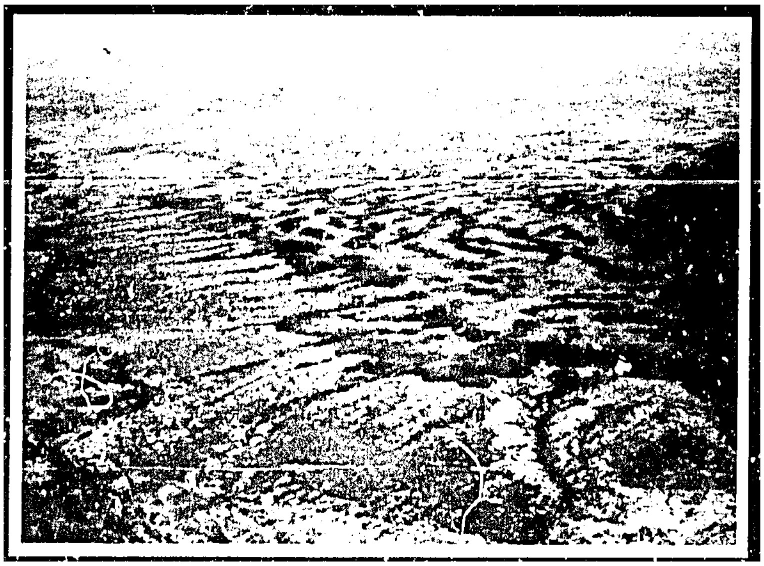
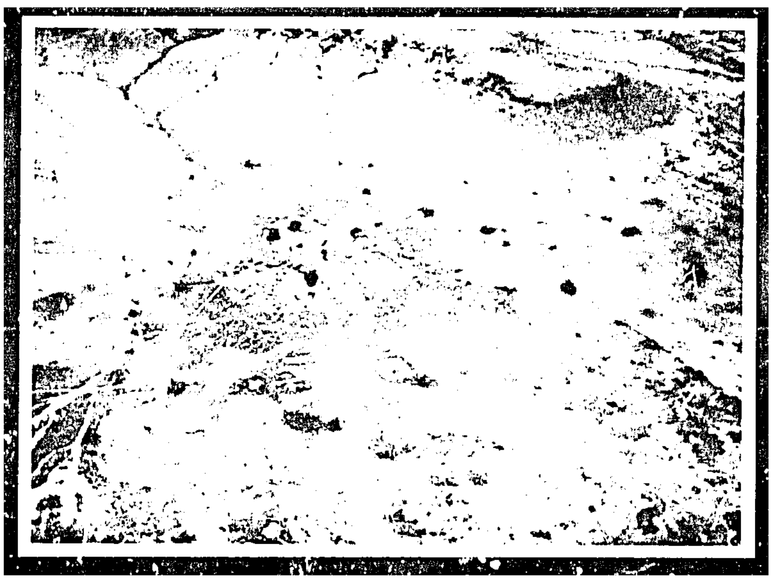
# Integrated Management of Agricultural Watersheds (IMAW)





## Characterization of a Research Site Near Hamdallaye, Niger

TropSoils Bulletin No. 91-03

November, 1991

Cover Photos:

*Left:* A small farming community surrounded by a eroded landscape.

*Right:* The "tiger bush" or thickets forming a tiger skin pattern, on a laterite plateau.

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**November, 1991**

# Foreword

Texas A&M University (TAMU), Soil Management Collaborative Research Program (TropSoils) in collaboration with Niger National Institute for Agronomic Research (INRAN) planned a joint project on Integrated Management of Agricultural Watersheds in Niger (IMAW). A major goal of the project is to improve agricultural productivity and enhance natural resource base through integrating indigenous knowledge with improved technologies for soil, crop, livestock and vegetation management within a well-defined watershed. In 1989, a proposal was submitted to the Agency for International Development Mission in Niamey for support and funding.

This report contains the findings of site characterization and feasibility study of a selected portion of the Hamdallaye watershed during 1989 cropping season assessing the practicability of managing a small watershed for sustained productivity in western Niger. The selection of Hamdallaye site was based on an earlier study conducted by Dr. Mamadou Ouattara of INRAN.

The efforts of many were required to complete this study. Dr. A.S.R. Juo and Dr. Ruben Puentes played an important role in planning this study and subsequently, the design the implementation of the project of Integrated Management of Agricultural Watershed in Niger (IMAW). Dr. Andrew Manu, Dr. Stephen C. Geiger, and Ms. Anne Pfordresher, TropSoils scientists based at INRAN, Niger collected and prepared soil data for this report. Dr. Ellen Taylor-Powell was contracted to conduct the indigenous knowledge survey of the farming communities in the watershed. Professor Saadou Mahamane of the University of Niamey conducted the vegetation survey. Mr. Moussa Salou supervised the analysis of soil samples. Ms. Anne Pfordresher, Dr. Larry Wilding and Mr. Mahamane Bachir were responsible for the development of the geographic information system (GIS) component used to integrate baseline data collected within the study area. Mr. Amadou Foumakoye, Mr. Moussa Kalla, Mr. Boukary Daouda, and Mr. M. Hama served as TropSoils local staff during the study. Ms. Kati Ferrari and Ms. Peggy King assisted with the editing and formatting of this report. Assistance in the planning and execution of the study was also given by several TropSoils/TAMU investigators including Dr. L.R. Hossner, Dr. T.L. Thurow, and Dr. C.W. Wendt.

The continued support, interest and encouragement from the Office of the Director-General of INRAN, and from the administrative and technical officers of the USAID Mission in Niamey, Mr. George Eaton, Director; Mr. John Mitchell, ADO; Mr. George Taylor, ADO; Mr. Ernest Gibson, former ADO, and Mr. Flynn Fuller, former ADO, are gratefully acknowledged.

The study was supported in part by USAID/Niger (USAID/REDSO/TAMU No. 683-0261-A-00-9042-00) and Soil Management CRSP (USAID Grant No. DAN-1311-G-SS-6018-00).

Roger G. Hanson, Director
Soil Management CRSP
November 15, 1991.

## Executive Summary

Reduced vegetative cover, declining soil fertility, increased wind and water erosion and shortened fallows are consequences of the climatic changes and population pressures affecting the Sahel. Past efforts in the region have been aimed primarily at increasing production through commodity improvements.

The site characterization study of the Integrated Management of Agricultural Watersheds (IMAW) project examined the physical and biological parameters relevant to sustainable agricultural production of a 500 ha watershed as well as social and cultural factors influencing land use, with particular focus on indigenous knowledge related to soil management. The watershed is located near the village of Hamdallaye approximately 35 km east northeast of Niamey, Niger. Intensive surveys were performed of watershed topography, soils/geomorphology, indigenous knowledge, and biodiversity during the 1989 cropping season. The major summarized findings follow:

1. The dominant geomorphological feature of the watershed is a laterite-capped plateau located at the northern end of the area. A toposequence of soils starts at the edge of the plateau and extends for approximately 1.5 km to the valley floor. The slope of the watershed is broken by two laterite formations, both exposed on the western side, but buried on the east. The slope decreases as the laterite formations are approached, but increases on the downslope side of each outcrop. Relief differences are greatest in areas where the laterite is exposed. The topographical difference between the laterite plateau and the valley floor is 40 m.

2. The watershed's hydrology is dependent on geomorphology. There is a large concentration of incipient gullies on the steep slopes directly below the plateau. These gullies also occur on soil below the second laterite outcrop. As gullies approach soils with gentle slopes -- above the first laterite formation and the valley floor, respectively -- water flow speed decreases and soil deposit fans are formed.

3. The watershed soils are a function of topography. Seven soil series were found, including seven erosional and depositional phases. Arable soils -- those used by farmers for food crop production -- are sandy to loamy sand in texture. Their poor fertility is reflected in low organic matter content (<0.4%), low cation exchange capacity (CEC) (<2.55 cmol (+)/kg) and low levels of available P (<4 ppm). Soil fertility improvement will be necessary for sustainable agricultural productivity.

4. Wind and water erosion are major drawbacks to soil productivity in the watershed. Degraded natural vegetation results in soil surfaces highly susceptible to wind erosion during the dry season. Water erosion is shown in gully, rill, and sheet eroded surfaces, and in the formation of sand

outwash fans and other isolated areas that are severely eroded. The control and rehabilitation of gully/outwash fan systems will require labor. Sheet erosion is evident on productive fields, but needs to be measured for loss of soil productivity to determine the need for erosion control programs. Crusting is also a watershed problem.

5. Two plant communities grow in the watershed: a "tiger bush" distributional pattern (*Combretum micranthum*) on the laterite plateau and first laterite formation, and Sahelian savanna (*Guiera senegalensis*) in the valley toposequence. A total of 119 plant species were identified, including 116 *Angiosperms* and 2 *Bryophytes*. Twenty-eight of these are extensively used by local villagers for fuel and construction wood, animal fodder, food, and medicine. The ratio of genus-to-species indicates an impoverished flora that is degraded to very degraded with respect to the original natural vegetation.

6. There are 56 farmers from four villages cultivating land within the watershed, although only one village is located within its boundaries. Land holdings for each household average 10.3 ha, with a range of 0.7 to 41.5 ha. Cultivated areas average 5.2 ha, and fallow areas average 5.1 ha. Approximately half of the watershed was in fallow during the 1989 season. Nearly one-half of the cultivators are farming on borrowed land. Various tenure systems exist depending upon land use and the user. Formal leases are being encouraged to guard against land claims by the borrowing family. Women reportedly have no land in their own rights. Farmers have exclusive use of cropped fields. Grazing land on the plateau is communal, as is arable land after harvest. Tenure rules related to fallow land vary depending upon season and whether the user is the landowner or borrower. Tenure rules applying to permanent land improvements prohibit leaseholders from digging wells or planting trees such as mango, citrus or baobab.

7. The principal cropping pattern is millet/cowpea intercropping. Farmers know the benefits of fertilizer and use of improved varieties of millet and cowpea. However, bird damage to the early maturing improved millet (HKP) has prevented the widespread adoption of this technology. This situation has been aggravated by the closing of the Seed Multiplication Center (SMC) located near the watershed, where improved varieties and fertilizer were available at good credit terms. Urea and triple superphosphate are the most commonly used fertilizers, but 40% of the farmers reported no history of fertilizer use.

8. Fallowing has been the traditional system used to increase and restore soil productivity. But fallow periods have reportedly been shortened from 10 years to 3 to 5 years. This is attributed to the cultivation of larger areas to make up for decreased land productivity; seeding all land to minimize crop failure and to preclude others from using it; pressures to loan land, which results in premature cultivation; and the breaking up of family holdings resulting in a greater cropping intensification. Farmers indicate that continuous cropping using animal manure is the preferred system for sustaining production. Manure availability in the watershed, however, is limited because there are fewer animals due to the drought of the past 20 years.

9. Millet stover and chaff, refuse of old granaries and cuttings from native shrubs (*Guiera senegalensis*, *Piliostigma reticulatum*, and *Combretum glutinosum* ) are used to rejuvenate eroded watershed areas. While farmers know the benefits of using ground mulches to control erosion, only 42% use them, and to a very limited extent.

10. Management of crop residues has reportedly changed over the past decade in response to increased wind erosion. Some millet stalks are removed for construction,

but the majority of millet residue is left standing in the field to "hold the soil." After crop residue grazing, stalks are uprooted and laid on the field, sometimes on severely eroded areas.

11. Nearly three-fourths of the households own livestock, mainly mixes of goats, sheep and cattle. Animals serve as an important source of investment for both men and women, manure, pack and transport, and food. Zarma-owned cattle usually are entrusted to Peul herders to spend the cultivation season outside the watershed -- returning for crop residue grazing. Animals are restrained from cultivated areas during the growing season on orders of the chef de canton. After all harvesting is completed, animals have free access to arable land. Planted cowpea forage and two native species, *Ipomoea involucrata* and *Merremia tridentata*, are cut and stored for dry season feeding or sold.

12. The laterite plateau and parts of the Tondo Kakasia and Gangani Kirey soils are seen by farmers as common lands. They believe that fuel and construction wood, fodder, food and medicine harvested in common lands will be naturally perpetuating and therefore see no need for any input to sustain production within these units.

13. Farmers view their land base as degrading due to climatic changes and vegetation loss. Problems about decreasing land productivity are most often related to declining soil fertility . . . "the land is old and tired." Wind erosion causing the loss of valuable topsoil and burial of millet seedlings is considered more of a problem than water erosion. For water erosion, sand deposition which limits the cultivable area and buries the crop is considered more widespread and harmful than gully erosion. Farmers plan for the short term and are concerned with minimizing the risks for meeting the food supplies for the household.

14. Farmers in the watershed are experimenting with multiple planting dates, mixing seed varieties, exploring favorable microenvironments -- defined as areas of favorable moisture and nutrient conditions -- priority weeding, and using surface mulches to control erosion. They have much experience in adapting to an unpredictable and changing environment. A wealth of indigenous technical knowledge exists that when integrated with appropriate modern technologies, should result in sustainable agricultural systems.

15. The data from the topographic, soils/geomorphology, indigenous knowledge and vegetation surveys were integrated with the aid of GIS. Five land management units (LMU) were delineated based on management needs. Plans for the management of each LMU for sustainable production will be presented in a subsequent report.

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## 1.0 INTRODUCTION

Over the last few decades, climatic conditions in the Sahel have been characterized by recurrent droughts. This, coupled with human misuse of the land, has contributed to a gradual, but significant decline in the region's natural resource base. However, it has been proven elsewhere in the tropics that improvements in land use technologies and the promotion of sustainable agricultural systems can reduce, if not stop, this decline.

The TropSoils Collaboration Research Project (CRSP), administered through Texas A&M University (TAMU), has conducted research in Niger in collaboration with Institute National de Recherches Agronomiques du Niger (INRAN) and other international research and development agencies since 1983. Results of various research activities point to a need for efficient management of the physical and biological systems associated with agricultural lands, forests, range, and water.

TropSoils and INRAN presented a project proposal, IMAW, to the United States Agency for International Development (USAID)/Niger. The goal is to conduct a feasibility study of the development of sustainable agricultural management technologies for western Niger. The Government of Niger and USAID agreed about the urgent need to improve and maintain the natural resource base of the country.

A cooperative agreement was signed in September 1989 between USAID/Niger and Texas A&M Research Foundation -- specifying TropSoils to conduct a 5-month feasibility study into an integrated approach to the management of small agricultural watersheds.

The following are the specific objectives of the study:

1. To undertake baseline studies in one agricultural watershed with a catchment area of 2-6 km2 and to identify two other similar size watersheds for future study. Specific components of the baseline studies are inventories of soil and vegetation resources and assessment of indigenous knowledge with respect to traditional farming systems and farmers' conceptions of soil conservation and land degradation.

2. To integrate baseline information into a Geographic Information System (GIS) to characterize land management units within the watershed to serve as a basis for establishing sustainable management strategies.

At the end of the 5-month period, TropSoils agreed to make an assessment to USAID/Niger as to the continuation or redefinition of a full 5-year project to develop and implement appropriate integrated land management technologies for small agricultural watersheds in Niger.

### 1.1 Site Selection

#### 1.1.1 Niger Context

The Niger Republic covering 1,267,000 km2 is the second largest Sahelian country with an estimated population of 7.2 million people. A land-locked country, Niger has a semiarid and arid climate. Rainfall decreases sharply from south to north with high rates of evapotranspiration. More than 75% of the country lies above the 300-350 mm isohet where rainfed agriculture is untenable. The northern part of the country is entirely desert.

Agriculture, the primary economic activity, is concentrated in the south where over 80% of Niger's population depends on the rural economy. Major cereal crops include millet and sorghum that cover 70% of the cultivated area. Other products include cowpea, onions, rice, cotton, peppers, peanuts, hides, and animals.

The annual population growth rate of 3.2% is outstripping agricultural production where increases of 1.5% each year over the past decade are largely attributed to the extension of the cultivated area rather than production increases. Droughts are a regular occurrence. The most recent droughts occurred in 1968-1974 and in 1983-84.

**1.1.2 IMAW Watershed**

The approximately 500 ha project area is located 2 km east northeast of the village of Hamdallaye in the Kollo arrondissement of the Niamey department (Fig. 1.1).

The region was originally settled and claimed by Zarma cultivators. Oral history of the area dates back to the mid-19th century. Immigration into the region and the watershed, in particular, was stimulated by the desire to leave more populated areas to claim virgin land for individual families.

The IMAW project watershed falls in the western Sahelian zone with a valley-plateau geomorphology characteristic of western Niger. Total rainfall in 1989 was 402 mm and 390 mm in 1990. Natural vegetation in the region is of the savanna-type. Soils are generally highly weathered

**1.1.3 Pilot Site**

The pilot site for the IMAW project was selected near the village of Hamdallaye, in the Kollo arrondissement, Tillabery department, in western Niger. The study area occupies an area of 500 ha, located east of the village.

The selection was based on a pedological study by M. Ouattara, a Ph.D dissertation at TAMU. Favoring the site for study was its favorable reception by villagers; familiarity of TropSoils and INRAN researchers with the area; closeness to the Niger capital of Niamey, approximately 30 km; proximity to a paved road for easy site access, and the fact that it was representative of watersheds in region.

The site is located in an area where improved varieties of millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*) and fertilizers (urea and simple or triple superphosphates) are readily available. The mixture of available technologies and the farmers' familiarity with them were also considered in choosing the site. Since the end result of the IMAW project is the improved management of lands by farmers, it was felt that those familiar with the concept of newer technologies would be more receptive to the research innovations to be tested during the project.

**1.2 Site Description**

**1.2.1 Villages**

Four villages have administrative territory within the watershed (Fig. 1.1). Farmers from these villages manage nearly all of the watershed land.

Approximately 13% of the land falls within the territory of Hamdallaye, the largest village located 2 km west of the watershed. It is the chef-lieu de canton, and as such, has a chef du canton and well as chefs du village. Hamdallaye has an important regional market, held weekly on Tuesday, and is home to the district agricultural office with an agent serving the region. The most important market in the region, however, is in Dantiandou, located about 30 km southeast of Hamdallaye.

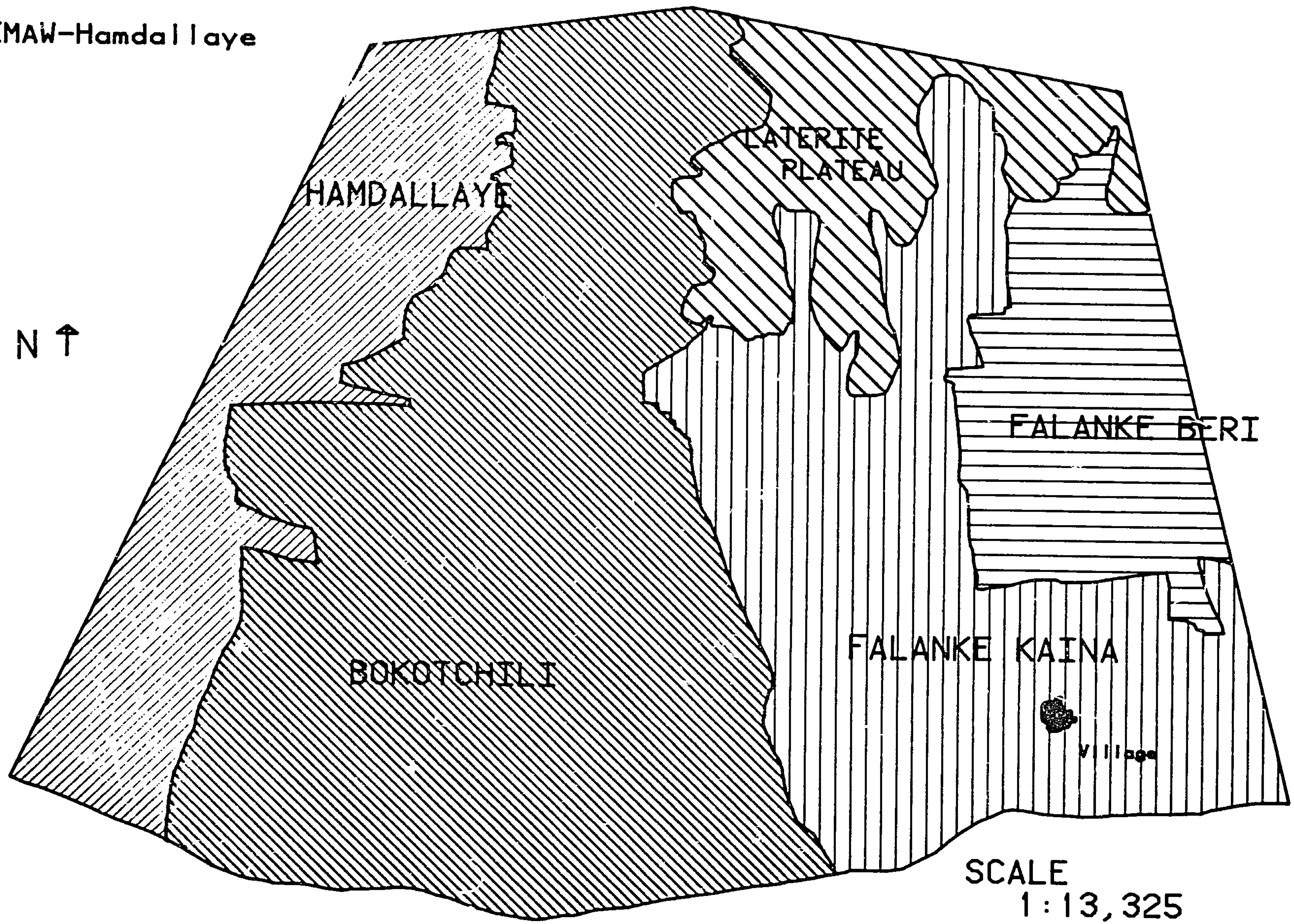
The village of Bokotchili Kaina, 4 k east of Hamdallaye by sand track, falls outside the project boundaries, but 56% of the watershed land area lies within its territory. Eighteen farmers from this village farm in the watershed.

Falanke Kaina, a hamlet entirely located within the project boundaries, lies about 6 k east of Hamdallaye. A quarter of land within the watershed boundaries comes under the administration of the chef de

FIGURE 1.1

# ADMINISTRATIVE BOUNDARIES

IMAW-Hamdallaye



famille of Falanke Kaina. All villagers have land within the study area.

Outside the watershed boundaries on the easternmost corner lies Falanke Beri whose administrative district covers about 6% of the watershed land. Three farmers from this village farm in the northeast corner of the watershed.

**1.2.2 Local Influences**

A seed multiplication center is situated on the southern side of the watershed valley. The center, created with USAID funding, is now completely financed by the Government of Niger. The center produces improved varieties of millet (HKP) and cowpea (TN578) on an experiment station and in local farmers' fields. Farmers can obtain seed, fertilizer, and pesticides necessary to grow pure stands of either millet or cowpea. A rental tractor is available to farmers, but the farmers contend the fee is too high.

The proximity of Hamdallaye to Niamey on a major road provides access to all markets in Niamey. A cooperative in Hamdallaye provides fertilizers, pesticides, seed, and other products and equipment used for farming.

A U.S. Peace Corps training center is located on a small laterite plateau on the western side of Hamdallaye. While training activities are confined to the center, the possibility of having Peace Corps Volunteers act as liaisons between local farmers and IMAW project coordinators should be explored.

**1.3 Initial contacts**

A local representative from Hamdallaye was chosen to act as a link between watershed farmers, village chiefs, the chef du canton, and TropSoils/INRAN personnel. He also acted as interpreter (Djerma-French) between farmers and project personnel. Other duties included supporting project technical activities, such as reading rain gauges and monitoring instruments.

The project began September 20, 1989, following approval by local authorities and farmers.

## 2.0 SOIL/GEOMORPHOLOGY AND TOPOGRAPHIC SURVEYS

**2.1 Aerial Photography**

Aerial photographs were used in mapping soils, geology, vegetation and spatially locating information obtained in the farmer survey. Photos were also used to estimate the size of farmers' fields. Stereo photos taken in 1975 at a scale of 1:70,000 were obtained from a USAID project. This imagery was useful in delineating general geomorphology within the watershed, but could not be used to determine present land use.

Three flights in a Piper Saratoga aircraft totaling 8.75 hours of flying time were made over the watershed. Elevations for these flights varied between 2,000 and 14,000 feet to obtain 1:5,000 to 1:10,000 scale photographs. During the first two flights, black and white and color film was used in 35 mm cameras mounted with 50 mm lenses. Photographs were made of transects running from the valley floor to the laterite plateau, with a 60% overlap between photos to permit development of stereo photopairs. These were used in the delineation of topography and as an aid in mapping soils and geology. Overview and oblique angle photos of the watershed were also taken. Additional aerial coverage was collected with a Biovision color infrared video camera during the last flight. This coverage will measured the percentage of farmers' fields that are productive, non--productive, and in fallow. It also enabled an assessment of total biomass changes during the life of the project. The TAMU Forestry Department will process the video imagery and results will be reported in a future publication.

**2.2 Topographic Survey**

A survey team constructed a topographic map of the watershed. Elevation measurements were made every 50 m on a grid pattern to produce a map with a minimum contour interval of 1 m [2m in figure 2.1] (Fig. 2.1.). The survey covered 589 ha.

**2.3 Watershed Geomorphology**

The watershed lies within a plateau and valley geomorphic zone and consists of a toposequence extending from the laterite-capped plateau to the valley floor. The topographical difference between the plateau and the valley floor is 40 m within a distance of 1500 m -- a 2.6% grade. This toposequence includes several geomorphic subunits reflecting the underlying geology. A broad, level laterite-capped plateau occurs on high peneplain remnants. Directly below the plateau are 2-8% slopes that are covered with laterite cobbles and pebbles near the surface. Below this is a large region of broad 0.5-2% slopes which lead down to short 5-7% slopes of the valley floor. Vertical relief between the laterite plateau and the valley floor is approximately 40 m. Laterite outcrops occur in two areas below the plateau.

One nearly level outcrop area, the first laterite formation, is located in the northern region of the watershed below outwash fans leading from the plateau. Laterite here occurs within 80 cm of the surface and, in places, occurs at the surface. The second laterite formation is found nearer the valley floor and forms a 5-7% slope composed entirely of ironstone concretions and a broader region of shallow soils overlying laterite. A break in the slope caused by the laterite formations is evident where the laterite is exposed. On the eastern side of the watershed the breaks are gentle, presumably due to a greater depth of the laterite formations.

**2.4 Soil Survey**

**2.4.1 Soil Survey Methods**

Soil mapping units were delineated from a preliminary survey conducted along five transects traversing the watershed along a toposequence from the plateau to the valley floor (Fig. 2.2). Sample sites were chosen along each transect based on geomorphic position. The number of sites varied between 4 and 10 depending on the distance from the plateau to the valley floor and the number of geomorphic units traversed. Soil samples determining soil texture, pH, structure, and color were taken with a bucket auger to a depth of 3.2 m, or to the depth where a laterite layer prevented drilling.

Seven major mapping units were identified within the watershed boundaries (Fig. 2.3). Eleven pedons were sampled for soil physical and chemical properties. Only one pedon was described near the first laterite formation due to the limited area of the mapping unit. Two pedons were described in all other units (Fig. 2.2). Phases of several mapping units were also identified. These included stoniness, erosion, overwash deposition and depth to laterite. A separate study was done on the laterite plateau, consisting of soils characterization in bare areas and within thin bands, or thickets.

FIGURE 2.1

# TOPOGRAPHIC MAP

## IMAW-Hamdallaye

Contour interval = 2 m

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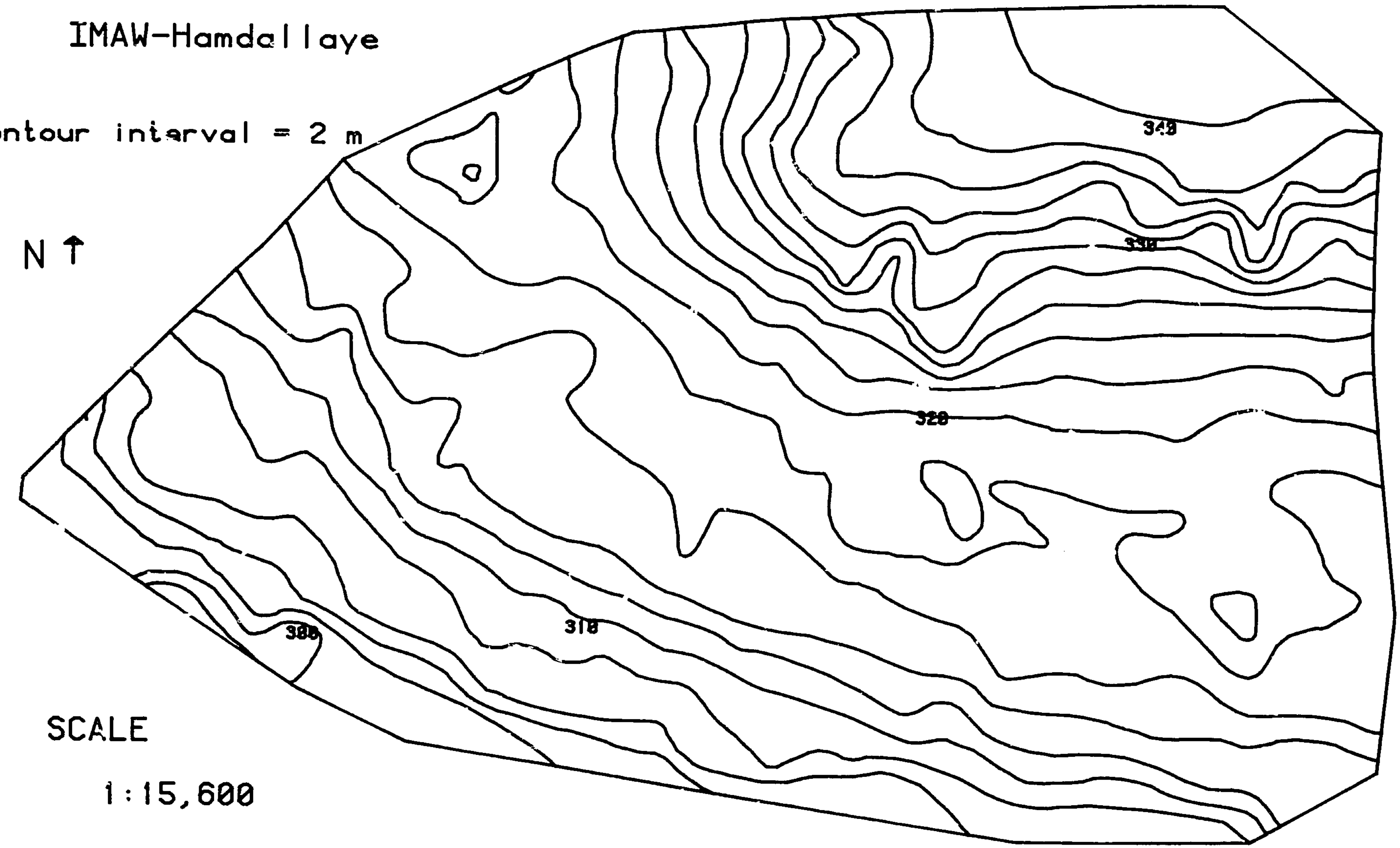


SCALE

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FIGURE 2.2

# SOIL SAMPLE LOCATIONS

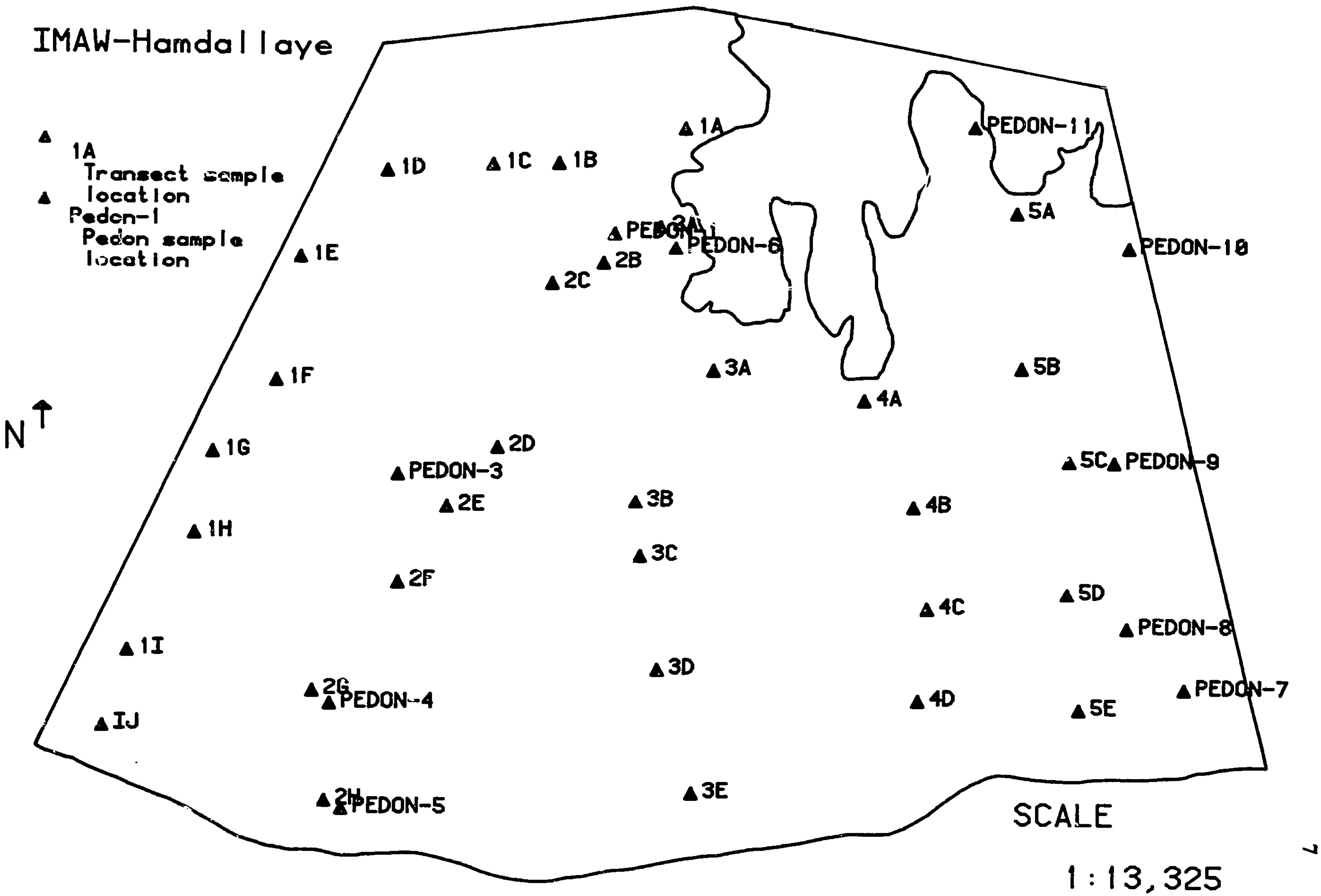
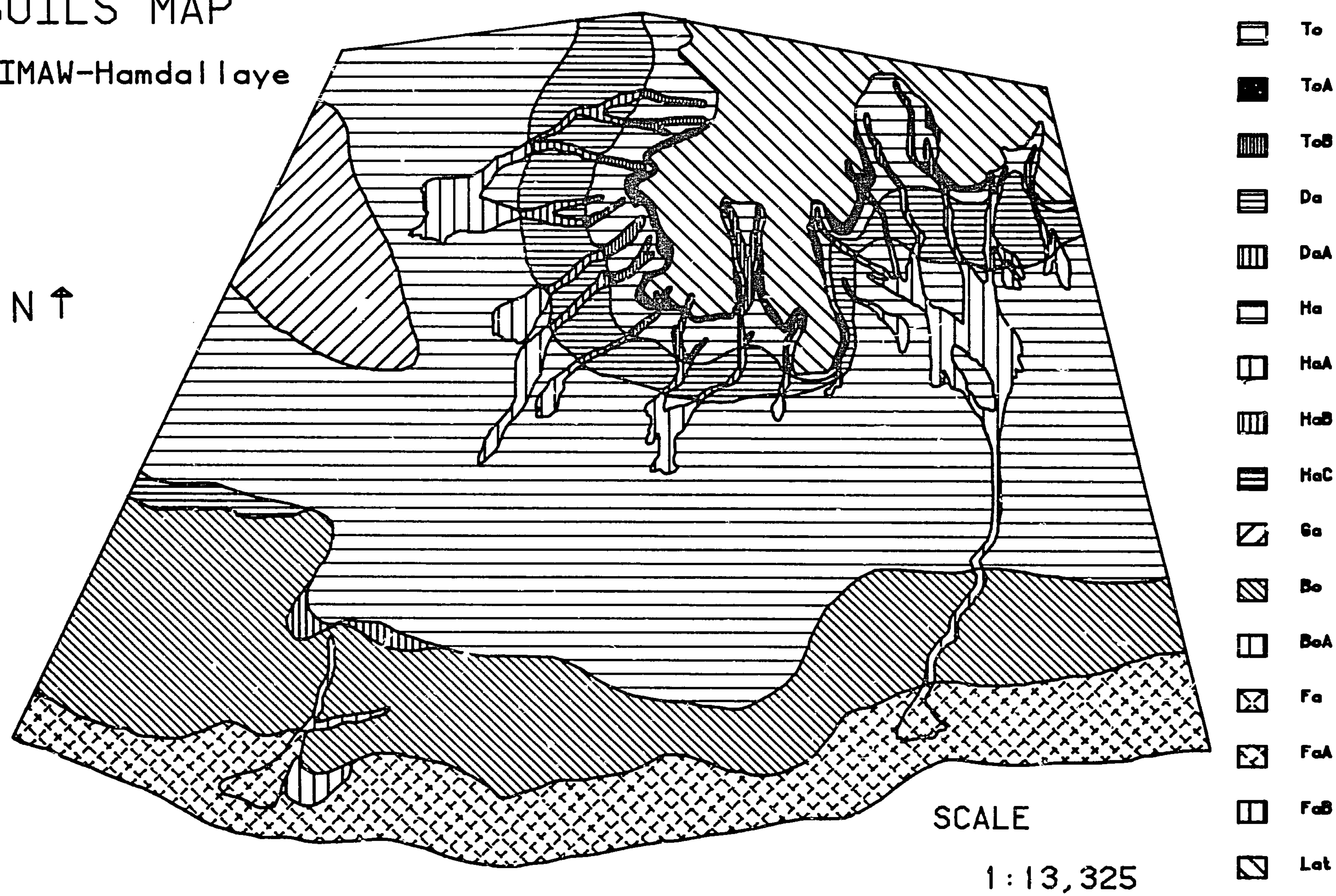


FIGURE 2.3

# SOILS MAP

IMAW-Hamdallaye



## SOIL MAP LEGEND

| SYMBOL | MAP UNIT |
|---|---|
| Lp | Plateau sandy loam, 0-1% slope |
| To | Tondo Kakasia sandy loam, 3-8% slope |
| ToA | Tondo Kakasia sandy loam, stony phase, 3-8% slope |
| ToB | Tondo Kakasia sandy loam, gullied phase, 3-8% slope |
| Da | Dantiandou sand, 2-3% slope |
| DaA | Dantiandou sand, gullied phase, 2-3% slope |
| Ha | Hamdallaye sand, 1/2-2% slope |
| HaA | Hamdallaye sand, overwash phase, 1/2-2% slope |
| HaB | Hamdallaye sand, lithic phase, 2-3% slope |
| HaC | Hamdallaye sand, lithic phase, 5-7% slope |
| Ga | Gangani Kirey loamy sand, 0-1/2% slope |
| Bo | Bokotchili sand, 1/2-2% slope |
| BoA | Bokotchili sand, gullied phase, 1/2-2% slope |
| Fa | Falanke loamy sand, 5-7% slope |
| FaA | Falanke loamy sand, overwash phase, 5-7% slope |
| FaB | Falanke loamy sand, lithic phase, 5-7% slope |

Pedons were described from a pit wall to a depth of 2 m or a lithic contact using standard procedures. Observations of soil color, texture, horizonation, structure, and the presence of crusts, roots, lateritic gravels, and termite activity were noted. Samples of each horizon were analyzed for bulk density, texture, moisture retention, pH, CEC, exchangeable bases, total nitrogen, organic carbon, available P, and exchangeable acidity.

To understand the variability within each mapping unit, six satellite samples were taken at four cardinal points relative to each pedon (6 of 11 pedons). Samples were taken 100 m and 200 m from the pedon in an east-west direction and 100 m in a north-south direction. Satellites were sampled to a depth of 2 m with a bucket auger. Observations were made of soil texture and color, and bulk samples were analyzed in a laboratory. Mapping unit descriptions are presented in their order of occurrence from the plateau to the valley floor. The soil map is shown in Fig. 2.3. A soil map legend and pedon descriptions are given in Appendix A.

**2.4.2 Map Unit Descriptions**

I. Plateau series (Lat) -- 0-1% slopes

This shallow, level to slightly sloping soil is located on the laterite plateau and varies in thickness over the indurated laterite layer. The laterite layer is gently undulating, with depth to contact varying up to 50 cm over lateral distances of less that 1 m. Vegetation on the laterite plateau occurs in thickets, separated by barren areas. Vegetated soils have profiles slightly deeper to laterite than unvegetated areas, with mean values of 53 cm and 49 cm, respectively. The surface soil in both vegetated and unvegetated areas is approximately 6 cm of dark brown to reddish brown fine sandy loam composed of thin lamellae. Consistence is hard to extremely hard throughout. A hard surface crust exists in unvegetated areas. Subrounded to subangular laterite gravels dominate the soil below the sandy loam surface with approximately 60% of these horizons composed of gravels. The upper portion of this gravelly zone (A2) is strong brown gravelly sandy clay loam to sandy loam. The lower portion (Bt) is yellowish red gravelly sandy clay loam. Structure is virtually nonexistent within these gravelly horizons as the soil is primarily a coating on laterite gravels.

II. Tondo Kakasia series (To) -- 3-8% slopes

This deep, severely eroded, (looks like the whole isn't eroded; the eroded phase Figures 2.2 and 2.3. being applied to areas with gullies). Soil occurs on undulating slopes adjacent to the laterite plateau. The surface soil is typically 30 cm of dark red sand to loamy fine sand with weakly developed lamellae in the upper 6 cm. Cryptogamic crusts are commonly seen on the surface. The Bt horizon is a red loamy coarse to loamy fine sand that extends below a depth of 2 m. Soil structure below 6 cm is strongly developed subangular blocky, and consistence ranges from very hard to extremely hard. Roots are commonly associated with biopores or biochannels in this soil. Permeability is slow and surface runoff is high due to the crusted nature of the soil and steep slopes. Hydraulic conductivity is low due to the compact structure of the soil. Lateritic gravels were found from samples taken 310 cm below the surface. A stony phase (ToA) was identified adjacent to the laterite plateau where ironstone cobbles dominate soil composition. An eroded phase (ToB) was found in areas where intermittent streams have made gullies up to several meters in depth.

III. Dantiadou series (Da) -- 2-3% slopes

This very deep gently sloping soil lies downslope of the Tondo Kakasia series. The surface horizon of this soil is yellowish red and is comprised of 2-3 cm of loose, structureless sand over 7-8 cm of thin sand lamellae. Below the sand lamellae is 30 cm of strong brown sand. Soil pH in the upper soil zone ranges from 5.2 to 6.3. The Bt horizon is a yellowish red to red sand that extends to below 2 meters and has pH values between 5.0 and 5.2. Weakly developed subangular blocky structure occurs throughout this soil and no indurated lateritic materials were found within 3 m of the surface. An eroded phase (DaA) was seen where intermittent streams have formed gullies to a depth of 100 cm. Hydraulic conductivity of these soils is high and surface runoff is low.

V. Hamdallaye series (Ha) --0.5-2% slopes

This very deep, gently sloping soil is found in the middle backslope region of the toposequence. The surface soil is yellowish red sand up to 50 cm thick with pH values between 5.0 and 5.2. Some platiness is shown in the upper 7 cm of the surface. The Bt horizon is a red sand (pH 4.9-5.3) that extends to a lateritic contact. Depth to laterite ranges from 110 to 300 cm with an average depth of 160 cm. Weakly developed subangular blocky structure was observed throughout the profile. A depositional phase (HaA) of this soil was identified where intermittent streams have formed outwash fans. These fans are wide areas in which 10-20 cm of loose sand has been deposited in shallow channels cut by the stream. A lithic phase was identified in two locations near the western portion of the Hamdallaye soil series (HaB and HaC). Laterite is found at the surface in this area and surrounding soils become shallower as the outcrop is approached. Hydraulic conductivity of these soils is related to the depth at which lateritic contact is made.] In the lithic phase, hydraulic conductivity is low compared to the rest of the series, where it is moderate. Surface runoff is low.

V. Gangani Kirey series (Ga)-- 0-0.5% slopes

This shallow, nearly level soil occurs in the northeastern section of the watershed. The surface soil is 8 cm of yellowish red sand that is stratified and has a 5.6 pH, and a crust of vesicular pores. A buried layer of dark brown loamy sand 20 cm deep was identified below the topsoil. The Bt horizon is a red sandy loam that extends to lateritic contact. It has a 5.0-5.1 pH and 2-10% ironstone gravels. Contact of laterite occurs at a depth of between 30 cm and 80 cm. Coarse subangular blocky structure is found in all horizons except the stratified surface. Consistence is hard throughout. In approximately 40% of the region where this soil is found, surface horizons have been eroded, and there is 10 cm or less loamy sand over the Bt horizon. These eroded areas have no vegetation and generally have a vesicular or cryptogamic crust. Hydraulic conductivity in these soils is low due to laterite lying within 1 m of the surface. Surface runoff is low.

VI. Bokotchili series (Bo) -- 0.5-2% slopes

This very deep, gently sloping soil is located in the lower backslope region of the toposequence, just up from the valley bottom. The surface soil is a strong brown sand up to 32 cm deep, the upper 5 cm occurring as thin lamellae. The Bt horizon is a yellowish red sand extending to a depth of 1 m. It overlies a C horizon that extends below 2 m. Weakly developed coarse subangular blocky structure exists throughout this soil and indurated laterite lies within 3.5 m of the surface. Hydraulic conductivity is rapid and surface runoff is low. An eroded phase (BoA) of this soil was found in two places where intermittent streams have cut deep gullies. One gully on the eastern side of the watershed measured 2 m deep and 8 m wide -- the largest within project boundaries.

VII. Falanke series (Fa) -- 5-7% slopes

This very deep, moderately sloping soil is located on the valley walls. The surface soil consists of 15 cm of strong brown sand, the upper 4 cm composed of thin lamellae. The Bt horizon is a yellowish red loamy sand that extends below a depth of 2 m. Weakly developed coarse subangular blocky structure was observed to a depth of about 1 m, below which the structure is nearly massive. No indurated laterite was found to depths of 325 cm. Eroded areas exist at the crest of the slope into the valley. A lithic phase (FaB) was found in the eastern area where indurated laterite was found 140 cm below the soil surface. This lithic phase is adjacent to a gully and may be the result of erosion that has truncated the soil profile. A depositional phase of this mapping unit (FaA) was identified at the base of gullies where there are extensive outwash fans. Hydraulic conductivity of the Falanke soils is rapid except in the lithic phase where it is low. Surface runoff is high because of the large slope.

**2.5 Watershed Hydrology**

Watershed hydrology is dependent on geomorphology. Intermittent water courses occur throughout the watershed (Fig. 2.4). On slopes greater than 2% an intricate network of gullies is found. These discontinuous gullies, up to 1 m deep and generally less than 2 m wide, start at the edge of the laterite plateau. Thirteen of these gullies cut across the Tondo Kakasia and Dantiandou soils. Another intricate network of gullies begins at the second laterite formation and extends directly to the valley floor.

Water running off the laterite plateau and the second laterite outcrop loses speed as the slope decreases to less than 1% in the Hamdallaye and Falanke soils. This leads to the formation of outwash fans. These fans can be 3-4 m wide and generally more than 100 m long, depending on their location. In the Gangani Kirey soil series, run-on water from the gully system and surface runoff from the Hamdallaye soils can result in ponding.

One watercourse in the eastern portion of the watershed extends from the plateau to the valley floor. This gully is relatively shallow near the plateau but forms a ravine that is 2 m deep and over 10 m wide in places.

**2.6 Soil properties and management constraints.**

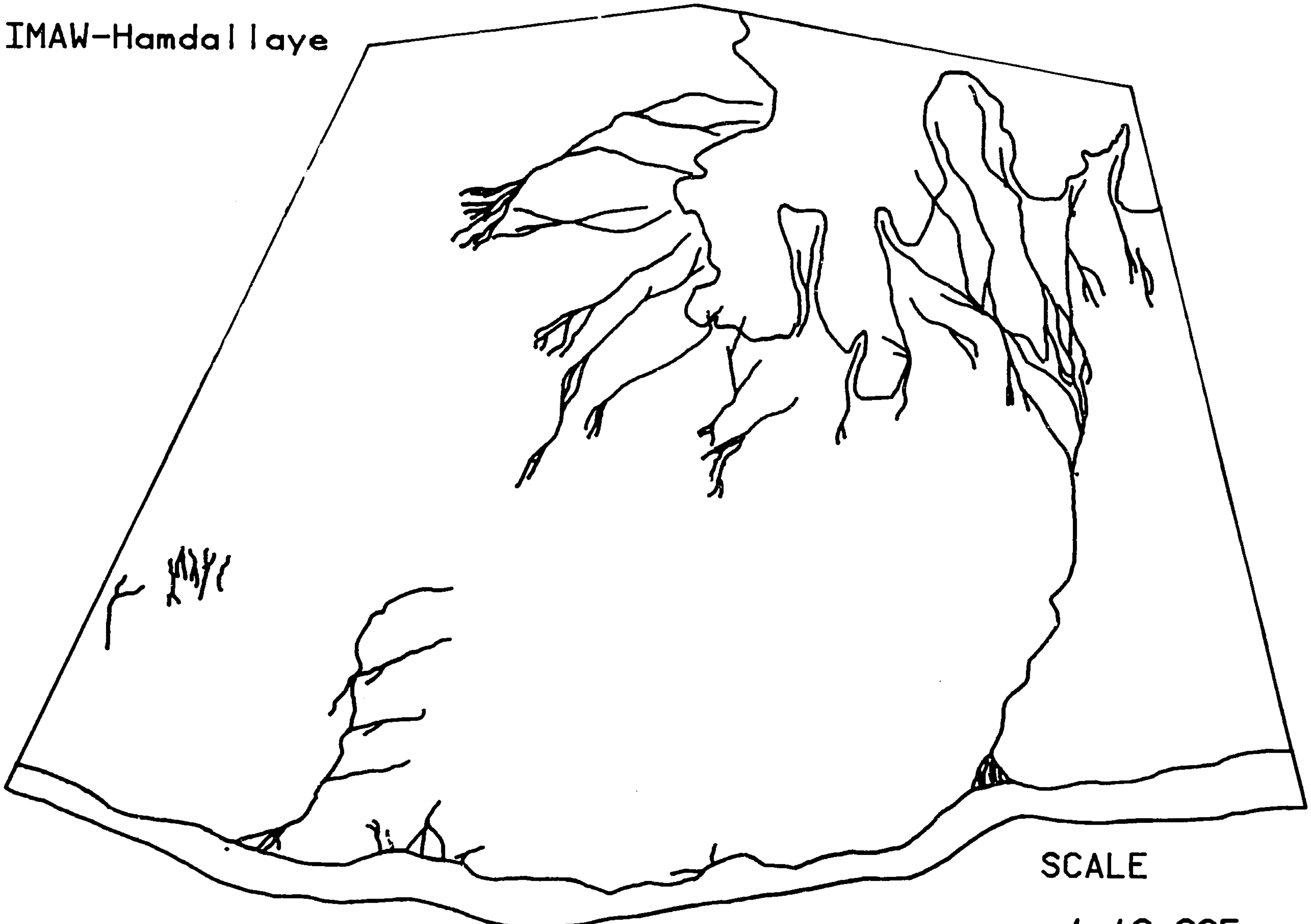
**2.6.1 Soil physical and chemical properties**

Soil texture is sandy to loamy sand throughout all soil profiles. Clay contents are highest in the Gangani Kirey soil. The Tondo Kakasia and Falanke soils have clay contents in the subsoil slightly greater than

FIGURE 2.4

# HYDROLOGIC NETWORK

IMAW-Hamdallaye



SCALE

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10%, while other soils are much lower (Fig. 2.5). All surface profiles are sandy textured. Total sand contents range from 78% in the relatively heavier textured horizons to 94% in the sandy horizons. Difference in water retention, measuring between 0.1 and 1.5 bar moisture tension units, are very small (Fig. 2.6). The higher moisture retention difference in the Gangani Kirey soil is likely a result of higher clay contents.

Organic carbon contents are extremely low (Fig. 2.7). Surface A1 horizons range from 0.08% to 0.14% organic carbon. The content increases slightly in the A2 horizons for all soils, from 0.07% to 0.30%, then decreases with depth. Organic carbon levels are higher in the Gangani Kirey soils, likely from an accumulation of suspended organic materials from upslope erosion, the presence of a buried horizon at 8 cm, and greater native biomass productivity.

Total N in these soils ranges from 0.004% to 0.025%, with a slight increase in the A2 horizons associated with an increase in organic carbon. The C/N ratio reflects the distribution of organic carbon and total N, ranging from 6.1 to 15.0 in the A1 horizons and 7.0 to 22.9 in the A2 horizons.

CEC ranges from 0.84 to 2.55 cmol(+)/kg. Highest CEC values are found in the transitional A/B horizons of all soils. Base saturations range from 28% to 100% of the CEC (NH4OAc) (Fig. 2.8). Highest base saturations occur in A1 horizons, especially in the Dantiandou and Gangani Kirey series due to deposits of base rich material from the upslope. After a sharp decrease in the top 40 cm, base saturation increases gradually with depth in all soils.

Soils are slightly acid on the surface and become strongly acid with depth. Soil pH (H2O) ranges from 4.9 to 6.3, with KCl pH ranging from 3.7 to 4.8. Aluminum saturation ranges from 0 in the surface A1 horizon to 44% in the Bt horizons.

Available P contents are generally below the critical levels required for most crops -- approximately 8 ppm Bray 1 P (Fig. 2.9). They range from 3.8 ppm P at the surface, decreasing sharply to a minimum of 1.8 ppm at the 2 m depth.

Citrate dithionite extractable Fe (free Fe) increases with depth in all soils except the Falanke series, in which free iron does not vary appreciably with depth (Fig. 2.10). Significantly high amounts of free iron occur in the Gangani Kirey soil, a reflection of the heavier soil texture, because free iron oxides are mostly concentrated in the clay fraction of the soil.

**2.6.2 Fertility capability classification**

All soils in the watershed are classified as Sdehk, except for the Gangani Kirey, which has the R substrata type due to the laterite layer. The k modifier is of little concern, as detailed studies of K dynamics in Sahelian soils show little indication of K response, even at very low levels of exchangeable K (Table 2.1).

**2.7 Constraints to production**

Based on soil physical and chemical properties and other field observations, productivity of soils within the watershed are related to a lack of moisture, crusting, depth to restricting layer, wind and water erosion, and nutrient deficiencies.

The sandy nature of the soils favors rapid water infiltration and low moisture retention. Water retention at 0.1 bar ranges from pF 2.0 to pF 6.5. Low moisture

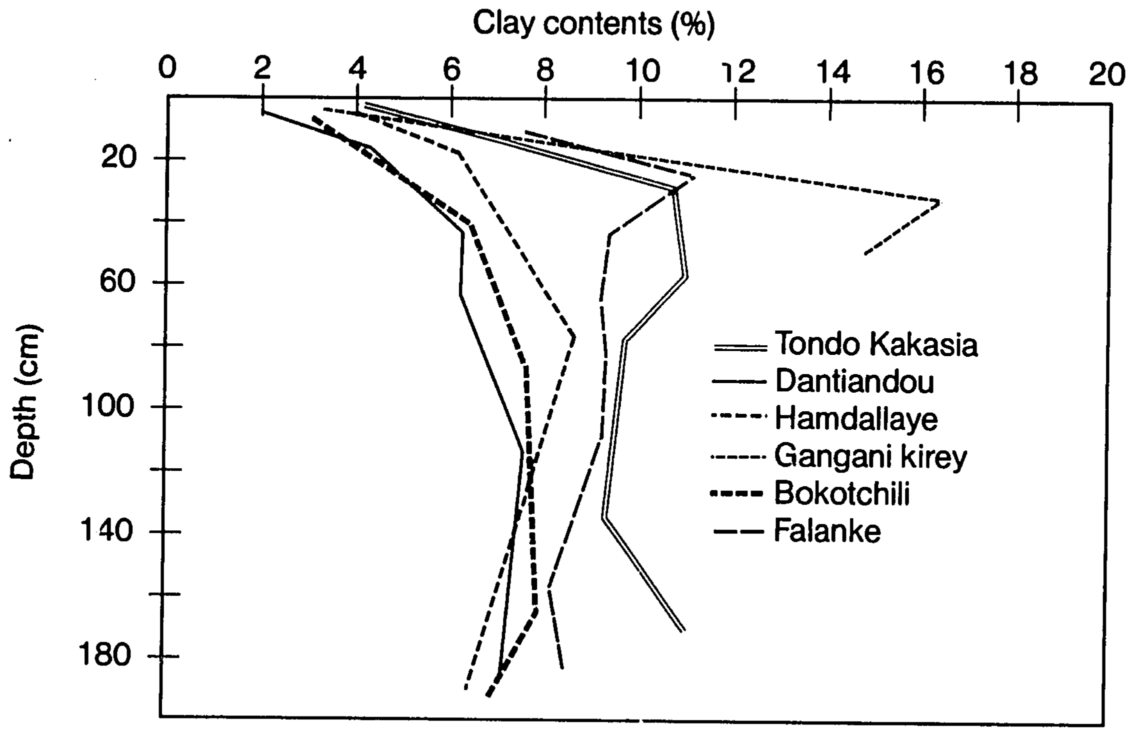



Fig. 2.5 Depth distribution of clay.

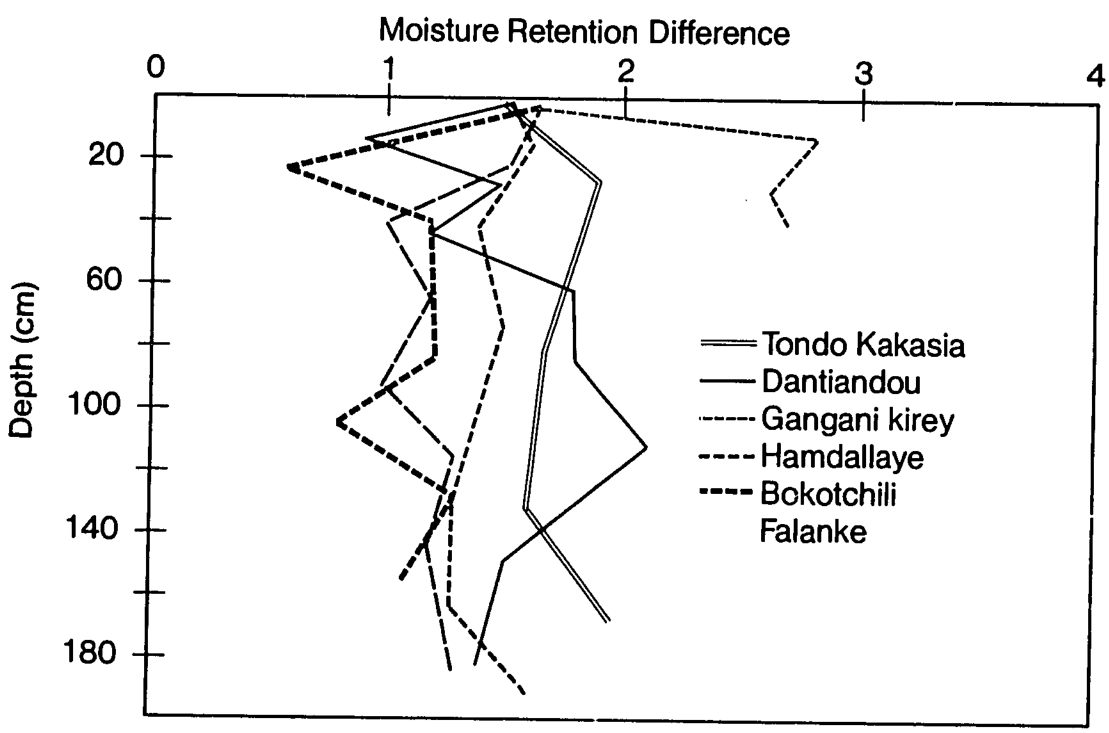



Fig. 2.6 Moisture retention difference (pF 2.5 – pF 4.2) with depth.

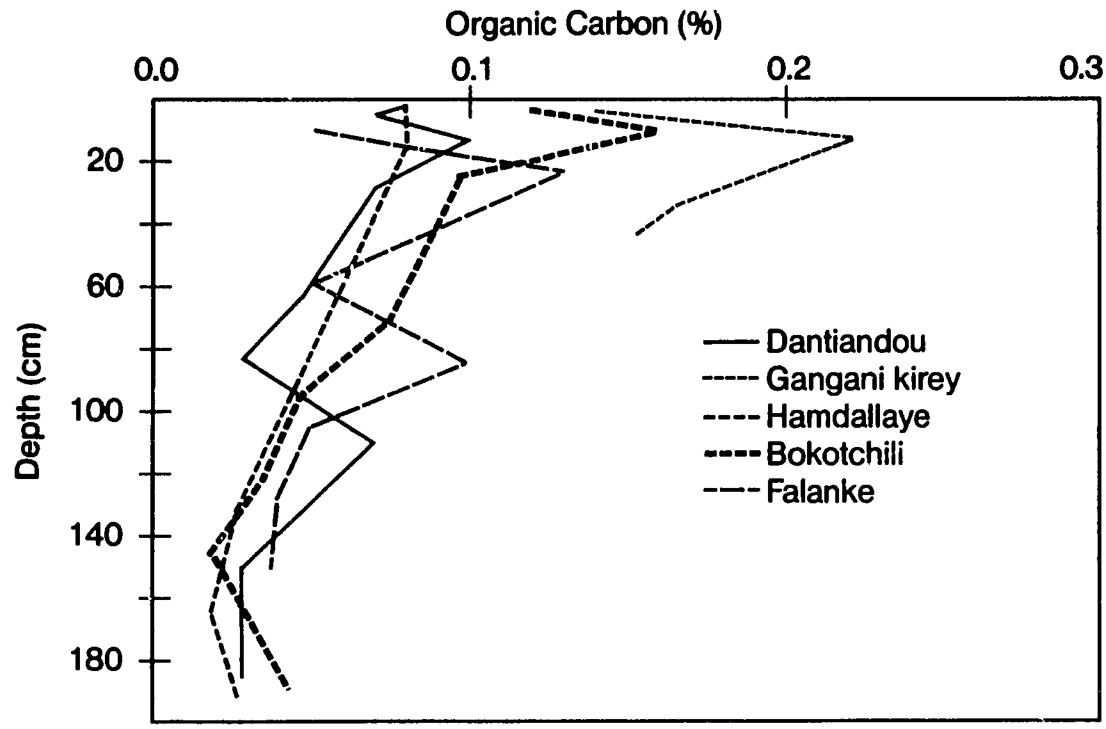



Fig. 2.7 Depth distribution of organic carbon.

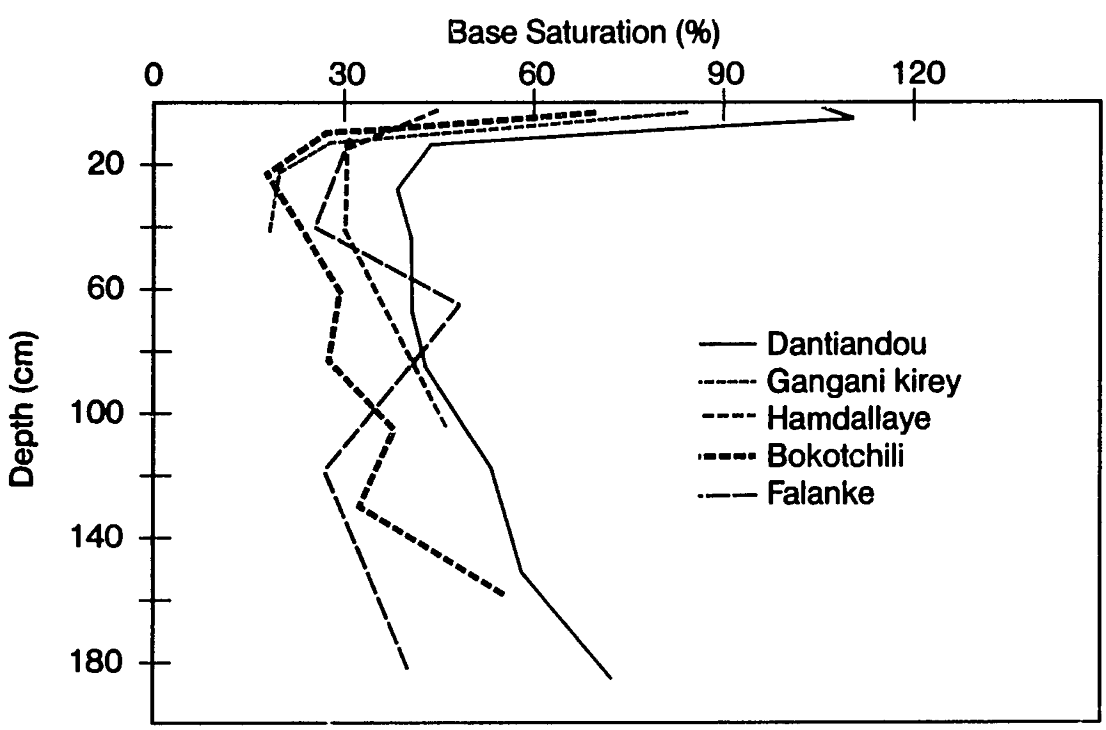



Fig. 2.8 Depth distribution of base saturation.

retention capacities, coupled with high evaporation characteristic of the Sahelian environment, result in moisture deficits during crucial periods of the growing season. There is no gardening potential during the nongrowing season within the valley floor due to a lack of moisture retention after the rainy season.

Crusting, the formation of a thin, sealed surface, is a drawback to production. It is prominent on the Tondo Kakasia and Gangani Kirey soils where vesicular, Bt, and algal (cryptogamic) crusts are found. Crusting also occurs in isolated land patches (gangani) within the sandy soils used for farming (Dantiando, Hamdallaye, Bokotchili, and Falanke soils).

Where it forms an impermeable layer at depths less than 1 m from the surface, laterite influences water movement and root distribution. The entire Gangani Kirey soil series lies over laterite. Lithic phases of the Hamdallaye and Falanke series were also mapped. On the Gangani Kirey series, laterite combined with run-on water leads to periodic ponding which harms crop growth and eventually causes surface crusts.

Strong harmattan winds prevail during the dry season when vegetative cover is at a minimum. Loss of the more fertile loose sandy texture surface soils from wind reduces soil productivity and increases susceptibility to water erosion. Large amounts of loose sand during high winds preceding rainstorms also result in the sandblasting of young seedlings.

Severe water erosion occurs on the Tondo Kakasia soil, evident by an intricate network of gullies and sheet and rill erosion on the side slopes. Roots of many shrubs and small trees have been exposed. The accelerated erosion results from runoff water from the laterite plateau.

The Falanke soil occurring on the steep valley wall slopes is interspersed with small gullies. There is sheet erosion on other productive soils (Dantiandou, Hamdallaye and Bokotchili), however, the effect on crop output has not been determined.
Erosion has led to the development of isolated nonproductive land masses (gangani) within these mapping units.

In addition to removing fertile topsoil and creating gullies, water deposits material downslope on Dantiandou and Hamdallaye soils and, to a lesser extent, on the Falanke soils in outwash fans. These areas generally have no vegetation. Periodic flooding by runoff water and burial of seedlings make crop establishment very difficult.

Soil fertility is a major constraint to crop production in the watershed. Soils are characterized by low nutrient contents, low pH values, high aluminum saturation, and lack of primary weatherable minerals necessary for nutrient recharge. Little nutrient recycling occurs because most of the crop biomass is grazed by livestock or removed by farmers for other uses.
Aluminum saturation is not high enough to warrant a modifier in the fertility capability classification, indicating that toxic conditions most likely do not prevail.

Table 2.1. Fertility capability classification.

| Soil | Type | Substrata type | Condition modifiers |
|---|---|---|---|
| Tondo Kakasia | S | -- | d,e,h,k |
| Dantiandou | S | -- | d,e,h,k |
| Hamdallaye | S | -- | d,e,h,k |
| Gangani Kirey | S | R | d,e,h,k |
| Bokotchili | S | - | d,e,h,k |
| Falanke | S | - | d,e,h,k |

S = sandy to loamy sand surface soil texture
R = restrictive layer
d = dry environment
e = low CEC values
h = acid conditions (10%-60% Al saturation)
k = possible K deficiency

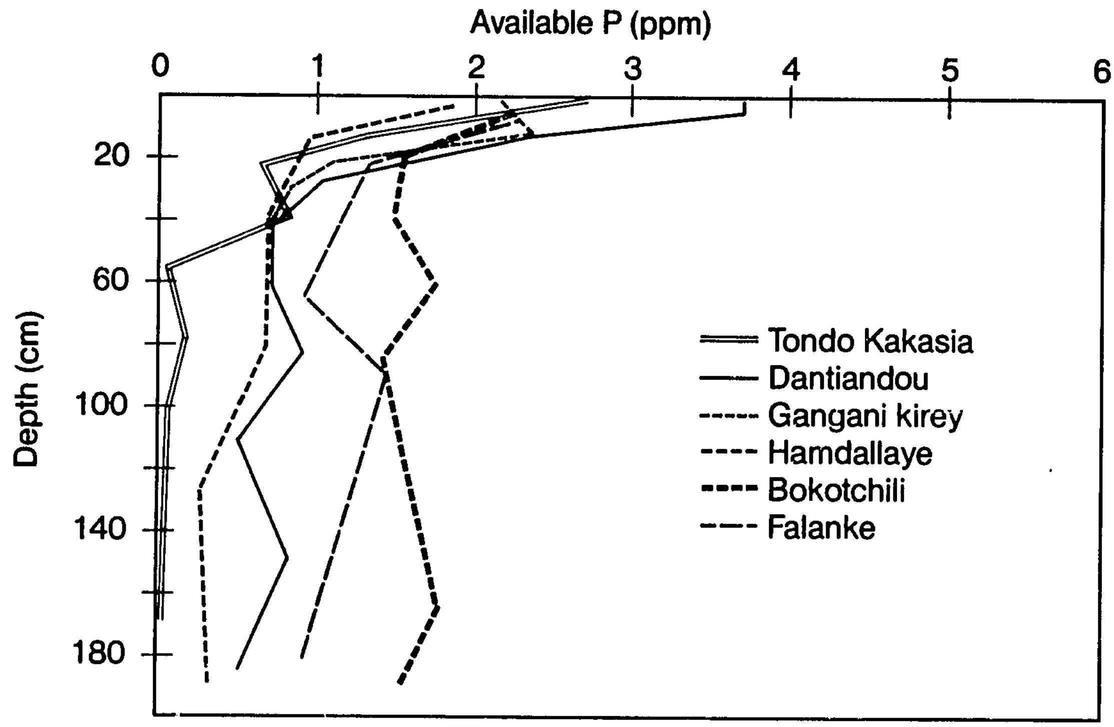



Fig. 2.9 Depth distribution of Bray 1 phosphorus.

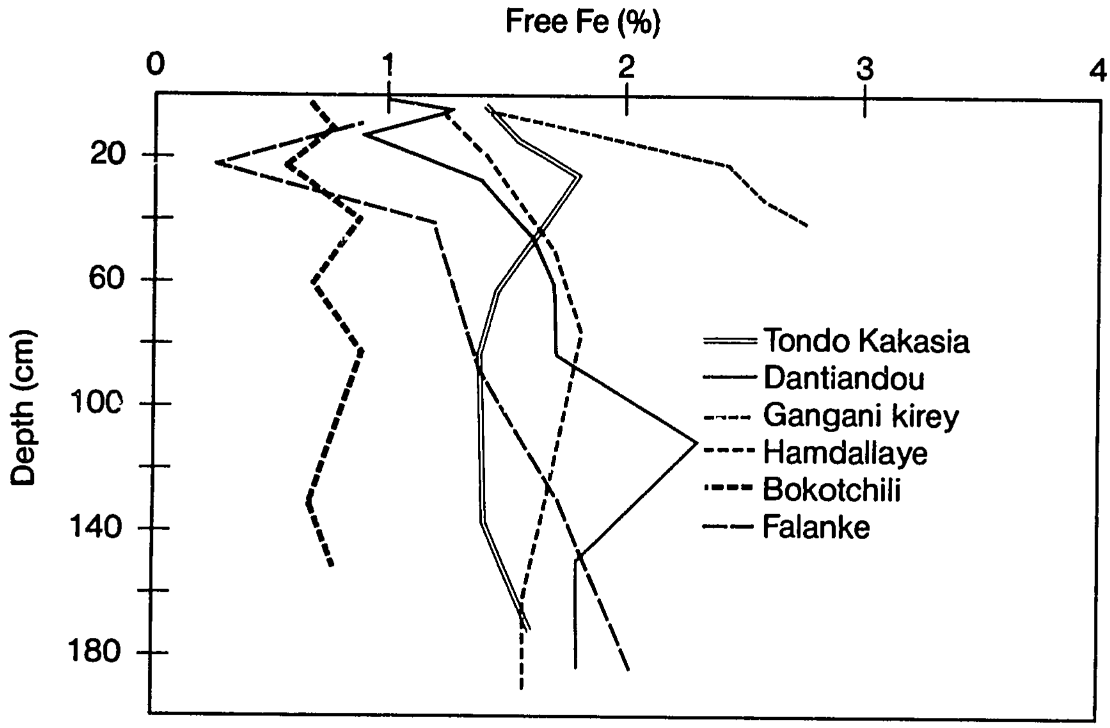



Fig. 2.10 Depth distribution of free Fe oxides.

## 3.0 INDIGENOUS KNOWLEDGE SURVEY

An indigenous knowledge survey was conducted within the Hamdallaye watershed between October and December 1989. The specific objectives were the following:

+ Conduct interviews with village chiefs and elders to obtain historical and demographic descriptions of the watershed
+ Identify all farmers within the watershed and document the land history of cultivated and fallow areas
+ Conduct individual farmer interviews to obtain a general assessment of land tenure, native knowledge of soil and crop management, and farmers' perceptions of problems and solutions

### 3.1 Methods

To identify farmers cultivating or owning land in the watershed, the researcher walked the area with knowledgeable natives, obtaining native names associated with each cultivated and fallow field.

Maps prepared from aerial photographs were used as the base of reference. Of the 56 farmers identified, interviews were conducted with 42, a 75% population sample. Several group interviews were held with village elders and three village chiefs having administrative responsibility for watershed land.

During the interview process, the researcher walked with farmers on their fields asking for comments and seeking explanations of their soil management practices.

### 3.2 Description of the Watershed

The watershed is located 2 km east of Hamdallaye village in the Kollo arrondissement of the Niamey department. Hamdallaye has a major paved road that connects it to Niamey, the capital of Niger, and Filingue. A system of secondary roads and paths link surrounding villages to Hamdallaye, which has a weekly Tuesday market. Villagers also travel to the more important markets in Dantiandou, 30 km southeast; Baleyara, 65 km northeast; or to Niamey, 30 km west.

Various public services and development assistance programs are centered in Hamdallaye. There are two schools -- a private Arabic school of three classes and a public school with seven classes. There is a private pharmacy and a government dispensary. The district agricultural officer works out of Hamdallaye with responsibility for the entire canton. Through the assistance of the Cooperative League of USA (CLUSA), a local cooperative was created in 1986. In 1989 it set up a millet marketing program.

In the early 1980s the U.S. Peace Corps established a permanent training center on the edge of Hamdallaye. Volunteers reside in the village, but most training activities are confined to the hillside training center. A seed multiplication center was established in 1968 under USAID funding to provide seed and other agricultural inputs to area farmers. Program sponsorship was transferred to the Niger government in June 1989. During the mid-1970s, the Sahel Verte program established a tree plantation near Hamdallaye which provided villagers with tree seedlings.

#### 3.2.1 Administration

Four villages have administrative territory within the watershed (Table 3.1). Approximately 14% of the land falls within the territory of Hamdallaye, the administrative seat of the canton. The village of Bokotchili Kaina, 4 km east of Hamdallaye, is outside the watershed boundaries, but 42% of the watershed land falls under its administ/ration. Falanke Kaina, a hamlet entirely located within the watershed boundaries, lies about 6 km east of Hamdallaye. Twenty-five percent of the land comes under the administration of the family chief of Falanke Kaina. Outside the watershed, located in the easternmost corner, is Falanke Beri, whose administrative district covers about 10% of the watershed.

**Table 3.1 Land area in each village district**

| Village territory | Land area (ha) |
|---|---|
| Hamdallaye | 70 |
| Bokotchili Kaina | 209 |
| Falanke Kaina | 125 |
| Falanke Beri | 49 |
| Laterite Plateau | 43 |
| TOTAL | 496 |

### 3.2.2 Village Histories

Hamdallaye. Two Zarma families are said to have been the first settlers in Hamdallaye. Originating from near Baleyara in the canton of Tagazar, they settled in N'Dounga before finally establishing themselves in Hamdallaye about 1854. The current chief, installed in 1988, is the fifth in the patrilineal descent. The current population of Hamdallaye is about 1200 households, predominantly Zarma. Some Hausa have settled in Hamdallaye as well as some Tuareg and Arabs. A settlement of Peulh, "Hamdallaye Peulh", is found on the southwest side of town.

Bokotchili Kaina. The founder of Bokotchili Kaina originated from Bokotchili Beri in the canton of Koure. After settling and claiming land in Bokotchili Kaina, he moved on to settle the village area of Binni Bokotchili. Today, descendants from the same lineage claim land in all three villages. The current population of Bokotchili Kaina is Zarma consisting of about 800 people in 88 households. Reportedly, the village population has decreased since the recent droughts. Bokotchili Kaina has no governmental services nor market.

Falanke Kaina. The history of Falanke Kaina dates back five generations when a Zarma pioneer came from Allahoni to cultivate and claim surrounding virgin land. The hamlet consists of about 100 people in 11 families. All are descendants of the original pioneer except one Peuhl family who established herding relationships with the cattle-owning Zarma and is now a year-round resident.

### 3.2.3 Characteristics of Farmers

Of the 42 interviewed farmers, 32 are Zarma (76%), 6 are Hausa (14%), and 4 are Peul (10%). All are male except two, 1 Hausa woman and 1 Peul woman who in absence of husbands are de facto heads of households. Age of household heads range from 22-70 years with an average age of 42 years. Fifty-four percent of the household heads are between 22 and 40 years old with 12% over the age of 61. Household sizes for the 42 farmers average 9 persons ranging from 2 to 20 persons.

Traditionally, Zarma are agriculturalists with a production objective of meeting household cereal needs and selling the surplus to meet cash needs.

Given recent droughts and poor rainfall conditions, producers have increasingly engaged in multiple off-farm activities, particularly seasonal migration to coastal countries as unskilled laborers. Other activities include transport with donkeys and ox carts, petty commerce, crafts, tailoring, butchering, brickmaking, barbering, and herding by the Peul. Two of the 42 farmers have salaried employment. Other sources of household income include remittances from nonresident household members.
Availability and allocation of capital and labor by households was not documented but is clearly diverse.

### 3.2.4 Farming System

A millet-based mixed farming system is the watershed's dominant agricultural system. The production objectives are to provide subsistence food grains and to market a portion of the harvest to meet cash needs. Land holdings fall under the control of household heads. In addition to family fields, household members such as unmarried men and women often cultivate individual fields, thereby establishing subeconomies within the household.

Field Sizes. Field sizes in the watershed were calculated by TropSoils staff using an electronic planimeter to measure fields identified on aerial photographs and verified on the ground.

Fallow and cultivated fields per household average about 10 ha, evenly divided between the two. Eighty-three percent of the households were cultivating land in the watershed in 1989 and 62% had land in fallow.

Cropping Patterns. Millet dominates the cropping pattern, generally as an intercrop with cowpea (Table 3.2). Sorrel is often intercropped with millet and millet/cowpea combinations. More favorable microenvironments within a field are cultivated to sorghum, maize, sorrel, and okra. Unlike Hausas, Zarma women are minimally involved in crop production, but often keep personal peanut plots, garden near the compound, interplant sorrel into main crops, and harvest *sunne* (undeveloped grain heads) and various other native plants for home use and sale.

Besides planted millet, two other types of millet are important in the production system. *Diaraou*, volunteer millet, competes with planted millet but ripens first, thus becoming important in providing food during the so-called "hungry gap." Its residue is used in building construction and is fed to animals.

*Sunne* is any undeveloped millet grain head produced by local varieties. It is harvested, often by women, prior to the regular harvest, and is useful during the hungry season.

Farmers in the watershed either seed during the dry season or with the first rains in mid to late June. Replanting is often necessary when seed germinates as a result of early season rains but dies during a following dry spell or is buried by wind-blown sand. Planting continues through July in some years. Harvesting is usually done in mid to late October. In 1989, harvesting began the week of October 16.

Use of Inputs. Improved millet (HKP) and cowpea (TN578) varieties have been available in the region through the SMC

**Table 3.2. Crop pattern in Hamdallaye watershed, 1989 (n = 46 fields)**

| Crop | Fields No. | Fields % |
|---|---|---|
| Millet/cowpea | 30 | 65 |
| Sole millet | 7 | 15 |
| Sole millet; millet/cowpea | 4 | 9 |
| Sole millet; sole cowpea | 2 | 4 |
| Millet/cowpea; sole cowpea | 2 | 4 |
| Millet/cowpea/sorghum | 1 | 2 |
| TOTAL | 46 | 99* |

* Does not total 100% due to rounding

**Table 3.3. Millet and cowpea varieties used in the Hamdallaye watershed, 1989 (n = 42 farmers)**

| Variety | Farmers No. | Farmers *% |
|---|---|---|
| Local millet | 35 | 83 |
| Improved millet (HKP) | 13 | 31 |
| Local cowpea | 39 | 93 |
| Improved cowpea (TN57N) | 3 | 7 |

* Totals may exceed 100% since farmers may mix local and improved varieties.

[How many used mixed varieties]

since about 1982-83. Local varieties, how ever, dominate (Table 3.3). Two local varieties of millet -- *tchumo* (dark colored millet) and *drankoba* (light colored millet) -- are typically sown together and may be mixed with HKP as a means of minimizing risks. Thirty percent of the farmers inter viewed used fertilizer in 1989. Quantities and timing of application varied.

There are varying opinions about the productivity of the improved versus the local millet varieties. Three main disadvantages exist with the improved variety:

1. Because the improved variety ripens earlier, it is more susceptible to bird and insect attacks.
2. The improved variety must be weeded sooner after planting since it ripens more quickly. This competes with other labor priorities.
3. The improved variety produces well only if fertilizer is used and all recommendations followed. Many farmers in 1989 thought the SMC was losing support. Seed and fertilizer availability were said to be uncertain, and terms of credit less favorable.

Prior to 1989, farmers reimbursed the seed multiplication center with millet and cowpea grain at the rate of 2.5 k for every 10 k of seed obtained. Triple superphosphate and urea were available at the cost of 3,750 CFA and 3,250 CFA per 50 k bag of triple superphosphate and urea, respectively. However, farmers had an option to repay fertilizer in a grain equivalent at the fair market price. Cowpea insecticide was provided free of charge.

Actual use of improved seed varieties and fertilizers depended on affecting decisions farmers made about the climate, availability of resources and inputs, and expected returns. For example, one cultivator sought out an improved, early maturing millet variety when the rains were late. Another farmer put off using fertilizer because poor yields were expected due to of poor rains and an inability to repay production costs.

Labor. Manual cultivation is done with long-handled hoes (*hilere*) involving surface rather than deep cultivation. Most field labor is done by household males. Work is done first in family fields, then by household members in individual fields. One farmer interviewed used oxen in the field, but more often as transport. Two used tractors - one for opening up new lateritic land close to the plateau, the other was a businessman from Niamey who also used hired labor. These two cultivators had the largest cropped areas in the watershed, 16.4 and 15.1 ha, respectively. Tractor rental was available at the seed multiplication center for 40,000 CFA a day, or 10,000 CFA per ha.

By households, actual field labor ranged from 1 to 7 persons, averaging 2.5 persons. During weeding and harvesting, households may participate in *bougou*, requested collective work, or *gayan*, volunteered help. Payment was generally in meals. Paid labor was rare. Three farmers in 1989 hired labor. Payment was by the day, a minimum of 750 CFA a day, or by the job. During the 1989 harvest, laborers received 50 CFA for each tied bunch of millet heads. Zarma women in the region principally assist in planting and harvesting on the common household field as well as post-harvest activities

Livestock. All interviewed farmers report fewer livestock in the region since the drought culminating in 1984, although numbers are said to be increasing. Nearly three-fourths of the households owned livestock, principally mixes of goats, sheep, and cattle (Table 3.4). Of the 30 households with animals, 60% owned one or two species, 33% owned three to four types of animals, and 6% owned five or six species. Women often kept small livestock to provide more

**Table 3.4. Livestock held by watershed cultivators (n = 41 farmers)**

| Category | Farmers No. | % |
|---|---|---|
| Households with no animals | 12 | 27 |
| Households with animals | 30 | 73 |
| Type of specie owned: | | |
| Cattle | 15 | 37 |
| Sheep | 21 | 51 |
| Goat | 25 | 61 |
| Donkey | 9 | 22 |
| Camel | 1 | 2 |
| Horse | 2 | 5 |

security than the crop land allotted by men (Painter, 1980). A small number of ruminants, donkeys, and horses were kept on the farm, whereas cattle were usually entrusted to Peul herders. Cattle were either managed all year in the watershed or outside the area during the growing season and brought back after the harvest to graze on crop residue and for manure fertilizer. Farmers reportedly paid 1,000 CFA an animal for the three-month herd care.

Livestock were kept off cultivated land during the cropping season by order of the canton chief. They grazed fallow fields, except fields producing economic resources such as *Andropogon gayanus* and *Aristida sieberiana*. After harvest, animals were given free access to all land. Zarma, Hausa, and Peul farmers gave slightly different priorities and value to livestock. Peul farmers who maintain on-farm herds (two of four resident Peul) more fully integrated livestock into the production system, balancing labor between crops and livestock. For these two Peul, the cropped area was relatively small, 2.7 ha and 3.8 ha, respectively, but land productivity was relatively high because of animal manure use.

### 3.3 Land Tenure

The land tenure system in the watershed was based on the settlement history of the region. Zarma pioneers, usually single families, moved into areas of virgin land and gained rights to the land they cleared as the first cultivators. Today, all land in the watershed is claimed by families of the original settlers. Forty-one families from four villages claim rights to the land cultivated by 56 farmers (Table 3.5). Thirty-two, or 57%, of those farmers were farming family land. Six, or 15%, were absentee landowners. Holdings are recognized through the use of permanent markers such as trees or unweeded borders.

#### 3.3.1 Customary Land Rights

Under Zarma land tenure, rights to the watershed land rests in the lineage of the original Zarma settlers. Land passes from father to sons through a patrilineal inheritance system. When a son marries, he is allocated land for his household needs. Over time through this inheritance process, land has come under the management of

**Table 3.5. Number of family land holdings and cultivators by village territory in the watershed.**

| Village territory | Claimants No. | Claimants % | Cultivators No. | Cultivators % |
|---|---|---|---|---|
| Hamdallaye | 7 | 17 | 9 | 16 |
| Bokotchili Kaina | 18* | 44 | 23 | 41 |
| Falanke Kaina | 13 | 32 | 21 | 38 |
| Falanke Beri | 3 | 7 | 3 | 5 |
| TOTAL | 41 | 100 | 56 | 100 |

* Three of these claimants do not actually live in Bokotchili Kaina but in the villages of Binni Bokotchili, Fandougou and Bokotchili Beri.

individual household heads (windi koy), resulting in the breakup of the original family land.

These houschold heads have a strong sense of ownership, calling land their "own" fields. Tenure is secure and management decision making rests with the farmer for as long as the land is used, including fallow periods. The land, however, belongs to the lineage. The head of the extended family presides over decisions about the allocation and arbitration of family land. Land not yet inherited is under the household head's control as is land which has reverted to the family through disuse.

Women have no land rights, but are allocated land for personal crops of peanuts or household gardens. In cases where a man falls to the daughter. A woman may become the designated title holder at her husband's death until a son comes of age or in the absence of the husband or son.

Some expansion of the cultivated area has occurred in the past decade on marginal land near the plateau. One field, opened up in 1988, is situated on land previously used as a cattle marketing route and over which ownership is uncertain. The current farmer expressed no problems in retaining use rights as long as he cultivates the land. Once fallowed, however, it was felt that owners of bordering fields would claim the land. Likewise, land on the plateau was said to be common grazing land, unsuitable for cultivation. Yet farmers said if land on the plateau were made productive, it would be claimed by those who own bordering land. Unused land was not equated with being vacant, available, or unclaimed. Except for two recently opened fields, all other land had passed through a succession of users.

### 3.3.2 Land Agreements

Besides inheritance, cultivators acquire land through loan. Forty-three percent of the farmers in the watershed were cropping on borrowed land. Verbal agreements are reached between the household head and the borrower. No formal time periods are set. The general understanding is that the land will be cultivated until the "field becomes too old and too difficult to cultivate," at which point it is fallowed and ownership reverts to the lending family. The borrower may acquire another field from the same family, negotiate land use with another family, or subdivide the field so that portions can be fallowed. A few instances were reported where land was reclaimed. Tenure security appears to exist through established lender-borrower relationships. Several farmers were acting as subleasers, allowing others to use parcels of their borrowed land.

Of the 24 cultivators using borrowed land, 15 moved into the area and 9 are natives. For the latter, the typical reason for seeking a field distant from the village residence is insufficient family land to meet household needs. It is uncertain whether "insufficient" refers to the quantity of family land available or its level of productivity.

For use of land, the farmer typically gives the lending household head a proportion of the harvest, reportedly 10%, although the amount varies according to relationship and yield. No money transactions are used, nor is land sold. A typical remark was that if one sells land, the money will soon be gone, whereas land lasts forever.

The use of borrowed land passes in patrilineal succession to the borrower's sons, allowing its use to pass through multiple generations. This provides tenure security to nonlandowners. It also is a source of the major land disputes, whereby succeeding users develop a sense of ownership over someone else's land. Formal leases obtained through the canton chief were being encouraged to prevent misunderstandings. If a land dispute occurs that the village chief cannot settle, the canton chief calls knowledgeable elders to clarify the original settlement history.

**3.3.3 Land Availability**

Land availability in the watershed is uncertain. Surplus family land appears to exist in Falanka Kaina, but the elders of Bokotchili said village land is limited. Farmers contended land is available for anyone who wants to cultivate it. For example, "All the good, strong workers have left. They've gone elsewhere. They don't want to farm. They want to find work in the cities. All that is left is the old men. So, there is land here for anyone who wants to work."

Such perceptions may be typical of the deep-seated belief over much of Africa that land is to be shared (de Wilde, 1967) or be opened up by government policies encouraging use of land by anyone willing to cultivate it. The result has been a disruption of the fallow system, which causes land degradation (Arnould, 1982).

Land availability is not synonymous with accessibility or its quality. Much of the land in the watershed is distant from the village centers of Hamdallaye and Bokotchili Kaina. Some farmers living in Hamdallaye travel 4 to 6 km to their fields. Peul have been loaned land and are well established in the Falanke Kaina region, but no Peul reside in the Bokotchili Kaina territory. It appears that newcomers, especially those without previous attachments to the region, receive the least desirable land.

Access to land depends upon the

personal characteristics of the lender as well as the borrower. Heads of families are known according to their temperament and generosity. For borrowers, it is said land is loaned to serious farmers; to those who want to work.

Land quality in the watershed is typically characterized in terms of cultivation history and soil structure. Fallow fields may be available for cultivation, but are low in productivity when brought into cultivation prematurely. Likewise, land quality relates to slope, drainage, and its location in the watershed. Land closer to the plateau is less desirable because of lower fertility and harder structure, as is land which has been in long-term cultivation. Thus, land may be available, but productivity levels vary.

**3.4 Farmer Perceptions of Agricultural Problems**

In an uncertain environment where annual crop yields vary greatly, the primary production objective is securing a reliable food supply. Rather than speaking of changes or yield decreases, farmers view each year as different and unique. Principal problems expressed by farmers are related to the agro-ecological changes affecting the region:

+ Inadequate and irregular rainfall
+ Low soil fertility
+ Lack of animal manure and limited access and money to purchase chemical fertilizer
+ Labor shortages due to young men leaving home and expense of hired labor
+ Wind erosion

Farmers considered rainfall the principal factor determining crop production. In good rainfall years production levels are sufficient regardless of land quality. But under increasingly drier and erratic weather conditions, farmers stressed the combination of poor rainfall and soil fertility for reduced production. Rainfall patterns were considered a particular problem because the "land is old and tired," a common phrase among farmers. Soils, they said, were cultivated too long, the soil structure is weak, and rainfall infiltration is low. While farmers considered the start and pattern of rainfall of foremost importance, they appeared increasingly concerned about soil fertility. Agricultural practices have changed in response to the environmental circumstances affecting the region.

Farmers spoke of a 7- to 8-month dry season in the past when they could count on 4 months of rain. Today they can depend on only 3 months of good rain. Most have abandoned samno, late season millet, because of the shortened rainy season and insufficient soil fertility. Many farmers plant mixed varieties and follow varying management strategies to minimize risks.

Fallowing practices have changed because of uncertain yields and increasing pressure on the land. Farmers say fields cannot be left to regenerate while another field is cultivated. Farmers also noted increased wind erosion of valuable topsoil -- causing a change in crop residue management.

Farmers spoke about increased risks in agriculture. In the past they were assured an adequate harvest if a crop was planted. Today, even producing a crop is uncertain. In this setting, farmers were more concerned with minimizing risks, thus assuring subsistence, than with maximizing production.

Insects and pests were not often mentioned in discussions of agricultural problems. This may be due to the variability in pest populations related to rainfall conditions. When inspecting fields, farmers quickly pointed to insect damage. In this context, farmers attributed 1989 yield losses to mice, a nocturnal millet beetle, grasshoppers, and various millet-eating worms.

Animal manure and chemical fertilizer were considered the primary means for improving productivity. In general, farmers reported shortages and higher costs of animal manure due to fewer numbers of permanent and nomadic cattle in the region. Changes during 1989 in fertilizer availability and costs appeared to limit its usage.

**3.4.1 Perceptions of Land Degradation**

Land degradation was referred to as the decreased production potential of the land.

Most commonly, degradation was attributed to a loss of vegetation and an increase in wind. Declining land productivity was viewed as a self-perpetuating phenomenon over which farmers expressed little control. Decreased vegetation resulted in the loss of fertile soil and its incapacity to support vegetation. Farmers attributed loss of vegetation to general climatic changes, the severe drought that ended in 1974, increased cultivation where more land is under the hoe, and to shorter fallow periods. They also spoke of changes in the composition of plant species.

Farmers noted an increase in the frequency and velocity of the dry-season wind, hawou, which means wind that takes the soil. These winds carry away topsoil, leaving unproductive gangani, literally meaning bare earth. Farmers further complained of millet damage when wind-blown soil buries seedlings. Farmers plant seeds amid millet residue to protect germinating seedlings.

Water erosion was seldom mentioned as a problem by farmers. Wind erosion emerged as a larger concern because all farmers face its potential damaging effects. Water erosion, in contrast, depends on the location and slope of fields and is considered less severe. A representative comment: "Even with water on the field you can still get some harvest, but with wind damage you won't get anything." There appear to be differences in the ability to combat wind and water erosion. More techniques are used to control wind erosion. In contrast, farmers said they were almost powerless to combat water erosion.

**3.5 Indigenous Classification Systems**

**3.5.1 Land Types**

Three major land types based on differences in elevation were classified by farmers:

*Gorou* means either bas-fond, gully, or gully erosion. *Gorou* is also a general name for any low-lying land. It can mean the entire bas-fond area, the lower portion of a field, or low-lying areas within a field.

*Fondu* means any upland area. Besides describing the whole region between the bas-fond and plateau, fondu is used to refer to elevated areas within a field such as mounds of deposited soil or the higher portion of a sloping field.

*Tondo bon* means plateau. In general, the nonarable and a communal grazing reserve.

*Tondo kakasia* refers to land just below the plateau which is unproductive due to surface crusting. Farmers said tondo kakasia can be made productive through tractor cultivation.

General land quality is associated with these major topographical divisions.

Typically, farmers classified higher elevations as less fertile due to water and nutrient runoff. Land closest to the plateau is considered the poorest in terms of soil structure. Farmers recognized, however, that management practices affect land productivity, and they distinguished attributes of particular soils within a topographical sequence. Consequently, farmers tended to associate land quality more with cultivation/fallow practices than with topography. For example, recently cultivated marginal land near the plateau was considered more productive than older fields farther down the slope.

### 3.5.2 Field classification

The field classification system reflects the importance of cultivation history. A field was defined by farmers as contiguous land under household control. Fields were distinguished as follows:

*Sacara*: land returned to cultivation after a one-year fallow

*Lalibanda*: first year of cultivation after sacara

*Kwarkwari*: land under cultivation for three to four years

*Blanga*: land under cultivation for five or more years

*Farezenou*: land in fallow

Fields often contain parcels of various fallow lengths. Within a single field, a farmer may distinguish a portion as sacara, another area as lalibanda, and another portion as blanga.

### 3.5.3 Soil Classification

When describing their land, farmers commonly used the phrases *labu zenou* or *labu farga*, meaning the soil is tired or the soil is old. These soils, farmers said, have been cultivated too long, and their fertility depleted. To restore productivity, farmers typically fallow or apply animal manure.

Another phrase used to describe less common soils is *labu sida bani*, meaning the soil is not fertile, or "sick." This condition is found by looking at millet roots soon after planting. If the new roots fail to form or the existing ones are dry and black, the soil is considered "sick." Farmers said they are powerless to rectify this condition.

Farmers use sight and touch to determine soil physical properties. Attention is given the top soil layer and the rooting zone for millet and cowpea. Properties that farmers distinguish are color, organic matter, texture, drainage condition, and depth. Chemical properties did not figure in their classifications.

Three dominant soil types are determined by color:

+ *labu biri*: black soil
+ *labu kware*: white soil
+ *labu kirey*: red soil

Soil color is related to the presence or absence of organic matter, the process of soil erosion, and subsoil character. Black soil contains more organic materials and is considered more fertile. Nutrients are depleted by cultivation and erosion, leaving a less productive white soil. Further degradation results in red soil. Within a class, farmers distinguished gradations in fertility. A soil may be typified as a mixture of black and white, for example.

The second major soil classification system is related to texture in three major types:

+ *tassi*: sandy soils
+ *botogo*: soils with some clay content
+ *gangani*: concreted, lateritic soils

Properties used to describe tassi soils

include light weight, sandy texture, soft, porous, and dry. The botogo soils, in contrast, are darker in color, heavier textured, with good water retention. They are described as being more difficult to cultivate, but more fertile. Weeds grow faster in botogo soils, which also influences crop choice and management. For example, because weeds inhibit growth, millet grown in botogo soils must be more carefully weeded than would be sorghum, for example. Also, botogo soils are difficult to cultivate without rain, leading, at times, to a bad decision of delayed weeding.

Distinctions were made relative to soil contents of clay, sand, or laterite. Better quality land contains some clay. Soil that is too sandy is considered too light and more susceptible to wind erosion. By contrast, soils with some clay content are heavier and can trap and hold plant and other debris, leading to an organic matter build up.

*Gangani* refers to denuded ground. Farmers typically listed *gangani* as any land where plants do not grow. There are two major types of *gangani* related to soil formation:

+ *Gangani kware* means white gangani caused by wind erosion. These hard, non-sandy surfaces are typically found in cultivated fields. *Gangani kware* may be made productive by mulching with crop residue, branches, and twigs.

+ *Gangani kirey* means red *gangani* caused either by water erosion, flooding, or abandoned termite casts. It is characterized by heavier concentrations of clay, stones, or exposed lateritic subsoil. It is more difficult to restore the productivity of *gangani kirey* than *gangani kware*.

*Gangani* may be found over large areas, or may occur as small bare earth patches within a field. Most farmers regenerate small patches of *gangani*. Over large areas, however, animal traction or tractor cultivation is considered necessary to restore productivity. Additions of organic matter such as manure, chaff, and crop residue are also needed.

Water retention capacity of the soil is linked to length of cultivation as well as to clay content. Rainfall amounts are not considered critical to yields if fields are newly cultivated. Rain is not considered as much a problem on clayey soils as on sandy soils. In a few cases, farmers described a hardpan layer that restricts infiltration of water and plant roots.

### 3.5.4 Within Field Variability

In general, soil types were classified according to topographical location.

Bas-fond land typically consisted of clayey soils, while upland soils were generally characterized as sandy. However, variability exists within fields. Different intercrop patterns maximize these microenvironments. For instance, sorghum, sorrel, okra and maize may be grown in small water catchments with heavier textured soils. Locations with a higher productivity potential -- areas where animals have been kept and at bonfire and grain pounding sites where litter has accumulated -- are similarly used.

Wind-blown soil forms natural mound-gully cultivation systems. Soil is deposited around plants, debris, and stumps resulting in concentrations of greater soil depth and fertility. Also, wind may move soil from one side of a field to another, resulting in higher productivity on the lee side.

Higher productivity sites within a field are associated with ant (*n'kondo*) and termite (*tcharra*) colonies. Termite casts are considered rich in clay and plant nutrients, while tunnels loosen and mix the soil. Farmers noted that productive plants found at the edges of mounds demonstrate the positive effect on soil fertility. During the dry season termites attack crop residues, resulting in decomposition and organic matter enrichment.

### 3.5.5 Classification of Vegetation in the Watershed

Various native plant and tree species ar valued in the production system. Listed in order of priority in Table 3.6 are the principal plants and trees and their uses as identified by farmers.

Grasses. *Andropogon gayanus* is widely found throughout the watershed. It is used for construction, but an excess in fields lowers millet yields. Farmers contend hardier *andropogon* roots compete with millet, that morning dew on *andropogon* is too humid for millet, and that large plants shade the millet. *Andropogon* and millet are harvested simultaneously. Surplus andropogon is sold, but its income does not exceed that of millet.

Animals are kept from grazing fallow fields with *Andropogon gayanus* and *Aristida longiflora* -- signifying their importance in the production system. Besides *Aristida longiflora*, farmers use two other similar grasses in thatching roofs. *Bata kirey* (*Heteropogon contortus*) is found on the plateau and *bata kwarey* (*Ctenium elegans*) is found in fields.

Trees. Of the woody species found in the watershed, *kosey* (*Piliostigma reticulatum*) is given primary importance. Its impact on productivity occurs because its leaves contain nutrients that increase soil fertility, and wind-blown soil collects around the base of the plant. The most productive millet occurs on mounds of raised earth at the site of *kosey* shrubs. *Kosey* rejuvenates land similar to fallowing, farmers claimed. *Korkorbey* (*Combretum glutinosum*) has a similar effect on soil fertility.

*Sabara* (*Guiera senegalensis*) is another common woody species. It grows on the harder, hotter, more lateritic soils near the plateau. Portions of *kosey* and *sabara* are eaten by animals. *Guiera senegalensis* and *Combretum nigricans* are considered good fuel. Along with *Combretum micranthum*, they are the three principal firewood species sold in Niamey (Heermans, 1986).

On cultivated fields, shrubs are cut twice a year. This practice

+ Provides mulch to boost soil fertility and inhibit wind erosion,
+ Reduces shade which retards millet growth, and
+ Takes advantage of the high nutrient content of young foliage.

Few large trees are found in the watershed. Fruit trees around household compounds and villages are few. Lack of water and roaming animals that eat seedlings discourage tree planting. Trees, however, serve to mark field boundaries. Farmers attribute the main benefit of trees to the shade they provide during fieldwork rest periods. The leaves and fruit of some trees are eaten. Higher soil fertility in the vicinity of the *zamturi* (*Prosopis africanus*) is associated with leaf and bark decomposition and manure deposited by animals seeking shade. Nigerien law prohibits cutting live trees.

Farmers indicate a preference for *gao* (*Acacia albida*) and *garbey* (*Balanites aegyptica*). *Gao* enhances soil fertility. It is used in native medicines, and the fruit and leaves are fed to animals. However, *gao* needs water and is found near waterways but not on upland cultivated land (*fakara*). *Garbey* also is linked to enhanced soil fertility. Its fruit and leaves are used as livestock feed, food for the household, and for sale. (Table 3.6)

Attitudes toward large trees are positive, but there is no custom of planting trees. Misgivings were expressed about small trees in fields because their shade hinders millet growth. A Zarma phrase indicates the importance of clean fields, "*Da turi kaina go faro ra haino si kasu gumo*," meaning, "millet will not grow large if there are small trees in the field." The established practice is to cut bushes to make space for millet. In the farmers' words, "Millet needs air and sun to grow."

Livestock feed. Several plants are harvested and stored for animal feed in the dry season. Two are considered to be of equal nutritive value to the cowpea: *fugutu* (*Ipomoea involucrate*) and *kongo zora* (*Merremia pinnata*). *Ipomoea involucrate* is found in fertile soils, whereas *Merremia pinnata* grows on less productive soils. Only the farmer has the right to harvest these plants, indicating their importance in the production system. They are stored for dry season feed or sold. A third specie, *Eragrostis tremula*, does not have the same feeding value, and anyone may cut and use it. Branches of two large trees, *Prosopis africana* and *Terminalia avicenioides*, are often cut and fed to animals late in the dry season.

## 3.6 Soil Management Practices

### 3.6.1 Fallowing

Fallowing continues to be the main management practice to restore soil productivity.

About half of the watershed was in fallow during the 1989 cultivation season (Fig. 3.1). The traditional practice of a long bush fallow, however, is breaking down. Farmers reported that former fallow periods, generally 10 years or more, now do not exceed 3-5 years on land that is owned. On borrowed land, the fallow period is only 2 to 3 years. Otherwise, the land is considered unneeded and the owner loans it to someone else.

One exception to short-term fallowing was a 24 ha block of land that has been fallow for 10 years. The landowner reportedly refuses to loan this land, contrary to the custom.

The four main types of fallowing include the following (Table 3.7):

1. Half-year fallow. The land is not used during the period between harvest and the next planting. Crop residues are grazed by livestock or mulched. Half-year fallowing is practiced by all farmers.
2. Full-field fallow. Land productivity declines to a point that further cultivation is uneconomic. The entire field is left fallow. The usual fallow interval is 2 to 5 years. Approximately 65% of the farmers interviewed indicated entire fields had been left in fallow. Leaving a whole field in fallow means having access to another field to crop during the period. Fifty-seven percent of the farmers had more than one field, which provided them some management flexibility.
3. Within-field fallow. Least productive areas within a field are fallowed, with the remaining land cultivated. With-in field fallowing implies having sufficient contiguous land to move cultivated areas around within the field. In this manner, a field can be composed of several parcels of

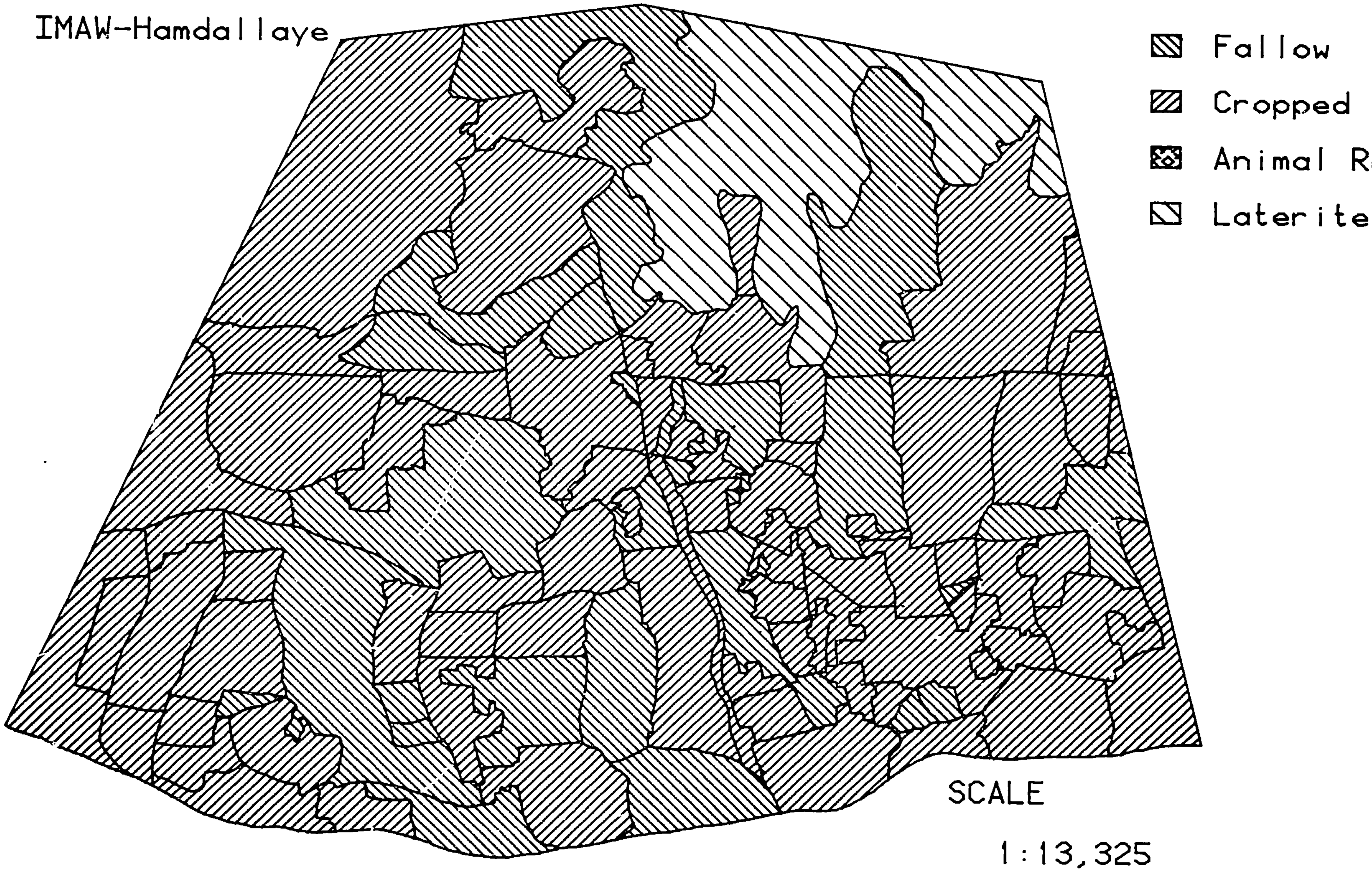
Table 3.6 Farmer listing of beneficial plants and trees in the watershed

| Zarma name | Scientific name * | Use |
|---|---|---|
| | PLANTS | |
| Subu nya | *Andropogon gayanus* | mats; roofing; leaf sheath fed to animals |
| Bata | *Aristida sieberiana* | mats; roofing as underneath layer to Andropogon |
| Borboto | *Pennisetum pedicellatum* | animal feed; can replace Aristida in roofing |
| Ganda bani | *Cassia mimosoides* | soil fertility; mats; can replace Aristida in roofing |
| Haramdam | *Diheteropogon hagerupii* | animal feed;roofing as underneath layer to Aristida |
| Tutu | *Setaria pallide-Fusca* | animal feed |
| Fugatu | *Ipomeoa ivolucrate* | animal feed |
| Kongo zara | *Merremia pinnata* | animal feed |
| Kullum | *Eragrostis tremula* | animal feed |
| | TREES | |
| Kosey | *Piliostigma reticulatum* | bark used for cord; soil fertility;consume fruit; dried fruit and new leaf growth as animal feed |
| Korkobey | *Combretum glutinosum* | medicine; soil fertility |
| Darey | *Ziziphus mauritiana* | consume fruit; leaves as animal feed;thorny branches used to protect mats and granaries from animals |
| Zamturi | *Prosopis africana* | construction; soil fertility; cut branches for animal feed in late dry season; wood for mortar, daba, etc. |
| Sabara | *Guiera senegalensis* | medicine; leaves as sheep feed; firewood |
| Deli-nya | *Combretum nigricans* | firewood; consume/sell fruit |
| Gao | *Acacia albida* | enhance soil fertility; traditional medicine; fruit and leaves as animal feed |
| Garbey | *Balanites aegyptiaca* | enhance soil fertility; fruit and leaves as animal feed and human nutrition |
| Farka hanga | *Terminalia avicenioides* | animal feed |

* For complete scientific names, see the section of this document concerning the vegetation survey.

Figure 3.1
LANDUSE MAP

IMAW-Hamdallaye



varying fallow lengths. Usually the fallow interval is 2 to 3 years. Thirty-five percent of the farmers practice with-in field fallowing.

4. Emergency fallow. A field or portion of a field may also be fallowed due to illness, lack of labor or other circumstances that hold up planting. Two farmers reported emergency fallows in 1989 due to lack of labor.

Seven farmers reported no fallow practice. Cultivation periods ranged from 10 to 50 years, with an average of 23 years. Some form of land regeneration management is practiced to sustain productivity. Three farmers, for example, use substantial amounts of manure. If the field or parts of it are uneconomic, it is abandoned. A common practice among Bokotchili farmers is a 3 -year fallow followed by a 7-year cropping period.

Farmers consistently said that a 3-year fallow is necessary to regenerate soil productivity, but this may be shortened depending on how the rainy season unfolds. Late rains in 1989 brought fields back into cultivation prematurely. Soil characteristics, state of the land when fallowed, rainfall, family needs, and resource availability interact in determining actual crop/fallow intervals.

Another fairly common practice is to seed all land. Fields or portions of fields may be later abandoned if labor is unavailable to weed or if the chance of obtaining a harvest becomes too low due to poor rainfall. Also, seeding all land spreads out risks. Farmers evaluate fields and concentrate labor where it is likely to be most cost effective. Another reason for planting all the land is to show use to preclude others from farming it. Pressures exist to loan fallow land to family or outsiders. Land must be used in order to maintain land rights. At least 25% of the farmers in the watershed seeded entire fields, but did not weed all or portions of those fields. Such land is called a "disguised fallow" (McIntire, et al. 1989), and it does not benefit from being unused.

**3.6.2 Use of Animal Manure**

Farmers believe -- Peul farmers in particular -- that owning livestock can sustain crop production.

Animal manure is preferred to chemical fertilizers because it is said to last from 5 to 10 years, depending on amount and type applied (goat, sheep, cattle or donkey), soil type, method of application (kraaling or hauling manure from the compound to the field), and whether it is the rainy or dry season. Eleven of 39 farmers (28%) with cropped fields reported applying animal manure in 1989, principally by kraaling (corralling) animals on crop land (Table 3.8).

Manure application through kraaling is said to last up to 10 years as opposed to a 3-year impact on soil fertility with transported manure. Wet season kraaling is considered better because of easy manure infiltration into the soil. Often, however, animals are not available for wet season kraaling. Zarma typically entrust their cattle to Peul herders. Cattle may be moved out of the watershed for the cropping season, returning to graze crop residues after the harvest. If cattle are maintained close to cropped fields and are available for wet season kraaling, the Peul herder receives the manure. Three resident Peul managed herds in the watershed during the 1989 cultivation season.

Soil fertility from manure droppings during crop residue grazing is considered insignificant. Animals must be kraaled, or significant amounts of manure must be hauled and spread to obtain an increase in productivity, farmers said. Often sites where donkeys and goats are gethered are planted to crops such as okra, lama and sorrel, which require high levels of fertility.

Fifteen of the interviewed farmers (37%) own cattle, but the amount of available manure was not known.

Several circumstances appear to limit the use of manure in sustaining land productivity. First, fewer livestock are found in the region since the droughts of the past two decades, although numbers are now said to be increasing. There has also been a reduction in Peul throughout the watershed. In the past Peul herds would rest for several nights on farmers' fields or were available for longer kraaling. Second, farmers consider the costs of manuring to be high. Peul reportedly receive a daily payment in grain -- a precious commodity for many farmers -- or 7,500 to 10,000 CFA a month, depending upon herd size. During the 1989-90 dry season, one farmer paid 2,500 CFA for each 10 days of kraaling. Third, it is generally said that Peul are available to work as herders, but few own their animals. Thus, to ensure a reliable manure supply, farmers need to own their own animals, but are handicapped by lack of money and livestock feed.

### 3.6.3 Use of Fertilizer

Nearly 60% of the farmers interviewed have used fertilizer (Table 3.9). Half discontinued its use in 1989. These decisions appeared to be affected by the transfer of the seed multiplication center in Hamdallaye from USAID to Niger government funding. Terms of credit and the availability of fertilizers had changed.

Reported usage ranged from one 50-kilo bag of either triple superphosphate or urea to the 20 bags of phosphate and 14 bags of urea that were used by one Niamey--based businessman (Table 3.10). Overall, fertilizer application rates were minimal compared to the total cultivated area per household. Timing of applications also varied depending upon when farmers obtained their supplies. In four cases, fertilizer was reserved strictly for crops of improved cowpea (TN578).

### 3.6.4 Use of Compound Sites and Sites of Refuse Accumulation

Peul living in the watershed move their family compounds up to three times a year to take advantage of the accumulated household and animal refuse in improving land productivity. Compounds are purposefully chosen where fertility amendments are most needed. Three Zarma farmers who live on their fields also move their compounds at least once a year in order to fertilize cropland.

Another practice to improve productivity is to cultivate sites formerly used for pounding grain into meal. Some farmers burn accumulated grain refuse, which is thought to produce a particularly fertile area. Typically, these sites are in the shade, or on *gangani*, where millet is dried. Reportedly, men may have their wives pound grain at the site of a particular gangani they want to restore to fertility.

### 3.6.5 Crop Residue Management

Farmers reported they have changed crop residue management over the last 10 years because of wind erosion. Previously, unused crop residue and debris was gathered and burned on the field. Now, crop residues and small bushes are left on the field. Said one farmer, "Before there were many trees. how the wind carries the soil away. It is better to leave the stalks on the field to save the soil."

Grain heads, millet stalks, cowpea vines, and other forages are harvested for fodder, construction materials in building granaries, sun shelters, and other enclosures. Cowpea forage is an economically important part of the harvest and a primary reason for its cultivation, according to some farmers. This residue is harvested and sold to livestock merchants, stored for future sale, or stored and fed to household animals.

Farmers said a market for millet residue has existed since the 1984 drought. Reportedly, however, farmers do not sell millet residue except when there are inadequate amounts to graze livestock.

Crop residue remaining in the field after harvest is left standing for animals to graze. A general order from the canton chief at end of November 1989 granted livestock free access to the cultivated area. "Now the land is like the bush, and animals can go anywhere," one farmer said. Animals strip the millet of edible leaf and sheath. The remaining stalk serves as a windbreak and holds the soil.

In southern areas where considerable amounts of crop residue are produced and there is competition for it, elaborate herder -farmer negotiations and systems of payments have evolved (Powell and Taylor-Powell, 1984; Perrier, 1984).

Crop residue is returned to the fields in late December through January after grazing or in April during land preparation. This latter practice involves uprooting dead millet plants using a long-handled tool, called a some. The stalks are laid on the field, sometimes on gangani, to rebuild eroded soil.

Whether farmers uproot millet during the December-January period or later in April depends on their willingness to continue field work after the harvest and whether labor is available during the dry season. Uprooting millet after grazing is considered beneficial because the stalks attract termites, decompose over the dry season, and trap wind-blown soil. In addition to soil enrichment, uprooting millet prevents injury during weeding when the hoe could catch embedded roots. It also destroys insects that otherwise might live through the dry season in roots under the ground.

**3.6.6 Mulching**

Mulching is practiced principally to build up eroded soils and to cut down on wind erosion. Various crop, plant, and household residues are used as mulch, including branches of native shrubs, *Piliostigma reticulatum*, *Combetum glutinosumand Guiera senegalensis*; millet stalk residue; refuse from old granaries; old roof thatching from dismantled homes; fallen tree limbs; and cut grasses.

Typically, native shrubs are trimmed twice a year and used as mulch between December (after harvest) and April (before planting) and at the time of the second millet weeding. The last trimming provides space and sunlight for the millet.

Mulching materials may be distributed over fields or placed on severely eroded areas to trap wind-blown soil. This practice provides an adequate soil depth for plant growth without having to break up the lateritic crust. Mulch also is placed on the windward side of a field to cut down on wind erosion.

**3.6.7 Other Soil Management Practices**

Other soil conservation measures are practiced on a more limited scale. For example, weeding operations may be suspended on unproductive areas to establish plant cover and trap wind-blown soil. Women may break up crusted patches of wind-eroded land, which, with additions of millet mulch and manure, can be made productive within one year.

Fewer practices exist to prevent water erosion. This is due to the difficulty of making improvements. Grass waterways were seen, but, in general, farmers said there was a greater need to clear and cultivate all land for maximum production. A few farmers experimented with blockades made of branches or stones to combat gulley erosion. Success in halting gulley erosion is limited because of the high force of the water in comparison to the strength of the blockade. Contour plowing with a tractor is seen slowing deposits of sand and sheet erosion, but few farmers have resources to hire a tractor. Farmers mentioned dam construction as the only way of combating severe gulley erosion found on the eastern side of the watershed - an alternative not within local farmers' means.

**3.7 Extent of Erosion within the Watershed**

A survey was conducted to measure the distribution of eroded surfaces and farmers' attempts to control wind and water erosion.

Five types of erosion were found:

1. *Tassi gande*: Surface deposits of alluvial sand fans resulting from a decrease in slope at the end of a gully, rill, or ravine. Usually, there is no vegetation due to a strong water flow during heavy rains. There is good water balance for crop growth, but the soil is generally depleted of nutrients and organic matter. Farmers said that once millet is established, it grows well in these areas.

2. *Gorou gande*: Sheet erosional surface, as evidenced by stratification of the surface horizon.

3. *Gorou*: Gully erosion as a result of water collection from impermeable surfaces, such as those found on the laterite plateau and outcrop surfaces, and To and Gak soils.

4. *Gangani kware*: White *gangani*, a denuded soil resulting from the effects of wind erosion, where part of the surface soil is removed exposing the lower A horizon and sometimes upper Bt horizon.

5. *Gangani kirey*: Red *gangani*, which is a denuded soil resulting from water erosion, where the surface horizons are completely removed and the Bt horizon is exposed. These soils are generally crusted, are more difficult to regenerate than the gangani kware, and represent sites of old termite mounds, etc.

Of these types of erosion, tassi gande was cited most frequently as a drawback to production because more fields are subject to sand deposits. Deep sand on fields is seen as a short-term problem because it limits the cultivated area and buries the crop. In contrast, gully erosion was seen as a long-term problem where "water eats the field away little by little", thereby reducing the area available for future cultivation. Subsistence farmers by necessity have short time views.

*Gangani kirey* comprises the largest erosional surface within the watershed, followed by *tassi gande*. However, less than 2% of farmers' fields are affected by *gangani kirey*. A mean of 3.69% of farmers' fields were affected by one of the five types of erosion. However, distribution of erosional surfaces was not uniform, as evidenced by the large standard deviations for each type of surface (Table 3.11).

*Gangani kware* is associated with wind erosion by farmers. Results of the survey indicate that as a percentage of the total fields surveyed, *gangani kware* is not very pronounced. However, *gangani kirey* also results in part from wind erosion, so that the two *gangani* surfaces indicate a substantial contribution of both wind and water to the erosion process.

**3.7.1 Farmer Practices to Control Erosion**

Several native plant species are used by farmers to control wind erosion, primarily on gangani kware areas (Table 3.12). Branches from these plants are generally cut twice a year and placed over the eroded surfaces to trap wind-borne soil.

**Table 3.7. Fallow practices on fields currently under cultivation (n = 40 farmers)**

| Full Field Fallow | Farmers No. | % |
|---|---|---|
| Fallowed within past 1-5 years | 15 | 38 |
| Fallowed within past 6-10 years | 4 | 10 |
| Fallowed over 10 years ago | 7 | 18 |
| Within Field Fallow | 14 | 35 |
| TOTAL | 40 | 100* |

* Exceeds 100% due to rounding.

**Table 3.8. Methods of manure application for 11 farmers, 1989.**

| Application | Farmers No. | % |
|---|---|---|
| Kraaling | | |
| Wet season | 4 | 36 |
| Dry season | 10 | 90 |
| Transport | 3 | 27 |

Other methods used to control erosion (Table 3.13) include the use of millet stover and chaff as a surface mulch, animal manure to build up soil fertility and trap wind-borne soil, and animal traction to break up gangani kirey soils.

*Guiera senegalensis* is the dominant shrub of the semiarid savannah lands of West Africa, and it is not surprising the plant most used by farmers to control erosion. Both *G. senegalensis* and *Piliostigma reticulatum* are widespread throughout the watershed, primarily due to their unpalatability to browsing livestock.

**3.8 Summary Comments**

Farmers in the watershed are resilient and adaptable in responding to agroecological changes. They experiment in various ways to lessen the risk of crop failure by using multiple planting dates, mixing seed varieties, using favorable microenvironments, priority weeding, using soil estoration techniques, and controlling wind erosion by mulching with crop residues and native woody species.

Unfavorable rainfall patterns and

**Table 3.9. Fertilizer use among 39 farmers, 1989**

| | Farmers No. | % |
|---|---|---|
| Used fertilizer in 1989 | 12 | 30 |
| Used fertilizer in previous year(s) (not in 1989) | 11 | 28 |
| Never used fertilizer | 16 | 41 |
| TOTAL | 39 | 99* |

* Does not total 100% due to rounding.

**Table 3.10. Fertilizer use by 12 farmers, 1989**

| Fertilizer type and amount (50 kilo bags) | Number of Farmers |
|---|---|
| 1 TSP | 1 |
| 1 Urea | 2 |
| 1 TSP and 1 Urea | 4 |
| 2 TSP and 1 Urea | 1 |
| 2 TSP and 2 Urea | 2 |
| 4 Urea | 1 |
| 20 TSP and 14 Urea | 1 |
| TOTAL | 12 |

declining soil fertility are considered the primary drawbacks to crop production. Farmers typically describe their land as "old and tired." Fallowing and use of manure continue as the principal ways of sustaining land productivity. However, fallow periods have gone from 10 years down to 2 to 5-year periods, depending on tenure security. Pressure to crop land to maintain rights to its use discourages fallowing. Manure availability is limited because of a decline in livestock numbers and less fodder because of recent droughts. Animals are important in the production system -- for manure, transportation, and food -- so improvements in forage to provide a soil cover and as animal feed hold possibilities. Native plant species currently valued include cowpea, fugutu (*Ipomoea involucrata*), and kongo zara (*Merremia pinnata*).

Nearly half of the farmers are cropping on borrowed land. Tenure security appears to exist through established lender borrower relationships, and the custom of passing borrowed land to sons. As land becomes scarcer and values increase, however, it is likely these customary laws will change. Encouragement to obtain formal leases may indicate change is likely. The watershed operates on a multitenure land system (Bruce, 1986) where a mixture of tenures exists, depending on use of the land (cropping, fallow or grazing) and the user (household, individual farmer, or women). Farmers have exclusive use of their cropped fields, including various native species and crop residues. Grazing land on the plateau is considered communal, as is arable land within the watershed after harvest. Tenure rules related to fallow land vary, depending on the season and whether the user is the landowner or borrower. These multiple tenure arrangements need to be considered in the watershed's project design and implementation. Likewise, it will be important to recognize that land in the watershed falls under the jurisdiction of four villages.

Subsistence economy households inherently have short time views. Water erosion is not seen by farmers to be a major problem. A more widespread concern is the loss of topsoil by wind erosion. Farmers see problems in terms of the individual households and threats to their subsistence as opposed to community concerns or the long-term consequences of land degradation. They will participate in land conservation work when it is profitable from a labor standpoint and does not compete with subsistence food grain needs. The size of land holdings and its quality vary greatly in the watershed, as does the ability of households to acquire and allocate other resources.

This research does not fully capture the diversity and complexity of these rural households. Information being collected in village case studies by the International Food Policy Research Institute of Washington, D.C., and the International Crops Research Institute for the Semi-Arid Tropics near Hyderabad, India, will contribute to the current understanding of Nigerien peasant economies and the effect household and production economics have on farmer decision making.

The IMAW project started with the objective of incorporating native technical knowledge and farmers' perspectives into program design. It is hoped farmers will be encouraged to continue as active participants in carrying out and evaluating project activities. Currently, farmers consider employment as hired labor by the project as its single most important benefit. This indicates the importance of wage labor in making up for agricultural shortfalls to meet cash needs.

**Table 3.11. Frequency and standard deviations of erosional surfaces within the watershed (n = 25 fields)**

| Erosion type | % of field | Std Dev. |
|---|---|---|
| *Tassi gande* | 0.73 | 2.07 |
| *Gorou gande* | 0.50 | 1.48 |
| *Gorou* | 0.25 | 0.58 |
| *Gangani kware* | 0.23 | 0.46 |
| *Gangani kirey* | 1.98 | 2.73 |
| MEAN | 3.69 | |

**Table 3.12. Native plants used for erosion control (n = 25 farmers)**

| Botanic name | No. of fields used | % of fields used |
|---|---|---|
| *Guiera senegalensis* | 12 | 48 |
| *Piliostigma reticulatum* | 10 | 40 |
| *Combretum glutinosum* | 6 | 24 |
| *Cassia mimosoides* | 1 | 4 |
| *Combretum micranthum* | 1 | 4 |

**Table 3.13. Different methods of erosion control practiced by local farmers (n = 25 farmers)**

| Method | # fields used | % fields used |
|---|---|---|
| Millet surface mulch: | | |
| stover | 4 | 16 |
| chaff | 1 | 4 |
| Animal manure | 2 | 8 |
| Animal traction | 1 | 4 |

# 4.0 VEGETATION SURVEY

## 4.1 Objectives

Between October and December 1989, a survey of native vegetation was conducted in the watershed for the following purposes:

+ Examine the present vegetation groupings and study their ecological significance

+ Study the flora, specifically their taxonomic, bio-geographic, and ecological significance

+ Obtain baseline information on present vegetation groupings to permit monitoring of changes resulting from future use of this natural resource

The two principal components of this study were the distribution and description of vegetation and their biological and ecological classification.

## 4.2 Vegetation

Two distinct types of vegetation which occur as a function of geomorphology were found within the watershed: vegetation on the laterite plateaus and vegetation in the valley toposequence.

### 4.2.1 Vegetation of the Laterite Plateau

Typical vegetation of laterite plateaus of the Continental Terminal consists of a thicket of Combretum micranthum. This type of vegetation occurs in a "tiger bush" pattern.

The vegetation (forest) is extensively used by villagers. Being uncultivated, it serves as a path for livestock, especially during the rainy season when animals are banned in cultivated areas. The area is characterized by termite mounds mostly located outside the thickets. Vegetation on the plateau serves as an important source of wood and medicine.

Description of vegetation. The vegetation forms a series of thickets of varying size and floral composition. They are separated by bare areas where a few trunks of disseminated woody species and small pockets of herbaceous species growing on small mounds of sand are found. These mounds form around stumps of living and dead woody species and play an important role in the lamina flow of sheet water that covers the plateau after a substantial rain. The mounds slow down the speed of moving water. This allows greater water percolation into the soil, and sets up small ponds in which certain semiaquatic species can grow -- especially *Microchloa indica*, *Tripogon minimus*, and *Pycreus macrostachyos*.

Vegetation on the laterite plateau is structured into three strata:

+ Herbaceous strata with an open nature within bare areas and a dense growth within the thickets. It can range up to 40 cm high.

+ Strata of shrubs with an open nature in bare areas and a dense growth at the thicket fringes. Strata height varies between 0.5-2.5 m.

+ Strata of trees at the center of the thicket can attain a height of up to 10 m.

The thicket fringes are composed principally of *Combretum micranthum* and *Guiera senegalensis*. They create a thick canopy that diverts air currents, reflects solar radiation and catches rain water. They also trap eolian sands, which gradually create a loose sand layer on the thicket floor.

At the center of thickets are found lignaceous species with high water requirements, such as *Combretum nigricans*, *Acacia macrostachya*, *Grewia flavescens*, *Acacia erythroculyx and Acacia ataxacantha.* These species often have creeping roots which permit a more efficient use of rainwater. Plant species found in the thicket understory include *Microchloa indica*, *Tripon minimus*, *Triumphetta pendandra*, *Cardiospermum halicacabrum, Aspilia kotschyii, Commelina forskalaei, Ipomoea heterotricha, Sporobolus panicoides, Borreria scabra, Hybanthus enneaspermus, Cyanotis lanata, Archidium tenellum, and Riccia trichocarpa.* The presence of the last two species, which are Muscinees, indicates good soil moisture in the thickets.

In bare areas between thickets are found *Combretum glutinosum, Commiphora africana, Boscia senegalensis, Boscia augustifolia, Schyzachirium exile, Aristia adscencionis, Evolvulus alsinoides, Indigofera bracteolata, Jacquemontia tamnifolia, Brachiaria disticophylla, Merrimea pinnata, Polycarpaea* spp., *Dactyloctenium aegyptium, Schoenefeldia gracilis, and Alysicarpus ovalifolius.*

**4.2.2 Vegetation of the Valley Toposequence**

The vegetation of the valley toposequence can be referred to as a shrub savanna of *Guiera senegalensis*, which is defined as a dominant strata of shrubs at least 80 cm high that influence an inferior strata of annual grasses and lignaceous plants.

Vegetation on the toposequence is structured into three strata: herbaceous strata dominated by grasses, strata of scattered shrubs, and strata composed of a few trees higher than 10 m.

The horizontal structure of the vegetation allows solar radiation to reach the soil. In areas where fallows have existed for a long time, vegetation is reconstituted and some trees are permitted to develop.

The spatial distribution of vegetation follows topography, where most water demanding species are found close to gullies that collect water running off the plateau after a rain.

**4.2.3 Detailed Study of Vegetation**

The distribution of vegetation was studied along a transect running from the surface of the primary plateau to the valley bottom. This transect followed transect A of the soil survey and is located on the western side of the watershed. Study areas within the transect were located on the primary plateau, the secondary plateau, and in seven positions within the toposequence. All sample areas within the toposequence were in fallow, allowing a better idea of native vegetation. Specific sites can be located on the soil survey map (Fig. 2.2) and correspond to the following:

1. Primary plateau
2. Toposequence 1: natural vegetation (never cultivated) near IA*
3. Toposequence 2: recent fallow near IB
4. Toposequence 3: recent fallow near IC, not far from the secondary plateau
5. Secondary plateau: near ID
6. Toposequence 4: fallow of unknown age near IE
7. Toposequence 5: fallow of unknown age near IF
8. Toposequence 6: fallow of unknown age near IH
9. Toposequence 6: fallow of unknown age near II

* IA-I indicates sites described for transect A of the soil survey.

Two methods were used to determine the distribution of vegetation: the linear or transect method, which is best adapted to the study of herbaceous vegetation, and the surface area method, best adapted to the distribution of lignaceous species.

The linear method consisted of measuring the distribution of all species along a fixed line. For the toposequence,lines were 50 m long, with 0.5 m intervals. For the plateaus, lines were 100 m long with 1.0 m intervals. In each case 100 segments were studied. Each individual species was counted only once within a segment, so the final frequency represents linear distribution, not total numbers along the study line.

The surface area method used to measure the distribution of lignaceous vegetation was determined to be 100 m x 50 m (5000 m2) in the valley toposequence. The non-homogeneity of vegetation distribution on the plateau did not permit an accurate determination of the minimal surface area for counting vegetation.

From data collected at sampling points within the watershed the following parameters were determined:

+ Specific frequency (SF) = number of segments in which a given species occurs.

+ Relative frequency (RF) = Specific frequency (SF)/total number of segments (N). RF tends to be an estimation of "recovery" when the observed surface area was reduced to a point.

+ Specific contribution frequency (SCF) = the ratio of individual species SF to total species SF. The Gini-Lorenz law of concentration permits an explanation of pytocenose structure as defined by the relation between cumulated percentages obtained in a sampling unity and their cumulated SCF.

A plot of SCF versus cumulative percentage permitted the classification of species into least dominant (SCF 1-4%), non-dominant (SCF <1%), dominant (SCF >1%) and very dominant (SCF >4%) species. Table 4.1 lists the degree of species dominance found within each position along the transect.

The distribution of species in toposequence 3 (T3) is similar to those of the plateaus (P1 and P2). Since this site was located close to the secondary plateau, these data indicate it might consist of very degraded tiger bush.

Tables 4.2 and 4.3 list the dominant species found within each linear measurement for each site. Tables 4.4 and 4.5 show species distribution along each segment.

**4.3 Species of Plants Used**

*Andropogon gayanus*: A perennial grass used to make mats for construction of fences, roofs, walls of houses, and granaries. Pasture species with high productivity. Serves to stabilize dunes and soils from wind erosion.

*Aristida sieberiana*: A perennial grass used to construct curtains, mats and brooms. Used to thatch roofs in the absence of *Ctenium elegans*.

*Ctenium elegans*: An annual species very sensitive to variations in rainfall. Preferred species for house roof construction.

*Cenchrus biflorus*: A pasture species with a very high distribution due to barbed grains which attach themselves to animals.

*Pennisetum pedicellatum*: An annual grass not very dominant within the watershed. Used to make cord and as fodder when fresh.

*Dactyloctenium aegyptium*: An annual pasture in great demand.

*Digitaria horizontalis*: An annual pasture in great demand.

*Branchiaria disticophylla*: An annual used as fodder for horses.

*Brachiaria xantholenca*: An annual pasture with good productivity.

*Corchorus tridens*: A widespread annual species. Fresh or dried leaves used to thicken sauces.

*Ceratotheca sesamoides*: An annual found on dune fallows. Fresh or dried leaves used as a thickening agent.

*Zornia glochidiata*: An annual pasture legume.

*Alysicarpus ovalifolius*: An annual used as fodder for horses.

*Cassia italica*: A perrenial used to

cure constipation.

*Merremia tridentata*: An annual found on dune fallows and used as fodder for small ruminants.

*Pergularia tomentosa*: A perennial containing tanins and used to tan hides.

*Calotropis procera*: A perennial used for construction framing. Wood is resistant to insects.

*Leptadenia hastata*: A perennial whose boiled leaves are eaten with peanut cake.

*Citrillus colocynthus*: A perennial whose water-laden fruit is eaten by humans and animals.

*Prosopis africana*: Wood used to make mortars, pestles, and other household utensils. It also makes good charcoal, preferred by blacksmiths, jewelers, and launderers.

*Acacia albida*: A woody Sahelian species with an atypical phenology: loses its leaves during the rainy season, regains them in October-November, and flowers in the winter. The species is protected by the state and farmers due to its beneficial effect on the environment. Its wood is used to make ortars, and its fruit is fed to small ruminants.

*Terminalia avicennioides*: A woody Sahelian species popular among herders as livestock feed during the rainy season. Endangered species due to incessant pruning.

*Combretum aculeatum*: A climbing woody Sahelian species. Its fruit is eaten by humans and small ruminants.

*Balanites aegyptica*: Used as fodder for small ruminants. Rich in protein, its fruit is used to prepare millet paste. The nut is eaten boiled. Its flower is mixed with peanut, boiled, and eaten. The sap is used as a perfume.

*Commiphora africana*: A woody species used as a living fence.

*Boscia senegalensis*: Used as animal fodder during the rainy season on the plateau. Its grain boiled and eaten in the same way as cowpea during famine periods. The fruit eaten by children.

*Piliostigma reticulatum*: The flowers and young leaves are eaten, although slightly acid in taste. Immature fruit is roasted. Fibers from the bark are used as cord material.

*Combretum migricans*: A shrub with early bud emergence producing gum arabic. Its straight branches are used to roast meat. It is a preferred fuelwood, along with Combretum micranthum, Combretum glutinosum and Guiera senegalensis.

Species parasitic on cultivated plants: *Striga gesnerioides* on *Vigna unguiculata* (cowpea) and *Striga hermontheca* on Pennisetum glaucum (millet).

Species found on poor soils: *Borreria radiata, Fimbristylis hispidulla, Mitrocarpus scaber, Indigofera berhautiana, Ceratotheca sesamoides, Aristida stipoides.*

**4.4 Study of Flora**

There were 119 plant species found within the watershed along the chosen transect, of which 117 species were *angiosperms* and 2 species were *bryophytes*. There were 34 families of *angiosperms*, of which four were monocots (representing 31 species) and 30 were dicots.

Families most represented along the transect were *Poaceae* (23 species), *Fabaceae* (15 species), *Conolvulaceae* (8 species), and *Combrataceae* (6 species). There were 24 species of *Leguminoseae*.

The most represented genuses were *Acacia* (4 species), *Indigofera* (5 species), *Tephrosia* (4 species), Combretum (4 species) and *Ipomea* (4 species).

The generic coefficient (# genuses/# species) is 0.73. This is indicative of an impoverished flora that can be described as being degraded to very degraded. The vegetation has evolved due to the climate, which is characterized by low rainfall and a long dry season (8-9 months); soil instability (especially on the toposequence); and human activities.

Annual plants are predominant in the watershed (66% of all species), which indicates their adaptation to the arid conditions found in this ecological zone (Table 4.6). The hemicryptophytes (2% of all species) are well adapted to the environment with their lack of numbers compensated by a larger occupation of space.

### 4.4.1 Biological Classification

#### 4.4.1.1 General Biological Spectrum

The Raukiauer classification system was adopted to assess the biological spectrum, with the following biological types identified:

Mesophanerophytes (mP): trees 8-30 m high.

Microphanerophytes (mp): shrubs 2-8 m high.

Nanophanerophytes (np): shrubs 0.25-2 m high.

Chamephytes (CH): woody perennials and sufrutescent or woody plants 0-25 cm tall.

Geophytes (G): plants with underground perennial organs -- geophytes with bulbs (Gb), geophytes with rhizomes (Gr),

*Therophytes* (T): plants which complete their cycle in a maximum of one year, especially when the season is conducive.

The biological spectrum indicates an important predominance of therophytes, followed by microphanerophytes, chamephytes, nanophanerophytes, mesophanerophytes, hemicryptophytes, and geophytes with tuber, bulb, and rhizomes in decreasing order. This situation can be attributed to the dry region. Therophytes are most adapted to dry environments.

The presence of significant numbers of chamephytes is due to their adaptability to dry environments as opposed to that of large trees.

*Hemicryptophytes* are normally abundant in these environments, but are not prominent in the watershed. This environment does not favor the development of large trees, so that tree and shrub species are dominated by the micro- and nano- and geophytes with tubers (Gt).

Hemicryptophytes (H): perennials with buds placed under the soil. phanerophytes and the chamephytes (16%, 5%, and 6% of all species, respectively). There is a predominance of species generally found within the Guineo-congolais and Soudano-Zambesien (46%) and the Soudano-Zambesien (51%) ecological zones.

#### 4.4.1.2 Chorologic Affinities

Chorologic affinities of the flora of the watershed are shown on Table 4.7.

#### 4.4.1.3 Botanical Classification

Botanical classification of the species is given in Table 4.8.

**Table 4.1. Degree of dominance of species within the watershed transect.**

| Category | P1 | T1 | T2 | T3 | P2 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|---|---|
| | Position on transect | | | | | | | | |
| | % of species | | | | | | | | |
| Dominant: | 80 | 61 | 93 | 76 | 62 | 50 | 70 | 79 | 72 |
| Very dominant | | 36 | 26 | 29 | 24 | 21 | 23 | 33 | 2222 |
| Less dominant | | 44 | 35 | 64 | 42 | 41 | 27 | 37 | 5750 |
| Non-dominant | 20 | 39 | 7 | 24 | 38 | 50 | 30 | 21 | 28 |

P1 and P2 are the primary and secondary plateaus
T1-T7 are the toposequence positions

**Table 4.2. Dominant species of the laterite plateau.**

| Very dominant | Less dominant |
|---|---|
| Firewood: | |
| *Combretum micranthum* | *Combretum nigricans* |
| *Guiera senegalensis* | |
| *Pasture:* | |
| *Zornia glochidiata* | *Alysicarpus ovalifolius* |
| *Schoenefeldia gracilis* | |
| *Aristida adscencionis* | |
| *Brachiaria disticophylla* | |
| *Dactyloctenium aegyptium* | |
| others: | |
| *Microchloa indica* | *Tripogon minimus* |
| *Aristida adscencionis* | *Polycarpaea eriantha* |
| *Pandiaka heudelotii* | *Evolvulus alsinoides* |
| *Borreria scabra* | *Ipomoea vagans* |
| *Eragrostis pilosa* | *Sporobolus festivus* |
| *Achyranthes aspera* | *Sprorbolus panicoides* |
| *Desmodium setigerum* | *Mitracarpus scaber* |
| | *Setaria pallide-Fusca* |
| | *Digitaria horizontalis* |
| | *Mollugo nudicaulis* |
| | *Panicum laetum* |
| | *Pycreus macrostachyos* |
| | *Acacia erythrocalyx* |
| | *Persitrophe bicalyculata* |

**Table 4.3. Dominant species of the toposequence.**

| Very dominant | Less dominant |
|---|---|
| Firewood: | |
| | *Piliostigma retiulatum* |
| | *Guiera senegalensis* |
| | *Combretum micranthum* |
| | *Combretum glutinosum* |
| Pasture: | |
| *Eragrostis tremula* | |
| *Aristida adscencionis* | |
| *Zornia glochidiata* | |
| *Cenchrus biflorus* | |
| *Digitaria horizontanlis* | |
| *Dactyloctenium aegyptium* | |
| *Alysicarpus ovalifolius* | |
| Fabrication: | |
| | *Aristida sieberiana* |
| | *Ctenium elegans* |
| | *Andropogon gayanus* |
| Others: | |
| *Mitracarpus scaber* | *Waltheria indica* |
| *Borreria radiata* | *Ceratotheca sesamoides* |
| *Merrimia pinnata* | *Digitaria gayana* |
| *Indigofera herhautiana* | *Annona senegalensis* |
| *Jacquemontia tamnifolia* | *Monechma ciliatum* |
| *Tephrosia linearis* | *Schoenefeldia gracilis* |
| *Cassia memosoides* | *Ipomoea vagans* |
| *Indigofera bracteolata* | *Guiera senegalensis* |
| *Kohautia senegalensis* | *Pennisetum pedicellatum* |
| | *Combretum micranthum* |
| | *Piliostigma reticulatum* |
| | *Polycarpaea linarifolia* |
| | *Chrozophora brocchiana* |
| | *Indigofera pilosa* |
| | *Aristida stipoides* |
| | *Fimbristylis hispidula* |
| | *Stereospermum kunthianum* |

**Table 4.4 Frequency of species occuring on the 2 laterite plateaus as determined by the linear method.**

| Species | Plateau # 1 | Plateau # 2 |
|---|---|---|
| | species # | |
| *Acacia erythrocalyx* | 4 | |
| *Achyrantes aspera* | 3 | 19 |
| *Alysicarpus ovalifolius* | | 7 |
| *Aristida adscencionis* | 17 | 6 |
| *Borreria scabra* | 8 | 6 |
| *Brachiaria disticophylla* | 9 | |
| *Brachiaria xantholenca* | | 2 |
| *Cassia mimosoides* | 1 | |
| *Cenchrus biflorus* | | 3 |
| *Celosia trigyna* | | 3 |
| *Citrillus lanatus* | | 1 |
| *Combretum micranthum* | 17 | 31 |
| *Combretum nigricans* | 5 | 4 |
| *Commelina forskalai* | | 1 |
| *Corchorus tridens* | | 1 |
| *Cyanotis lanatus* | 2 | |
| *Dactyloctenium aegyptium* | 8 | 11 |
| *Desmodium setiferum* | | 19 |
| *Digitaria horizontalis* | | 7 |
| *Eragrostis pilosa* | | 27 |
| *Eragrostis tremula* | | 1 |
| *Evolvulus alsinoides* | | 1 |
| *Guiera senegalensis* | | 1 |
| *Ipomoea vagans* | | 9 |
| *Jacquemontia tamnifolia* | | 1 |
| *Microchloa indica* | | 15 |
| *Mitracarpus scaber* | | 12 |
| *Mollugo nudicaulis* | | 6 |
| *Pandiaka heudelotii* | | 3 |
| *Panicum laetum* | | 6 |
| *Panicum subalbidum* | 1 | |
| *Panicum subgloborus* | 1 | |
| *Pennisetum pedicellatum* | | 1 |
| *Peristrophe bicalyculata* | | 4 |
| *Polycarpaea eriantha* | | 3 |
| *Pycreus polystachyos* | | 6 |
| *Riccia trichocarpa* | 1 | |
| *Schoenefeldia gracilis* | 5 | 13 |
| *Setaria pallide-Fusca* | | 9 |
| *Sesbania pachycarpa* | | 1 |
| *Sida cordifolia* | | 1 |
| *Sporobolus festivus* | 2 | 2 |
| *Tephrosia purpurea* | 1 | |

**Table 4.4 Frequency of species occuring on the 2 laterite plateaus as determined by the linear method. (Cont.)**

| Species | Plateau # 1 | Plateau # 2 |
|---|---|---|
| | species # | |
| *Tripogon minimus* | 6 | |
| *Triumphetta pentandra* | 2 | 20 |
| *Waltheria indica* | | 1 |
| *Zornia glochidiata* | 41 | 30 |

**Table 4.5.** **Frequency of species occuring on the toposequence as determined by the linear method.**

| Species | Toposequence position 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | number of species | | | | | | |
| *Acanthospermum hispidum* | 1 | | | | | | |
| *Achyrantes aspera* | | 2 | | | | | |
| *Alysicarpus ovalifolius* | 2 | | 10 | 33 | 11 | 47 | 8 |
| *Andropogon gayanus* | | 3 | 1 | | | | |
| *Annona senegalensis* | | 2 | | | | 7 | 3 |
| *Aristida adscencionis* | 65 | 18 | 6 | 7 | 4 | 14 | 4 |
| *Aristida sieberiana* | 6 | | | 6 | | | 1 |
| *Aristida stipoides* | | | | | | 6 | |
| *Blepharis linarifolia* | 1 | | | | | | |
| *Borreria radiata* | 25 | 1 | 1 | 42 | 14 | 76 | 55 |
| *Borreria scabra* | | | 6 | 1 | | | 5 |
| *Brachiaria disticophylla* | | 3 | | | | 1 | |
| *Calotropis procera* | | | | 1 | | | |
| *Cassia mimosoides* | 8 | | 7 | 6 | 25 | 4 | 9 |
| *Cenchrus biflorus* | 24 | 6 | 52 | 20 | 17 | 54 | 22 |
| *Ceratotheca sesamoides* | 5 | | | 1 | 9 | 5 | 5 |
| *Chrozophora brocchiana* | | | | | | 4 | 6 |
| *Combretum aculeatum* | | | | | | 2 | |
| *Combretum glutinosum* | | | | 3 | 4 | 7 | |
| *Combretum micranthum* | | | 3 | | | | |
| *Crotalaria atrorubens* | | | | | | 2 | 2 |
| *Ctenium elegans* | | | 11 | 7 | | 14 | 1 |
| *Dactyloctenium aegyptium* | | | 13 | | | | |
| *Digitaria gayana* | 5 | 3 | | | | | |
| *Digitaria horizontalis* | | 21 | 2 | | | | |
| *Eragrostis tremula* | 72 | 78 | 36 | 81 | 80 | 50 | 88 |
| *Fimbristylis hispidula* | | | | 1 | | 3 | 9 |
| *Gueira senegalensis* | | 4 | 7 | 8 | 5 | 6 | 2 |
| *Indigofera berhautiana* | 10 | | 1 | 10 | 14 | 6 | 34 |
| *Indigofera bracteolata* | | | | | 16 | | |
| *Indigofera pilosa* | 1 | | | | | 4 | |
| *Indigofera secundiflora* | | | | | | 2 | |
| *Ipomoea coscinosperma* | | | | 3 | 2 | | |
| *Ipomoea vagans* | | | 10 | 1 | | | |
| *Jacquemontia tamnifolia* | | 2 | 10 | 10 | 9 | 16 | 2 |
| *Kohautia senegalensis* | 4 | | | 1 | 15 | | |
| *Merremia pinnata* | 25 | 9 | 1 | 13 | 3 | 10 | 18 |
| *Merremia tridentata* | | | | | | | |
| *Mitracarpus scaber* | 66 | 39 | 24 | 88 | 99 | 6 | 27 |
| *Monechma ciliatum* | | | 10 | 3 | 6 | | |
| *Panicum laetum* | | | 2 | | | | |
| *Pennisetum pedicellatum* | | | 4 | | | | |
| *Phyllanthus maderaspatensis* | 2 | 3 | | 2 | 3 | 1 | |
| *Piliostigma reticulatum* | | 3 | | 7 | | | |
| *Polycarpaea linarifolia* | 1 | 1 | | | 1 | 7 | |
| *Schoenfeldia gracilis* | | | 10 | | | | |
| *Schyzachirium exile* | 3 | 2 | | | | | |
| *Sesamum alatum* | 1 | | | | 2 | | |
| *Sprorobolus festivus* | 2 | | | | 1 | | |
| *Stereospermum kunthianum* | | | | | | 6 | |
| *Tephrosia linearis* | 5 | | | 2 | 7 | 15 | 11 |
| *Tephrosia lupunifolia* | | | | | | | 1 |
| *Tephrosia purpurea* | 2 | | | | | | |
| *Terminalia avicennoides* | 1 | | | 1 | 1 | | |

**Table 4.6. Number and percent of species within the biological classification.**

| | Biological forms | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | mP | mp | np | CH | H | Gr | Gb | Gt | T |
| # species: | 4 | 19 | 6 | 7 | 2 | 1 | 1 | | 178 |
| % species: | 3.4 | 16.0 | 5.0 | 5.9 | 1.7 | 0.8 | 0.8 | | 0.865.5 |

**Table 4.7. Chorologic affinities.**

| | Chorologic affinities | | | |
|---|---|---|---|---|
| | Gc-SZ | Gc-SZ-Dah.S. | SZ | SZ-Sah.S |
| Species # | 55 | 2 | 61 | 1 |
| Percent | 46.2 | 1.7 | 51.3 | 0.8 |

Gc-SZ: *Guineo-congolese and Sudano-Zambesian taxon*
Gc-SZ-Sah.S.: *Guineo-congolese, Sudano-Zambesian and Saharo-Sindien taxon*
SZ: *Soudano-Zambesian taxon*
SZ-Sah.S.: *Soudano-Zambesian and Saharo-Sindien taxon*

**Table 4.8. Botanical classification of species.**

| Family and Species | Ecological zone | Biological type |
|---|---|---|
| ANGIOSPERMS | | |
| *Acanthaceae* | | |
| *Blepharis lenariifolia Pers.* | *SZ* | *T* |
| *Monechma ciliatum (Jacq) Milne. Redhead* | *Gc-SZ* | *T* |
| *Peristrophe bicalyculata (Retze) Nees.* | *SZ* | *T* |
| *Amaranthaceae* | | |
| *Achyranthes aspera L.* | *Gc-SZ* | *T* |
| *Amaranthus graecizans L.* | *Gc-SZ* | *T* |
| *Celosia trigyna L.* | *Gc-SZ* | *T* |
| *pandiaka heudelotii Hook. F.* | *Gc-SZ* | *T* |
| *Anacardiaceae* | | |
| *Sclerocarya birrea (A. Rich.) Hochst.* | *SZ* | *mp* |
| *Annonaceae* | | |
| *Annona senegalensis Pers.* | *SZ* | *np* |
| *Asclepiadaceae* | | |
| *Calotropis procera (Ait.) f.* | *Gc-SZ Sah.S* | *mp* |
| *Caralluma dalzielle. NE. Br.* | *SZ* | *CH* |
| *Ceropegia rhyndantha Schl.* | *Gc-SZ* | *Gt* |
| *Leptadenia hastata (Pers.) Devne* | *SZ* | *mp* |
| *Pergularia tomentosa (L.) Mant.* | *SZ Sah.S* | *np* |
| *Asteraceae = Composeae* | | |
| *Aspilia kotschyi (Sch. Bip.) Oliv.* | *SZ* | *T* |
| *Balanitaceae* | | |
| *Balanites aegyptiaca (L.) Del.* | *SZ* | *mp* |
| *Bignoniaceae* | | |
| *Stereospermum kunthianum Cham.* | *SZ* | *mp* |
| *Burseraceae* | | |
| *Commiphora africana (A. Rich.) Engl.* | *SZ* | *mp* |
| *Capparidaceae* | | |
| *Polycarpaea corymbosa (L.) Lam.* | *SZ* | *T* |
| *Polycarpaea eriantha Hochst. ex A. Rich.* | *SZ* | *T* |
| *Polycarpaea linearifolia (DC.) DC.* | *SZ* | *T* |
| *Combretaceae* | | |
| *Combretum aculeatum Vent.* | *SZ* | *mp* |
| *Combretum glutinosum Perr. ex DC.* | *SZ* | *mp* |
| *Combretum micranthum G. Don.* | *SZ* | *mp* |
| *Combretum nigricans var. elliotii (Engl. et Diels.) Aubrev.* | *SZ* | *mp* |
| *Guiera senegalensis J.F. Gmel.* | *SZ* | *mp* |
| *Terminalia avicennioides Guill. et Perr.* | *SZ* | *mp* |
| *Commelinaceae* | | |
| *Commelina forskalaei Vahl.* | *SZ* | *T* |
| *Cyanotis lanata Benth.* | *Gc-SZ* | *T* |
| *Convolvulaceae* | | |
| *Evolvulus alsinoides (L.) L.* | *Gc-SZ* | *T* |
| *Ipomoea captica (L.) Roth.* | *Gc-SZ* | *T* |
| *Ipomoea coscinosperma Hochst. ex Choisy.* | *SZ* | *T* |
| *Ipomoea heterotricha F. Didr.* | *Gc-SZ* | *T* |
| *Ipomoea vagans Bak.* | *SZ* | *T* |
| *Jacquemontia tamnifolia (L.) Griseb.* | *Gc-SZ* | *T* |
| *Merremia pinnata (Hochst.) Hallier.* | *Gc-SZ* | *T* |
| *Merremia tridentata (L.) Hallier.* | *Gc-SZ* | *T* |
| *Cucurbitaceae* | | |
| *Citrillus coloapnthis (L.) Schrad.* | *SZ* | *CH* |
| *Citrillus lanatus (Thunb.) Matsumara et Nakai.* | *SZ* | *CH* |
| *Cyperaceae* | | |
| *Bulbostylis barbata (Rottb.) C.B.Cl.* | *Gc-SZ* | *T* |
| *Bulbostylis coleotricha C.B.Cl.* | *Gc-SZ* | *T* |
| *Cyperus amabilis Vahl.* | *Gc-SZ* | *T* |
| *Fimbristylis hispidula (Vahl.) Kunth. subsp. hispidula* | *Gc-Sz* | *T* |
| *Pycreus macrostachyas* | *SZ* | *T* |
| *Euphorbiaceae* | | |
| *Chrozophora brocchiana Vis.* | *SZ* | *np* |
| *Phyllanthus maderaspatensis L.* | *Gc-SZ* | *T* |
| *Liliaceae* | | |
| *Aparagus africanus Lam.* | *SZ* | *Gr* |
| *Dipcadi tacazzeanum (Hochst.ex A.Rich) Bak.* | *SZGb* | |
| *Malvaceae* | | |
| *Hibiscus asper Hook.* | *Gc-SZ* | *T* |
| *Sida cordifolia L.* | *Gc-SZ* | *T* |
| *Sida ovata Forsk.* | *SZ* | *CH* |

**Table 4.8. Botanical classification of species. (Cont.)**

| Family and Species | Ecological zone | Biological type |
|---|---|---|
| *Molluginaceae* | | |
| *Mollugo nuducaulis Lam.* | Gc-SZ | T |
| *Pedaliaceae* | | |
| *Ceratotheca sesamoides Endl.* | SZ | T |
| *Sesamum alatum Thon.* | SZ | T |
| *Poaceae* | | |
| *Andropogon gayanus var. gayanus* | SZ | H |
| *Aristida adscencionis L.* | Gc-SZ | T |
| *Aristida sieberiana Trin.* | SZ | H |
| *Aristida stipoides Lam.* | SZ | T |
| *Brachiaria disticophylla (Trin.) Stapf.* | Gc-SZ | T |
| *Cenchrus biflorus Roxb.* | Gc-SZ | T |
| *Ctenium elegans Kunth.* | SZ | T |
| *Dactyloctenium aegyptium (L.) P. Beauv.* | Gc-SZ | T |
| *FABACEAE* | | |
| *Caesalpinioideae* | | |
| *Cassia italica (Mill.) Lam. ex F.W.Andr.* | SZ | CH |
| *Cassia mimosoides L.* | Gc-SZ | T |
| *Detarium microcarpum Guill. et Perr.* | SZ | mp |
| *Piliostigma reticulatum (DC.) Hochst.* | SZ | mp |
| *Mimosoideae* | | |
| *Acacia albida Del.* | SZ | mp |
| *Acacia ataxacantha DC.* | SZ | mp |
| *Acacia erythrocalyx Brenan.* | Gc-SZ | mp |
| *Acacia macrostachya Reich. ex Benth.* | SZ | mp |
| *Prosopis africana (Guill. et Perr.) Taub.* | SZ | mp |
| *Papilionoideae* | | |
| *Alysicarpus ovalifolius (Schum. et Thonn.) J. Leonard.* | Gc-SZ | T |
| *Crotalaria atrorubens Hochst. ex Benth.* | SZ | T |
| *Desmodium setigerum (E.Mey.) Benth. ex Harv.* | Gc-SZ | T |
| *Indigofera berhautiana Gillet.* | SZ | T |
| *Indigofera bracteolata DC.* | SZ | T |
| *Indigofera lepricurii Bak. f.* | Gc-SZ | T |
| *Indigofera pilosa Poir.* | SZ | T |
| *Indigofera secundiflora DC.* | SZ | T |
| *Sesbania pachycarpa DC.* | SZ | T |
| *Stylosanthes erecta P. Beauv.* | Gc-SZ | T |
| *Tephrosia linearis (Willd.) Pers.* | SZ | T |
| *Tephrosia lupunifolia DC.* | SZ | CH |
| *Tephrosia pedicellata Bak.* | Gc-SZ | T |
| *Tephrosia purpurea (L.) Pers. sp. Leptostachya (DC.) Brumm. var. Leptostachya* | Gc-SZ | CH |
| *Zornia glochhidiata Reichb. ex DC.* | Gc-SZ | T |
| *BRYOPHYTES* | | |
| *Mousses* | | |
| *Archidium tenellum* | SZ | T |
| *Hepatiques* | | |
| *Riccia trichocarpa* | SZ | T |
| *Digitaria gayana (Kunth.) A. Chev.* | Gc-SZ | T |
| *Digitaria horizontalis Willd.* | Gc-SZ | T |
| *Diheteropogon hagerupii Hitch.* | SZ | T |
| *Eragrostis pilosa (L.) P. Beauv.* | Gc-SZ Sah.S | T |
| *Eragrostis tremula Hochst. ex Stend.* | Gc-SZ | T |
| *Microchloa indica (L.) R. Beauv.* | Gc-SZ | T |
| *Panicum subalbidum* | Gc-SZ | T |
| *Penisetum pedicellatum Trin.* | Gc-SZ | T |
| *Schyzachirium exile (Hochst.) Pilger.* | Gc-SZ | T |
| *Schoenefeldia gracilis kinth.* | Gc-SZ | T |
| *Setaria pallide Fusca (Schummach.) Stapf et C.E. Hubb.* | Gc-SZ | T |
| *Sporobolus festivus Hochst. ex A. Rich.* | SZ | T |
| *Sporobolus panicoides A. Rich.* | SZ | T |
| *Tripogon minimus (A.Rich.) Hochst. ex Stend.* | Gc-SZ | T |
| *Rhamnaceae* | | |
| *Ziziphus mauritiana Lam.* | SZ | mp |
| *Rubiaceae* | | |
| *Borreria radiata DC.* | Gc-SZ | T |
| *Borreria scabra (Schum. et Thonn.) K. Schum.* | Gc-SZ | T |
| *Mitracarpus scaber Zucc.* | Gc-SZ | T |
| *Kohautia senegalensis Cham. et Schlecht.* | Gc-SZ | T |
| *Sapindaceae* | | |
| *Cardiospermum halicacabum L.* | Gc-SZ | np |
| *Scrophulariaceae* | | |
| *Striga gesnerioides (Willd.) Vatke.* | SZ | T |
| *Striga hermontheca (Del.) Benth.* | SZ | T |
| *Sterculiaceae* | | |
| *Waltheria indica L.* | Gc-SZ | np |

**Table 4.8. Botanical classification of species. (Cont.)**

| Family and Species | Ecological zone | Biological type |
|---|---|---|
| *Tiliaceae* | | |
| *Corchorus tridens L.* | *Gc-SZ* | |
| *Grewia flavescens Juss.* | *SZ* | *mp* |
| *Triumphetta pentandra A. Rich.* | *Gc-SZ* | *T* |
| *Verbenaceae* | | |
| *Vitex doniana Swest.* | *Gc-SZ* | *mp* |
| *Violaceae* | | |
| *Hybanthus enneaspermus (L.) F.V. Muell.* | *Gc-SZ* | *T* |

## 5.0 DESIGNATION OF LAND MANAGEMENT UNITS

One of the objectives of this report is to integrate baseline information obtained during the feasibility study phase to delineate and characterize land management units (LMU) within the watershed. Land management units can be defined as recurring series of surveys encompassing watershed topography, soils/geomorphology, land use, the distribution and diversity of native vegetation, the degree of land degradation, and native knowledge of farming systems and natural resource management within the watershed. From these surveys a reference data base was developed and integrated into a geographic information system (GIS).
The data from the surveys and used in designating boundaries of individual LMU's include the following:

+ Topographic map (Fig. 2.1)
+ Soil characterization and pedon description (Fig. 2.2)
+ Watershed hydrology (Fig. 2.4)

technologies tested on the experimental watershed to similar LMU sub-systems located within the region.

The attributes were studied through a

+ Distribution of fallow/cropped land (Fig. 3.1)

The topographic, soils, and watershed hydrology maps were combined with the use of GIS to delineate LMUs (Fig. 5.1).

The following LMUs were identified:

LMU-I Laterite plateau
LMU-II Tondo Kakasia
LMU-III Arable land or Fondu
LMU-IV Gangani Kirey
LMU-V Gully/outwash fan systems

### 5.1 Description of Land Management Units

#### 5.1.1 LMU-I: Laterite Plateau

The laterite plateau is a striking geomorphological feature on the landscape. It occupies the highest relief position. The total surface area of this LMU within the watershed is 42.7 ha and includes the Plateau (Lp) and Tondo Kakasia stony phase (ToA) soils. The plateau surface is characterized by a flat, crusted bare surface interspersed by a series of thickets of varying sizes. From the air, the distribution of the thickets and bare areas take on the appearance of tiger stripes. This pattern of vegetation distribution has been labeled "tiger bush."

The laterite plateau LMU can be further divided into two subunits -- thickets and bare areas. A detailed description of the soils associated with the two subunits are presented in section 2.3.2 (Mapping unit descriptions).

The plateau is viewed by farmers as a common area providing a perpetual source of fuel, construction wood, medicines, and food. Livestock are grazed on the plateau without regulation. Despite its overall importance, farmers express little interest in managing these resources. Laterite plateaus have been successfully developed as forest reserves in Western Niger. However, this has required the development of local cooperatives to carry out and manage the forest and share earnings. Without this local structure, plateau resource development at the farmer level will be difficult.
Lateral water flow on the plateau following rain is great because of the crusted surface. The use of digettes, bunds, and other erosion control works to decrease runoff and increase infiltration. This results in higher biomass productivity through natural revegetation, while requiring a minimal input. Water running off the plateau creates severe erosion problems in soils located downslope.

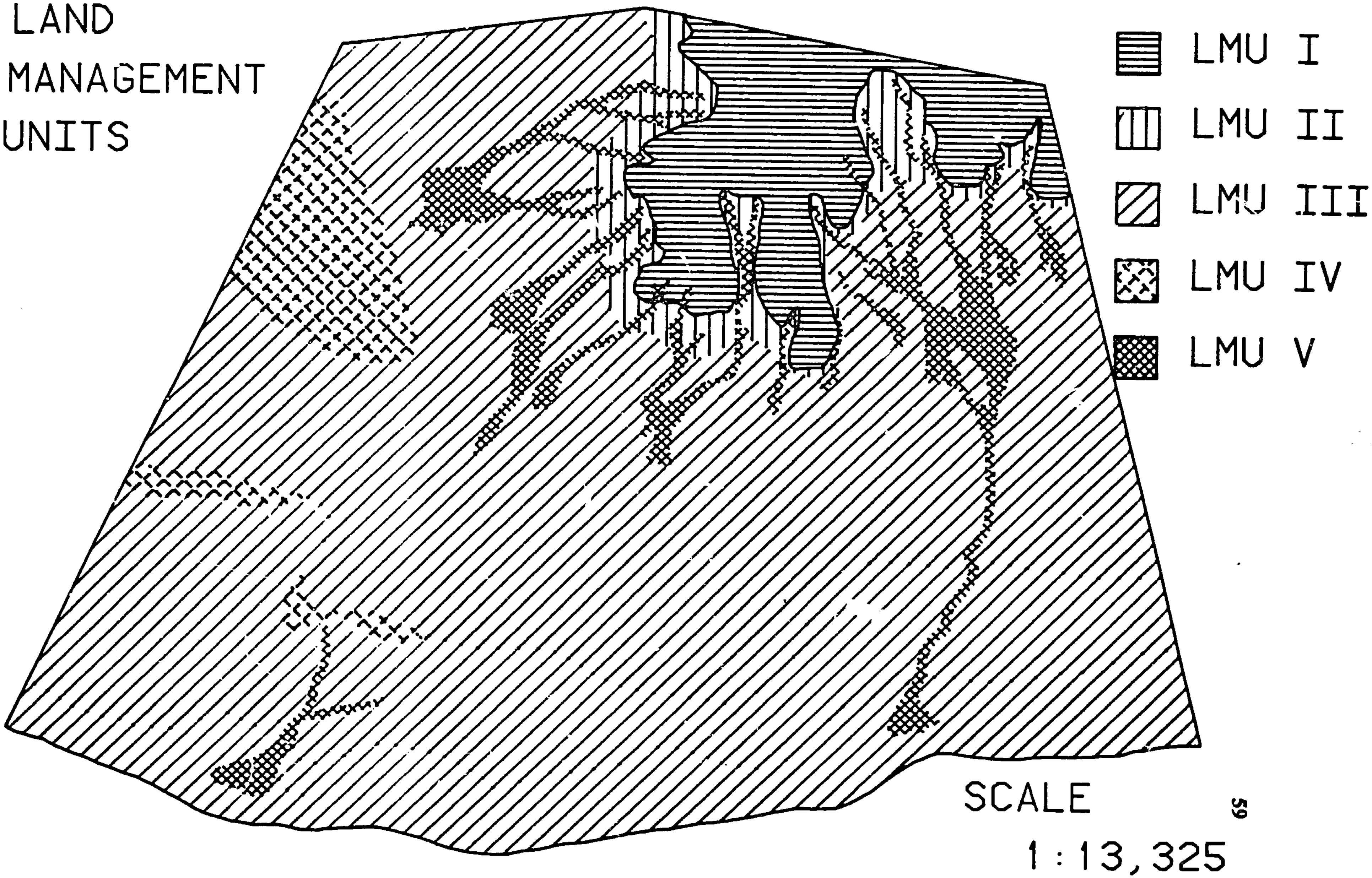
#### 5.1.2 LMU-II: Tondo Kakasia

Tondo Kakasia is the Djerma name for the soil directly below the laterite plateau. Slopes are generally steep (3-8%) and the soils, although very deep, are severely eroded with exposed Bt horizons. The surface is covered by a thin impermeable crust. The total surface area of this LMU is 20.0 ha and consists of the To mapping unit.

The Tondo Kakasia is generally not used for production agriculture. The steep slope, surface crust and high bulk density

FIGURE 5.1

LAND MANAGEMENT UNITS



inhibit infiltration and accelerate runoff. This results in a low soil water recharge. One farmer tried to recuperate these soils by plowing in animal manure to loosen the soil -- the manure preventing the reformation of the surface crust. This process involved animal traction, which most farmers cannot afford. Villagers harvest medicinal herbs and gather food as well as *Andropogon gayanus* for construction material from this area.

Serious drawbacks to production are water erosion and low water infiltration. Water runoff from the laterite plateau has resulted in very extensive gully systems, which have been identified within another LMU (gully/outwash fan systems).

**5.1.3 LMU-III: Arable land or Fondu**

The Dantiando, Hamdallaye, Bokotchili, and Falanke soil series (Do, Ha, Bo, Fa, and FaA mapping units) are deep sandy soils most extensively used for crop production. These soils occur on moderate slopes and have similar chemical and physical characteristics (See 2.6.1: Soil Physical and Chemical Properties). The total surface area is 379 ha, the largest LMU in the watershed (76%). This LMU will be extensively used for the demonstration of improved farming system technologies.

The major drawbacks to agricultural production of the LMU are low soil fertility, wind erosion, and to a lesser extent, water erosion. Soils are sandy to loamy sand in texture and have low moisture retention capacities. They are inherently poor in fertility and are characterized by low organic matter content, barely measurable total N, and low CECs. Available P content is below the critical levels required by most crops.

These soils typically have high infiltration rates and rapid permeability. However, stratification of the soil surface indicates sheet erosion is prevalent, especially in areas with moderate slopes. This is confirmed by observations during the rainy season. Extensive water erosion results in the formation of *Gangani Kirey*, areas here surface horizons have been removed and surface crusts have formed. These aggravate the erosion problem and can be the source of rills and small outwash fans.

Wind erosion is a large problem on these soils. The loose and light-textured surface horizons plus sparse vegetation during the dry season make these soils particularly susceptible. Deflation areas are common, as are "microhigh" areas associated with shrub growth and field borders. These act to trap eroded soil material.

Subunits: Within the *Fondu* soils LMU are four subunits that could be considered as separate entities for successful management of the watershed:

+ Cropped land (*sacara, lalibanda, kwarkwari, blanga*)
+ Fallow land (*farezenou*)
+ Gangani (*kware* and *kirei*)
+ Low-relief areas

The cropped/fallow land subunits, although temporary, will affect management options at different points within the LMU. The gangani subunit consists of water- and wind-eroded surfaces, which do not support good vegetative growth.

Low relief areas occur in landscape positions above the two laterite formations, causing a break in slope. Slopes decrease to 0% and may even be negative (formation of a depression). Low relief areas are generally less than 0.25 ha. Soils are slightly heavier textured, and their nutrient status is better than the surrounding productive soils. Water accumulates as run-on from upslope, allowing farmers to grow crops such as sorghum and corn that require higher soil moisture than millet.

**5.1.4 LMU-IV: Gangani Kirey**

The *Gangani Kirey* (Ga) and Hamdallaye lithic phase (HaB and HaC) soil series are located above the first laterite outcrop in the northwestern section of the watershed. This LMU occupies 23.0 ha, and has the characteristics:

+ Shallow to a restricting laterite layer (40-80 cm)

+ High clay and free Fe oxide contents
+ High moisture retention capability
+ Exposed B horizons which are generally crusted

Vegetation is similar to that on the laterite plateau. However, the production potential is much greater due to a more favorable water balance and enriched soil fertility resulting from deposits of eroded sediments from upslope runoff. Ponding occurs after rains, inhibiting growth of some crops.

This LMU has severely crusted soils and is not used much for farming. Crops are grown only in areas where a 10-20 cm layer of sand overlays the crusted soil. There is a large distribution of *Andropogon gayanus* and *Aristida sieberiana*, local grasses used for construction.

**5.1.5 LMU-V: Gully/Outwash Fan System**

The gully and outwash fan system is comprised of the gullied phases of the *Tondo Kakasia, Dantiandou* and *Bokotchili* soils (ToB, DaA and BoA) and the overwash phases of the Hamdallaye and Falanke soils (HaA and FaA). The LMU area is 31.1 ha. There are 13 gullies that originate from the laterite plateau and two originating from the secondary laterite outcrop. The gullies running through the *Tondo Kakasia, Dantiandou*, and *Bokotchili* mapping units are generally shallow (<1 m deep). As the gullies approach the Hamdallaye and Falanke mapping units, the slope decreases. This causes a reduction in water speed and the deposit of soil to form outwash fans that spread through productive fields.

Gullies dissect and scar the landscape, reducing land area that could be used for crop production. They act as conduits through which water is lost. The outwash fans have no natural vegetation. Millet seedlings rarely survive due to periodic flooding by runoff water and burial by sands.

Farmers are concerned with the loss of productivity associated with outwash fans, but feel powerless to do anything about them. The gully/outwash fan system has been included as one unit because the rejuvenation of the outwash fans will require control of the water flow through the gullies from upslope.

**5.2 Production Constraints and Management Options**

Production constraints have been listed for each LMU and the subunits within them (Table 5.1.). Overall management options for [illegible] LMU are presented in Table 5.2. [illegible]tailed consideration of both production constraints and management options are discussed in a separate document dealing with the implementation plans for the IMAW Project.

**6.0 CONCLUSIONS AND RECOMMENDATIONS**

It can be concluded from this study that a complete physical and socioeconomic characterization of a single watershed combined with management technologies adopted by its farmers can be put to use in other watersheds with similar attributes.

Changes in climatic conditions over the last few decades and excessive use of the vegetation resource have left the study watershed in a degraded state. To promote sustainable agricultural production, agronomic, ecological and socioeconomic improvements involving a multidisciplinary approach need to be adopted.
Watershed soils are nutrient deficient, prone to crusting and vulnerable to wind and water erosion. Farming systems packages incorporating modern techniques and traditional methods of maintaining soil fertility should be developed. Specific areas of improvement should center on better traditional fallow systems, efficient use of manures and fertilizers, use of residues such as surface mulches, and the development of efficient crop rotation and intercropping systems that can sustain continuous crop production.

Consideration should be given to restoring the soil and vegetation on the plateau. The lack of defined land ownership -- hence the lack of interest in managing the plateau -- will require adoption of low input management options. Revegetation of bare areas and control of water runoff should be given priority in the management of the plateau.

Rainfall is extremely variable in the watershed. The sandy to loamy sand textures of these soils lead to high infiltration rates and low moisture retention capacities. However, rainfall amounts may exceed infiltration rates, resulting in surface run off. Soil water management techniques to improve water use must be put into place.

Wind erosion was cited by farmers as a major production drawback. Winds that reduce productivity by removing fertile topsoil, which can lead to the sandblasting of young plants. Measures to control wind erosion, including the use of windbreaks and surface mulches should be employed.

Farmers do not see water erosion as a serious threat to productivity, although there are large gullies in the watershed. These gullies end in outwash fans that inhibit establishment of seedlings. To control this type of erosion, methods to slow the speed of water flowing through the gullies must be installed. This will require installation of erosion control works on the laterite plateau and the Tondo Kakasia soil.

**Table 5.1. Production constraints**

| LMU | R | WD | C | P | S | WE | WIE | F |
|---|---|---|---|---|---|---|---|---|
| | | | Production constraints | | | | | |
| Laterite plateau: | | | | | | | | |
| bare areas | x | x | x | | | x | x | x |
| thickets | x | | | | | | | x |
| Tondo Kakasia | | x | x | | x | x | | x |
| Fondu | | | | | | | | |
| cropped land | | | | | | x | x | x |
| fallow land | | | | x | | | | |
| gangani | x | x | | | x | x | x | |
| low-relief areas | x | | | x | | | | |
| Gangani Kirey | x | x | x | x | x | | | |
| Gully/outwash fan system | | | | | | | | |
| gully | | | x | x | | x | | |
| outwash fan | x | x | | | | | | |

R = restricting layer
WD = relative water deficit
C = surface crust
P = ponding
S = steep slope
WE = water erosion
WIE = wind erosion
F = soil fertility

**Table 5.2. Management options**

| LMU | Water erosion | | Wind erosion | | Farming* systems | Natural** vegetation |
|---|---|---|---|---|---|---|
| | D | B | W | M | | |
| Laterite plateau | | | | | | |
| bare areas | x | x | | | | x |
| thickets | | | | | | |
| Tondo Kakasia | x | x | | | | x |
| Arable land or Fondu | | | | | | |
| cropped land | | | x | x | x | |
| fallow land | | | | | | x |
| gangani | x | x | | | | |
| low relief areas | | | | x | | |
| Gangani Kirey | x | | | x | x | x |
| Gully/outwash fan system | | | | | | |
| gully | x | x | x | | | |
| outwash fan | x | | x | x | | x |

D = digettes or small earthworks
B = contour bunds
W = windbreaks
M = surface mulches

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# APPENDIX A

## SOIL DESCRIPTIONS

I. **Plateau soil series (Lp)**

WITHIN vegetated area

Location: IMAW watershed. This pedon is located in the middle of the laterite plateau within a vegetated area.

| | | |
|---|---|---|
| Landform: | laterite plateau | Slope: 0-1% |
| Topography: | level | Drainage: poorly drained |
| Parent Material: | laterite | |

| Horizon | Depth (cm) | Soil description (colors are for moist soil) |
|---|---|---|
| A1 | 0-8 | Dark brown (7.5YR 4/4) fine sandy loam; brown (7.5YR 5/4) dry; thin platy; hard; friable; many fine, few medium roots; intense biologic activity on the surface (termites); common biocasts, biochambers, biotubules, and biochannels; clear smooth boundary. |
| A2 | 8-16 | Strong brown (7.5YR 4/6) gravelly sandy clay loam; brown (7.5YR 5/4) dry; weak coarse subangular blocky (between gravels); hard; friable; many fine and medium roots; many biopores; many biochannels; many biocasts with infilling of dark grayish brown (10YR 4/2) sand; gradual smooth boundary. |
| Bt1 | 16-34 | Yellowish red (5YR 5/6) gravelly sandy clay loam; reddish yellow (5YR 6/6) dry; granular (between gravels); hard; firm; many fine and medium and few large roots; many biopores; gradual smooth boundary. |
| Bt2 | 34-60 | Yellowish red (5YR 5/8) gravelly clay; reddish yellow (5YR 6/6) dry; granular (between gravels); no consistence; many medium and fine roots; abrupt wavy boundary. |
| | >60 | Laterite |

**I. Plateau soil series (continued)**

OUTSIDE vegetated area

Location: IMAW watershed. This pedon is located in the middle of the laterite plateau outside of a vegetated area.

| | | | |
|---|---|---|---|
| Landform: | Laterite plateau | Slope: | 0-1% |
| Topography: | level | Drainage: | poorly drained |
| Parent Material: | laterite | | |

| Horizon | Depth (cm) | Soil description (colors are for moist soil) |
|---|---|---|
| A1 | 0-4 | Reddish brown (5YR 4/4) fine sandy loam; light brown (7.5YR 6/4) dry; strong coarse subangular blocky parting to thin platy; extremely hard; friable; hard surface crust (1 mm thick); some vesicular pores; few fine roots; few biochannels; few ironstone gravels; abrupt wavy boundary. |
| A2 | 4-18 | Strong brown (7.5YR 5/6) gravelly fine sandy loam; light brown (7.5YR 6/4) dry; granular (between gravels); no consistence; few fine (dead) roots; very few biochannels; ironstone concretions up to 15 cm dia.; clear smooth boundary. |
| B | 18-35 | Strong brown (7.5YR 5/6) gravelly sandy clay loam; reddish yellow (7.5YR 6/6) dry; weakly developed subangular blocky; few fine (dead) roots; few biochannels; gradual smooth boundary. |
| BC | 35-54 | Strong brown (7.5YR 5/6) gravelly sandy clay; reddish yellow (7.5YR 7/6) dry; weakly developed subangular blocky (between gravels); very few fine (dead) roots; no biochannels; few laterite cobbles; abrupt wavy boundary. |
| | > 54 | Laterite |

**II. Tondo Kakasla soil series (To)**

Location: IMAW watershed. This pedon is located 390 meters NW of permanent marker Archie.

| | | | |
|---|---|---|---|
| Landform: | upper backslope | Slope: | 3-8% |
| Topography: | undulating | Drainage: | well drained |
| Parent Material: | Continental Terminal | Pedon #: | 5-B |
| Pedon Location: | fallow area | | |

Horizon Depth (cm) Soil description (colors are for moist soil)

A 0-4 Strong brown (7.5YR 4/6) fine sand, reddish yellow (7.5YR 6/6) dry; thin platy; hard; firm; few fine roots associated with biopores; common biochannels (2-3 mm); common biochambers (5 mm); many biopores; large rounded quartz grains; horizon is layered with lamellae 2-3 mm thick; pH 5.9; abrupt wavy boundary.

A2 4-19 Yellowish red (5YR 5/6) loamy fine sand; strong coarse subangular blocky; slightly hard; very firm; common fine roots; few medium roots; many biochannels (1-5 mm); few biopores; common biochambers; laterite gravels up to 1 cm dia.; few charcoal fragments; pH 5.3; clear smooth boundary.

AB 19-35 Red (2.5YR 4/8) loamy fine sand; strong coarse subangular blocky; hard; firm; common fine roots associated with biopores; common biochannels; few biochambers (2 cm dia.); root channels (2 cm); consistence is variable throughout the horizon; pH 5.2; gradual smooth boundary.

Bt1 35-47 Red (2.5YR 4/8) loamy fine sand; weak coarse subangular blocky; slightly hard; firm; common fine roots; few medium roots; common biochannels; small charcoal fragments; clear smooth boundary.

Bt2 47-64 Red (2.5YR 4/8) loamy coarse sand; weak coarse subangular blocky; hard; friable; common fine roots; few medium roots; common biochannels; very few laterite gravels; pH 5.5; gradual smooth boundary.

**II. Tondo Kakasia soil series (continued)**

Bt3 64-87 Red (2.5YR 4/8) loamy fine sand; weak coarse subangular blocky; slightly hard; friable; few fine and medium roots; few large roots; common biochannels; pH 5.4; gradual smooth boundary.

BC 87-119 Red (2.4YR 4/8) loamy fine sand; coarse subangular blocky; slightly hard; friable; few large biochannels; few laterite gravels (to 1 cm dia.); pH 5.2; gradual smooth boundary.

C1 119-145 Red (2.5YR 4/8) loamy fine sand; coarse subangular blocky; slightly hard; friable; very few fine roots; few small (<1 cm) and few large (4 cm) laterite gravles; pH 5.2; consistence is variable throughout the horizon.

C2 145-200 Red (2.5YR 4/8) loamy fine sand; strong coarse subangular blocky; very hard; friable; very few fine roots; very few medium roots; pH 5.3; dry in the upper 20 cm of the horizon and moist below.

** Laterite was found in hand auger samples taken from a depth of 310 cm below the soil surface.

**III. Dantiandou soil series (Da)**

Location: IMAW watershed. This pedon is located 250 m west of the permanent rain gauge on the plateau.

| | | | |
|---|---|---|---|
| Landform: | upper backslope | Slope: | 2-3% |
| Topography: | gently sloping | Pedon #: | 1-A |
| Parent Material: | eolian sand | Drainage: | well drained |
| Pedon Location: | millet field | | |

Horizon Depth (cm) Soil description (colors are for moist soil)

Ap1 0-3 Yellowish red (5YR 4/6) sand; yellowish red (5YR 5/6) dry; loose grains; extremely weak; pH 6.3; abrupt smooth boundary.

Ap2 3-7 Yellowish red (5YR 4/6) sand; yellowish red (5YR 5/6) dry; thin platy with bands of dark reddish brown (5YR 3/4) sand; slightly hard; friable; few fine roots; common vesicular pores; few biopores (1-3 mm dia.); pH 6.0; abrupt smooth boundary.

**III. Dantiandou soil series (continued)**

A 7-20 Strong brown (7.5YR 4/6) fine sand; strong brown (7.5YR 5/6) dry; weak coarse subangular blocky structure; slightly hard; friable; few fine roots; common biochannels, biocasts, biotubules (1-3 mm dia.); few charcoal fragments (1-2 mm); pH 5.3; gradual smooth boundary.

B/A 20-36 Strong brown (7.5YR 4/6) sand; strong brown (7.5YR 5/6) dry; weak coarse subangular blocky structure; slightly hard; friable; few fine roots; common biopores; few biochannels (up to 1 cm); few crotovinas (3-4 mm); pH 5.2; gradual smooth boundary.

Bt1 36-52 Yellowish red (5YR 5/8) fine sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky structure; slightly hard; friable; few fine roots; common biopores, biochambers (1-2 mm); pH 5.0; gradual smooth boundary.

Bt2 52-73 Yellowish red (5YR 5/8) sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky structure; slightly hard; friable; few fine roots; few biochambers (1-2 cm); few root channels (to 4 cm); few crotovinas (to 9cm); charcoal fragments (1-3 mm); pH 5.1; gradual smooth boundary.

Bt3 73-93 Red (2.5YR 4/8) sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky structure; slightly hard; friable; few fine roots; few biocasts; few biochannels ( 2mm); few biopores (4 mm); few crotovinas; few root channels (up to 1.5 cm); charcoal fragments (1-3 mm); few laterite gravels (to 3 cm); pH 5.1; gradual smooth boundary.

Bt4 93-130 Red (2.5YR 4/8) loamy fine sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky structure; slightly hard; friable; few fine roots; very few biopores; few charcoal fragments; pH 5.0; gradual smooth boundary.

* Samples below 130 cm were taken with a hand auger.

Bt5 130-170 Red (2.5YR 4.8) sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky structure; slightly hard; friable; pH 5.2.

Bt6 170-200 Red (2.5YR 4/8) sand; red (2.5YR 5/8) dry; pH 5.2.

** Auger samples taken to 300 cm below the soil surface contained no laterite gravels.

**IV. Hamdallaye soil series (Ha)**

Location: IMAW watershed. This pedon is located 470 m SE of permanent marker I-F.

| | | | |
|---|---|---|---|
| Landform: | middle backslope | Slope: | 1/2-2% |
| Topography: | gently undulating | Pedon#: | 3-A |
| Parent Material: | eolian sand | Drainage: | well drained |
| Pedon Location: | millet field | | |

Horizon Depth (cm) Soil description (colors are for moist soil)

A1 0-7 Yellowish red (5YR 4/6) sand; strong brown (7.5YR 5/6) dry; weak coarse subangular blocky structure; hard; friable; common fine roots; few biochambers (2.5 mm); few biochannels (2.3 mm); thin vesicular crust (1 mm thick) at upper boundary; subtle reddish brown (5YR 5/4) banding of sand throughout horizon; pH 5.2;clear wavy boundary.

A2 7-24 Yellowish red (5YR 4/6) sand; yellowish red (5YR 5/6) dry; weak coarse subangular blocky structure; hard; friable; common fine roots; common biopores; many fine biochannels; few crotovinas (up to 3 cm); few pottery shards; charcoal fragments; pH 5.1;gradual smooth boundary.

A/B 24-50 Red (2.5YR 4/8) sand; yellowish red (5YR 5/8) dry; weak coarse subangular blocky structure; slightly hard; friable; common fine roots; few medium roots; few biochannels (1-3cm); very large crotovina (15 cm); few laterite gravels (1-2 mm); pH 5.0; gradual smooth boundary.

Bt1 50-102 Red (2.5YR 4/8) sand; red (2.5YR 5/8) dry; weak coarse subangular blocky structure; slightly hard; friable; common fine roots; few medium roots; few large roots; few small biochambers; few large crotovinas (up to 2 cm dia.); charcoal fragments; pH 5.1; gradual smooth boundary.

Bt2 102-148 Red (2.5YR 4/8) sand; weak coarse subangular blocky structure; slighty hard; friable; few fine roots; few medium roots; few biochannels (2-3 mm); few ironstone concretions (2-5 mm); termite activity indicated in presence of very hard nodules formed of biochannels; pH 4.9; gradual smooth boundary.

Bt3 148-179 Red (2.5YR 4/8) sand; pH 5.2.

Bt4 179-200 Red (2.5YR 4/8) sand; pH 5.3.

*Samples below 150 cm were taken with a hand auger.
**Laterite gravels were found 300 cm below the soil surface.

**V. Gangani Kirey soil series (GaK)**

Location: IMAW watershed. This pedon is located 360m SW of permanent marker I-C.

| | | | |
|---|---|---|---|
| Landform: | footslope | Slope: | 0-1/2% |
| Topography: | planar | Drainage: | mod. well drained |
| Parent Material: | Continental Terminal | Pedon#: | 2-A |
| Pedon Location: | fallow area | | |

| Horizon | Depth (cm) | Soil Description (colors are for moist soil) |
|---|---|---|
| Ap | 0-8 | Yellowish red (5YR 4/6) sand; strong brown (7.5YR 5/6) dry; thin platy structure with bands of reddish brown (5YR 4/4) sand; slightly hard; friable; many fine roots; many vesicular pores; many biopores; few biochambers (to 1 cm); few biochannels (1-4 mm); pH 5.6; abrupt smooth boundary. |
| 2A | 8-17 | Dark brown (7.5YR 3/4) loamy sand; dark brown (7.5YR 4/4) dry; strong coarse subangular blocky structure; hard; firm; many fine roots; common biochannels (1-3 mm); common biopores (1-4 mm); few biochambers (to 5mm); pH 5.1; clear smooth boundary. |
| 2A/B | 17-27 | Yellowish red (5YR 4/6) loamy sand; strong brown (7.5YR 5/6) dry; moderately weak coarse subangular blocky structure; hard; friable; few fine roots; few biopores (to 3 cm); ironstone concretions comprise 5% of soil material; pH 5.1; gradual smooth boundary. |
| 2Bt1 | 27-35 | Red (2.5YR 4/6) sandy loam; yellowish red (5YR 5/8) dry; weak coarse subangular blocky structure; hard; friable; many fine roots; few medium roots; many biopores (1-3 mm); few charcoal fragments; ironstone concretions comprise 2-5% of soil; pH 5.0; abrupt wavy boundary. |
| 2Bt2 | 35-53 | Red (2.5YR 4/6) sandy loam; reddish yellow (5YR 6/8) dry; moderately weak coarse subangular blocky structure; slightly hard; friable; many fine roots; few medium roots; few large roots; many biopores; many biotubules; subrounded ironstone concretions comprise 10-20% of soil; pH 5.1; abrupt wavy boundary. |
| 2C | >53 | Indurated laterite. |

**VI. Bokotchili soil series (Bo)**

Location: IMAW watershed. This pedon is located 450 meters NE of the village of Falanke Kaina.

| | | | |
|---|---|---|---|
| Landform: | lower backslope | Slope: | 1/2-2% |
| Topography: | gently undulating | Pedon#: | 3-B |
| Parent Material: | eolian sand | Drainage: | well drained |
| Pedon Location: | fallow area | | |

Horizon Depth (cm) Soil description (colors are for moist soil)

A1 0-13 Dark brown (7.5YR 4/4) sand; brown (7.5YR 5/4) dry; thin platy; weak; friable; banded sand grains; many fine and common medium roots; common biopores and biochambers (up to 1 cm); pH 6.0; many laterite gravels (2-3 mm); clear smooth boundary.

A2 13-30 Dark brown (7.5YR 4/4) sand; strong brown (7.5YR 5/6) dry; weak coarse subangular blocky; slightly hard; friable; common fine roots; few medium roots; few biochambers (2-4 mm); few crotovinas (to 4 cm); pH 5.6; clear smooth boundary.

A/B 13-49 Strong brown (5YR 4/6) sand; yellowish red (5YR 4.6) dry; weak coarse subangular blocky; weak; friable; common fine roots; few medium roots; many biochannels (2-3 mm); few crotovinas with infilling of very pale brown (10YR 7/3) sand; pH 5.3; few laterite gravels (2-3 cm); few charcoal fragments (up to 5mm); clear smooth boundary.

Bt1 49-74 Yellowish red (5YR 5/8) sand; red (2.5YR 4/8) dry; weak coarse subangular blocky; slightly hard; friable; common fine and few medium roots; few biochannels; few biochambers; few crotovinas (to 3 cm); few charcoal fragments (5 mm); few laterite gravels (2-3 cm); pH 5.0; gradual smooth boundary.

Bt2 74-95 Yellowish red (5YR 5/8) sand (both humid and dry); weak coarse subangular blocky; weak; friable; common fine roots; few medium roots; few biochambers (5 mm); few laterite gravels (2-3 cm); pH 5.1; gradual smooth boundary.

Bt3 95-144 Red (2.5YR 5/8) sand; reddish yellow (5YR 5/8) dry; weak coarse subangular blocky; slightly hard; friable; few fine and medium roots; few biochambers; few biochannels; pH 5.4; gradual smooth boundary.

**VI. Bokotchili soil series (continued)**

B/C 144-182 Red (2.5YR 4/8) sand; yellowish red (5YR 5/8) dry; weak, coarse subangular blocky; slightly hard; friable; few medium roots; few fine roots; few biochambers; few biochannels; few crotovinas (2-4 cm dia.); few laterite gravels (2-3 mm); pH 5.4; gradual smooth boundary.

C1 182-200 Red (2.5YR 4/8) sand; yellowish red (5YR 5/8) dry; coarse subangular blocky; slightly hard; friable; few fine roots; few laterite gravels (1-2 mm); pH 5.7; gradual smooth boundary.

* Auger samples taken to 350 cm below the soil surface contained no laterite.

**VII. Falanke soil series (Fa)**

Location: IMAW watershed. This pedon is located 470m east of Falanke Kaina, 25m upslope of the valley floor.

| | | | |
|---|---|---|---|
| Landform: | toeslope | Slope: | 5-7% |
| Topography: | undulating | Pedon#: | 4-B |
| Parent Material: | eolian sand | Drainage: | well drained |
| Pedon Location: | millet field | | |

Horizon Depth (cm) Soil description (colors are for moist soil)

A1 0-4 Strong brown (7.5YR 4/6) sand; thin platy structure; hard; friable; vesicular pores; common fine roots; common medium roots; common biochannels (2-3 mm); inclusions of reddish yellow (7.5YR 7/6) sand; abrupt wavy boundary.

A2 4-15 Strong brown (7.5YR 6/4) loamy sand; weak coarse subangular blocky; very hard; friable; common fine roots; few biochambers (to 1cm); common biopores; few charcoal fragments; inclusions of dark brown (10YR 4/3) sand; pH 5.3; abrupt wavy boundary.

A/B 15-31 Yellowish red (5YR 5/8) loamy sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky; extremely hard; friable; common fine roots; few medium roots; common biopores; common biochannels (1-3 mm); common biochambers (to 1 cm); many biocasts with dark brown (7.5YR 3/4) infilling; few charcoal fragments; pH 5.1; abrupt smooth boundary.

**VII. Falanke soil series (continued)**

Bt1 31-51 Yellowish red (5YR 5/8) loamy sand; reddish yellow (5YR 6/8) dry; weak coarse subangular blocky; weak; friable; common fine roots; common biochambers (to 1 cm); common biopores; few biochannels; few charcoal fragments; pH 5.3; gradual smooth boundary.

Bt2 51-79 Yellowish red (5YR 5/8) loamy sand; reddish yellow (7.5YR 6/8) dry; nearly massive parting to weak coarse subangular blocky; weak; friable; common fine roots; few medium roots; common biochannels (1-3 mm); common biochambers (4-7 mm); common biopores (1-2 mm); few charcoal fragments; pH 5.4;gradual smooth boundary.

Bt3 79-105 Yellowish red (5YR 5/8) loamy sand; reddish yellow (7.5YR 6/8) dry; nearly massive; weak; friable; few fine roots; few large roots; common root channels (5 mm dia.); common biocasts with yellowish brown (10YR 5/4) sand infilling; pH 5.2; gradual smooth boundary.

B/C 105-126 Yellowish red (5YR 5/8) loamy sand; reddish yellow (7.5YR 6/8) dry; nearly massive; weak; friable; common biochambers (to 3 cm); very hard biocasts related to termite activity; pH 5.6; gradual smooth boundary.

C1 126-164 Yellowish red (5YR 5/8) loamy sand; reddish yellow (7.5YR 6/8) dry; nearly massive; slightly hard; friable; few fine roots; few biochambers; few biochannels; common biopores; pH 5.8; gradual smooth boundary.

C2 164-200 Yellowish red (5YR 5/8) sand; reddish yellow (7.5YR 6/8) dry; massive; slightly hard; friable; few fine roots; few biopores; few biocasts with reddish yellow (7.5YR 6/6) sand infilling; pH 5.8.

** No laterite gravels were found in samples taken to 325 cm below the soil surface with a hand auger.

# APPENDIX B
# SOIL CHEMICAL PROPERTIES

**Soil Pedon: 1-A** **Pedon 1-A was located in a field planted with millet in 1989**

**Series: Dantiandou**

| Horizon (depth) | ----pH---- | | Ca | Mg | K | Na | SB | CEC | H | Al | P | Fe | C | OM | N | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_2O$ | KCL | -------------------- Meq/100g | | | | | | | -------------------- | ppm | -------- % | | | ---------- | C/N |
| Ap1 (0-3cm) | 6.3 | 4.8 | 1.10 | 0.05 | 0.05 | 0.03 | 1.23 | 0.85 | 0.06 | ---- | 3.7 | 1.03 | 0.08 | 0.13 | 0.010 | 8.0 |
| Ap2 (3-7cm) | 6.0 | 4.4 | 0.80 | 0.03 | 0.06 | 0.03 | 0.92 | 0.84 | 0.11 | 0.02 | 3.7 | 1.33 | 0.07 | 0.12 | 0.010 | 7.0 |
| A3 (7-20cm) | 5.3 | 3.9 | 0.40 | 0.09 | 0.04 | 0.02 | 0.55 | 1.24 | 0.48 | 0.25 | 2.4 | 0.86 | 0.10 | 0.17 | 0.025 | 4.0 |
| A/B(20-36cm) | 5.2 | 3.9 | 0.33 | 0.07 | 0.02 | 0.01 | 0.43 | 1.11 | 0.59 | 0.45 | 1.1 | 1.44 | 0.07 | 0.12 | 0.008 | 8.8 |
| Bt1(36-52cm) | 5.0 | 4.0 | 0.38 | 0.07 | 0.01 | 0.01 | 0.47 | 1.14 | 0.53 | 0.40 | 0.8 | 1.56 | 0.06 | 0.10 | 0.007 | 8.6 |
| Bt2(52-73cm) | 5.1 | 4.0 | 0.30 | 0.07 | 0.01 | 0.01 | 0.39 | 0.95 | 0.53 | 0.42 | 0.8 | 1.68 | 0.05 | 0.09 | 0.008 | 6.3 |
| Bt3(73-93cm) | 5.1 | 4.0 | 0.35 | 0.08 | 0.02 | 0.01 | 0.46 | 1.06 | 0.48 | 0.35 | 0.1 | 1.66 | 0.03 | 0.05 | 0.007 | 4.3 |
| Bt4(93-130cm) | 5.0 | 4.0 | 0.50 | 0.19 | 0.01 | 0.01 | 0.71 | 1.37 | 0.50 | 0.35 | 0.6 | 2.30 | 0.07 | 0.11 | 0.006 | 11.7 |
| Bt5(130-170cm) | 5.2 | 4.1 | 0.42 | 0.15 | 0.01 | 0.01 | 0.59 | 1.01 | 0.34 | 0.19 | 0.9 | 1.78 | 0.03 | 0.04 | 0.004 | 7.5 |
| Bt6(170-200cm) | 5.2 | 4.2 | 0.40 | 0.26 | 0.01 | 0.02 | 0.69 | 0.95 | 0.18 | 0.07 | 0.6 | 1.79 | 0.03 | 0.04 | 0.010 | 3.0 |

pH = measured at 1 to 2.5 soil to solution ratio;
SB = sum of exchangeable bases (Ca, Mg, K, Na) in meq/100g soil;
CEC = cation exchange capacity determined by 1M ammonium acetate displacement at pH 7.0 with ethanol washing;
H = total exchange acidity (H + Al) by 1M KC1;
Al = 1M KCl exchangeable aluminum;
P = Bray No. 1 extractable phosphorus in ppm;
Fe = % total free iron oxides;
C = % organic carbon;
OM = % organic matter;
N = % total nitrogen.

**Soil Pedon: 2-A Pedon 2-A was located in a fallow area**
**Series: Gangani Kirey**

| | ----pH---- | | Ca | Mg | K | Na | SB | CEC | H | Al | P | Fe | C | OM | N | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horizon (depth) | $H_2O$ | KCL | -------------------- Meq/100g | | | | | | | -------------------- | ppm | -------- % | | ----------- | | C/N |
| A1 (0-8cm) | 5.6 | 4.3 | 0.68 | 0.21 | 0.04 | 0.02 | 0.95 | 1.13 | 0.22 | 0.05 | 2.2 | 1.42 | 0.14 | 0.24 | 0.14 | 10.0 |
| 2A (8-17cm) | 5.1 | 3.7 | 0.48 | 0.17 | 0.02 | 0.02 | 0.69 | 2.31 | 0.83 | 0.62 | 2.4 | 1.75 | 0.22 | 0.37 | 0.020 | 11.0 |
| 2A/B(17-27cm) | 5.1 | 3.7 | 0.38 | 0.11 | 0.03 | 0.02 | 0.54 | 2.55 | 1.16 | 0.91 | 1.2 | 2.38 | 0.19 | 0.33 | 0.017 | 11.2 |
| 2Bt1(27-35cm) | 5.0 | 3.8 | 0.35 | 0.14 | 0.02 | 0.02 | 0.53 | 2.52 | 1.16 | 0.95 | 0.9 | 2.50 | 0.17 | 0.29 | 0.018 | 9.4 |
| 2Bt2(35-53cm) | 5.1 | 3.8 | 0.30 | 0.13 | 0.02 | 0.02 | 0.47 | 2.41 | 1.07 | 0.85 | 0.8 | 2.75 | 0.15 | 0.25 | 0.021 | 7.1 |

**Soil Pedon: 3-BPedon 3-B was located in a fallow area**
**Series: Bokotchill**

| | ----pH---- | | Ca | Mg | K | Na | SB | CEC | H | Al | P | Fe | C | OM | N | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horizon (depth) | $H_2O$ | KCL | -------------------- Meq/100g | | | | | | | -------------------- | ppm | -------- % | | ----------- | | C/N |
| A1(0-5cm) | 5.5 | 4.0 | 0.35 | 0.12 | 0.02 | 0.04 | 0.53 | 1.20 | 0.29 | 0.16 | 2.3 | 0.88 | 0.14 | 0.24 | 0.011 | 12.7 |
| A2(13-30m) | 5.2 | 3.8 | 0.13 | 0.05 | 0.02 | 0.04 | 0.24 | 1.47 | 0.65 | 0.49 | 1.6 | 1.14 | 0.12 | 0.20 | 0.008 | 15.0 |
| A/B(30-49cm) | 4.8 | 3.8 | 0.10 | 0.06 | 0.02 | 0.05 | 0.23 | 1.49 | 0.74 | 0.57 | 1.6 | 1.31 | 0.11 | 0.18 | 0.008 | 13.8 |
| Bt1(49-74cm) | 5.1 | 3.9 | 0.15 | 0.06 | 0.02 | 0.01 | 0.24 | 1.39 | 0.68 | 0.46 | 1.8 | ---- | 0.08 | 0.13 | 0.007 | 11.4 |
| Bt2(74-95cm) | 5.0 | 3.9 | 0.20 | 0.07 | 0.03 | 0.01 | 0.31 | 1.29 | 0.60 | 0.38 | 1.5 | 1.51 | 0.05 | 0.09 | 0.007 | 7.1 |
| Bt3(95-144cm) | 4.9 | 3.9 | ---- | ---- | ---- | ---- | ---- | 1.20 | 0.42 | 0.28 | 1.6 | 1.43 | 0.04 | 0.07 | 0.006 | 6.7 |
| B/C(130-170cm) | 5.2 | 4.1 | 0.42 | 0.15 | 0.01 | 0.01 | 0.59 | 1.01 | 0.34 | 0.19 | 0.9 | 1.78 | 0.03 | 0.04 | 0.004 | 7.5 |
| C(182-200cm) | 5.2 | 4.1 | 0.43 | 0.22 | 0.02 | 0.01 | 0.68 | 1.18 | 0.26 | 0.15 | 1.6 | 1.38 | 0.02 | 0.04 | 0.010 | 2.0 |

**Soil Pedon: 4-B Pedon 4-B was located in a fallow area**
**Series: Falanke**

| Horizon (depth) | ----pH---- $H_2O$ | KCL | Ca | Mg | K | Na | SB | CEC | H | Al | P | Fe | C | OM | N | C/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ---------------------- | | | Meq/100g | | | | ---------------------- | ppm | -------- | % | ----------- | | |
| A1(0-4cm) | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | --- | --- | --- | ---- | ---- | --- |
| A2(4-15m) | 5.3 | 3.9 | 0.35 | 0.13 | 0.03 | 0.01 | 0.52 | 1.61 | 0.61 | 0.42 | 2.2 | 0.92 | 0.05 | 0.08 | 0.007 | 7.1 |
| A/B(15-31cm) | 5.1 | 3.8 | 0.38 | 0.17 | 0.03 | 0.03 | 0.61 | 2.04 | 0.74 | 0.51 | 1.4 | 0.32 | 0.13 | 0.23 | 0.011 | 11.8 |
| Bt1(31-51cm) | 5.3 | 3.9 | 0.28 | 0.09 | 0.02 | 0.01 | 0.40 | 1.54 | 0.66 | 0.45 | 1.2 | 1.15 | 0.09 | 0.15 | 0.010 | 9.0 |
| Bt2(51-79cm) | 5.4 | 3.9 | 0.33 | 0.10 | 0.02 | 0.03 | 0.48 | .97 | 0.60 | 0.41 | 1.0 | 1.27 | 0.08 | 0.14 | 0.008 | 8.0 |
| Bt3(79-105cm) | 5.2 | 3.9 | ---- | ---- | ---- | ---- | ---- | 1.00 | 0.58 | 0.43 | 1.5 | 1.36 | 0.05 | 0.09 | 0.008 | 6.3 |
| B/C(105-126cm) | 5.6 | 3.9 | 0.25 | 0.09 | 0.02 | 0.03 | 0.39 | 1.41 | 0.50 | 0.32 | 1.4 | 1.56 | 0.04 | 0.07 | 0.008 | 5.0 |
| C1(126-164cm) | 5.8 | 4.0 | 0.23 | 0.11 | 0.03 | 0.03 | 0.40 | 1.23 | 0.46 | 0.32 | 1.2 | 1.78 | 0.02 | 0.04 | 0.007 | 2.9 |
| C2(164-200cm) | 5.8 | 4.0 | 0.30 | 0.12 | 0.03 | 0.03 | 0.48 | 1.18 | 0.40 | 0.26 | 1.0 | 2.01 | 0.04 | 0.06 | 0.006 | 6.7 |

**Soil Pedon: 5-B Pedon 5-B was located in a fallow area**
**Series: Tondo Kakasia**

| | ----pH---- | | Ca | Mg | K | Na | SB | CEC | H | Al | P | Fe | C | OM | N | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horizon (depth) | $H_2O$ | KCL | ---------------------- | | | Meq/100g ---- | | ---------------- | | | ppm | -------- % | | ----------- | | C/N |
| A(0-4cm) | 5.9 | 4.4 | 0.70 | 0.30 | 0.06 | 0.03 | 1.09 | 1.89 | 0.36 | 0.08 | 2.8 | 1.35 | 0.11 | 0.18 | 0.018 | 6.1 |
| A2(4-19cm) | 5.3 | 3.8 | 0.23 | 0.10 | 0.09 | 0.04 | 0.46 | 1.70 | 0.33 | 0.18 | 1.5 | 1.49 | 0.30 | 0.51 | 0.022 | 13.6 |
| A/B(19-35cm) | 5.2 | 3.7 | 0.035 | 0.13 | 0.04 | 0.04 | 0.56 | 1.93 | 0.77 | 0.50 | 0.7 | 1.75 | 0.13 | 0.23 | 0.024 | 5.4 |
| Bt1(35-47cm) | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | --- | --- | --- | ---- | ---- | --- |
| Bt2(47-64cm) | 5.5 | 3.8 | 0.13 | 0.16 | 0.03 | 0.04 | 0.36 | 1.82 | 0.70 | 0.42 | 0.1 | 1.52 | 0.05 | 0.09 | 0.025 | 2.0 |
| Bt3(64-87cm) | 5.4 | 3.8 | 0.15 | 0.24 | 0.02 | 0.04 | 0.45 | ----- | 0.64 | 0.35 | 0.3 | 1.39 | 0.04 | 0.07 | 0.008 | 5.0 |
| B/C(87-119cm) | --- | --- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | --- | --- | --- | ---- | ---- | --- |
| C1(119-145cm) | 5.2 | 3.8 | 0.25 | 0.34 | 0.03 | 0.04 | 0.66 | ---- | 0.36 | 0.17 | 0.1 | 1.35 | 0.02 | 0.03 | 0.007 | 2.9 |
| C2(145-200cm) | 5.3 | 4.0 | 0.43 | 0.36 | 0.04 | 0.04 | 0.87 | ---- | 0.29 | 0.12 | trace | 1.55 | 0.02 | 0.03 | 0.007 | 2.9 |

**Soil Pedon: 3-A Pedon 3-A was located in a field planted with millet in 1989**
**Series: Hamdallaye**

| Horizon (depth) | pH $H_2O$ | pH KCL | Ca | Mg | K | Na | SB | CEC | H | Al | P | Fe | C | OM | N | C/N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Meq/100g | | | | | | | | ppm | % | | | | |
| A1(0-7cm) | 5.2 | 4.0 | 0.35 | 0.12 | 0.02 | 0.03 | 0.52 | 1.19 | 0.46 | 0.30 | 1.9 | 1.22 | 0.08 | 0.14 | 0.008 | 10.0 |
| A2(7-24cm) | 5.1 | 3.9 | 0.28 | 0.11 | 0.01 | 0.02 | 0.42 | 1.33 | 0.64 | 0.30 | 1.0 | 1.42 | 0.08 | 0.14 | 0.011 | 7.3 |
| A/B(24-50cm) | 5.0 | 3.9 | 0.23 | 0.09 | 0.02 | 0.05 | 0.39 | 1.29 | 0.63 | 0.48 | 0.8 | 1.57 | 0.07 | 0.11 | 0.006 | 11.7 |
| Bt1(50-102cm) | 5.1 | 4.0 | 0.03 | 0.14 | 0.01 | 0.02 | 0.47 | 1.19 | 0.52 | 0.38 | 0.8 | 1.75 | 0.05 | 0.09 | 0.010 | 5.0 |
| Bt2(102-148cm) | 4.9 | 4.0 | 0.60 | 0.05 | 0.02 | 0.03 | 0.70 | 1.23 | 0.36 | 0.25 | 0.4 | 1.72 | 0.03 | 0.05 | 0.011 | 2.7 |
| Bt3(148-179cm) | 5.2 | 4.0 | 0.25 | 0.17 | 0.01 | 0.02 | 0.45 | 1.13 | 0.39 | 0.27 | 0.4 | 1.59 | 0.02 | 0.03 | 0.013 | 1.5 |
| Bt4(179-200cm) | 5.3 | 4.0 | 0.25 | 0.27 | 0.01 | 0.04 | 0.57 | 1.09 | 0.36 | 0.22 | 0.4 | 1.60 | 0.03 | 0.04 | 0.010 | 3.0 |

**Soil Pedon: 5-IN This pedon was located within a vegetated**
**Series: Plateau soilarea.**

| Horizon (depth) | Ca | Mg | K | Na | H | Al | P(ppm) |
|---|---|---|---|---|---|---|---|
| | ---------------- | Meq/100g | ---------------- | | | | |
| A1 (0-7cm) | 1.44 | 0.89 | 0.27 | 0.05 | 0.37 | 0.18 | 7.53 |
| A2 (7-15cm) | 0.94 | 0.63 | 0.17 | 0.05 | 1.36 | 0.85 | 5.43 |
| Bt1 (15-34 cm) | 0.79 | 0.60 | 0.26 | 0.01 | 2.14 | 1.50 | 2.47 |
| Bt2 (34-60 cm) | 0.89 | 0.65 | 0.32 | 0.01 | 2.35 | 1.67 | 1.28 |

**Soil Pedon: 5-OUT This pedon was located outside of**
**Series: Plateau soil, vegetated areas.**

| Horizon (depth) | Ca | Mg | K | Na | H | Al |
|---|---|---|---|---|---|---|
| | ---------------- | | Meq/100g | | ---------------- | |
| A1 (0-4 cm) | 1.0 | 0.42 | 0.31 | 0.09 | 0.26 | 0.19 |
| A2 (4-18 cm) | 0.67 | 0.41 | 0.23 | 0.13 | 0.90 | 0.56 |
| Bt1 (18-35 cm) | 0.32 | 0.40 | 0.09 | 0.14 | 1.84 | 1.35 |
| Bt2 (35-54 cm) | 0.26 | 0.53 | 0.12 | 0.17 | 2.25 | 1.67 |

# APPENDIX C

## SOIL PHYSICAL PROPERTIES

* All particle sizes expressed in terms of percent.

**Soil Pedon: 5-In**
**Series: Plateau soil,**
**Vegetated area**

| Horizon (depth) | Clay | Silt fine | Silt coarse | Sand fine | Sand coarse |
|---|---|---|---|---|---|
| A1 (0-8 cm) | 14.5 | 8.8 | 10.6 | 35.3 | 30.7 |
| A2 (8-16 cm) | 20.1 | 8.5 | 6.4 | 34.4 | 30.5 |
| Bt1 (16-34 cm) | 1.7 | 8.3 | 7.7 | 26.8 | 25.5 |
| Bt2 (34-60 cm) | 40.1 | 9.2 | 6.4 | 22.9 | 21.5 |
| > 60 cm Laterite | | | | | |

**Soil Pedon: 5-Out**
**Series: Plateau soil,**
**Unvegetated area**

| Horizon (depth) | Clay | Silt fine | Silt coarse | Sand fine | Sand coarse |
|---|---|---|---|---|---|
| A1 (0-4 cm) | 12.3 | 8.3 | 8.1 | 38.6 | 32.7 |
| A2 (4-18 cm) | 17.4 | 6.1 | 5.3 | 36.7 | 34.6 |
| B (18-35 cm) | 29.8 | 6.0 | 4.4 | 27.4 | 32.3 |
| BC (35-54 cm) | 40.1 | 8.0 | 6.7 | 22.5 | 22.6 |
| > 54 cm Laterite | | | | | |

**Soil Pedon: 5-B**
**Series: Tondo Kakasia**

| Horizon (depth) | Clay | Silt fine | Silt coarse | Sand fine | Sand coarse | Water Retention pF 2.5 | Water Retention pF 4.2 |
|---|---|---|---|---|---|---|---|
| A (0-4 cm) | 4.1 | 2.8 | 4.4 | 52.8 | 35.8 | 3.1 | 1.6 |
| A2 (4-19 cm) | 6.9 | 1.9 | 3.3 | 53.5 | 34.3 | 3.3 | 1.6 |
| AB (19-35 cm) | 10.5 | 1.6 | 1.5 | 50.6 | 35.7 | 3.9 | 2.0 |
| Bt2 (47-64 cm) | 10.7 | 0.7 | 2.2 | 49.1 | 37.3 | 3.6 | 1.8 |
| Bt3 (64-87 cm) | 9.5 | 0.9 | 1.0 | 52.3 | 36.3 | 3.3 | 1.6 |
| C1 (119-145 cm) | 9.1 | 0.9 | 2.0 | 56.8 | 31.1 | 3.2 | 1.6 |
| C2 (145-200 cm) | 10.9 | 1.0 | 2.0 | 51.5 | 34.5 | 4.0 | 2.0 |

**Soil Pedon: 1-A**
**Series: Dantiandou**

| Horizon (depth) | Clay | Silt | | Sand | | Water Retention | |
|---|---|---|---|---|---|---|---|
| | | fine | coarse | fine | coarse | pF 2.5 | pF 4.2 |
| Ap1 (0-3 cm) | 2.1 | 1.0 | 1.8 | 36.4 | 58.5 | 2.2 | 0.7 |
| Ap2 (3-7 cm) | 2.0 | 1.0 | 1.7 | 37.1 | 58.2 | 2.0 | 0.6 |
| A (7-20 cm) | 4.2 | 1.1 | 1.5 | 50.6 | 42.5 | 2.3 | 1.4 |
| A/B (20-36 cm) | 5.3 | 1.1 | 1.7 | 49.4 | 42.5 | 2.9 | 1.4 |
| Bt1 (36-52 cm) | 6.2 | 0.8 | 1.5 | 52.0 | 39.4 | 2.7 | 1.5 |
| Bt2 (52-73 cm) | 6.2 | 1.3 | 1.5 | 48.0 | 42.9 | 3.3 | 1.5 |
| Bt3 (73-93 cm) | 6.9 | 1.1 | 1.5 | 47.1 | 43.4 | 3.6 | 1.8 |
| Bt4 (93-130 cm) | 7.5 | 0.8 | 2.1 | 53.4 | 36.3 | 4.1 | 2.0 |
| Bt5 (130-170 cm) | 7.3 | 1.2 | 1.5 | 47.8 | 42.2 | 3.4 | 1.9 |
| Bt6 (170-200 cm) | 7.1 | 1.0 | 1.1 | 40.1 | 50.8 | 3.3 | 1.9 |

**Soil Pedon: 3-A**
**Series: Hamdallaye**

| Horizon (depth) | Clay | Silt fine | Silt coarse | Sand fine | Sand coarse | Water Retention pF 2.5 | Water Retention pF 4.2 |
|---|---|---|---|---|---|---|---|
| A1 (0-7 cm) | 4.0 | 1.2 | 1.1 | 41.7 | 52.1 | 2.6 | 1.1 |
| A2 (7-24 cm) | 5.9 | 0.7 | 1.5 | 45.4 | 46.4 | 3.0 | 1.4 |
| A/B (24-50 cm) | 6.9 | 0.7 | 1.2 | 38.9 | 52.2 | 2.9 | 1.5 |
| Bt1 (50-102 cm) | 8.6 | 0.6 | 1.2 | 39.8 | 49.7 | 3.5 | 2.0 |
| Bt2 (102-148 cm) | 7.6 | 0.7 | 1.4 | 44.3 | 45.9 | 3.1 | 1.8 |
| Bt3 (148-179 cm) | 6.9 | 1.0 | 1.8 | 46.7 | 43.6 | 3.0 | 1.7 |
| Bt4 (179-200 cm) | 6.4 | 0.8 | 1.4 | 45.0 | 46.4 | 3.1 | 1.5 |

**Soil Pedon: 2-A**
**Series: Gangani Kirey**

| Horizon (depth) | Clay | Silt fine | Silt coarse | Sand fine | Sand coarse | Water Retention pF 2.5 | Water Retention pF 4.2 |
|---|---|---|---|---|---|---|---|
| A1 (0-8 cm) | 3.3 | 1.4 | 1.3 | 40.8 | 53.2 | 2.6 | 1.0 |
| 2A (8-17 cm) | 6.9 | 4.5 | 2.8 | 38.2 | 47.6 | 4.9 | 2.1 |
| 2A/B (17-27 cm) | 11.9 | 3.6 | 2.4 | 36.1 | 46.0 | 5.8 | 3.1 |
| 2Bt1 (27-35 cm) | 16.1 | 3.5 | 2.7 | 35.2 | 42.5 | 6.5 | 3.7 |
| 2Bt2 (35-53 cm) | 14.8 | 3.0 | 2.6 | 31.0 | 48.6 | 6.3 | 3.6 |

**Soil Pedon: 3-B**
**Series: Bokotchili**

| Horizon (depth) | Clay | Silt fine | Silt coarse | Sand fine | Sand coarse | Water Retention pF 2.5 | Water Retention pF 4.2 |
|---|---|---|---|---|---|---|---|
| A1 (0-13 cm) | 3.2 | 0.8 | 1.9 | 44.8 | 49.3 | 2.2 | 1.2 |
| A2 (13-30 cm) | 4.9 | 0.9 | 1.1 | 43.6 | 49.6 | 2.5 | 1.4 |
| A/B (30-49 cm) | 6.3 | 0.8 | 0.8 | 44.7 | 47.3 | 2.7 | 1.7 |
| Bt1 (49-74 cm) | 6.9 | 0.6 | 1.2 | 42.3 | 49.0 | 2.6 | 1.8 |
| Bt2 (74-95 cm) | 7.4 | 0.8 | 0.7 | 35.0 | 56.1 | 3.1 | 2.1 |
| Bt3 (95-144 cm) | 7.7 | 0.9 | 0.8 | 37.9 | 52.7 | 3.6 | 2.2 |
| B/C (144-182 cm) | 7.7 | 0.8 | 1.2 | 40.8 | 49.5 | 3.1 | 2.1 |
| C1 (182-200 cm) | 6.7 | 0.7 | 0.9 | 38.3 | 53.3 | 3.2 | 1.8 |

**Soil Pedon: 4-B**
**Series: Falanke**

| Horizon (depth) | Clay | Silt | | Sand | | Water Retention | |
|---|---|---|---|---|---|---|---|
| | | fine | coarse | fine | coarse | pF 2.5 | pF 4.2 |
| A1 (0-4 cm) | ---- | ----- | ----- | ------ | ----- | --- | --- |
| A2 (4-15 cm) | 7.4 | 1.4 | 1.2 | 46.1 | 43.9 | 3.8 | 2.2 |
| A/B (15-31 cm) | 11.0 | 0.9 | 1.1 | 39.6 | 47.5 | 4.4 | 2.9 |
| Bt1 (31-51 cm) | 9.2 | 1.3 | 0.6 | 40.5 | 48.3 | 3.5 | 2.5 |
| Bt2 (51-79 cm) | 9.0 | 0.6 | 1.5 | 37.4 | 51.4 | 3.7 | 2.5 |
| Bt3 (79-105 cm) | 9.1 | 0.7 | 1.1 | 40.6 | 48.5 | 3.7 | 2.7 |
| B/C (105-126 cm) | 8.9 | 0.9 | 1.5 | 45.2 | 43.5 | 3.6 | 2.3 |
| C1 (126-164 cm) | 8.6 | 0.9 | 1.4 | 46.5 | 42.8 | 3.5 | 2.3 |
| C2 (164-200 cm) | 8.2 | 0.8 | 1.2 | 41.7 | 48.1 | 3.5 | 2.2 |

# APPENDIX D

## Surface areas of LMU and mapping units

| | | Surface area | | |
|---|---|---|---|---|
| | | map unit | | LMU |
| LMU | Symbol | m2 | ha | ha |
| I | Lp | 395,271 | 39.52 | 42.7 |
| | ToA | 31,955 | 3.20 | |
| II | To | 200,060 | 20.01 | 20.0 |
| III | Da | 277,730 | 27.77 | 378.7 |
| | Ha | 1,973,981 | 197.40 | |
| | Bo | 943,072 | 94.31 | |
| | Fa | 580,394 | 58.04 | |
| | FaB | 12,128 | 1.22 | |
| IV | Ga | 187,769 | 18.78 | 23.0 |
| | HaB, HaC | 42,369 | 4.24 | |
| V | ToB | 52,881 | 5.29 | 31.1 |
| | DaA | 52,404 | 5.24 | |
| | HaA | 164,336 | 16.43 | |
| | FaA | 25,918 | 2.59 | |
| | BoA | 15,393 | 1.54 | |
| TOTAL | | | | 495.5 |