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Improvement of cultivated slopes in sudano-sahelian areas thanks to permeable microdam systems. An existing need to improve setting up and cropping conditions.

Aménagement des pentes cultivées soudano-sahéliennes grâce à des réseaux de microbarrages isohypses et filtrants. Nécessité d'une amélioration de leurs conditions de mise en oeuvre.

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"Improvement of cultivated slopes in sudano-sahelian areas, thanks to permeable microdam systems.
An existing need to improve setting-up and cropping conditions".

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In the province of Yatenga, situated in the North-West of Burkina-Faso, cultivated fields are often located at the base of impermeable uplands. On one hand runoff constitutes an adding water resource concerning the millet fields and on the other hand an erosive factor. If there is neither impluvium nor coming running water, one must improve rain infiltration in order to reduce the effect of pluviosity shortage and to complete the water balance.

Increasing upperlayer's porousness and roughness with ploughing may be a factor of soil erodibility raising and does not suit with socio-economic conditions of small farms. Setting up permeable microdam systems in fields may be considered as a solution, but interdisciplinary studies have recently pointed out some limitations in their efficiency. In order to avoid this, one must take into account the setting-up and cropping conditions :

- conditions due to hydrological patterns of cultivated fields. They impose some particular techniques to set-up microdam systems. They require a short topographical pitch for the definition of contour lines, a compartmentalization, and an improvement of porousness and roughness conditions. An adaptation of the system pattern to soil water reserve must be done.
- conditions linked to cropping fields development. They require adding weed control and fertilization.
- socio-economic conditions for the setting-up of microdam systems. These result in land status clearing and in an increased force during the dry season.

"Les aménagements des pentes cultivées soudano-sahéliennes au moyen de réseaux de micro-barrages isohypses et filtrants. Nécessité d'une amélioration des conditions de mise en oeuvre."

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Dans la province du Yatenga, au Nord-Ouest du Burkina-Faso, les terrains de culture sont fréquemment surmontés d'impluviums peu perméables. Le ruissellement des eaux de pluies constitue alors une ressource d'appoint en eau pour la culture mais aussi un facteur d'érosion. En l'absence de ces ruissellements entrants, il est nécessaire d'améliorer l'infiltration des pluies pour compenser les effets de la réduction pluviométrique sur le bilan hydrique des cultures.

La solution du travail du sol est intéressante mais rend le sol plus sensible aux érosions et n'est pas toujours compatible avec les contraintes socio-économiques des petites exploitations. La constitution de réseaux d'obstacles filtrants dans les champs peut être considérée comme une bonne solution mais il apparaît à l'étude un certain nombre de conditions de mise en oeuvre pour que l'aménagement ait les fonctions attendues :

- conditions liées au fonctionnement hydrologique des pentes aménagées qui imposent des règles de constructions particulières : pas topographique court et cloisonnement latéral, adaptation du modèle d'aménagement à la réserve en eau et aux capacités de drainage, création d'un état de surface favorable au régime du ruissellement (poreux et rugueux).
- des conditions liées au fonctionnement du champ aménagé qui imposent une adaptation des systèmes de culture, en particulier l'intensification de l'entretien de l'état de surface, l'amélioration de la maîtrise de l'enherbement et de la fertilité chimique.
- des conditions socio-économiques de l'aménagement lui-même, à savoir la clarification du statut de la terre à moyen terme et l'accroissement de la force en travail en saison sèche.

Le présent document porte spécialement sur les conditions du fonctionnement hydraulique d'un champ aménagé.

The original paper is written in French. This paper summarizes its main results and conclusions.

Actual sudano-sahelian climatic conditions, influence of the lack of vegetation, tillage and cattle practices involve surface crusting and soil and water losses in Yatenga (province of Burkina Faso, figure 1). It occurs particularly at the bottom of degraded and impervious uplands. This erosion crust impedes infiltration and fosters self accelerating erosion processes. In response to drought, farmers do not give up traditional varieties and practices. They try to increase cultivated areas and add microcatchments and ploughing to usual cropping systems. Against erosion they set up stone lines in the running water ways... But ploughing increases soil losses risks and traditional stone lines do not lead to a global influence on waterbalance and yields.

Since 1980, development organisations have been introducing a new field structure, namely *microdam systems at contour.* Microdams are stone lines or *Andropogon gayanus* closed hedges or wood and straw fascines. These structures are now adopted on a large scale by farmers in Yatenga but also in the Ader Dutchi region in Niger.

An on-farm research has been carried out for five years in Yatenga by ORSTOM and Burkina partners in order to study the evolution of farming systems in sudano-sahelian conditions. A trial under scientist's management has been set up in a farmer field in 1985. Its aims were multiple. First, increasing the knowledge on determinism of runoff and erosion at field scale. Secondly, estimating advantages, shortcomings and directions for use of adding microdam systems, microcatchment and ploughing to traditional cropping systems.

MATERIAL AND METHODS (cf. figure 2)

Three plots of 150 meters long are set up, including a control plot. The upper 50 ms consist of an uncultivated microcatchment with three main types of surfaces :
- erosion crust,
- pavement crust,
- sandy micromounds.

The lower 100 meters are cultivated. They collect running water from the upper part.

Plots are equiped with two runoff recorders and a sediment trap, 8 sites for neutronic soil moisture measurment and numerous sites for vegetation evaluation. These plots were all cultivated with a local millet variety, along the same usual "bush fields cropping system" : 10 years of millet cropping followed by 5 years of fallow ; direct seeding in seed holes, two mound-hoeings and very light NPK fertilising ; no organic manure.

The stoneline system installed on plot B ("harnessed plot") is made of ferrugineous cuirass blocks (40 kg/m) ; stonelines are 20 cm high and 40 cm wide. The lines are 20 m spaced (mean slope : 2,5 %). The plot C is like B except an additionnal ploughing. In this paper we shall only discuss results concerning plot B and control plot A.

Running water getting from microcatchments into the cropped plots is estimated by hydrodynamic formulas of ALBERGEL (1987), CASENAVE and VALENTIN (1986). Microcatchment was partly removed in august 1987.

DATA ANALYSIS AND RESULTS

On a yearly based analysis it comes out that (table 1) :
- the inflow from the upper part provides extra-water ranging between 15 to 20% of the annual rainfall,
- the physical structures are effective in reducing water and soil losses,
- they generally increase yield. The reduction found in 1988 can be ascribed to weed infestation and waterlodging due to structures themselves under very rainy conditions.

In addition data were processed on a storm-event basis. In this respect classes of storm events were arbitrarily discriminated depending upon an intensity/depth ratio (figure 3). Afterwards, we shall speak of three classes of "rainfall intensity" : standard, intense, light.

Table 1 : Yearly records of BIDI trial.

	1985				1986				
	07/10 to 10/15				06/01 to 10/15				
	P	LE	LR	Y	P	LE	LR	ET	Y
	mm	mm	mm	kg/ha	mm	mm	mm	t/ha	kg/ha
control plot	239	34	70	163	530	96	127	5,2	196
harnessed plot	242	43	58	180	528	106	124	3,4	330
différence (%)			-17	+10			-2	-36	+88

	1987					1988				
	06/01 to 10/15					04/01 to 10/15				
	P	LE	LR	ET	Y	P	LE	LR	ET	Y
	mm	mm	mm	t/ha	kg/ha	mm	mm	mm	t/ha	kg/ha
control plot	483	92	53	1,7	309	561	11	96	3,0	395
harnessed plot	484	107	42	0,6	402	561	22	52	0,9	290
différence (%)			-21	-68	+30			-46	-69	-27

P : Depth of rainfall at soil level
LE : Running water coming from microcatchment into the millet field
LR : Runoff measured in outlet of millet field
ET : Total Soil losses
Y : Yield of millet (down half of the field)

Other variables are considered:

- antecedent soil moisture as assessed with antecedent precipitation index,
- soil surface conditions, namely vegetation cover, surface roughness and porousness, as associated to surface crusting and compacting.

Limits of each class are arbitrarily determined, in order to get the better discrimination and if possible similar sizes of classes. Therefore, numerous combinations of these variables are analysed. It leads first to an analysis of runoff and soil losses determinisms. The method uses a graphic analysis and a statistical analysis on a diagramm crossing rainfall and runoff.

Graphic analysis : on a diagramm (figure 4), for each class of conditions, a "field" is clearly defined by :

- the line of runoff maxima (slope k max = maximum runoff coefficient after initial rainfall),
- the line of minima,
- the maximum initial rainfall,
- the minimum initial rainfall.

Statistical analysis : the group determined by all floods under a special environnement may undergo a regression analysis and be compared with other groups through a covariance analysis if number of events is sufficient.

DETERMINISM OF RUNOFF

Standard storms (figure 5).
Soil roughness and porousness conditions seem to be the principal factor limiting runoff coefficient but do not modify initial rain. Soil moisture is an important factor of decreasing initial rain but apparently does not modify runoff coefficient.
Millet cover does not seem to have any clear effect on runoff limitation, within each soil surface classes, except :
- in the case of surfaces propitious to runoff (smooth and humid), it increases the initial rain (from 10mm up to 15 mm),
- it increases the duration of roughness after hoeing if we compare first hoeing (growth stage) and second (fructification stage).

Intense rainfalls.
On one hand, small intense rainfalls generate the same runoff than standard storms. On the other hand intense rainfall exceeding 20mm depth produce runoff near 90% of rainfall after initial rainfall, even on a rough surface.

Light rainfalls.
They increase initial rainfall up to 50 mm, particularly on dry surfaces.

Effect of microcatchments.
The comparison between runoff before and after removal of the microcatchments points out that microcatchment produces running water which is partly soaked up in field. The part of soaked running water depends on the size of rainfall.

DETERMINISM OF EROSION

Results are similar to usual theories :(figure 6)
Small rainfalls : soil losses depend on the determiners of runoff.
High rainfalls : the relationship of soil losses and depth of rainfall follows a power fonction. It depends on intensity, conditions of millet cover and soil surface.
A bare, removed and rough surface will generate more erosion than a smooth one in case of high and intense storm.

EFFECT OF STONELINE STRUCTURES

Runoff.

There are strong interactions between the efficiency of structures and two conditions : soil surface conditions and rainfall intensity. These interactions are found significant after doing a covariance analysis on diagrams crossing square root of "runoff coefficients" as defined as :(figures 7 and 8)

$$rc = o / (p + n)$$

rc = "runoff coefficient"
o = runoff (mm)
p = depth of rainfall measured at soil level
n = running water from upper microcatchment

In very bad conditions (intense or standard rainfall on smooth and humid surfaces), the effect of structures on infiltration is significantly negative.
An other apparent interaction with depth of rainfall is found : it is due to a bias in the population of events : there are more floods on smooth surfaces after small rains than after big storms, so the effect of surface condition looks like an effect of size of storm.

Finally, hoeing induced surface enhances the beneficial effect of structures, except under intense rainfall. This effect is cancelled or even becomes negative as soon as soil is wet and capped with a smooth erosion crust, except under light rainfall.

These two results help to interpretate the variations among yearly records.

Soil losses.

Whatever soil moisture and surface conditions are, whatever rainfall intensity is, sediments from the treated plot are significantly lower than those from the control plot. However further analysis is still needed regarding sediment particle size distribution. (figure 9)

Pattern of floods at outlet.

Stonelines have the same effect than structures in a river. They reduce and delay the peak discharge. They greatly foster the deposition of biggest detached particles (figure 10).

INTERPRETATION

First, the conditions of infiltration are conditions of efficiency of structures too, since stone lines increase infiltration duration of running water. Secondly zero or negative effects of stone lines when conditions are very bad for infiltration (intense rain, smooth and humid surface), can be explanated if the scale effect is taken into account. On a large area, running water may take different patterns : regular sheet flood, confused rills or localised rills. Structures, even pervious, increase rilling, but rough surfaces splits a rilling running water, up to a confused rill flood. Splitted rilling flood should produce more infiltration than rilled flood or perfect sheetflood. This hypothesis fits with field observations, effect of compartmentalization, discovered interactions and COLLINET (1988) results.

CONCLUSION

Such a microdam system can be recommended in the sudano-sahelian zones under conditions.

First, the willing participation of farmers must be gained. Due to drought and traditional economic system, farmers of Yatenga are usually aware of land degradation and ready to fight against. Dry season is apparently the only free time to do it but it is time to practice activities for getting money (commerce, handy craft, gold washing, market gardening, migrations of work). In addition neither cutting and transport cuirass blocks, setting up 50 kg/m nor planting Andropogon during hoeing time are easy works. In some cases, some food, money or mechanical power incentives should be provided.

Secondly, it is a crucial point that the stonelines are at perfect contour,in order to avoid rilling. Experience shows that farmers can be rapidly and properly trained in that field, using a simple water level.

Once the structures are set up, it is essential to obtain an optimal distribution of water flow on surface. This distribution should neither be too much concentrated (which should increase rilling ,splash erosion and water losses) nor too much laminar (which should encourage the erosion crust development).

In this respect, mounding is a manual weeding practice which may be considered. Moreover , herringbone ridges must be set up in the flooded area near the stone lines in order to partition it and avoid flood concentrating and rilling. Very pervious soils (sandy soils) should be more valorizating for these structures than quite impervious soils (brown soils ...) except if stone lines are closer set up.

In order to reduce splash erosion and crust formation and to enhance surface roughness, weeding should be made earlier than usual and the surface should be protected by intercrops and growth accelerating technics (early fertilisation for exemple).

Finally, provided some conditions, water harvesting from degraded uplands, combined with this microdam systems improves the waterbalance security and limits soil losses.

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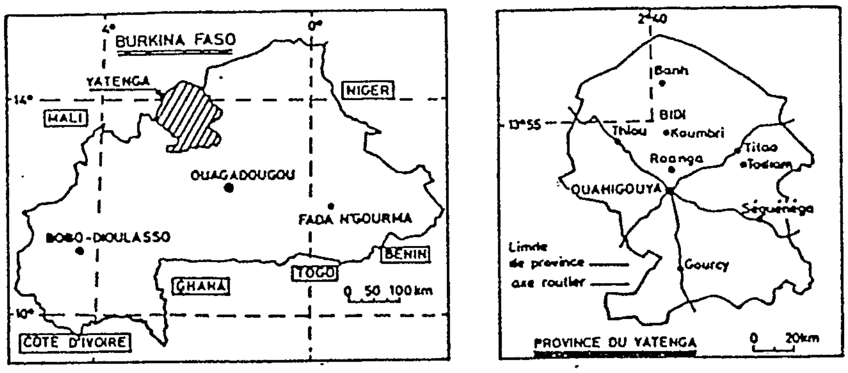


Figure 1 : Situation map.

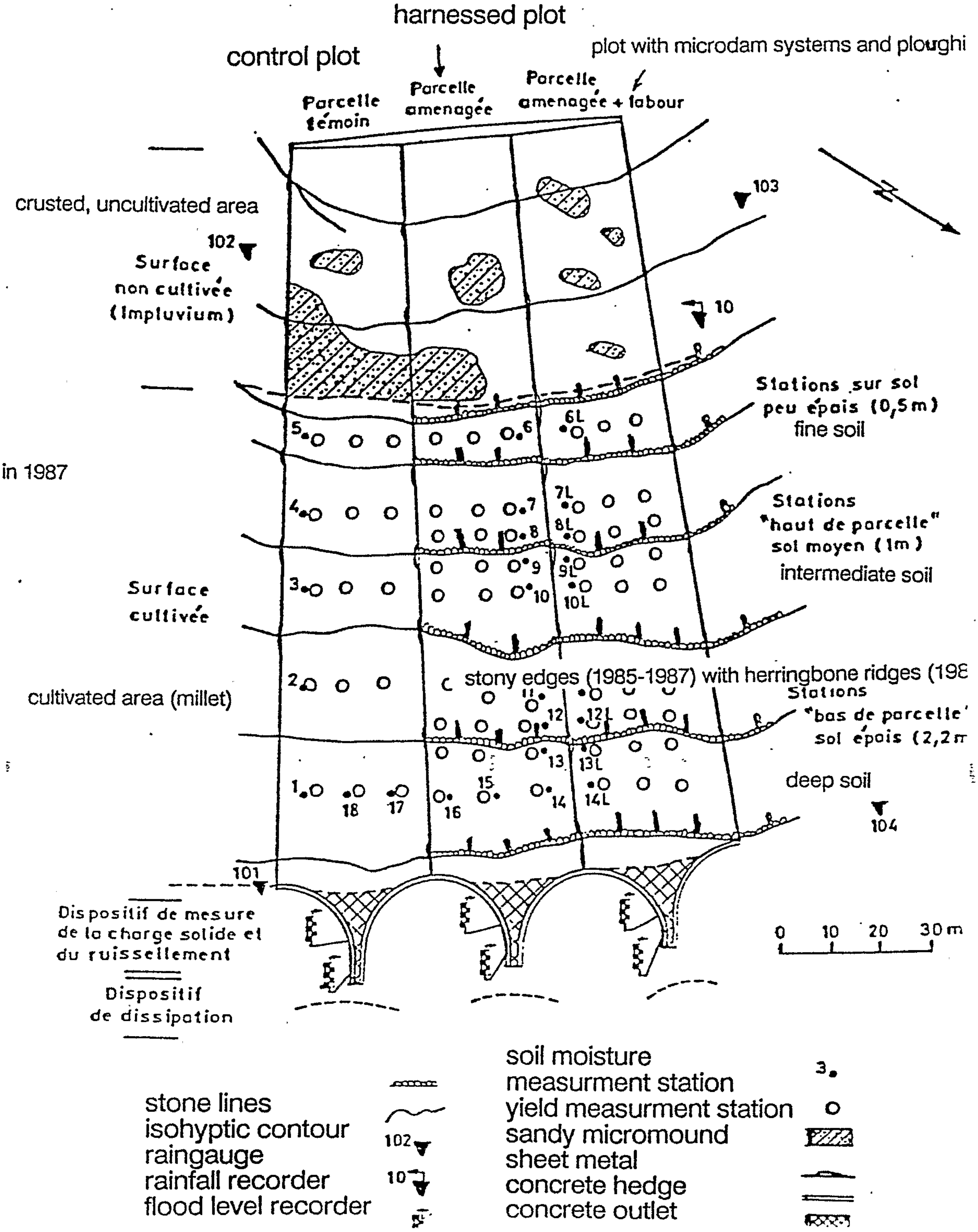


Figure n° 2 : BIDI TRIAL in 1987

Figure 3 : Relation ship of depth of rainfall and maximum rainfall intensity in 15 mn.

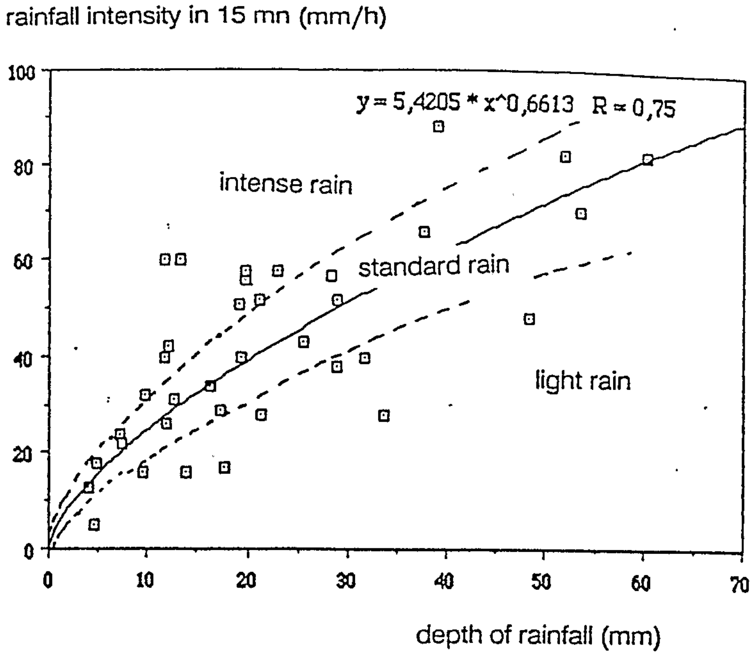


Figure 4 : Relationship of rainfall and runoff.

Graphic analysis.

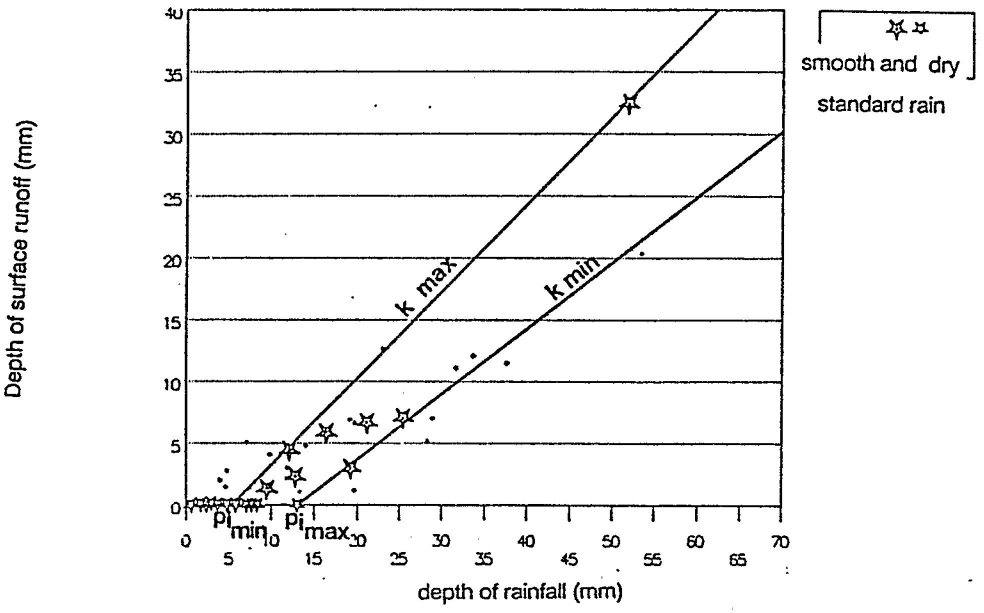


Figure 5 : Relationship of rainfall and runoff.

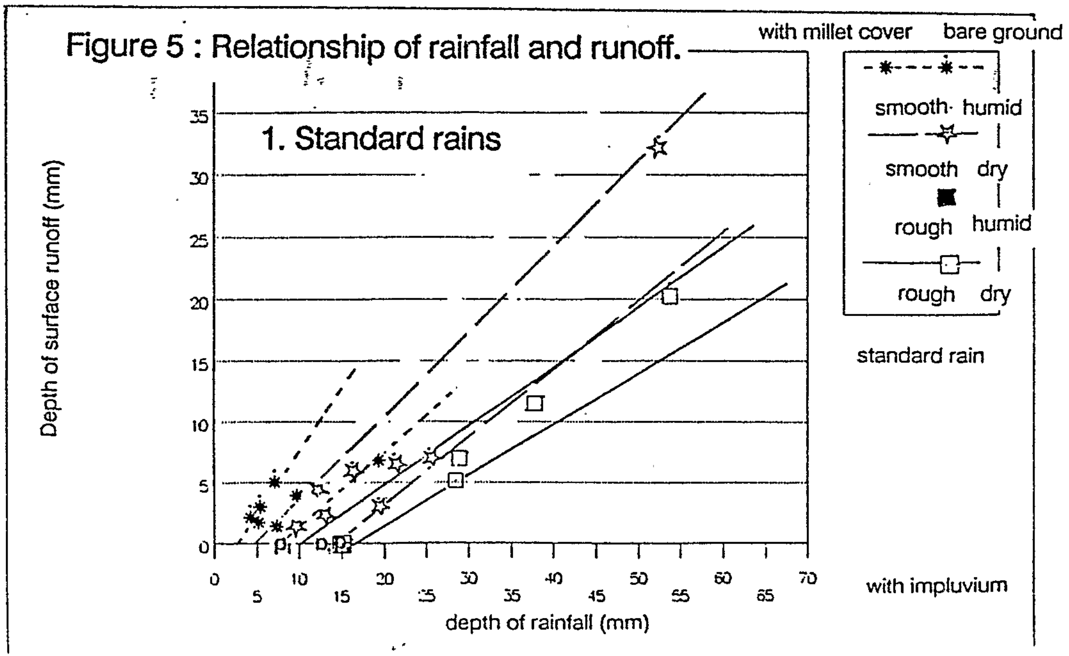
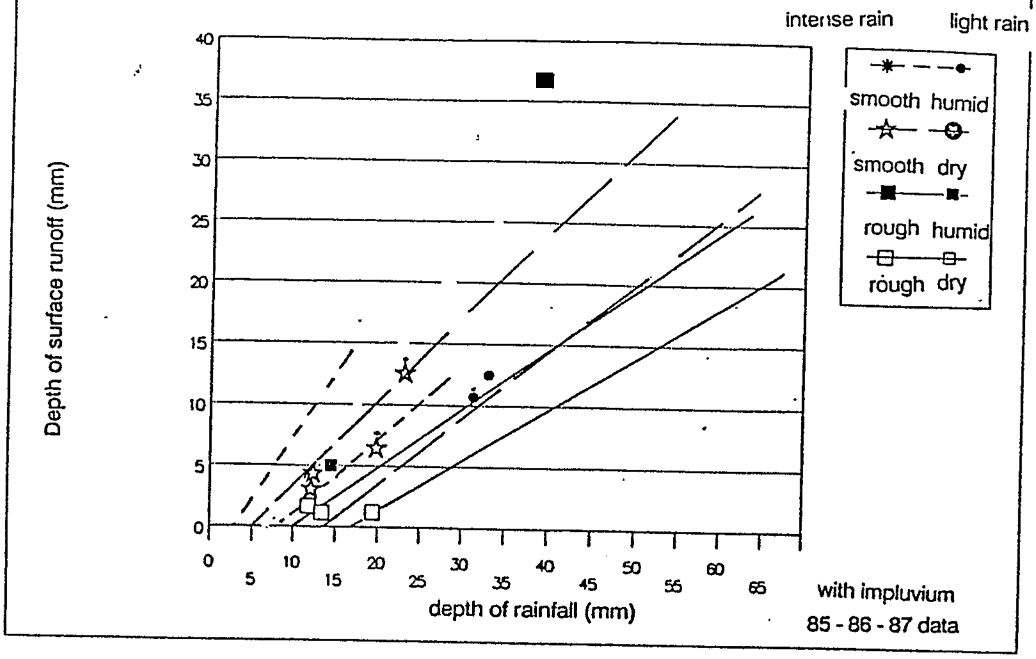


Figure 5 - 2 : Intense and light rainfall



with impluvium
85 - 86 - 87 data

Figure 6 : Relationship of rainfall and erosion.

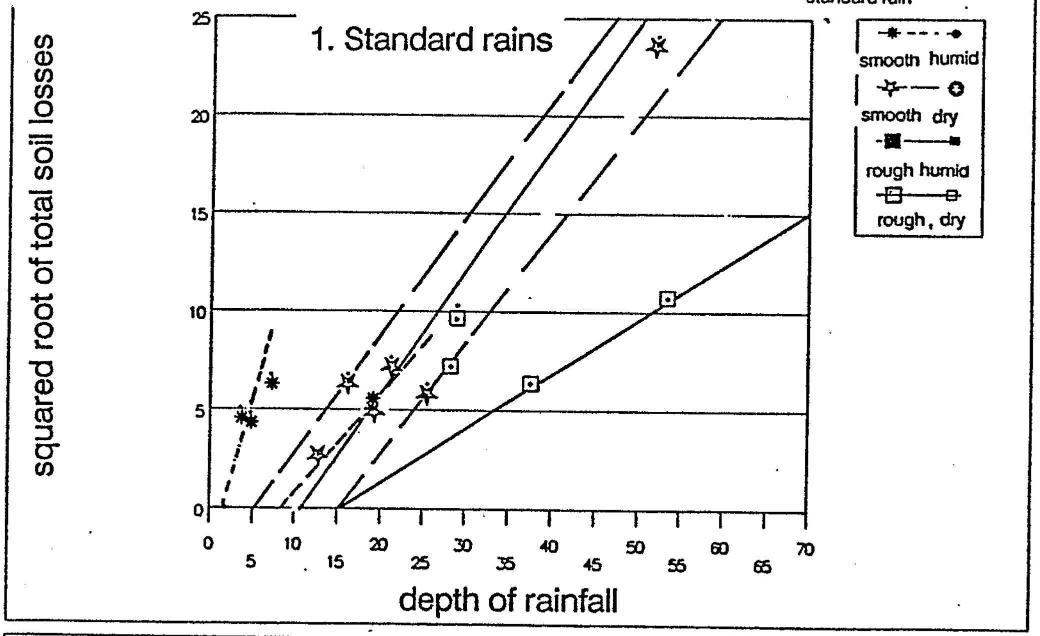
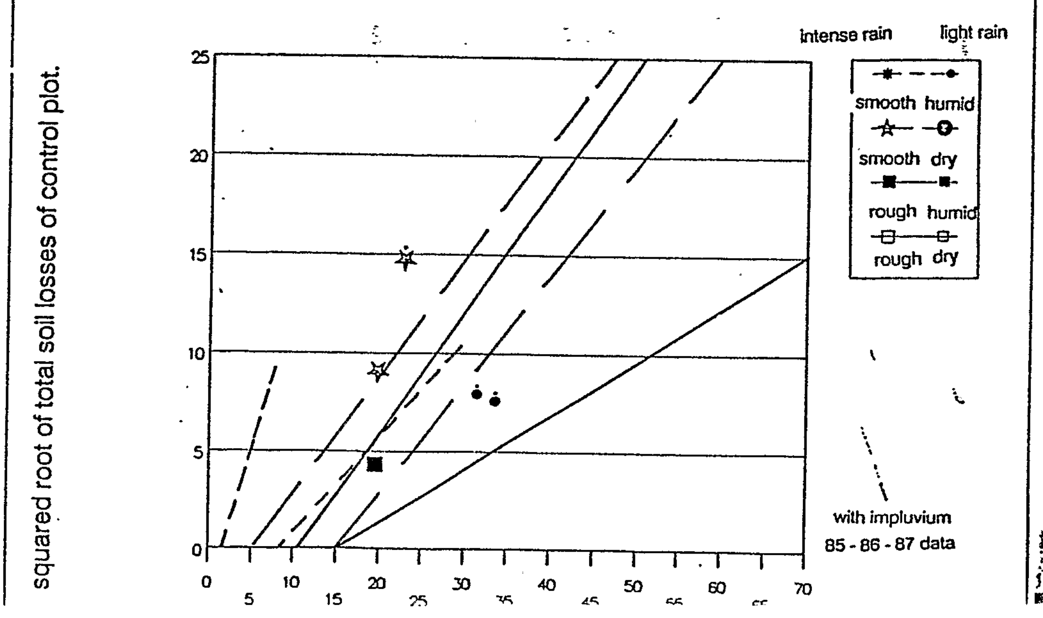


Figure 6 - 2 : Intense and light rainfall



with impluvium
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Figure 7 Comparison of runoffs between control plot and harnessed plot (all events)

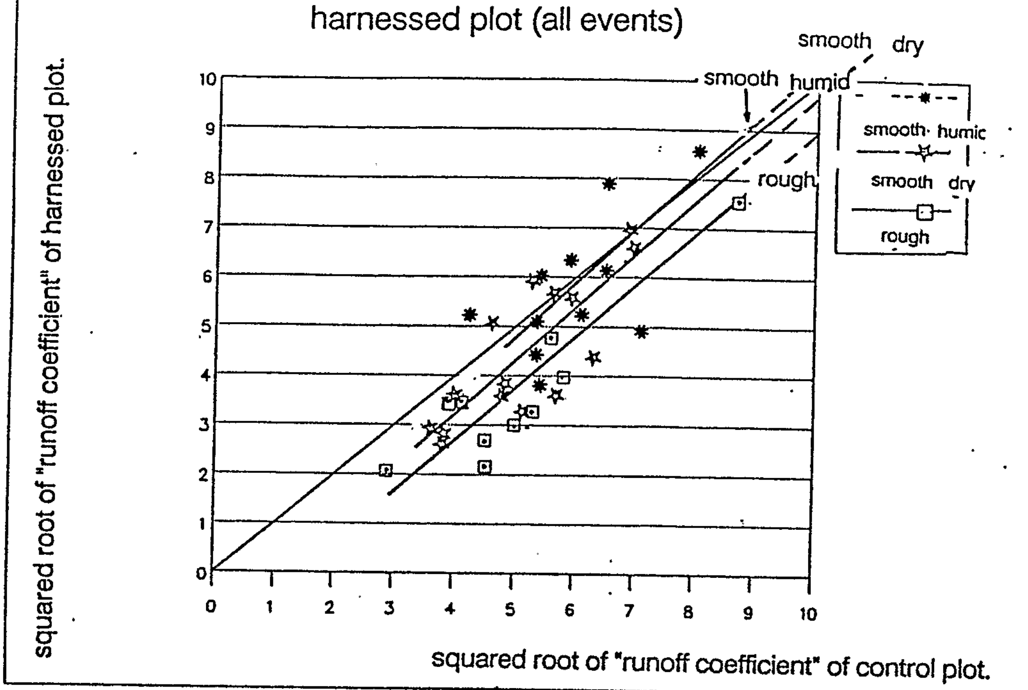


Figure 8 Comparison of runoffs between control plot and harnessed plot (intense and light storms only)

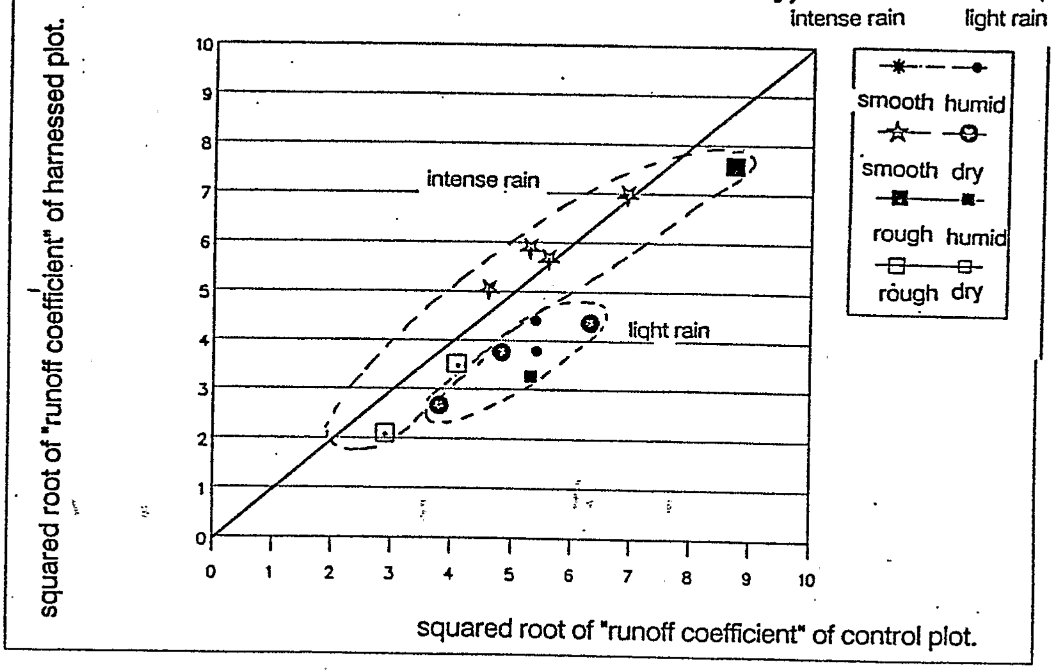
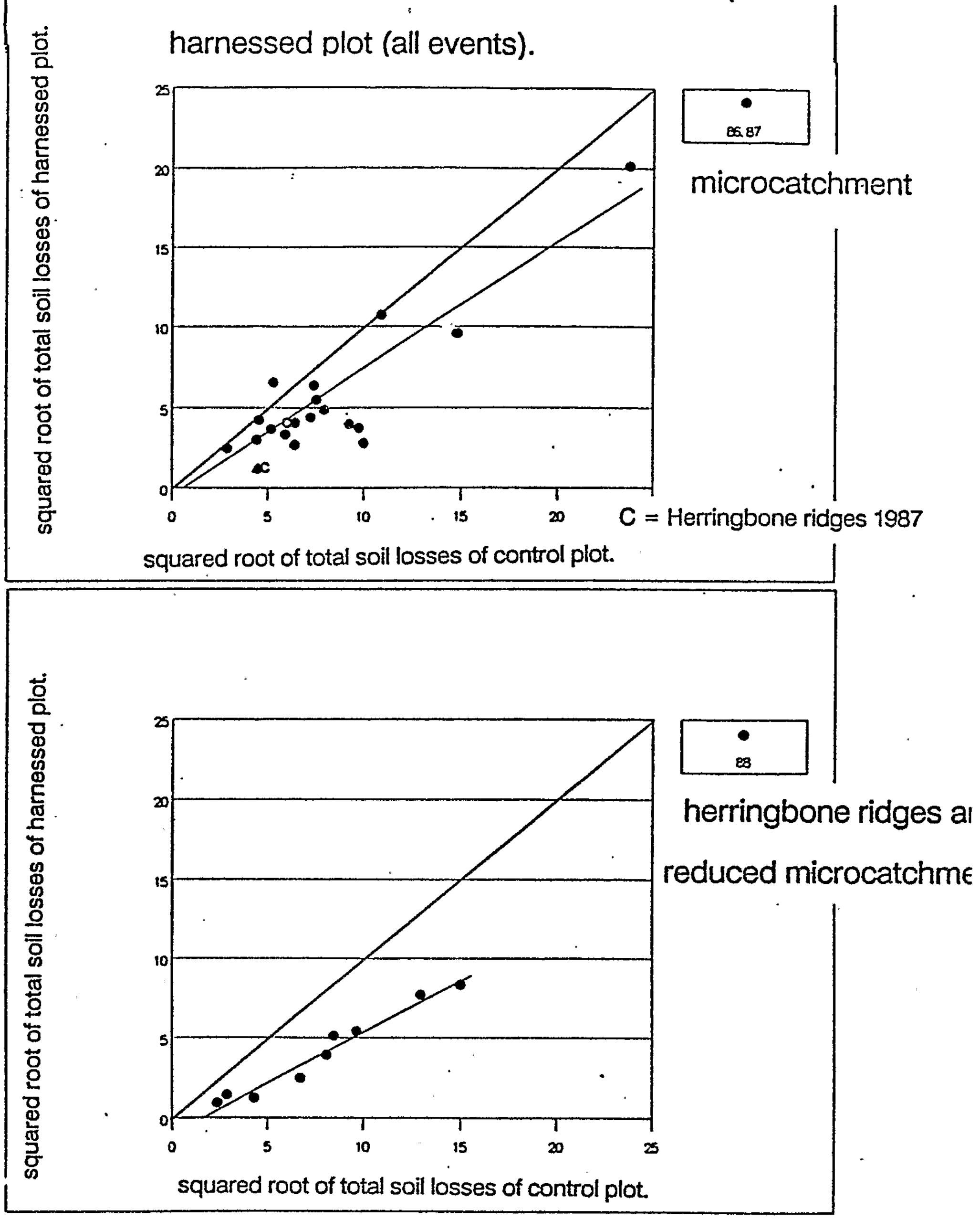


Figure 9 : Comparison of soil losses between control plot and harnessed plot (all events).



microcatchment

herringbone ridges a

reduced microcatchm

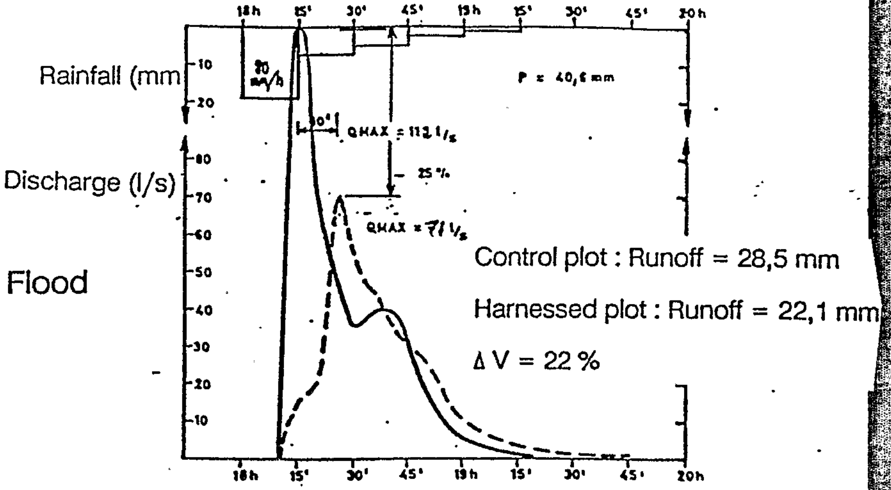


Figure 10 - 1   1/13/86 Flood

Control plot : Runoff = 28,5 mm

Harnessed plot : Runoff = 22,1 mm

Δ V = 22 %

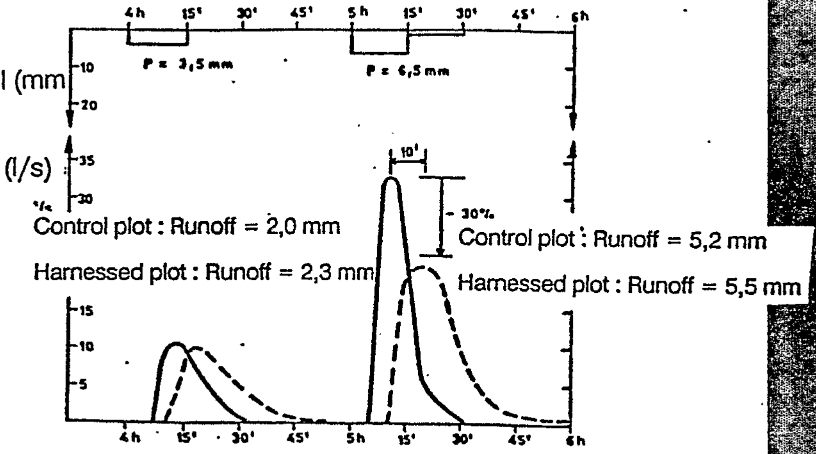


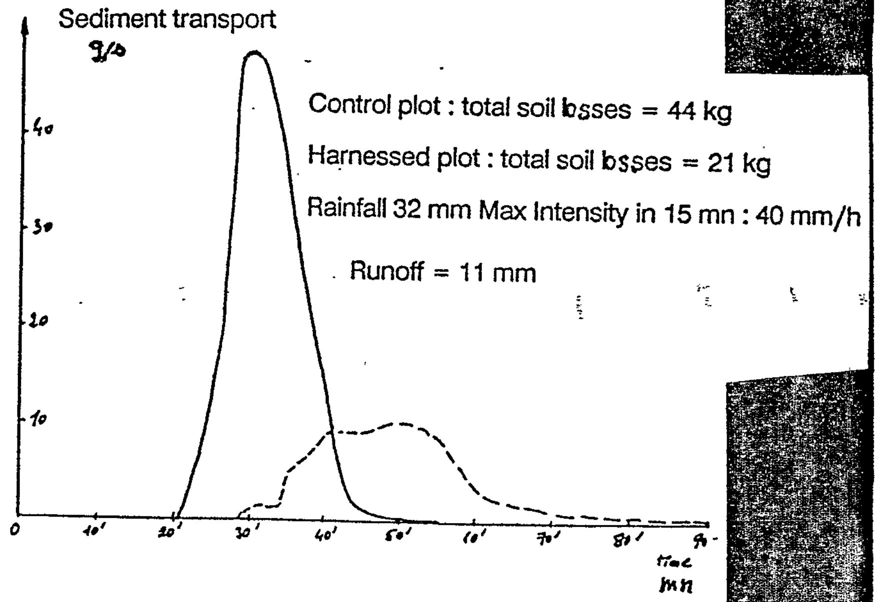
Figure 10 - 2   7/28/86 Flood

Control plot : Runoff = 2,0 mm

Harnessed plot : Runoff = 2,3 mm

Control plot : Runoff = 5,2 mm

Harnessed plot : Runoff = 5,5 mm



re 10 - 3   7/29/86 Sediment transport curve

Control plot : total soil losses = 44 kg

Harnessed plot : total soil losses = 21 kg

Rainfall 32 mm Max Intensity in 15 mn : 40 mm/h

Runoff = 11 mm