A Study on Conservation of Millet Fields in the Southwestern Niger, West Africa

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Abstract: To study basic functions of land conservation techniques, an on-farm observation was conducted at a moderately sloped pearl millet field in the southwestern part of Niger, West Africa, during the rainy seasons of 1998 through 2000. Water balance elements and plant growth were observed. Application of crop residue before the onset of the season proved very effective in reducing surface runoff rate by attracting soil dwelling termites which break soil crust and create vertical macro-pores in the soil. Permeable stone lines contributed to braking the speed of runoffs and decreased runoff at a constant rate. High spatial variability of permeability was observed even within a same slope. The middle to upper slope showed a lower infiltration rate, as a result of erosion history, compared to the higher infiltration rate at down slope with sand accumulation. The water harvesting effect of contour soil bunds provided soil moisture condition excessive for millet growth and probably of nutrient leaching due to poor water-holding and nutrient-holding capacity of sandy soil. The bunds were more effective in stopping surface runoff and conserving coarse sands on the surface. In a long-term, improvement of infiltration in the low infiltration surface may be brought by accumulation of coarse sand, which prevent development of hard crust.
Keywords: sahel, termite, millet, contour bunds, runoff, water balance

1 Introduction

Niger in the West African Sahel relies much of its food production on rain-fed pearl millet cultivation (*Pennisetum glaucum (L.) R. Br.*) which is still carried out in an extensive style. A great increase in population in the last 40 years caused expansion of farm land to marginal area and over-use of existing farm land. Due to erosion and nutrition deficiency, productivity of millet per unit area is declining. There have been efforts to establish simple and cost-effective techniques to raise and sustain productivity of millet fields. Examples of common conservation techniques for millet production are contour stone lines and mulching. However, working mechanisms of these techniques have not been well described until now. This includes basic principles for determining intervals of stone lines, degree of water harvesting, and prospects of conservation. Therefore this study aimed to clarify functions of conservation works or techniques on a sloped pearl millet field, which would lead to better understanding of prospects of conservation by farmers. A Study on site was carried out from 1998 to 2000.

2 Materials and methods

2.1 Situation of the study site

The study was conducted in the experimental farm of Japan Green Resources Corporation in Magou village in the canton of Torodi, situated about 60km southwest of Niamey, the capital of Niger, West Africa (13° 6′ North, 1° 44′ East, Fig. 1). The climate is Sudano-Sahelian according to Sivakumar

(1989). Rainy season generally lasts 3 months and a half from mid-June to the end of September with the average rainfall of 566.8mm (1961—1990, Sivakumar *et al.*; 1993).

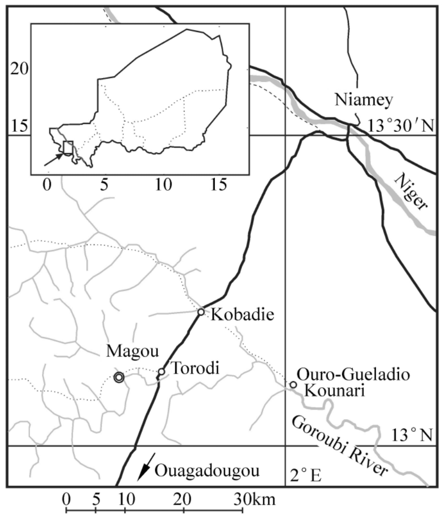

Fig.1 Situation of the study site

2.2 Design of the test field

As shown in Fig. 2, a test field was created on a moderate slope (2.8%,) formerly a millet field. It was divided into 5 blocks, 20m in width and 60m in slope length. In these blocks, contour soil bunds were created at different intervals so that water harvested at bunds would be of different quantity. Bunds were created using the topsoil in location, wetted and tapped for consolidation. They were 30cm in height and 60cm in width when freshly made, and after one rainy season, they became about 20cm high. On the bottom of the field, four runoff plots were created to quantify surface runoff. Four different treatments were set up where;

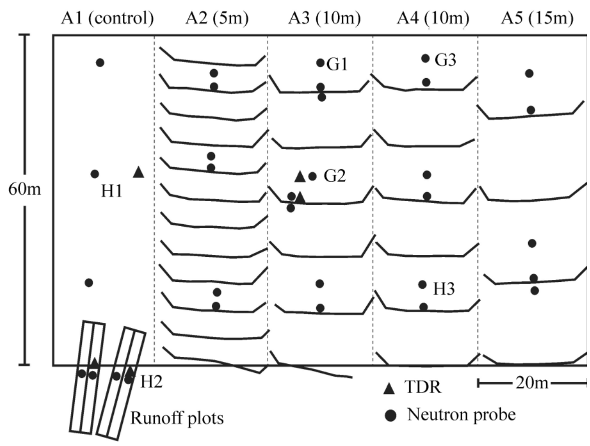

Fig.2 Design of the test field

MM: Millet cultivation with manure application (mulching added in 1999),
M : Millet cultivation with no inputs,
B : Bare plot,
BS: Bare plot with Stone Lines as tied ridges.

Before the onset of rainy season each year, farmland manure, consisting of cattle dung and crop residue, was applied at a rate of 1.5t • ha^{-1}. Phosphate was also applied at a rate of 40kg P_2O_5 ha^{-1} before the onset of the season. All field including runoff plots received weeding tillage twice. Nitrogen was applied as urine after each tillage at a rate of 20kg • N • ha^{-1}. The quantity of fertilizer application followed recommendation of ICRISAT for the region and it was considered enough to correct the spatial variability of fertility in the field. Cultivated millet variety was ICMV89305, an improved variety adopted to 450mm—800mm of rainfall with growing period of 90—105 days. Grown intensity was 10,000 pockets per hectare.

2.3 Measurements

Soil moisture was monitored at three points in the field using TDRs. As shown in Fig.33, neutron probe access tubes were placed in different blocks in the field to assess spatial variability of the soil water regime. Measurements were carried out every two weeks. Depths of access tubes were 2m and measurements were made at 15cm intervals down to 1.8m. A Bowen ratio method was employed to measure evapotranspiration in the field. A Tension Disk Infiltrometer with a disk diameter of 20cm was used to measure changes of soil surface hydraulic conductivity due to crust formation and treatments. Height and leaf area index of millet were measured.

3 Result and discussion

3.1 Soil property

Millet is cultivated on the sandy soil accumulated in the lower valley. It is generally very sandy acidic soil. Table 1 shows the soil profile at two different points in the test field, G2 and H1 marked in Fig.2. Figure 3 shows soil texture in these profiles . There were a distinct argilic horizon and impermeable plinthite layer observed in the profile at G2. The deeper in the profile, more dense and less permeable it was. At H2, it was more sandy and permeable in all horizons. The hydraulic conductivity near the surface was high in both profiles, however formation of crust greatly reduced infiltration. Water-holding capacity was low in all horizons. At 0.1 Bar, volumetric water content was around 0.15. Clay mineral in this soil was Kaolinite. Because of the low clay and organic matter content near surface, nutrient holding capacity was very limited. The soil in the test field was *Isohyberthermic Psammentic Paleustalf* on the USDA classification.

Table 1 Soil profile of the two points (G2 and H1) in the test field

	Depth cm	Bulk density g • cm^{-3}	Sat. conductivity cm • s^{-1}	Features
G2	0—21	1.62	1.73×10^{-3}	Top soil. sandy, loose, yellowish.
	21—34	1.58	2.04×10^{-3}	Sandy, not distinctive from top soil.
	34—52	1.61	7.06×10^{-4}	Argilic horizon.
	52—79	1.61	1.34×10^{-3}	Hard when dry. Reddish.
	79—102	1.64	6.92×10^{-4}	More clayey Yellowish.
	102—135	1.72	1.03×10^{-5}	Very clayey, iron stone gravels mixed.
	135—	1.78	7.42×10^{-6}	Slightly reduced. close to Plinthite.
H1	0—10	1.56	3.54×10^{-3}	Top soil. sandy, loose, yellowish.
	10—42	1.49	3.39×10^{-3}	Sandy, loose and soft when dry.
	42—67	1.58	1.61×10^{-3}	Transition to reddish color.
	67—92	1.71	4.69×10^{-4}	Argilic horizon.
	92—125	1.72	1.70×10^{-4}	Reddish, hard when dry.
	125—	1.67	2.75×10^{-4}	More reddish than the upper layer.

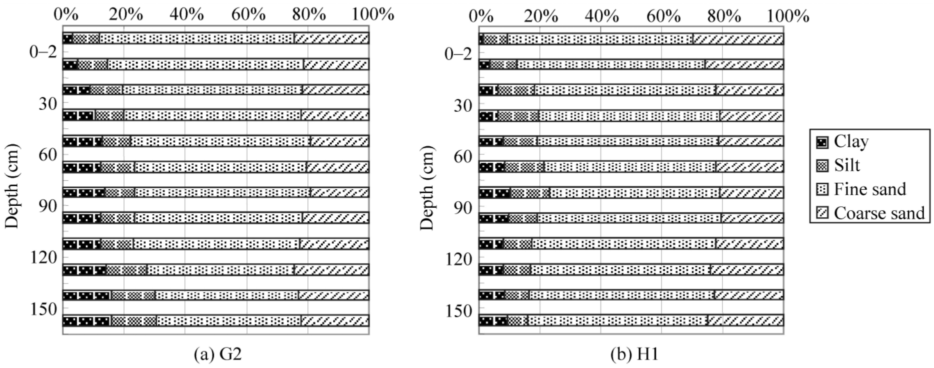

Fig.3 Soil texture profiles of G2 and H1 in Fig. 2

3.2 Surface runoff characteristics

(1) General trend

In Fig. 4, cumulative runoffs are plotted against cumulative P_r , where P_r is defined as rainfall depth of the event which caused any runoff in either one of the four plots. Phenomena which are apparent from the figure are; i) a lower runoff rate (runoff / P_r) in the **MM** in the beginning, compared to the **M** or the **B**, until the first weeding tillage, ii) nearly the same runoff rates in the **M** and the **B**, until after the first weeding tillage, iii) a decrease of runoff rates for all plots after the weeding tillage, iv) a lower runoff rate in the **BS** compared to the **B**.

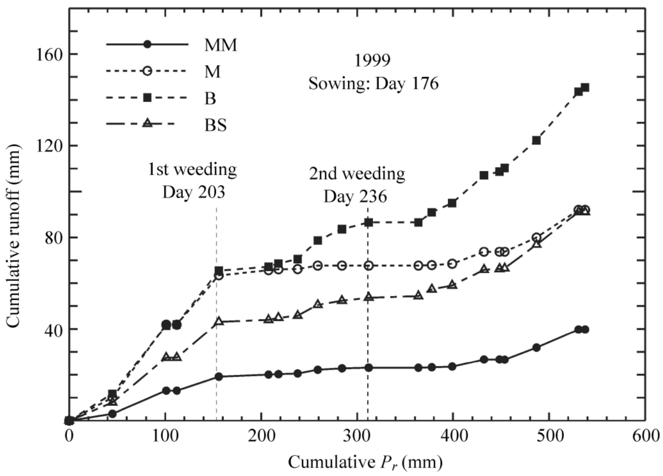

Fig.4 Cumulative runoff against cumulative P_r in 1999

(2) Effect of manure and mulch application

The lower runoff rate in the **MM** in the beginning of the season was a result of soil-dwelling termites' activities. When manure was applied before the onset of the season, termites were attracted to the crop residue in the manure and they came up to the surface from their nest, a few meters underground, to ingest cellulose. In their course of coming up and going back to the nest, the soil crust, which developed on the surface, was destroyed and vertical pores were created in the soil profile. This greatly increased water infiltration in the beginning of the season. This phenomenon had been observed by Mando (1997, 1998) in a series of studies in Northern Burkina Faso. Mulching is expected to bring the same effect. It can also contribute to increasing surface roughness, which slows surface runoff and enhances infiltration. This enhancement of infiltration in the **MM** diminished after the first weeding tillage due to disturbance of the top soil.

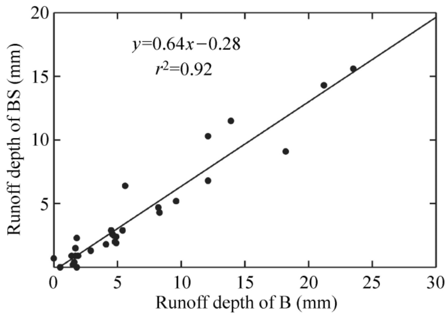

Fig.5 Correlation of runoff depths between the B and the BS for each runoff event.

(3) Effect of millet growth

The same runoff rates of the **M** and the **B** in the beginning of the season confirmed that, until a certain growth stage, millet field without any input could be assumed as a bare field. The difference became significant, a few rainstorms after the first weeding tillage onward. It was 38 days after sowing and the Leaf Area Indices at that moment (total leaf area of a plant / unit cultivated area [$m^2 \bullet m^{-2}$]) was 0.2–0.3. This was when millets were tillering fast after thinning and LAI was increasing rapidly. Hydraulic conductivity measured in between rows of plants in the **MM** and in the **B**, showed no significant difference. Therefore the reduction in runoff may be attributed to interceptions of rain by plants, or to partially high conductivity of soil under the plant. It means that conservation of soil water is more important in the beginning of the season when soil is close to bare.

(4) Effect of tillage

The change in the runoff rate of the **B** reflected the sole effect of weeding tillage. Break-down of soil crust largely increased infiltration. However, crust redeveloped after a few rainfall events.

(5) Effect of the stone line

The **BS** showed lower runoff rate than the **B** and yet the trend of the change was very similar. Figure 5 shows the correlation of runoff depths between the **B** and the **BS** for each runoff event. A good linear relation was obtained and the regression line passed near (0,0), which confirmed that stone lines do not stop runoff but rather break the speed of the flow and enhance infiltration.

(6) Soil erosion

Soil erosion was generally more severe in the beginning of the season. It was because of the coarse fraction outcropping loose on the surface as a result of structural crust formation (van der Watt and Valentin, 1992) in the former season. Therefore it could easily be washed off by runoffs at the beginning of the following season when the soil surface was dry. After the weeding tillage, the same phenomena took place, but the soil surface was wetter and more coherent, which kept erosion at a low level. The total amount of erosion in the plots was not of a severe degree because the runoff path was limited to 20m and the flow speed did not rise as highly as to cause a turbulent flow. Therefore the main function of conservation works like stone lines seems to be breaking the speed to prevent soil erosion.

3.3 Water-harvesting effect at the bund

Figure 6 shows soil moisture profile around the bund in the early growth stage. If soil moisture profile between bunds (5m away from the bund) is considered as a control, on the upper side of the bund, infiltration increased much due to water-harvesting effect. On the lower side, soil moisture slightly increased, possibly due to the lateral movement of infiltrated water from the upper side of the bund. Growth of millet however, was very poor on the upper side. It was probably because the soil was too wet for millet growth and because of leaching of nutrients with excess water drainage. On the lower side of the bund, millet growth was generally enhanced. These good and bad growths traded off so that no substantial growth enhancement was achieved by water-harvesting effect of the bund, and changing intervals of the bunds showed no trend in productivity. For making an efficient use of harvested water on the upper side, planting millet is not appropriate. Planting trees or shrubs with deep rooting depth would seem more effective.

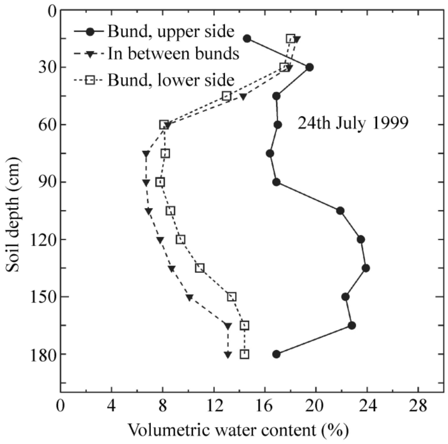

Fig.6 Soil moisture profile around the bund

3.4 Spatial variability of surface permeability

Figure 7 shows surface permeability measured at different points in the field (shown in Fig.2.) The measured points are in between the bunds so that their effects would be minimal. At the time of measurement, crust was fully developed. Final infiltration rate of the crusted surface was 28%—40% to that of the underlying soil. Although the clay content of the soil surface was generally very low, its content and infiltration rate seemed to correlate. The less clayey the surface soil, the more permeable it was. Though it is not shown here, the hardness of soil surface also reflected infiltration rate well. Low infiltration was observed at points situated upper to middle=slope of the field and high infiltration was observed at points on the lower end. At the high infiltration points, coarse and loose sand layer on the surface was observed. At the upper andmiddle points, this layer was absent because of erosion history before the test field was set up. This spatial variability of surface permeability was well reflected on soil water regimes. Figure 8 shows the soil moisture change of the 6 points chosen in Fig. 7. In 1998, rainfall was a little less than the average in quantity and regular in distribution. In the upper 0cm—60cm layer, there was no recognizable difference in water storage between the high and low infiltration points. However, difference was apparent in the 60cm—120cm layer. It was because the water retention capacity of the soil was low that the infiltrated water descended to the deeper layer even in an early growth stage. Weeding tillage also enhanced this by increasing infiltration and by decreasing upward water movement due to evaporation. Therefore merely increasing infiltration quantity by water-harvesting techniques for this kind of soil may result in enhancing loss of nutrients from the root zone with draining water.

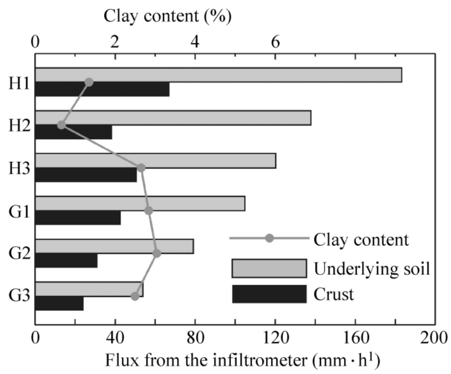

Fig.7 Final infiltration rate measured by TDI (at-294Pa) and clay content at different points in the field, shown in Fig.2

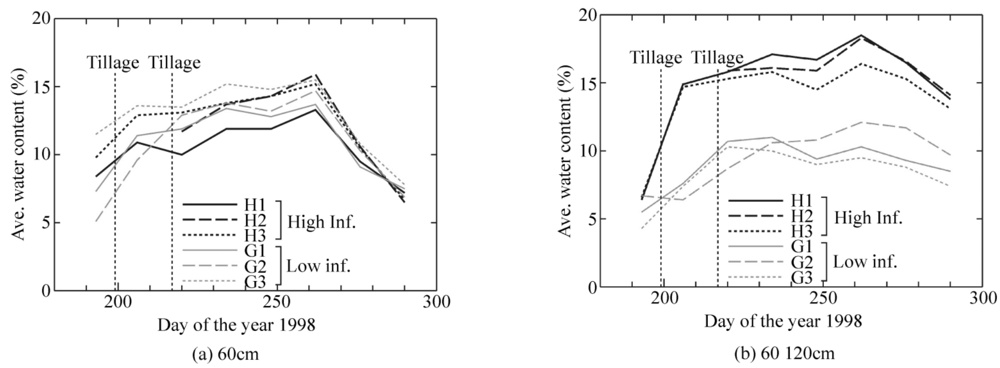

Fig.8 Soil moisture change in different points in the test field (shown in Fig.2)

3.5 Growth of millet in relation to water availability

From a viewpoint of soil water availability, high infiltration surface seems preferable for millet cultivation. However in high rainfall years, wet front progresses too fast and subsequent leaching of nutrients can actually bring down growth of millet. Figure 9 shows inferior growth of millet in high infiltration points in 1999. That year, abundant rainfall at the onset of the season and towards the flowering period resulted in the seasonal rainfall of 686.3mm, which exceeded the average by more than 100mm. In this condition, millet growth in low infiltration surface was less affected. Less infiltration and better nutrient holding of soil profile due to more clay content have probably contributed. In this study, millet growth was good in low infiltration points in years of average or slightly less rainfall, too. It was because infiltration at the beginning of the season was improved by termite activity and bunds decreased surface runoff and consequent formation of harder crust on the surface.

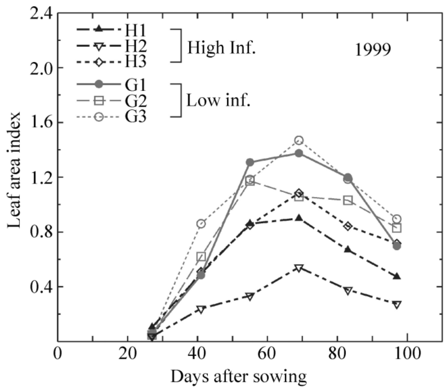

Fig.9 Leaf area index change of millet in different points in the field

4 Discussion

4.1 Effect of constructing contour bunds in the studied region

In the study, soil contour bund showed no growth-enhancement effect by water-harvesting. This was firstly because millet was not suited for cultivation under a very wet soil condition and secondly due to poor water-holding and nutrient-holding capacities of the soil. Seasonal evapotranspiration measured by the Bowen ratio method in the field was around 390mm, in a regular year without any dry spell. Therefore, if rainfall is to infiltrate without too much loss by surface runoff, average rainfall of 550mm seems quite enough and additional water-harvesting seems unnecessary. As stated in section 3.4, conservation of coarse sand fraction on the surface can enhance infiltration by preventing development of hard crust. Therefore the main function of contour bunds in this region seems to be prevention of generation of large-scale surface runoff for soil conservation. If generation of surface runoff is kept at a low level, permeability of previously eroded surface can be regained. Application of manures or mulching can greatly contribute to this as it decreases surface generation at the onset of the season. As shown in Fig. 10, if trees are to be planted by the bund, deeply infiltrated water can be recycled and falling leaves can, in turn, attract termites again to improve infiltration.

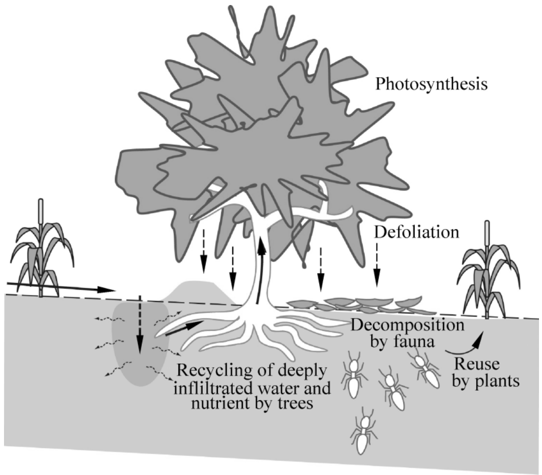

Fig.10 Ideal image of land conservation utilizing activities of flora and fauna

4.2 Optimum material and interval for the contour bund

For suppressing runoff speed, permeable contour stone line proved sufficient. Releasing excess water downstream seems more efficient than stopping runoff completely by soil bund. Unless availability of stones is limited, soil bund is not recommended, for it requires a lot of maintenance.

From section 3.2.6, optimal interval for contour bunds can be assumed as maximum distance, within which surface runoff would not turn to a turbulent flow with a greater erosive force. This threshold value depends on inclination, surface roughness, and topography. Although it is case by case and difficult to calculate, careful observation of the distance between the origin of runoff and points of rill erosion should help determine intervals at practice.

4.3 Surface permeability and management options

The test revealed large spatial variability of infiltration within the same slope. Farmers in the study area actually distinguish soil surface condition largely by two names, which are *Hondou* and *Gangani* in the local language. Hondou means sandy soft surface and Gangani means clayey, hard, and eroded surface. Millet is usually cultivated on Hondou because Gangani has limited infiltration. This study revealed high production potential of Gangani under improved infiltration. Though Hondou has good infiltration, a risk of nutrient leaching and subsequent low growth of millet in years of excessive rainfall was also shown. Therefore different strategy of conservation should be applied to these surfaces. For Gangani, emphasis should be put on improving infiltration. For Hondou, fertility management should be more focused. If these two surfaces are cultivated in combination, risk of low harvest in both dry and wet years can be reduced.

Acknowledgements

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