DIVERSION CHANNEL TERRACES OR PERMEABLE MICRODAMS? ANALYSIS OF TWO SOIL AND WATER CONSERVATION APPROACHES IN THE LITTLE FARMS OF SOUDANO-SAHELIAN AREA OF WESTERN AFRICA

E. Roose

Since 1950 and especially since the long drought period, it has been observed a deep evolution of the landscapes of Soudano-Sahelian area of Western Africa: degradation of the vegetation (disappearance of trees and perennials grass) denudation, encrusting, then scouring of soils, runoff development, hillslope gullies, changes in the river regime, decline of the regional climate (**Mullard and Groene, 1961; Marchal, 1979; Roose, 1985**). The chief causes are demographic (high level of human and animal density) and socio-economic pressures which lead to extension of cleared, destocked and mechanized plought area, overgrazing, bush fires, etc.. The drought, longuer than usual (already 17 years) has only increased the unbalance between the biomass producted and the consumption needs (**Peyre de Fabregues, 1985; Roose, 1985**).

Facing this land degradation, it was often recommended the classical antierosive method of channel terrace diverging excess runoff water to grass waterways (**Bennet, 1939; FAO, 1967; Hudson, 1973; CTFT, 1980**). Considering the failure of this approach in the west african peasant environment, an analysis of the basic principles, of the measurements data and of field observations could enlighten this problem. An other approach could be suggested which concern the traditionnal method of permeable microdams: vegetation or stone strips, buffer strips, quickset hedge, row of trees, etc.

The objective of this note is to catch the eye of professionals.

- on the limits of terracig methods application in african peasant sphere
- on the interest of simple and unexpensive methods like permeable microdams abutting progressively to sweet slopes terraces.

It must be underlined the necessity of a more flexible and global approach taking into account the peasant needs and possibilities and aiming not only at soil and water conservation but also at the harmonious development of animal and plant production.

THE SOUDANO-SAHELIAN MIDDEL IS FRAGILE

Annual rainfall amounts varies from 1200 to 600 mm to the North, but they have decreased about 250 mm on average during the ten last years. It rains during 4 to 6 months with very high intensities (55 to 80 mm/H during 30 minutes) comparing with the low infiltration capacity of soils. Dayly rainfall can reach 60 to 75 mm/day each year, 120 mm all the ten years and 150 mm all the 50 YEARS (**Brunet and Moret, 1963**). The erosivity index "Rusa" decreases from 600 to 300 when we draw nearer to sahelian area (**Roose, 1977; 1980**).

- The most common landscapes on granit and sand-stone (**Figure 1**) are composed of a plateau with iron hardpan, a short escarpment of rock scree, a long gravelly pediment recovered by a silty loam dim more and more thick, a river bank and a narrow riverbed. Most of the slopes are gentle (0 to 3 %) but very long.

- The ferruginous tropical soils are more or less leached or hydromorphic in depth. The tropical brown soils are more or less hydromorphic or vertisolic. They are poor chemically (N, P, K carencies, pH 5 to 4) and unstable structurally (low organic matter level, a lot of loam and fine sand). As soon as it is bare, the topsoil gets a sealing crust little or not permeable. After some years of continuous cropping

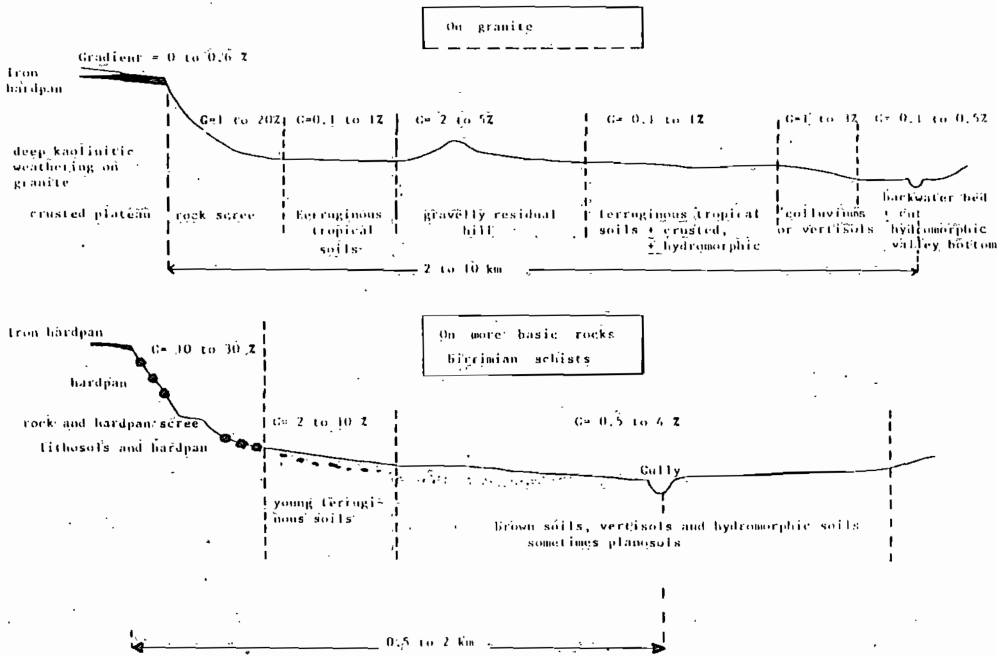

FIG.1 Typical catenas on the Mossi plateau.

(cotton or peanuts, then cereals like sorghum or millet) with plowing, two weedings, and ridging a year with oxen drawn farm equipment, becomes around 12-15 cm depth a compacted plow pan impenetrable to roots (compactness, pH, carencies or toxicity?).

Thus, the pedoclimate is still much dryer for plants. Fallow are disappearing, too brief and overgrazed to regenerate soil fertility efficiently.

- Crops release too few residues: cotton stalks are burned, peanuts and cereal leaves are used as forage and remaining cereal stalks are usefull for house craft work.

- Vegetation, a dense tree savana at the origine, was hardly degraded these last years because the need of ground for cropping extension, dryness, runoff and decrease of water-table level, because wood cutting to satisfy the villages need for fuel, and because overgrazing and bushfires. Cattle has much developped itself during the wet years all over the Sahel. Also during the actual dry period, with decreasing biomass, it is no more possible to feed all cattle from the village and those of the transhumance going south to more humid pastures (**Hallam and van Campen, 1985**).

Measurements on runoff plots (100 to 500 m^2) (**Roose and Piot, 1984**) on four stations around Quagagadougou have shown:

- a very strong runoff on the hillslopes, intolerable in that regions where crops lack of water to finish their cycle,

- annual runoff coefficient averages

  - 40% on bare plots
  - 20 to 30 % on weeded crops = sorghum, millet, cotton
  - 0.2 - 2 - 20 % on protected fallow, early and late burnt

- Runoff can attain 60 to 70 % of a big shower on little covered ground

- Soil losses are moderate (0.1 to 20 t/ha/year) because the slopes are gentle (0 - 3 %); but erosion is very selective about colloids (clay and organic matter) and nutrients. On moderately intensive crops (plowing, ridging + fertilizing), soils losses have still overtaken (3 to 14 t/ha/year) the tolerable limits for soils which weather slowly.

These results were confirmed with the help of rainfall simulators which showed moreover that more the soils have an unstable structure, more they are erodible and more the benefits of soil working on infiltration is limited (**Collinet and Valentin, 1979**).

GRADED CHANNEL TERRACES FOR DIVERSION OF RUNOFF METHOD

Principles

It is considered that soil cannot infiltrate completely high intensities of rainfall. Thus runoff must be safely evacuated to grass waterways, or it will accumulate speedness and supplemental energy

$$\text{E. Runoff} = \frac{\text{Mass x speedness}^2}{2}$$

Limiting slope length will limit linear erosion risk, but not splash erosion nor soil degradation between dykes.

Runoff plot measurements (Table 1)

The seldom runoff plots data obtained in Western Africa (Benin: **Verney and Willaime, 1965; Roose, 1976**)

(Senegal: **Roose, 1967**) (Nigeria: **Lal, 1975**) and the 532 plot-years analysed in the USA **Wischmeier et al., 1958**) demonstrated that runoff and even erosion do not increase necessarely with the slope length and can sometimes decrease. The relationship of soil loss to slope length often varied more from year to year on the same plot, than it varied among locations. At the runoff plot scale, there are interactions between the slope length effect and the soil surface state effect (particularly surface roughness, cover, soil type and crop residue management).

If generally soil loss increases exponentially with the slope length, this exponent varies from 0.1 to 0.9 in relation with the runoff volume. For field use, a group study at Purdue University in 1956 concluded that the average value of the length exponent should be 0.5 $\pm$ 0.1 (**Smith and Wischmeier 1962**).

On Table 1 there are summarized the data of trials made by "the Centre Technique Forestier Tropical" (C.T.F.T.) on the research station of Gampela, 25 km East from Quagadougou (Upper Volta). Comparing the data from plot (diversion dykes and ridging across the slope, tied ridging in 1967 - 68 and 72) and plot 2 (diversion dykes and ridging along the slope, no tied ridging) to plot 3 (reference = traditionnal Mossi agricultural system = sowing directly in seed-holes with hoe but similar planting density and fertilizing), it is easy to conclude that the surface state (direction and tied ridging) is much more efficient to modify runoff and erosion than the management (= diversion terracing).

Observations on the field

In 1962-65, **GERES** (Groupement européen de restauration des sols en Haute - Volta) realized a large programme of soil conservation in the Quahigouya area of 120.000 ha of hillslopes managed qith diversion channel terraces (35.000 km of drain), 650 ha of waterways treated

Table 1. Results from Gampela (CTFT/HV)

Location: Longitude 1°21'W; latitude 12°25'N; altitude 280 m.
Instrumentation: 3 plots of about 5000 m^2, length 100 m, gradient 0.8%, 1 standard Wischmeier plot of 200 m^2, length 25 m.
Soils: Gravelly ferruginous soil not very thick (30 cm) on hardpan.

Year		1967	1968	1969	1970	1971	1972	Mean
Rainfall (mm)		636*	722	773	720	720	817	731
RUSA index		270	254	449	266	308	366	319
RUNOFF								
KRAM %	P1	4	2.3	10.1	18.1	20.5	7.6	10.4%
	P2	12	12.6	23.3	31.5	45.3	17.1	23.7%
	P3	22.2	15.1	15.8	23.1	32.4	26.2	22.5%
KRMAX %	P1	29	14	37	33	31	31	31
	P2	46	70	40	45	57	39	45
	P3	42	38	43	39	37	51	40
EROSION (t ha^{-1})								
	P1	Unchecked	0.64	1.67	6.12	5.43	2.14	3.20
	P2	"	2.53	4.22	8.18	10.28	4.27	5.90
	P3	"	1.56	2.54	5.12	6.54	4.52	4.06
	PW	"	Unchecked	10.60	21.07	18.12	14.38	16.04
K index			0.05**	0.09	0.32	0.24	0.16	0.20
CROPS		Local sorghum	Sorghum*** striga	IRAT millet	TE3 peanut	IRAT millet	TE3 peanut	
YIELDS (t ha^{-1})								
	P1	0.83	0.43	1.08	1.58	1.35	1.46	1.12
	P2	0.85	0.46	1.01	1.46	1.03	1.40	1.03
	P3	0.76	0.43	1.24	1.63	0.99	1.25	1.05

* Beginning 8 June 1967.
** E = 2.73 t for R = 212.
*** Considerable development of striga = sorghum parasite.

P1 Ridges at a height of 40 cm, gradient = 0.2% (diversion); isohypse and tied ridging in 1967, 1968 and 1972; non tied ridging in 1969, 1970 and 1971; isohypse tractor ploughing, recommended fertilizer application rate.

P2 Tractor ploughing along the steepest gradient, harrowing and ridging along the slope, recommended fertilizer application rate.

P3 Traditional sowing with daba (hoe) but similar density of planting, unridged harrowing, same amount of manure as P1 and P2.

PW Bare soil tilled each year plus harrowing each time the soil is sealed, namely every 3 weeks (i.e. above the standard conditions defined by Wischmeier).

KRAM : Average annual runoff coefficient

KRMAX : Maximum runoff coefficient for one rainfall event.

with lateritic parpen walls and 24 earth dams (2,5 Milliards US dollars). **Marchal (1979)** has clearly shown how this program, technically well organized, failed because he did not taken into acount traditional space organization nor peasant possibilities to maintain and valorize the soil conservation management. Since 1965, BDPA established the unadjustment to regional environment not only on the human level, but also on the technical point of view. "It is questionable to manage hillslopes of less than 2% with channel terraces when grass strips are so efficient. Improving crops must go together with soil conservation" (**B.D.P.A., 1965**).

Since 1972, the FDR (Fond de Développement Rural) in Upper Volta helps villager associations who ask for it, to establish the countour lines on which peasants themselves build their diversion dykes. The management is already less expensive and peasants are concerned at all levels: but the managed surfaces (15.000 ha) do not reach 20% of the degraded space to manage. **Mietton (1981)** observed that maintenance is not completed (dykes are bare and often sinking) and setting terraces is a considerable work (15 days/men/ha to move one hundred m^3 of ground).

In the Southern part of Mali, **Hallam and van Campen (1985)** show that this management system was partly successfull by some senoufo leader farmers (because the runoff was running beside their own fields) but did not extend really.

In Benin, this channel terraces system was applied on the hilly and overcrowded area of Boukombe around 1962 but it was quickly abandonned (**Roose, 1976**).

In fact, this method was not succesfull with the West African farmers, not only for economical reasons (too much work setting and maintaining dykes, loss of cultivated ground) but also for technical reasons (low efficiency, breaking risks) that we must analyse now more accurately.

Analysis

1. This method needs a carefull ingraft and thus a competent and very conscientious team of topografers because dykes and ditches must drain off excess water with a slope of 0,2 to 0,5 % which is very difficult to do in these gentle rolling hillslopes (less than 2%). Consequently it is observed some dyke failures because errors of construction: local reverse slope, not high and compacted enough dykes, too wide fields (optimum is between 20 and 50 meters).

2. This method needs a heavy work for setting (15 days/men/ha) and maintening terraces each year (2 days/men/ha). Indeed, dykes must be covered with grass to be protected against splash and wandering cattle. Ditches must be cleaned out because ground eroded on the fields deposits necessarily in the ditches with the decreasing slope steepness (2% to 0,2%) and water competence.

The waterways must be covered with grass or stones. But it is very difficult to grasses to grow if the humiferous horizon has been scoured; moreover the violent current erodes the bottom of waterways and the young plants.

This maintainance is quasi never made because lack of means and misunderstanding of the system: so, after 2 to 6 years, numerous failures can be observed.

3. Anyway, dykes must be broken, a day or another, because these impermeable structures are calculated to evacuate runoff from decennal rainfall event; it would be too expensive to size channels to evacuate flow from rarer events. Moreover, we often ignore the runoff coefficients on cultivated ground. They could be 2 or 3 times those observed by hydrologist at the watershed scale in relation with surface sealing, saturated topsoil and light green cover. Chiefly it could happen each year, somewhere in the village territory, a rainfall event of a succession of rains from 1/20 to 1/50 return

frequency who induces the overflowing of ditches, the break of dykes, gullies in waterways, silting up and flood in the river plain.

4. The diversion dykes must necessarily be set around the contour (from 0,2 to 0,5 % slope); as hill-slopes are not regular and the width of cultivated strips varies. Moreover, 6 to 14 % of the cultivated land is lost for ditches and dykes which may not be cultivated. These are two major inconvenients to mechanization and intensification of agriculture in dense populated areas.

5. These hollowing structures "Tear the territory" and "kill the soil" say the old peasants: they superimpose on traditional soil organization. As it is very difficult to change the habits, numerous failures are observed at the crossing of dykes and ancient paths for people and cattle (**Marchal, 1979**).

After few years, one can observe that sheet erosion has been changed into gully erosion localized in waterways, but the problem of soil degradation in cultivated strips has not been solved: splash erosion continues.

There was not modified nor the slope gradient, nor the green cover nor the seedbed preparation, but only the slope length and sometimes the cultural practices orientations. At Quahigouya, comparing (with aerial photographs from 1952 and 1973) the bare eroded surfaces of ten village territories situated into the managed area and ten similar villages outside the managed area "leave no doubt on the lack of channel terraces efficiency".

Not only this management was not able to stop erosion but it allowed an extension of eroded areas greater than the reference. **Mietton (1981)** still observed an increase of soil water storage capacity around the dykes and an increase of yield during dry years.

If this method did not safisfied West Africa farmers, **let** us look if it is possible to use and generalize traditional conservation methods which efficiency cannot be in doubt.

PERMEABLE MICRODAMS AND PROGRESSIVE TERRACES METHOD

Facing to diversion terraces methods imported and imposed from outside, it exists in african landscapes, as in Europe and Asia, all kinds of very simple conservation devices which are tested during the last centuries and which can be adapted to various circumstances. I want to speak about trees row, quickset hedges, grass buffer strips, lines of rocks, branches or straw. They work like permeable microdams which create "progressive terraces".

Principles

When slope steepness decreases and soil surface rugosity increases, the runoff flow velocity is restrained as their competence and capacity to transport sediment: it can be observed a deposit of coarse, sediments (sand, aggregates and organic matter). Accumulating, these permeable deposits modify progressively the slope steepness. Moreover, if microdams and cultural practices are more or less on the contour, at each soil cultivation, 1 to 10 tonnes/ha of earth are pushed down (or up) so that the landscape is rapidly modified (4 to 10 years) in a succession of steep grass embankments and cultivated field on gentle slopes. The erosion risks decrease naturally with the slope steepness. Excess water runs safely above the grassed embankment and arrive without energy and coarse sediment to the downstair terrace. There, a ditch may drain them to waterways if necessary.

Runoff plots measurements (Table 2)

On runoff plots of Guinean forest area, grass buffer strip cropping of two meters wide have reduced erosion to 0,3 - 0,1 and runoff to 0,6 to 0,3 of the check. Even in Sahelian area, a triple rank of grass (Andropogon) or a stone line were very efficient to catch water and eroded ground (**Roose and Bertrand, 1971; Delwaulle, 1973**).

Table 2. Influence of grass buffer strip cropping on annual runoff (Kr %) and erosion (t/ha/year or % of reference).

1) Adiopodoumé (Ivory Coast) 1965 - Cassava, 7% slope.

Width of butter strips	0 m	2 m	4 m	Efficiency ratio
Runoff Kr %	16,5	10,3	6,0	1/0,6/0,36
E t/ha/year	18,9	5,7	1,8	1/0,3/0,1
2) Bouaké (Ivory Coast) Kr %	9,4	3,2	0,8	1/0,34/0,19
1965 Peanuts + maize E t/ha	4,6	0,54	0,19	1/0,12/0,04
1966 maize + maize Kr %	15,4	6,7	5,5	1/0,04/0,36
Isohypse ridging E t/ha/year	10,6	1,2	1,1	1/0,11/0,10

(Roose and Bertrand, 1971)

3) Allokoto (NIGER) 1966-70: sorghum, cotton, cotton, peanuts, millet.

	Runoff	E t/ha/year	Efficiency ratio	
- Reference without management (hoe minimum tillage)	17,6 %	9,5	1	1
- Buffer strip cropping (isohypse-plowing-ridging-weeding)	5,2 %	1,1	0,3	0,11
- Stone lines (dh = 0,8 m) (isohypse-plowing-ridging-weeding)	3,8 %	0,5	0,2	0,05
- Earth dykes with stones (isohypse-plowing-ridging-weeding)	0,9 %	0,2	0,05	0,02

(Delwaulle, 1973)

Observations on the field

In Ivory Coast (at Bouaké and Man centers of agricultural research) and in Madagascar (Manankazo, etc.), antierosive management of hillslopes (4 to 9 % steepness) with grassed buffer strips (2 - 4 m width) covered with various grasses and legumes developed embankments of 50 to 100 cm in 4 to 6 years (**Roose and Bertrand, 1971**).

In Burkina Faso, Mossi from Ouahigouya region, without any help, have restored the fertility of soils completely scoured and encrusted. With lines of stones and grasses,. they have catched runoff and sediments (sand, aggregates and organic matter); then they have enriched sediments with manure (necessity of carbon and microbes) and improved infiltration rate with plowing (**Roose and Piot, 1984**). After only one year, the ground was enough improved to produce 1,5 t/ha of sorghum grain; a new stone line was installed above to restore a new field.

In the Southern part of Mali (cooperation between IER and KIT in the Koutiala area) overgrazed and over-cultivated for cotton and cereals, quickset hedges were planted first for demonstration (Euphorbia balsamifera + grasses and multiobjective trees), then by associated peasants from three villages (**Roose, 1984; Hallam and van Campen, 1985**). The objective is to delimit cultivated strips of constant width (23 to 48 meters according to erosion risks) facilitating introduction of modern intensification technics (fertilizers, manure, pesticides, agroforestery, cultural practices on the contour, etc.).

This method, more supple and easier to adapt on the field, was well accepted by villagers, but it is too soon to conclude about its efficiency and the spreading in the country.

Analysis

1. The soil conservation method uses only simple and cheap means and lean on a well known technic in traditional environment. It does not need specialist topographer because quickset hedges can be planted more or less in a parallel direction with a chief contour of the hillslopes.

2. Terraces are built naturally, progressively, without additional work for peasants. Planting hedges and maintenance work is reduced to a minimum if rustic plants have been selected.

3. The microdams being numerous, low and permeable there are no risk of catastrophic events during the most intensive showers; indeed, excess water, not infiltrated or stored in the field (tied ridging) may flow over grass protected embankments. If slopes are very steep it may be prudent to organize draining these clear waters, after the embankment, to the waterways.

4. Cultivated strips have a constant width to allow a mechanized and really intensive agriculture. Their length can reach 200 to 400 meters, which is the optimum for oxen drawn work. For longuer distance, very little time could be earned but erosion risks increase significantly because of irregularities of hillslopes. There is no ground lost because, after some years people may yield on buffer strips mulching, forrage, fruits, fuel wood and some perch which could be commercialized (**Gorse, 1985**).

5. Although, there is a limitation of this method: the thickness of arable soil. If erosion and cultural practices push progressively the ground down the cultivated strips, the arable layer will increase at the lower part, but decrease at the upper part. As long as the ground is light is possible to compensate the losses of the upper part by bringing preferentially nutrients and organic matter. But if rocks appear at less than 50 cm depth, cultivation practices must be made alternatively in the each direction to keep a soil volume enough for the root system.

CONCLUSION

The analysis of principles, data of measurements and field observations shows clearly that the "permeable microdams" or the "progressive terracing" system is better adapted to West African environment than "diversion channel terraces".

But we must do two remarks:

1. There are very few experimental valuable data demonstrating the efficiency and rentability of those managements for soil and water conservation on a watershed scale. Although people continue to apply blindly methods defined half a century ago by Bennet for intensive agriculture and temperate environment of the Great Plain of America.

2. The rare data on runoff plots show that, even if these management are efficient (P factor varies from 1 to 0,3 - 0,1), they are much less efficient than biological practices on the field (C factor varies from to 0,1 - 0,01).

Once the antierosive management is well done and adapted to each part of the landscape it remains to define agrosylvopastoral systems allowing to really intensify simultaneously the production of crops (industrial and food), wood (chief energy source in West African environment) and cattle to answer to elementary needs of increasing population.

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