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Water harvesting in Bakel, Senegal

Photo M. Hallberg

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Sem. upps.

Abstract

This is the result of a field study performed during July - September 1990 in Bakel, eastern Senegal. The village Bakel is in a semi-arid region with low agricultural productivity as a result of drought, degraded soils and excessive rainwater runoff. The thesis presents environmental conditions of the region and the water harvesting techniques introduced by a Swedish funded reforestation project. A series of mesurements were made in a drainage basin used by the project as an experimental area to reveal the effect of stone and earth bounds on the plant available soil moisture. The bounds' function is to decrease runoff, thereby increasing infiltration. The results of the study do not support the hypothesis that the bounds increase soil moisture. In addition, no differences were found between the two bound types in their ability to increase soil moisture.

Acknowledgments

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THE ROYAL INSTITUTE OF TECHNOLOGY

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Preface

This study has been carried out within the framework of the Minor Field Studies (MFS) Scholarship Programme, which is funded by the Swedish International Development Authority (SIDA).

The MFS scholarship programme offers Swedish undergraduate students or recent graduates an opportunity to carry out two months' field work in a third world country for their Masters theses or similar in-depth studies. The study should primarily be conducted in a country supported by the Swedish development aid programme.

The main purpose of the MFS programme is to create interest among Swedish university students to work in developing countries, providing them with an initial experience of conditions in the third world. A further purpose is to attract students to enter into professions suitable for this kind of work, thus supplying SIDA staff and widening the Swedish personnel resources for recruitment into international organisations.

The International Unit at the Royal Institute of Technology (KTH), Stockholm, administers the MFS programme for all faculties of engineering and natural sciences in Sweden.

Sigrun Santesson
Programme Officer
MFS-programme

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1 INTRODUCTION

1.1 THE SAHEL

The Sahel is an arid or semiarid belt stretching across the African continent from Senegal in the west to Ethiopia in the east. By climatological criteria, the Sahel is the zone south of the Sahara that receives between 100-600 mm of annual rainfall. It can be divided into the northern Sahel, with precipitation less than 300 mm, and southern Sahel, which receives more than 300 mm. These subzones are followed by the Sudanian zone receiving up to 1200 mm per year, and thereafter is the Guinean zone. This thesis concerns a zone which is usually referred to as the Sudano-Sahelian.

In these semiarid regions the limited availability of water is in most cases the major constraint to rainfed agriculture. In the arid regions the amount of rainfall is usually not sufficient to sustain a crop, whereas in the semiarid regions it is not so much the quantity, but the uneven distribution of rainfall in time and space which makes rainfed agriculture a risky enterprise. The variability of rainfall, or the inter- and intra- annual variation, is very high in semiarid zones (25-50 %). This implies occasional long periods of drought between rainfalls, that may cause crops to die so that farmers have to reseed their fields. If this reseeding occurs too late the crop can not mature before the end of the wet season. Dry spells might thus lead to complete crop failures (Fries 1989).

Even where the amount of rainfall is sufficient for crop production, part of the rainfall may be lost as surface runoff before even reaching the root zones of the crops. Surface runoff is likely to occur when rainfall intensities are high and the infiltration properties of the soil are poor, circumstances which are common in tropical arid and semiarid regions. Either the rainfall intensity exceeds the infiltration rate or the duration exceeds the soils storage capacity. The threshold amount of rainfall required to generate runoff depends on the conditions of the soil (surface retention, hydraulic permeability, porosity, moisture etc.) and the vegetation cover. Not only moisture is lost through runoff, but also nutrients and even land since the running water often has a considerable erosive effect on the surface. The proportion of rains producing erosion in tropical climates is 40 %, as compared with 5% in temperate climates.

The continuing degradation of the environment in these regions has led (and still leads) to a further disturbance of its water balance as a result of higher runoff rates, lower infiltration capacity and a reduction of soil storage capacity. These factors reduce the amount of water available to crops as well as to natural vegetation.

An increase in the quantity of water available to crops can lead to an improvement in the reliability of production, as well as to the level of production, and it can sustain a crop during an otherwise damaging dry spell. It can even make crop production possible where none is viable under existing conditions. The water availability for crop production can be improved through erosion control measures and water harvesting. Water harvesting can be defined as the collection and concentration of surface water runoff in drylands. (Reij 1988, Fries 1989)

1.2 SENEGAL

The Republic of Senegal, the most westerly state of Africa, has an area of 196200 km^2 and had a population of 6.8 million in May 1988. The southern border is with Guinea-Bissau, and also with Guinea on the northern edge of the Primary sandstone outcrop of Fouta Djallon. In the east the border is with Mali, the only area of bold relief in Senegal where there are Pre-cambrian rocks (in the Bambouk mountains). The northern border with Mauretania lies along the Senegal river. Much of this area is semi-desert and as in most parts of the country, water for crops and domestic use is very scarse. (Europa publications 1990)
The main physical regions of Senegal are: 1. Cayor or the western plains, 2. the Ferlo desert, 3. the Senegal valley, 4. the Upper Gambia Basin, 5. the Saloum-Casamance region (Figure 1).

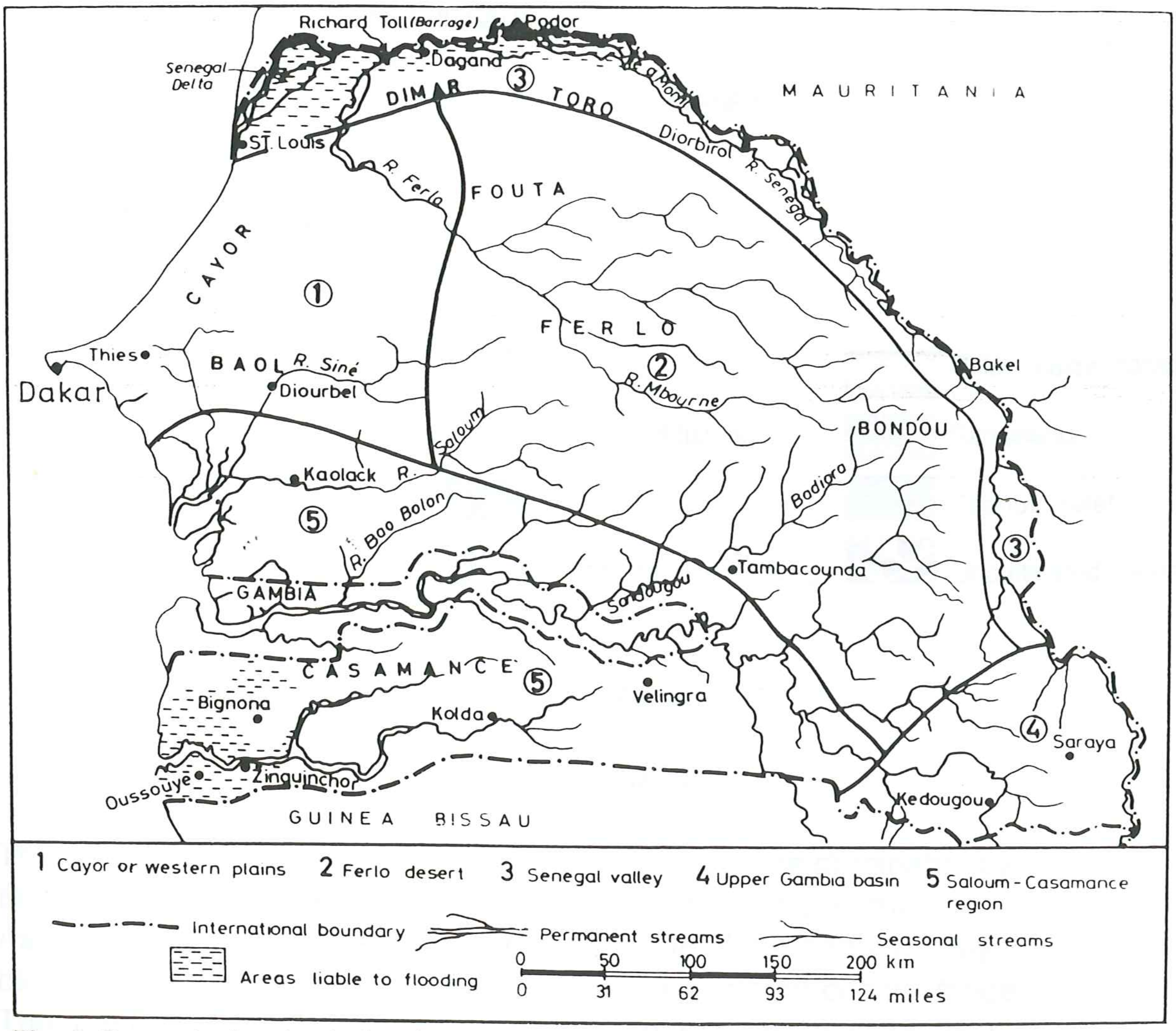


Fig. 1. Senegal - the physical regions and drainage. (Udo 1978)

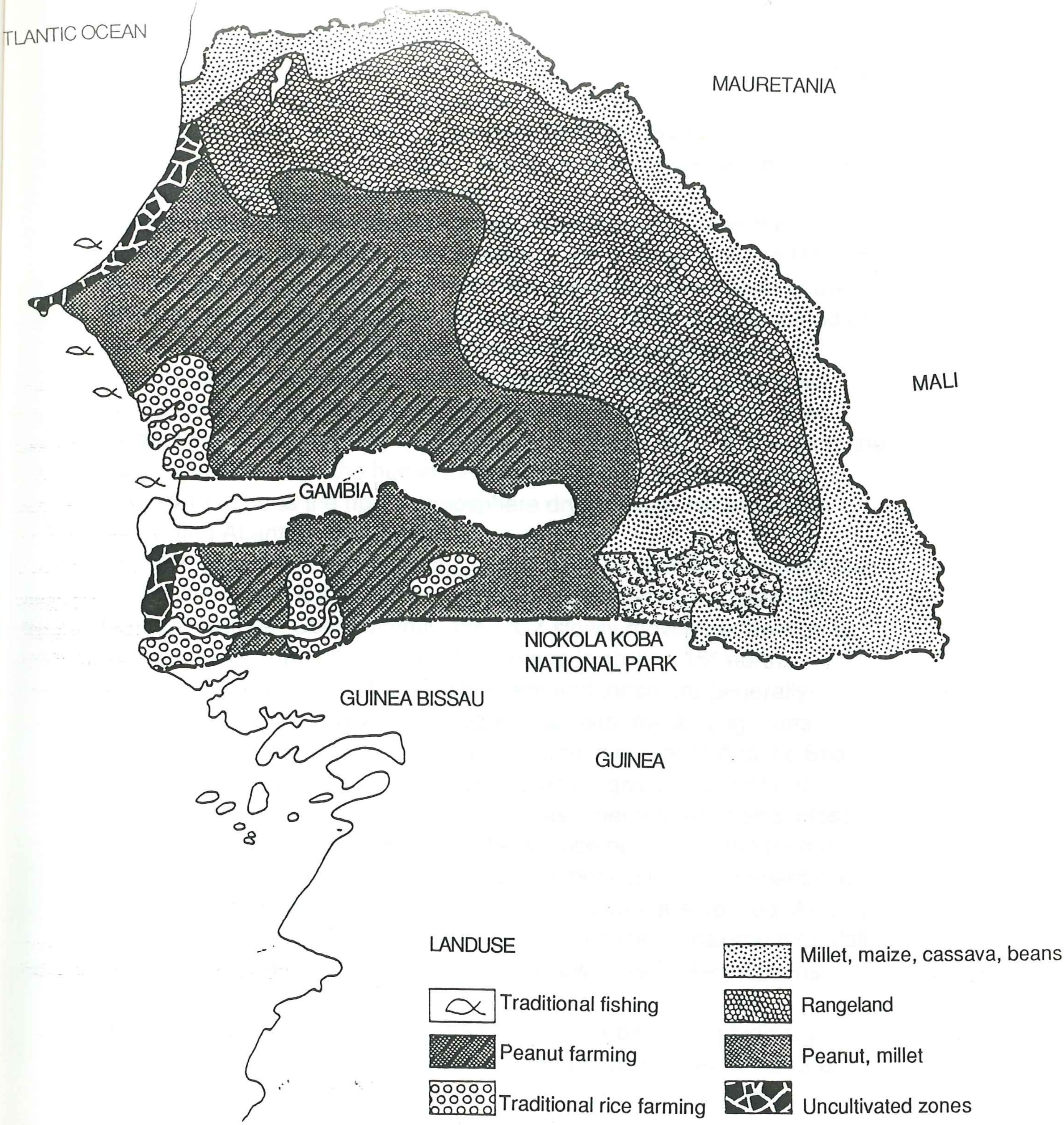


Fig. 2. Use of land in Senegal. (Les éditions jeune Afrique 1983)

1.3 CLIMATE

The air masses occurring over the Senegal territory are dominated by three types with different extent and duration. The first one, the *maritime trade winds,* stem from the anticyclone of the Azores. They blow in a NNW direction and influence only the northern coastal fringe. The maritime winds are incapable of discharging humidity since their

vertical structure blocks the development of cloud formations.
Of greater importance are the *monsoon* and the *harmattan*. Where they meet, the Inter Tropical Convergence Zone (ITCZ) is formed. This zone moves seasonally according to the strength of the two opposing airmasses. The movement ot the ITCZ determines the location and depth of the humid area over the continent.
During the northern hemisphere winter, West Africa is under the influence of the harmattan or *northeasterly trade winds* and the ITCZ is close to the equator. The northeasterlies prevail to an elevation of about 3000 m, bringing dry and stable air masses and often carrying a load of dust in suspension as a dry haze. The harmattan is a branch of the continental Sahara trade wind. It dominates the majority of Senegal during the dry season and is characterised by a pronounced diurnal thermal amplitude. Moving westwards and approaching the coastline, the harmattan rises over the humid airmass of the maritime trade wind. It thereby reinforces the upper atmosphere dryness and contributes in preventing Atlantic precipitation.
During the northern hemisphere summer, high temperatures prevail over the continent and a thermal low pressure area builds up at about 20° northern latitude. Consequently, the ITCZ slowly moves northwards to reach a position which at the earths surface is around 15° north. *Southwesterly winds* invade the continent and these are generally referred to as the monsoon. This equatorial maritime air originates from the Saint Helene trade wind anticyclone in southern Atlantic Sea. It benefits from a long maritime crossing which gives it humidity. It enters the country in April-May and dries as it penetrates inland. Most rainfall is usually not received near the surface position of the air mass discontinuity, but further south. This occurs because the continental air masses are warmer than the oceanic ones, so they are uplifted. As only the oceanic air produces the precipitation, the zone of maximum rainfall is where these air masses are thicker. (Nieuwolt 1978, Les éditions jeune Afrique 1983)
An important feature of the West Africa Sahel are the longitudinally periodic and progressively westward moving disturbances which are called Easterly Waves. These are bands of storm activity, often associated with squall lines, which originate north of the semipermanent Congo Basin convection region. They move from east to west, with their general surface position lying between two fast moving airstreams several kilometres up in the atmosphere, the Tropical Easterly Jet (TEJ) and the African Easterly Jet (AEJ). The TEJ, occuring roughly at an altitude of 12 km, is a continuation of the Indian Ocean summer monsoon circulation system. The AEJ is a function of the thermal contrast between the hot Sahara and the cooler ocean, particularly the upwelling areas of the Gulf of Guinea. As the Easterly Wave disturbances move further west into the Atlantic Ocean, a significant fraction of them develop into tropical storms. (IUCN 1990)

The climatic year is divided into two principal seasons using precipitation criteria. For the study area, the rain season starts in June and lasts until September or infrequently October, with a peak in August. The phenomena that cause precipitation are the earlier mentioned squall lines, improperly called tornadoes, that sweep the territory from east to west. The rains deposited by squall lines are from storms, accompained by blasts of wind, thunder and lightning. They mark the debute and end of the rainy season in the south of the country, but are also the most essential precipitation sources. The first few rainstorms are violent and come from the NE, since the maritime winds tend to turn at ground level. As the rainy season progresses, the rains come from SW. The dominant cloud type is cumulus because of the upward movements of the maritime airmass. As a result, the rainfall pattern is unpredictable. The dry season is divided into three parts; the warm-dry in October-November, the cool-dry in December-February and the hot-dry in March-May. Throughout the dry season the winds are northeasterly and carry large quantities of dust. Temperatures vary with season and continentality. Both diurnal and annual amplitudes increase eastwards. (Les éditions jeune Afrique 1983)

Bakel, the study area, is situated at latitude 14°54'N, longitude 12°28'W at an altitude of 25 m a.s.l. Its climate can be classified as a hot, dry steppe (BSh), according to the Köppen classification system.
Table 1 provides a general idea of the climate in Bakel (1990 serving as an example).

Table 1. Mean temperature, total potential evaporation and total rainfall for Bakel, 1990. (Station Météorologique, Bakel)

	month											
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
mean temperature, °C	24.1	28.8	32.5	33.8	35.8	45.4	30.1	29.1	28.8	31.0	29.0	26.5
rainfall, mm	-	-	-	-	-	106.7	28.7	184.3	72.4	6.4	-	-
potential evaporation, mm	334.5	379.9	510.6	447.4	497.2	399.8	222.7	152.2	178.1	186.2	280.0	318.1

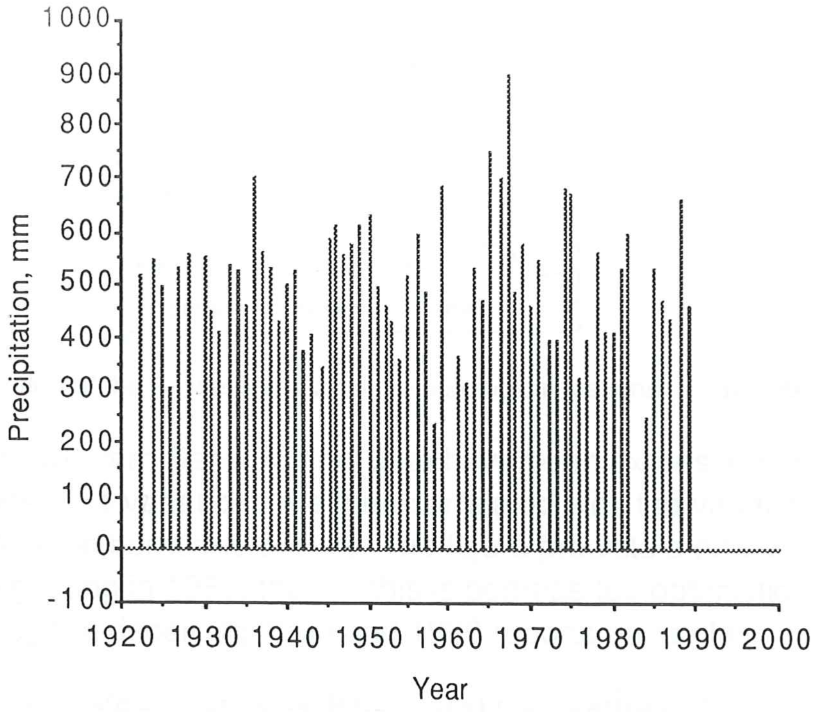


Fig. 3. Rainfall in Bakel during 1922 to 1990. Values from 1929, 1960 and 1983 are missing. (Station météorologique, Bakel)

Figure 3 shows the large fluctuations in annual precipitation for the period 1922 - 1990. The annual mean is 505.1 mm. The amount of rainfall fluctuates not only in time, but also in space - closely situated regions show conciderable differences. Figure 3 can be compared with figure 4, showing seasonal precipitation anomalies from 38 western Sahel stations (figure 5) expressed in terms of the standard deviation of June through September average rainfall for 1947 - 1989.

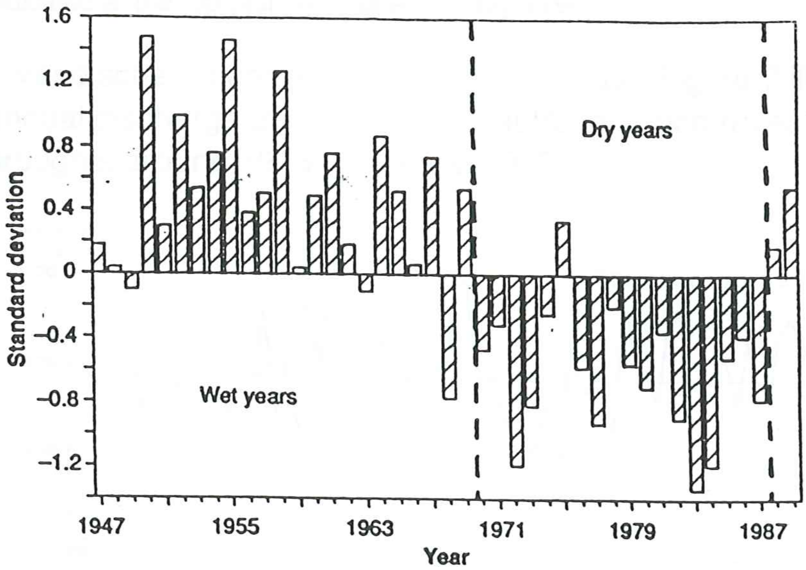


Fig. 4. Seasonal precipitation anomalies from 1947 - 1989 in standard deviation of average rainfall. (Gray 1990) (For further discussion on these anomalies, see article by Mattsson and Rapp in AMBIO no. 5, 1991.)

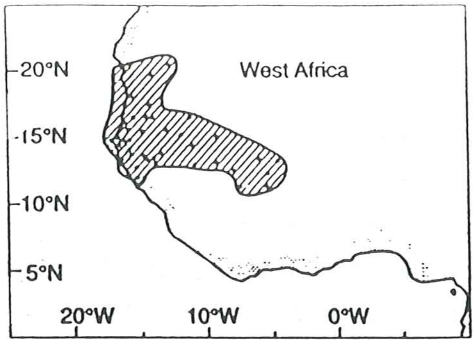


Fig. 5. Location of the 38 western Sahel meteorological stations. (Gray 1990)

In figure 6, western Sahel rainfall data have been expressed as wet and dry periods. The variations are then correlated with the variations of intense Atlantic hurricane activity. The figure predicts a new wet period beginning in 1988, though this is perhaps too optimistic considering the deceiving 1989 and 1990 reports on rainfall.

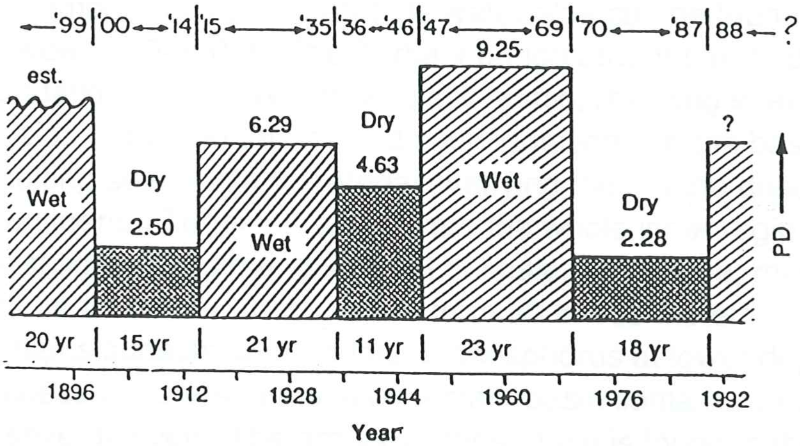


Fig. 6. Rainfall periods in western Sahel separating selected mean annual values of hurricane potential destruction (PD). Mean annual PD and dates for each periods are indicated at the top (est., estimated). (Gray 1990)

River discharge correlates closely to climate. Figure 7 illustrates the annual discharge of river Sénégal at Bakel which reveals major droughts around 1913, 1944 and 1972.

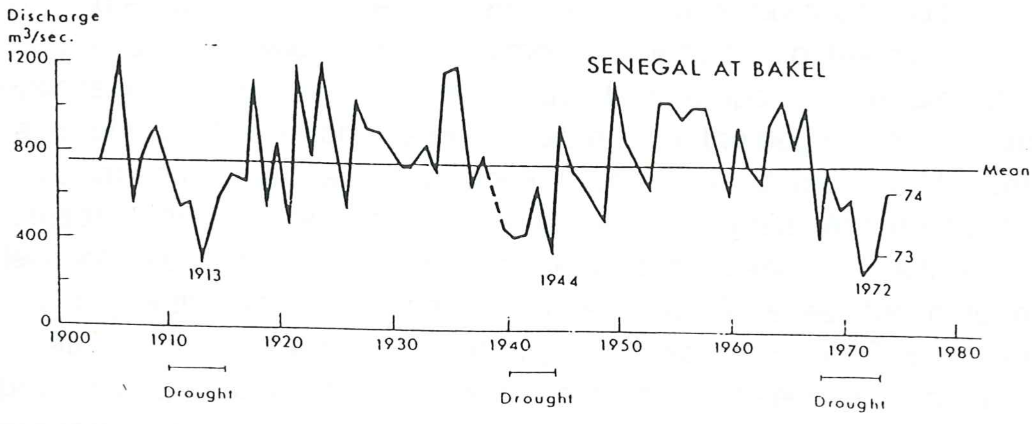


Fig. 7. Annual discharge of river Sénégal at Bakel. (Sircoulon in Rapp et al 1976)

1.4 GEOLOGY

The African continent is an unbroken crystalline basement complex formed during the Precambrium period. It corresponds to an ancient granite-injected mountain range, which has been eroded . The basement complex is composed of green and chloritic schists and quartz, which are folded, slightly metamorphosed and traversed by various granites. It is 2000 million years old. The precambrian base becomes visible only in south-eastern and eastern Senegal.
During the Cambrian to Devonian periods, the basement complex went through an erosion cycle with general uplifting and mountain building. This dry period was followed in the Carboniferous to Cretaceous periods by a wet cycle of marine inundation, due to subsidence of northern and central Africa. The sea occupied the majority of modern Senegal. Sediments from the end of the Cretaceous are found at 200 m depth and are visible around the Cap Vert peninsula. The clayey chalk of the period is an important aquifer, and the watertable can be found at depths between 100-350 m. The Tertiary period brought an end to marine inundation, but the region was still humid, resulting in extensive erosion of the mountains and sedimentation into the basins. The resulting sedimentary material overlying the marine deposits is called "Continental Terminal" and covers the whole inner region of Senegal. The consolidated sediments consist of shale, sandstone, marl, sand and clay. The sediment thickness varies from 20 to 100 meters, and sometimes contains substantial amounts of phosphorus at lower depths. The successive layers in the sedimentary basin contains underground water at several levels. The groundwater surface is found in the sandstones of Continental Terminal or in the Eocene limestones. The village wells reach them at 30-100 meters of depth. It was probably during the Miocene and Pliocene epochs of late Tertiary that laterite began to be formed on the upper 1.5-2.5 m of the Continental Terminal, resulting in the extensive laterite plateaus evident today. The origins of laterite are still not well known, but some factors were imperfect drainage and flat land. At the beginning of Quaternary period, the Senegal river began to form and erode the Continental Terminal, so that today the floodplain which is 10-15 km wide, had dug almost to the bottom of the marine deposits, exposing many schists and quartz outcrops. On the "almost island" of Cap Vert which has been visible since the beginning of Eocene, the volcanoes of the Mamelles appears; Goree island and Cap Manuel represents the most recent (Tertiary) volcanic outbursts. At the end of Pleistocene epoch the region was cooler and more arid than before, coinciding with glaciation in the temperate zones. This resulted in dune formation in the Sahara, and dune migration into the Sahel. The Holocene epoch was once again humid, and the processes of sedimentation and laterization continued. The climate was reversed to a drier regime during 5000-2000 BC, resulting in dune movements as far south as

Bakel (as deduced from the high amount of coarse silt and fine sand in the soils). The Ferlo plain became a land without surface water. From 2000 BC to the present, the region has been generally semihumid. (Deschamps 1964, Sadjo 1988, Éditions jeune Afrique 1983, Furon 1963, Haughton 1963)

1.5 GEOMORPHOLOGY

Senegal is mostly flat and at low elevation. The low plateau continues as far as the eye can see, and the altitudes are less than 130 meters except for the southeast region where the relief is more broken.
The zone of action for the project covers an area of 2500 km^2. It stretches from 80 km north of Bakel to just south of Kidira. In the west it is limited by the Ferlo cuirasse plateau and in the east by the Sénégal and Faleme rivers. The terrain in the study area belongs partly to the base, and partly to mesozoicum-tertiary sediments immediately superimposed onto it. The base terrains are usually referred to as Cambrium or Infra cambrium and they usually appear metamorphosed or folded.
Three major geomorphological ensembles can be distinguished in the landscape:
1) In the west, the Ferlo cuirasse plateau which developed on the continental terminal sandstone. A well marked corniche of 1.5-2.5 m thick laterite, consisting of well consolidated base laterite and residually brown, lightly sandy clay mixed with metallic oxides, overlayers light colour sand and quartz. Sometimes this sandstone matrix present a 30-35 m thick silty-clayey character.
2) In the east, quaternary alluvial formations from primarly the Sénégal and Faleme rivers. A system of levées with sandy to silty-clayey texture, typically cross-stratified,10-15 m thick, and basins of decantation with clayey texture along the two rivers. The alluvial valley, rather large in the north zone, diminishes towards the south and along the Faleme river where it is reduced to a strip, two km wide. The hydrogeographical network of temporary flow has also deposited alluvails, especially developed in the most southern part.
3) A vast ensemble of paleocene age stretches between the two former formations. There are two types of formations: massives or banks of hard rock, originally of important relief, surrounded by colluvial piedmonts with a downhill decreasing amount of coarse material; and vast surfaces or plains, locally with rocky parts, eroded by a hydrographic net. The lithology varies- sandstone, quartzite, schistose and volcanic rock. (Mougenot 1984, Les éditions jeune Afrique 1983)

There has probably been intense tectonic activity in this area. The breaks generally follow a direction SO-NE parallel with the principal structures.

1.6 SOILS

The different geomorphological phases and the formations they have created have had a great influence in the pedogenesis of Senegalese soils. In the zone covered by the project, the following groupings can be distinguished: raw mineral soils, weakly developed soils, ferroginous tropical soils, vertisols and hydromorphe soils (dr Sadjo personal information).

The name raw mineral soils (entisol, yermosol) is used to describe materials in which the horizon development is minimal. They have a type (A)C profile. This weak evolution is due to either the nature of the material or the reorganisation of the profile from erosional phenomena. The soil's top layer is eroded by either wind or water, thus preventing a distinct evolution of horizons. Among the raw mineral soils one can distinguish 1; lithic soils, formed on sandstone gravel or on schistoses which often have a ferralitic or ferroginous crust, and 2; regolith soils, formed on Continental Terminal and characterized by a strong restructuring of materials by hydrological erosion. The regoliths generally correspond to the formations of Continental Terminal, have little agricultural value and are very sensitive to hydrological erosion. The vegetation growing on this soil is composed of *Combratum spp.*, *Acacia macrostachya* and *Sterculia setigera.* The principal soils found in the maritime sand dunes are also raw mineral soils. They are more or less uniform, with 95% sand content, with a meager vegetation of *Aristida sp.* and *Hypomea sp.,* and very vulnerable to eolian erosion.

Weekly developed soils, are a group which is more developed than the former type. They have a reorganized profile caused by either erosion or eolian/colluvial contributions. Their texture is sandy, silty with a gravel content of 40-60%; the finer materials in the soils are lost by hydrological erosion. The weekly developed soils are well represented in eastern Senegal, and are found as gravel material on ferroginous crusts on the quartzites of Bakel. They are often found in the recent colluvial banks and in recent sandy alluvial levées, in the Senegal river valley or in the valleys of Continental Terminal.

Ferroginous tropical soils have a distinct ABC profile. They are mainly leached savanna soils with little organic content (< 2%). The most leached ferroginous tropical soil is characterized by an ironoxide accumulation in the B horizon, under a light A2 layer. The less leached soil type has ochreous to ochre–reddish horizons less differentiated than the more leached type. Especially where drainage is poor, ironoxides accumulate and ferroginous concretions may occur. More than 50% of the country is covered by these soils, on sandy to sandy-clayey regions on the Continental Terminal. The vegetation type varies with climate. The ferroginous tropical soils sandy texture make them vulnerable to erosion. Also, where the ferroginous crust is near the surface, the infiltration capacity is weak and the risk for runoff erosion

is high.
Hydromorphe soils and vertisols are found somewhat all over the country. Their presence is connected with carbonates and limestone. These are the principal soils of flooded or irrigated ricefields, and are not subject to erosional phenomena.
(Sadjo 1988, Bridges 1990)

1.7 THE PROJECT

The PROBOVILs, *villagers reforestation project*, are found in the Senegalese departments of Louga and Bakel. The projects started in 1982 as a part of the Swedish Sahel programme. They were financed by SIDA and administered by FAO. In 1986 the project was taken over by a Swedish forestation firm, SILVI NOVA AB, and FAO was replaced by UNSO.

The long-term aims and principal objectives for both areas are:
-to provide food sufficiency and better living conditions for the rural population;
-to develop and implement methods for a wiser use of natural resources, respecting the rural need of forestry products: firewood, fodder and wood for construction;
-the reestablishment of the ecological equilibrium: organisation of, and technical assistance to the villagers in the combat against the degradation (desertification) of their immediate environment
-to support the intervening capacities of the provincial forestry commision.

An important purpose of the projects is that the villages reach the highest possible independence in their actions. The first step is discussions with the villagers to formulate their needs and problems. The realization of these ideas should be done by the farmers with the project providing technical advice, information, training and a minimum of material. The aim is a high participation of villagers at both the planning-decision level as well as in the technical implementation. The techniques used should be locally adjusted, as far as possible. In dealing with agriculture, animal husbandry and forestry, the village should be seen as a unit. The project cooperates with organisations (women-, village-) as well as with individuals and families.

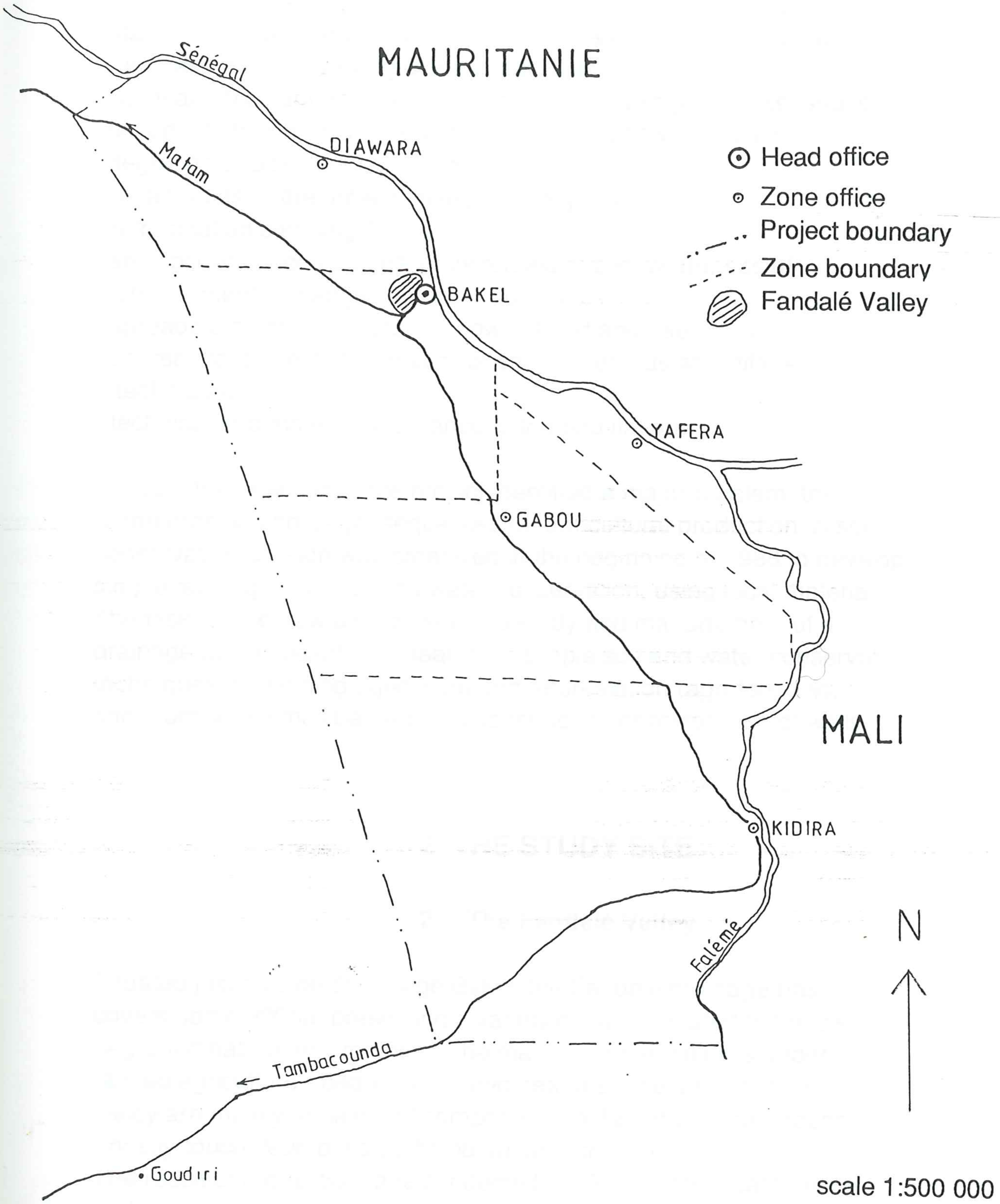


Fig. 8. The location of PROBOVIL (Ndiaye & Hallberg 1989).

1.7.1 Bakel

The area of operation in the department of Bakel covers 2708 km^2 (figure 8). It is divided into five subzones, each with a responsible forester, and covering 8-12 villages. The subzone foresters' task is to establish a collaborative relation with the villagers in assisting them to express their needs and propose activities.
The head office of the project is situated in the village of Bakel and is divided into four divisions: forestry, sensibilisation/vulgarization, integration and soil conservation.
The activities of the project have principally been
- reforestation campaigns
- sensibilisation; campaigns for increased public awareness of environmental changes and land husbandry
- spreading of improved stoves; how to build and use them
- courses for project staff in sensibilisation methods and different techniques
- technical and material assistance to the population.

In 1987, the direction of the project identified a major problem: the runoff erosion and its consequences for agricultural production. A soil conservation division was organized in the beginning of 1988 to develop simple techniques of soil and water conservation, using local material. The task for the new division was the study and management of a drainage basin, including research on simple soil and water conservation techniques, combining agriculture and reforestation (agroforestry), construction of small barriers and construction or restoration of wells.

2 THE STUDY SITE

2.1 The Fandalé Valley

Situated just outside the village Bakel, the Fandalé drainage basin covers some 900ha, presenting a variety of cases related to the clearly degraded natural environment. The majority of the valley is under rainfed agriculture - beans, millet and peanuts. The farmers of the valley are mainly female and composed of different ethnical groups (mostly *toucouleur*, but also *bambara* and *soninké*).
The result of a questionnaire conducted in 1987 by the local forestry authorities indicated that harvests had been sufficient until 1970, when a decline in harvest due to drought and soil degradation resulted in the partial abandonment of arable land. Aware of the situation, the farmers had already contacted GRED (research and realisation group for eco-development) in order to find a solution. A cooperative agreement

was signed, defining the responsibilities of the farmers' groups (which consists of 150 members of COMEF- the Fandalé valley farmers' committee) and the project.

An inconvenience for the protection of the basin is the proximity to the village Bakel. Grazing livestock move more or less freely, grazing non- or poorly fenced fields and browsing the tree-bush vegetation. Also, the cutting of wood for fires further reduces the already degraded forest. On the quartzite hills the natural community of *Combretum glutinosum, Pterocarpus lucens, Guiera senegalensis* etc has been replaced by *Jatropha chevalieri*, a species with low economic value. Nevertheless, the proximity to the village could also be an advantage, facilitating studies and visits. Also, the valley can serve as an example for the rest of the Department, because the valley has the same relief and principal soil types.

2.1.1 Physical conditions of the Fandalé valley

The drainage basin is formed on Cambrian ground and has a west-east orientation. It is limited by the large levees of the Senegal river where the ephemeral streams of the valley turn north, paralleling the river. Roughly a third of the drainage area consists of rocky hills of slightly metamorphosed quartzite, hard sandstone and more rarely schistose. Their altitude is approximately 60 meters and their westward hillsides slope more gently than those facing east. Areas between loose stones and boulders are occupied by tropical ferroginous leached soil, rich in organic material.

On the piedmonts, ferroginous crusts are found. They are formed on gravel at the same level around the hills and are discontinuous with the bedrock.

The gentle sloping silty areas closest to the hills, or the central sandy zones, are usually planted with peanuts. The lower and clayey part, which often inundates from rains, is cultivated with millet and sorghum.

The drainage basin is characterised by a dendritic net of ephemeral streams. The gradients of the hillslopes are about 15%, progressively diminishing to 2% on the piedmonts.

The vegetation is essentially of the bush-savannah type, characteristic for the north sahelo-sudanian zone. It is generally meager, except along the ephemeral streams where the vegetation is more dense. The vegetation is degraded and consists primarly of bushes less than 6-7 meters high. *Combretum spp.*, *Balanites aegyptica* and *Acacia Senegal* are the predominant species.

High runoff on gentle slopes (1-2%, as in most cases of West Africa) occurs on soils of poor permeability. The impermeability of the subsoil

facilitates the quick runoff. This is especially true for silty soils with poor vegetation cover. The absence of a vegetation cover exposes the soil, which already is of weak structural stability due to a high proportion of silt and lack of organic material, to the force of rains. The impact of raindrops disaggregates the soil and the dispersed particles are quickly swept away. The infiltration pores are blocked and impermeability is common. For a soil in this condition, even a three millimeter rain is enough to cause erosion. (Wright)
In the valley, the silts are almost totally impermeable, and the sand which is found on some surfaces is too shallow to have any effect on the percolation. Also, the ferroginous crusts which are porous but widely spread are too limited to influence the drainage. The areas of loose stones or cracked rock, found on the hills, permit infiltration of water to some tens of centimeters. Where the slopes are accentuated the surface is left bare. (Dubois 1989) In the beginning of the rainy season, the runoff as a part of total precipitation reaches 60-70 % (Ndiaye, pers. comm.). As the season proceeds, the erosive potential of the rains decrease while the infiltration capacity of the soil increase, thereby causing the runoff rate to diminish.
A well dug in the lower, clayey area has a water level at approximatly six meters depth, while another further upstream situated on bedrock provides water at twenty-three meters. The water is usually used for watering fruit trees or trees planted as protection against the wind.

2.1.2 Methods for erosion control

During the sensibilization meetings the farmers recognized that environmental degradation is a complex problem which demands total management both up- and downstream from their land, in order to preserve the soils and improve the agricultural conditions. The principal objective of the project is to reduce the velocity of the water (to increase infiltration) by application of simple water and soil conservation techniques in different zones of the valley.

Several techniques to protect cultivated land and restore abandoned fields have been tested in the valley. These are:
- stone bounds;
- earth bounds;
- reforestation trenches;
- demilunes;
- filtering barriers in the ravines;
- vegetation lines;

and combinations of the above.

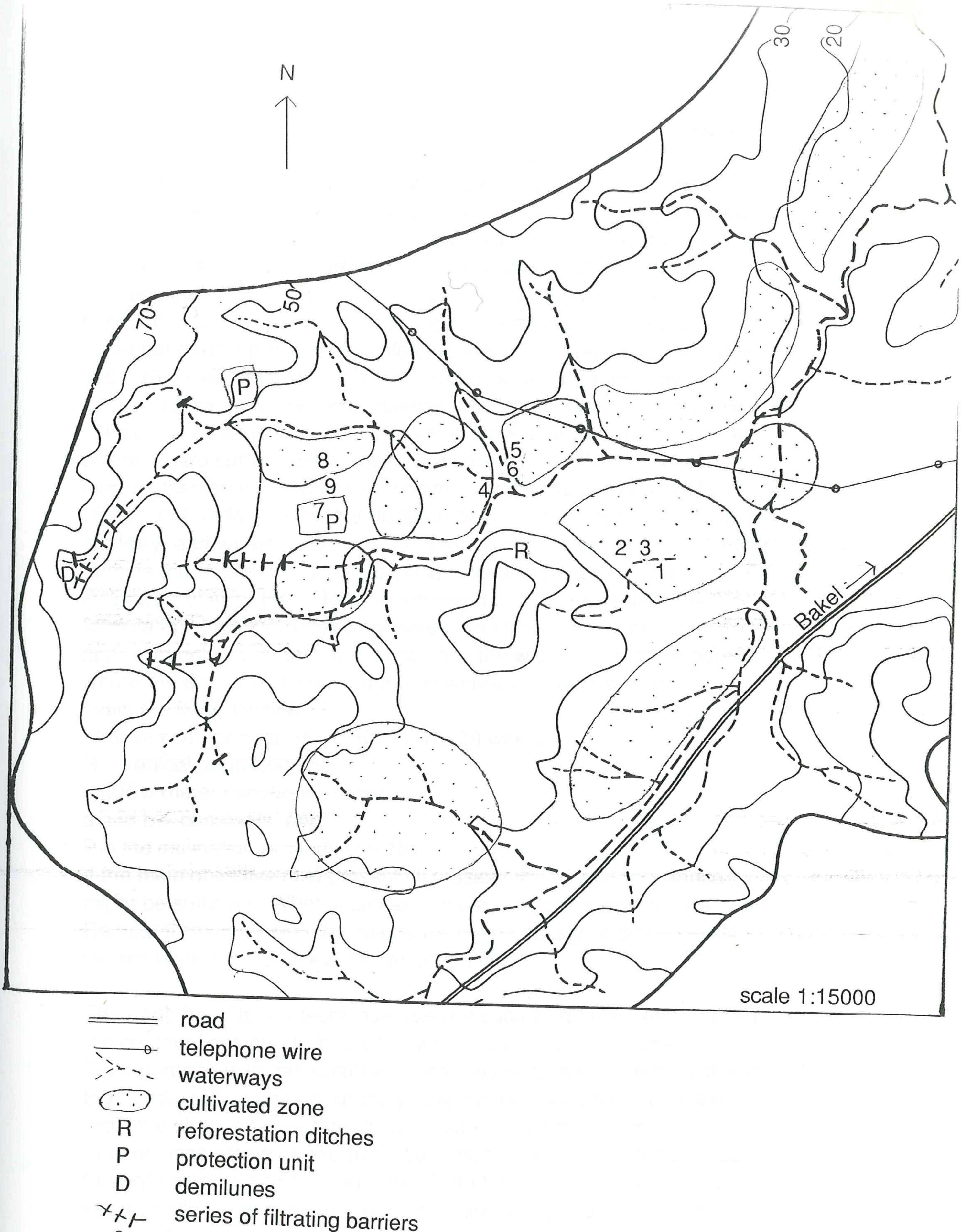


Fig. 9. Conservation measures in the Fandalé valley.

The following measures taken on cultivated land are performed by the farmers themselves.
The stone bounds are ridges made of stones, constructed along the contour lines. They are usually 15-30 cm high, depending on the size and quantity of available stones. Stone bounds are permeable structures; they do not concentrate runoff but when properly built, slow down running water, increase infiltration and decrease loss of soil. The great advantage of stone bounds are their permeability; not only crops planted in front of the bounds benefit from reduced runoff, but also those planted behind them. (Reij 1988) The stone bounds will hopefully form bands of natural vegetation consisting of grasses and bushes which will serve the double purpose of reinforcing the bounds plus yielding fodder and fuel (Fries 1989). Also they are not so quickly damaged by runoff or passing cattle, which reduces maintenance. The stone bound technique is used on fields as well as on uncultivated slopes further up in the valley, where a hard surface crust exists. They are easy to design by the farmers themselves, though a problem could be the availability of stones. In Fandalé valley, the distance between the bounds was made arbitrary, and varies between six and ten meters. According the Ramser formula the bounds are built too close since the slopes have an inclination of 4° or less. Neme recommends following the Ramser formula in letting the distance between the stone bounds be approximately 25 meters, but to increase the width of the stone bounds where the drainage ditches form, and where the livestock passes, to avoid breaking the line.
The Ramser formula: $H = 0.305 (a+P\%/b)$ where:
H = vertical denivellation,
0.305 = meter conversion factor,
a and b = constants, and
P = the inclination in %. (Neme 1990)
If the main objective is to prevent rill erosion, the 25 meter distance might be sufficient. When it comes to increasing soil moisture, the Ramser formula recommendations will not be satisfying since ideally the moisture should be evenly spread on the field.

The earth bounds is a technique used on cultivated fields. After tracing the contour lines of a field, the farmer completes a small ridge of soil. Their purpose is to halt runoff and retain water plus sediments to avoid the seeds getting unearth or the young plants having their roots exposed, with little chance to live through a dry spell. Their construction requires less time than the stone bounds, but they are more vulnerable to strolling cattle and running water. It is of vital importance that they keep strictly to the contour line, if not, water will gather and may break through the bound. This is why the farmer is recommended to also make perpendicular walls with a length of one meter every tenth meter of the earth bounds, as a safety mesure should the bound be somewhat imperfectly designed. Once the bound is broken, erosion is fast and the crop may be washed away. The earth bounds are, unlike the stone bounds, impermeable, if the running water does not exceed a certain amount. Stone pavement on the earth bounds reduce their fragility but this demands more labour time.

As a complement to these constructions on the fields, the farmers are encouraged to plough following the contour lines, to make hedges of thorny bushes (i.e. *Euphorbia balsamifera*) around their land to keep animals out, to dig diversion drains and plant trees above their fields.

In the non-cultivated part with accented slopes, degraded shallow soils and severe surface erosion, the following techniques have been tested. They were constructed during the dry season by temporarily recruited labour.

During the dry season 1989, 145 metres of trash lines were constructed. Sticks of 0.8 m length were placed following the contours of the slope, and twigs of *Gueria* or *Combretum* were used to braid between the sticks. The use of trash lines as a runoff controlling measure is not recommended in areas were stones are available since the trash line technique demands much wooden material, already in short supply. They also require a frequent maintenance in replacing twigs and protecting against fire and straying cattle. The erosion preventing capacity of the trash lines are inferior to that of the stone bounds. Even if stones are unavailable it is better to use other anti-erosion techniques such as reforestation ditches or *demi-lunes* which require no use of wooden material.

Reforestation ditches have been carried out on hillslopes. The technique to reafforestate degraded slopes reduces erosion risks and increases soil accumulation by consolidation of the existing soil layer. In order to avoid young trees getting drenched from a long period of submersion following the rains, they were planted on elevated couches in the centre of the ditches. The species used were *Prosopis juliflora, Prosopis africana, Parkinsonia aculeata, Eucalyptus camaldulensis, Acacia holosericea, Acacia senegal* and *Bauhinia rufescens.* Since many of the trees died from drowning even though precautions were taken, the recommendation is that the trees should be planted upon the rim of the ditch. Also, a better protection against browsing cattle must be arranged.

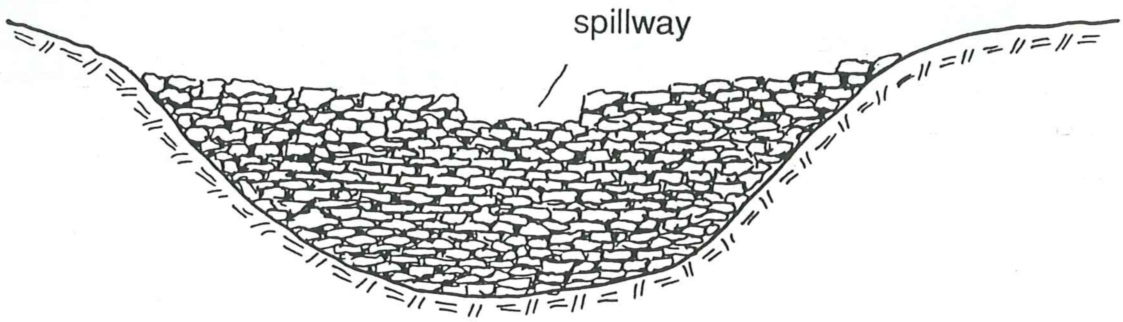
A demilune is a small, semi-circular microcatchment on flat or near flat land. They are used for tree planting; the increased moisture in the pit lead to higher survival rate and faster growth rate for the trees (Reij 1988). Not many of the trees planted by the project in these

demilunes have survived, due to the same problems as with the trenches, namely browsers and submersion.
Agroforestry is one of the activities which creates the most enthusiasm among the peasants, since it corresponds to their former occupation. It consisted of improving or maintaining their revenue from cultivated surfaces, trying to avoid impoverishment of the soil which demands movement to new land. The solution for the farmer is the conservation of the existing vegetative cover to maintain soil fertility, but also the planting of trees and the use of earth/stone bunds, demilunes and trenches. This combination of techniques has been tried on two *protection units*.
The purposes of these protection units are to halt runoff on a large area and to make the plants profit from this retention, to create a herbaceous recolonisation between the stone bounds and to avoid erosion further downhill. One of the units is situated rather high up in the valley, in an area which is considered too remote by the farmers. This unit has not been cultivated, but is planned to be used as a demonstration. In the other unit, a small field has been treated with the *zay*-technique. A zay is a water collecting pocket with a depth of 5-15 cm and a diameter of 10-30 cm, preferably combined with the use of manure. Usually millet or sorghum is grown in the zay. It is not known how successful this technique is, since the field was not used during the 1990 season.

Ravine erosion: three techniques have been tested in the two main runoff streams of the drainage basin. The measures were done by the COMEF and the workers were rewarded with food.
During the dry season 1989 eight permeable barriers of different dimensions (according to the terrain) were constructed upstream on the slope were one of the ravines starts to form. In the 1990 dry season, another five barriers were built in a ravine situated further south. The permeable barrier is an effective erosion control where the erosional forces, the amount and velocity of the water, still is moderate. The barrier, or preferably series of barriers considerably reduces the velocity of running water, dispersing its kinetic energy and catching the debris brought by the flood. The construction of a Fandalé type barrier starts with a ditch to anchor the structure. Stones of differing sizes are then piled up, with alternate layers of gravel, to increase the water retention capacity of the barrier. The top layer consists of big stones, resistant to the floods. In order to avoid the stones getting flushed away by the water, they are placed at an angle (figure 10). To keep the water at an acceptable level also during heavy rains the barriers are constructed with a spillway. Finally, on the leeside of the barrier a dissipation bank is made to avoid undercutting and reduce the force of the water leaving the barrier.
In 1989 a ninth barrier was built, at the request of the farmers

downstream in the ravine, but this barrier was destroyed by the first seasonal rain. Two additional barriers were built downstream during winter 1990, with netted stones. Even then, barriers built downstream were the force of the water is considerable, must be reinforced and be very well anchored at the brinks to reduce the risk of water passing by the sides or undermining the structure.
For future barrier construction it is recommended that:
1) Barriers should be placed so the crest of one barrier is at the same height as the base of the preceding barrier. This will provide maximum water retention.
2) Gravel should not be used to fill the spaces between stones, since this causes the stones to slide during floods. It also increases construction time. Leaves, twigs and debris that are trapped by the structure during floods are sufficient for keeping the basin watertight.
3) The use of artificial pavement above the barrier be increased to diminish the talus and reinforce the structure. (Neme 1990, Ndiaye & Hallberg 1989)

frontal view



transversal cut

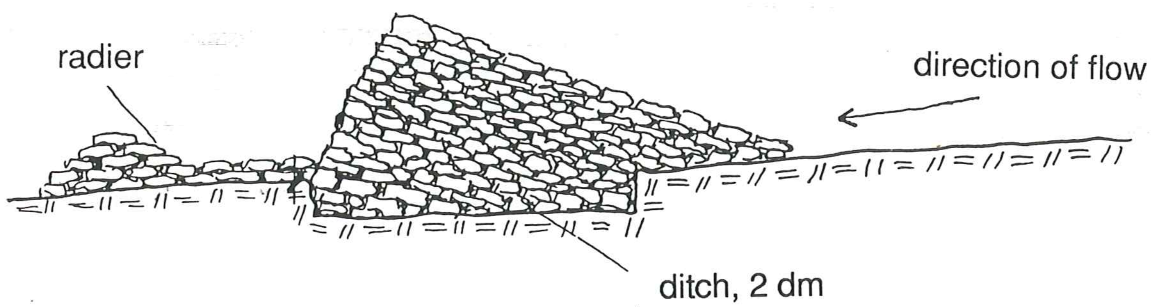


Fig 10 and 11. Principles of a permeable barrier (Ndiaye & Hallberg 1989).

The hope is that in the future, irrigation will be possible with the water gathered above the barriers. Another objective is to increase the ground water level.

Another technique which is to be tested in the waterways is the <u>vegetation lines</u>. These are lines of resistant grass plants, placed in the smaller waterways to slow down water and halt sediments.
Three guides concerning contour line tracing, barrier construction and

runoff control measures have been produced by the project and are given to the COMEF farmers.

Fig 12. The building of a barrier. (Photo M. Hallberg)

Table 2. Farming calendar for Bakel district.

Season	Month	Agricultural activity
Dry season	January	Cleaning of previous year's farms, branches and twigs collected for construction of fence. Weeding the vegetables.
	February	Bush cleaning continues. Harvest of vegetables. Temperature begins to rise.
	March	Cassava and beans are planted along the river.
	April	Harvest of tree crops like gum from *Acacia Senegal*, fruits from *Adansonia Parkinson.*
	May	Harvest of cassava and beans. Land is cleared by burning.
Rainy season	June	Waiting for the first sufficient rain. When it arrives, fields are plowed or treated by hand. At next rain, sowing of millet and sorghum, maize and peanuts are planted. Rice is planted in irrigated fields along the river.
	July	Weeding.
	August	Plowing, reparing ridges and fences.
	September	Harvest of rice, peanuts and maize. Drying of peanuts.
Dry season	October	Harvest of cereals. Drying and milling.
	November	Beginning of cool period. Maize is planted in irrigated fields. The "reverse seasons"- vegetables such as cabbage, lettuce, carrots are planted along the river.
	December	Millet and maize stalks are collected for house reparations.

(Farmer's personal information, Udo 1978.)

3 SOIL MOISTURE CONTENT STUDY

The availability of water to plants depends on soil factors (moisture content at wilting point, soil depth, etc.), on plant factors (rooting depth, hydraulic resistance, plant root system) and on the amount of water in the topsoil. The amount of water in the topsoil varies from day to day as a result of infiltration, transpiration, soil evaporation and percolation. (In the Sahel the soil and water conditions are generally such that percolation below rootzone or capillary rise from a water table is negligable.) Through water, soil and crop management practices that intervene in one of these components, the water availability to plants can be influenced. Water harvesting will only be effective if the infiltration or the profile water retention capacity is sufficiently high to store the incidently large amounts of harvested water. (Reij 1988)

The purpose of this pedologic study was to determine the influence of the stone/earth bounds on the soil moisture. The runoff decreasing effect of the bounds must lead to an increased water content in the topsoil. The first hypothesis is that fields with bounds will have a generally higher amount of soil moisture available for plants than fields without bounds. The organic content of the soil will also be influenced by the bounds, but the eventual difference will not be measurable for several years.
The second hypothesis is that earth bounds are more effective than stone bounds in decreasing runoff due to their impermeability. Therefore fields with earth bounds should have a higher general plant available soil moisture as well as greater differences between the positions at the field. The same applies to the reinforced earth bounds.

3.1 Description of the sample areas

All of the study fields are situated in the higher part of the Fandalé valley (see figure 9, page 16); they all suffer from excessive runoff, not from inundation which is the problem in the lower parts of the valley. The cultivated fields are all tilled by hand at the same time following the rains. The gradient for the study sites is 2-4%.

For the first group of sample sites: (1, 2 and 3) the predominant vegetation in the area are the bushes of *Balanites spp.* and *Combretum spp.* Site 1 is a peanut field and has a system of stone bounds that were introduced during the 1990 dry season. A waterway passing on the west side is slowly eroding its way into the field. Along this ravine, *Euphorbia sp.* have been planted in an effort to stabilize the rims. Due to the fine fractions of the field the soil surface is hard, and some spots on the cultivated fields have been left bare; tillage is virtually impossible. Hedges of thorny bushes protect the field against cattle. Site 2 is also used for peanuts mixed with beans, while site 3, the reference, is uncultivated.

The second group of sample sites; (4, 5 and 6) are situated in a better agricultural zone, with darker soils and a vegetation of *Balanites aegyptiaca, Bauhinia rufescens* and *Combretum spp.* Site 4 is planted with millet and has been prepared with earth bounds. It is surrounded by hedges. A waterway, passing on the south side of the field, diminishes the area of the the field. Site 5 is also a millet field, discontinously hedged, and sample site 6 is an uncultivated area between fields 4 and 5.

Sites 7, 8 and 9 are situated in the highest zone. *Acacia senegal, Balanites spp.* and *Combretum spp.* are the predominant vegetation types. Sample site 7 is situated in one of the protection units. It is a hedged peanut field prepared with stone reinforced earth bounds. *Euphorbia sp.* is planted along the bounds and around the unit. Site 8 is a peanut field located 100 meters north of site 7 and site 9 is uncultivated, situated between fields 7 and 8. The most coarse soils are found in this zone.

3.2. Methods and material

A series of samples were taken to reveal the fluctuations of the soil moisture content. The sampling started immediately after a 18 mm rain (which ideally should have been greater), and continued for a period of seven days until the next rain (16 mm). The study fields had been prepared with stone bounds, earth bounds or reinforced earth bounds. Samples were also taken on closely situated unprepared fields with the same crop, and on unprepared, uncultivated spots, serving as indications of the tillage's influence. A total of nine fields were studied. The samples were taken at 15-20 cm depth (rootlevel) using a core, weighed on a triple beam balance then dried at approximately 90-100°C until constant weight so the percent water content could be calculated. Efforts were made during soil sampling to avoid extreme microtopography and former sample pits. For analyzing the bounds' influence on different parts of the prepared fields, the soil was sampled at different distances from the bounds - "top", refers to samples taken about one meter below the bound, "middle" is at the same distance from two bounds, and "bottom", one meter above the next bound. A similar procedure was followed on the unprepared and reference fields; samples were taken as for the prepared fields.
Soil samples from all the sample areas were analysed to establish the field capacities and wilting points. This was done by the Department of Soil Science at Ultuna Agricultural University, Uppsala. The field capacity is the condition reached when a soil holds the maximum possible amount of water in its voids and pores after excess moisture has drained away. It is a measure of the soils water holding capacity when drained. The pF (pF being the $\log_{10}$ of pressure from a water column of a specific height) is 1.7 (which equals a 3.3 meter high water column, or 1/3 bar). The wilting point is the state of dryness where the remaining soil moisture is so tightly held by the soil that plants can no longer benefit from it, which empirically occurs at pF=4.2. These maximum and minimum soil water

contents were needed as references and comparisons for the obtained moisture contents. (Troedsson & Nykvist 1980, Wiklander 1976) A fraction analysis was made to verify the comparability of the sample sites. Soil fractions were classified according to the Swedish Geotechnical Association system. Furthermore the pH (water and KCl) and the organic content were defined. The pH values are indications of the acid-alkali properties in the soil. When using water as extraction fluid, the obtained pH value corresponds to the prevailing soil fluids' pH, while the pH KCl indicates the amount of exchangeable hydrogen ions in the soil under normal conditions. (Ekologisk metodik 1977) The differing depths at which the samples were taken reflects the soil profile; samples were taken in each identified layer. In site 9, no horizon limits were identified and only one sample was taken.

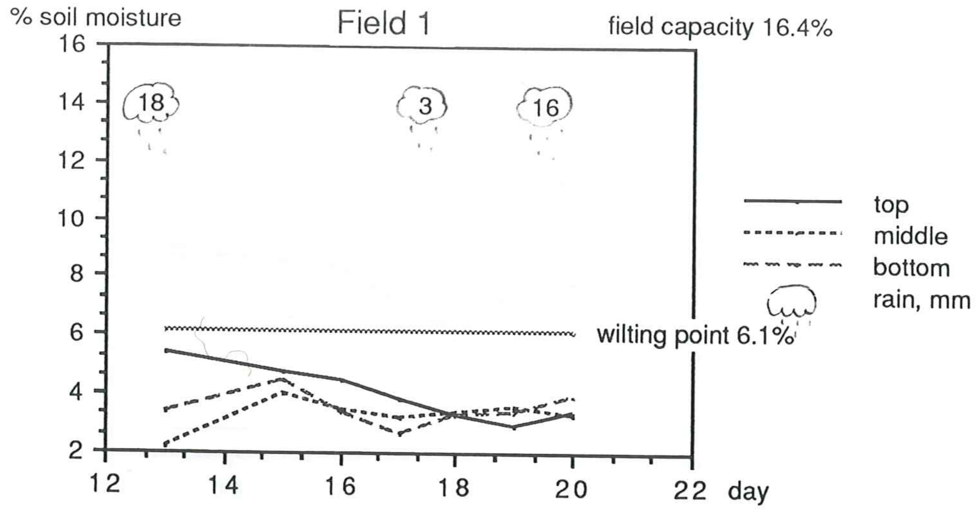
3.3. Results

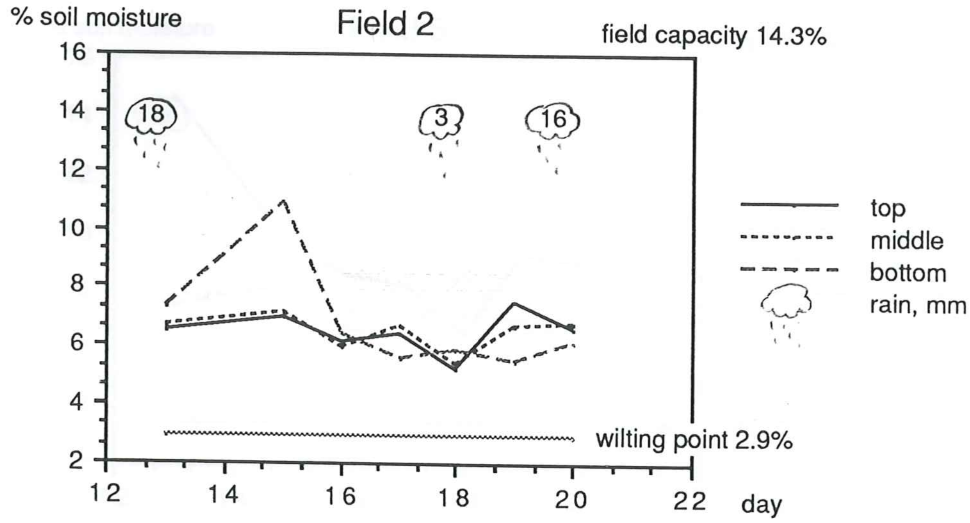
Table 3 presents data from the samples for each study site.

Table 3. Values for the study areas. For the preparation abbreviations, see "description of the sample areas".

field	depth (cm)	pH water	pH KCl	org. cont.(%)	fraction	% clay	preparation
1	15-20	8.5	7.6	2.3	sandy silty coarse clay	17.0	stone b.
	30-35	7.8	7.6	2.6	sandy silty coarse clay	19.0	+ cultiv.
2	15-20	4.9	3.7	1.0	clayey sandy silt	7.0	cultiv.
	40-45	5.2	4.3	1.5	clayey sandy silt	10.0	
3	15-20	4.9	3.8	1.2	clayey sandy silt	8.0	
	50-55	5.7	4.6	1.1	clayey silty sand	7.5	uncultiv.
4	15-20	6.8	5.8	1.3	clayey sandy silt	6.0	earth b.
	50-55	7.0	6.6	1.6	clayey sandy silt	10.0	+ cultiv.
5	15-20	6.1	5.1	1.3	clayey sandy silt	9.0	cultiv.
	50-55	6.7	5.6	1.6	clayey sandy silt	13.0	
6	15-20	5.4	4.4	1.2	clayey sandy silt	7.5	uncultiv.
	50-55	5.2	4.1	1.3	clayey sandy silt	9.5	
7	15-20	4.9	3.7	1.5	clayey silty sand	10.0	reinf.e.b.
	30-35	5.4	3.9	1.9	clayey sandy silt	12.0	+ cultiv.
8	15-20	5.1	4.0	0.8	silty sand	2.5	cultiv.
	50-55	5.3	4.0	0.9	silty sand	4.5	
9	15-20	5.4	4.1	0.9	silty sand	6.5	uncultiv.

How moisture contents fluctuate relative to wilting points and field capacities is presented for each study site in graphs 1 to 9.





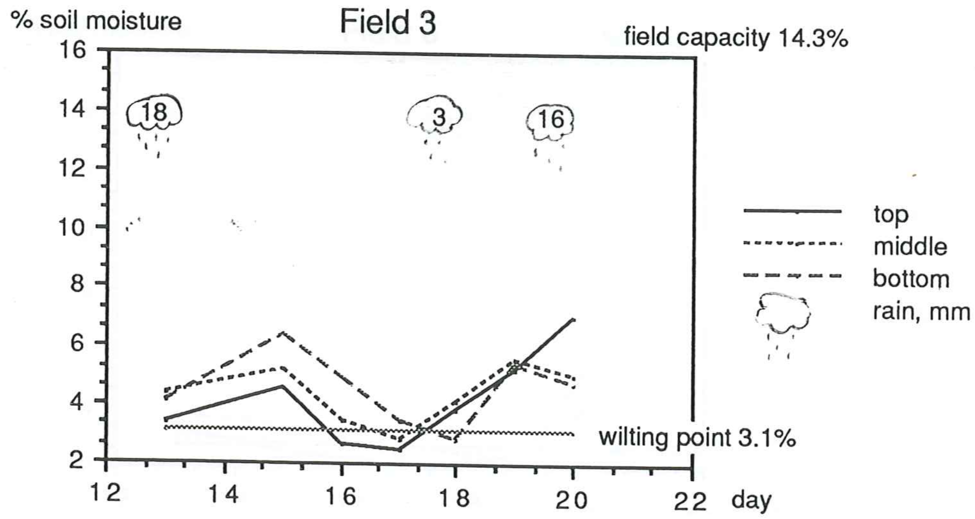


Fig. 13. Soil moisture contents for 13-20 September 1990, at the three positions "top", "middle" and "bottom", in fields 1, 2 and 3.
Field 1 is a peanut field with stone bounds, field 2 is a peanut field and field 3 an uncultivated reference. The rains fell on the 13:th, the 18:th and the 20:eth of September.

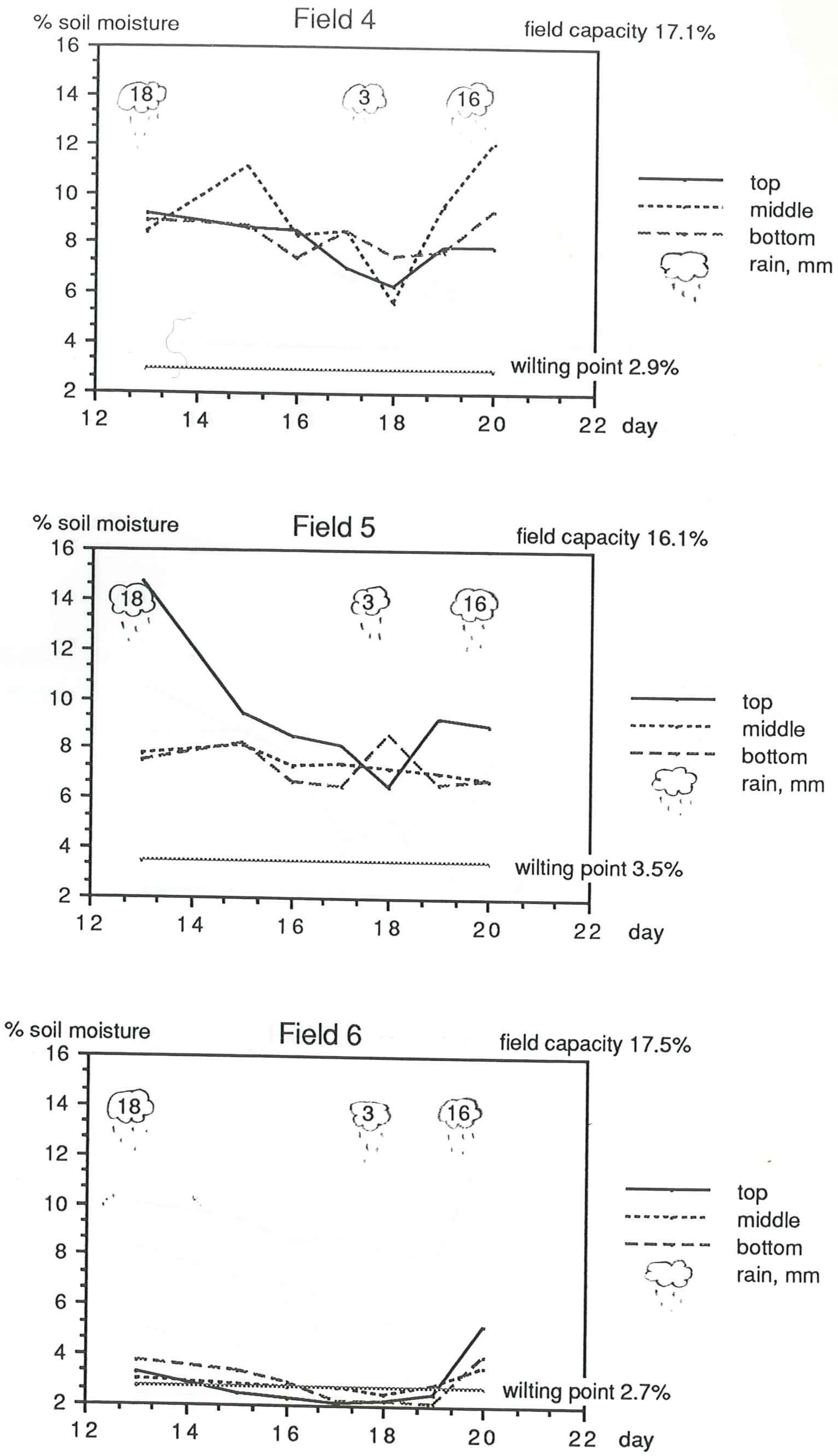


Fig. 14. Soil moisture contents at field 4, 5 and 6 for 13-20 September 1990. Field 4 is a millet field with earth bounds, field 5 is a millet field and field 6 is an uncultivated reference. The rains fell on the 13:th, the 18:th and the 20:eth of September.

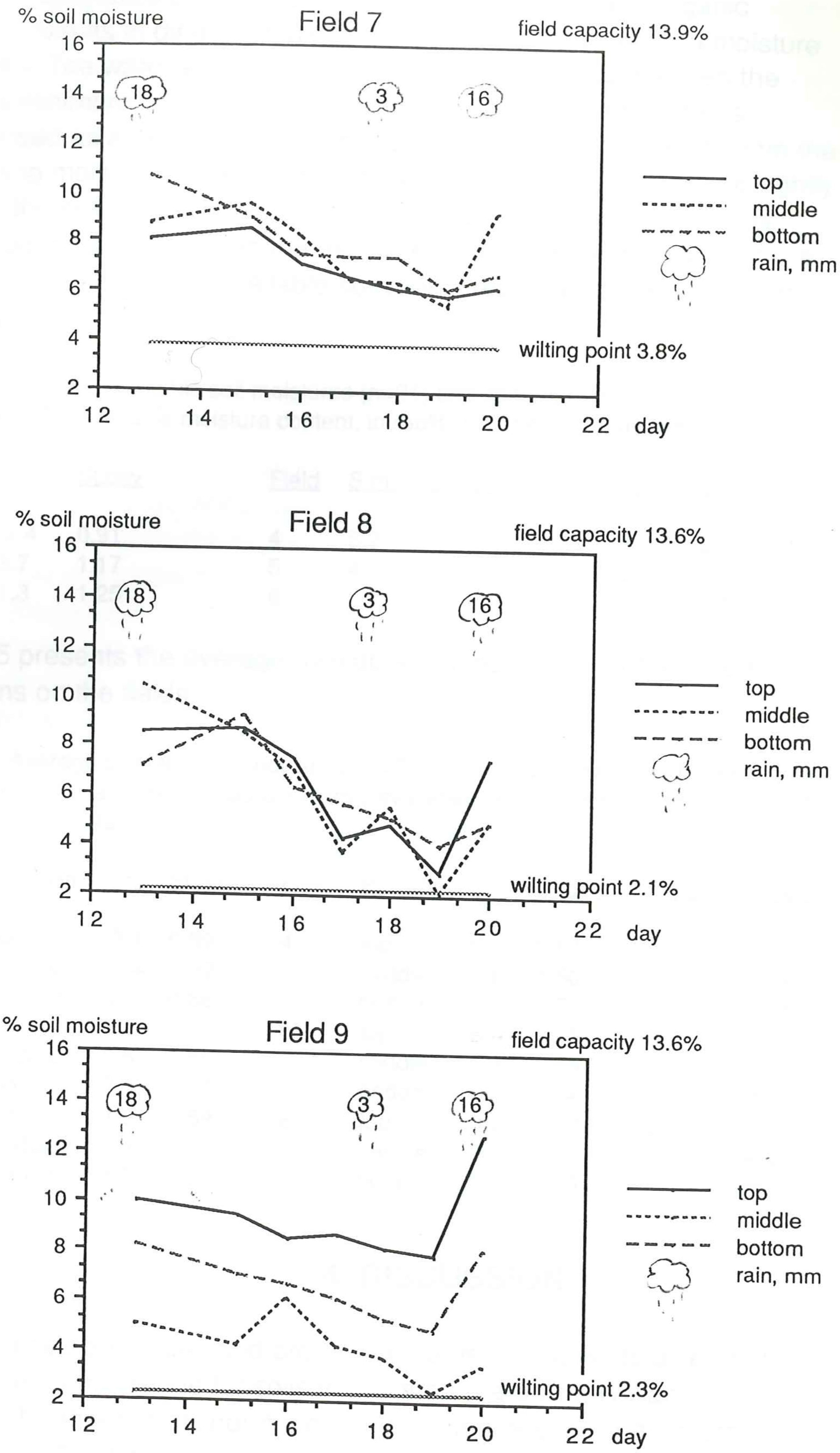


Fig. 15. Soil moisture contents at fields 7, 8 and 9 for 13-20 September 1990. Field 7 is a peanut field with stone reinforced earth bounds, field 8 is a peanut field and field 9 is an uncultivated reference. The rains fell on the 13:th, the 18:th and the 20:eth of September.

The characteristics of a soil, the fraction, clay content and organic content, results in different maximum, minimum and prevailing moisture contents. The water available to plants is the difference between the natural minimum and the natural maximum soil moisture contents (expressed as a percentage). This means the plants can benefit from the prevailing moisture content minus the amount of moisture which is tightly held in the soil, as reflected by the wilting point. In figures 13-15 this would be the area between the moisture curve and the wilting point line. Table 4 presents these available soil moistures for each field during the study period.

Table 4. Average available soil moistures (n=21) and standard deviation. In the table field 1 has a negative available moisture content, in reality this means no available moisture.

Field	S.m.	St.dev	Field	S.m.	St.dev.	Field	S.m.	St.dev
1	-2.4	0.91	4	5.7	1.27	7	3.7	1.38
2	3.7	1.17	5	4.5	1.79	8	4.0	2.21
3	1.3	1.25	6	0.2	0.77	9	4.4	2.49

Table 5 presents the average available soil moistures for the different positions on the fields.

Table 5. Average available soil moistures (n=7) and standard deviations for each position on the fields. In the table field 1 has a negative available moisture content, in reality this means no available moisture.

Field	Position	S.m.	St.dev.	Field	Position	S.m.	St.dev.	Field	Position	S.m.	St.dev.
1	top	-2.1	0.89	4	top	5.0	0.97	7	top	3.1	1.02
	middle	-2.4	1.22		middle	6.6	1.50		middle	3.9	1.56
	bottom	-2.6	0.58		bottom	5.4	0.75		bottom	4.0	1.50
2	top	3.5	0.70	5	top	5.8	2.55	8	top	4.2	2.28
	middle	3.6	0.59		middle	3.9	0.45		middle	3.9	2.84
	bottom	3.9	1.91		bottom	3.8	0.84		bottom	3.9	1.71
3	top	1.0	1.59	6	top	0.2	1.10	9	top	7.0	1.65
	middle	1.3	1.00		middle	0.2	0.35		middle	1.9	1.03
	bottom	1.5	1.21		bottom	0.2	0.79		bottom	4.3	1.30

4 DISCUSSION

The obtained pH values and organic contents for the fields differ, but are within the normal range for soils in this area (Lars-Erik Williams, pers. comm.). Neither the pH nor the organic content are limiting factors for the vegetation. The limiting factor is the supply of water at rootlevel in the soil.

Another method to compare the conservation methods would be to measure the harvests per unit of land from different fields. Such a study would not only require equal soil types but also identical cultivation methods. The soil moisture content is less dependent from other factors than the harvest quantity.

The first hypothesis is that the stone and earth bounds decrease runoff, thereby increasing infiltration. From this it follows that the amount of available water should generally be higher in fields with bounds, than in fields without bounds.
The results as seen in the graphs and in table 4 do not verify the first hypothesis; the average available moisture is higher in field 4 than in field 5 and 6, while field 7 has less available moisture than field 8 and 9. It is not possible to establish the distinctive effects of the bounds.
The second hypothesis is that the earth bounds are more effective in halting runoff than the stone bounds since they are impermeable (up to a certain level of collected water, when it will overflow or break the bound). With time the stone bounds will gain equal impermeability, as enough debris have gathered. Fields prepared with earth bounds should have a generally higher amount of available water than stone bound fields, but with greater differences between the at-field positions. Position "bottom", just above the bound, should be the wettest in a earth bound field, while in a stone bound field, position "top", which is below the permeable bound, should also have increased humidity.
The second hypothesis can be neither rejected or approved, since the results from the field treated with stone bounds (field 1) are incomparable to the other results. The same applies to the prospective at-field differences. Unfortunately for the study (and for the farmers), field 1 has an odd soil type, with a high clay content and a high wilting point. This reduces the comparability of the fields and the conservation methods. Note how the moisture content of field 1 never exceeds the wilting point, implying that the crops can not benefit from the rain. More extensive rains, more effective conservation methods or even irrigation seems to be a necessity here. Because of this, the soil moisture increasing effectiveness of the stone bounds will remain unknown. This situation could have been avoided if the soil types had been analysed before the investigation started.
The uncultivated, unprepared sites (site 3, 6 and 9) serves as references to reflect the tillage factor; they show "normal" fluctuations in soil moisture. With modern cultivation machinery, the difference in soil moisture between a tilled and an untilled field would be more obvious than where the tillage is done by hand as in the study area. Tilling by hand seldom affects soil layers below 25 centimeters of depth.
Local differences in tillage, microtopography, evaporation and precipitation have as far as possible been excluded, but could nevertheless have influenced in this investigation of small proportions. A thorough investigation should preferably include measurements from the whole rain period, or even better several rain periods. 1990 was a dry year, the precipitation was approximately 100 mm less than the annual average for 1922-1990. The result of the measurements might get more encouraging for a year with more ample precipitation. The investigation may also have been affected by the time. The measurements were made at the end of the rain season, when the runoff rate is lower than otherwise. It is possible

that the bounds are most profitable at the beginning of a rain season, when the runoff rate is highest.

The methods described in this thesis are relatively new in Senegal. In many other Sub-Sahara African countries (i.e. Mali, Burkina Faso, Niger, Chad, Sudan and Somalia) the techniques often have a longer tradition, even if they can not be called common. Only a few data as yet support the assumption that the use of water harvesting techniques in semi-arid Sub-Saharan Africa leads to substantial and sustained yield increases. There are only a few water harvesting projects in the S.S.A., and most projects do not systematically monitor the impact of water harvesting on crop yields. One of the exceptions to this concerns the stone bounds, which are reported (Reij 1988) to be increasingly popular in the northern part of the Central Plateau of Burkina Faso. The technique was introduced in the Yatenga region in the beginning of the 80's by the Agro-Forestry Project (OXFAM). The bounds have proven their ability to increase yields, and have been adopted among the farmers. Reports confirm that for plots treated with stone bounds during 1981-1984, the average annual yields were 12 - 90% higher than on adjacent control plots. The reasons for the bounds' success in the Yatenga region are said to be:

- the training, which is concentrated on stone bounds. They were prefered by the farmers after initial experimentation. The earth bounds require less labour for construction than stone bounds, but if maintenace requirements are considered, the stone bounds have a lower total labour input.
- the stone bounds permit short-term yield increases and the rehabilitation of degraded and abandoned land.
- the Yatenga region has a high density population and the soils are degraded, so farmers have no option but to improve the land or migrate.

The environmental conditions of Bakel are similar to those of the Yatenga region, though farmer motivation appears to be lower as migration is extensive in the region.
Another of the possible reasons for the slow adoption of the bound technique in the Fandalé Valley (as well as in other project areas) is the lack of direct benefit to farmers constructing bounds, and the systematic use of incentives for other activities (such as barrier building and tree planting). The benefit from the bounds apparently has not convinced the farmers, and the large labour requirement overshadows the prospective benefit. The surveying of contours appears to be a critical constraint in many projects, and also in Bakel. The training session with the water tube seem to be inadequate. In Fandalé valley, the last constructed bounds were determined by project staff using theodolites.
Reij (1988) states that "water harvesting programmes will be sustainable when the structures are maintained as well as replicated by the farmers themselves". He adds that "training is essential and should be built on indigenous techniques and local environmental knowledge".
In Bakel, the approach and the training seem to fulfill these criteria.

SUMMARY

1. The drainage basin in which this field study was conducted is situated near the village Bakel in eastern Senegal. It receives an average annual rainfall of 505.1 mm (1922-1990). The rainfall is erratic and dry spells are current. The soils are compact with a large portion of fine fractions, degraded and very vulnerable to eolian as well as hydrological erosion. Rainfall runoff is a major problem for the agriculture in the area. The excessive runoff means loss of water, nutrients and sometimes even land, the running water having a considerable erosive effect on the surface. The Swedish funded reforestation project PROBOVIL has been operating in the area since 1982. A soil conservation division was organized in 1988.

2. The techniques to protect cultivated land and restore abandoned fields which have been tested by the soil conservation division were :
- stone bounds, lines of stone 15-30 cm high following the contour lines of cultivated fields as well as uncultivated slopes.
- earth bounds, ridges of soil along the contour lines of cultivated fields. The purpose of the bounds is to decrease the rainwater runoff and increase infiltration, thus creating better conditions for the vegetation.
- trash lines, small fences of braided twigs. The purpose is the same as for the bounds.
- reforestation trenches, ditches along hillsides in order to make tree seedlings benefit from increased soil accumulation.
- demilunes, pits for tree planting that create a steadier moisture access.
- filtering barriers, dams of stones in gullies which reduces the eroding potential of running water in the ephemeral water ways.
- vegetation lines, lines of grass planted in smaller waterways to halt sediments.

3) Primary emphasis was placed on the bounds and a more detailed study of their effectiveness was conducted.
A series of soil samples were collected during a period from one rain till the next rain (seven days), in order to compare the soil moisture fluctuation at different positions in:
a) cultivated fields treated with stone or earth bounds, b) untreated, cultivated fields and c) untreated, uncultivated fields. Fields b and c had the same crop. It was the further interest of this study to establish the soil moisture increasing effectivity of the bounds, as well as the potential difference in soil moisture increasing capacity of stone and earth bounds. Analyses were made for each fields' soil fractions, clay content, pH, organic content, field capacity and wilting point.
The results of the measurements did not verify the assumption that fields with bounds have a generally higher soil moisture. The difference between the positions in a treated field were also not as anticipated: driest between two bounds and wetter above and under. The comparison was unfortunately reduced by the soil type in the only field treated with stone

bounds, which had a different soil composition. The moisture content on this field never exceeded the wilting point.
The obtained results might have been affected by the chosen study time; at the end of the rain season.

4) Recommendations for further developments concerning
a. the bounds. In deciding the distance between the bounds, the distance should be kept within 10 meters for maximum benefit of the collected runoff, not following the Ramser formula. The earth bounds are easier to construct but more vulnerable than the stone bounds. A pavement of stone may reduce the vulnerability of the earth bounds. The design of the earth bounds must ensure that they stick to the contour line to prevent water gathering and breaking the bound. Perpendicular walls every tenth meter can be used as a safety measure for the earth bounds.
b. the trash lines. The use of trash lines is not recommended since their construction and maintenace demands much wooden material. Their runoff halting capacity is low.
c. the reforestation ditches. Trees should be planted on the rim of the ditch, not in the ditch were the young trees often drown. A better protection against browsers must be arranged.
d. the demilunes. See above.
e. the permeable barriers. For maximum water retention the crest of one barrier should be at the same height as the base of the preceding barrier. Gravel between the stones in the barrier was found unnecessary and should be avoided. Above the barrier, the reinforcing pavement should be increased.

5) So far, the water harvesting techniques have had a slow adoption rate among the farmers in the Fandalé valley. The techniques would generate more interest, and the motivation to use them would be enhanced when and if benefit can be demonstrated.

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