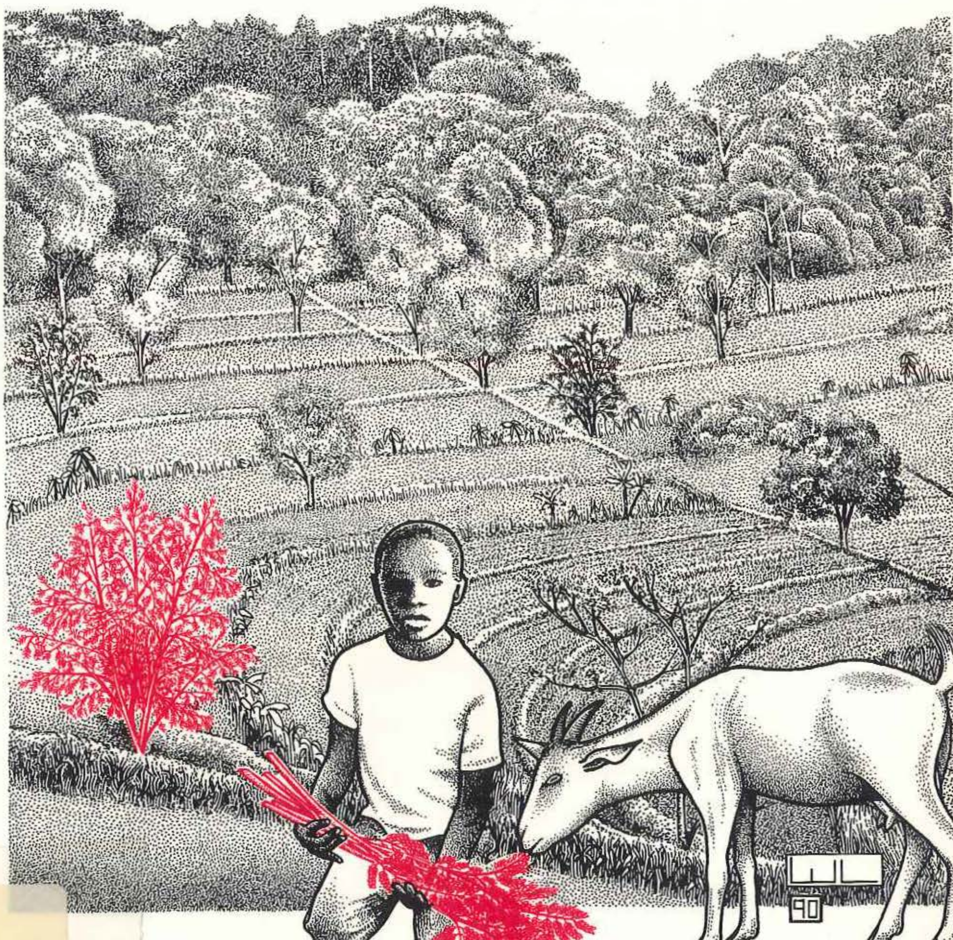
TROPICAL AGROECOLOGY |5|

ECOFARMING PRACTICES

for tropical smallholdings



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VII. Low–cost soil and water conservation measures for smallholders in the Sudano–Sahelian zone of Burkina Faso

Helmut Eger[1]

1. Introduction

Since the 1950s, significant changes have occurred in the Sudano–Sahelian environment of West Africa. Especially the long drought caused degradation of vegetation and soils and an increase of runoff and soil erosion, which led to a lowering of the groundwater table and to microclimatic changes (REIJ 1983, MARCHAL 1983, ALBERGEL et al 1984, BROEKHUYSE 1985, ROOSE 1986).

The drought, together with a high population pressure and profound socioeconomic changes, also caused severe environmental problems in the major part of the study region, the Central Plateau of Burkina Faso (MARCHAL 1983, ROOSE & PIOT 1984). Consequently, sheet and gully erosion on the glacis and silting up of the lower–lying areas occurred.

Already between 1962 and 1965, the Water and Forestry Branch of Yatenga Province in cooperation with the European Group of Soil Restoration (GERES) attempted to overcome this land degradation process with a rather technocratic top–down approach which turned out to be a complete failure (KOTSCHI et al. 1986).

Other organisations and approaches followed in the endeavour to combat the degradation of this fragile environment (PAE 1985, MINOZA et al 1986). Within this framework, an on–farm research

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project was started in 1985 by the German Sahelian Programme (Programme Allemand CILSS, PAC) in which soil and water conservation measures were developed and tested as land resource management aspects of smallholder farming systems (PAC 1986). The results of a selection of measurements regarding the suitability of these biological and mechanical soil and water conservation measures for different environmental and socioeconomic conditions are reviewed below.

2. The Sudano–Sahelian environment

The study region is part of the Sudano–Sahelian zone of Burkina Faso, extending between 12°30'N and 14°30'N latitude and between 1°W and 2°20'W longitude (Fig. 1).

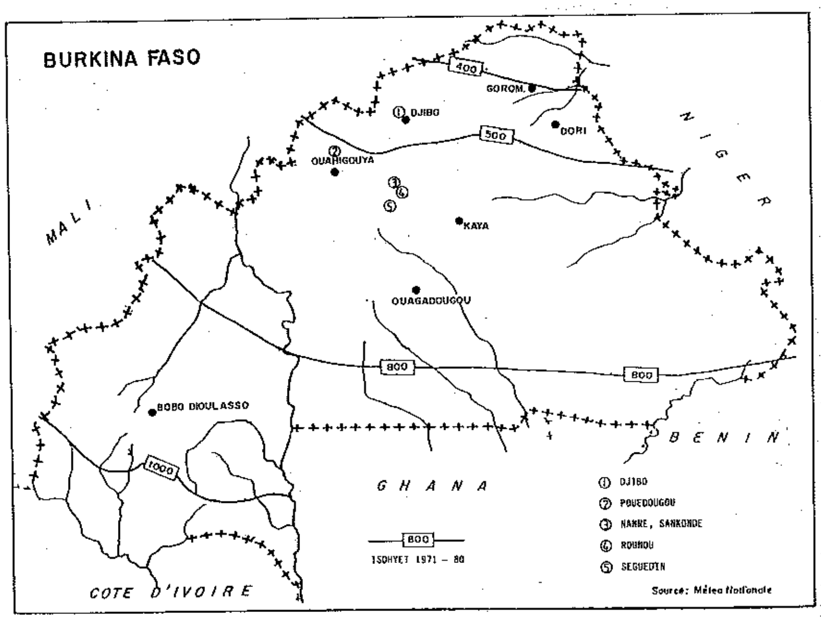


Figure 1: Burkina Faso, on-farm research sites and rainfall

Most parts of the Central Plateau of Burkina are underlain by granites. Their relief is characterized by an extensive peneplain with ferruginous crust capped hills or inselbergs and glacis.

From SE to NW an area of metamorphic, mostly basic rocks traverses the Central Plateau. The different geology results in a differing relief: large dissected plateaux of ferruginous crusts, steep slopes and long–gravel glacis with a silty–clay cover of variable thickness, leading very often to a low–lying valley traversed by a gully (ROOSE 1986). Steep slopes and height differences of 150 m are common in this zone from Kaya to Ouahigouya.

The soils under cultivation on the glacis are more or less leached ferruginous tropical soils, hydromorphic in depth. On the lower slope phase or in the valley bottom are brown soils, which are also more or less hydromorphic or vertic (BOULET 1976, ROOSE 1978). The sandy clays or loamy sands in the top layer become rather clayey with increasing soil depth, show weak external and internal drainage, and have a medium content of bases; the A–horizon is mostly compacted (BOULET 1976, HULLUGALE 1988).

The region is characterized by a strongly latitudinal orientation of climate and vegetation, resulting in a north–south sequence of

Table 1: Climatic characteristics of the study region

Location Zone	Ouagadougou S of Sudano-Sahelian zone	Ouahigouya N of Sudano-Sahelian zone	Dori Sahelian zone
Mean annual rainfall (mm)	862	715	563
Mean annual ETp[1] (mm)	2098	1698[2]	2225
Total length of growing season (days)	136	111	92
Average temperature (°C):			
coldest month	25.5	24.1	23.6
warmest month	32.3	33.5	33.5
Mean wind speed (m/s)	2.3	0.8	2.2

Source: FAO (1984).

[1] Potential evapotranspiration according to the Penman formula.
[2] ETp of Ouahigouya seems very low: this may indicate a data error.

ecological zones which are similar throughout the whole of West Africa.

The typical climatic pattern in the study region is illustrated by the climatic diagramme of Ouahigouya (Fig. 2).

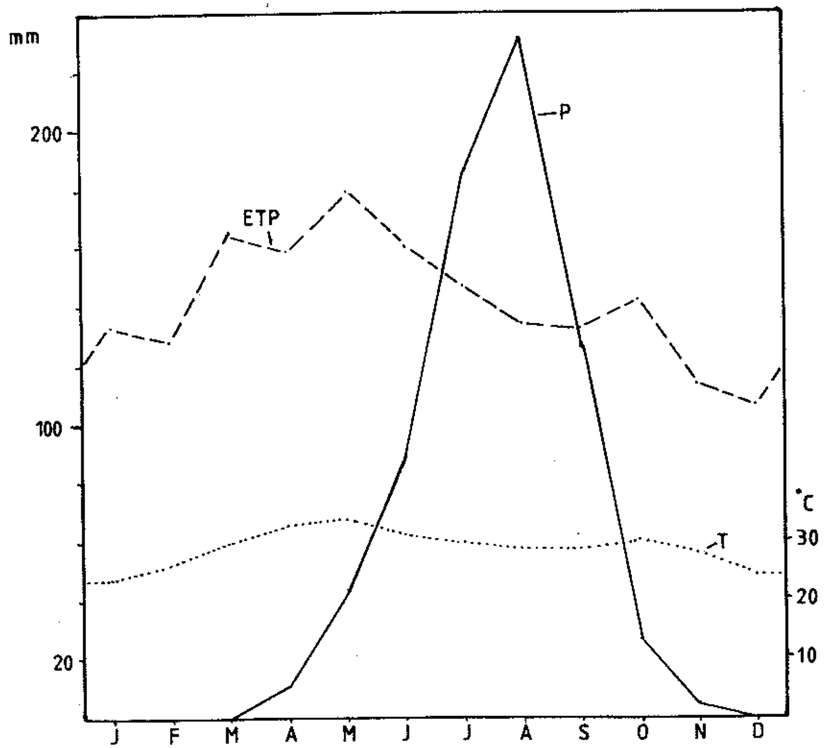


Figure 2: Climatic diagramme of Ouahigouya
(P = precipitation, ETP = potential evapotranspiration, T = temperature)

Source: FAO (1984).

Four hygric seasons can be distinguished (FAO 1984):

- a long dry season (255 days) beginning on 1st October and ending on 12th June; followed by
- a transitory, pre-humid period of 19 days, when rains are still uncertain but, on average, sufficient for commencement of crop growth;

- a humid period of 72 days from July to mid-September, which is sufficient only for early-ripening crops; and
- a second transitory regime (post-humid period of 19 days), when the stored soil moisture and intermittent rains may suffice for ripening crops.

These characteristics indicate a climate suitable for growing early-maturing crops. However, this is valid only under "long-term average" conditions. Rainfall varies greatly in time and space, and prolonged dry spells of up to 15 days are frequent. The annual rainfall during 1986-87 was ca 550 mm for the wider Kongoussi area and decreased to 300 mm (1986) in Djibo, the southern part of the Sahelian zone, where a significant drop during the past 36 years has been noted. During the last few years, a later start and a shift of the last rains to October could be observed (PUECH 1983).

High rainfall intensities (55-80 mm/h during 30 minutes) are common and, under the predominantly sparse ground cover, lead to serious soil erosion by water. On sandy soils further north in the Sahelian zone, wind erosion adds an additional burden on the fragile ecosystem.

The natural vegetation formation can be classified as a degraded Sudanese tree savanna with the dominant species being *Butyrospermum parkii, Parkia biglobosa, Khaya senegalensis, Faidherbia albida, Adansonia digitata,* and *Combretum, Cassia* and *Bombax spp*; the perennial grasses include *Andropogon gayanus* and *Cymbopogon spp.* Towards the north and on stony, marginal sites, thorn shrub savanna with generally sparser vegetation becomes dominant. It is composed in its woody layer of *Acacia spp, Balanites aegyptiaca* and others, and in its grass layer of *Cenchrus biflorus* and other annuals (ROOSE 1978, PENNING DE VRIES & DJITEYE 1982).

3. Smallholder farming systems in the Sudano–Sahelian zone of Burkina Faso

The Central Plateau of Burkina Faso is inhabited by two major ethnic groups, the Mossi and the Peul–Rimaibe.

The Mossi are sedentary peasants and livestock–keeping farmers in the core land of the Central Plateau. The seminomadic or nomadic Peuls are pastoralists at the northern fringe of the Plateau or practise a form of transhumant agropastoralism in the Sudano–Sahelian zone. The population density varies between 15 persons/km^2 in the north (Soum Province) and 45 persons/km^2 on the Central Plateau (Bam Province). The latter is very high relative to the low ecological carrying capacity of the region. About 90% of the population live in villages, and about 80% are engaged in agriculture. A large percentage of the young male population works during the dry season or year–round in the towns or abroad (Ivory Coast).

Agriculture in the zone is subsistence–oriented. On the Central Plateau ca 15% of the land is cultivated. Extended families of around 10 members have about 6 ha land under cultivation (BELEM 1985). On 80–90% of the cultivated land, sorghum and/or millet are grown, mostly undersown with cowpeas *(Vigna sinensis)*. Also sesame, groundnuts, peas and cotton are grown (Table 2). Animal husbandry and horticultural activities are sometimes found in the lower–lying areas or around ponds. Cultivation operations are carried out jointly by men, women and children during the months of April–August and November–December (harvesting). Weaving and construction are done during the dry season. This is also the period when training courses on various subjects are attended.

The degree of farm mechanization is very low. The traditional tool is the "daba", a hoe which is used for all cultivation activities. Animal traction has rarely been adopted. Mineral fertilizer is not used. Traditionally, some type of mulching with sorghum and millet stalks was practised, but the shortage of fodder makes this more or less impossible.

Table 2: Characteristics of a typical smallholder farm unit on the Central Plateau, Burkina Faso

General	
Farm holding organisation	Family holding (ca 10 members)
Production strategy	Subsistence, little market-oriented production
Arable farming	
Cultivable area	6 ha
Cropping pattern	5 ha cereals (mixed-cropping with legumes) 1 ha miscellaneous (groundnut, sesame, cotton)
Fallow	Rarely observed, sometimes extensive
Farm equipment	Hoe, cutlass
Fertilization	C-increase through mulching with sorghum and millet stalks sometimes observed; N-increase through dung of transhumant herds
Average crop yields:	
Millet	450 kg/ha
Sorghum	550 kg/ha
Maize	400 kg/ha
Rice	1200 kg/ha
Cereals self-sufficiency	81.5%
Animal husbandry	
Animals per holding:	
Cattle	0.75
Sheep	1.0
Goats	1.0
Donkeys	0.5
Poultry	4.0
Organisation	Extensive herding
Feeding	Only ca. 80% of animal requirements can be covered by village pastures
Forest utilisation	
Collection of firewood:	
Consumption of wood	ca. 400 kg/capital/year

Sources: ZOUNGRANA 1984, BELEM 1985, MÄRZ 1985, TAOKO 1985, PAC 1986, DAMIBA 1987.

During the dry season the Peuls herd their animals on the arable land, which is the only form of manuring practised. Crop rotation is not normally practised.

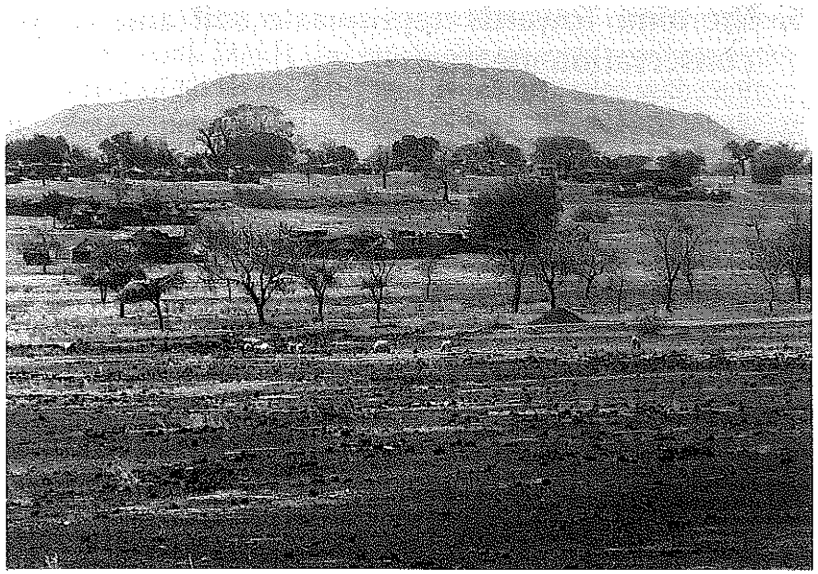
With respect to livestock, small ruminants are dominant in the households of the settled peasants. Cattle are often given to the Peuls for herding. The number of animals is beyond the carrying capacity of the land, e.g. in the village of Séguédin only about 80% of the animals could be fed adequately on the village pastures (Table 2). This overstocking leads to degradation of the vegetal cover.

4. The problem: Degradation of the environment

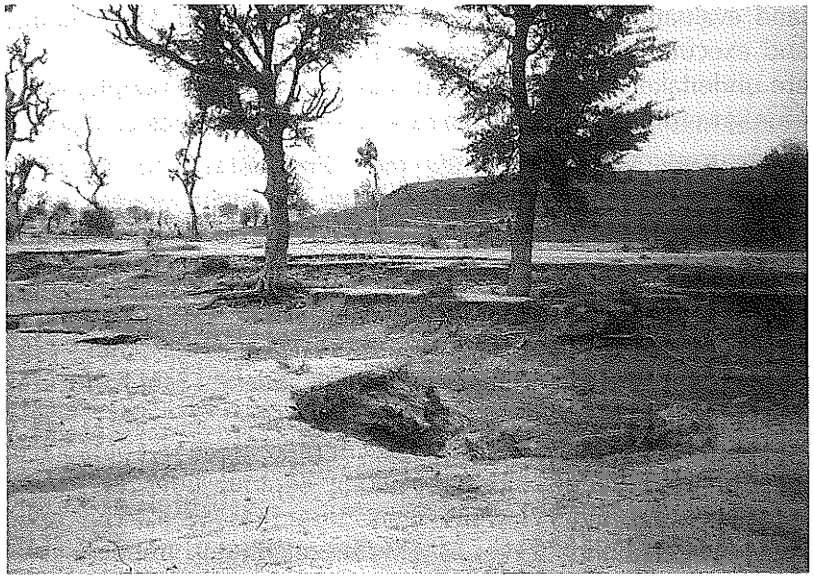
The smallholder farming systems of the Central Plateau of Burkina Faso exert a very high pressure on the environment under the existing high population density. Destruction of vegetation by overgrazing, land clearing and fuel cutting is the starting point of the process of degradation. On cultivated land the traditional technique of soil recovery under a long fallow can no longer be observed.

Breakdown of soil structure and loss of soil organic matter follow. The soil surface becomes sealed by a crust formed by the impact of raindrops. Increased surface runoff then leads to sheet and gully erosion: hilltops and upper slopes become denuded, and lower slopes and valley bottoms dissected by deep gullies which destroy scarce cultivable land. A comparative study using aerial photographs in a Central Plateau watershed showed a 20–30% decrease of cultivable acreage within the last 30 years (GROTEN 1984).

Soil and water conservation measures are therefore the most pressing need in agricultural development on the Central Plateau. Without them any other agricultural development activity will lose its base, and the region will be left to complete devastation within the near future.



Landscape of the Central Plateau of Burkina Faso. As shown by a study with the aid of aerial photographs, about 20–30% of the arable land has been lost to soil erosion in the last 30 years.



In the depressions, valuable cropland is being lost through gully erosion. Even old trees cannot stop this process and are being unrooted.

5. The aim: Towards appropriate soil and water conservation measures

Among its project activities, the German Sahelian Programme considered appropriate, site–specific soil and water conservation measures as key activities in the battle against land degradation and desertification. However, the mechanical and biological conservation measures were seen only as part of a wider land resource management concept for the gradual return from mere survival to sound subsistence.

The intervention strategy, based on the recommendations of the Regional Seminar on Desertification in Nouakchott (1984), is centred in the participation of the population. The local people are to carry out soil and water conservation measures in a bottom–up approach within a multisectorial framework (CILSS et al 1984). In practice, this means carrying out a thorough landuse planning study and subsequent land resource management on a small catchment level (‹ 20 km²), incorporating the principles of land evaluation and land suitability classification. All planning and execution stages including the on–farm research activities are undertaken in collaboration between the local people, local (non)governmental agencies and rural development assistance.

Since water availability is the most important factor for crop growth in the Sudano–Sahelian zone, the main interest of research was the influence of soil and water conservation measures on soil moisture status, erosion control mechanism, and comparative crop yields of test and control plots.

Promising soil and water conservation measures for halting soil degradation and desertification in the Sudano–Sahelian zone are:

- **Bunds** ("diguettes") ca 20–30 cm high made of compacted soil or boulders, normally along contour lines 10–20 m apart but other layouts were tested as well. The area between bunds serves as a water catchment. Impermeable bunds made of earth collect all rainfall whereas permeable stone bunds merely slow down surface runoff and thus in-

crease infiltration rate. Intermediate types of both systems exist: earth bunds can be combined with overflow outlets made of stone, and stone bunds can be sealed with earth.
- **Small permeable dams** ("digues filtrantes") made of boulders. These dams are 50–300 cm high, 50–300 m long and can be used to stabilize gullies to a depth of 150 cm. Deeper gullies require gabion reinforcement. The dams are permeable, but reduce runoff velocity considerably and thus lead to soil sedimentation and increased water infiltration. Alluvial deposits reduce slope and form fertile land of 0.25 – 6.0 ha.
- **Runoff agriculture** involving stabilization of gullies deeper than 150 cm by weirs made of gabions and diversion of water to neighbouring fields equipped with appropriate contour bunds. This system is by far the most sophisticated technically and financially but, in some situations, it is the only way to stop gully erosion.

An economic evaluation of these measures should allow conclusions to be drawn as to their suitability for extension.

6. Methods

The on–farm research activities were focused on developing and/or improving soil and water conservation techniques which can be carried out by local farmers without the use of sophisticated surveying, land–moving or other techniques. In the following, the trials are described in detail.

6.1 Analysis of the effects of earth and stone bunds as soil and water conservation measures

6.1.1 Comparison of the effects of three types of earth bund arrangements on crop and biomass production

Location: Djibo, on silty loam.
Design: Block design, 4 treatments, 3 replications, total 12 ha, plot size 100 x 100 m.

Crop: *Pennisetum typhoides,* local variety, 2000 pockets/ha.

Treatments:
1. Control (no bunds).
2. Earth bunds along the contours (contour bunds), traditional method, 30 cm high.
3. Earth bunds, rhombic arrangement, perpendicular to the slope, diameters 12 x 24 m.
4. Earth bunds, square arrangement, 10 x 10 m.

Measurements: Crop yield and spontaneous biomass weight along 3 transects of 80 m x 1 m per plot (100 x 100 m); study of plant cover composition and its nutritive value.

6.1.2 Comparison of the effects of earth and permeable stone contour bunds on soil moisture status and crop yield

Locations: Pouedougou, Séguédin, Rounou, Djibo; different soil types.

Design: Earth and permeable stone contour bunds, 30 cm high, 8–20 m apart; crops: sorghum and millet, traditional cultivation.

Measurements: Soil moisture status (gravimetric) at different depths (according to soil profile) along transects parallel to and across bunds. Crop yield measurements: randomly within stratification as function of distance to bund.

6.1.3 Stabilization of earth contour bunds

The "soil and water conservation farmer" often regards earth contour bunds as non–durable. This argument and a request from the German Volunteers Service's Agroecological Project was the starting point for research on mechanical and biological stabilization measures for earth contour bunds.

Location: Djibo.

Design: Block, 12 treatments, 6 replications on 5 ha, 10 contour bunds of sand to loamy sand, 30 cm high, 100 cm wide, 9–11 m apart, with vertical height difference of 25 cm; 6 of the bunds were each divided into 12 parts 15 m long, and were treated as follows.

Treatments:
1. Control: untreated contour bund 30 cm high.
2. Boulder core bunds: boulders of 15–30 cm diameter covered by compacted soil.
3. Acacia branches as bund cover on both sides of the bund.
4. Acacia branches as cover of the shallow ditch above the bund undersown by *Leucaena leucocephala*, spacing 25 cm.
5. *Dolichos lablab*, forage legume, sown in the ditch above the bund.
6. *Cenchrus ciliaris,* vigorous forage grass, planted and later sown all over the bund.
7. *Andropogon gayanus,* common perennial grass, planted and later sown in the shallow ditch above the bund.
8. *Andropogon gayanus,* planted and later sown below the bund.
9. *Cucumis melo*, a wild bitter melon, sown in 2 rows with 40 cm spacing above the bund.
10. *Crotalaria retusa*, vigorous forage legume not eaten by animals when fresh but good as hay, sown all over the bund.
11. *Jatropha curcas,* cuttings planted and later sown with 20 cm spacing above the bund.
12. Termite hill soil as cover (forming a crust after wetting) all over the bund.

Measurements: Analysis of the efficiency of the treatments as cover and stabilization factor of the bunds (biomass, standing crop, phenological observations, percentage soil cover). Erosion/accumulation differences on and between the bunds as a function of stabilization measures.

6.2 Analysis of the effect of permeable stone dams as soil and water conservation measures

Locations: Sankondé and Nanné (project sites of the French Volunteers).

Design: Permeable stone dams ("digues filtrantes") constructed in gullies and on adjacent land, up to 250 cm high, primarily for gully control, soil collection/conservation and temporary runoff water storage. Crop: sorghum, traditional cultivation (MINOZA et al 1986).

Measurements: Soil moisture status (gravimetric) in different depths along transects; crop yield measurements randomly within stratification as function of distance from dam.

6.3 Runoff–agriculture systems for increased crop production and gully erosion control

Locations: Séguédin and Rounou.

Design: Installation of runoff–agriculture systems for increased crop production and erosion control: in each case, 4 ha with contour bunds in prolongation of two gabion weirs in a gully. The contour bunds were equipped with overflows.

Treatments:

1. Main permeable stone contour bunds with overflows (50 cm high).

2. Stone contour bunds for water distribution within the system (20 cm high), floods overflow entire bund length.
3. Earth contour bunds for water distribution within the system (30–40 cm high), overflows made out of boulders.
4. Gully control system by gabion weirs.

Measurements: Soil moisture status along transects to analyse the influence of the different water retention and distribution structures.

Determination of threshold rainfall level to obtain a usable flood for runoff agriculture.

Determination of efficient rainfall for runoff agriculture, i.e., the percentage of rainfall events which produce a usable flood.

Analysis of the efficiency of gabion weirs for gully erosion control.

Crop yield measurements in combination with soil moisture status sampling (Fig. 10).

6.4 Economic aspects of the conservation measures

On the basis of a literature survey, personal communications and experiences, some calculations were made with respect to the economics of soil and water conservation measures.

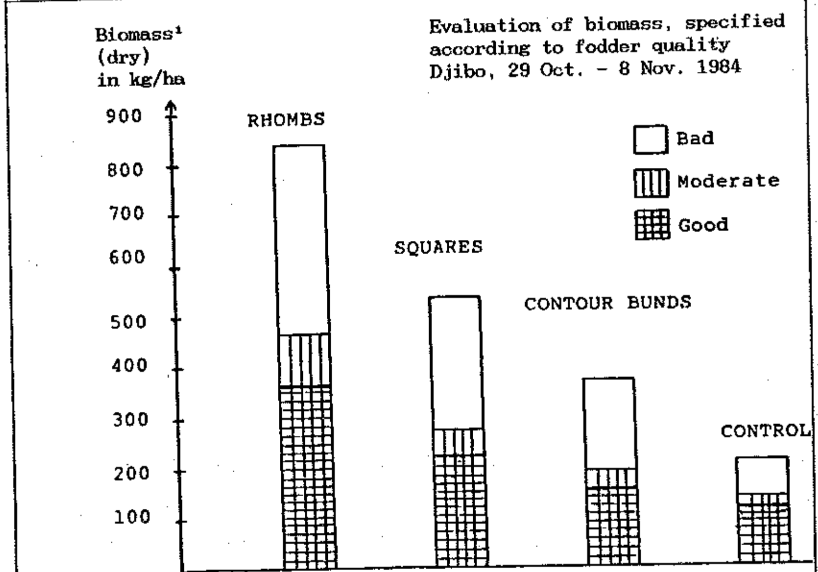
7. Results

7.1 Effects of earth and stone bunds as soil and water conservation measures

Several governmental bodies and projects are working with earth bunds (AFVP, FEER, OXFAM, PAE, ORSTOM, ICRISAT, ORD). However, discussions frequently arise about the use of different bund–building materials such as earth, stones or a combination of both, as well as about the use of different bund arrangements (PAE 1985, FEER 1986).

7.1.1 Effects of different earth bund arrangements on water–harvesting

Evaluation of the effects of three earth bund arrangements on crop and biomass production in Djibo (Fig. 3) clearly showed, although effective rainfall was only 150 mm, that:



	RHOMBS	SQUARES	CONTOUR BUNDS	CONTROL
Biomass (kg/ha)	836	533	366	209
Relative to control (%)	400	255	175	100
Earth bunds (m/ha)	1546	2000	392	0
Biomass increase (kg/m bund) compared to control	+ 0.405	+ 0.162	+ 0.400	-
Total biomass increase (kg/m bund) compared to control	+ 0.523	+ 0.227	+ 1.097	-

[1]Millet not included.

Figure 3: Evaluation of biomass production with tree earth bund arrangements

- **Contour bunds** are the most efficient arrangement with respect to total biomass production per meter bund, but require a higher level of technology (to determine the contours) than the other arrangements. To avoid breakthroughs the distance between the bunds should not exceed 20 m, but if the distance is less than 10 m, the rainwater harvesting effect would be lost.
- **Rhombs** generated the highest total biomass production per unit area, but considering the high labour input (1546 m bunds per ha) this method of soil and water conservation can be recommended only for highly valuable environmental sites, in difficult topographies or for afforestation purposes on degraded soils. Although easy to construct, the high maintenance inputs and the fact that mechanization in agriculture is not feasible, restrict this approach from wide adoption.
- **Squares** needed the highest labour input and, in 1984, did not yield better than the contour bund arrangement. In 1985, a year with poor rainfall, the yield of the squares was similar to that of the rhombs, but the performance of the contour bunds was better.

For all treatments it can be stated that, in the areas of water concentration, intensive cultivation is necessary in order to improve the infiltration capacity of the soils and to avoid any capping or clogging effect.

7.1.2 Infiltration characteristics of impermeable and permeable bunds

Part of an earth contour bund system is shown in Figure 4. In 1986 soil moisture status was determined during the dry season (30.04.86) and shortly after rainfall (02./03.07.86 and 26.08.86). The (loamy) sand contour bunds retained the runoff water completely. The water infiltrated above the bund via a sand cover (0–5 cm) into a sandy loam (5–30 cm) and a sandy clay layer (30–80 cm). The increase in clay with depth created a nearly impermeable layer which caused waterlogging and, in some

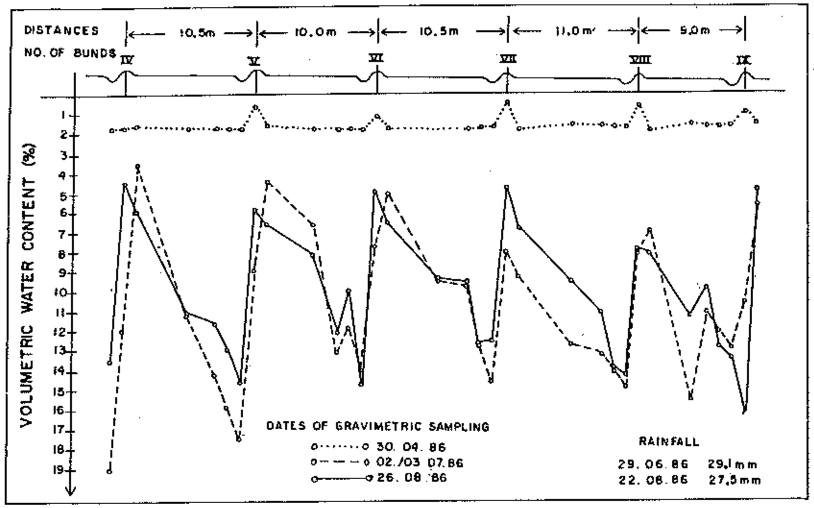


Figure 4: Djibo: soil and water content, transect across earth bunds, soil depth 0–20 cm

parts, the failure of a millet crop. These results indicate that an uneven water distribution can be expected with impermeable contour bunds. On soils susceptible to waterlogging, this may result in a negative effect of the bunds on crop yield in general, and particularly just above the bunds.

The situation changes significantly when permeable stone contour bunds are used. Under the same soil and morphological conditions, soil moisture minima and maxima oscillated between 8.5 and 13.5% volumetric water content for the July and August sampling dates, showing a more even water distribution compared to the minima and maxima between 3 and 19% in the case of earth bunds.

Similar results were obtained in other parts of the Sudano–Sahelian zone on slopes of ‹2%. The retention and filtering effects of earth and permeable stone contour bunds on soil moisture status are shown in Figure 5.

The soil is a sandy loam with a high gravel content (30% by volume) and a high infiltration rate when cultivated. Soil depth does not exceed 40 cm above a lateritic crust. Immediately

downslope from the earth bund, the moisture content in the cultivated soil is low (Fig. 5, P44), whereas downslope from the permeable stone contour bund, the soil moisture level (Fig. 5, P 41) is almost as high as above the bund. This is also true deep in the profile, where horizontal water movement might be considered. These results suggest that permeable contour bunds guarantee a more even water distribution over the whole field than impermeable earth bunds.

However, in a morphological situation with a higher slope gradient (›2%) and a low infiltration rate, it was observed that, for a good water supply to the soil, measures which significantly slow down the speed of runoff and retain the water for a longer period in the field are needed. This can be achieved either by a narrow spacing of the bunds or by impermeable bunds, preferably with overflow structures.

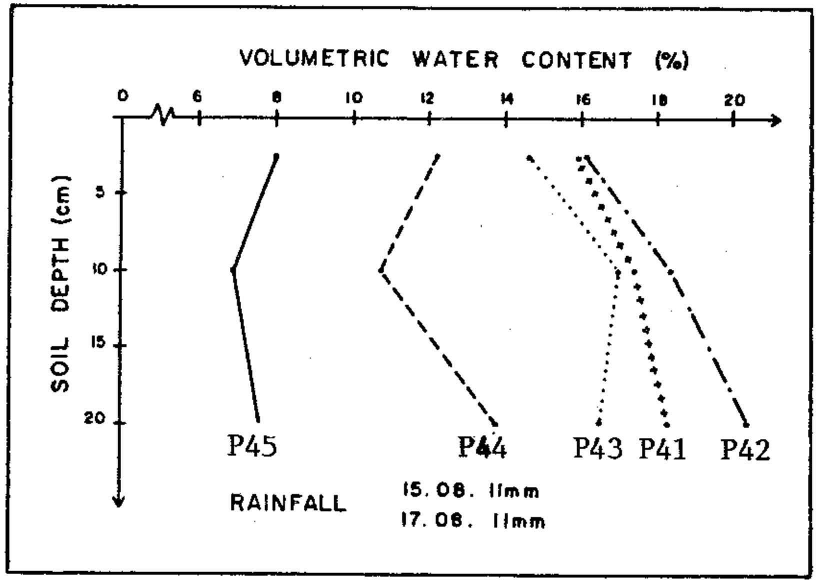
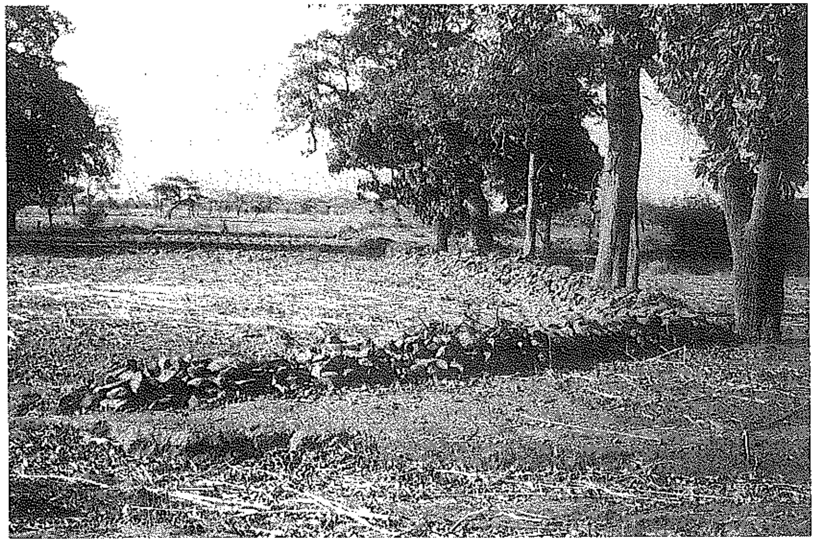


Figure 5: Pouedougou, soil water content above and below an earth bund and a permeable stone contour bund, 19.8.1986

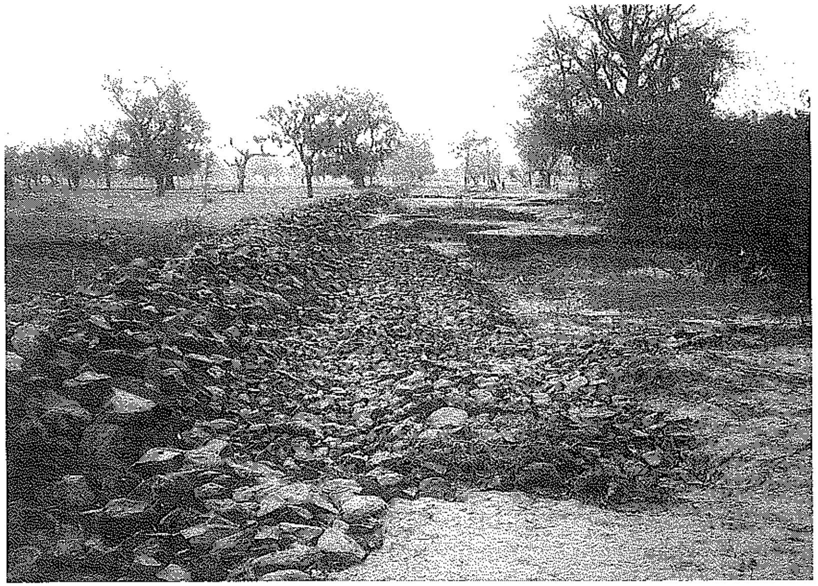
P 45: above the earth bund, fallow
P 44: below the earth bund, cultivated
P 43: ca. 1.5 m above the stone bund, cultivated
P 42: a few cm above the stone bund, cultivated
P 41: below the stone bund, cultivated.

Earth contour bunds lead to complete infiltration of the water above the contour bunds, so that water is unevenly distributed over the cropped area. Moreover, earth contour bunds are often not durable.

Stone contour bunds require more labour for construction than earth bunds., but are more durable and lead to a more even distribution of water over the cropped area. They are preferable to earth bunds wherever stones are available.



Small permeable dams are used to stabilize gullies. They reduce runoff velocity and lead to increased water infiltration and to soil sedimentation. Here, the gully above the dam (left) is already almost completely filled with sediment.



Small permeable dams are 50–300 cm high and 50–300 m long. A large amount of stones are needed for their construction. It is therefore reasonable to provide trucks to help the people transport the stones.

7.1.3 Stabilization of earth bunds

Concerning the question of stabilization of earth contour bunds, a rather elaborate trial conducted during 1985 and 1986 (PAC 1988) led to the following conclusions.

Acacia branches as bund cover not only conserved bund efficiency during the whole trial period, but also led to an increase in bund height on account of the sand trap effect of the branches. All other treatments were less promising, especially under the prevailing low rainfall conditions which make it difficult to provide sufficient soil moisture to establish any plant on a position exposed to wind and sun such as on a bund. In the second year, the branches treatment was modified by placing cut weeds on the bunds, and proved successful. This indicates that, under these extreme climatic conditions, mechanical stabilization of contour bunds is more promising than biological.

The erosion measurements also clearly indicated that, where animals are not allowed on the field, the annual decrease in bund height did not exceed 20 mm, i.e. that trampling greatly affects earth bund stability. This provides a further argument for the use of stone bunds, as crop residue grazing is necessary to manure the soil and for animal feeding in the dry season. It would also be very difficult to prevent crop residue grazing under the present system of landuse.

7.1.4 Summary: Stone versus earth bunds

The pros and cons of both systems can be summarized as follows. Stone bunds allow a more even soil moisture distribution in the field, thus avoiding the danger of waterlogging which exists near impermeable earth bunds. Permeable bunds also react more flexibly during heavy rainfall, whereas earth bunds break more easily and can then lead to increased erosion. The latter require more precise installation along contours and regular maintenance, and do not allow the field to be grazed during the dry season. Another important aspect is that farmers are mainly interested in water harvesting and not so much in perfect erosion control. Therefore, impermeable bunds are often rejected, as they prevent water flowing onto the field from higher parts of the slope.

Thus, permeable systems involving stone bunds are preferable wherever boulders are available. Where this is not the case, earth bunds must be chosen, preferably with overflow structures built with stones.

7.2 Effects of permeable stone dams ("digues filtrantes") on soil and water conservation

On the Central Plateau, the primary function of permeable stone dams is to obstruct a gully or depression and collect and filter out soil from the runoff in order to create a cultivable area behind the dam. Secondly, after the establishment of the cultivable area, the dam serves as a retention structure for runoff water in order to raise the soil moisture status for improved crop production. In general, this system proved to be a valuable mechanism for the reclamation of degraded land and for erosion control.

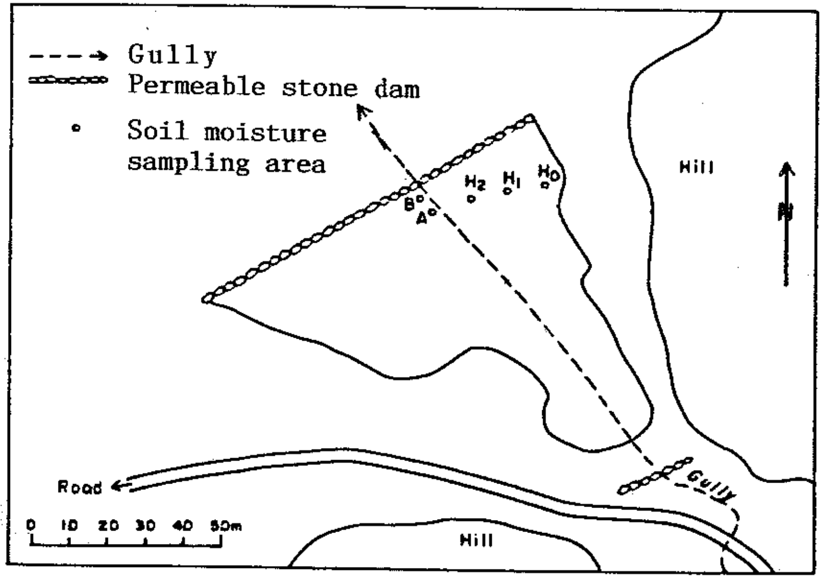


Figure 6: Nanné I, permeable stone dam research site

Analysis of soil moisture distribution in the field revealed that the distance to the dam and to the former gully bed are the major determinants for moisture variations. Along the former gully bed (Fig. 6; positions A, B) soil moisture content may reach 50% in a sandy loam for a prolonged period (over 8 days), which caused failure of a sorghum crop. The concentration of soil water in the former gully bed creates, in most cases, a considerable waterhead on a limited surface of the dam, which leads to piping at the centre of the dam. Mostly below the main root level of sorghum (ca 80 cm) large quantities of soil are lost due to this effect. However, this is only a fraction of what would have been lost without the permeable dam. On the periphery of the soil accumulation behind the dam, the soil moisture status does not attain exceptional levels (Fig. 7; positions H0, H1, H2).

In all cases, yield levels are considerably higher under permeable dam conditions than under average growing conditions and, in most cases, also higher compared to unimproved lowland conditions (Fig. 8).

Suggestions for an improvement of the idea could lie in a closer spacing of the permeable dams for more even soil moisture distribution, and in introducing a filter of gravelly material in the dam

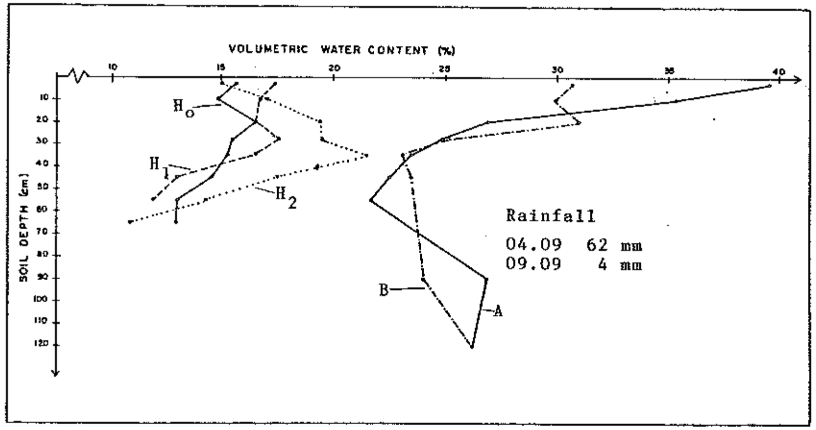


Figure 7: Nanné I, soil water content in relation to distance from permeable stone dam, 12.9.1986

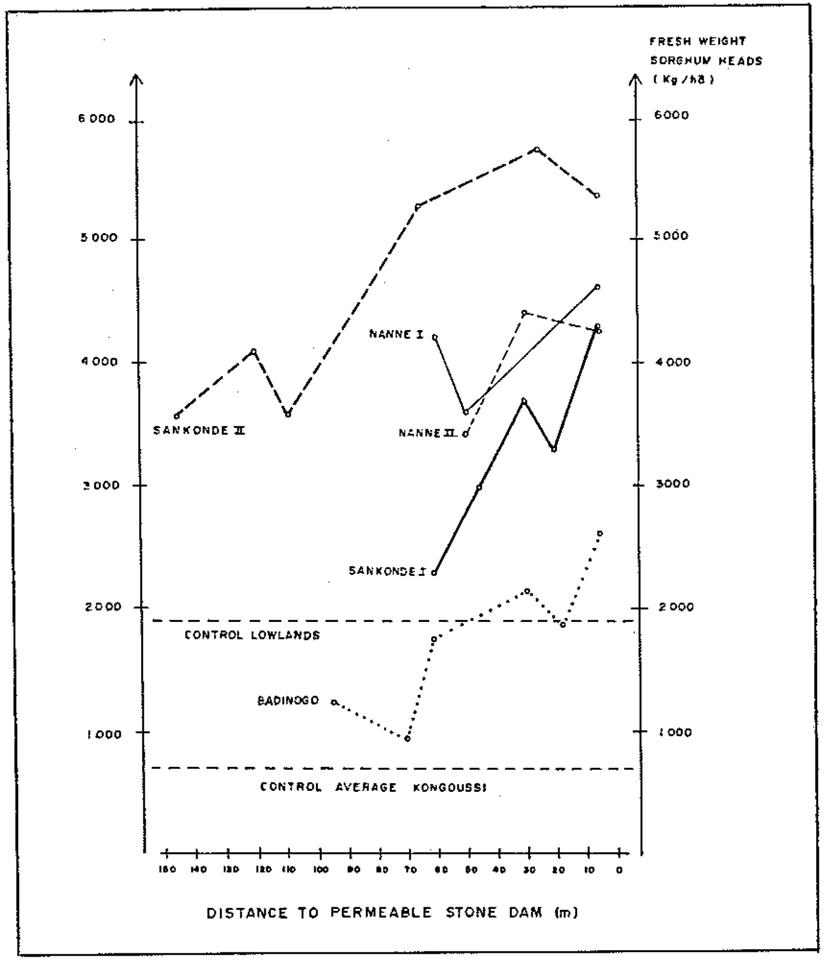


Figure 8: Sorghum yield in relation to distance from permeable stone dam

design in order to control piping. The areas of high soil moisture content could be used by introducing rice.

In view of the soil moisture development throughout the growing season, the introduction of sorghum varieties with a longer growing cycle and a tolerance to waterlogging might also be considered. This would imply that the animals in the area would have to be herded during the first part of the dry season.

7.3 Runoff–agriculture systems

The runoff–agriculture systems, like the soil and water conservation measures discussed above, caused a significant increase in soil moisture in the treated area (Fig. 10). The soil moisture content within the treated area is almost the same irrespective of position relative to the bunds and, in any case, considerably higher than on the control plot outside the runoff–agriculture system. This even distribution highlights the good efficiency of the runoff spreading system, reflected also in yield increases of 100% and more. It was found in this context that semipermeable

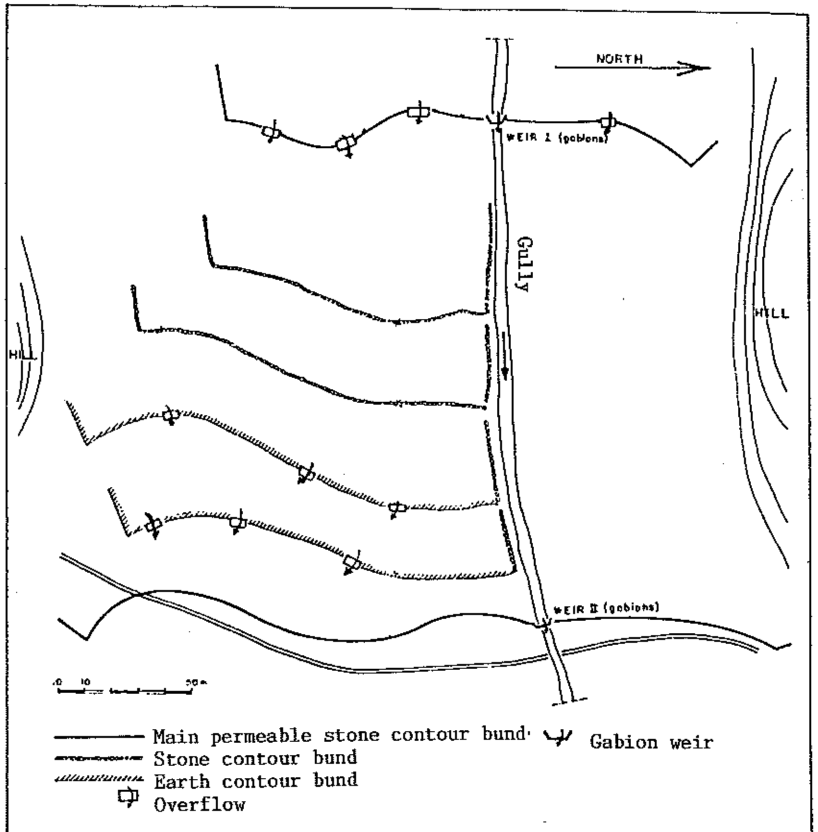


Figure 9: Séguédin, runoff-agriculture research site

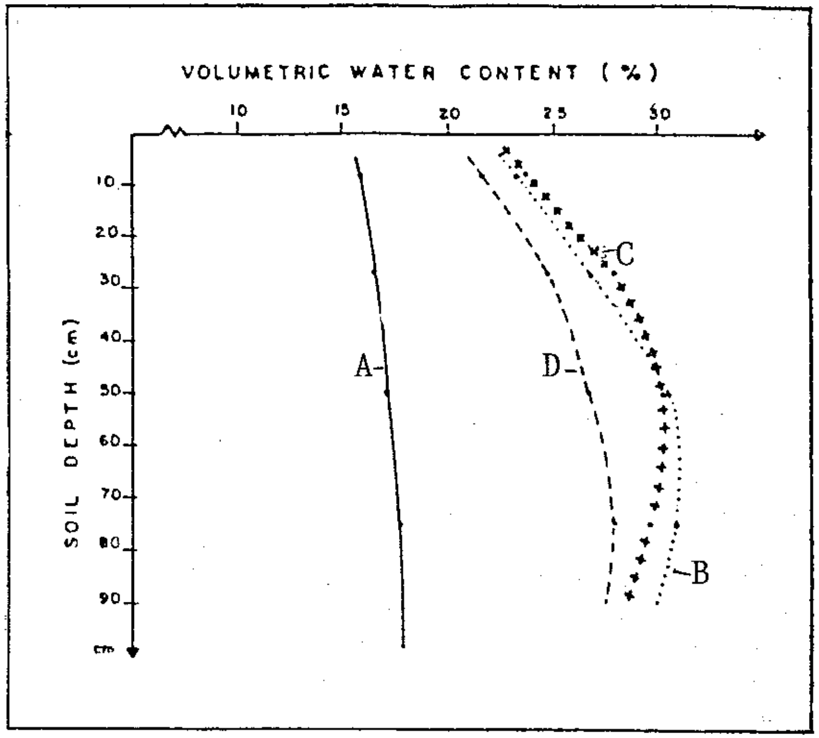


Figure 10: Séguédin, average soil moisture content 80–100 m south of gully
(sampling 22.6. – 14.7. – 11.8. – 19.9.87)
A control
B 0–5 m above contour bund
C middle, between two contour bunds
D 0–5 m below contour bund

stone bunds showed the same water retention efficiency as earth bunds.

For the runoff–agriculture systems tested, the threshold rainfall was found to be 10 mm, between 10–14 mm rainfall 67% of the rainfall events were "effective" in the runoff–agriculture context, and above 14 mm the efficiency was 100%. In the period 10.07–23.09.87, 46% of the rainfall events were effective in the Séguédin area.

The gabion weir also stabilized the gully far beyond the treated area. For the gully of the Séguédin catchment (2.3 km², 0.7–1%

slope, ‹500 mm rainfall, 410 000 m³/year discharge), preliminary results suggest that gabion weirs at 100 m distance could effectively control gully erosion.

The runoff–agriculture systems as tested in the Central Plateau area are considered a viable possibility for combating erosion and increasing crop yields. However, for extension purposes, a technician would be needed to help the local people design the systems and build the gabion weirs.

7.4 Economics of soil and water conservation

Little research has been done so far on the economic aspects of soil and water conservation. The few data available are very difficult to compare. Nevertheless, all studies clearly show the positive effect of soil and water conservation measures on crop yield, and a 50% yield increase compared to a control is not exceptional. The yield increase of sorghum is generally higher than that of millet on account of the former's better response to water. Depending on the system adopted, an amortisation of investment, excluding labour opportunity costs, is possible within 1–5 years.

Besides the direct yield increase attributed to soil and water conservation measures, the brake on the steady loss of cultivable land and on soil fertility decline as well as the increased yield stability have to be considered. Also the positive effect of soil and water conservation on the ecological system as a whole is an important factor, e.g. higher water table, decreased sheet and gully erosion, and increased crop yield and biomass production.

8. Conclusions and proposals for further research

Within the framework of the research project on the "development of sustainable smallholder farming systems in Burkina Faso", earth and stone contour bunds, small permeable dams and runoff–agriculture systems were analysed with regard to their potential as soil and water conservation measures to help combat soil degradation and desertification in the Sudano–Sahelian zone.

The influence of slope gradient and infiltration rate of the soil on the effectiveness of different arrangements of earth bunds and contour bunds was determined, and recommendations for their use were given. Analyses of soil moisture and crop yields clearly showed the strong and weak points of small permeable dams and runoff–agriculture systems as soil and water conservation measures.

During these research activities, new questions and research aspects arose, which fall into three scientific disciplines:

Natural, ecological sciences:

- The influence of biological bund reinforcement on bund–related piping and on soil moisture status of the cultivated areas.
- Agroforestry as part of soil and water conservation practices.
- Runoff water management, cultural practices, adapted crops and manuring related to runoff–agriculture systems.

Economical sciences:

- Investigation of input–output relationships.
- Establishment of a quantitive evaluation system for soil and water conservation measures.

Social sciences:

- Analysis of the workload of soil and water conservation activities for the rural communities (especially sex–specific division of work).
- Reasons for (non)acceptance of soil and water conservation measures by the rural communities.
- The impact of soil and water conservation measures on agricultural land use and land tenure.

In order to carry out these research activities, some prerequisites have to be met: firstly, possibilities to carry out a certain number of soil and water conservation measures; secondly, possibilities to introduce runoff–agriculture systems into the traditional farming systems; and thirdly, collaboration with an operational extension service. In Burkina Faso, these are not unsurmountable obstacles.

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Acronyms

AFVP	Association Francaise des Volontaires du Progrés
CILSS	Comité Inter–Etat de Lutte contre la Sécheresse dans le Sahel
FEER	Fonds de l'Eau et de l'Equippement Rural
GERES	Groupement Européen de Restauration des Sols
ICRISAT	International Crops Research Institute for the Semi–Arid Tropics
ORD	Organisation Regionale de Développement
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre–Mer
OXFAM	Oxford Committee for Famine Relief
PAE	Projet Agro–Ecologie
PAC	Programme Allemand/CILSS

VIII. Trials by scientists and farmers: Opportunities for cooperation in ecofarming research

Ann Waters-Bayer

1. Introduction

In field trials conducted by scientists[1] under controlled conditions, techniques of ecologically-oriented agriculture (hereafter, for the sake of brevity: ecofarming) have functioned well in biological terms. An example is the station- based research in Nyabisindu, Rwanda, in which green manuring with leguminous species resulted in much higher maize yields than in the "traditional" farming system (NEUMANN & PIETROWICZ 1983). However, the extent to which smallholders have adopted the green manuring system promoted by the Nyabisindu project has fallen far below expectations.

This has been the fate of most new ecofarming techniques generated on research stations. The techniques can seldom be directly applied in the diverse and difficult ecological conditions under which resource-poor farmers operate. Many of the innovations – even if technically feasible – do not fit well into the smallholder farm operation as a whole. Scientists' trials form only part of the research activities which lead to changes in farming practices. Particularly in the development of ecofarming techniques, which aim at working in harmony with the natural conditions rather than trying to change them and are therefore highly site-specific, it is important for scientists to link into the most applied form of

[1] The term "scientists" refers here to formally trained personnel in agricultural research and development systems, and includes extensionists involved in the research activities. The term "farmers" refers to persons who derive at least part of their livelihood from agriculture and includes both male and female farmers.

research: that of local farmers who experiment with new ideas to determine whether and how these could improve their way of farming and living.

In practice, although rarely recognized by formal science, appropriate innovations in ecofarming grow out of an iterative process of testing, evaluation, retesting and reevaluation by both scientists and farmers until techniques are designed, adapted and refined to suit specific farming systems and locations at the given time. It is a continuous process, as the appropriateness of techniques changes with changing conditions. This process involves several forms of experimentation which differ in terms of location and level of control by the scientists or farmers, which serve different purposes, and which complement each other. Five main types of plot or field trials can be distinguished:

- scientists' on–station trials,
- scientists' on–farm trials,
- farmers' on–farm trials,
- farmers' participatory trials,
- farmers' informal trials.

Reading from the top to the bottom, the involvement and influence of scientists decreases, while that of farmers progressively increases.

The first three types form part of the dominant top–down "transfer of technology" approach in agricultural research and development (R&D), i.e. the generation, screening, validation, adaptation and diffusion of new technologies by external agents who determine the necessity for them. Farmers' participatory and informal trials present possibilities of R&D from the bottom up: based on farmers' knowledge of local ecosystems and on their perception of local needs.

In the following, the different types of trials, the roles of scientists and farmers within them, and the functions of each type of trial within the agricultural R&D process are described. This is followed by a discussion of the complementarities between the

different trials which could be exploited to strengthen the links between modern and indigenous science in order to generate ecologically appropriate agricultural technologies.

2. Trials determined by scientists

2.1 Scientists' on–station trials

In conventional agricultural research, trials are conducted primarily on research stations and experimental farms. The research questions are deduced from scientific theories and often have little connection with agricultural practices in the immediate surroundings of the station. The trials are designed and managed exclusively by scientists, and implemented usually by employed technicians. The influencing factors can be tightly controlled, the effects can be frequently and exactly measured, and the resulting data can be subjected to complex statistical analysis.

Conventional on–station trials do not permit direct involvement of farmers. If the trials are preceded by a survey in the target area, the communication process is dominated by the scientists, who specify what information the farmers are to provide. The questions then investigated in trials reflect the scientists' interpretation of local problems. Limited exchange of information between scientists and farmers may be possible when farmers visit the station to view the trial plots, which are meant to demonstrate improved techniques. However, because station conditions (e.g. soil type, topography, availability of production inputs) differ from those on smallholdings, the farmers often cannot see how the innovations could apply to their own circumstances.

On–station trials are suitable for disciplinary research to gain an understanding of biological processes and for initial applied research to establish the basic biological potential of new agricultural technologies (new variety, new cultivation technique, etc.). In R&D programmes aimed at solving problems in specific farming systems, preliminary trials on stations rather than in farmers' fields are necessary if the suitability of a new technology is uncertain, i.e. when the risk of failure is high.

Comparisons between a new technology and local farming practices – if at all attempted on station – can be only very rough. The control "traditional practice" is inevitably simplified. The existing farming systems are much more complex and diverse, and the cultivation techniques much more multifaceted and multipurpose than outside observers initially assume. Attempted simulations of traditional farming systems by scientists fall far short of the reality. Particularly the flexibility of smallholder farm management cannot be captured in on–station simulations.

2.2 Scientists' on–farm trials

If agricultural scientists are at all involved in trials beyond the fence of the research station, these most commonly take the form of scientists' trials in farmers' fields or with farmers' livestock. In Farming Systems Research terminology (cf. SHANER et al. 1982), these are referred to as researcher–managed trials under farmers' conditions. The experimental design and procedure are very similar to those of on–station trials.

Farmers' involvement in scientists' on–farm trials is usually limited to allowing scientists to use part of their land for this purpose. The scientists supply the new inputs required. The farmers may supply labour (paid or unpaid) to help maintain the trials, but the scientists make the ultimate management decisions, possibly against the better judgement of the farmers. For this reason, all production risks must be borne by the scientists.

Measurement and recording of data are done by the scientists or hired assistants, who often also do the actual harvesting, in order to obtain reliable results according to formal scientific criteria. Fairly detailed data suitable for complex analysis can be collected from these on–farm trials, although normally not as frequently and precisely as data collected on station.

This type of trial permits better scientist–farmer communication than on–station trials. In the course of repeated visits to the plots,

the scientists are inevitably drawn into discussions with farmers about the trials. Ideally, they deliberately seek such discussions. The farmers' role is to provide feedback about the scientists' ideas, which – as in the case of on–station trials – are based on the latter's interpretation of agricultural constraints. The scientists do not welcome interference by the farmers in trial implementation, i.e. changes in keeping with indigenous ethnoscience and perception of constraints, as this complicates or prevents the intended scientific analysis of the results.

BIGGS (1987) describes this mode of researcher–farmer interaction as consultative rather than collaborative: farmers are consulted (interviewed) about their problems but the scientists decide which topics and trial designs are given priority. Farmers are likewise consulted about their reactions to the trials, but the final assessment of the suitability of new technologies is made by the scientists.

Multilocational on–farm trials under the control of scientists are suitable for testing the wider applicability of new technologies. With particular reference to innovations in ecofarming, KOTSCHI et al. (1988) stress that attention must be paid to their production variability and to the factors causing this variance. Scientists' on–farm trials can help in this regard by yielding a clearer picture of production variability in diverse environments.

Smallholders operate in a variety of production conditions and face a variety of risks which cannot be duplicated on research stations (GUPTA 1988). The stations are seldom located in the marginal agroecological environments (e.g. with steep slopes) where the poorest families are often found. By deliberately locating their on–farm trials in marginal environments, scientists can test the applicability of new technologies to resource–poor farmers and can select and/or adapt technologies to suit these farmers' conditions.

2.3 Farmers' on–farm trials

The pivotal activity in top–down programmes to generate improved technologies for specific farming systems is on–farm testing by farmers. The innovation to be tested and the trial design are determined by the scientists. The design is simplified so that the farmers can comprehend the differences between treatments. The farmers provide the labour and make the management decisions. Usually, in order not to obscure economic constraints, the farmers are expected to purchase the necessary production inputs. However, an improved infrastructure is often simulated in that the research programme makes the inputs available at official prices.

The scientists' role during implementation of these trials resembles that of an agricultural advisor: giving recommendations, e.g. about planting distances and general crop management, but leaving the final decisions to the farmers. As a result, trial management can vary widely. Recommended operations, cropping patterns, etc may be changed by individual farmers to suit their own particular circumstances. The trials must be closely monitored in order to keep track of what each farmer does, and communication between scientists and farmers must be open and frequent in order to discover why. This makes a high demand on research programme resources, particularly staff time.

The scientists make the final assessment of the innovations, but are more likely to take the farmers' views into account than in the case of scientists' on–farm trials, as the farmers have more opportunity to react and to make their views known. In any case, the farmers involved will make their own (private) assessment of the innovation which they personally tested. Because each farmer makes individual management decisions and because the recording of influences and effects within each plot can be only approximate, the data derived from farmer–managed trials can be subjected to only limited quantitative and statistical analysis. The most important data provided by this type of trial are the opinions and ideas of the farmers involved.

The degree of farmer participation is particularly high in those research programmes which allow farmers to decide which of several different varieties/techniques they will test. Researchers who leave this decision to the farmers assume that the latter know how their farming system functions and will therefore be

interested only in those alternatives which complement their resource management and production goals (FERNANDEZ 1988). In other words, the rationality and indigenous technical knowledge of the farmers are respected and deliberately incorporated into the research programme.

In farmers' on–farm trials, it can be established whether the innovations developed by scientists fit into the existing farming system in technical, economic and sociocultural terms. A direct comparison can be made of the farmer's present techniques and the new technique under the same farmer's management. Farmers' reactions to and assessment of the new techniques can be elicited. Promising new techniques can be improved or adapted to suit specific farming systems or ecological environments.

3. Trials determined by farmers

3.1 Farmers' participatory trials

In contrast to the trials discussed thus far, which are dominated by scientists, farmers play the dominating role in participatory trials. The questions investigated are determined by the farmers rather than the scientists. The latter serve as advisors. Participatory R&D involves close collaboration of farmers and scientists in all phases of the R&D process: defining the problems, choosing possible solutions to be tested, conducting the trials, and assessing and extending the results. As this form of research presents great potential for developing ecofarming techniques (cf. KOTSCHI et al. 1988), it is described here in more detail.

Situation analysis. In participatory R&D, joint situation analysis by farmers and scientists is a process of conscientization in which all participants begin to recognize and comprehend local problems and potentials. The scientists assist the farmers in prioritizing their needs and wants, analysing constraints to achieving them, identifying possibilities of improving their situation, and assessing their capacities for making these improvements. This often involves an historical approach in which the farmers recall past changes in crops, cultivation techniques, landuse and living conditions, and try to identify the causes of these changes. This approach to situation analysis has been taken, for example, by World Neighbors in Central America (BUNCH 1985) and GRAAP (1987) in West Africa, as well as by FLOQUET and her colleagues in Benin (this volume).

During situation analysis, it is often difficult for scientists to adjust from a dominating to a collaborative mode of interaction with farmers. Many scientists with the intention of promoting participatory research still tend to interview farmers and then to select those problems and possible solutions mentioned or demonstrated by farmers which correspond to the scientists' own (prior) assessment. In contrast, in a participatory approach, scientists discuss with farmers and stimulate discussion among the farmers themselves, and remain open to exploring farmers' hypotheses which are not immediately comprehensible to the formally–educated scientific mind but to which the farmers attach great importance.

Setting priorities. After discussions involving both scientists and farmers, the latter decide upon about the area of research to be given first priority and choose the potential improvements to be tested. It is important that the discussions continue until consensus among the farmers is reached: the innovations selected for investigation must be those which the majority of farmers in the group (and all farmers actually conducting the trials) regard as desirable, necessary and possible with the means available to them.

The scientists can offer options for testing, either innovations generated by formal science or existing technologies found in other farming systems. The degree to which farmers will initially articulate their own ideas of possible innovations will depend on their level of self–confidence and their past experience of interaction with scientists. Before group discussions to select innovations for testing, it may be necessary for scientists to delve into almost forgotten traditional practices, examine differences in farming methods practised by farmers in similar environments, and seek indigenous innovations in order to discover local ideas which could be tested (cf. FLOQUET, this volume).

In the course of situation analysis and setting research priorities, a fundamental contradiction of most "participatory" research programmes in agriculture – and particularly in ecofarming – becomes evident. The mandate of the scientists limits the range of options within which farmers can select topics for research. The most pressing problems from the farmers' point of view may have only distant connections with cropping or livestock–keeping. In wider–based participatory programmes (e.g. World Neighbors, GRAAP), the local people have the option to decide if attention should be paid initially to farming, health care, education or some other concern. For example, in Togo some farming communities regarded human disease as the most serious problem; only after eradication of guinea worm were they prepared to address agricultural problems (GUBBELS 1988).

Designing the trials. The scientists help the farmers plan how to conduct the trials and measure the results in such a way that both parties have an objective basis for assessing the innovation. The factors which farmers view as important in testing a new idea are determined, e.g. by asking farmers what they do with a new crop or variety, by observing their informal trials (see below), or by means of ranking techniques or games which reveal decision–making criteria. These factors are then incorporated into the trial design.

It is important that the trials be treated not as demonstrations of better techniques but rather as comparisons of different techniques, including those already being practised or tried by the farmers. Traditional techniques or farmers' indigenous innovations should be given the same value as the introduced techniques (cf. FLOQUET, this volume).

Conducting the trials. During the course of the trials, the farmers are likely to make changes to suit their specific circumstances, to integrate their individual ideas, and to adjust management according to their perceptions of changing conditions. To be able to analyse reasons for differences in farmers' results, scientists must monitor closely what is actually done in the trial plots, e.g. planting densities, grain harvesting dates, occasional harvesting of other plant parts such as leaves, additional fertilizer application. Some record–keeping of trial implementation can also be done by the farmers, even where literacy is not widespread, e.g. by using pictorial techniques such as those developed by HATCH (1980).

Evaluating the trials. Evaluation involves a continuous exchange of ideas and experiences between farmers and scientists during trial implementation. Either the scientists record the farmers' observations (e.g. growth habit, disease susceptibility, yield, marketability of a new variety), or the farmers do at least some of the recording themselves. Here, too, literacy is not a prerequisite; illiterate but highly motivated farmers can quickly learn to read and write numbers (cf. WATERS–BAYER 1985; also GUBBELS, pers. comm. 1988). For recording the results of farmers' trials, local units of measurement and local classifications of seasons, yield characteristics, etc are most suitable. The farmers and scientists then have a common basis of communication in assessing the results. Appropriate analyses of benefits and costs which are of concern to the farmers can be made, e.g. the prices of end products actually obtained and the costs of purchased inputs (cf. ASHBY 1986).

The farmers and scientists also collaborate in deciding on the next step: abandonment of the technique, further on–farm or on–station research to explain and verify results or to improve the technique, or wider dissemination of the technique. The experimenting farmers can also play an important role in the extension process (cf. CHAMBERS & JIGGINS 1986). The ultimate evaluation of the innovation will be the degree of acceptance by a larger number of farmers than those originally conducting the trials. If the innovation is not more widely accepted, further studies are required to discover why, and further adaptations may be necessary.

The foregoing description of participatory R&D is not merely a theory or an idealistic model. It is derived from actual experiences of numerous small teams of scientists involved in farm–

level research (cf. IDS 1987, ILEIA 1988). For example, with the encouragement and assistance of a team of scientists, Philippino farmers identified major local problems, diagnosed causes, listed potential solutions suggested by both farmers and scientists and, after lengthy discussion, came to a consensus about what they wanted to test. This has led to farmers' experiments with their own ideas of enriched fallows and live mulches (LIGHTFOOT et al. 1988).

The solution which the Philippino farmers are testing (sowing *Pueraria* to smother the grass weed *Imperata cylindrica*) is, in itself, not new to modern science. The novelty lies:

- in the fact that the farmers themselves had observed the effect of vining legumes on *I.cylindrica* and themselves suggested trials to find out how they could best use such legumes to reduce their weed problem;
- in the ways that the farmers, with their knowledge of the local agroecosystem, incorporated *Pueraria* into their cropping system;
- in the learning process by which the farmers, through their own experiments, discovered further benefits of legume fallows (soil fertility enhancement, lower labour requirements for recultivation); and
- in the farmers' newly found confidence in their ability to solve their farming problems with local resources, and to interact on an equal footing with scientists.

As is evident from this example, the participatory mode of research leads not merely to the design and adoption of ecologically sound techniques to solve pressing problems in farming. It also strengthens the knowledge–generating and self–help capabilities of the farmers, and paves the way for further cooperation and exchange of knowledge between scientists and farmers. It stimulates a sustainable process of learning and development. This and other actual experiences of scientists and farmers as partners in agricultural R&D are described in the issue of the British journal Experimental Agriculture (Vol. 24, Part 3) which is devoted to "Farmer Participatory Research".

3.2 Farmers' informal trials

Whereas the scientists take the original initiative in the trials discussed thus far, farmers' informal trials are conducted without the direct influence of research scientists. These trials involve indigenous generation of knowledge. Usually unheeded by formal science, farmers conduct small–scale, low–cost, low–risk trials: trying out a new technique, a new variety, a new crop mixture, often using ideas or materials acquired on a trip, from visitors or from neighbours whose experiments they have observed.

Farmers may also draw ideas from the results of formal agricultural research conveyed by official extension services or indirectly via farmer–to–farmer extension. Informal trials play an important role in the process of innovation adoption. Farmers do not simply adopt or reject a new package of techniques promoted by extension. Instead, they extract components which they regard as being potentially beneficial, experiment with these, and develop them further in line with their specific production conditions. Examples of farmers' informal R&D based on formal research are:

- farmers in Sierra Leone experimented with an "improved" rice cultivar and, through deliberate selection, developed an awned variant which they found useful in deterring birds; station–based plant breeders had been selecting against this property (RICHARDS 1985);
- smallholders in Malawi, who were offered an extension package of a high–yielding maize cultivar and chemical fertilizer, showed interest only in the fertilizer and conducted their own experiments to determine the optimal quantity and timing of fertilizer application to their local maize variety (HANSEN 1986).

Examples of farmers' R&D involving original ideas not derived from formal science are given by JOHNSON (1972), BIGGS (1980), BRAMMER (1980) and RICHARDS (1985). LIGHTFOOT (1987) made a systematic study of how smallholders in the Philippines lay out and evaluate their informal trials.

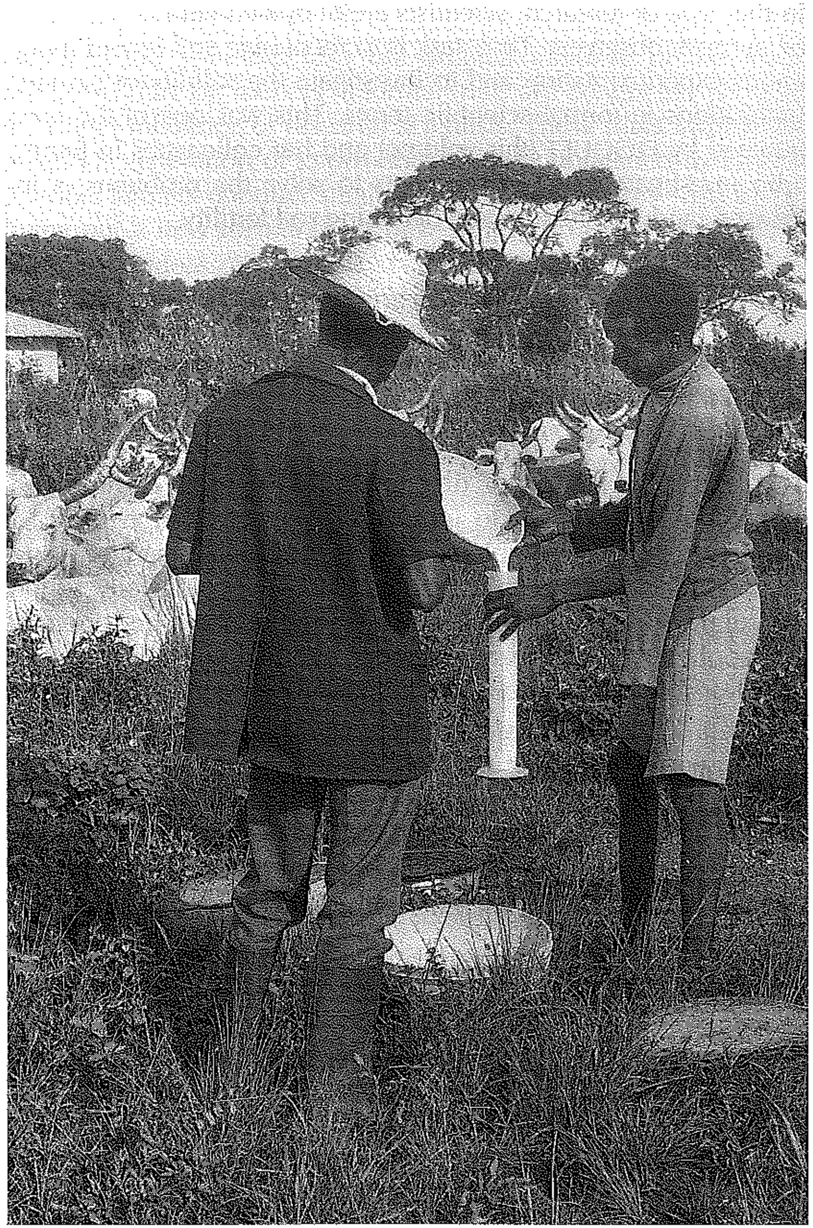
In this type of research, scientists are – by definition – outsiders or, at most, observers. Their task is to recognize and record indigenous experimentation and to investigate the validity of farmers' innovations in formal scientific terms. This was one of the aims pursued by FLOQUET (this volume) and her colleagues in Benin, who investigated farmers' attempts to solve the problems of increased landuse pressure and declining soil fertility.

4. Complementarities between scientists' and farmers' trials

The above description of different types of trials commenced with those best known to formal science: on–station trials. A discussion of the complementarities between scientists' and farmers' trials which could be exploited for ecologically sound agricultural development must begin with the most site–oriented and applied type of research: farmers' informal trials. This typifies the reversals that are necessary in current views of agricultural research.

Observation of **farmers' informal trials** helps scientists identify problems and potential solutions from the farmers' viewpoint. Particularly with respect to ecofarming technologies, farmers' informal trials can reveal possibilities not previously contemplated by scientists. These can then be further investigated in scientist–controlled trials.

Recording farmers' informal trials prepares scientists for participatory research: they gain experience in learning from farmers, they begin to appreciate indigenous knowledge and skills, and they become acquainted with the concepts and methods of "folk science" and are thus better able to communicate with farmers in planning and evaluating collaborative research. When scientists take genuine interest in informal trials, the farmers gain pride in their own knowledge. They are then more likely to feel and act like equal partners in collaborative research.



Measuring the effect of legume supplements on milk yield in a crop–livestock system. During on–farm trials, the farmers continuously evaluate the results on the basis of their own measurements and observations.

Literacy is not required to record trial results. Here, milk yields from cows grazing improved pastures are measured by the milk owners. This Fulani woman, with no formal education, quickly learned to read and write the weights.

In the process of helping farmers carry out **participatory trials**, scientists are confronted with the constraints faced by the farmers and become better acquainted with smallholder strategies to cope with risk and ensure family welfare. The differences between the priorities and objectives of the farmers and those of the scientists in R&D become obvious. The content, design and evaluation criteria of the scientists' trials can then be adjusted accordingly.

By collaborating with farmers in generating and testing new technologies, the scientists help strengthen the informal research process by increasing the farmers' ability and confidence to do their own research and to request information and services from formal R&D systems (BIGGS 1987). As a result, the farmers can adjust their production systems more quickly to changing conditions, and they can exert more "demand–pull" on agricultural research institutions toward problem–focused research.

Continuous monitoring of participatory trials helps identify questions to be addressed in scientists' trials. For example, when farmers begin to experiment with leguminous trees not only to improve the soil but also to provide fodder, scientists can design trials to investigate how the extent and frequency of lopping affects tree survival and its other functions within the agroecosystem. Agricultural advisors will then be able to provide the type of advice in which the experimenting farmers will be interested.

Also by observing and discussing farmers' modifications to introduced technologies during **farmers' on–farm trials**, scientists gain better understanding of local agroecological and socioeconomic conditions and how the technologies can be better adapted to them. Technology components can be identified which require study under controlled conditions to validate results or explore possible alternatives. Hypotheses about factors leading to yield differences in the farmers' trials can be developed for testing in controlled trials.

Several on–farm research teams have experienced how farmers' application of their own knowledge and ideas led to new variants which stimulated further ideas among the scientists. For example, in trials in Nigeria involving sown fallows the cattle-

keepers incorporated local fencing technology. This led to scientists' trials to investigate further possibilities for live fencing (WATERS–BAYER & BAYER 1988). Kenyan smallholders testing tree species for integration into cropping systems began to experiment with different planting sites, spacings, tree–crop mixtures and management methods. Many of these technical options which had not previously occurred to the scientists were incorporated into the design of new on–station trials (CHAVANGI & NGUGI 1987). Similarly, RAQUET (this volume) observed that Rwandan farmers extended the shrub fallow phase in order to produce firewood. He could thus identify the question of fallow duration as worthy of further investigation by scientists in order to improve their recommendations for intensive fallows.

By monitoring farmers' on–farm trials, the scientists also gain deeper insight into farmers' decision–making processes and the differing problems of individual farmers. This helps identify subgroups with different objectives and resources than those of the "average" farmer originally postulated by the scientists. The scientists may also discover where and how adjustments must be made to make the innovation more suitable for the "average" farmer, the resource–poor farmer, the woman farmer or other specific subgroups, depending on the aims of the research programme.

In **scientists' on–farm trials** conducted simultaneously or adjacent to farmers' trials, more frequent or complicated measurements can be made than in the latter. These data aid in interpreting the results of the farmers' trials. The scientists and farmers involved can observe, compare and discuss each other's results.

Scientists'on–farm trials are also suitable for testing new, promising technologies or systems which differ substantially from those presently practised by local farmers. Technical problems in specific agroecological settings can thus be identified. To the extent that farmers' opinions about the trials are heeded, the scientists can identify those innovations which farmers regard as relevant to their needs. The contact between scientists and farmers during on–farm trials can be instrumental in reducing mutual diffidence and facilitating interactions on future occasions when the farmers have the opportunity to visit on–station trials or take a more active part in the research programme.

As scientists gain a clearer picture of production variability from multilocational on–farm trials, they are in a better position to judge the situations and locations in which the new technology could be successfully applied (recommendation domains), to identify technologies which promise greater reliability of yield and, thus, less risk for the smallholder, and to conduct further on–station research to find ways of reducing variability/risk.

In applied research, **on–station trials** seek answers to questions of practical importance for agricultural development identified during on–farm research and produce results which can be fed directly back to the field. This focusing of research permits more effective allocation of the scientists' time and research funds in the service of the farmers.

On–station trials play a supportive rather than a leading role in ecofarming research, but this support is vital. They can play this role only if there is two–way communication between scientists on station and those in the field. On–farm trials are regarded by many scientists as an extension rather than a research activity. Station–based scientists with previous experience in working with and learning from farmers can better appreciate the findings of field scientists in direct and regular contact with farmers. Therefore, station–based scientists should be given an opportunity to gain some experience in on–farm research, at least in observing and discussing on–farm trials during field trips and meetings with on–farm researchers and collaborating farmers.

5. Combining scientists' and farmers' trials in ecofarming research

The scientists reporting the results of their ecofarming research in this volume have ventured beyond the research station and explored ways of combining station– or project– based work with various forms of on–farm or farmers' trials.

When farmers have an opportunity to apply their knowledge in on–farm trials, site–appropriate ideas can emerge. In trials with improved pastures in central Nigeria, cattlekeepers incorporated local live–fencing technology.

Farmers and scientists are partners in collaborative research. By discussing farmers' modifications to innovations, scientists gain better understanding of local conditions and how technologies can be adapted to them.

The farmers and scientists frequently visit the on–farm trials together and monitor progress. Here, Kenyan scientists and a woman farmer are checking for the presence of nodule bacteria living in symbiosis with the legume plants.

Farmers, such as these women in northern Kenya, who have collaborated with scientists in on–farm trials, gain self–esteem and confidence in their ability to do research and improve their farming systems.

In the work reported from **Tanzania**, on–station trials to determine the optimal combination of grasses, legumes, shrubs and trees to be planted along contour lines were followed by scientists' on–farm trials in farmers' fields. During the course of this work, the need was recognized to determine management requirements and appropriate designs of these "macro-contourlines" for different farm situations. To this end, trials under farmers' management will now be necessary.

The soil and water conservation techniques studied in **Burkina Faso** had already evolved out of a fusion of external scientific knowledge and indigenous experimentation (REIJNTJES 1986). The work described in this volume involves component research: scientist–controlled trials at five on–farm sites to investigate the relative advantages of different bund–building materials and configurations, so that appropriate recommendations can be made for specific environmental conditions. Unfortunately, indigenous knowledge in this regard and the reactions of the farmers to the results of the on– farm trials were not noted.

The work in **Colombia** likewise comprised scientist–controlled on–farm trials, in this case, to investigate the efficiency of a new cropping system (small plantations of deciduous fruit trees with undersown arable crops) which some smallholders had already begun to practise on sloped land. Now that the greater efficiency of this system in comparison with arable cropping alone or fruit tree plantations without arable crops has been established, trials with more active involvement of the fruit growers are underway in order to improve and intensify the cropping system.

The work in **Rwanda** grew out of the realisation that the standard recommendation for intensive fallow developed by project–based scientists could not be directly applied to the diverse types and qualities of soils in smallholders' fields. The suitability of various fallow species for different agroecological conditions was tested on station. The performance of the standard intensive fallow was tested in on–farm trials designed, managed, recorded and evaluated by scientists; the labour for establishing, cutting and incorporating the fallow plants was provided by the farmers. The survey of other farmers who had received seed for intensive shrub fallow amounted to an evaluation of farmers' trials. Here, it was discovered that the farmers applied their own ethnoscience in testing the innovation and even incorporated ideas which station–based researchers had rejected. Farmers who planted sweet potato as first crop after the sown fallow achieved satisfying results. This stimulated scientific reexamination of the merits of sweet potato as a post–fallow crop. Here, the complementary nature of farmers' and scientists' trials is exemplified.

The most innovative approach to combining farmers' and scientists' trials is reported from **Benin**. After project–based research was already well advanced, the field team sought indigenous ideas for adjusting the local farming system to greater land pressure. The results of the on–station trials and the farmers' informal trials are being linked in farmers' on–farm trials, in which both indigenous and exogenous innovations to maintain soil fertility are being compared with conventional smallholder practices. Of the cases reported in this volume, the work in Benin comes closest to participatory R&D. The team of young scientists involved had no previous experience in this nonconventional approach. However, they commenced their work with the conviction that peasant farmers are rational, knowledgeable and innovative people. This conviction is the scientists' key to entering a partnership with farmers in agricultural development.

It is noteworthy that the ecofarming research described in this volume was not conducted within formal research institutes, but rather within the framework of development projects. Through extension activities, project personnel had already made contacts with local farmers and had begun to recognize their greatest needs and constraints, on the one hand, and the inadequacy of existing extension content, on the other. Particularly in projects aimed at maintaining natural resources and improving the lives of resource–poor farmers, applied and adaptive research is a necessary component of project work in order to develop appropriate extension messages. Experiences reported here illustrate how farmer–scientist collaboration can greatly improve the impact of project–related research on the development of ecofarming techniques.

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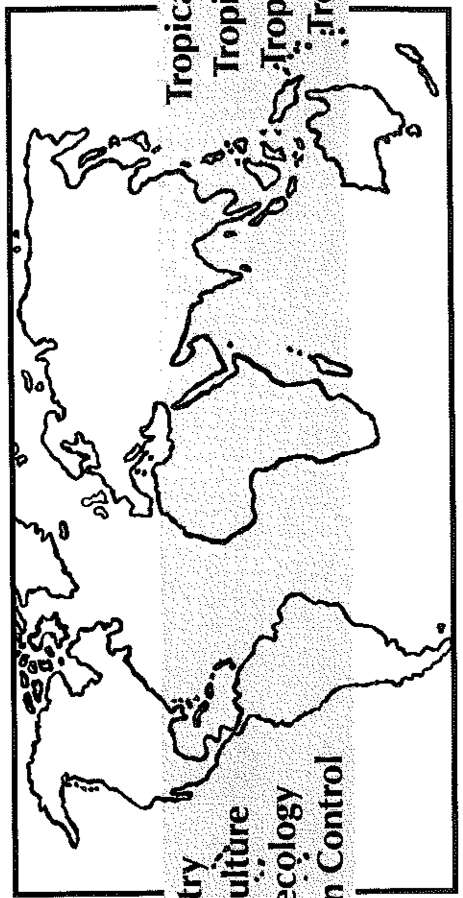

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