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Runoff, erosion and soil fertility restoration on the Mossi Plateau (central Upper Volta)

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ABSTRACT Man has had a major impact on the Sudanese landscape as a result of the long period of settlement, the high density of the human and animal population, the social structure and the fragile environment. Rainfall variability and intensities are high, the ferruginous soils or vertisols have low permeabilities, and the vegetation cover is poor as a result of overgrazing, bush fires and extensive cultivation. Field studies have revealed an extension of erosion and desertification. Measurements conducted on runoff plots at four sites have shown high levels of runoff ranging from an average of 20 to 40% per year on overgrazed lands and under extensive cultivation. Individual storm values were as high as 70% during heavy showers. Although slopes are gentle (<2%), soil losses are considerable and highly selective of colloids and nutrients. Soil losses depend mainly on the amount of vegetative cover and the roughness of the soil surface rather than on the type of soil and the cultivation practices. Given the scope of the problem of water and soil conservation and the failure of technical approaches, the authors advocate the use of traditional methods which combine the construction of numerous, low, filtering structures with the restoration of soil fertility.

Ruissellement, érosion et restauration de la fertilité des sols du Plateau Mossi, Haute Volta centrale
RESUME L'homme a marqué profondément ce paysage soudanien du fait de son implantation ancienne, de sa forte densité de population humaine et animale, des structures sociales, et de la fragilité du milieu: les pluies y sont très variables et agressives tandis que les sols ferrugineux ou bruns vertiques y sont peu perméables et mal couverts (surpâturage, feux de brousse et cultures extensives). Les observations de terrain ont mis en évidence une extension de l'érosion et de la désertification. Les mesures en parcelles d'érosion en quatre stations ont montré l'existence d'un fort ruissellement (20 à 40% si surpâturages et cultures extensives en moyenne annuelle et jusqu'à 70% lors des fortes averses) et des pertes en terre très sélectives vis-à-vis des colloïdes et des nutriments et relativement fortes vu la faiblesse des pentes (moins de 2% pour la

majorité); ils dépendent avant tout du couvert végétal et de l'état de la surface du sol, plutôt que du type de sol et du mode de travail. Vu l'étendue du problème de conservation de l'eau et des sols et l'échec des approches technocratiques, les auteurs suggèrent l'extension de méthodes traditionnelles simples alliant l'aménagement de structures basses, fréquentes et filtrantes à la restauration de la fertilité de sols.

INTRODUCTION

The Mossi plateau covers the central zone of Upper Volta which is characterized by long gently inclined glacis covered with Sudanese tree savanna (Roose, 1978, 1980; Piot & Millogo, 1980; Mietton, 1981). It provides for the needs of two communities. However, the pastoral and nomadic Peul are living on the fringe of an increasing agricultural population. The impact of man on the landscape has been very considerable, more especially because his settlement is of long standing, the density of the human and animal population is high and the environment is fragile (high rainfall and soils of low permeability). Moreover, the social structure has undergone significant changes leading to a considerable increase in cultivated lands (Marchal, 1979; Mietton, 1981).

As early as the end of the 1950s, the problems of soil degradation by erosion attracted the attention of foresters who developed a programme for the development of the Ouahigouya area (Mulard & Groene, 1961; BDPA, 1966). Twenty years later, new investigations have shown that desertification has spread to the most arid zones by the extension of areas covered with scoured and unproductive soils (Marchal, 1979; Grouzis, 1983) and that erosion has increased in the most humid southern zones where there has been a concentration of population, resulting in reduction of vegetative cover, sheet and gully erosion on the glacis and silting of valley bottoms (Mietton, 1981). It is not yet clear whether erosion will accelerate under extensive cultivation or whether it is a temporary condition related to the successive dry years. This paper reviews the results of measurements of erosion made on runoff plots on the Mossi plateau and of the various field experiments intended to maintain or restore soil fertility in one of the poorest countries in the world.

THE ENVIRONMENT

The central zone of Upper Volta (latitude 11° to 14°N; longitude 3°W to 1°E) is characterized by crust-capped hills, glacis and peneplains underlain primarily by granite but also by birrimian basic rocks. Figure 1 shows that most of the landscape is composed of low gradient slopes (3 to 0.1%) whose cultivated soils are of three types. The lithic soils are gravelly on the surface and infertile and possess low water reserves. The ferruginous tropical soils are leached and more or less hydromorphic. They are 0.2-2 m deep over a crust of more or less interlocked ferruginous gravels. These soils are deficient in N-P-(K) and are of low permeability; they form a sealing crust and are subject to sheet and gully erosion.

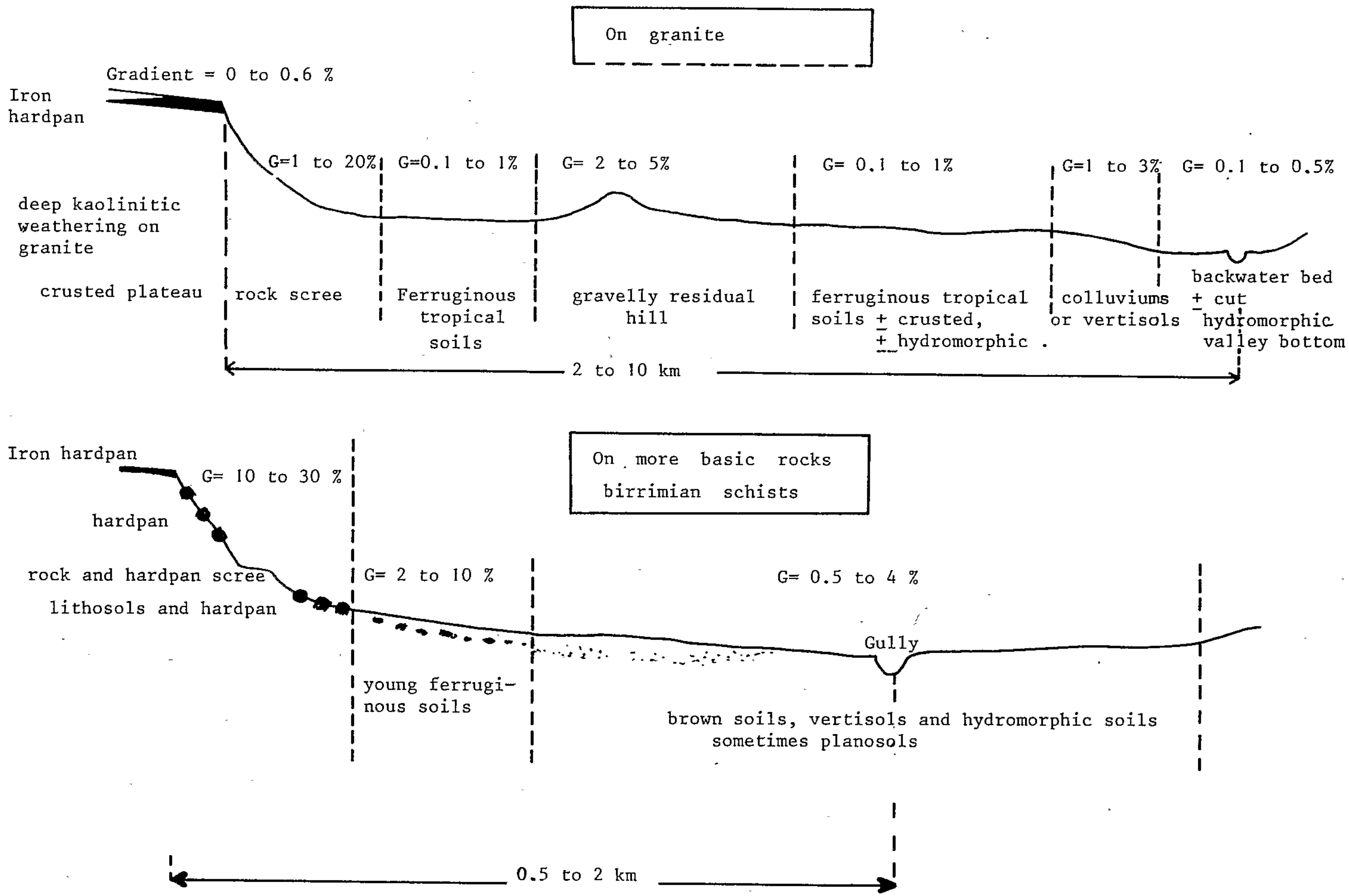

FIG.1 Typical catenas on the Mossi plateau.

Their agricultural potential depends on their water storage capacity. The tropical brown vertic or hydromorphic soils with swelling clay are richer chemically but rather more difficult to exploit; moreover, they are subject to gully erosion and waterlogging once desiccation cracks close. These three soil types have the following common characteristics: they are poor in organic matter, their structure is unstable, they are rapidly sealed by rainfall and they have low permeabilities as soon as they are overgrazed or cultivated.

The natural vegetation is a Sudanese tree savanna with *Butyrospermum parkii*, *Parkia biglobosa*, and various other species including *Combretum*, *Cassia*, *Bombax*, *Tamarindus*, *Andropogon* and *Pennisetum*. Vegetation becomes sparser and exhibits an increase in thorny species towards the Sahelian steppes. Man has used fire, grazing and selective clearing to improve the grazing and to preserve the useful or fireproof species. He has reduced the number of trees in the savanna to such an extent that it has the appearance of a park of old trees lying among crops or shrub fallow. The low vegetation is burnt almost every year, thus resulting in bare soils during the most aggressive showers at the beginning of the rainy season. At that time, crops such as millet, sorghum, cotton, peanut and niebe provide poor cover to the soil. Annual rainfall is highly variable (from 600 to 1000 mm) and its distribution is irregular (4 wet months with 100-250 mm of rainfall). Potential evapotranspiration exceeds 1900 mm. Drought can also occur in the middle of the rainy season, and yields are therefore closely related to the distribution of rainfall, the soil water reserve and runoff. Maximum daily rainfall depths range from 65 mm for a return period of 1 year to 107 mm for a return period of 10 years and maximum 30 minute intensities range from 60 to 80 mm h^{-1}. The rainfall erosivity index (R index, Wischmeier & Smith, 1978) ranges from 250 to 500.

METHODS

Runoff and sheet erosion have been measured on two types of runoff plot. Classical runoff plots of 100-250 m^2 with sediment traps and successive storage tanks connected by divisors have been installed at Gonse by ORSTOM and CTFT and at Saria by ORSTOM, IRAT and later CIEH. Plots similar in area to a cultivated field (5000 m^2), isolated by a ditch and a protective ridge, and equipped downstream with a big tank (4 m^2), a triangular weir (90°) and a Richard water-level recorder were sited at Gampela and Linoghin by CTFT. Rainfall depths and intensities have been recorded using tipping bucket raingauges. Rainfall simulation tests have been conducted by an ORSTOM interdisciplinary research group near lakes Bam and Loumbila (Collinet & Lafforgue, 1979).

RESULTS OF THE EROSION MEASUREMENTS

This paper will only consider the results of measurements of the annual precipitation, the annual rainfall erosivity index (Wischmeier

& Smith, 1978), the mean annual runoff coefficient (KRAM%), the maximum runoff coefficient during a storm (KRMAX%) and total erosion expressed in t $ha^{-1}year^{-1}$ (Tables 1 to 4).

Under the Sudanese savanna

On the gentle slopes (0.7-1.4%), runoff (KRAM ranging from 1 to 5%) and erosion (0.02 to 0.2 t $ha^{-1}year^{-1}$) are very low irrespective of the type of soil. However, the intensity and timing of repeated bush fires can profoundly modify the vegetative cover by decreasing the density and variety of species, inhibiting the young forest regrowth, reducing the biological activity in the soil/litter contact zone and modifying the physico-chemical properties of the soil surface through a decrease in the organic matter content and in structural stability and infiltration. Such changes can produce a considerable increase in runoff with KRAM increasing from 4 to 20% and KRMAX increasing from 1 to 50% at Gonsé and Saria). The increase in sheet erosion is also significant but it is lower owing to the low gradients (E increased from 50 to 500 kg ha^{-1} at Gonsé and from 100 to 700 kg ha^{-1} at Linoghin). Extensive grazing and removal of herbage (see Table 3, old fallow) have less disastrous effects than fire. Similar results have been observed further to the south of Upper Volta (Mietton, 1981) and in the Ivory Coast (Roose, 1980).

Under fallow

When soils exhausted by a few cultural cycles are no longer exploited, they are gradually covered by weeds, and their surface becomes sealed by a crust. A young fallow on a ferruginous tropical soil at Saria lost 20% of rainfall (50% during heavy showers) to runoff in the first year, but little soil was lost (0.7 t ha^{-1}) owing to the cohesive surface crust. As early as the second year of complete soil protection, water and soil losses are reduced to the levels found under savanna.

At Linoghin, on richer vertic brown soils, biological activity is re-established more rapidly and as early as the first year, runoff (KRAM ranging from 1 to 5%) and erosion (ranging from 0.1 to 0.4 t $ha^{-1}year^{-1}$) become insignificant under natural or cultivated fallow (Congo pea). Although there is a rapid decrease in soil loss owing to the protection of the degraded soils, it takes from 3 to 10 years to restore the soil fertility, especially as most of the fallows in the Mossi zone are subject to a large-scale grazing (and often to fire), which considerably reduces their efficiency. These grazed fallows whose soil is often crusted and poorly protected by vegetation are the origin of sheet flows which can give rise to small gullies even on low gradients.

Under crops

It is necessary to distinguish the different types of soil and the farming practices tested at each station.

At Gampela, on gravelly soil with low water and mineral reserves under traditional unridged crops (hoed and fertilized), high runoff

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 m², length 100 m, gradient 0.8%, 1 standard Wischmeier plot of 200 m², 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 amounting to about 20% and KRMAX amounting to about 50%), and mean soil losses of 4.1 $t\ ha^{-1}year^{-1}$ were observed. Crop yields

TABLE 2 Results from Gonsé (ORSTOM-CTFT)

Location: 12°22'N, 1°19'W, altitude 300 m.
Instrumentation: 1 plot of 250 m², gradient 0.5%, length 46 m under ungrazed tree savanna subject to early and late fire or under protected savanna.

Year	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*Median*
Treatment	*Early fires*		*Complete protection*		*Late fires*			*Dis-continuous vegetation cover*
RAINFALL								
Depth (mm)	*809*	*759*	*799*	*674*	*691*	*553*	*596*	*691*
R index	*355*	*407*	*407*	*321*	*293*	*318*	*189*	*321*
RUNOFF								
KRAM %	*3.0*	*2.3*	*0.3*	*0.2*	*8.9*	*16.1*	*14.9*	*3*
KRMAX %	*8.2*	*10.4*	*1.3*	*0.7*	*73.3*	*52.8*	*55.6*	*10*
EROSION								
(t $ha^{-1}year^{-1}$)	*0.149*	*0.047*	*0.018*	*0.047*	*0.408*	*0.304*	*0.321*	*0.149*

(Based on Roose, 1978).

varied according to location and to the level of fertilizer application. Mechanical tilling and slopewise banking (g = 0.8%) hardly improved the annual infiltration, soil loss (E = 5.9 t $ha^{-1}year^{-1}$) and crop yields. Isohypse and tied ridging had to be combined with deep tilling to appreciably reduce runoff (KRAM = 10%) and erosion (E = 3.2 t $ha^{-1}year^{-1}$). However, yields were not significantly higher in the dry years and they were sometimes lower in the wet years (waterlogging).

It must be recognized that erosion is selective in that it carries away fine particles, organic matter and nutrients, thus leaving only a sandy or gravelly skeleton which is unable to retain water and nutrients. Despite the low gradients, runoff ranges from 50 to 70% and potentional erosion ranges from 11 to 21 t $ha^{-1}year^{-1}$ on bare soil tilled slopewise; however, the formation of a protective mulch composed of coarse material leads to a decrease in erosion as early as the fourth year.

At Saria, on leached, shallow, crusted ferruginous soils, runoff averaged 40% on bare soils and 30% under sorghum although it increased to as much as 70% during heavy showers. Erosion ranged from 3 to 7 t $ha^{-1}year^{-1}$ under sorghum earthed up parallel to the slope, and to 35 t $ha^{-1}year^{-1}$ on bare soils (Roose *et al.*, 1979). The subsequent experiments conducted on the same plots by IRAT and CIEH from 1977 to 1981 provided further evidence of the high runoff and erosion rates, but they do not reveal the influence of hoeing or ploughing. The ploughing in of composted millet (4.2 t ha^{-1}) and sorghum (2.4 t ha^{-1}) straw increased the successive cotton and

TABLE 3 Results from Saria (ORSTOM/IRAT)

Location: 12°16'N, 2°9'W, altitude 300 m.
Instrumentation: 3 plots from 100 to 250 m², gradient 0.7%, leached ferruginous soil on hardpan at a depth of 50 cm. 1 plot of 250 m², gradient 1.4%, gravelly ferruginous soil to the surface.

Year	1971	1972	1973	1974	Median
Rainfall depth (mm)	602	724	672	714	643
RUSA	302	295	458	512	380
RUNOFF					
KRAM %					
Bare tilled soil	43	35	40	42	39
Earthed up sorghum	26	10	29	37	27
Young fallow (a)	20	5	6	8†	10
Old fallow (b)	10	0.4	0.3	3†	3
KRMAX %					
Bare soil	7	69	69	71	70
Earthed up sorghum	57	40	64	65	60
Young fallow	51	29	22	30†	30
Old fallow	41	2	1	8†	5
TOTAL EROSION (t $ha^{-1}year^{-1}$)					
Bare soil	3.4*	13.8	35.4	26.8	20
Earthed up sorghum	5.7*	3.2	6.2	14.3	6
Young fallow	0.70*	0.43	0.19	0.72†	0.5
Old fallow	0.17*	0.09	0.10	0.34†	0.15
SOIL EROSIVITY INDEX: K	0.06	0.21	0.35	0.23	0.23

** Erosion and runoff have been measured from 8 July 1971 on the basis of 461 mm of rainfall and R = 254.*
† Mowing and removal of all the straw on 15 May 1974 before the beginning of rainfalls, thus leading to a slight increase in runoff and erosion.
(a) Young fallow = natural regrowth after cultivation of millet, ensiling and harvesting in September 1970.
(b) Old fallow more than 30 years grazed each year on an extensive basis and not burnt.
(Based on Roose et al., 1979).

peanut yields and decreased runoff by 25%. The experiment has, however, not been sufficiently detailed to determine the chemical properties of compost or its influence on the soil physical properties (Forest & Poulain, 1978; Lidon *et al.*, 1983).

At Linoghin on brown vertisol, annual runoff ranges from about 47% on bare soils to 18% under unridged crops. Mean erosion rates of 3.2 t $ha^{-1}year^{-1}$ were measured under mechanized crops. Ridging slightly increased runoff (+5%) and erosion (+23%). Erosion increased from 7 to 35 t $ha^{-1}year^{-1}$ for a bare soil hoed every 3 weeks but decreased after 4 years. The development of a total

TABLE 4 *Results from Linoghin (CTFT/UV)*

Instrumentation: 4 plots of about 5000 m², gradient from 1.2 to 1.33%, length 92 to 140 m; 1 plot of 200 m², gradient 1%, length 25 m.
Soils: Vertic tropical brown soil.

Year		1973	1974	1975	1976	1977	1978	Median
Rainfall (mm)		>577	896	633	892	555	636	636 mm
Rusa		>185	485	309	452	202	223	309
RUNOFF								
KRAM %	P1	6.8	27.8	16.3	22.2	0.6	–	18%
	P2	6.8	31.9	13.2	25.8	0.8	4.6	19%
	P3	0.5	15.1	3.1	7.6	–	–	6.6%
	Sav.	18.9	21	4.5	3.3	18.2	3.2	b 19% nb 3.7%
	PW	incomplete	40.6	50.8	57.9	44	40	47%
EROSION (t ha^{-1})								
	P1	0.95	5.13	1.81	4.76	0.02	0	3.2
	P2	1.42	7.07	1.54	5.76	0.05	0.36	3.9 (+ 23%)
	P3	0.15	1.5	0.11	0.69	–	–	0.6 (-80%)
	Sav.	0.80	0.93	0.08	0.13	0.81	0.07	b = 0.8 nb = 0.09
	PW	incomplete	6.72	9.04	35.06	10.42	8.52	14.1
CROP		Cotton	Sorghum	Niebé	Maize	Fallow	Fallow	
	P1	unridged	earthed up	unridged	earthed up	natural fallow	natural fallow	
	P2	earthed up	earthed up	unridged	earthed up	Congo pea	natural fallow	
	P3	earthed up + ridges = total absorption						
	Sav.	burnt	burnt	protected	protected	burnt	protected	
YIELDS (kg ha^{-1})								
	P1	1140	2390	3075		–	–	
	P2	1390	2360	2725		–	–	
	P3	1140	1700	3075		–	–	
K (Wischmeier)		0.008	0.05	0.28		0.19	0.14	0.14

All the cultivated plots have been subject to subsoiling at a depth of 20 cm after clearing, to a pass of covercrop in 1973, to tractor ploughing and harrowing each year. P3, total absorption plot through isohypse ridges of 40 cm in height and 25 m apart.
(Based on Piot & Millogo, 1980).

absorption plot (isohypse ridges every 25 m) reduced runoff by 66% and erosion by 83% on average. However, crop yields have not significantly improved and the risks of discontinuity in the system are considerable in the case of rare rainfall events (frequency <0.1). Sheet erosion could then develop into a gully, thus removing as much soil as was lost in the previous 10 years. Suspended sediment accounts for 95% of the total erosion, but selective erosion is probably less serious than elsewhere due to the reserves of fine particles.

DISCUSSION

The influence of soil type, cultural techniques and the vegetative cover will be considered.

The influence of soil type

The vertisol, whether it is a bare soil under an unridged crop or under a slopewise ridged crop, is more resistant to erosion than the gravelly lithic soil and the leached ferruginous soil, but the interannual variations overlap considerably (E = 10 to 35 t $ha^{-1}year^{-1}$). The maximum soil erodibility indexes (K of Wischmeier & Smith, 1978) are 0.28, 0.32 and 0.35 respectively and the median values of 0.14, 0.20, 0.23 exhibit the same relative ranking. In all the observed cases, erodibility seems to reach a maximum level in the third or fourth year and to subsequently decrease. Such a phenomenon can be explained by
- a decrease in the organic matter reserve down to a minimum level,
- the formation of a protective mulch through the surface concentration of coarse particles, and
- preferential erosion in the central of the plot which produces a concave slope which is less erodible (Roose, 1980).

The selection of an appropriate value for this index remains a methodological problem which will be difficult to solve. There are two possibilities; either Kmax can be selected as a precautionary measure or the median K can be selected as being more representative of the mean phenomena studied by Wischmeier & Smith (1978). In practice, we observed that ferruginous tropical soils (poor in organic matter and richer in loam and fine sands) which have been cultivated for 2 years are more erodible than vertisols (more coherent) and ferrallitic soils (better structured) (Roose, 1980). The presence of gravels and rock debris on the surface considerably reduces the risks of erosion by affording protection from rainfall and runoff energy, as in the case of mulches (Dumas, 1965; Roose, 1980; Figueroa & Valentin, 1983).

Influence of soil tilling

Soil tilling is traditionally very limited in the Mossi zone. With the first useful rainfall, a stroke of the daba is given every metre, a handful of manure is deposited, 5 to 10 seeds of millet or sorghum are dibbled and the wet soil is compacted with the heel. Subsequently, two weeding operations carried out at an interval of

1 month break up the superficial soil crust and earth up seedlings. Each operation leads to a temporary increase in infiltration. The Mossi peasants are aware of the losses caused by runoff. They try, on the one hand, to check runoff by bounding their plots with an earth ridge protected by stones or grass, and on the other hand, to increase infiltration by roughening the soil surface by creating small water retention basins in the seed holes. They also make use of termites which bore through the sealing crust in search of organic matter associated with mulch applied to uncultivated areas and the manure placed in the seed holes, and redistribute nutrients by lining their galleries with excrement. Water which percolates preferably through these galleries into the seed holes allows young seeds to survive by developing roots at depth.

Numerous rainfall simulation experiments and field measurements have shown that soil tilling only increases infiltration for a short period because the soil structure is unstable and the soil surface is pulverized and compacted by the different kinds of equipment. Tilling needs considerable energy and results in a temporary increase in infiltration and a reduction in cohesion of the soil, making it more vulnerable to erosion. After a rainfall of 60-160 mm on tilled land it is observed that runoff and erosion exceed the original levels (before tilling) (Roose, 1977, 1978, 1980; Collinet & Lafforgue, 1979). Soil tilling exerts no appreciable influence on runoff, erosion and crop yields on low slopes over the year. In order that tilling should have a positive effect on water conservation it is necessary that the soil has an adequate water reserve, that the soil structure is improved by the restitution of organic residues and that tilling is followed by a sowing sufficiently dense to cover the soil as quickly as possible (Charreau & Nicou, 1971). Weeding and earthing up have a similar effect to tilling, though more temporary. Ridging is not a conservation method since it increases the soil slope and the area exposed to rainfall. Isohypse and tied ridging are very effective mainly under average rainfall conditions. However, the soil can be rapidly sealed and plants may be subject to waterlogging; therefore a drainage system for excess water must be planned. On the contrary, isohypse ridging seems to be effective in limiting erosion on the permeable ferrallitic soils of southern Upper Volta (Christoï, 1966) and of northern Ivory Coast (Roose, 1980).

Influence of vegetative cover

During the rainy season, the turbidity of runoff water decreases considerably, due to the fact that the growing vegetation cover intercepts the energy of raindrops. If a general comparison is made between erosion from a cultivated soil and erosion from a bare soil, rates are typically reduced to 40% under millet, maize and sorghum, to 30% under peanut, to 20% under creeping niebe, to 1-4% under young fallow or Congo pea, to 5% under burnt savanna and to less than 1% under protected savanna. The vegetation cover also has an influence on runoff, but it is less significant. It must be recognized that a vegetation cover lying on the soil itself (litter or crop residues) is much more effective than a vertical cover, for the litter absorbs all the energy from raindrops and slows down runoff. Moreover, mesofauna feeding on litter bore through the sealing crust which controls infiltration rates.

CONCLUSIONS

The basic problem centres on stopping the extension of desertification in a zone bordering the Sahel, whilst maintaining a dense population which depends on subsistence agriculture and the money sent by migrants. There is no work for them in towns. There are several stages of evolution in desertification and these include degradation of the tree cover and the herbaceous strata, thus producing bare areas; depletion of fine particles and nutrients and removal of soil humic horizons; increase of runoff on the glacis and gullying and degradation of the valley bottoms; and an increase in the aridity of the soil, the microclimate and the local climate.

Potential conservation strategies

During the period 1960-1965, the Forest Administration and the Gerès introduced land reclamation measures on an area of over 200 000 ha with the help of considerable financial and technical assistance. These measures included 35 000 km of diversion ditches situated at the top of glacis and absorption ditches situated downstream in cultivated areas; the development of natural spillways with low laterite walls; and the construction of 24 earth dams and numerous small crescent-shaped earth dikes in order to retain the runoff water for herds from neighbouring pasture lands and to protect the most heavily cultivated lowlands. This project, which was interesting from a technical point of view, failed because it did not take into account the socio-economic aspects of the problem. The local people were not consulted and continued working in the same way without taking account of the recommended conservation system. Moreover, they were not provided with the ploughs necessary to maintain it. From 1965 to 1972, soil conservation projects were viewed as part of the overall strategy of regional development. Since 1972, many improvements have been made under the auspices of the Fund for Regional Development by involving groups of peasants in the decision-making, in the construction of the diversion dikes and in their maintenance. However, these types of development have been extremely limited in extent when compared to the scope of the problem (only 18 000 ha have been developed in 7 years). There is therefore a need to make use of the traditional techniques of soil conservation.

Taking into account the results of field observations as well as the results given in this paper, a series of simple strategies intended to improve the total production of the agro-sylvo-pastoral system in both the short and long term by gradually reducing the water and nutrient losses may be proposed. These strategies are as follows:

(a) Base the land use planning on local conditions and employ only simple measures which require minimal outside assistance and which are consistent with the isolated fields, the slope and the basin. Favour numerous low (20-40 cm high) structures at a spacing of 10-25 m which are constructed of grass and laterite blocks and encroach slightly on the arable land. These structures should be permeable in order to trap part of the runoff and its associated sediment and to assist with the reconstitution of the humic horizons. Systematic development of the valley bottoms using low walls and grass strips should be undertaken.

(b) Improve the soil productivity through the following agricultural techniques: maximum return of organic matter to the soil surface or at a shallow depth, minimum mineral fertilization intended only to offset the main soil deficiencies, use of high-quality stock seed suited to the drought risks and unproductive soils, crop rotation in both space and time, intercropping, and limited soil tilling to avoid deterioration of soil structure.

(c) Closely link stock breeding, arboriculture and agriculture. Trees planted in fields and pasture lands (every 20-30 m in rows on antierosive structures) will produce wood, fruit and fodder, retain soil fertility and contribute to a favourable microclimate. Collective forests have not proved successful.

Although traditional techniques are not a universal remedy, if developed and improved they provide a means of involving the local population in soil conservation whilst at the same time improving their level of subsistence.

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