hillslopes	ferrallitic SC ± gravelly	leached ferruginous SC gravelly + vertisols + brown on basic rocks	leached ferruginous SC gravelly + vertisols + brown on basic rocks.	Not leached ferruginous, sandy sheet on red brown subaride soil.
Vegetation cover	Arborescent savanna, Daniella, Parkia biglobosa Butyrospermum + Andropogon + various grass	Arborescent savanna Daniella, Parkia biglobosa + thorny bushes + Andropogon + various grass	bush savanna Combretum, Baobab, Acacias + thorny + + scarce Andropogon	Steppe, bush, Baobab, Acacia, Balanites, Ziziphus annual grass
Farming system	<u>Drainage Farming</u> drainage of excess water	<u>Rainfed farming</u> Drainage of hillside runoff	<u>Runoff farming</u> trapping of rain and runoff	<u>Valley farming</u> intense cropping limited in valleys
Traditional management	Yams on large mounds. Maïze + intercropping on ridges. - Millet + peanut + various on ridges. Intercropping + agroforestry. Drainage between plots.	. Superficial tillage . Cropping on the flat . 2 weedings. Sorghum/cotton or. Millet + sorghum/ peanuts + cowpeas hillslope runoff on waterways. Total infiltration or rain in the field. Stone bunds and walls. Grassed, stone, cut branches lines.	. Superficial tillage . Cropping on the flat . 2 weedings Sorghum or millet then peanuts and cowpeas, Mulching Zai + Boli stone line/ bund stone, grass of branches, stalks lines On sandy soils out ridging sometines.	Sawing on the flat + 2 weedings. Millet on sandy soils Sorghum on clay soils of the lower grounds. Grazing on the hillslopes. Gardens in lower areas Retreat flooding farming around the "MARES". (natural pounds)
Modern management suggested	CES (1964-68) Aforestation of laterite sgrees. Grassed buffer strips Gully restoration Rice fields protection.	GCES Koutiala 1985 . Improvement of grassland . Protection diguettes . Living hedges + stone bunds or grassed buffer strips. . Grassed waterways. . Low grounds management.	DRS Gerès 1960-65 then CES by ORD then GCES by CIRAD/ORSTOM . Improvement of grassland. . Pounds for cattle watering + supplementary irrigation of gardens. . Stone bunds protected by Andropogon grass line. . Gully and lower grounds managements.	GCES . Shrub forrage plantation in half moon or diches. . Management of grassland. Pounds for cattle. . Trapping runoff on hillslopes. . Permeable diguettes and stones bunds on pediment. . Low ground management.

Table 1.Diversification of the Soudano-Sahelian area.

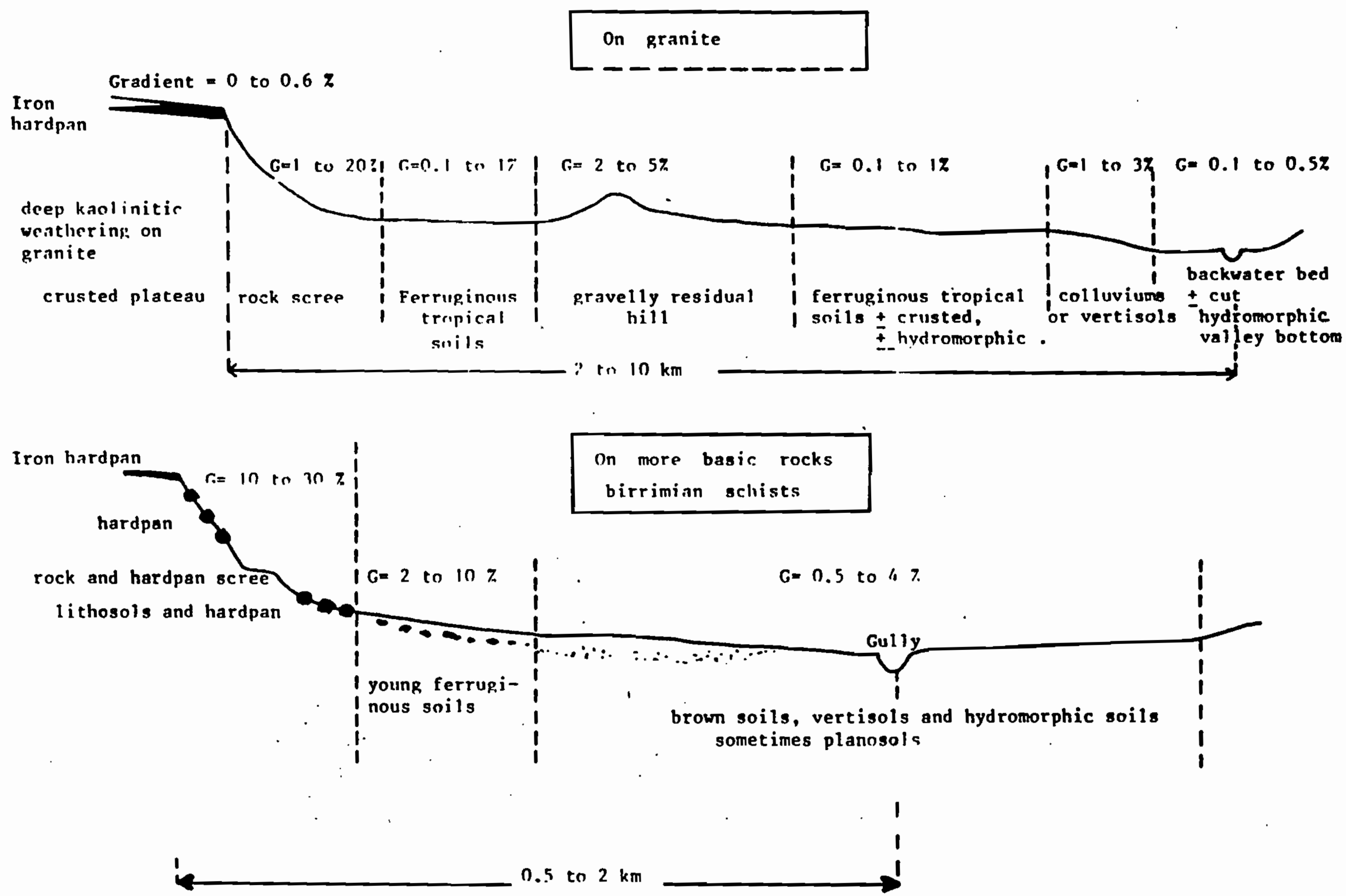


FIG.2 Typical catenas on the Mossi plateau.

(fig.1)
approach the Sahelian area (Roose, 1976-80). The most frequent landscapes on granit and sandstone are composed of a lateritic tableland, a short scree of lateritic blocks, a long glacis of gravelly soils covered with a sandy silt loam layer thicker near the river, which is more or less deeply embanked. Hillslopes are generaly gentle (0,5 to 4%) but very long : they can be covered by recent or ancient dunes, or they can be steeper on quartzitic or basic rocks. (see fig.2)

The soils of hillslopes (red tropical ferrugineous = alfisoils) are leached and often hydromorphic, generaly poor chemically (N-P and often K deficiencies, pH 6 to 4) and unstable physically (low organic matter content but rich in silt and loam). As soon as the soils are cultivated they develop a sealing crust decreasing drastically the infiltration capacity. After a few cropping seasons with plowing and two weedings made through animal traction, there appears a discontinuity (a kind of plow pan) that roots can hardly penetrate so that the pedoclimate is still dryer for annual crops than for trees and shrubs. In the Valleys, soils are hydromorphic or vertic, chemically richer but still more difficult to manage : hard to work when dried, and fluent during the rainy season.

Crops poorly cover the soil surface and leave very few residues. Cotton, peanuts, cowpeas and various beans are cultivated in rotation with cereals like sorghum, millet, fonio and some maïze and rice (in the hydromorphic areas). Cotton stalks are burnt. Peanuts and leguminous straws are used as fodder. Leaves of cereals are grazed in the field and their stalks are used for the roof or various handicrafts. Fallows are vanishing, too short and too overgrazed to efficiently regenerate the soil fertility.

The natural vegetation, an tree savanna originally dense, has badly deteriorated these last few decades because of drought, overgrazing, extension of cropping areas, needs of wood for fuel, erosion and decrease of the watertable level. Herds have been developed during the wet years in the Sahelian area. So, during the drought, the reduced biomass production cannot feed village herds and transhumant herds going from the Sahel to the Sudanian savanas (Quilfen, Milleville, 1984; Hallam, Van Kampen, 1985).

In this area, the most active erosion processes are sheet, gully and wind erosion, but sheet erosion research only has been well developed (Roose, 1988).

3-2 SOUTHERN SUDANIAN AREA : DRAINAGE FARMING.
A CASE STUDY OF THE SENOUFOS OF NORTHERN IVORY-COAST (KORHOGO).

32.1 THE ENVIRONMENT

The whole experimental device (raingauge, runoff plots, lysimeters) has been located in the Waraniene watershed, 5 km East of Korhogo in a representative tree savanna with Parkia biglobosa, Butyrospermum parkii and Daniella oliveri on granite. The herbaceous stratum is dense (Andropogon, Hypparenia, Pennisetum, Panicum). But this natural vegetation is deeply degraded by annual bush fires, selective clearing and traditional ridging.

The climate, transitional tropical, is dry and warm for 4 months but can be very rainy for 4 months (rainfall = 150 to 320 mm in August) during which 160 to 450 mm of drainage can be measured (Roose, 1979).

The toposequence is classic : a lateritic plateau (red ferralitic soil) one or two screes, a long concave pediment (2 to 4% slope) red gravelly ferralitic soils under the scree, ochre soils some 100 meters lower and grey hydromorphic soils in the colluvial plain.

Traditional cropping system begins with yams planted on very big mounts (80 cm high), during the cool dry season after progressive clearing and burning. Next year, the mounts are transformed into high ridges (60 cm at a distance of 150 cm). Then maïze and sometimes cassava are planted with various intercrops. For the 3rd and 4th years the ridges are broken and moved on the furrow (covering weeds and crops residues) to build a more modest ridge planted with millet, sorghum, maïze, tobacco, peanuts and various vegetables. The valley bottoms extended to lateral colluvium are covered with irrigated paddy fields.

32.2 EROSION AND RUNOFF

Sheet erosion, gravel spread on the topsoil, sandy colluvium and little gullies on hillsides are signals of abundant runoff during the rainy season. Measurements on runoff plots of Korhogo (Roose, 1979) and Niangoloko (Christoï, 1966) show that ferralitic soils are very permeable when covered with natural savanna (Kram* = 1 to 7%), but the topsoil structure can be degraded by cropping and provokes important runoff rate (Krmax* = 40 to 80%) during the decennial storm event falling on bare and moist soil surface. Soil losses under traditional crops are moderate (E = 0,2 to 6 t/ha/year) thanks to gravel mulch cover, moderate slopes and ridges along the contour.

32.3 TRADITIONAL SOIL AND WATER CONSERVATION MANAGEMENT

a) Hillslopes are covered with a patchwork of fallows and cropped fields ridged, some on the contour, ---- others along the slope. This system allows a good drainage at reduced speed thanks to rice cropping in the furrows or to oriented ridges, or to ties at the field borders. The fields are separed by a ditch draining excess water from the fields, but it is not uncommon for those ditches to turn into little gullies bringing a lot of sand and gravel to the plain, deeply pertubing paddy fields.

b) When clearing the savanna, farmers respect some useful trees and stumps of bushes (often leguminous) which will fast cover the land after the field has been abandoned to fallow. The mediocre level of fertility is maintained thanks to house hold ashes, dry faeces mixed to compost, ploughing in weeds and cropping residues when ridging and, of course by fallowing whose duration is depending on the demographic pressure. Senoufo farmers easily accept multiuse trees on their fields to produce fruits, medicins, fuel, perches and timbers.

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* KRAM = mean annual runoff coefficient
KRMAX = maximum dayly runoff coefficient

c) The spectacular soil cultural practices (mounds and ridges higher than 60 cm), improve the production of long tubers and also the soil infiltration capacity (Camus et al, 1976). Senoufo farmers also reshape the valleys to enlarge their paddy fields.

32.4 MODERN STRATEGIES OF WATERSHED MANAGEMENT

In 1964-68 a program for soil conservation (CES) was developed in the densely inhabited area of Korhogo with 3 objectives :

*protection of paddy fields against silting up from the gullies;

* reafforestation of the plateaus to produce firewood and insure a good flow in the river during the dry seasons;

* protection of cultivated land on the hillsides against runoff and gully erosion.

Lateritic screes were reafforested; bushfires were forbidden, firebreak tracks opened, grassed buffer strips were traced along the contour and planted with reference trees (Anacardium, Tectona, Gmelina). Finally, gullies were corrected and low grounds managed for irrigated rice-fields.

This management was made after failure of the DRS management of GERES near Ouahigouya (Burkina-Faso). Gosselin (1962-64) sought to reduce soil conservation investments (300 meters of buffer strip cost 650 CFA/ha against 7000 CFA for graded channel terraces), to select structures easy to achieve without expert topographer (grassed strips between two rippered lines) and asking very little maintenance but developing vegetation cover.

To reduce straying cattle he suggests :

* improvement of corrals to increase manure production,
* plantation of trees around villages as green peg for future cattle,
* improvement of fallows by sowing stylosanthes or legumes which remain green during the dry season,
* fencing pastures for rational and exhaustive grazing and elimination of bushfire hazards.

Currently we could schematize the management as follow :

* improve the drainage of excess rainfall by tied ridging and broad grassed waterways,
* improve infiltration, biomass production and therefore soil surface protection,
* improve the biomass management (fire, cattle, forrage, manuring, composting, mulching)
* improve the use of agroforestry,
* improve the livestock management in relation to forage availability.

CASE STUDY OF SENOUFOS OF SOUTHERN MALI

As part of the research and development program of IER (Institut d'Economie Rurale of Bamako), KIT (Koningklijke Instituut voor the Tropen of Amsterdam) and CMDT (Compagnie Malienne des Textiles) around Sikasso, the DRSPR (Division de Recherche sur les Systèmes de

Production Rurale) proposed to farmers an "antierosive equipment system" as follow : (Hallam, Van Campen, Ba, Vierstra et Kebe; 1985-86)

1) Above the cropped field blocks a strong earth dike diverting runoff to a wide waterway,

2) In the fields, earth-graded diguettes (0,3% slope) every 50 to 100 meters, protected by grass,

3) Plowing, weeding and ridging along these diguettes.

This classic soil conservation system satisfied only a few Senoufo farmers because runoff does no more flow over their fields (taking off young seedlings, manure and topsoils) but between the fields.

However farmers do not like sinuous diguettes on the contour because it is not easy to calculate the plot surface, and to mechanise cultural practices. This "equipment strategy" of cultivation blocks does not take into account the division into plots, nor the farming system, nor the economic needs of the farmers : it did not extend substantially. The loss of ground (10 to 14% of surface) is not compensated by substantial increase of yields. The drainage network has been destroyed fast by lack of maintenance : without grass protection, after 4 years, waterways used as fieldroad are gullied, ditches are sanded and diguettes compacted but often broken by runoff or by cattle. This management system requires a heavy labour investment of the owners and extension agents but has not led to conscientization of the rural community to manage its environment (Hallam, Van Campen, 1985; Roose, 1985).

3-3 NORTHERN SUDANIAN AREA : RAINFED FARMING
CASE STUDY OF MINIANKA AROUND KOUTIALA (MALI)

33.1 ENVIRONMENT (SEE TABLE 1)

The environment is very similar to that the Southern Sudanian area except for less frequent storms, a reduction of drainage risks, the development of many thorny bushes (like Acacia albida) and of leached ferrugineous tropical soils (alfisoils) much more fragile (more silt) than ferralitic ones and very long pediment of gentle slopes. The human environment is deeply influenced by the Koutiala cotton factory, by their extension agents and by the very efficient villager' organization. Clearings are fast extended keeping only 10 to 30 useful trees per hectare.

Formerly, in the traditional system, crops were chiefly cereals located on gravel soils of the pediment top. At present, crops of cotton (or peanuts, cowpeas on poor soils) in rotation with mixed cereals (often sorghum or millet and maïze) are developed on the silty glacis with animal traction. Planting occurs as soon as possible after plowing : after 3 and 6 weeks two weedings and sometimes tied ridging are carried out. After harvesting, the farmer concludes an agreement with a peulh pastoralist to graze the crop residues and leave the manure (pasturing/manuring contract). Then cotton stalks are burnt for phytosanitary reasons while most cereal straws are used for handicraft, for cooking and for livestock. The remaining stalks (10 to 25%) are burnt on the field before plowing. In the old days, the low grounds were a reserve of green forrage during the dry season. Currently they are grown in sorghum or in rice in hydromorphic area, or in kitchen gardens.

33.2 RUNOFF AND EROSION

Measurements in runoff plots have shown that ferrugineous tropical soils and brown tropical soils are as permeable as ferralitic soils as long as they are covered by a tree savanna or even an old bush fallow. But when cultivated, these soils are less stable and give a high level of runoff, not acceptable in semi-arid areas (Kram = 6 to 25% and up to 75% during the heaviest rainfalls). Despite smooth slopes (0,5 to 2%) and good cultivation practices, soil losses are too heavy on bare plots (14 to 20 t/ha/year) and on poorly covering crops (E = 3 to 6 t/ha/year) on the superficial gravelly soil of Gampela, the tied ridging system only retains better soil and water but it doesn't increase the yield because it can't store water. At Gonsé was observed a deep influence of the date of bushfire (KRmax may reach 1%, 15% and 75% if the fire is forbidden, early superficial or late and slow) (Roose, 1980). If the savanna burns late, the runoff can be as high as a bare cultivated plot (KRmax = 75%) (Roose et Piot, 1984).

33.3 TRADITIONAL SOIL CONSERVATION STRATEGIES

Traditional conservation practices are limited to stone walls if the soil is stony (on sandstone, quartzite and amphibolite) or to stone lines, grassed strips or cut-branch lines. Cultivation practices are superficial but repeated every 3-4 weeks before the crops cover seriously the soil surface : they break the sealing crust, eliminate the weeds and maintain a high infiltration rate in the profile.

33.4 ACTUAL MANAGEMENT STRATEGY OF VILLAGER LANDS

After the Fonsebougou (Southern Mali) experience, the research team of DRSPR developed in Kaniko (and 3 other villages) a more flexible approach where, after long discussion, the village association decided the following priorities for the general soil conservation planning (Hallam et al., 1985; Roose, 1985) :

1) Protection of the cropping blocks against runoff coming from the hilltops by extensive pasture management (total protection, reforestation in forrage bushes, grassed strips and stone bunds in the waterways), by earth dikes protection leading safely runoff to waterways and by a village tree nursery.

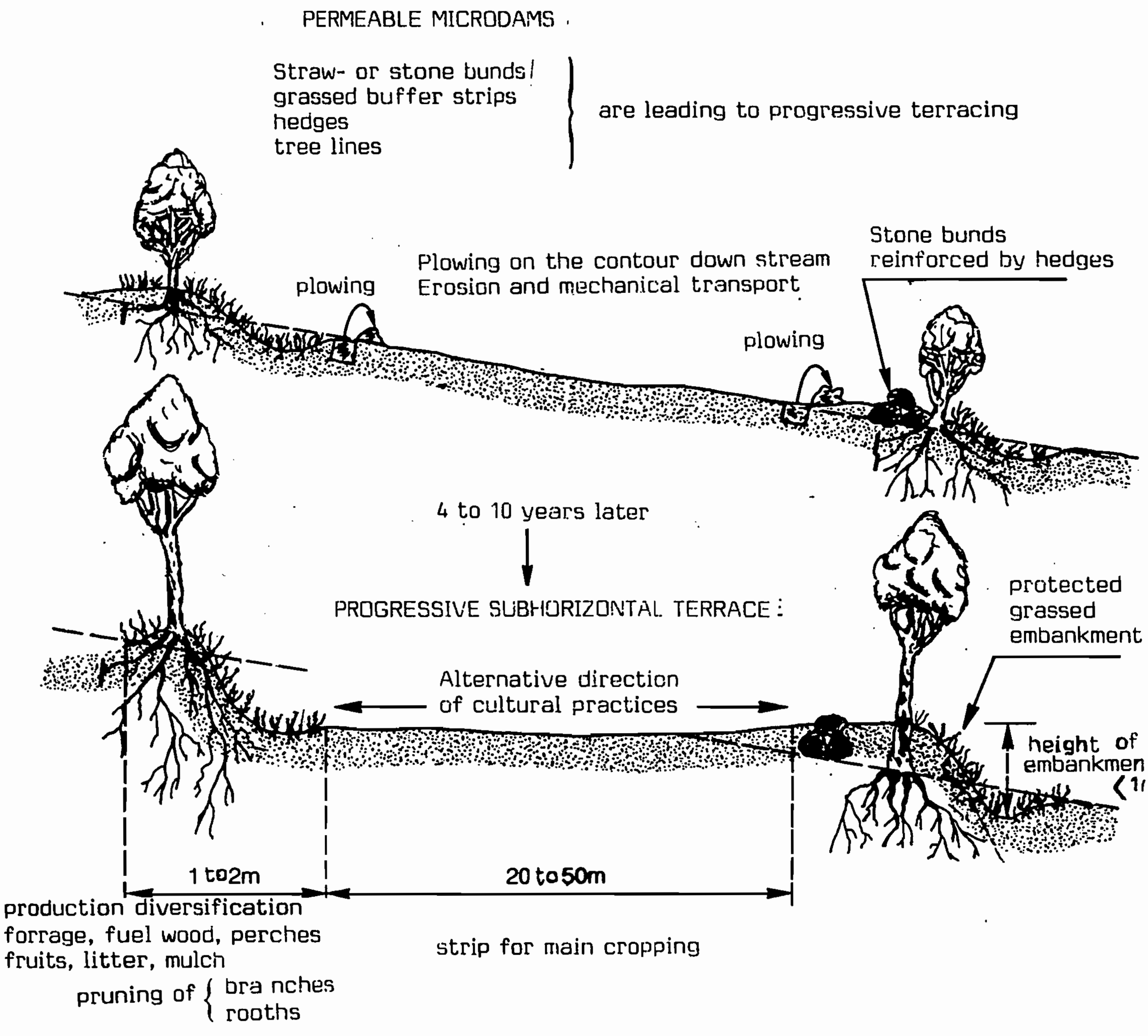
2) Protection of farming land and fields against the straying cattle by hedges and trees multiobjectives like Acacia albida, Parkia, Butyrospermum, etc... Management of stony and grassed waterways helping to export the yield during the dry season.

3) Improvement of infiltration on cropped fields :

- superficial rippering during the dry season, plowing on the flat, two weedings and finally tied ridging,
- introduction of leguminous in rotation or in association (Mucuna or cowpeas where the main crop hasn't grown),
- recycling maximum of crop residues (manuring, composting, and mulching),
- grassed buffer strips or stone bunds between the field, each 25 meters, to slow down runoff incoming on the field (see figure 3).

4) finally management of streambanks and low grounds (paddy fields or kitchen garden with multistory vegetation : vegetables or forrage crops, fruit trees and palmtrees with very high trees. Microdams, stone or earth diguettes (H<2 meters) with lateral rocky outlet.

Fig 3 : Method of permeable microdams



PROCESSUS

- Runoff speed reduction.
  deposit of { organic matter / coarses sediments
  increasing of infiltration
- Mechanical erosion by cultivation practices (1 to 10 t/ha/year) creeping of the top soil
- increasing of biological activities (roots, litter, mesofauna)

ADVANTAGES

- The nature makes the work
- Efficiency maintained during heavy storms
- Easy to build without topographer specialist
- Cheap and easy to maintain
- No place lost but production diversification of fuel wood, forrage, fruits, mulch
- Erosion risks decrease with year
- Formation of horizontal terraces
- runoff { does not waterlog above the dam / but irrigate the ground down stream

If the order of management is reversed, there is a risk of sanding up the valley. The system tries to encourage the farmer's initiatives even if the initial sequence of action isn't completely respected. So the whole village was involved in the village land management and its technical experience grew out of the community experience. This DRSPR-CMDT soil conservation project corresponds well to the "wasofman" strategy where the fight against runoff and erosion is an integral part of the improvement of the farming system.

3-4 SOUTHERN SAHELIAN AREA : RUNOFF FARMING.
CASE STUDY OF MOSSI OF YATENGA (N.W. BURKINA FASO)

34.1 THE ENVIRONMENT

It's much more arid than the Sudanian climate : even during the rainfall season, drought are frequent so that wind erosion can be observed (dust bowl, sandy sheet on the soil surface, sand mounds under tufts of perenial grass, nebka and ancient dunes spread on lateritic hills). Annual rainfall varies from 400 to 700 mm. The vegetation is stunted and scattered. Butyrospermum disappears for the benefit of Baobab, Pterocarpus lucens and thorny schrups (Balanites, Ziziphus, Acacia albida and others growing like parks in the valleys). Perennial grass (Andropogon) become infrequent leaving the ground to annual grass with short growing cycle (1 to 3 months).

The lateritic granitic landscapes disappear in the North under sand dunes (Sandy ferrugineous tropical soils) while brown and vertic soils on amphibolite are deeply gullied. Ground water tables are no longer nourished by hillslope deep drainage but by gravelly or stony area and by the colluvial valleys. Paradoxically the population, very dense in this area (70 to 110 inhabitants per km2), used to migrate for the dry season or for some years to coastal countries for better valorization of their labour. During the dry season, the country side is populated by old people, women and children : most of the working force moved to the coast; it will be necessary to take that aspect into account when planning the management of those rural countries.

34.2 RUNOFF AND EROSION

Measurements on large plots under impluvium are actually made on a sandy hillslope at Bidi (Lamachere, Serpantié, 1988). Surprisingly the annual runoff is not negligeable under traditional cropping system (Kram = 10 to 30%). Stone bunds haven't reduced so much the global runoff (1 to 5% less) nor the maximum runoff event (KRmax = 60 to 85%). Neverthless during the heavy showers, stone bunds have delayed and prolonged the runoff and reduced the maximum flow rate (25% less) and therefore reduced erosion risks (of 30 to 50%). Between stone bunds, intensive farming systems can be developed (progressive fertilization and repeated soil cultivation practices) which improve the infiltration capacity but decrease their resistance to rainfall erosivity. Impluvium of the hilltops brings about an additional income of 100 mm, which improves the water storage of the ground only if the infiltration rate capacity is improved by the rugosity of the soil surface : stonebunds (+ 25 mm) and deepplowing (+ 75 mm). This additional income gives an additional biomass production (chiefly near the stone bunds and the impluvium) and of yields (+ 33 to + 88%) except if rainfall stops too early (11% less of grain production in 1985). The efficiency of stone bunds on infiltration depens on rainfall events, on the soil surface status and on stone bunds quality. Maintenance of stone bunds and of soil surface rugosity must be forecast.

34.3 TRADITIONAL FARMING SYSTEM AND WATER MANAGEMENT

Mossi farmers have a pioneer behavior. They clear new fields burning almost all the trees (except some Acacia or Sclerocarya, etc...) and plant sorghum on the best soils and millet on sandy soils, after the first storms in seed holes one meter apart whitout working the soil. They will begin again the sawing 2 to 5 times if necessary, because of drought, then they ensure two hoe weeding.
On the sandy grounds of the Northern area, weeding takes place with off mounding which improves infiltration (Serpantié, 1986).
Animal traction is reduced since the long drought period they have sold animals and equipment. To avoid the complete soil depletion, farmers bring organic matters (5 t/ha of dry corral manure), house- hold ashes and compost or a light mulching of cereal stalks and legume bush branches which are not browsed by cattle (like Piliostigma reticulatum) or they let the field to the browsed fallow.

The Zai method of restoring degraded fields is quite original. It combines the runoff trapping, localised organic fertilisation and termite boring activity to improve infiltration. After a first storm, the farmers dig a little hole (10 to 50 cm of diameter, 10 cm deep) and put a little manure/compost : these organic matters attract termites which dig galeries through the topsoil and the sealing crust to feed from the organic matter. They cover their galeries with excreta. During the second storm, runoff flows through galeries and waters deeply percolate into the soil which is temporary protected from evaporation risks. The 5 to 15 seeds put in the seed hole the following day will quickly germinate and find water and nutrients stored in depth which will allow them to remain until the next storm. The influence of a light mulching (2 cm) set on infertile soil areas is similar : termites dig the macroporosity while straw protects the soil against raindrop splash (Roose, Piot, 1984).

Traditional, Mossi farmers are crop growers but keep some cattle : they used to dig holes, dispose spoil earth in half-moon shape in order to collect some m3 of runoff to water a few cattle just near the pasture land or to irrigate a little kitchen garden as well (Dugue, 1987).

Finally, when new ground is scarce, Mossi restore the fertility of degraded soils (Zipelle = bare compacted and crusted area) where infiltration capacity is so low that even the fallow can't grow. They surround their little field with stone, grass, branch lines to slow down runoff and provoke sedimentation of permeable particles (sand, agregats and organic matter). On the second year, this sandy horizon is cultivated, manured and planted : it isn't rare to harvest 600 to 800 kg/ha of sorghum grain (Wright, 1985). The next years, the restored plots are planted with legumineous trees and a new stone bund is positioned to trap the flow running from the hilltop.

34.4 THE YATENGA PROVINCE, A SOIL CONSERVATION LABORATORY

From 25 years, the Yatenga province knew a succession of soil conservation management on a large scale to slow down the fast degradation of vegetation and soil cover of these fragile landscapes at the Sahel border.

a) THE "D.R.S." FROM 1960 TO 1965

The forestry department and after the GERES (2) have managed 200 000 ha in 3 years, dug 35 000 km of diversion ditches, cross rooting of gravelly compacted area, built 70 km of rocky diguettes in the waterways, 24 earth dams between hills and other little half moon shaped pounds to increase infiltration on the extensively grassed hilltops and to protect cropped plains. This management, technically interesting appeared quickly to be a failure because farmers, not concerned, didn't ensure the maintenance of the management and continued to live on their traditional practices.

b) THE C.E.S.(3) FROM 1976 TO 1985.

The F.D.R. (4) called to farmers groups, decided to build diversion earth diguettes on cropped blocks of 25 to 100 hectares. More than 47 000 ha of cropped land were managed in ten years (Mietton, 1986). But because of the management rhythm (max 9000 ha/year) and the brief life span of hillslope managements (2 to 4 years without vegetation cover on the diguettes), it would take many centuries to protect all the fields where it should be necessary. Then it seems useful to come back to old traditional strategies which were study by various Non Governmental Organisation (Wright, 1985).

c) THE G.C.E.S. FROM 1985 UNTILL NOW

Among numerous antierosive projects which are developing fast (OXFAM, AFVP, PAF, PAE, etc...) we will talk here of the project of the research development team of INERA-CIRAD-DSA in the CRPA of Ouahigouya (Dugué, 1984-88; Rodriguez, 1989; Roose, 1986-87). The GCES strategy is the same as that applied in Koutiala (MALI).

1) Inquiries made closely to the farmers, on their own environment management problems : degradation of soil fertility, infiltration and organic matter content.

2) Experimental research on the best traditional system to improve infiltration rate, biomass production and insure a better cover on cultivated fields.

3) Conception with the farmers of a general schedule for soil conservation management for the whole landscape (Roose, 1987-88).

But the Mossi selection of priorities was different from those of Minianka (Mali).

1) Mossi prefered to begin with their own field management and try to capture all the runoff of the toposequence ;

- rock bunds or lines to be protected by Andropogon gayanus lines to spray runoff and with hedges to retain the rocks in place,

- trees plantations around the parcels,
- management of crop residues : manure pit near the village and compost pit on the fields.
- soils rippering after the first storms, plowing on the flats + 2 weedings and 1 tied-ridging in order to break the sealing crust as often as possible,
- recovering of road runoff on the neighbouring fields and diversion from little gullies

2) Management of gravelly top hills to capture runoff from grazing land : contract of rotational exclosure of grazing land with plantating of trees and fodder shrubs :

- cisterns on the gully heads developing into microdams to water the livestock and organize suplementary irrigation on 1000 m2 (first maïze and then water melon).
- earth or rocky bunds trapping runoff from the hilltop in order to give additional water to a field (Bedu, 1986).

3) **PROGRESSIVE MANAGEMENT OF LOW GROUNDS**

- At the head of the valleys, "permeable rocky diguettes" (cfr AFVP at Rissian, ORSTOM at Bidi)
- Micro earth dam (H < 2 m) with rocky lateral outlet;
- Gabions microdams with central outlet.

At each level of the landscape it is necessary to capture, slow down and redistribute runoff to increase the surface or deep-water storage in order to increase the food production and reduce risks. Bringing supplementary runoff on cultivated fields is hazardous (probable development of gullies). But digging cisterns or little ponds at the gully head should be more satisfactory (if we find a manual pump able to lift 10 m3/day, 1 meter above the soil level).

Where stones are scarce, biological microdams must be perfected : hedges and perennial grass buffer strips seem to be difficult to grow when cattle are free to move around everywhere during the dry season. Segments of earth bunds could be protected by a stony outlet for security each 25 meters.

3.4 NORTH SAHELIAN AREA : VALLEY FARMING.

CASE STUDY OF PEULH + SONGHAI + BELLA COMMUNITIES AROUND MARE D'OURSI (Burkina-Faso)

34.1 ENVIRONMENT

Annual rainfalls are inferior to 400 mm. The difference with the Sudanian area is evident. Rainfalls are erratic : their intensity and duration are much more limited in time and space (see table 1). If soils are sandy, runoff is limited on fallow and even on cultived fields but wind erosion is important (overgrazing and weak vegetation cover). But on piedmont and siltyloam glacis, cultivated soils are fast sealed : runoff is important and causes very active gullies under sorghum (Chevallier et al., 1985).

34.2 RUNOFF AND SHEET EROSION :

Measurements were made by C.T.F.T. for 3 years around the Mare d'Oursi, on a fine sandy dune at the botton of a gabbro hill. Runoff is generally low (5 to 10%). Cultivation practices, breaking the sealing crust, improve soil infiltration capacity which is already very high on these sandy dunes : nevertheless during intensive storms runoff increases up to 40% even on protected fallow. Erosion is still important on bare fields (5% slope) but moderate on dry years on millet and fallow. We can't dicuss here wind erosion which is very intensive as soon as any sandy area is cultivated.

34.3 TRADITIONAL FARMING AND MANAGEMENT SYSTEM.

When in the Mediterranean area of Northern Africa (rainfall during the cool season) there are numerous well known systems for collecting rainfall and runoff to grow trees and cereals (ex : jessour, tabia, meskat, foggara, cistern) the runoff farming systems in tropical Sahel are very limited. In reality they concern the selection of crops and cultivation practices in relation to soils (millet on sandy soils, sorghum on heavy clay soils and low grounds, irrigated kitchen garden around ponds), adaptation to storm opportunity (very weak cultivation practices, direct sowing repeated if necessary because it's very cheap : 3 kg/ha of seeds and 9 hours of cultivation practices), very large surface sowed (even if they can't insure the weeding) and migrations on short distance to harvest fonio and nenuphar bulbs. They live on the cultivated fields from November to August near granaries and migrate with the livestock to an occasional grazing land during the rainy season (Milleville, 1982).

After Milleville (1982) the cereal cropping limit is situated around 350 mm of average annual rainfall. The selection of Mare d'Oursi case is a bit limited to talk about this area, but annual rainfall has been 130 mm lower these last 15 years and the yields are deeply depending on soils and rainfall distribution. Furthermore, the grain yields (150-250 kg/ha/year) are so low that livestock and nomadism are necessary to insure survival in the Sahel.

34.4 MODERN MANAGEMENT SYSTEM

The environment being so fragile, it's dangerous to advise the development of agropastoral system at the same rhythm as the demographic growth rate. Today it seems that the development is stopped because almost all the ground suitable for cultivation is already cultivated : fallows are disappearing, soils are exhausted and the cost of fertilization, short cycle selected seeds is only profitable the years when rainfall is abundant and well distributed during the growth season. (Milleville, 1982).

Nevertheless it could be experimented on lands like Keita in Niger :

a) plantation of living hedges or thorny bushes of forrage like Balanites or Acacia albida on sandy dunes,
b) impluvium collecting runoff water to bring supplementary water to little fields ridged on the glacis,
c) agroforestry management of low grounds with stone bunds, hedges, fruit or forrage trees,
d) the management of the "mare" borders in order to intensify and diversify crops (forrage for milk cows, cereals, vegetables and some fruittrees). But it must be clear that the agricultural production is located in the valley and that livestock and nomadism over short distances are better adapted to this very fragile sahelian area.

4 - CONCLUSIONS

The semi arid zone of Western Africa is very diversified in space (water resource, localizated storms, infiltration capacity of various soils) and in time (interseasonal and interannual). The natural vegetation changes differently according to climatic area and the use by man and cattle. Furthermore, the various ethnical groups living today in these landscapes have adapted their exploitation system, their management systems of water economy and maintenance of soil fertility to this diversity.

Facing demographic and socio-economic pressure, these traditional management systems are no more adapted and the vegetation and soil cover are deteriorating. The modern strategies of rural equipment imposed by central administration engineers are too rigid, badly adapted to the ecology and human diversity : their failure often can be explained by the traditional resistance of the farmers.

Facing these failures, observed in the USA as well as in Northern and Western Africa the author suggests a new approach oriented to rural development : water and soil fertility management (WASOFMAN or GCES in french). This approach begins with inquiries about degradation risks and traditional soil, water and fertility conservation strategies. Then the most feasible and suitable techniques are tested on the farmers fields to look to their efficiency on infiltration rate, biomass production and erosion risk. Finally a general program of soil management is scheduled with the village community.

Generally, runoff is abundant on long, weakly-covered pediment in these semi-arid areas. To reduce water and nutrient losses, the antierosive structures are not sufficient. Often they are useful to establish a more intensive production system with a better infiltration rate (superficial work breaks the sealing crust), a better structural stability (crop and animal residues management) and better growth conditions for plants (mineral and organic fertilization).

Water and soil fertility management takes time and it is difficult to fund but it's a new experimental field open to interdisciplinary research teams. Indeed we are cruelly lacking in good quantitative measurements of productivity and soil conservation, of economic and sociological aspects of erosion, of methods to improve the security of the production systems and even of measurement methods for wind and water erosion in Sahelian area.

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- ABREVIATION LIST -

R.T.M.	= Restauration des Terrains de Montagne = Montaineous Ground Restauration
D.R.S.	= Défense et Restauration des Sols = Complete Protection and Soil Restauration
C.E.S.	= Conservation de l'Eau et des Sols = Soils and Water Conservation
G.C.E.S.	= Gestion Conservatoire de l'Eau et des Sols = WASOFMAN = Water and Soil Fertility Management
ORSTOM	= Institut Français de Recherche Scientifique pour le Développement en Coopération
C.T.F.T.	= Centre Technique Forestier Tropical
O.R.D.	= Office Régional de Développement = Regional Office for Development
GERES	= Groupement Européen de Restauration des Sols = European Group of Soil Restauration
KRAM	= Mean Annual Runoff Coefficient
KRMAX	= Maximal Daily Runoff Coefficient
KUSA	= Soil erodibility after Wischmeier and Smidt (1960) in USA units.
AFVP	= Association Française des Volontaires du Progrès = French Volunteer for the Progress Association
P.A.E.	= Projet Agriculture Ecologique = Ecological Agriculture Development Program
P.A.F.	= Projet Agro-Forestier = Agro-Forestry development program
CIRAD	= Centre International de Recherche en Agronomie et en Développement
D.S.A.	= Département des Systèmes Agraires du CIRAD. = Farming System Department of CIRAD
INERA	= Institut National d'Etude et de Recherches Agronomiques du Burkina Faso.
CERPA	= Centre d'Encouragement Régional à la Production Agricole.

Table 2 Runoff and erosion measurement on runoff plots in the South Sudanien area.

	RUNOFF KRAM %	RUNOFF KR Max %	EROSION t/ha/year
KORHOGO (ROOSE, 1979)			
. Degraded savanna early burned	3,2	28	0,2
. Bare fallow, cultivated each month.	33	89	5,4
NIANGOLOKO (CHRISTOI, 1966)			
. Fallow	0,4	1	0,09
. Cropping on the flat	6,6	39	25,4
. Cropping on ridge //slope	2	23	6,34
. Cropping on ridge on the contour	0,3	3	1,5

Korhogo : gravelly ferrallitic soil, 3 % slope, 200 m² and 22 meters long
1967-65 Rainfall 1280 Rusa = 658 K = 0,021 0,011

NIANGOLOKO : S. clay ferrallitic soil, 2,5 % slope
1955-61 Rainfall = 1048 mm Crops = millet - peanuts.
q

TABLE 3 : EROSION MEASUREMENT ON RUNOFF PLOTS IN NORTH SUDANIAN AREA

	RUNOFF		EROSION
	KRAM %	KR MAX %	t/ha/year
GAMPELA (Roose, Piot, 1984)			
- Bare fallow	-	-	16,0
- Tradition, on the flat	22,5	40	4,1
- Diguettes + ridging//slope	23,7	45	5,9
- Diguettes + ridging on the contour	18,2	37	4,4
- Diguettes + tied ridging on the contour	4,6	31	1,4
GONSÉ (Roose, 1980)			
- Sav. Integral protection	0,3	1	0,033
- Sav. early bushfires	2,6	10	0,147
- Sav. lately bushfires	15,3	73	0,344

GAMPELA 1967-72 : tropical ferrugineous soil on lateritic ironpan around 25 cm.
Slope 0,8 %, surface 5000 m2, crops = sorghum, millet, peanuts.
Rainfall : 731 mm/year, RUSA = 319

GONSÉ : leached tropical ferrugineous soil on ironpan around 150 cm.
Slope 0,5 %, surface 250 m2.
Rainfall : 691 mm/year ; RUSA = 321
Tree Savanna + Andropogan = influence of bushfire date.

TABLE 4 : EROSION MEASUREMENTS ON RUNOFF PLOTS IN NORTH SUDANIAN AREA

	RUNOFF		EROSION
	KRAM %	KR Max %	t/ha/year
SARIA (Roose et al, 1979)			
- Bare fallow monthly cultivated	39	70	20
- Sorghum on mounds // slope	27	60	6
- Young fallow	10	30	0,5
- Old fallow	3	5	0,15
LINOGHIN (Piot, Millogo, 1980)			
- Bare fallow daily cultivated	47		14,1
- Crops on the flat	18		3,2
- Diguettes + ridging // slope	19		3,9
- Diguettes + ridging on the contour	6,6		0,6
- Old fallow - burnt	19		0,8
- not burnt	3,7		0,09

SARIA 1971-74 : leached tropical ferrugineous soil on ironpan around 50 cm.
Slope 0,7 %, surface 100 m2, length = 22 m.
Rainfall : 643, RUSA = 380, K = 0,06↗ 0,35↘0,23

LINOGHIN 1973-78 : Brown vertic soil
Slope 1-1,3 %; surface 100 to 5000 m2.
Cotton, sorghum, maïze, cowpeas, fallows.
Rainfall : 636 mm, RUSA = 309; K = 0,008↗ 0,28↘0,14

TABLE 5 : RUNOFF AND EROSION IN SOUTH SAHELIAN AREA

		RUNOFF		EFFECT ON GRAIN YIELD	
		KRAM %	KR MAX %		
BIDI (LAMACHERE, SERPANTIE, 1988)					
1985 : 239 mm	1 tradit	29	75		
	2 tradit + rock bunds	24	57	- 11 %	
	3 tradit + R.B. + plowing	–	–		
1986 : 530 mm	1	24	85		
	2	23	67	+ 81 %	
	3	–	–		
1987 : 484 mm	1	11	62		
	2	8,7	60	+ 31 %	
	3	3,4	–		
MARE D'OURSI (Piot, Millogo, 1980)				EROSION t/ha/year Md	Dry years
Bare fallow, daily cultivated		6	37	17,8	16
Cultivated for millet		5,5	44	2,2	0,6
Integral protected fallow		9,7	44	1,6	0,2

BIDI
1985-89 : Sandy ferrugineous tropical soil with lateritic ironpan between 25 to 220 cm.
Slope 2,5 % ; plot 100 x 20 m with impluvium 50 x 20 m.
Millet traditional, idem + rock bunds, idem + plowing.

MARE D'OURSI
1977-79 : Sandy ferrugineous tropical soil with sandy sheet.
Slope 5 % ; surface 100 to 2800 m2 ; millet.
Rainfall : 279 to 388 mm ; RUSA = 53 to 171.

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