Inland Valleys in West Africa:
An Agro-Ecological Characterization
of Rice-Growing Environments

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(Editors)

Introduction

In 1981, the International Institute of Tropical Agriculture/IITA at Ibadan, Nigeria, submitted a proposal for the Wetland Utilization Research Project/WURP to The Netherlands' Directorate General for International Cooperation/*DGIS*, with a request for technical and financial assistance. The main objective of the Project was to develop the inland valley bottoms, which occur, characteristically and abundantly, in the West African landscape, for wetland rice cultivation. The first phase of this Project consisted of an inventory of existing information in order to identify the extent and categories of wetlands, including the valley bottoms, in West Africa and to assess their capabilities and constraints for rice-based smallholder farming systems.

The collection and synthesis of the available information started in August 1982 in The Netherlands as a joint undertaking by the International Institute for Land Reclamation and Improvement/ILRI, the then Netherlands Soil Survey Institute/*STI-BOKA**, and the Royal Tropical Institute/*KIT*. ILRI had the overall responsibility of coordination (J. de Wolf). Contributions were made by P. Hekstra (Team Leader) on the climatological and hydrological aspects, by W. Andriesse on geology, geomorphology, and soils, by C.A. de Vries and G. Bus on the agro-socio-economic aspects, and by W. Linklaen Arriëns on water-borne diseases. The results of this inventory, covering the (humid) Equatorial Forest Zone and the (sub-humid) Guinea Savanna Zone of West Africa, and including all coastal countries from Guinea Bissau through Cameroon, came out in April 1983 as the WURP Report, which comprised four volumes, including one volume with five maps (Hekstra et al. 1983). This Report, however, has never been published officially and remained in a grey literature circuit, available only with difficulty to researchers outside The Netherlands.

In view of the great interest shown in the Report by many organizations and institutions, the continuing high topicality of increasing rice production in West Africa in the actual programs of national and international agricultural research institutes in the region, and the availability of new information, ILRI decided, in cooperation with the Winand Staring Centre/WSC, to officially publish, in its Publication series, an updated edition of the WURP Report. At the same time, in order to widen the geographic scope of the study, it was decided to include in its coverage the (semi-arid) Sudan Savanna Zone, north of the original inventory area.

The result of this update, as edited by P.N. Windmeijer and W. Andriesse, both of the Winand Staring Centre, is presented here. The information about the ecology of West Africa was compiled by Ms. L. Jansen (WSC). Drafts of (part of) the text were critically read by R. Oosterbaan (ILRI), E.M.A. Smaling (WSC), and O. Gordon (Land and Water Development Division, Sierra Leone). Special words of thanks go to the International Soil Reference and Information Centre/ISRIC, Wageningen, for the use of the library and cartographic collection.

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* In 1990, The Netherlands Soil Survey Institute merged with the Institute for Land and Water Management Research, the Department of the Environment of the Institute for Pesticide Research, and the Department of Landscape Planning of the Research Institute for Forestry and Landscape Planning, to form the new Winand Staring Centre for Integrated Land, Soil, and Water Research.

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1   Background, Area, and Subject of This Study

Over the last decades, the total agricultural production in West Africa has increased quite reasonably. In a large number of West African countries, however, a rapid growth in population, the prevalence of traditional farming systems, and increasing urban migration have caused per capita agricultural production to increase only slightly, or even to decrease. Domestic production that lags far behind the demand for a number of food crops has resulted in a strong increase in imports of these staples.

These general statements about the agricultural problems in West Africa are particularly valid for the production, consumption, and import of rice. Even though total rice production in West Africa has increased by about 75% over the last fifteen years, rice imports have increased a multiple thereof.

In an attempt to improve agricultural production in Africa, the Food and Agriculture Organization of the United Nations has identified four main problems that have to be addressed if programs for agricultural development are to be successful (FAO 1986):
- In West Africa, there is limited scope for the expansion of rain-fed cultivation. There are only limited reserves of good arable land relative to population growth. Large areas are only marginally suitable or are too dry for rain-fed agricultural production. If grazing and forest land requirements are taken into account, the situation is even more critical;
- Rural labour shortages are a significant constraint. These shortages are the result of the prevalence of traditional cropping systems employing manual labour only, low labour productivity, low rural incomes with subsequent rural-urban migration, low status of agricultural labour and, finally, women, who are responsible for many farming activities like weeding and harvesting, are spending more and more time on non-farming activities like collecting water and fuel;
- Although, in many places in West Africa, enough water is present to irrigate large areas, large-scale irrigation projects are not the solution for increased food production. Even in cases where both the need *and* the potential exist, irrigation may not be viable, financially. Modern irrigation development in Africa, with full water control, tends to cost two to three times as much as in India. With such costs, it is impossible to irrigate staple food crops and earn a satisfactory return on capital;
- Finally, it has been proposed that the 'green revolution' technology could be readily transferred to Africa. This is generally not correct. New varieties of rice and wheat that formed the basis of the green revolution in Asia yield well only if reliable rainfall or irrigation provide sufficient moisture. Large areas of West Africa suffer from highly unreliable rainfall while irrigation, as stated above, is generally too costly for staple food production.

In view of these considerations, inland valleys, which occur so abundantly in West Africa's undulating landscape, appear to have a high potential for the development of rice-based smallholder farming systems at village scale, without major inputs. Their favourable production potential, for rice, is mainly due to the specific hydrological

conditions prevailing in the valley bottoms where (ground)water is at or near the surface during most of the year or seasonally, depending on the climatological zone. In the transition between these valley bottoms and the adjacent uplands, lateral inflow of groundwater from the higher parts of the landscape effectively prolongs the growing period for crops.

Inland valleys are defined here as the upper parts of river drainage systems. Although, naturally, any valley occurs 'in-land', and the term inland valley implies a pleonasm, the name inland valley has been adopted in this study because of its widespread use in (anglophone) West Africa. It refers to the valleys, inland in respect to the main rivers and main tributaries, where river alluvial sedimentation processes are absent or imminent only: they do not yet have any distinct floodplain and levee system. In francophone West Africa, inland valleys are best known as *bassins versants*.

The concept of inland valleys as used in this study comprises the toposequence, or continuum, from the uplands to the valley bottom. A continuum is in itself a landscape concept describing an environment in which a diversity of ecosystems occur. The upland/inland swamp continuum refers to a sequence of land types and associated ecosystems located along the slopes of the local topography. The ecosystems vary from upland in the highest parts, through hydromorphic conditions lower down the slopes, to swampy in the valley bottoms. Soil and water key-parameters, determining the potential for (rice) cultivation, are closely related to the location on the toposequence.

Based on differences in morphology and flooding regime, two types of inland valleys can be distinguished:
− **Stream inland valleys,** which are defined here as the uppermost parts of the natural drainage systems. They have a centrally-located stream which is shallow and only up to a few metres wide, or it does not exist at all. Flooding of stream inland valleys is mainly the result of the accumulation of surface runoff and groundwater flow from the adjacent uplands and from rainfall (inflow flooding regime);
− **River inland valleys** are situated downstream of the stream inland valleys. They are wider, have a larger, and more distinct, water course and there is some floodplain development. The main source of flooding water is the river itself, overflowing its banks (overflow flooding regime).

This study is an inventory of the physical, biotic, agronomic, and socio-economic aspects of inland valleys in West Africa, and is aimed at their agro-ecological characterization for rice cultivation. As such, the present publication is an update of the inventory report of the Wetland Utilization Research Project/WURP (Hekstra et al. 1983).

Geographically, the WURP Report covered the area of West Africa with a growing period of 165 days or more. For this update, the inventory area was expanded to include the zone with a growing period of 90 days or more. It therefore now covers the (humid) Equatorial Forest Zone, the (semi-humid) Guinea Savanna Zone, and the (semi-arid) Sudan Savanna Zone. The extent of the inventory area is about 3.14 million km², and the following countries, or parts thereof, are covered: Senegal, The Gambia, Guinea Bissau, Guinea, Mali, Sierra Leone, Liberia, Ivory Coast, Burkina Faso, Ghana, Togo, Benin, Nigeria, Niger, and Cameroon (Figure 1.1).

In the inventory area, the diversity and complexity of (agro-)ecological systems is large. In view of the failure of green-revolution technology in Africa, an accurate char-
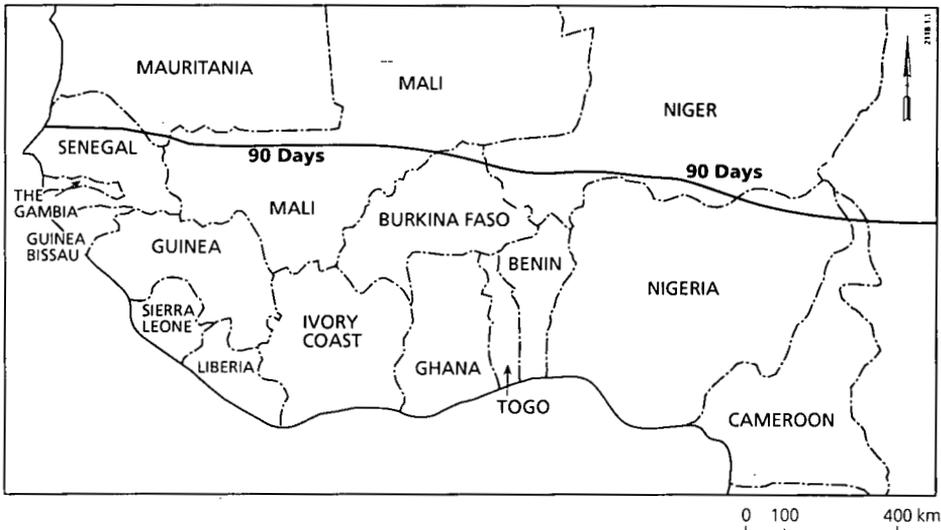
Figure 1.1 The inventory area, south of the 90-day growing period isoline in West Africa.

acterization of West Africa's rice-growing agro-ecosystems is necessary for the efficient planning and targetting of rice research in the region. In the long term, research thus directed should effectively help to increase the productivity of rice cropping systems in West Africa, and ultimately to obtain self-sufficiency.

In this book, the various environmental characteristics that determine the rice-growing environments in West Africa are described. Based on ecological, agronomic, and socio-economic data from secondary sources, this involves a description and grouping, in general, for the whole inventory area. Wherever additional data were available, more detailed descriptions of the inland valleys are given.

Chapter 2 outlines the physical environment of West Africa in terms of its climate and agro-ecological zones, geology and geomorphology, hydrology and drainage, and soils. Four major land regions are distinguished in the inventory area and these have been further differentiated into 27 sub-regions. Within the land regions, 3 major categories of wetlands occur, including the inland valleys. Their morphology, hydrology, and soils are described in specific sub-chapters. The physical characteristics are also shown in the Annexes 1, 2, 3 and 4.

Chapter 3 deals with the ecology of the inventory area. Here, the main characteristics of the forest and savanna ecology and their types of vegetation are described, as well as the uses of, and interventions in, the ecological systems of the inland valleys. Little specific information was found, however, about the ecology of inland valleys in West Africa.

For a long time, inland valleys were disregarded for agricultural uses, one reason for this being the prevalence of water-borne diseases. Chapter 4 discusses the main water-borne diseases of West Africa (malaria, bilharzia, sleeping sickness, river blindness, and guinea worm). Special attention is given to the possible impact of the cultivation of inland valleys on the distribution of these diseases.

Chapter 5 describes various farming systems, defined by the length of the fallow

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period and input levels of technical innovations, capital, and labour. It then discusses the different rice-cropping systems (pluvial, phreatic, and fluxial) along the toposequence of the inland valleys.

Demographic and socio-economic aspects of rice production in West Africa are the subject of Chapter 6. Population growth and its density and distribution are discussed as well as the production levels of rice, the imports, and the consumption. (National) self-sufficiency rates are calculated and assesments are made of investment costs and net returns at farm and national level.

Chapter 7 describes the main constraints to rice production in inland valleys and makes some recommendations on fertilizer use and water management in the valleys. This chapter also provides an overview of a number of existing valley-suitability classification systems. A general description of rice-growing environments in West Africa completes this chapter.

Chapter 8 comprises a summary of the information in the preceeding chapters. Additionally, this chapter contains an inventory of the actual state of rice research in West Africa, while also making some recommendations for further research.

2   The Physical Environment of West Africa

2.1   Climate

2.1.1   General

The climate of West Africa, or parts of it, has been described in many publications, quite often as a sectoral part of land inventories or general studies. It has been treated most extensively by Walter and Lieth (1960), Rodier (1964), Papadakis (1966), Landsberg and Griffith (1972), Ojo (1977, 1983, 1987), and most recently by Hayward and Oguntoyinbo (1987). The impact of the climate on vegetation and on agricultural production in West Africa has been described by Kowal and Kassam (1978), TAMS/CIEH (1976-1978), FAO (1978), Buddenhagen (1978), Lawson et al. (1979), and Lauer and Frankenberg (1981).

2.1.2   The Air Masses

The climate of West Africa is determined by the interaction of two air masses with distinctly different moisture characteristics:
- The maritime (humid) air mass originating from the Atlantic Ocean and associated with the south-western winds. This air mass is commonly referred to as the south-west monsoon;
- The continental (dry) air mass originating from the African continent and associated with the north-eastern Harmattan winds (trade winds).

The narrow, more or less east-west-orientated zone of discontinuity between these two air masses is called the Inter Tropical Convergence Zone/ITCZ. Other names used for the ITCZ in literature are the Inter Tropical Discontinuity Zone and the Inter Tropical Front.
   The seasonality of the West African climate results from the annual north-south migration of the ITCZ, which is due to the yearly positional changes of the earth in relation to the sun. Figure 2.1 shows the movement of the ITCZ along 3°E (Kandi, northern Benin) in 1957. The ITCZ has its most northerly position in August and its southernmost position in January. During its migration, however, it shows clear fluctuations.
   In connection with the position of the ITCZ, at least four, and sometimes five, zones with distinctive weather, paralleling the ITCZ, are experienced over much of West Africa. It is their passage across the region that determines the different seasons. These different zones are (Hayward and Oguntoyinbo 1987; see Figure 2.2):
- **Zone A**, which lies north of the ITCZ. Its weather is characterized by little clouds, dry air, east-northeasterly winds, and low rainfall. This Zone has a large diurnal temperature range: day temperatures are 35 to 40°C, whereas the nights range from 18 to 24°C;
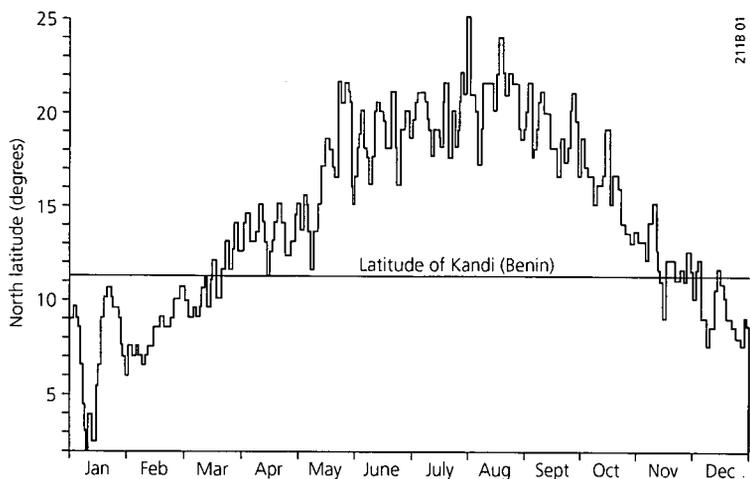
Figure 2.1 Movement of the Inter Tropical Convergence Zone along 3°E longitude in 1957 (source: Hayward and Oguntoyinbo 1987).
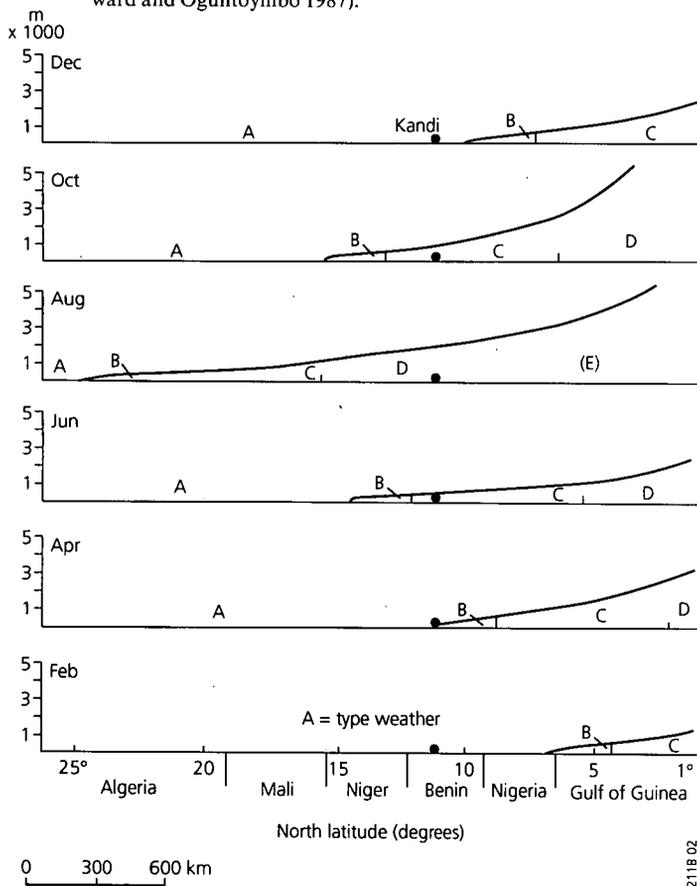
Figure 2.2 Location of the Inter Tropical Convergence Zone in West Africa with the different weather zones along 3°E longitude (source: Hayward and Oguntoyinbo 1987)

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– **Zone B**, which occurs south of the ITCZ over some 320 km. Weather conditions are mainly rainless but humid. Isolated thunderstorms can occur in the late afternoon or evening. Cloud development is restricted;
– **Zone C**, which extends south of Zone B in a belt about 800 km wide, north to south. The humidity is as in Zone B, but daytime convectional activity is pronounced. Local thunderstorms and westward-moving line squalls are prominent. Rainfall occurs in heavy showers;
– **Zone D**, which occurs south of Zone C for a further 300 km. The humidity is high and rain is an almost daily phenomenon. Showers commonly last for five to six hours, but sometimes they persist all day. Skies are generally cloudy and overcast, but on most days a few hours of sunshine may still be recorded. Day temperatures are 24 to 26 °C; the nights are 3 to 6 °C cooler;
– **Zone E**, which lies south of Zone D. The weather conditions are much less rainy than in Zone D, although the cloud cover remains extensive. Temperature and humidity are similar to those in Zone D. This Zone affects only the southernmost coastal areas in July and August.

The annual migration of the ITCZ causes a more or less zonal pattern of the different climatic parameters in West Africa. Also, the values of these parameters change, in general, more strongly in the north-south direction than in that of the east-west.

The following sections will discuss the main climatic parameters: sunshine and solar radiation, temperature, precipitation, humidity, and evapotranspiration.

2.1.3   The Climatic Parameters

Sunshine and Solar Radiation
The amount of incoming radiation is a function of the number of hours of actual sunshine. The latter varies with latitude, season, and cloudiness. Cloudiness, in particular, is strongly related to the position of the ITCZ.

In Figure 2.3, the distribution of mean daily hours of sunshine in West Africa is given for four different months. The figure is based on data from 54 stations.

There is a clear regional differentiation in daily sunshine, the coastal area being much less sunny than the Sahel and Sahara margins. The greatest contrast occurs in August. The gradation from south to north in West Africa is not regular. A well-known exceptional area is the so-called Togo Gap in southeast Ghana, southern Togo, and Benin. Here, at any point in time, there is more sunshine than in the surrounding areas. The least sunny parts of West Africa are southern Sierra Leone, western Liberia, southern Nigeria, western Cameroon, and central Ivory Coast-Ghana.

The net radiation (i.e. the balance of incoming and outgoing radiation) is shown in Figure 2.4. This balance is positive throughout the year and ranges between 65 and 100 Kcal/cm². The net radiation is lowest in the coastal regions, mainly as a result of fewer sunshine hours. In spite of the many hours of sunshine in the Sahara, the net radiation there is only slightly higher than in the coastal areas because of the high outgoing radiation during night time. The net radiation is highest, however, in between these zones.
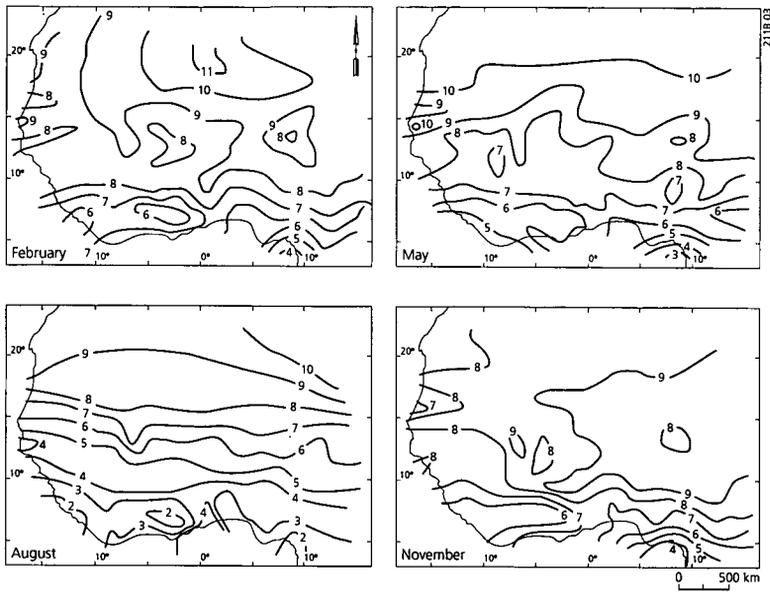
Figure 2.3 Mean daily hours of sunshine for February, May, August, and November in West Africa (source: Hayward and Oguntoyinbo 1987)
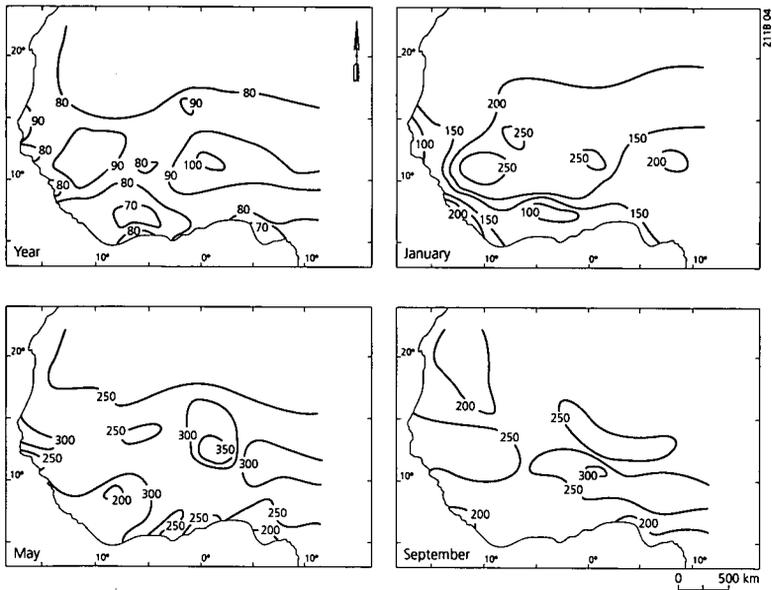
Figure 2.4 Net radiation in West Africa in Kcal/cm^2 per year, and in cal/cm^2 per day for January, May, and September (source: Ojo 1977)

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Temperature

The distribution of the mean daily temperature in West Africa is given in Figure 2.5 for four different months. This figure is based on data from 128 stations.

January shows a clear decline in temperature from the south to the north. The low temperatures in the north (Sahara) reflect the very low night temperatures that occur there because of the high outgoing radiation and the relatively low day temperatures during that month. This temperature distribution is associated with the Harmattan winds, the influence of which decreases in southerly direction. The smooth general pattern of parallel isotherms is disrupted by the local influence of altitude (e.g. in the Fouta Jallon in Guinea and on the Jos Plateau in Nigeria).

In April, the mean daily temperature is higher than in January because of the more northern position of the sun. From January to April, the temperature rises more strongly in the north than in the south. In August, when the marine influence is highest and many clouds are present, the temperature in the southern part of West Africa is relatively low. The highest temperatures in this month occur in the north.
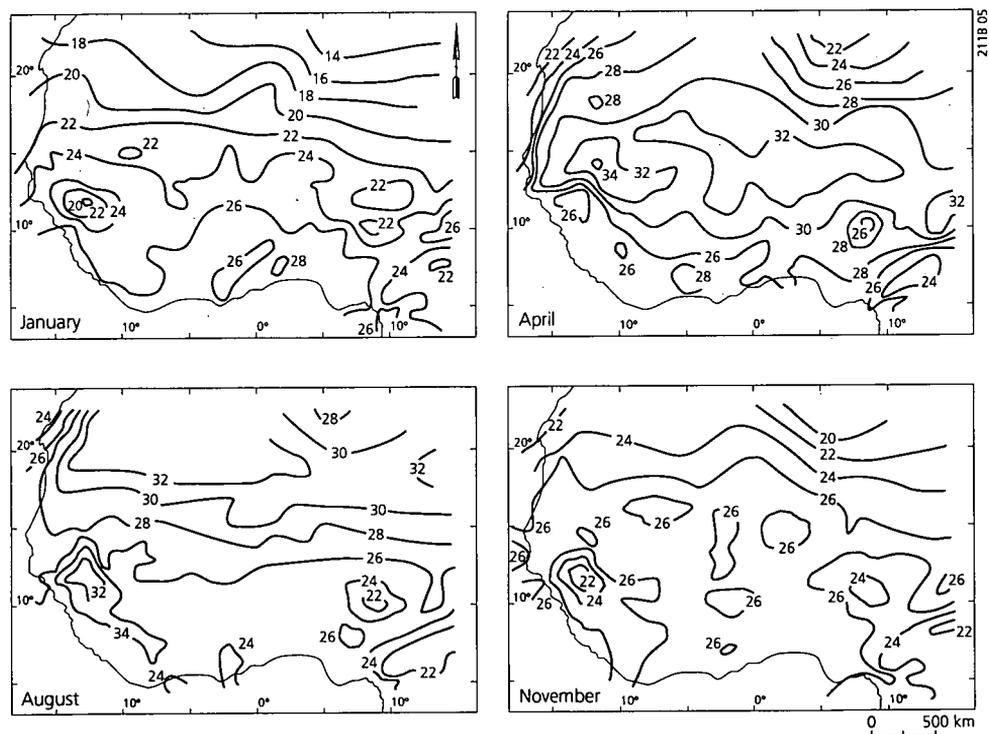
Figure 2.5 Mean monthly temperatures (°C) for January, April, August, and November in West Africa (source: Hayward and Oguntoyinbo 1987)

From an agricultural point of view, besides the mean daily temperature, the differences between the daily maximum and minimum temperatures are of great importance. These are shown in Figure 2.6. The lowest values are recorded along the south coast,

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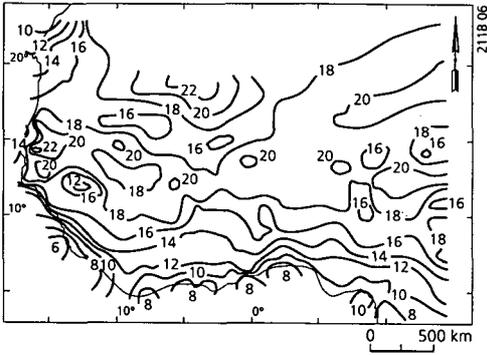
Figure 2.6 Differences between mean daily maximum and minimum temperatures (°C) in West Africa (source: Hayward and Oguntoyinbo 1987)

where sea surface temperatures are high throughout the year and direct onshore winds blow from a warm ocean. The highest values occur in northern Mali.

Precipitation
The geographic distribution of rainfall in West Africa, like the other climatic parameters, is zonal. The mean annual rainfall distribution is shown on the map of Annex 2. In Figure 2.7, mean monthly precipitation of January and August is given in relation to the position of the ITCZ. This figure is based on data from 144 stations.

The relation between the mean annual precipitation and the geographic position (latitude) is approximately hyperbolic (Figure 2.8). There are some exceptions, however. In Liberia, Sierra Leone, Guinea Bissau, and southwest Guinea (Group I in Figure 2.8), rainfall is relatively high (i.e. more than 2,000 mm per year) with respect to the latitude, whereas in the Togo Gap (southeast Ghana, Togo, and Benin: Group II in Figure 2.8), mean annual precipitation is relatively low. The latter is mainly due
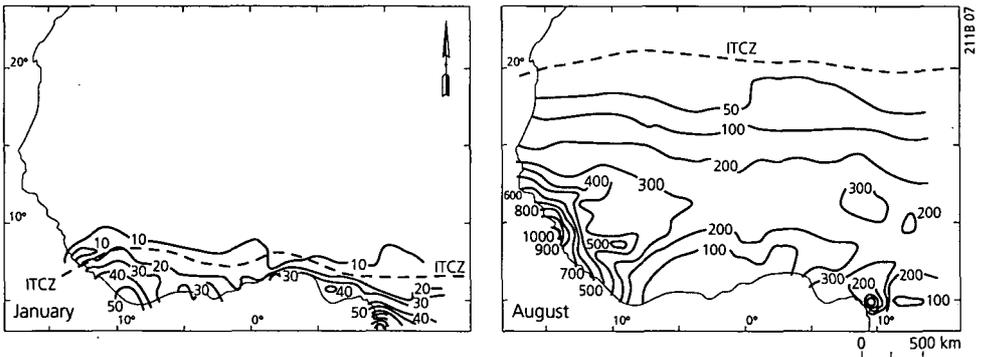
Figure 2.7 Mean precipitation (mm) and position of ITCZ for January and August in West Africa (source: Hayward and Oguntoyinbo 1987)

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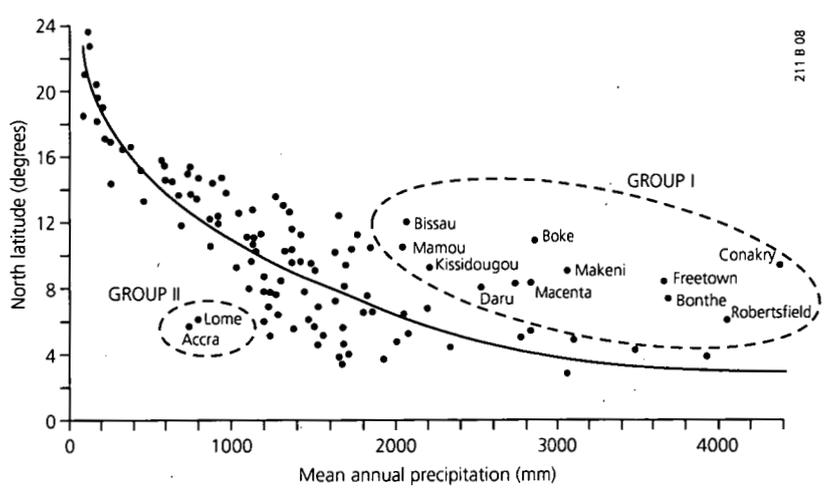
Figure 2.8 Mean annual precipitation (mm) at a number of stations in West Africa in relation to geographic latitude (source: Hayward and Oguntoyinbo 1987)

to the low precipitation in August. In this month, the whole coastal region between Abidjan and Lagos is significantly dry, whereas elsewhere August rainfall is preeminent. This dry period, the so-called short dry season, usually begins in the last week of July and ends in early September (see Figure 2.9).

In addition to the total amount of rainfall, rainfall intensity is an important charac-
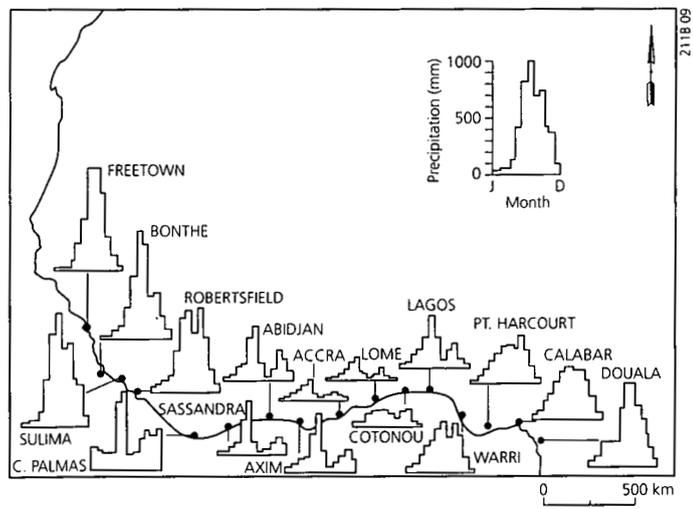
Figure 2.9 The short dry season between late July and early September in West Africa (source: Hayward and Oguntoyinbo 1987)

teristic of the climate of West Africa. Part of the precipitation falls in heavy storms with intensities of 50 mm per hour or more (Weather Zones B and C; see Section 2.1.2). Peaks may even reach 200 mm per hour over short periods. In the southern part of West Africa, storm activity decreases during the rainy season and precipitation tends to occur in steady rains (Weather Zone D). If expressed in terms of millimetres per hour, however, these rains are not less intensive.

These high rainfall intensities often result in rain splash, surface crusting, and soil compaction which, in turn, lead to high runoff, sheet and gully erosion, and, finally, to soil loss.

Air Humidity
The pattern of mean relative air humidity in West Africa is given in Figure 2.10 for the months of February and August. The mean annual range of the relative humidity is shown in Figure 2.11. Both figures are based on data from 126 stations.

In the coastal areas, air humidity is high throughout the year. In the central and
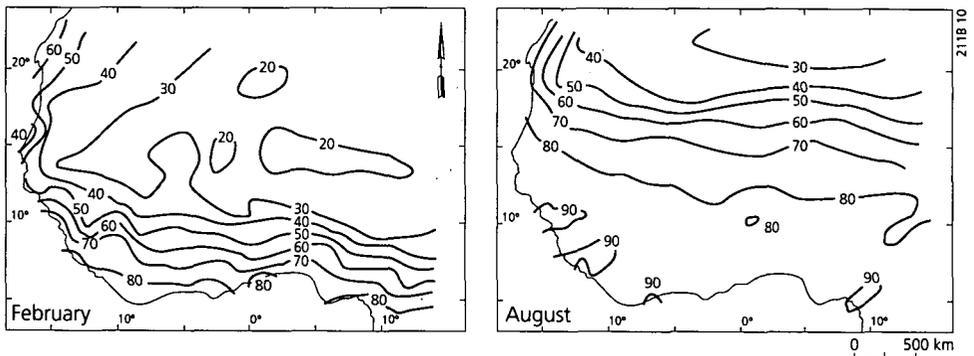
Figure 2.10 Mean air humidity (%) for February and August in West Africa (source: Hayward and Oguntoyinbo 1987)
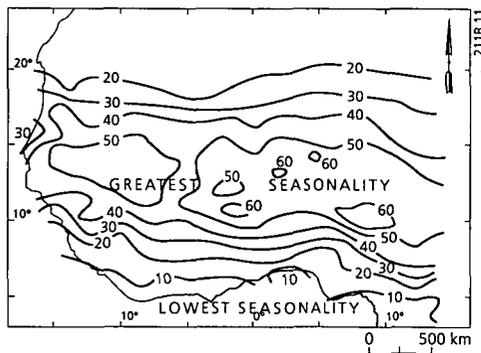
Figure 2.11 Mean annual range of air humidity (%) in West Africa (source: Hayward and Oguntoyinbo 1987)

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northern parts of West Africa, relative humidity values below 40% are widespread in January, whereas values over 60% are common in August.

The widest annual ranges of relative humidity occur across the central part of West Africa. The seasonality is lowest along the Guinea Coast.

Potential Evapotranspiration

The potential evapotranspiration depends on temperature, radiation, wind speed, and relative humidity. In West Africa, therefore, the potential evaporation is strongly related to the position of the ITCZ.

Measuring potential evaporation is difficult, and the lysimeter method, which is most commonly used in West Africa, has a low accuracy. An additional problem in West Africa is that there are only a few stations where potential evaporation is deter-mined. Because of this lack of data, evapotranspiration is often calculated from other climatic parameters like temperature and relative humidity.

Delineated in Figure 2.12 is the potential evapotranspiration in mm for January and July, calculated on the basis of a modified version of the Penman method. In large parts of West Africa, the potential evaporation is low in July because of the prevailing rains and associated high humidity and cloudiness. In January, when the ITCZ is at its southernmost position, the potential evapotranspiration remains relati-vely low in the coastal region. To the north, however, it increases sharply.

In a study covering Liberia, Ivory Coast, Ghana, Togo, Benin, and Nigeria, Papa-dakis (1966) calculated the evapotranspiration, using the meteorological parameters saturation vapour pressure at the monthly mean daily maximum temperature and the monthly mean vapour pressure. Papadakis defines drought stress as the difference between this calculated potential evapotranspiration and the precipitation during the dry season (i.e. the season when precipitation plus the water stored in the soil from previous rains amounts to 50 per cent or less of the potential evaporation).

This drought stress increases strongly from the coast to the north. In the southern part of the area (Liberia, southern Ivory Coast, southern Ghana, the coastal strip of Benin and Togo, and southern Nigeria), the drought stress ranges between almost zero to about 400 mm. North of this zone, the drought stress is some 900 mm in northern Ivory Coast and 1,700 mm in northern Ghana, Togo, Benin, and central
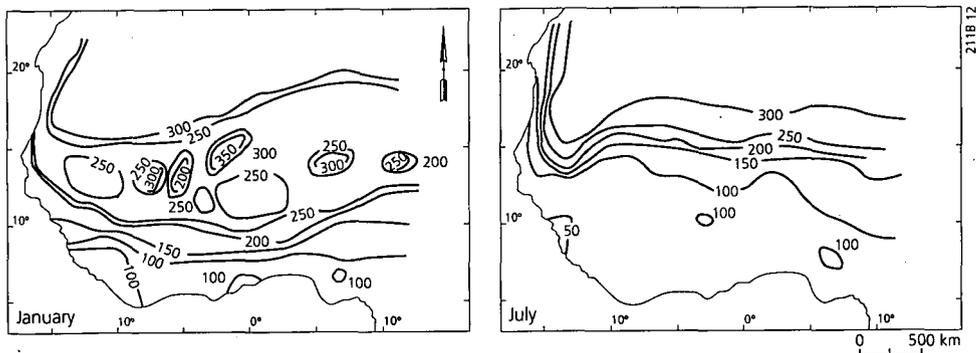
Figure 2.12 Potential evapotranspiration (mm) for January and July in West Africa (source: Ojo 1969)

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Nigeria. The highest values are found in northern Nigeria where the water shortage reaches values of up to 2,300 mm. Plants can hardly sustain such high water stresses and large amounts of water will be needed if irrigation is to be practised.

2.1.4   Climate Variability

In the preceding sections, the data of the climatic parameters were given as mean values over longer periods. Where such data are presented in maps, these show the overall trends of spatial increase or decrease, but they neglect the large annual variations in the parameters, especially those in precipitation.

The variations in the climatic parameters in West Africa are generally attributed to the irregular movement of the ITCZ (see Figure 2.1). Local factors, however, such as atmospheric disturbances, orography, and surface conditions are important too.

Figure 2.13 shows the precipitation variability in West Africa, averaged for 60 stations. The symbol σ used here is the standard deviation of the mean annual precipitation. A period is significantly drier or wetter than average if the deviation of the precipitation is greater than $-\sigma/2$ or $+\sigma/2$, respectively. The precipitation in a certain period or year may be regarded as near-normal if the deviation has a value between plus or minus $\sigma/2$. These limits are indicated in Figure 2.13 as dotted lines.

Ojo (1987) concludes from this figure that the period 1900-1925 was dry. Only three years in this period (1907, 1910, and 1920) could be regarded as relatively wet. The period 1928-1960 was characterized by periods of two or three years that were relatively wet, followed by periods with near-normal conditions. Only three years in this period were dry: 1928, 1944, and 1946. Between 1960 and 1970, the precipitation was near-normal, whereas from 1970 to 1985 conditions were relatively dry again: deviations were greater than $-\sigma/2$. In this period, only a few years had a near-normal precipitation.

The annual variability of the precipitation at some selected climatic stations is given in Figure 2.14. The graphs in this figure show the annual precipitation in the period
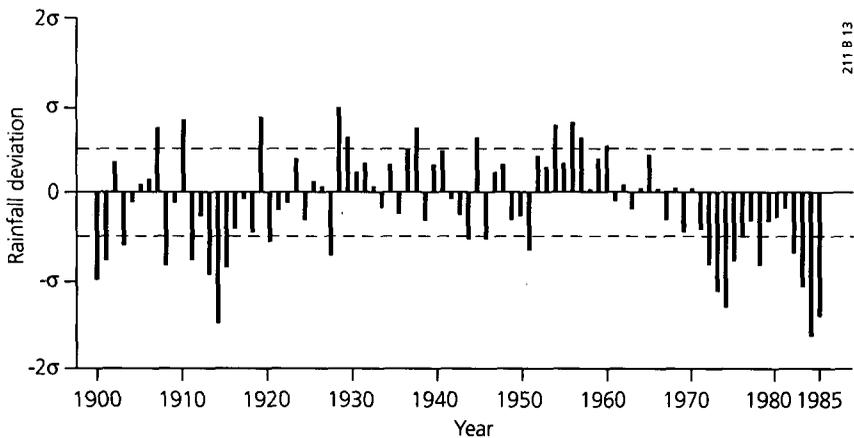
Figure 2.13 Deviation of the annual precipitation from the long-term mean (1900-1985) in West Africa (after: Ojo 1987; adapted)

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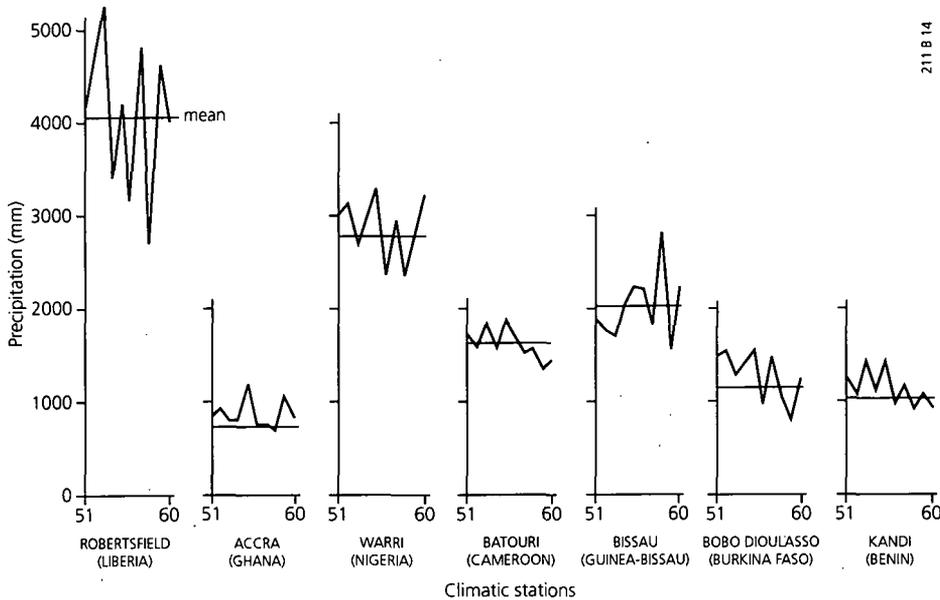
Figure 2.14 Variability of the precipitation (1951-1960) in respect of the long-term mean annual precipitation for some selected stations in West Africa (after: Hayward and Oguntoyinbo 1987; adapted)

1951-1960, as well as the mean annual precipitation calculated over a longer period. The latter is represented by a horizontal line.

The precipitation in Robertsfield shows the strongest fluctuations. The location of Bobo Dioulasso initially had a precipitation higher than the annual mean (1951-1954), whereas in Bissau the first years were relatively dry. In Accra, on the other hand, precipitation was higher than the mean annual rainfall in almost all the years between 1950 and 1960.

Listed in Table 2.1 are relatively wet and dry years as measured at five stations in Nigeria in two different agro-ecological zones (for descriptions of these zones, see Section 2.1.5). Dry and wet years are defined here as years with a deviation from the long-term mean annual precipitation greater than the standard deviation (Ojo 1983). Table 2.1 clearly shows that large variations occur between and within the agro-ecological zones.

In only a few years did all stations simultaneously show a near-normal precipitation (1930, 1933, and 1966). In all other years, at least one of the stations showed a significantly higher or lower rainfall than the mean annual precipitation. The year 1946, for instance, was a wet year in the Sudan Savanna Zone, but a dry year in the Equatorial Forest Zone. The dry years of the early seventies (see Section 2.1.3) are obvious in the Sudan Savanna Zone, but are less expressed in the Equatorial Forest Zone.

Within the Sudan Savanna Zone, large variations were recorded in 1932, 1934, 1948, 1949, 1951, 1958, 1976, and 1977. In those years, wet, dry, and normal conditions occurred at all of the three different stations. In 1939, wet and dry conditions were recorded within the Equatorial Forest Zone.

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Table 2.1 Wet and dry years for five stations in Nigeria (after: Ojo 1983; adapted)

Year	Sudan Savanna Zone			Equatorial Forest Zone	
	Kano	Sokoto	Maiduguri	Lagos	Calabar
1927	Normal	Normal	Normal	Normal	Wet
1928	Normal	Normal	Normal	Normal	Wet
1929	Normal	Normal	Normal	Wet	Wet
1930	Normal	Normal	Normal	Normal	Normal
1931	Wet	Normal	Wet	Normal	Normal
1932	Wet	Normal	Dry	Dry	Dry
1933	Normal	Normal	Normal	Normal	Normal
1934	Normal	Dry	Wet	Normal	Dry
1935	Normal	Normal	Normal	Normal	Wet
1936	Normal	Wet	Wet	Normal	Normal
1937	Normal	Normal	Normal	Normal	Dry
1938	Wet	Normal	Wet	Dry	Normal
1939	Normal	Normal	Wet	Dry	Wet
1940	Normal	Normal	Normal	Normal	Wet
1941	Normal	Normal	Dry	Normal	Wet
1942	Dry	Dry	Dry	Normal	Normal
1943	Dry	Normal	Dry	Normal	Normal
1944	Dry	Normal	Dry	Normal	Normal
1945	Wet	Normal	Wet	Dry	Normal
1946	Wet	Wet	Wet	Dry	Dry
1947	Normal	Normal	Normal	Wet	Normal
1948	Dry	Wet	Dry	Dry	Dry
1949	Dry	Wet	Dry	Dry	Normal
1950	Normal	Wet	Normal	Dry	Normal
1951	Wet	Dry	Normal	Normal	Normal
1952	Wet	Wet	Wet	Normal	Normal
1953	Dry	Normal	Dry	Normal	Normal
1954	Wet	Wet	Normal	Normal	Wet
1955	Wet	Normal	Wet	Normal	Normal
1956	Normal	Normal	Normal	Dry	Normal
1957	Wet	Wet	Wet	Wet	Normal
1958	Normal	Wet	Dry	Normal	Normal
1959	Wet	Normal	Normal	Normal	Normal
1960	Normal	Wet	Normal	Normal	Normal
1961	Normal	Normal	Normal	Normal	Wet
1962	Wet	Normal	Normal	Normal	Normal
1963	Dry	Normal	Normal	Normal	Normal
1964	Normal	Normal	Dry	Dry	Normal
1965	Normal	Wet	Normal	Wet	Normal
1966	Normal	Normal	Normal	Normal	Normal
1967	Normal	Normal	Wet	Normal	Normal
1968	Dry	Dry	Normal	Wet	Normal
1969	Normal	Normal	Normal	Normal	Normal
1970	Normal	Normal	Normal	Wet	Normal
1971	Dry	Dry	Dry	Dry	Normal
1972	Dry	Dry	Dry	Dry	Normal
1973	Dry	Dry	Dry	Normal	Dry
1974	Dry	Dry	Normal	Normal	Dry
1975	Dry	Dry	Normal	Normal	Normal
1976	Dry	Wet	Normal	Normal	Normal
1977	Dry	Wet	Normal	Normal	Normal

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The date of the onset of the rains can be highly variable too. The beginning of the rainy season is correlated with the south-north migration of the ITCZ and will occur earlier in the south than in the north. As was shown in Figure 2.1, however, the position of the ITCZ fluctuates strongly, resulting in a variable onset of the rains at a given location. Since the onset of the rains determines the length of the growing period, this has important implications for the possibilities for agricultural use.

In Table 2.2, the probability of exceedence of specific lengths of the growing period is given for different dates of the onset of the rains for Niamey in Niger (the Sudan Savanna Zone). The average date of the start of the rains at Niamey is 12 June, and the average length of the growing period is 95 days. If the rains start on 2 July, there is a probability of only 1% that the growing period will exceed 95 days. If, however, the rains start on 24 May, there is an almost 100% probability that the growing period will be longer than 95 days.

Table 2.2 Probability of exceedence (%) of specific lengths of growing period for different dates of onset of rains for Niamey, Niger (source: Sivakumar 1989)

Date of onset of rains	Probability of exceedence of length of the growing period (%):			
	75 days	95 days	115 days	135 days
24 May	100	99	48	1
2 June	100	87	11	0
12 June	99	48	1	0
22 June	87	11	0	0
2 July	48	1	0	0

2.1.5   Climatic Regimes

Rainfall and its distribution pattern are the most striking features of the climate of West Africa. Based on the temporal and spatial variations in precipitation and evapo-transpiration, three climatic regimes can be distinguished (see Annex 1).

The Monomodal Regime
The Monomodal Regime has a rainfall distribution which is characterized by one single peak. After the start of the rains, they gradually increase in amount and frequency, reaching a maximum in August/September when the full effect of the ITCZ is felt. After this peak has been reached, the rains rapidly decline to complete cessation. The mean annual precipitation varies from less than 500 mm in the extreme north to more than 3,000 mm in the southwest of the inventory area.

In the northern and northeastern parts of the area, the potential evapotranspiration shows two peaks of about 6 to 8 mm/day, the first in March/April and the second in November. Minima of about 3 to 5 mm/day occur in January and during the rainy season. In the southwest, the potential evapotranspiration is always low (2-5 mm/day).

The length of the humid period, during which the precipitation is higher than the potential evapotranspiration ($P > ET_p$), ranges from two months in the north to six months in the southeast and to eight months in the southwest of this zone.

The Bimodal Regime
The Bimodal Regime is found in the south-central part of West Africa. The mean annual rainfall varies from less than 1,000 mm to 2,000 mm/year. Longitudinally, this distribution pattern is restricted roughly to the zone between 8°W and 4°E.

The rainfall distribution is characterized by two peaks. The first occurs in June/July and the second in September. The total humid period ranges from five to nine months. There is, however, an intervening period with $P < ET_p$ between late July and September, the short dry season, which constitutes a distinct break between the two humid seasons.

In the coastal region between Accra and Lomé, there are less than five humid months because the second rainy season is not very pronounced and the precipitation does not exceed the potential evapotranspiration.

The potential evapotranspiration is characterized by a well-defined and pronounced maximum of about 7 mm/day in March and a minimum of 3 to 4 mm/day in August. A minor and diffuse maximum of 5 to 7 mm/day follows in October and November, prior to a diffuse minimum of 3 to 5 mm/day from December to February.

The Pseudo-Bimodal Regime
The Pseudo-Bimodal Regime extends into the eastern part of West Africa, south of the Monomodal Regime, whereas in the central and western part this Pseudo-Bimodal Regime is found as a transitional zone between the areas with a Monomodal and a Bimodal Regime. There is a decline in rainfall in July and August but the precipitation still exceeds the potential evapotranspiration. The humid period is therefore continuous from March/April to October/November. The mean annual rainfall varies from 1,250 to 1,500 mm in the north, to more than 3,000 mm in the southwestern and southeastern parts of West Africa.

The potential evapotranspiration is generally low throughout the year, ranging between 2 and 5 mm/day.

2.1.6   Agro-Ecological Zones

Within West Africa, different agro-ecological zones can be distinguished. Initially, these zones were defined by the mean annual precipitation only. Different authors, while using the same names for the various zones, have used different rainfall limits in their separation.

From an agricultural point of view, a division of West Africa into agro-ecological zones based on the length of the growing period is more convenient. The growing period has been defined by FAO (1978) and TAMS/CIEH (1976-1978) as follows:

> *A continuous period during the year when the precipitation is more than half the potential evapotranspiration ($P > 0.5\ ET_p$), plus a number of days required to evaporate an assumed 100 mm of water stored in the soil after the rains have ceased. The growing season must exhibit a distinct humid period during which the precipitation is more than the potential evaporation ($P > ET_p$).*

On the basis of the zonality of the annual precipitation, the length of the growing

period, and the vegetational and agricultural potential, West Africa south of the Sahara can be divided into four agro-ecological zones. These are shown in Annex 2 and are described below.

The Sahel Zone
The Sahel Zone is the transitional zone between the (Sahara) desert and the true savanna. The southern boundary of the Sahel Zone roughly corresponds with the 90-day growing-period isoline. The vegetation cover is sparse. Nomadic agriculture is dominant. In the southern part, millet, requiring a minimum growing period of 75 days, can be grown. The Sahel Zone is not included in the area of this inventory.

The Sudan Savanna Zone
The Sudan Savanna Zone extends south of the Sahel Zone. The length of the growing period ranges from 90 days at its northern boundary to 165 days in the south. This Zone has a monomodal precipitation regime. The mean annual precipitation varies from 550 mm in the north to 900 mm in the east and 1,500 mm in the west. Drought stress during the dry season is high. The temperature in this Zone shows a large diurnal variation.

A wide range of crops can be grown. The main limitations to crop production are the deficiency in soil moisture, particularly in the beginning and at the end of the growing period, and the great diurnal temperature ranges.

The Sudan Savanna Zone covers 0.92 million km^2 or 29.4% of the inventory area.

The Guinea Savanna Zone
The Guinea Savanna Zone extends south of the Sudan Savanna Zone. The growing period ranges between 165 and 270 days. The rainfall in this agro-ecological zone is not uniformly distributed. In the northern part, the precipitation regime is monomodal. The mean annual rainfall varies between 1,100 and 2,500 mm in the west and from 900 mm to 1,500 mm in the east. The radiation characteristics are favourable for plant growth.

In the central-southern part of this Zone, the precipitation has a bimodal pattern. The two rainy seasons are of unequal duration and rainfall is irregular. Drought hazards occur here and the radiation is sub-optimal. The value of the mean annual precipitation lies between 1,000 and 1,500 mm. Because of the bimodal precipitation pattern, the growing period comprises a major season of four to five months from March/April through July and a minor one from the end of August through October/November. The coastal area near Accra forms an exception. Here, the growing period has a length of two to three months only.

Between these zones of monomodal and bimodal precipitation, there is an area with a pseudo-bimodal regime with intermediate characteristics.

Hence, the agro-ecological conditions in the south are less favourable than in the north. The main constraint to crop production in the zone with the bimodal regime is the irregularity in precipitation, especially within the seasons.

The Guinea Savanna Zone covers 1.35 million km^2 or 42.9% of the inventory area.

The Equatorial Forest Zone
The Equatorial Forest Zone extends southeast and southwest of the Guinea Savanna

Zone. It has a growing period of more than 270 days. The rainfall pattern is pseudo-bimodal in the east and monomodal in the west, with a mean annual precipitation of 1,250 mm to more than 3,000 mm. The central-southern part has a bimodal rainfall pattern, with a mean annual precipitation between 1,250 and 2,000 mm.

The drought stress and the diurnal temperature fluctuations are low. The main constraints to crop production are the sub-optimum solar radiation and the high air humidity, which cause a high incidence of pests and diseases.

The Equatorial Forest Zone covers 0.87 million km² or 27.7% of the inventory area.

2.2   Geology and Lithology

2.2.1   General

The description of the geology and lithology of West Africa is based on a large number of reports with accompanying maps. Coverage at a scale of 1:2,000,000 was available for almost all the countries in the inventory area (Barrère and Slansky 1965; Blanchot et al. 1973; Geological Survey Division 1964; Nicklès and Hourcq 1952; and Directorate Overseas Surveys 1960). For Guinea Bissau, use was made of the geological map at a scale of 1:1,000,000, which formed part of the soil survey report by Da Silva Teixeira (1962). For Mali, Niger, Burkina Faso, Senegal, and The Gambia, information was taken from the *Atlas de la Haute Volta* (1975), Nahon (1976), ORSTOM (1970), and Jansen and Diarra (1990). The information for Liberia was drawn from the *Geological Atlas of the World* at a scale of 1:10,000,000 (UNESCO 1976). For the whole region, use was also made of the descriptive text in *Geology of Africa* (Furron 1963).

Additional detailed information was available for most countries, either in the form of specific geological studies and maps (Cameroon: Dir. des Mines et de la Géologie 1953-59; Nigeria: Directorate Geological Surveys 1962), or as sections in reports on soil surveys or land resources inventories.

2.2.2   The Main Geological Units

From a geological point of view, West Africa can be divided into a southern zone where the rocks of the Basement Complex of Precambrian age predominate, and a northern zone where marine and terrestrial sediments and rocks occur, formed in huge tectonic basins (Figure 2.15).

It is thought that the African shield originally formed part of Gondwanaland, the ancient continent which comprised Africa, South America, Madagascar, India, Australia, and Antarctica. During the Mesozoic era (lower Cretaceous), this continent broke up into the present blocks, which drifted apart (continental drift). Concurrently and following the displacement of Gondwanaland, horizontal and vertical epeirogenic movements fractured the continents. In West Africa, these movements resulted in the formation of seas and lakes in basins like the Chad Basin in the northeast of the inventory area and troughs like the ones in which the Benue and Niger Valleys are situated in Nigeria. These depressions are filled up with more recent sedimentary deposits.

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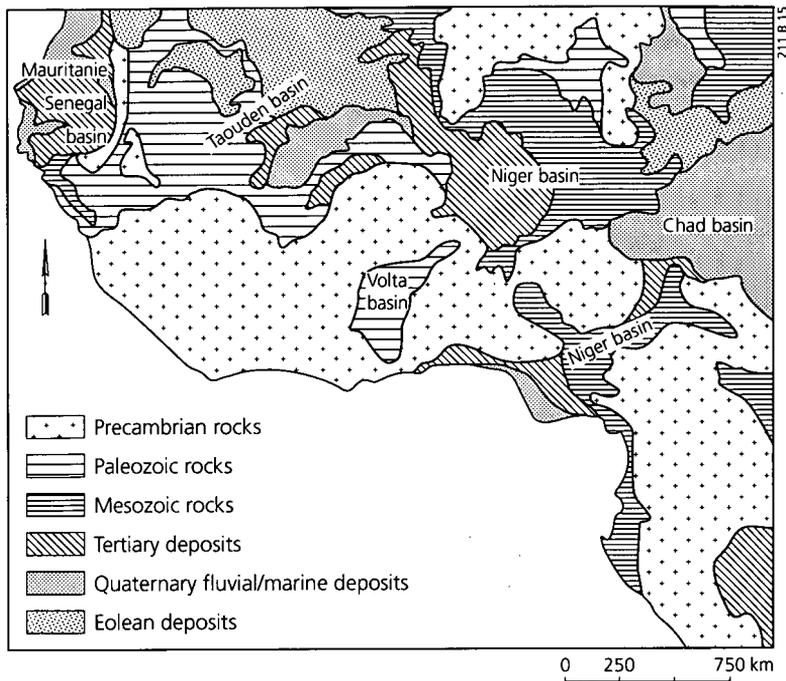
Figure 2.15 The main geological units of West Africa (after: Ribstein 1990; adapted)

The **Basement Complex** comprises granites and associated metamorphic rocks of Precambrian age. The Basement Complex, which forms the African continental shield, underlies the whole inventory area. It appears in most of Guinea, Sierra Leone, Liberia, Ivory Coast, Togo, Benin, Nigeria, Burkina Faso, and Cameroon, as well as in parts of Guinea Bissau, Mali, Niger, and Ghana.

The composition of the Basement Complex varies strongly. There are four different formations distinguished within the Basement Complex. These are the lower Precambrian rocks, the Birrimean rocks (middle Precambrian), the Tarkwaian rocks (upper Precambrian), and de Buem series (terminal Precambrian).

The **lower Precambrian rocks** predominate in south-eastern Guinea, Sierra Leone, Liberia, western Ivory Coast, Ghana, central Togo, Benin, Cameroon, Burkina Faso, and Mali. They are mainly granite-migmatite-gneiss complexes.

Middle Precambrian (Birrimean) rocks comprise mainly schists, quartzites, and other metamorphic rocks, including micaschists, greenstones, amphibolites, arkoses, and graywackes. These rocks crop out in Burkina Faso, southern Mali, northeastern and southern Guinea, in eastern Ivory Coast, and in southern Cameroon. They appear as north-northeast/ south-southwest folded bands in the western part of Ivory Coast, in western Ghana, and in the Atacora Range in Togo and Benin. Also of Birrimean age are the charnockites of the Man Massif in Ivory Coast. In southwestern Ghana, the Birrimean rocks also comprise basic and acid extrusives (lavas and tuffs). They occur in complexes with Upper Precambrian (Tarkwaian) rocks.

The **Tarkwaian rocks** were defined at Tarkwa in southwest Ghana and comprise

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folded conglomerates, (feldspathic) quartzites, sandstones, and shales. These formations also occur locally in Ivory Coast.

Terminal Precambrian rocks (Buem series) are important in Togo and north Benin, where, together with the Birrimean micaceous quartzites, they form the Atacora Range of high relief and topography. The Buem series includes shales, arkoses, sandstones, conglomerates, and some volcanic rocks, mostly basalts and dolerites.

The Precambrian rocks in Nigeria have not been well differentiated, but they include granites, gneisses, migmatites, micaschists, and amphibolites with intrusions of 'younger' granites. The latter form the core of the Jos Plateau in central Nigeria, which has resisted various erosion cycles. Precambrian intrusion phases have given rise to the occurrence of laccoliths, sills, dikes, etc. In other parts of the inventory area (e.g. in Guinea and Mali), these formations comprise dolerites and gabbros.

The **sedimentary rocks** and deposits formed after the Precambrian era are divided into Paleozoic, Mesozoic, Tertiary, and Quaternary formations.

Paleozoic formations (Cambrian, Ordovician, Silurian, and Devonian) of sandstones, shales, mudstones, and pebbly conglomerate beds occur in the central part of the Volta Basin and in Mali, Burkina Faso, and Guinea (Sikasso Plateau, Manding Plateau, and Fouta Jallon). In northern Burkina Faso, dolomitic limestone occurs as part of the Paleozoic deposits. Slightly older are the Infracambrian sandstones that form the upwarped fringes to the north, west, and south of the Volta Basin.

The **Mesozoic formations**, called the Continental Intercalaire, consist of a wide variety of Cretaceous marine and continental, locally weakly metamorphosed, sandstones, shales, and coal measures. These deposits occur in the Benue and Niger troughs in Nigeria (Nupe and Bima sandstones, Illo formations, etc.) and in southwestern Niger.

Tertiary sedimentary deposits, called the Continental Terminal, consist of weakly cemented sands, sandy clays, clays, and marly clays. These deposits occur in fringes along the coast of Sierra Leone, Ivory Coast, Togo, Benin, Nigeria, and Cameroon. They include the deposits that are locally known as *Terres de Barre* (Togo and Benin) and Coastal Plains Sand (Nigeria). The Kerri-Kerri formation west of the Gongola River in Nigeria also consists of continental sandstone deposits.

These deposits cover large areas in Guinea Bissau, The Gambia, and Senegal, where they consist mainly of unconsolidated sands with inclusions of sandstone, shales, marls, and clays. Near Dakar, these sediments consist of an alteration of limestones, marls, clays, and phosphates.

Other regions where these deposits occur extensively are northern Burkina Faso, southern Mali, and southwestern Niger (the Taouden and Niger Basins).

Recent (Quaternary) deposits, comprising riverine and marine silts and clays, occur in river plains (Senegal, Gambia, Casamance, Volta, Oti, Niger, and Benue Rivers), deltas (Niger River), and estuaries (Rio Geba, Sassandra River, and several smaller rivers). More sandy deposits are found in the inland Niger Delta (Mali and Burkina Faso), and in the Chad Basin. Locally, in the Sudan Savanna Zone, they occur as aeolian deposits (dunes, etc.).

Elongated coastal sand bars (beach ridges) have formed along most of the West African coastline.

During Tertiary and Mesozoic times, **volcanic intrusions and extrusions** formed, among other things, the Jurrassic basalt flows and ash cones near Jos, the Cretaceous and Tertiary outcrops in the Benue trough, and the Cretaceous basalt plateaux in

west and central Cameroon (Mungo and Adamawa). Volcanic activity on the Jos Pla-
teau has continued into the Pleistocene. Mount Cameroon, still an active volcano
near the Gulf of Guinea, is of Quaternary origin.

In terms of soil formation in relation to lithology, it can be stated that in general
in West Africa the soils derived from sedimentary materials are chemically less fertile
then those developed on Precambrian Basement Complex rocks. The latter contain
silicate minerals which, upon weathering, release nutrients. The sedimentary materials
have been subjected to more than one weathering and erosion cycle and consist mainly
of residual materials like quartz, kaolinite, and gibbsite.
    Within the varied complex of sedimentary deposits, weathering of sandstone gives
rise to very poor sandy soils. Shales tend to form more clayey soils, which are, to
some extent, chemically richer.
    Within the Basement Complex, the metamorphosed rocks (schists, amphibolites,
etc.) form relatively fine-textured soils (light clays) which are chemically richer than
the soils formed over granitic material. In addition, the soils over granites have coarser
textures (sandy clays, sandy loams, loamy sands, and sands). The poorest Basement
Complex soils are those over quartzites.

2.3   Geomorphology

2.3.1   General

The existing literature does not provide a comprehensive map coverage of the geomor-
phology of West Africa. Therefore, the geomorphological information that underlies
the division of the inventory area into land regions had, by necessity, to be derived
mainly from the text and small sketch maps as presented in soil and land inventory
reports for individual countries or parts thereof. In particular, studies that are based
on the so-called land system analysis proved very useful. In such an analysis, land
systems (i.e. recurrent patterns of land form, soils, hydrology, and vegetation) are
subdivided into their constituent units: the land facets. These are usually further de-
scribed in detail and illustrated in block diagrams. Information on specific land facets
(e.g. inland valleys) within a land system, or data on broad groupings of land systems
(i.e. land regions) can easily be extracted from such reports and compiled for further
elaboration. Land system analysis has been applied in Sierra Leone, in northwestern
Liberia, in large parts of Nigeria, and in some parts of northern Ivory Coast.
    The geomorphology has been described by Avenard (1971), Brouwers and Raunet
(1976), FAO (1979), King (1967), Small (1972), Turner (1985), Murdoch et al. (1976),
and Wall (1979). For more detailed information on the morphology, see the publica-
tions listed in 'References not cited in text'.

2.3.2   The Landscape of West Africa

The landscape of West Africa is characterized by the occurrence of large, nearly level
plains (peneplains), formed by intensive erosion over long periods. In Africa, different

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erosion cycles have resulted in a number of peneplains at different altitudes. In West Africa, at least relicts of these peneplains can be found.

During the Jurassic era, preceding the lower Cretaceous disruption of Gondwanaland, the surface of the super-continent was subjected to intensive erosion, which caused the formation of a nearly level plain, the Gondwana peneplain. Simultaneously, continental basins (e.g. the Congo Basin) were filled with detritus from adjacent areas. This sedimentation process further contributed to the smooth appearance of pre-Cretaceous Africa.

The dislocation, fracturing, and faulting of the African continent in the Cretaceous era caused a new erosion cycle to form the post-Gondwana peneplain. Associated with this Cretaceous faulting, volcanic activity started mainly in West Cameroon and in central Nigeria, locally forming extensive basalt plateaux.

Erosion cycles during the Eocene and Plio-Pleistocene eras caused further planation (the African and post-African planation, respectively) and the formation of the extensive, remarkably level peneplains and plateaux that make up most of the inventory area. The majority of the West African plains are of Plio-Pleistocene age. They occur at elevations between 50 and 700 m above sea level (a.s.l.). The various peneplains are commonly separated from each other by distinct scarps or by dissected transitional zones of broken relief. Occasionally, the transition is smooth and hardly discernable.

Remnants of the older peneplains occur in West Africa as highlands, which are strongly dissected and have a steep relief. Relics of the Gondwana surface can still be found in the West Cameroon Mountain Range, the Jos Plateau in Nigeria, the Fouta Jallon in Guinea, and on the summit of Mount Nima in the Guinean Highlands.

The Fouta Jallon in Guinea consists of extremely dissected, flat sandstone and shale plateaux at an elevation of 1,000 to 1,500 m a.s.l. Hard iron crusts (bowals) formed at the surface of these deposits have contributed to their preservation. The deeply and steeply incised fault-controlled valleys form a rectangular drainage pattern. To the west, these plateaux decline in a series of fault steps to the coastal plains of Senegal. In the east (Manding Plateau), a more gentle transition occurs towards the interior plains of Guinea and Mali (100 to 400 m a.s.l.), in which the Niger has formed an extensive inland delta.

In sharp contrast to the high plateaux of the Fouta Jallon and the Manding Plateau are the rounded but steep hills and mountains of the Guinean Highlands (French: *Dorsale Guinnéenne*). These mainly comprise granitic rocks, which rise to over 1,900 m a.s.l. in the Loma Mountains of Sierra Leone. Mount Nimba, on the border between Guinea, Ivory Coast, and Liberia, is 1,752 m a.s.l. and, further to the east, the Man Massif attains heights of up to 1,400 m.

In central Nigeria, the Jos Plateau is a granitic plateau with some volcanic hills and basalt flows up to 1,600 m a.s.l. At its southern margin, the Jos Plateau is separated from the high plains of Hausaland by extremely deep and steep scarps of approximately 600 m.

The post-Gondwana peneplain comprises parts of the high plateaux surrounding Jos, portions of the Cameroon Highlands including the plateaux of the Adamawa Range, and the crests of the Atacora Range in northern Benin.

The Atacora Range, east of the Volta Basin, is a belt of parallel ridges trending north-northeast to south-southwest through southern Ghana, Togo, and northern Benin. These ridges rise to over 1,000 m a.s.l. (Mount Segou). The steep-sided and

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narrow valleys in between the mountains are locally more than 300 m deep.

The West Cameroon Highlands comprise undulating to rolling plateaux formed in granite and basaltic lava flows at altitudes of 1,500 m a.s.l. and more. Volcanic cones on these plateaux reach heights of more than 2,500 m (Mounts Oku and Mba Kokeka, and the Santa Peak). Stretching west of these highlands is the Yade Plateau in the Adamawa Range at an altitude of approximately 1,200 m. The Mandara Mountains, further to the north, also belong to the Cameroon Mountain Range. Mount Cameroon (4,070 m a.s.l.) forms a spectacular solitary dome to the south of the Cameroon Mountain Range. It is a still-active volcano.

Eocene peneplains comprise the high plains of Hausaland in Nigeria, which occur at altitudes of 600 to 1,000 m a.s.l. Probably most of the plateaux of south Cameroon, which have approximately the same elevation, belong to these peneplains too.

As stated earlier, most of the plains and plateaux found in West Africa are of Plio-Pleistocene origin. These plains and plateaux have an undulating relief and are dissected to various degrees by streams and rivers, usually in a dendritic (non-orientated) drainage pattern. Locally, steep-sided remnants of older plateaux (mesas), granitic inselbergs, and hill ridges rise from these plains. Granitic inselbergs and ridges have resisted ongoing weathering and erosion because of their hardness. They can be as high as 200 – 300 m. The mesas, which can stand about 10 – 200 m above the ground surface, have formed because of the occurrence of ironstone hardpans (cuirasses, carapaces, duripans, lateritic pans, etc.) at their surfaces. These hardpans have been formed through a downward movement and subsequent accumulation in lower soil horizons of sesquioxides, notably iron oxides, under conditions of alternating wetness and drought. On the level peneplains formed by the various erosion cycles, massive sheets of iron accumulation could develop. The stripping of overlying soil material during new erosion cycles, caused by the uplifting or other relative lowering of the erosion base, proceeded down to the indurated iron pan, which now appears at, or near, the surface.

Locally, lithological variations have caused pronounced relief in these peneplains. For example, the Ashanti Hills in southwestern Ghana comprise folded ridges of hard rocks (granites, quartzites, and diorite sills) and softer formations (conglomerates, sandstones, shales, and phyllites) in a northeast-southwest alignment. Differential erosion has caused steep relief with slopes up to 35%, separating the relatively level remnants of former peneplains from wide, flat-bottomed valleys. Also in Ghana, the fringes of the Volta Basin have been formed by uplifting, resulting in steep and deep outward-facing scarps reaching down to the gently undulating plains to the north, west, and south. The upturned edges rise up to 400 m (the Gambaga Scarp in the north) and 500 m (the Mampong Scarp in the south) above the adjoining plains. These plains have an elevation of 100 – 200 m a.s.l. The plains between the Atacora Range (Togo and Benin) and the lower Niger Valley (Nigeria) are distinctly stepped and warped. Locally, they are nearly level to gently undulating; in other places, successive planation cycles have caused a broken topography consisting of scarps and dissected areas.

The Bolilands in Sierra Leone form a particular part of the peneplains. They are a complex of seasonally flooded, wide and shallow depressions, and low river terraces of negligible relief, associated with Precambrian sandy and clayey consolidated sediments.

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In West Africa, only relatively small areas do not consist of strongly dissected, undulating, or nearly level peneplains. They include the coastal and alluvial plains.

The coastal plains in the inventory area comprise recent marine and riverine alluvial deposits occurring as coastal sand bars, beaches, lagoons, and estuarine and deltaic swamps.

At its mouth in Nigeria, the Niger River has formed an extensive delta consisting of freshwater swamps, basins, and levees in the central and interior parts, while mangrove swamps surrounded by tidal creeks prevail towards the coast. The coastline along most of West Africa consists of a series of sandy beach ridges.

Locally (Ivory Coast, Togo, Benin, Nigeria, and Cameroon), the coastal plains include low plateaux of the (Tertiary) Continental Terminal deposits. These plateaux have a gently undulating relief. They have been upwarped slightly towards the interior, resulting in their separation from the interior plains by a distinct scarp which, in Ivory Coast, Togo, and Benin, may attain a height of several tens of metres. Rivers have cut steep-sided courses into the elevated parts of the coastal plains (Sassandra, Bandama, and Komoe Rivers in Ivory Coast, Sio and Haho Rivers in Togo, and the Ouème River in Benin, among others). The Hollis Lama Depression in Togo and Benin is a low-lying area of Eocene marly clays within the Continental Terminal plateau. It was probably formed by the erosion of the soft marls.

In Nigeria, the transition between the coastal plains and the interior plains is formed by a zone of Tertiary and Cretaceous sandstones, shales, sands, and coal measures of distinct dissection with high scarps (the Enugu Scarp is 350 m high) and dipslope features.

The low, nearly level plains in Guinea Bissau, Senegal, and The Gambia are aggradation surfaces comprising the Continental Terminal deposits of mainly sandstones and sands. They have an elevation of approximately 20 to 50 m a.s.l., and are dissected by the valleys of the Coruba, Geba, Casamance, Gambia, and Senegal Rivers.

Most of the large rivers in West Africa have nearly level floodplains in which terraces have formed locally. Extensive floodplains and terraces occur, particularly along the Black Volta in Ghana, the Oti in northeastern Ghana and northern Togo, the Niger in Guinea, Mali (inland delta), and Nigeria, the Benue River in Nigeria and Cameroon, the Senegal and Gambia Rivers, and in the Chad Basin.

2.3.3   The Land Regions

For the characterization and mapping of the geomorphological differences described above, the inventory area was divided into so-called land regions. Land regions are broad landscape units with recurrent physiography. Four land regions have been distinguished:
– Coastal and alluvial plains;
– Interior plains;
– Plateaux;
– Highlands.

These land regions are further subdivided according to lithology, and related features

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like degree of dissection, relief, and the occurrence of inselbergs, hill ridges, and laterite-capped mesas. In total, twenty-seven subregions have been distinguished. They are briefly described in Table 2.3. Their distribution is shown in the land region map of Annex 3. More elaborate descriptions of the map units, including descriptions of the main soils of the various subregions, are given in the legend of the land region map in Annex 4.

2.3.4   Morphology of Inland Valleys and Their Distribution

Significant work on the characterization of West Africa's inland valleys has been done by IRAT (Kilian 1972; Kilian and Teissier 1973; Gillet 1973), Avenard (ORSTOM 1971), FAO (1979), Murdoch et al. (1976), Savvides (1981), Raunet (1982, 1984, 1985), Turner (1985), Millington et al. (1985), Moormann (1981), Smaling et al. (1985a, 1985b), Andriesse (1986), and Hakkeling et al. (1989).

Inland valleys can be defined as the upper reaches of river systems (inland with respect to the main rivers and main tributaries) in which river alluvial sedimentation processes are absent or imminent only: they do not yet have any distinct system of floodplains and levees. In francophone (West) African countries, inland valleys are known as *bassin versants*. Local names for inland valleys include *fadamas* in northern Nigeria and Chad, and inland valley swamps in Sierra Leone. Inland valleys are comparable to the *dambos* or *mbugas* of eastern and southern Africa. All these names refer to seasonally or perennially waterlogged valley bottoms and depressions.

Raunet (1985) divides the inland valleys longitudinally into three parts: the valley head, the midstream part, and the downstream part, each with its own morphological characteristics (Figure 2.16).

The valley head forms the most upstream part of the valley. It has a concave profile, there is no stream channel, and the morphology and the soils are dominated by colluvial processes.

The midstream part of the valley is wider, the central part of the concave valley bottom is almost flat, and a shallow stream channel is present in the central part of the valley. Although some river flooding and associated sedimentation may occur, colluvial processes still dominate the morphology and the soils.

The downstream part of the valley shows limited development of levee systems, and alluvial soils occur. River flooding and subsequent sedimentation are more important than in the upstream part, but colluviation remains significant at the fringes of the valley bottom. The downstream part changes gradually into a floodplain proper.

The subdivision as applied by Raunet does not differentiate inland valleys according to morphological and hydrological characteristics. In the present study, where these factors are deemed of major importance for the possibilities of agricultural use, a morpho-hydrological subdivision is adhered to.

The uppermost part of inland valleys is defined here as the **stream inland valley**. Stream inland valleys have an imminent centrally-located stream channel, which is shallow and only up to a few metres wide, if present at all. The bottoms of the stream inland valleys vary in width from about 10 m in their upper reaches to about 100 m in their lower reaches. The morphological processes in stream inland valleys are

Table 2.3 Land regions and subregions and their summary descriptions

Land Region	Subregion[1]	Physiography	Geology and Lithology
Coastal and Alluvial Plains	1.1	Beach ridges, alluvial plains, deltas, tidal swamps, etc. Nearly level to gently undulating.	Recent coastal sands, alluvial silts and clays, some peats.
	1.2	Slightly dissected coastal terraces. Nearly level to gently undulating.	Tertiary, weakly cemented sands, sandy clays, marly clays and clays.
	1.3	Strongly dissected coastal terraces. Undulating to gently rolling	Tertiary and Cretaceous sandstones, siltstones, shales, sands and coal measures.
	1.4	Slightly dissected aggradational coastal plains. Nearly level to gently undulating.	Tertiary sandstones, shales, marls, sands and clays, locally nummulitic limestones.
	1.5	Slightly dissected aggradational coastal plains. Nearly level to gently undulating.	Tertiary sandstones, shales, marls sands and clays.
	1.6	Recent floodplains of the rivers Gambia, Senegal, Benue and Niger. Nearly level to gently undulating.	Recent sandy, silty and clayey alluvial deposits.
	1.7	Recent floodplains and sub-recent terraces of the Chad Basin. Nearly level to gently undulating.	Recent and sub-recent sandy, silty and clayey alluvial deposits.
	1.8	Inland delta of the Niger river. Nearly level to gently undulating.	Recent medium and fine-textured alluvial deposits.
Interior Plains	2.1	Slightly dissected peneplains with inselbergs, hill ridges and mesas. Undulating.	Lower Precambrian (Archean) undifferentiated granites, migmatites and gneisses.
	2.1.a	Non-dissected large drainage depressions and low terraces. Nearly level. (Bolilands)	Lower Precambrian (post Archean) consolidated sandy and clayey deposits.
	2.2	Slightly dissected peneplains, with inselbergs, hill ridges and mesas. Undulating.	Middle Precambrian (Birrimean) undifferentiated schists, quartzites and other metamorphic rocks.
	2.3	Strongly dissected peneplains. Rolling to steep.	Complex of Precambrian (Tarkwaian and Birrimean) metamorphic, sedimentary and volcanic rocks.
	2.4	Dissected and upwarped peneplains. Undulating to gently rolling.	Paleozoic (Infracambrian) sandstones.
	2.5	Slightly dissected peneplains. Nearly level.	Paleozoic (Cambro-Ordovician) sandstones, shales, mudstones and pebbly conglomerates.
	2.6	Slightly dissected peneplains with mesas and volcanic cones. Nearly level to gently undulating.	Mesozoic (Cretaceous) marine and continental sandstones, shales and coal measures.
	2.7	Strongly dissected peneplains. Undulating.	Mesozoic (Upper Cretaceous) continental sandstones and conglomerates.
	2.8	Slightly dissected peneplains with hills and mesas. Gently undulating	Paleozoic (Cambro-Ordovician) sandstones and tillite.
	2.9	Slightly dissected peneplains. Nearly level to gently undulating.	Tertiary poorly consolidated sandstones, mudstones, conglomerates, sands and clays.
	2.10	Slightly dissected to dissected peneplains with hills and mesas. Gently undulating.	Cambrian calcareous schists, quartzites, pellites, sandstones and tillite.
	2.11	Dissected peneplains with mesas. Gently undulating to undulating.	Complex of Continental Terminal, Continental Intercalaire, Cretaceous sandstones and marls, and Paleocene limestones, marls and shales.

Valley head

Midstream part

Downstream part

[Non-weathered granite pattern]	Non-weathered granite	[Upland soils pattern]	Upland soils
[Weathered granite]	Weathered granite	– – – –.	Highest groundwater level
[Colluvial deposits pattern]	Colluvial deposits	↘	Lateral groundwater flow
[Colluvial-alluvial deposits pattern]	Colluvial-alluvial deposits		
[Alluvial deposits pattern]	Alluvial deposits		

Figure 2.16 Valley head, midstream part, and downstream part of an inland valley (after: Raunet 1985; adapted)

dominated by colluviation. They extend over distances of up to 25 km and sometimes more. Stream inland valleys include the valley heads and the midstream parts of the inland valleys as described by Raunet (1985).

River inland valleys occur downstream of the stream inland valleys. They are wider and have a larger, and more distinct, water course. As alluvial processes are more prominent than in the stream inland valleys, there is some floodplain development. These floodplains may be up to 200 m wide. River inland valleys include the downstream parts of the inland valleys as distinguished by Raunet.

The subdivision into stream and river inland valleys given above coincides with two different flooding regimes. The stream inland valleys are characterized by an inflow flooding regime, whereas the river inland valleys have an overflow flooding regime. A further description of these flooding regimes is given in Section 2.4.4.

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Table 2.3

Land Region	Subregion[1]	Physiography	Geology and Lithology
Plateaux	3.1	Slightly dissected plateaux with insel-bergs, hill ridges and mesas. Gently undulating.	Lower Precambrian (Archean) undif-ferentiated granites, migmatites and gneisses.
	3.2	Slightly dissected plateaux with insel-bergs, hill ridges and mesas. Gently undulating.	Middle Precambrian (Birrimean) undifferentiated schists, quartzites and other metamorphic rocks.
	3.3	Dissected plateaux with mesas. Nearly level to gently rolling.	Paleozoic (Cambro-Ordovician) sandstones.
	3.4	Dissected plateaux. Undulating to rolling.	Tertiary (Paleocene) sandstones.
Highlands	4.1	Strongly dissected mountain ranges with remnants of old planation sur-faces. Very steep.	Lower Precambrian (Archean) undif-ferentiated granites, migmatites and gneisses.
	4.2	Complex of strongly dissected, steep mountain ranges and rolling to steeply sloping plateaux.	Complex of Precambrian 'older' gra-nites, migmatites and gneisses, Juras-sic 'younger' granites and more recent basalts.
	4.3	Strongly dissected, folded and faulted mountain ranges with remnants of old planation surfaces. Very steep.	Complex of Middle and Terminal Precambrian sedimentary, metamor-phic and extrusive formations.
	4.4	Strongly dissected high plateaux. Gently undulating to undulating.	Paleozoic (Ordovician, Silurian, Devonian) sandstones and shales.

[1] Subregion codes refer to the land region map, Annex 3

To indicate the area covered by the different categories of inland valleys, Table 2.4 shows the extents of several kinds of wetlands. Broadly, three major categories of wetlands can be distinguished:
− Coastal plains and inland basins, including deltas, estuaries, tidal flats, and the *bolis* in Sierra Leone;
− River floodplains;
− Inland valley bottoms and footslopes.

For the category of inland valleys, Table 2.4 makes a further distinction between river and stream inland valleys, as defined above. The area estimates have been derived from (semi-) detailed and reconnaissance soil and physiographic maps. The distinction between river inland valleys and stream inland valleys, however, was not always clear on the available maps.

Table 2.4 also shows the area and relative distribution of the various categories of wetlands (in %) in relation to the agro-ecological zones, the land regions, and the main geological/lithological substrata. From these data, it could be calculated that roughly between 11 and 28 million ha (3.5 to 8.9%) of the inventory area is occupied by stream inland valleys and that river inland valleys cover between 10 and 23 million ha (3.2 to 7.3%).

As the result of the interaction between lithology, climate, and morphological pro-

Table 2.4 Area (in km^2) and relative distribution (in %) of the various categories of wetlands in the different agro-ecological zones, land regions and main geological units in West Africa

Agro-ecological zone	Land region	Total area (x1000 km^2)	Relative Area Occupied by Wetlands (%)			
			Deltas, tidal swamps, inland swamps, etc	River flood-plains	River inland valley bottoms and footslopes	Stream inland valley bottoms and footslopes
Equatorial Forest Zone	Coastal and alluvial plains	100	25–40	1– 5	1–4	1– 3
	Interior plains					
	Basement Complex	376	0– 1	2– 5	5–13	6–16
	Sedimentary deposits	51	3– 8	5–10	3– 8	1– 6
	Plateaux					
	Basement Complex	220	–	1–2	2– 7	2– 7
	Sedimentary deposits	0	–	–	–	–
	Higlands					
	Basement Complex	118	–	1– 4	2– 7	5–10
	Sedimentary deposits	0	–	–	–	–
Guinea Savanna Zone	Coastal and alluvial plains					
	Coastal-aggradational plains	56	8–10	1– 4	4– 6	3– 8
	Floodplains	18	–	70–90	–	–
	Interior plains					
	Basement Complex	389	0– 1	5– 8	7–12	3–11
	Sedimentary deposits	241	3– 8	5–10	3– 8	1– 3
	Plateaux					
	Basement Complex	374	–	1– 5	1– 5	8–13
	Sedimentary deposits	54	0– 1	2– 7	4– 9	4– 9
	Highlands					
	Basement Complex	149	0– 1	3– 8	8–13	3– 8
	Sedimentary deposits	70	0– 1	3– 6	1– 5	6–11
Sudan Savanna Zone	Coastal and alluvial plains					
	Coastal-aggradational plains	140	3– 4	1– 4	4– 6	3– 8
	Floodplains	83	–	60–90	–	–
	Interior plains					
	Basement Complex	87	–	1– 3	3– 5	4– 9
	Sedimentary deposits	371	–	2– 3	2– 3	2– 5
	Plateaux					
	Basement Complex	151	–	0– 1	1– 4	5–10
	Sedimentary deposits	77	–	0– 2	2– 8	2– 9
	Highlands					
	Basement Complex	5	–	2– 5	6–10	2– 5
	Sedimentary deposits	7	–	2– 5	1– 3	3– 6
Total inventory area		3140				

cesses, inland valleys vary widely in their shape and extent. The morphology of the valleys can be characterized by their longitudinal and cross-sectional profiles.

Longitudinally, the inland valleys may be continuous and smooth or interrupted and stepped. Continuous inland valleys occur in lithological formations with little

structural variation, such as the sedimentary deposits. Stepped valleys have been reported to occur in the interior plains and plateaux over the Basement Complex in Nigeria, Sierra Leone, and Liberia. In these formations, hard rocks (granites, quartzites) alternate with softer materials like schists and gneisses. The flatter sections that develop on the more weatherable rock types are separated by short, relatively steep and narrow valleys in the more resistant rock formations.

The overall longitudinal slope of the inland valleys in most of the interior plains and the plateaux is low (1 to 2%), but it can be up to 5% in the highlands.

Raunet (1982, 1985) describes three different cross-sectional profiles of inland valleys formed on granite-gneiss complexes in relation to precipitation (Figure 2.17). These are:

– **Rectilinear inland valleys.** These are found in areas with a mean annual precipitation of 800 – 1,100 mm. The valleys are broad with straight (rectilinear) slopes of less than 3%. The valley bottoms are flat and relatively broad (> 300 m wide) and the transition into the side slopes of the valley is gradual. The difference in height between the valley bottoms and the top of the interfluves is small, generally not more than some 20 m;

– **Concave inland valleys.** These occur in the zone with a mean annual precipitation between 1,100 and 1,400 mm. They have concave side slopes between 3 and 8%. The valley bottoms are relatively narrow (< 300 m wide) and are flat in the central part and concave (1 – 2%) towards the sides. The valley bottoms transfer gradually into the side slopes. The difference in height between the valley bottoms and the top of the interfluves is 20 to 40 m;

– **Convex inland valleys.** These valleys are formed in areas with an annual precipitation of more than 1,400 mm. The valleys have moderately steep and convex side slopes of up to 25%. The valley bottoms are flat and are 20 to 400 m wide. There is a distinct bend between valley bottom and the steep side slopes. The interfluves are up to 50 m above the valley bottoms.

The above subdivision is mainly based on differences that are assumed to result from different amounts of precipitation. The lithology underlying the valleys, however, can have a strong influence on the valley morphology as well. Moormann (1981) describes (river) inland valleys formed on different rock types in southern Nigeria as follows:

– On intermediate rocks (mainly mica schists and gneisses), the valleys are distinctly U-shaped with concave or flat valley bottoms. These are narrow in the Equatorial Forest Zone and wide in the Guinea Savanna Zone. The valley bottoms transfer gently into the concave lower and middle slopes of the valley sides. The upper slopes of the surrounding uplands are mainly convex, as are the crests. The relief varies from rolling in the Equatorial Forest Zone to gently undulating in the Guinea Savanna Zone. Elevation differences between the crests and the valley bottoms are some 20 to 40 m;

– On acid crystalline rocks (quartzites and quartz schists), the valleys are V-shaped, deep and narrow. The crests are narrow and sideslopes are mainly convex and steep, transferring into concave footslopes and valley bottoms. The relief is hilly. The crests are 100 to 200 m above the valley bottoms;

– On basic crystalline rocks (amphibolites), deep and narrow U-shaped valleys occur, with oval crests, steep and convex upper slopes, moderately steep and concave mid-

dle slopes, and convex lower slopes. There is a distinct bend between the sides and the concave valley bottom. The crests are up to 60 m above the valley bottoms;
- On the sedimentary deposits of the 'Coastal Plains Sand' along the coast (see Section 2.2.2), the valleys are deep, broad, and U-shaped. There is a distinct bend between the flat valley bottoms and the concave lower side slopes. Valley crests are flat, transferring into convex upper slopes and concave middle and lower slopes. Height differences between crests and valley bottoms are up to 80 m. ·

Smaling et al. (1985a, 1985b) studied some stream inland valleys in Sierra Leone and Nigeria. They describe the most upstream parts of the drainage system (i.e. where a stream channel is virtually absent).

The valleys in Nigeria are located in the Guinea Savanna Zone and are formed
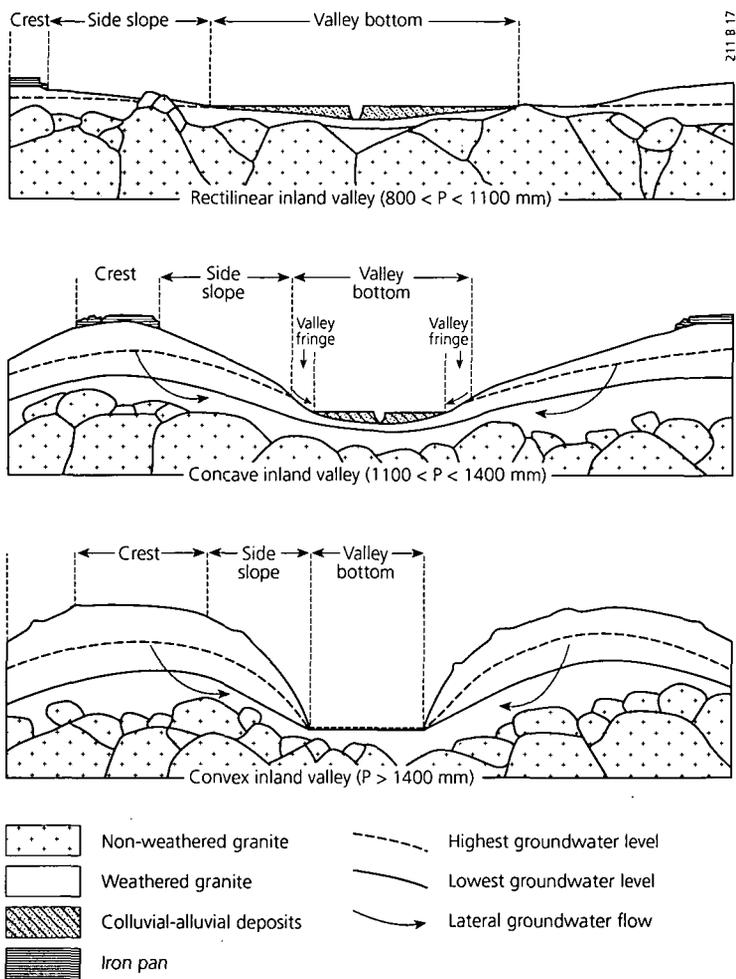
Figure 2.17 Cross-sections of inland valleys in West Africa, developed in granite-gneiss in different rainfall regimes (after: Raunet 1985; adapted)

in the Mesozoic sandstones of the Niger Trough. The side slopes of these valleys are slightly convex and almost flat in the upper part. They are slightly steeper (2 – 5%) down the slope. The valley fringes, the transitional zones between the slopes and the valley bottoms, are narrow (20 – 80 m), rectilinear to slightly concave, and (gently) sloping (2 – 8%). The valley bottoms are narrow (20 – 50 m) and almost flat. The crests are up to 8 m above the valley bottoms.

The valleys in Sierra Leone are located in the Equatorial Forest Zone and have formed in granites of the Basement Complex. The upper slopes of these valleys are convex to rectilinear and range between 2 and 8%. The lower slopes are steeper, locally up to 20%. Locally, gently sloping (2 – 5%) colluvial footslopes and nearly level (0 – 2%) colluvial terraces form the transition between the uplands and the valley bottoms. The valley bottoms are 30 to 100 m wide and are almost flat. The interfluves are up to 15 m above the valley bottoms.

Hakkeling et al. (1989) describe a stream inland valley in Ivory Coast. The valley is situated in the Guinea Savanna Zone and was formed in Precambrian granites and associated metamorphic rocks. The crests and upper slopes are almost flat (0 – 2%), giving way to slightly steeper middle and lower slopes (2 – 4%) that are slightly convex. Rectilinear to slightly concave colluvial footslopes form the transition between the valley sides and the valley bottoms. They are almost flat to gently sloping (1 – 4%) and usually narrow (20 – 100 m). The valley bottoms are almost flat and their width varies from 20 to 50 m (in small tributaries) up to 100 – 250 m (in the main valley). The crests are up to 50 m above the valley bottoms.

From these descriptions of different inland valleys, it will be clear that the interactions between climate, geology, and geomorphology result in valleys with different morphological characteristics. The morphology of inland valleys is important in view of their agronomic suitability. The soil drainage and flooding regimes of inland valleys, for instance, are influenced by the shape of the valley (see Section 2.4).

2.4 Hydrology

2.4.1 General

This section describes the natural land drainage systems of the major catchment areas in the inventory area, as well as the flooding regimes of the inland valleys, their hydrology, and their water balances.

In a study of the West African savanna, TAMS/CIEH (1976-78) collected and elaborated a substantial amount of information on the surface and subsurface water regimes in part of the inventory area. Atavion (1979) also described aspects of land drainage in the inventory area.

Catchments and sub-catchments have been described in varying detail by ORSTOM (1970) and Argoulon (1972) for the Niger Basin, by Chaumény (1972) and Reichhold et al. (1978) for the Senegal Basin, by Mitchel (1973) for the Gambia and Senegal Basins, by the Ministry of Overseas Development (1976) for the Gambia Basin, by Bertrand (1973) for the Casamance Basin, by Girard et al. (1971) for the rivers in

Ivory Coast, by Quartey-Papafio and Kemevor in an undated study for the Volta Basin, by Rodier and Sircoulon (1963) and Moniod (1973) for the Ouémé Basin, by Murdoch et al. (1976) and Wall (1979) for the rivers of southwest and central Nigeria, and by Olivry (1976) and Casenave (1978) for the rivers in western Cameroon.

The natural drainage systems of the land regions and subregions in the study area, as discussed in Section 2.3.2 and shown in Annex 3, are described in terms of their pattern, density, and texture on the basis of information obtained mainly from semi-detailed soil surveys.

Significant investigations on river discharges in small catchments have been conducted in the francophone countries of West and Central Africa by Rodier (1964, 1976 a and b), Roudier and Auvray (1965), Chevalier (1990), Ribstein (1990), HYPER-BAV (1990), and Bourges (1991).

Descriptions of the hydrological processes and flooding characteristics in inland valleys are given by Millington et al. (1985), Turner (1985), Raunet (1985), and Ooster-baan et al. (1987).

General reports on water balance computations are given by Beven and O'Connell (1985), Ojo (1985), Iwata et al. (1986), and LaBaugh (1986).

Measurements and computations of the water balance (or components thereof) for individual valleys or groups of valleys have been made by ORSTOM in Ivory Coast and Burkina Faso (Dubreuil 1966, Matthieu 1971, Molinier 1976, Lenoir 1978, Boulet 1978, and Collinet and Valentin 1979), by van der Sommen and Geirnaert (1988) in Burkina Faso, by the Institute for Agricultural Research Samaru (1972) in northern Nigeria, by IITA for southwest Nigeria (Moormann 1973, Moormann and Veldkamp 1978, Moormann et al. 1974, 1976, and Veldkamp 1979), Gunneweg et al. (1986) for the Bida area in central Nigeria, and by Ledger (1975) for an extremely wet catchment in southern Sierra Leone.

2.4.2   Catchment Areas

The catchment areas (drainage basins) of the major rivers in West Africa can be divided into two main groups. These are:
- The huge catchment areas of the large rivers which initially flow in a northerly direction and then turn either to the west (the Senegal, Gambia, and Casamance Rivers) or to the east and subsequently to the south (the Niger and partly the Volta Rivers). The length of these rivers is more than 1,000 km (Gambia 1,100 km; Senegal 1,400 km; Volta 1,500 km; and Niger 4,100 km).
  These rivers rise in the Fouta Jallon and associated mountain ranges in the western part of West Africa. With the exception of the Senegal River and the Niger, they all lie entirely in the inventory area. Only the upper catchment of the Senegal River is located in the inventory area, whereas a part of the middle stretches of the Niger River is outside the inventory area.
  The Benue River, a tributary of the Niger with a length of 1,050 km, follows a similar pattern as described above but it originates in the Cameroon Highlands, flows north initially, turns west and then, further downstream, to the south;
- The less extensive catchment areas of the relatively smaller rivers which flow from the inland almost directly to the coast. They have a general north-south direction

in Ivory Coast, Ghana, Togo, Benin, and Nigeria, and a northeast-southwest orientation in Senegal, Guinea Bissau, Guinea, Sierra Leone, Liberia, and Cameroon. The length of these rivers hardly exceeds 500 to 600 km. All these rivers are entirely located within the inventory area.

The catchment areas of the main rivers (high-order rivers) are composed of numerous smaller catchments with their own tributaries (lower-order rivers). With decreasing order, the rivers become smaller and drain a less extensive drainage basin. The inland valleys are drained by the lowest order rivers of the drainage system.

2.4.3   Natural Drainage Systems

Natural drainage systems can be characterized in terms of drainage pattern, density, and texture. The drainage characteristics of the different land regions and subregions are described in the legend of the land region map in Annex 4.

The **drainage pattern** refers to the spatial arrangement of the drainage ways, which may or may not be systematic, depending on lithology and relief.

In the lowlands of the coastal plains (Subregion 1.1), estuarine and deltaic drainage patterns are obvious, and (tidal) swamps occur locally (Nigeria and the coastal strip in Sierra Leone, Guinea, Senegal, and The Gambia). In Subregions 1.2, 1.3, 1.4, and 1.5, a dendritic (i.e. non-orientated) drainage pattern occurs, but sedimentary stratification coupled with slight dipslopes in the coastal terraces have locally given rise to a trellis drainage system (Subregions 1.2 and 1.3).

Rivers that have formed large floodplains (Subregion 1.6) show a meandering drainage pattern (the Gambia, Senegal, Niger, and Benue Rivers). A braiding pattern is locally found in the floodplains of the Chad Basin (Subregion 1.7).

Dendritic drainage patterns also prevail in the interior plains and the plateaux (Land Regions 2 and 3). Within the subregions of those interior plains and plateaux that comprise rock formations of the Basement Complex (Subregions 2.1, 2.2, 3.1, and 3.2), the distinct orientation of the subparallel and locally trellis drainage pattern is caused by the structural differences of the underlying rock, which may result in outcrops of more resistant formations (quartzitic bands, granitic hills and ridges). In areas underlain by sedimentary rocks (Subregions 2.8, 2.10, and 2.11), the stratification and the slight dipslopes of those formations locally result in rectangular and subparallel drainage patterns.

The outer fringes of the Volta Basin in Ghana (Subregion 2.4) have been upwarped. Under the influence of the resulting inward overall slope, a distinct subparallel drainage pattern has developed in this area.

In the Highlands (Subregions 4.1, 4.2, and 4.3), the drainage patterns are predominantly subparallel. The rectangular drainage pattern occurring in the high sandstone and shale plateaux of the Fouta Jallon (Subregion 4.4) is controlled by faults, along which streams have extended their courses by headward erosion.

The **drainage density** is the total length of all streams in a drainage basin per unit area and is expressed in km waterway per km^2 basin. The **drainage texture** refers to the number of streams per unit area, expressed in number per km^2. The latter is closely

related to relief and dissection. High drainage density and fine drainage texture generally occur on hard rock formations such as granites and quartzites, which force precipitation largely to run off superficially. On softer and more permeable formations such as the sedimentary deposits, more water is discharged internally and therefore the drainage density is lower and the texture is coarser.

The ratio between drainage density and drainage texture indicates the average length of the streams. If this average is low, the streams are generally short and the area concerned is most likely to comprise a relatively large number of stream and river inland valleys.

Drainage density is related not only to lithology but also to the amount of precipitation. In the Sudan Savanna Zone, drainage densities vary, depending on the rock type, from 0.1 to 0.6 km/km^2. In the wetter Guinea Savanna Zone, drainage density ranges from 0.3 to 1.2 km/km^2 while in the Equatorial Forest Zone, it is between 0.6 and 2.4 km/km^2.

Drainage patterns, densities, and textures of the individual land subregions in West Africa are shown in the legend of the land region map in Annex 4.

2.4.4   Flooding Regimes of Valleys

The flooding regime of valleys depends on their position in the natural drainage system. With regard to natural flooding (i.e. flooding without embankment of the river or other artificial drainage structures), two regimes can be distinguished. These are (Figure 2.18):
- **The inflow flooding regime**, in which flooding is the result of the accumulation in the valleys of surface runoff and groundwater flow from the adjacent uplands and from rainfall. This flooding regime is characteristic of the stream inland valleys;
- **The overflow flooding regime**, which is mainly the result of riverbank overflow. When so much rain falls that a river channel becomes incapable of carrying the greater volume of water, the flood water escapes on to the floodplain or beyond. This flooding regime is characteristic of the river inland valleys and of the large floodplains of the higher-order rivers (see Section 2.4.3).

2.4.5   Physio-Hydrology of Inland Valleys

Inland valleys comprise the toposequence, or continuum, of the uplands to the valley bottom (Andriesse and Fresco 1991). A continuum is in itself a landscape concept describing an environment in which a diversity of ecosystems occur. The upland/inland swamp continuum refers to a sequence of land types and associated ecosystems located along the slopes of the local topography. The ecosystems in this continuum vary from upland in the highest parts, through hydromorphic conditions lower down the slopes, to swampy in the valley bottoms. Key parameters of soil and water, which determine the potential for cultivation, are closely related to the location on the toposequence (Moormann et al. 1977, Moormann and van Breemen 1978, Veldkamp 1979, WARDA 1988, and Andriesse and Fresco 1991).

Different parts of these toposequences have their own typical hydrology.
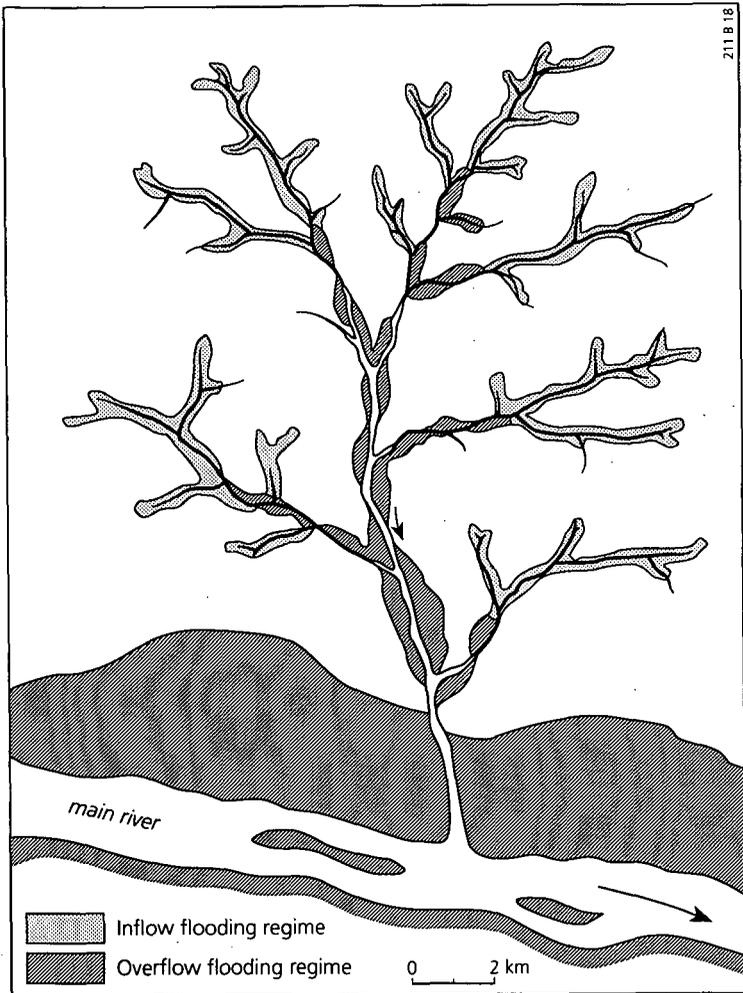
Figure 2.18 Schematic location of the different flooding regimes along natural drainage ways (after: Sav-
vides 1981; adapted)

Figure 2.19 shows a schematic toposequence of an inland valley and its landscape
elements, each with its typical hydrological regime. The classification of the different
physio-hydrographic units was derived from Moormann and van Breemen (1978) and
was further elaborated by Andriesse and Fresco (1991).

In **the pluvial zone** (i.e. the crests, upper slopes, and middle slopes of the uplands),
the only source of water for plants is precipitation. Groundwater is not a source of
water because it remains too deep in the soil profile, even in the rainy season. Excess
rain water not stored in the soil is discharged by runoff or by percolation to the ground-
water. There is a lateral flow of groundwater to the lower positions of the topose-
quence.

On the lower slopes of the toposequence (i.e. **the phreatic zone)**, groundwater,
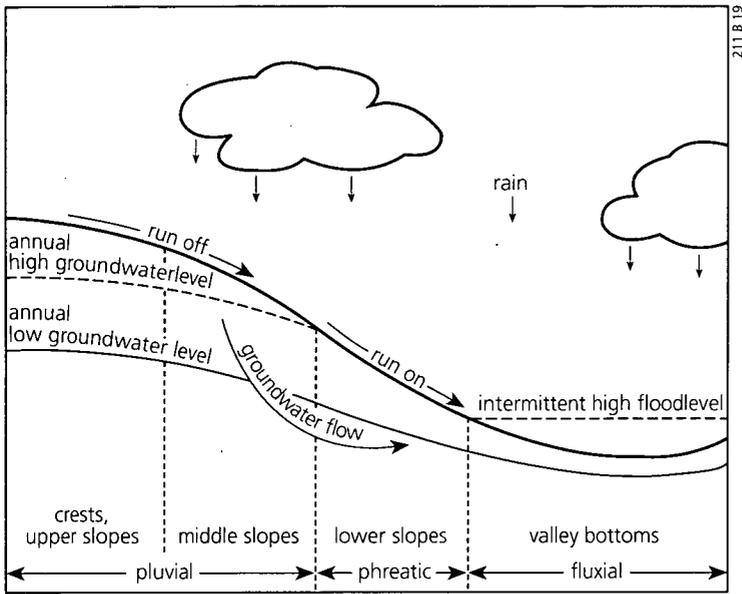
Figure 2.19 Landscape elements and hydrological regimes along an inland valley toposequence (after: Andriesse and Fresco 1991; adapted)

together with precipitation, is the major source of water for plants, at least during the rainy season, but also in the beginning of the dry season. In the course of the rainy season, the watertable rises to shallow depths or appears at the surface. This is caused by the lateral flow of groundwater from the higher parts of the toposequence. In the dry season, the watertable will fall to a lower level, depending on the climate and on the morphology of the valley.

The fluxial zone (i.e. the actual valley bottom) is saturated and inundated in the rainy season and, depending on the climate and on the morphology of the valley, for a certain period after the rains have stopped. In this physio-hydrographic zone, the main sources of water are surface flow (runoff from the uplands and flooding by the stream, if present), groundwater inflow from the uplands, and precipitation. In the dry season, groundwater inflow is the only source of water that may cause continued inundation.

Groundwater fluctuations are most pronounced in the uplands and in the upper slopes, and they become less distinct towards the valley bottoms (Lenoir 1978; Hakkeling et al. 1993). An example of the rise and fall of the watertable in inland valleys in central Ivory Coast is shown in Figure 2.20. In the uplands, the fluctuations can be up to 4 m, in the lower slopes up to 2 m, and in the valley bottoms, which are inundated for short periods only, they are less than 50 cm (Lenoir 1978). Hakkeling et al. (1989) found the same pattern in a footslope of a stream inland valley in central Ivory Coast. The higher parts of the footslope show strong fluctuations of the groundwater during the year, while the watertable remains close to the surface in the lower positions.

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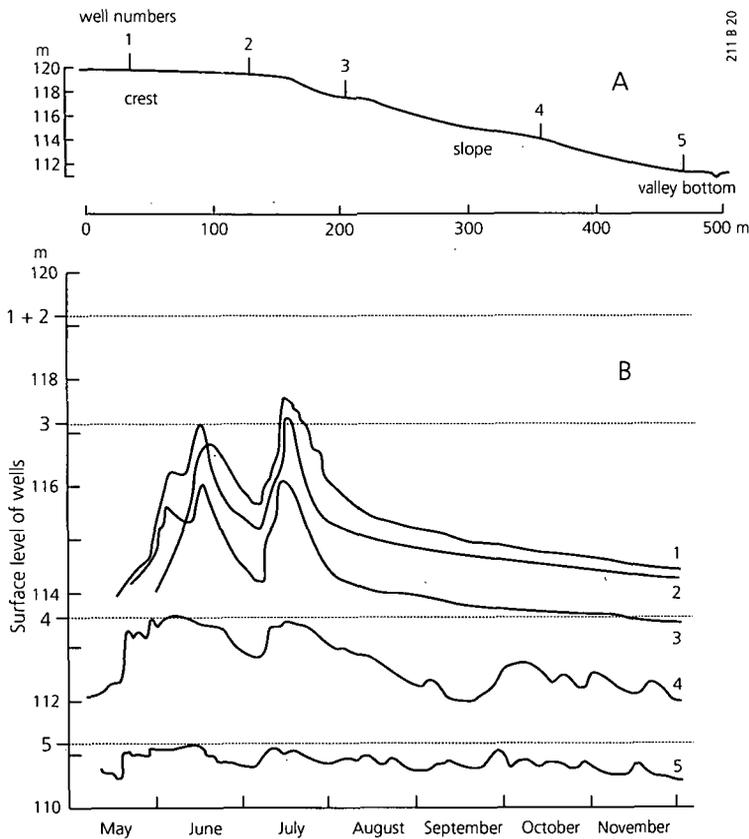
Figure 2.20 Groundwater fluctuations in an inland valley toposequence formed in granite, central Ivory Coast, A: Location of the piezometer wells, B: Rising and falling watertables (after: Lenoir 1978; adapted)

At a specific location, the fluctuation of the watertable varies from year to year according to the annual variation in the precipitation. Variations between different sites during the seasons are the result of local differences in precipitation, valley morphology, and infiltration rates. Because of the north-south increase in precipitation in West Africa, the fluctuations of the watertable in the uplands are relatively small in the Sudan Savanna Zone, moderate in the Guinea Savanna Zone, and relatively large in the Equatorial Forest Zone. In the latter Zone, however, groundwater fluctuations in the valley bottoms are relatively small in comparison with those in the other agro-ecological zones. The reason for this is that, in this Zone, there is a larger and more continuous flow of groundwater from the uplands into the valley bottoms (Raunet 1985).

In addition to the annual fluctuations of the watertable, there are long-term fluctuations too. Between 1978 and 1985, for example, the average groundwater level of a catchment in Burkina Faso fell almost 4 m from the long-term average (van der Som-

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men and Geirnaert 1988, Martin and Thiery 1987). Although, in this catchment, the influence of groundwater extraction from wells and the effect of a decreased infiltration capacity due to sealing were considerable, the largest share in the fall of the groundwater level was attributed to the low precipitation during those years. According to Martin and Thiery (1987), if the precipitation returns to its long-term average, it will take 7 to 10 years before the groundwater level is back at its normal position.

Lowering the groundwater level strongly influences the hydrology of the inland valleys. Because of the subsequent decreased groundwater flow, the valley bottoms receive smaller amounts of water and they dry up earlier in the dry season. In southern Mali, this phenomenon was noticed by Jansen and Diarra (1990).

2.4.6 Water Balances of Inland Valleys

From a hydrological point of view, whether, and for which period, inland valleys can be used for agricultural purposes depends on the magnitude of the normal and peak discharges of the valleys, the amount and duration of the superficial and subsurface water influx from adjacent uplands, the height and duration of inundation during the rainy season, and the depth of the watertable during the dry season.

The water fluxes can be expressed in water balances. Based on descriptions given by various authors (LaBaugh 1986, Beven and O'Connell 1985, Oosterbaan et al. 1987, Ojo 1985, van der Sommen and Geirnaert 1988, Iwata et al. 1986, and Gunneweg et al. 1986), the water balance of the uplands can be written as:

$$\Delta H_u = P - E_u - R_u - Q_u$$

and, for the valley bottoms, as:

$$\Delta H_v = P + (Q_u + R_u)\, ^{A_u}/_{A_v} - E_v - R_v$$

where:

ΔH = change in amount of water stored
P = precipitation
E = evapotranspiration
R = runoff
Q = groundwater flow
A = area
u = suffix indicating upland
v = suffix indicating valley bottom

All water balance components, except the area, can be expressed in mm.

Surface runoff from the uplands (R_u) is a fraction, determined by the runoff coefficient, of the total amount of rainfall (P). The runoff coefficient depends on a large number of parameters: rainfall in terms of quantity, intensity, and duration, the size and shape of the catchment area, the vegetation, the soil texture, the soil structure, and the degree of saturation of the soil. Because of the variability of these factors, the runoff coefficient may range between almost 0% to almost 100% for different areas and for different seasons.

During inundation or complete saturation of the valley bottoms, the upland runoff (R_u) and the valley runoff (R_v), consisting of streamflow (if a stream channel is present) and non-channelized surface flow, will be much greater than the lateral subsurface flow. If the rains fall at the time when saturated soil conditions exist, peak discharges are likely to occur. The valley discharge will reduce to base flow if the runoff from the uplands into the valley bottom decreases to nil and the stream is fed by lateral groundwater flow (Q_u) only.

The change in the amount of stored groundwater (ΔH) is the sum of water inflow and outflow at a certain site. Water that does not run off or evaporate from a site and that is not stored in the unsaturated zone of the soil will be added to the groundwater reservoir, causing a rise of the watertable. This rise of the watertable in the uplands is the driving force for the increase of the groundwater flow from the uplands to the valley bottoms. Upon cessation of the rains, this groundwater flow results in the fall of the watertable.

During the dry season, water availability in the valley bottoms depends to a large extent on the groundwater flow from the uplands. In the course of the dry season, the inland valleys may dry up. In that case, ΔH is zero over the period since the beginning of the preceding rainy season, both in the uplands and in the valley bottoms.

The subsurface water movement in the uplands and valley bottoms is governed by a number of interrelated variables. The values of these variables are restricted in time and place.

- The hydraulic gradient, i, is the difference in height between two points on the watertable, divided by their horizontal distance. The position of the watertable depends on the fill and depletion of the groundwater reservoir and on the position and slope of the underlying bedrock or other impermeable layer;
- The hydraulic conductivity, K, is the resistance coefficient of the aquifer. The value of K is determined by the soil texture and structure. For a uniform soil mass, K is near constant under completely saturated conditions. In a layered soil, the overall horizontal hydraulic conductivity is the weighed average of the water-carrying soil layers;
- The thickness of the water-carrying layer, D, changes with the fill and depletion of the groundwater reservoir. It is the depth of the groundwater from its upper level to the impermeable (bedrock) layer. The combined KD value expresses the transmissivity of the soil.

At the transition zones of the valley sides to the valley bottom, groundwater may appear at the surface during and after rains. This is often referred to as seepage and the area where this occurs is called the seepage zone (phreatic zone). The occurrence of this phenomenon implies that the soil overlying the impermeable (bedrock) layer is too shallow, or too contracted, to accommodate the KD value of the moment. Once the KD value has decreased or the hydraulic gradient has increased, seepage will stop. The hydraulic gradient may increase, because of a lowering of the (ground) water level in the valley bottom. The subsurface flow will continue until D has become nil.

2.4.7   Factors Affecting the Water Balances of Inland Valleys

Water balances of inland valleys in West Africa vary considerably with the general

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north-south increase in rainfall, with the different lithological substrata, and with the valley morphology. Raunet (1985), Millington et al. (1985), and Turner (1985) give information about these water balances, from which the following general conclusions have been drawn:

- In the Sahel Savanna Zone, upland groundwater replenishment is nil, even during the rainy season. Rainfall is lost by evaporation and, more importantly, to surface runoff. Therefore, also lateral groundwater flow is absent, except perhaps in a few rather flat areas. Hence, valley stream discharges are high during rain showers, but they are very irregular during the rainy season. There is no effective prolongation of the growing period due to seepage in the lower slopes of the valleys. In the valley bottoms too, even though accumulation of water takes place, soils usually do not become completely saturated for long periods;
- In the Sudan Savanna Zone, during the rainy season, rainfall is not entirely lost by evaporation and surface runoff. Some upland groundwater replenishment and subsequent groundwater flow may occur in flat to rolling land. In this agro-ecological zone too, stream discharges can be high during rain showers. The presence of a base flow, however, causes discharges in the rainy season to be somewhat more regular than in the Sahel Zone. Nevertheless, the effect of this groundwater flow on the prolongation of the growing period in the valley is too little to be taken into account;
- In the Guinea Savanna and the Equatorial Forest Zones, watertables in both the uplands and the valley bottoms rise considerably during the rainy season. The base flow is substantial and continues after the rains. Although peak flows occur regularly, valley streamflows generally have a rather equable nature. In these agro-ecological zones, growing periods in the valleys are prolonged considerably owing to the relatively long periods of groundwater flow from the uplands to the valleys. Valley bottom soils may be completely saturated for long periods. In the Equatorial Forest Zone, in particular, these soils can be saturated throughout the year.

The depth and duration of flooding depends on the morphology of the valleys, their longitudinal gradient, the lithology of the substratum (permeability), and on the precipitation.

Millington et al. (1985) found that 10% of the (forested) stream inland valleys in Sierra Leone (Equatorial Forest Zone; humid period May-November) had standing water throughout the year. The other valleys dried up at least by late April or long before then. Floods in these valleys reached levels of up to 1.4 m.

In the Guinea Savanna Zone, Hakkeling et al. (1989) and Smaling et al. (1985a) observed flooding periods from two to five months in stream inland valleys over granites and sandstones respectively. Groundwater levels in the colluvial footslopes, valley fringes, and valley bottoms of these valleys remain within the rootzone for nine to twelve months.

In Mali (Sudan Savanna Zone), the soils in the valley bottoms are moist only during the rainy season. Floods occur only temporarily upon heavy rains in the most humid months (Brouwers and Raunet 1976).

With respect to lithology, Millington et al. (1985) concluded that the discharge rates in inland valleys formed in granites are higher than in valleys over finer-textured rocks.

Also, in granitic areas, valleys dry up quicker.

Turner (1985) found that inland valleys in northern Nigeria (the transitional zone between the Guinea Savanna and the Sudan Savanna) are perennially moist if the longitudinal slope of the valley bottom is less than 1%. The valley bottoms are seasonally moist if the gradient varies roughly between 1 and 2%.

Vegetation and cultivation strongly influence the water balance of inland valleys. Under natural vegetation, the runoff from uplands to valley bottoms is generally low and precipitation will largely infiltrate into the soil and accumulate in the groundwater.

Dense vegetation on the valley bottom hampers the surface drainage of inland valleys. Clearing a stream inland valley will change its water balance. Under protracted cultivation, the structural stability of soil aggregates may deteriorate, resulting in surface sealing and/or compaction of the subsoil. This decreases the infiltration rates and causes increased runoff.

An example of different water balances in inland valleys under natural vegetation and in cleared inland valleys under cultivation is shown in Figure 2.21. Under natural vegetation, this specific inland valley has relatively low peak discharges and there is a steady base flow from the uplands. Under cleared conditions, peak discharges are much higher. Also, because of the decreased infiltration rate of the soils, there is hardly any base flow and this results in a faster drying up of the inland valley after the rains have stopped (Fiselier 1990).

The morphology of inland valleys determines the soil drainage within the valley toposequences. Concave valleys show a gradual transition from well drained conditions on the valley crests and upper slopes (the pluvial zone), through moderately good drainage on the lower slopes (the phreatic zone), to imperfect to poor drainage (the fluxial zone) in the valley bottom. If floods occur, their depths and durations vary widely according to the topography in the valley.
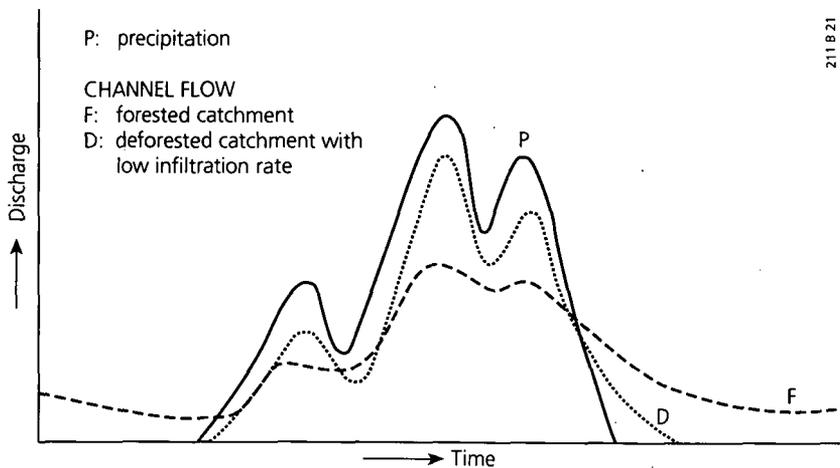
Figure 2.21 Changing discharge characteristics of an inland valley due to deforestation (after: Fiselier 1990; adapted)

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Convex valleys have an abrupt change in drainage conditions between the two main valley facets: the flat valley bottoms have poor drainage, whereas the steep side slopes are well drained. The phreatic zone in these valleys is very narrow. Watertables or flood levels do not show much spatial variation over the whole of the valley bottom.

2.5   The Soils

2.5.1   Soil Formation

As was discussed in Section 2.3, large parts of West Africa consist of old peneplains formed during different erosion cycles. Because of the lack of tectonic activity, these peneplains have not been rejuvenated, and have old and often strongly weathered and leached soils. The degree of soil depletion shows a general increase from north to south, and coincides largely with the distribution of present-day rainfall zones in the inventory area.

Soils with the strongest leaching are found in the southwestern part of West Africa (Liberia and Sierra Leone) and in the southeast (Cameroon). They are rich in kaolinitic clay minerals and sesquioxides (aluminium and iron oxides), and have an adsorption complex that is predominantly occupied by hydrogen and aluminium ions, resulting in a (very) low base saturation.

Soils further to the north and in the Togo Gap, the 'dry corridor' of southern Ghana, Togo, and Benin, have higher base saturation. As most landforms in West Africa are of Plio-Pleistocene age and are thus older than the present geo-climatic era, there is, however, no single causal relationship between present climate and soils.

In addition to paleo-climate, lithology has a pronounced effect on soil formation and properties. Basement Complex metamorphic rocks (schists, amphibolites, and green-stones) have weathered into relatively fine-textured soils (light clays). Soils on amphibolites are rich in ferro-magnesium minerals like olivine, pyroxene, and hornblende. On the other hand, the relatively high iron (and manganese) content of these minerals causes a high incidence of layers of ironstone concretions and hardpans. Soils developed on intermediate (mica schists, gneisses) and acid (granites, quartzites) Basement Complex rocks have textures ranging between sand and sandy clay. Ironstone sheets and hardpans also occur in soils over these rock types, but less frequently than in areas with more basic rocks.

The parent material of soils developed in sedimentary formations has been subjected to more than one weathering cycle. As a result, soils are chemically poor, with quartz, kaolinite, and gibbsite as the main constituents.

2.5.2   Distribution, Properties, and Classification of the Soils

Properties of soils in the inland valleys are strongly correlated with their position in the toposequence. The main landscape elements of the inland valleys in West Africa are the crests and the upper, middle, and lower slopes (together referred to as 'uplands'), the valley fringes and colluvial footslopes, and the valley bottoms.

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There are two major soil types in the uplands: deep to very deep, red soils, and shallower, gravelly soils that overlie indurated ironpans. Both soil types are moderately well or well drained. Their relative importance depends on the degree of dissection of the uplands and on the interplay between weathering and surface erosion.

On the colluvial footslopes and valley fringes, soils have been rejuvenated somewhat by colluviation, although this colluvium material was already poor when being transported. Through lateral groundwater flow, there may be a subsurface accumulation of nutrients from the uplands. As, in these physiographic units, groundwater is within the rootzone for part of the year, drainage ranges from moderately well in the upper parts to poor in the lower parts.

The valley bottoms are made up of colluvial-alluvial deposits, and have weakly developed, (very) poorly drained soils. Their flat topography and alternating hydrological conditions largely determine their agricultural potential.

The following descriptions of soil properties are mainly based on D'Hoore (1965), Ahn (1970), FAO (1977a), and Driessen and Dudal (1989). Soil classification refers to the Revised Legend of the Soil Map of the World (FAO/UNESCO/ISRIC 1990).

Soils of the Uplands

Based on the degree of weathering and leaching, three major soil groups can be distinguished in the uplands of the inventory area: Ferralsols, Acrisols, and Lixisols.

Ferralsols are predominant in the humid southwestern and southeastern parts of the inventory area (Sierra Leone, Liberia, and Cameroon). They are strongly weathered, leached soils with a ferralic B-horizon, i.e. a horizon characterized by, amongst other things, a cation exchange capacity (CEC) below 16 cmol(+)/kg clay (1M NH_4OAc at pH 7). Because of strong weathering, even the more resistant primary minerals have been removed from the soil profile, rendering quartz, kaolinite, goethite, hematite, and gibbsite as the major components. As a consequence, Ferralsols have a very low inherent fertility, and a relatively low organic-matter content in the topsoil. The Ferralsols in the inventory area are mainly medium-textured (sandy clay loams to light clays) and deep to very deep. They have a weak macro-structure but a well-developed micro-structure. Kaolinite, together with sesquioxides, forms strong micro-aggregates of silt or sand size. As a result, Ferralsols have a high porosity and permeability, and high infiltration rates. Ironstone hardpans and layers of indurated plinthite (French: *cuirasse, carapace*) can occur in Ferralsols, especially in areas with parent materials that are rich in iron and magnesium (e.g. amphibolites). They are, however, less common than in the Lixisols and Acrisols.

Acrisols are the major soils in the transitional area between the Equatorial Forest Zone and the Guinea Savanna Zone (eastern Guinea, Ivory Coast, southwestern Ghana, and southeastern Nigeria). Acrisols are soils which have an argic B-horizon, characterized by clay illuviation, with a cation exchange capacity of less than 24 cmol(+)/kg clay, and a base saturation of less than 50% in at least some part of the B-horizon within 125 cm of the surface. Acrisols have few weatherable minerals, and the clay fraction consists mainly of kaolinite and some gibbsite. Acrisols in the inventory area are coarse- to medium-textured, overlying a finer-textured B-horizon. Ironstone sheets and hardpans are more common than in the Ferralsols. Most Acrisols have a massive macro-structure and a micro-structure that is weaker than in Ferralsols.

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This causes Acrisols to be more susceptible to erosion than Ferralsols, particularly if their organic matter content is low.

Lixisols are the major soils in the northern and central parts of the inventory area (southern Senegal, Gambia, parts of Guinea Bissau, southern Mali, Burkina Faso, northern, central, and eastern Ghana, Togo, Benin, and western, central, and northern Nigeria). They have an argic B-horizon with a cation exchange capacity of less than 24 cmol($+$)/kg clay, at least in some parts of the B-horizon, and a base saturation of 50% or more throughout the B-horizon. Strong weathering during the early stages of soil formation may have been followed by chemical enrichment in more recent times due to capillary rise of the groundwater, eolean deposition, biological activity, or lateral seepage. Occurrence of fossil plinthite or indurated ironstone nodules are indications of wetness in the past.

The topsoils are coarse- to medium-textured (sandy loams to light clays), overlying a finer-textured subsoil, with clay mineralogy being dominated by kaolinite. Lixisols have a higher pH than Acrisols and Ferralsols. They are mainly moderately deep to deep, and often (very) gravelly, especially when developed from parent material rich in quartz (granites, quartzites, some gneisses). The soils often overlie continuous ironstone hardpans or sheets of ironstone aggregates at shallow depth (petroferric contact), especially in areas with parent materials that contain much ferro-magnesian minerals (e.g. amphibolites). Lixisols have a lower structure stability than Ferralsols and Acrisols. Slaking and compaction of these soils is common under continuous cultivation and poor land management.

Other soils: The soils on the Cretaceous sedimentary formations occupying the Niger and Benue River troughs are mainly Dystric Nitisols, with textures ranging from sandy clay loam to clay. These soils are very deep and have a thick argic B-horizon with a clay distribution that does not show a relative decrease from its maximum of more than 20% within 150 cm of the surface. Nitisols are also the major soils of the coastal terraces and the aggradational plains of western Gambia and southwestern Senegal.

In the drier, northern part of the inventory area, soils with little profile development have developed on Tertiary sedimentary deposits. They are very sandy and have some clay bands (Luvic Arenosols) or a cambic B-horizon (Cambic Arenosols).

Cracking clay soils (Vertisols) occur in the marly sediments of the Hollis Lama depression in Togo and Benin, the clayey Tertiary deposits in Mali and Burkina Faso, the clayey Cretaceous rocks in northeastern Nigeria (Benue trough), the Precambrian fine-textured rocks in northern Cameroon, and the Dolerites in Mali.

The soil types described above are the most common soils found on the uplands (crests, upper, middle, and lower slopes) of the toposequences of the West African inland valleys. On strongly eroded valley side slopes, however, soils are generally weakly developed; these soils classify as Cambisols or Leptosols. The latter soils, in particular, are shallow, having either parent rock or ironpans within 30 cm of the surface. In locations with relatively high groundwater levels and lateral groundwater flow from the sideslopes, plinthite can be formed.

Soils of the Colluvial Footslopes and Valley Fringes

Colluvial deposits of upland soil material constitute the parent material of the soils of the colluvial footslopes and valley fringes. These soils generally have a low fertility

because, even before the transport and sedimentation of this parent material, it was already strongly weathered. The colluvium may include gravelly layers of quartz or ironstone concretions which were either formed in the soils of the upper parts of the toposequence, before these eroded, or are formed in situ. The extent of the colluvium depends largely on local meso-relief. In the Equatorial Forest Zone, where relief is generally more pronounced than in the Guinea Savanna and Sudan Savanna Zones and where drainage texture is higher, the colluvial zones are narrow. In the Guinea Savanna and Sudan Savanna Zones, relief is gently undulating and colluvial zones are wider.

Most soils classify as Cambisols (i.e. soils with a cambic B-horizon, showing little profile development), Gleysols (soils with gleyic properties within 50 cm of the surface; gleyic properties refer to signs of periodic wetness), and Arenosols (soils with a coarse sandy texture). Also Lixisols and Acrisols are found on these positions. If the gleyic properties occur between 50 and 100 cm from the surface, these soils are classified as Gleyic Cambisols, Gleyic Arenosols, Gleyic Lixisols, or Gleyic Acrisols, respectively. If plinthite is predominant, soils may classify as Plinthosols.

Soils of the Valley Bottoms

The lowest parts of the toposequence are occupied by the valley bottoms. In the river inland valleys, the valley bottoms consist mainly of alluvial material, originating from areas upstream. The soils of the stream inland valleys are mainly formed in colluvial material from adjacent uplands.

Most soils of the valley bottoms have gleyic properties (i.e. characteristics associated with wetness) and, unless artificially drained, have reduced conditions for at least some period of the year. If periods of flooding and/or saturation are short, reduction of the soil environment is incomplete and hydromorphic properties are hardly developed, if at all.

Under prolonged waterlogged conditions, plant remnants are slow to decompose, and humic topsoils may be formed which have relatively high organic-matter contents compared to those of the soils of the adjacent uplands.

The soils of the valley bottoms differ strongly, both within and between individual valleys. This is caused by their morphogenesis as (stratified) alluvial and colluvial deposits, the wide range of valley shapes with different hydrological regimes, and different lithologies.

Soil texture varies all the way from sand to clay. Because of the alluvial and colluvial origin of the parent material, the soils can be strongly stratified, including gravelly layers and/or layers with iron concretions. The inherent fertility ranges from very low to moderate. In terms of texture and fertility of their mineral fraction, soils of the valley bottoms reflect the characteristics of the parent material of the surrounding uplands. Coarse texture and very low fertility prevail in areas with sandstones and quartzites, coarse texture and low fertility in granitic areas, and medium to fine texture and low to moderate fertility in areas with shales, siltstones, and intermediate to basic rock formations.

Actual soil fertility is largely governed by the prevailing hydrological conditions. Temporary waterlogging results in low decomposition rates of organic matter, and thus relatively high CEC in the surface horizons. In addition, upon waterlogging, the soil pH tends to rise to values of 6 to 7, increasing the availability of phosphorus

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and major cations to values above those under dry conditions. The availability of nitrogen under waterlogged conditions is reduced, however, owing to low mineralization rates and the risk of denitrification under alternating wet and dry conditions.

The poorly drained soils of the valley bottoms, and of the lower colluvial footslopes, often show Fe^{2+}-toxicity. When the soils are submerged, insoluble Fe^{3+} compounds will be reduced to soluble Fe^{2+} compounds. A second source of Fe^{2+} is the seepage flow from the adjacent uplands, which commonly contains high concentrations of ferrous iron. Under acid conditions, Fe^{2+} concentrations of about 50 ppm have been found to harm rice if nutrient concentrations are very low, whereas, in fertile soils, up to a few hundred ppm Fe^{2+} are still tolerated (van Mensvoort et al. 1985; van Breemen and Moormann 1978; IITA 1982).

In the FAO Soil Classification (FAO/UNESCO/ISRIC 1990), the presence of gleyic properties is used to distinguish hydromorphic soils. The vast majority of the soils in the valley bottoms do indeed have gleyic properties (i.e. the occurrence of mottling, bleaching, or reduction colours) within 50 cm of the surface, and they classify as Gleysols. Based on differences in base saturation and/or organic matter content of the topsoil, Gleysols are divided into Mollic, Dystric, and Eutric Gleysols.

Stratified soils and soils with a peat cover of at least 40 cm also occur and classify as Fluvisols and Histosols, respectively. In the FAO system, soil units can be further divided into sub-units based on gleyic properties (e.g. Gleyi-dystric Fluvisols).

2.5.3 Soil Fertility Data and Nutrient Balance Studies

Luiten and Hakkeling (1990) studied fertility characteristics of soils in 86 complete topo-sequences of inland valleys formed on different Basement Complex and sedimentary deposits in the three agro-ecological zones of the inventory area. The soils were grouped according to physiographic position (i.e. uplands, footslopes, and valley bottoms). Average values of fertility-related characteristics of these soils are given in Table 2.5.

Soil fertility in West Africa has been thoroughly described by Pieri (1989) and other workers, who largely published their research findings in the francophone journal *l'Agronomie Tropicale*, or in separate publications by ORSTOM and CIRAD/IRAT. In addition to studies on momentary soil fertility, emphasis has been on the different components of the soil nutrient balance, and on ways and means of redressing this often 'unbalanced ledger'. Stoorvogel and Smaling (1990) and van der Pol (1992), in their efforts to quantify the nutrient balance in West African uplands, came to the conclusion that nutrient mining is taking place in most land-use systems. More nutrients leave the soil in crop parts, and through erosion, leaching, and denitrification, than are being added through fertilizers and manure, atmospheric deposition, and biological nitrogen fixation. The negative trend seems to increase over time, largely because of shortened fallow periods, less ground cover, and topsoil compaction.

2.5.4 Detailed Descriptions of Some Toposequences

This section presents descriptions of a number of inland valley toposequences. They are examples of the different lithological substrata of West Africa (Basement Complex

Table 2.5 Chemical characteristics of soils of inland valley toposequences in West Africa (source: Luiten and Hakkeling 1990)

Physio-graphy	Agro-ecol. zone	Rock type	Depth (cm)	pH (1:2.5)		C (%)	N (%)	CEC (meq/ 100 gr soil)	BS (%)	P (ppm, P)	
				H₂O	KCl					P-Bray 1	P-total
Uplands	Equatorial Forest Zone	Basic	0-20	5.9	3.6	2.04	0.160	9.58	36	n.d.	198
			20-50	5.6	3.7	0.76	0.074	6.37	26	n.d.	138
		Acid	0-20	5.3	4.3	2.45	0.160	8.81	21	12.07	628
			20-50	5.1	4.2	1.54	0.103	8.63	16	6.57	644
	Guinea Savanna Zone	Basic	0-20	6.4	5.5	1.42	0.114	11.14	78	n.d.	514
			20-50	6.0	5.1	0.64	0.058	9.87	59	n.d.	333
		Acid	0-20	5.7	5.1	1.17	0.139	6.25	60	2.38	392
			20-50	5.5	4.9	0.68	0.079	5.55	42	0.80	390
		Sedim.	0-20	5.4	4.1	1.04	0.036	3.95	69	3.41	196
			20-50	5.2	3.9	0.61	0.031	4.28	51	1.85	106
	Sudan Savanna Zone	Basic	0-20	6.4	5.0	0.58	0.056	10.68	69	1.82	305
			20-50	6.4	5.0	0.47	0.052	12.16	69	0.70	330
		Acid	0-20	6.8	5.4	0.33	0.049	9.31	93	n.d.	287
			20-50	7.1	5.3	0.43	0.061	8.67	90	n.d.	285
		Sedim.	0-20	6.2	5.1	0.68	0.051	7.34	66	n.d.	159
			20-50	5.9	4.4	0.42	0.034	5.10	33	n.d.	113
Foot-slopes	Equatorial Forest Zone	Basic	0-20	6.2	3.9	1.71	0.077	13.04	48	n.d.	117
			20-50	7.5	3.9	0.26	0.021	10.99	46	n.d.	129
		Acid	0-20	5.3	4.2	1.62	0.162	7.25	21	7.82	279
			20-50	4.9	4.0	0.82	0.061	5.15	11	3.26	163
	Guinea Savanna Zone	Basic	0-20	6.4	5.7	1.55	0.123	16.62	65	n.d.	273
			20-50	6.4	5.5	0.79	0.072	15.59	54	n.d.	273
		Acid	0-20	5.9	5.3	0.65	0.087	4.50	67	22.60	402
			20-50	5.2	4.5	0.30	0.054	3.39	56	14.14	344
		Sedim.	0-20	5.3	3.9	0.54	0.033	3.57	58	3.35	152
			20-50	5.4	4.0	0.37	0.027	5.03	52	2.07	216
	Sudan Savanna Zone	Basic	0-20	5.7	4.7	0.85	0.061	9.97	61	4.11	330
			20-50	6.2	5.1	0.34	0.035	5.06	56	1.67	280
		Acid	0-20	6.7	5.3	0.14	0.016	4.80	89	n.d.	91
			20-50	6.6	5.0	0.14	0.051	5.82	91	n.d.	65
		Sedim.	0-20	6.2	5.0	0.64	0.049	8.39	73	n.d.	136
			20-50	5.9	4.5	0.27	0.039	5.78	48	n.d.	77
Valley bottoms	Equatorial Forest Zone	Basic	0-20	6.5	3.8	1.93	0.042	4.04	59	n.d.	148
			20-50	6.4	3.6	0.20	0.010	1.39	21	n.d.	30
		Acid	0-20	5.1	4.3	2.54	0.209	9.62	27	8.19	198
			20-50	4.5	4.1	0.88	0.071	5.11	29	4.28	128
	Guinea Savanna Zone	Basic	0-20	6.4	5.5	2.04	0.156	18.28	70	n.d.	641
			20-50	6.4	5.5	0.81	0.069	16.27	68	n.d.	311
		Acid	0-20	5.6	4.6	1.13	0.209	8.09	61	7.20	263
			20-50	5.7	4.6	0.39	0.081	6.45	59	2.28	157
		Sedim.	0-20	5.1	4.1	1.04	0.088	9.73	51	3.04	272
			20-50	5.1	4.1	0.63	0.051	7.15	31	4.30	137
	Sudan Savanna Zone	Basic	0-20	6.0	4.7	0.85	0.065	12.10	66	1.98	430
			20-50	6.0	4.6	0.33	0.051	8.89	72	0.92	230
		Acid	0-20	6.4	5.0	0.52	0.021	6.43	89	n.d.	105
			20-50	6.5	4.9	0.06	0.020	4.26	97	n.d.	42
		Sedim.	0-20	5.7	4.6	0.94	0.072	9.04	61	n.d.	133
			20-50	5.5	4.1	0.52	0.041	6.92	50	n.d.	64

n.d. = not determined

and sedimentary deposits) and the three agro-ecological zones (Equatorial Forest, Guinea Savanna, and Sudan Savanna).

A Stream Inland Valley Formed on Acid Granite in the Equatorial Forest Zone (Sierra Leone)

Smaling et al. (1985b) describe the morphology and soils of two asymetric stream inland valleys in the Makeni area of central Sierra Leone (Equatorial Forest Zone, Land Subregion 2.1). This subregion consists of slightly dissected, undulating to rolling peneplains over granite, with common granitic inselbergs and hill ridges. The main morphological and soil characteristics of these valleys are shown in Figure 2.22.

The (very) deep soils of the uplands are somewhat excessively to well drained and have a texture of sandy clay loam with gravel or overlie a gravelly subsoil, starting below 80 cm on the crests and between 40 and 80 cm on the upper and middle slopes. On the lower slopes, these soils may be gravelly throughout. The soils of the steep lower slopes have an indurated ironpan within a depth of 1 m from the surface. Most soils have an umbric A-horizon overlying a ferralic or an argic B-horizon or intergrades between these two (Humic Ferralsols and Ferri-humic Acrisols).

On the colluvial footslopes, soils are well drained, deep to very deep, with a sandy clay loam texture, overlying white granite residuum below 80 cm. Locally these soils are sandy throughout. Most soils have an umbric A-horizon and a ferralic or cambic B-horizon (Humic Ferralsols and Ferro-humic Cambisols).
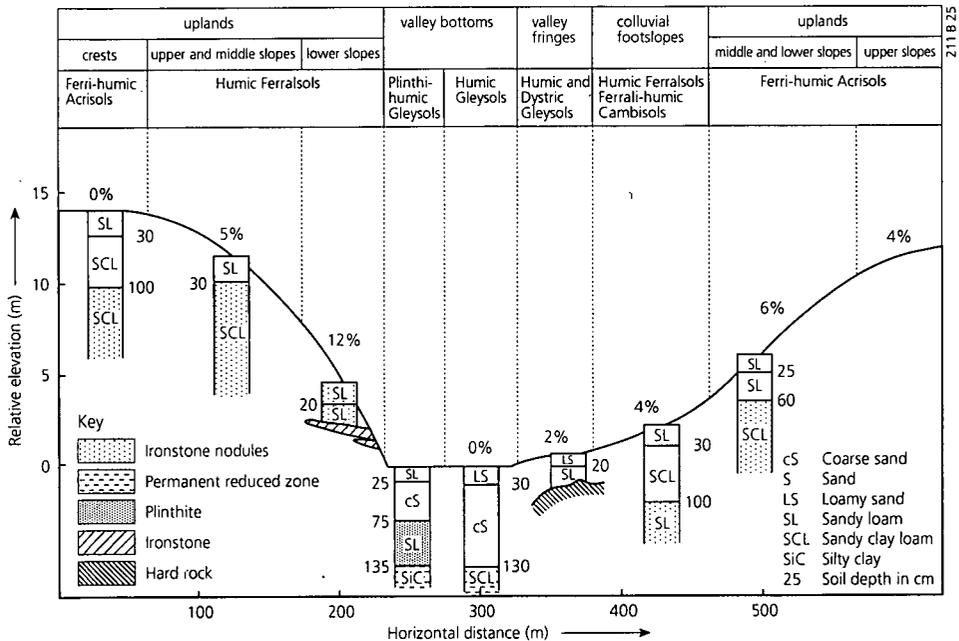
Figure 2.22 Schematic cross-section of a stream inland valley formed on acid granite in the Equatorial Forest Zone, Sierra Leone (after: Smaling et al. 1985b; adapted)

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Soils of the valley fringes are moderately well to poorly drained and moderately deep. They have a texture ranging from coarse sand to clay loam (Humic and Dystric Gleysols, locally with a lithic phase).

The valley bottoms are submerged for more than six months of the year and the soils are poorly drained. They are deep and have varying textures. The umbric A-horizon overlies a cambic B-horizon or a stratified C-horizon (Humic Gleysols and, if plinthite is present, Plinthi-humic Gleysols).

Chemical properties, as listed in Table 2.6, show that these soils are strongly weathered and have a low inherent fertility. All soils are strongly acid (pH-H_2O 5.0-5.5), with a low effective CEC and base saturation.

Available phosphorus (P-Bray) is less than 4 ppm in all soils. Exchangeable acidity is high ($> 60\%$), particularly on the colluvial footslopes and valley fringes ($> 85\%$). Sanchez et al. (1983) consider 60% Al-saturation the lower limit of Al-toxicity.

A Stream Inland Valley Formed on Coarse Acid Granite in the Guinea Savanna Zone, Ivory Coast
Hakkeling et al. (1989) describe the morphology and the soils of a stream inland valley near Bouaké in central Ivory Coast (Guinea Savanna Zone, Land Subregion 2.1).

Table 2.6 Chemical properties of the soils of a toposequence on acid granite, Equatorial Forest Zone, Sierra Leone (source: Smaling et al. 1985b)

Chemical properties	Depth cm	Uplands	Coll. footslopes/ Valley fringes	Valley bottoms
pH H_2O	0-20	5.5	5.2	5.0
(1:2.5)	20-40	5.1	5.3	5.1
pH KCl	0-20	4.2	4.0	4.2
(1:2.5)	20-40	4.1	4.1	4.4
Org. C	0-20	1.5-4.0	1.0-2.5	1.5-9.0
(%)	20-40	0.5-2.0	0.5-1.5	<0.5
CEC pH=7	0-20	4-11	4-7	15-17
(meq/100gr soil)	20-40	4- 8	3-6	<13
ECEC	0-20	2.0-3.0	1.9-2.5	1.0-5.0
(meq/100gr soil)	20-40	1.5-3.0	1.0-3.0	0.5-1.5
Base sat.	0-20	5-50	5-20	5-10
(%)	20-40	4-15	3- 6	n.d.
Ex. Acid.	0-20	10-90	30-90	<65
(% of ECEC)	20-40	>60	>85	>65
N-total	0-20	0.1-0.3	0.1	0.2-0.4
(%)	20-40	n.d.	n.d.	n.d.
P-Bray 1	0-20	1- 4	2-4	3-4
(ppm P)	20-40	0- 1	0.5-1	0-4
P-total	0-20	45-60	35-50	40-100
(ppm P)	20-40	35-50	35-45	10- 50
S-available	0-20	8-35	9-15	3-8
(ppm SO_4)	20-40	n.d.	n.d.	n.d.
Fe-total	0-20	1-1.8	0.3-0.8	0.1-0.4
(%)	20-40	n.d.	n.d.	n.d.

n.d. = not determined

This subregion consist of slightly dissected, (gently) undulating peneplains formed in coarse acid granite with scattered inselbergs. A schematic cross-section of the topo-sequence is given in Figure 2.23.

In the upper slopes and the upper parts of the middle slopes, soils are deep to very deep and well drained, with a sandy clay loam topsoil overlying an argic B-horizon with a sandy clay to clay texture. Ironstone gravel (30-60 wgt %) occurs in the profile, but size and amount decrease with depth. Because of their low base saturation, kaolinitic clay mineralogy, and red colour, these soils classify as Rhodi-humic Acrisols. Locally on the upper slopes, an indurated ironpan is present within 50 cm of the surface. In such places, texture varies strongly and soils are classified as Orthi-dystric Leptosols, petroferric phase. The middle slopes, which, in places, have hardpans too, have a very gravelly sandy clay loam topsoil, mostly overlying a sandy clay to clayey argic B-horizon (Chromi-haplic Acrisols, and to a lesser extent, Orthi-ferralic Cambisols).

Soils of the colluvial footslopes have a coarse texture and a weak profile development. In the upper parts, soils are moderately well to well drained and deep, and have a texture of coarse to medium sand in the surface horizon and sand to loamy sand in the subsurface horizons, with some clay illuviation (Orthi-luvic Arenosols). In the lower parts of the footslopes, soils have imperfect to poor drainage, and gley mottles occur throughout the soil profile (Orthi-gleyic Arenosols).

In the valley bottoms, soils are (very) poorly drained, with mottles in the topsoil and permanent reduction colours below. Texture ranges from sandy clay loam to clay. In places, soils are stratified with thin lenses of coarse sand or loamy sand (Molli-eutric Gleysols and Gleyi-eutric Fluvisols).
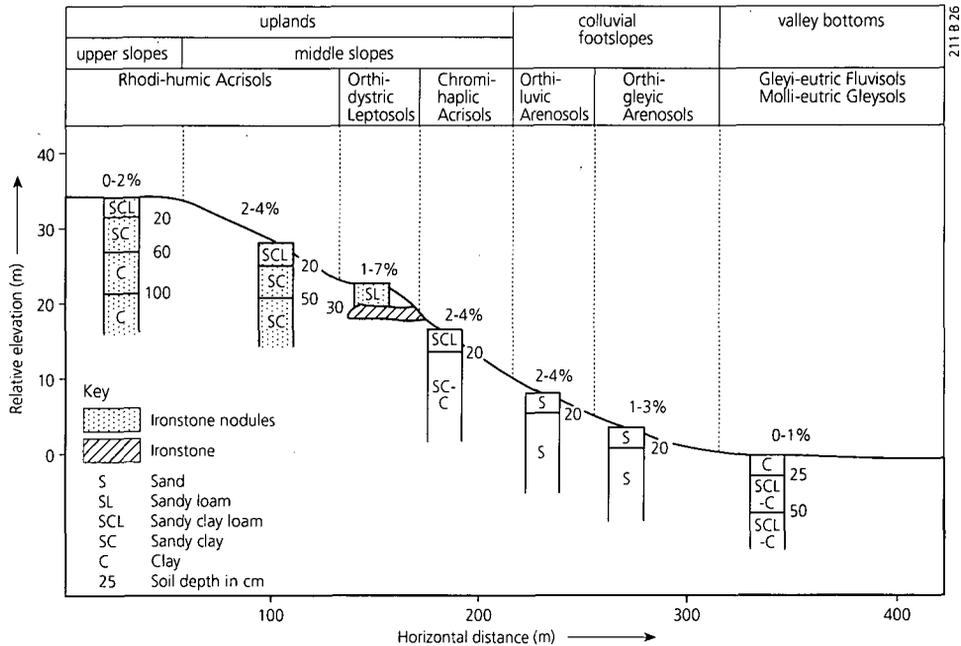
Figure 2.23 Schematic cross-section of a stream inland valley formed in coarse acid granite in the Guinea Savanna Zone, Ivory Coast (after: Hakkeling et al. 1989; adapted).

Table 2.7 Chemical properties of the soils of a toposequence formed on acid granite, Guinea Savanna Zone,
Ivory Coast (source: Hakkeling et al. 1989)

Chemical properties	Depth cm	Upper and middle slopes	Colluvial footslopes	Valley bottoms
pH-H$_2$O	0-20	6.3	6.0	5.8
(1:2.5)	20-40	5.9	5.8	6.3
Org. C	0-20	0.7- 2.1	0.3	2.1
(%)	20-40	0.7- 1.0	n.d.	0.7
CEC pH = 7	0-20	4.0-11.0	2.5	14.1
(meq/100gr soil)	20-40	4.0-10.8	1.5	10.3
Base sat.	0-20	63-73	56.8	63.8
(%)	20-40	28-41	41.3	65.1
N-total	0-20	0.6-1.2	0.3	1.7
(%)	20-40	0.5-0.8	n.d.	0.6
P-Olsen	0-20	4-18	3.0	15.0
(ppm P)	20-40	2- 3	0.5	4.0

n.d. = not determined

Table 2.7 shows that, in the upper and middle slopes, topsoils have a moderate fertility. The sandy soils of the colluvial footslopes are chemically very poor. Owing to low contents of organic matter and clay, and kaolinitic clay mineralogy, the cation exchange capacity is very low. The soils of the valley bottoms are relatively fertile.

A Stream Inland Valley Formed on Sandstone in the Guinea Savanna Zone, Nigeria
Smaling et al. (1985a) studied two stream inland valleys in the Bida area of central Nigeria (Guinea Savanna Zone, Land Subregion 2.6). This subregion consists of slightly dissected, nearly level to gently undulating peneplains with common mesas, formed on Nupe sandstone of the Niger River trough. The main morphological and soil characteristics are shown in Figure 2.24.

On the upper slopes, well drained, moderately deep soils occur with a sand to loamy sand texture. Within a depth of 50 to 80 cm, red, porous, and massive, in places gravelly, sandy clay loam to sandy clay underlies the sandy surface layer (Ferri-chromic and Ferric Lixisols).

On the middle and lower slopes, soils are well to somewhat excessively drained, moderately deep to very deep, and have a texture of (loamy) sand. Topsoils are much thicker than on the upper slopes (Cambic and Luvic Arenosols and, to a lesser extent, Petri-ferralic and Albic Arenosols).

Soils of the valley fringes are coarse-textured and have gleyic properties. Soil drainage is moderately well on the higher parts and poor on the areas adjacent to the valley bottoms. Texture varies from sand to sandy loam (Dystric and Humic Gleysols).

The soils of the valley bottoms are imperfectly to poorly drained, shallow to moderately deep, and of sandy loam to clay loam texture. In places, these soils are stratified with layers of loamy coarse to medium sand and coarse sand (Humic Gleysols and Dystric Fluvisols).

Some chemical properties of the soils of this toposequence are given in Table 2.8. The fertility is low, generally: all soils have (very) low contents of exchangeble K, Mg, and Ca and available P.

uplands			valley fringes		valley bottoms
upper slopes	middle slopes	lower slopes			
Ferri-chromic Lixisols	Cambic and Luvic Arenosols	Albic Arenosols Petri-ferralic Arenosols	Dystric Gleysols	Humic Gleysols	Humic Gleysols Dystric Fluvisols

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Key

- Ironstone nodules
- Permanent reduced zone
- Gley mottling

S — Sand
LS — Loamy sand
SL — Sandy loam
SCL — Sandy clay loam
CL — Clay loam
25 — Soil depth in cm

Relative elevation (m)

Horizontal distance (m)

Figure 2.24 Schematic cross-section of a stream inland valley formed on Nupe sandstone in the Guinea Savanna Zone, Nigeria (after: Smaling et al. 1985a; adapted)

Table 2.8 Chemical properties of the soils of a toposequence on Nupe sandstone, Guinea Savanna Zone, Nigeria (source: Smaling et al. 1985a)

Chemical properties	Depth cm	Upper, middle, and lower slopes	Valley fringes	Valley bottoms
pH-H_2O	0-20	6.3-6.6	5.3	4.6-5.2
(1:2.5)	40-60	5.2-5.6	5.6	4.9-5.8
Org. C	0-20	0.5-0.6	0.7	1.5
(%)	40-60	0.4	0.3	0.4-1.5
C/N ratio	0-20	20-24	19.0	10-15
P-Bray 1	0-20	2.5-3.5	5.0	2.5-4.4
(ppm P)	40-60	3.0-4.5	3.2	4.8-7.0
Sum bases	0-20	0.9-2.1	0.9	1.7-3.0
(meq/100gr soil)	40-60	0.6-2.5	0.7	0.8-1.3
Exch. K	0-20	0.06-0.14	0.08	0.07-0.24
(meq/100gr soil)	40-60	0.05-0.13	0.03	0.07-0.10
Exch. Ca	0-20	0.9-1.4	0.5	1.0-1.8
(meq/100gr soil)	40-60	0.4-1.1	0.5	0.5-0.8
Exch. Mg	0-20	0.3-0.9	0.1	0.3-0.4
(meq/100gr soil)	40-60	0.1-0.7	<0.1	0.1-0.3
Exch. Na	0-20	0.05-0.27	0.08	0.18-0.42
(meq/100gr soil)	40-60	n.d.	n.d.	n.d.

n.d. = not determined

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A Stream Inland Valley Formed on Granite in the Sudan Savanna Zone, Burkina Faso
Smaling (1985) and Stoop (1987) describe the soils of a stream flow valley near Ouagadougou in Burkina Faso (Sudan Savanna Zone, Land Subregion 3.1). This subregion consists of slightly dissected, gently undulating plateaux over granite with common inselbergs and mesas. The landscape elements of this toposequence are plateaux, upper (erosional) slopes, middle slopes, lower (colluvial) slopes, and valley bottoms.

The plateau soils are (very) shallow over petroferric hardpans at depths between 25 to 50 cm, with (very) gravelly sandy loam to sandy clay textures (Eutric Leptosols and Haplic Ferralsols, both with petroferric phase).

The upper slopes have very deep, well-drained sandy clays to clays, with 10-40 vol.% iron and manganese concretions. Because of topsoil erosion, the argic B-horizon is found directly at the surface (Ferric Lixisols).

On the middle slopes, non-eroded, complete profiles are found. These soils are deep, imperfectly to well drained, sandy (clay) loams overlying gravelly clay. Strong mottling is found within a depth of 50 cm and, in places, plinthite is formed (Ferric, Gleyic, and Plinthic Lixisols).

On the lower colluvial slopes, soils are moderately well to poorly drained, very deep, with some mottling and, in the lower parts of the profiles, permanent reduction colours. Textures range from sandy clay loam to clay, and are occasionally gravelly (Gleyic Cambisols and Eutric Gleysols).

The soils of the valley bottoms are moderately deep to deep and moderately well to poorly drained. Soils are wet during the rainy season. Texture varies from (silt) loam in the topsoil to loamy sand and sandy loam in the subsoil. Mottling and reduction features occur at shallow depth (Gleyic Cambisols and Eutric Gleysols).

Some chemical properties of the soils of this toposequence are shown in Table 2.9. The clay fraction is predominantly kaolinitic, but the relative importance of illite,

Table 2.9 Chemical properties of the soils of a toposequence on granite, Sudan Savanna Zone, Burkina Faso (sources: Smaling 1985; Stoop 1987)

Chemical properties	Depth cm	Plateaux	Upper slopes	Middle slopes	Lower slopes	Valley bottoms
pH-H_2O	0-20	5.5-6.3	6.4	5.4	5.4	6.5
(1:2.5)	40-60	n.d.	7.8	6.2	5.7	6.6
pH-KCl	0-20	3.9-5.2	5.7	4.2	4.4	5.2
(1:2.5)	40-60	n.d.	6.7	4.5	4.3	5.2
Org. C	0-20	0.6-0.8	0.35	0.42	1.14	1.36
(%)	40-60	n.d.	0.25	0.26	0.55	0.53
N-total	0-20	0.06	0.03	0.03	0.80	n.d.
(%)	40-60	n.d.	0.02	0.02	0.28	n.d.
CEC pH = 7	0-20	2.5-3.3	5.0	2.0	4.0-7.5	5.5
(meq/100gr soil)	40-60	n.d.	5.0	6.0	4.5	5.3
Base sat.	0-20	56-85	74	65	55-72	98
(%)	40-60	n.d.	98	58	38-56	100
P-Bray I	0-20	1.5-4.4	1.4	3.8	2.8-4.3	1.3*
(ppm P)	40-60	n.d.	1.6	0.2	0.7-1.4	0.6*

n.d. = not determined
* = P-Olsen

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montmorillonite, and various interstratified clay minerals, including chlorite, increases with soil depth and towards the lowlands. This, along with the higher contents of clay and organic matter, is responsible for the higher fertility of the soils on the lower slopes and in the valley bottoms as compared to those of the higher parts of the toposequence.

A River Inland Valley Formed on Intermediate Crystalline Rock in the Equatorial Forest Zone, Nigeria

Moormann (1981) describes several toposequences on different lithological units in the Guinea Savanna and the Equatorial Forest Zones. An example of a toposequence formed on a mica granitic-gneiss in the Equatorial Forest Zone is presented here. This valley is formed in Land Subregion 2.1, which consists of slightly dissected interior plains with common inselbergs and mesas. The major morphological and soil characteristics are shown in Figure 2.25.

On the crests and upper slopes, moderately well drained, deep soils occur, with an argic B-horizon of gravelly loamy sand to sandy clay loam texture. Below 60 cm, plinthite is present (Plinthic Acrisols).

On the middle and lower slopes, well drained, deep soils occur, with a sandy loam topsoil overlying gravelly sandy clay loam (Ferric Acrisols).

In the colluvial depressions, more than 50 cm colluvium of loamy sand texture overlies the argic B-horizon as described for the soils of the crests and upper slopes. These soils are well to somewhat excessively drained and show a weak profile development (Eutric Regosols).

Soils in the valley bottoms have a sandy clay loam texture and are stratified with thin sandy layers. Mottles occur throughout the profile. In the surface horizon, organic litter and roots are abundant (Eutric Gleysols).
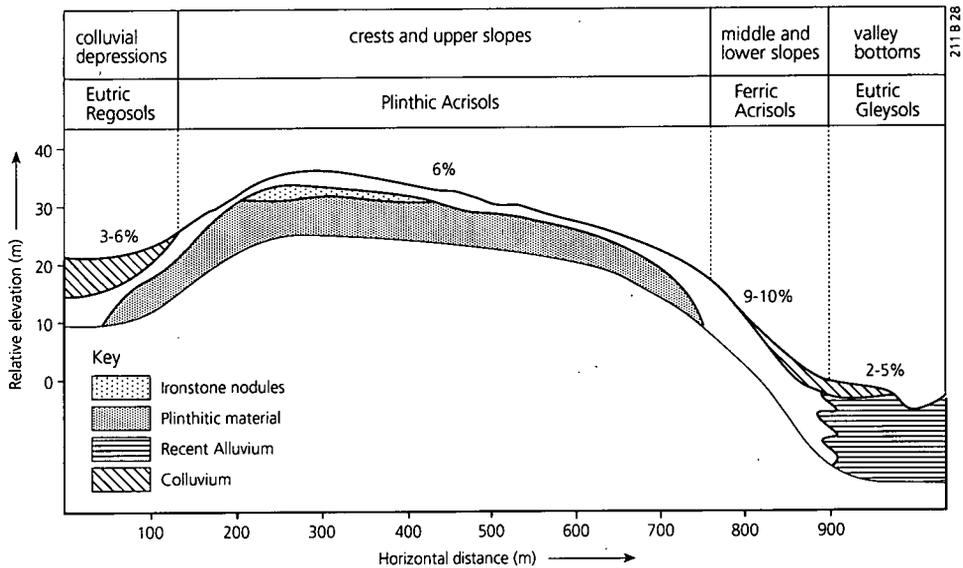
Figure 2.25 Schematic cross-section of a river inland valley formed on mica granitic-gneiss in the Equatorial Forest Zone, Nigeria (after: Moormann 1981; adapted)

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Table 2.10 Chemical properties of the soils of a toposequence formed on mica granitic-gneiss, Equatorial Forest Zone, Nigeria (source: Moormann 1981)

Chemical properties	Depth cm	Crests and upper slopes	Middle and lower slopes	Colluvial depressions	Valley bottoms
pH-H_2O	0-20	5.9	6.0	5.9	5.2
(1:2.5)	40-60	4.9	5.1	5.4	n.d.
Org. C	0-20	1.75	2.37	2.87	7.36
(%)	40-60	0.30	0.25	0.15	n.d.
N-total	0-20	0.23	0.27	0.32	0.45
(%)	40-60	0.05	0.04	0.02	n.d.
CEC pH=7	0-20	8.3	11.1	13.2	19.3
(meq/100gr soil)	40-60	3.3	6.8	1.1	n.d.
Base sat.	0-20	100	94	97	82
(%)	40-60	39	44	64	n.d.
P-Bray 2	0-20	13.9	10.8	17.2	27.5
(ppm P)	40-60	4.4	5.7	3.2	n.d.

n.d. = not determined

Chemical properties of these soils are given in Table 2.10. As a result of high organic-matter contents, the topsoils have a relatively high fertility, especially in the colluvial depressions and the valley bottoms. Base saturation is almost 100%, and the availability of P, K, Ca, and Mg is high. Only pH and available nitrogen are low to moderate.

3   Ecology

3.1   Principal Ecological Systems

In the inventory area, two principal ecological systems can be distinguished: forest and savanna. The boundary between these two systems is perhaps the most basic divide in the ecology of West Africa. This boundary is gradual; there is no abrupt change from forest to savanna. Nor does this boundary deny the variability that occurs within each system. Within the forest system, different types of forest can be distinguished and the same holds for the savanna.

Ecological systems show very complex interrelations between their different compounds (e.g. climate, soils, hydrology, flora, and fauna, including man). In describing ecological systems, it is hardly possible to separate the plant component from the soil, or to distinguish these from the animal component. Furthermore, most agricultural systems have striking ecological implications and it is often useful to treat man and his agricultural behaviour as an integral part of the (agro-)ecological complex.

It is beyond the scope of this book to describe in detail the complexity of the different ecological systems. Chapter 2 has already discussed the climatological parameters, the morphology, the hydrology, and the soils of West Africa. The present chapter will discuss only the major differences between the forest and savanna ecologies, the vegetation, and the effects of human interventions on these ecological systems.

3.1.1   Main Characteristics of the Forest Ecology

In West Africa, the extent of the forest is restricted to the Equatorial Forest Zone, as was described in Section 2.1. This Zone occurs in the southwestern and the southeastern parts of the inventory area, where the mean annual precipitation varies from 1,250 to more than 3,000 mm. The rainfall pattern can be monomodal, pseudo-bimodal, or bimodal. The factors that determine the differences in floristic composition of the forests are the amounts and distribution of rainfall, and the differences in soils, physiography, and hydrology.

The structure of these rain forests is very dense, with a closed canopy of woody plants. The sheer bulk of the forest vegetation is as high as 335,000 kg/ha (oven-dry weight), excluding roots (Nye and Greenland 1960). Internally, the forest is vertically arranged in different distinct layers: the undergrowth, tall trees which form the closed canopy, and very tall trees which tower above the closed canopy. Generally, intermediate layers are also present.

Because of the structure of the forest vegetation, the food niches and the microclimate within the forests are layered too. The plant-faunal relationships are strongly correlated with this layered structure (Figure 3.1).

To some extent, the ecological system of the forest is buffered against changes in atmospheric conditions. The dense canopy of the forest vegetation protects the inner microclimate from the effects of short-term atmospheric changes outside. Conse-

Metres

40 — EMERGENTS

30 — MAIN CANOPY

20 — UNDERSTOREY

10 —

5 — SHRUB LAYER

0 —

211 8 29

RED COLOBUS MONKEY

GIANT FOREST SQUIRREL

PEL'S FLYING SQUIRREL

TREE HYRAX

GREEN MAMBA

PUTTY-NOSED MONKEY

GAMBIAN AND RED-LEGGED SUN SQUIRRELS

MONA MONKEY

TWO-SPOTTED PALM-CIVET

GENET

BOSMAN'S POTTO

BLACK COLOBUS MONKEY

TWIG SNAKE

LESSER BUSH BABY

WHITE-BELLIED PANGOLIN

TREE SNAKE

AFRICAN PYTHON

SIDE STRIPED SQUIRREL

GREEN TREE VIPER

AFRICAN PYTHON

AFRICAN PYTHON

MAXWELL'S DUIKER

GIANT GROUND PANDOLIN

GREEN SNAKES

BEAUTY SNAKE

BROWN MONGOOSE

CUTTING GRASS

BRUSH-TAILED PORCUPINE

AFRICAN CIVET

POUCHED OR GIANT RAT

RED RIVER HOG

BLACK BACKED DUIKER

BLACK DUIKER

| FILE SNAKE | CALABAR GROUND PYTHON | PUFF ADDER | BURROWING VIPERS | | RHINOCEROS VIPER | BLACK COBRA | GABOON VIPER |

FOREST CLEARINGS | FOREST EDGE | HIGH FOREST

Figure 3.1 The structure of the lowland rain forest and the stratification of the habitat of some mammals and snakes (after: Moss 1969; adapted)

quently, changes in temperature, relative humidity, and other variables are much less in magnitude, and lag behind those outside the canopy. This is mainly related to the decreased air movement effected by the forest.

Because of the long humid period ($P > ET_p$; see Section 2.1.6) and the forest-induced humid microclimate, the soils of the forests remain moist throughout the year.

Under the high rainfall occurring in the Equatorial Forest Zone, the soils of the forests are strongly weathered and leached. The mineral fraction of these soils consists mainly of kaolinite and sesquioxides with a very low inherent fertility. The fertility of the forest soils is mainly stipulated by the organic matter content of the topsoils.

The rapid rate of mineralization of the organic matter is another striking characteristic of the forest ecological system.

3.1.2   Main Characteristics of the Savanna Ecology

The savanna of West Africa occurs in the northern and central-southern parts of the inventory area. It occupies the Guinea Savanna and the Sudan Savanna Zones, as described in Section 2.1. The mean annual precipitation varies from 550 mm in the north of the Sudan Savanna Zone to 2,500 mm in the southwestern part of the Guinea Savanna Zone. The rainfall pattern is predominantly monomodal, but locally it is pseudo-bimodal or bimodal. The latter pattern occurs only in the southernmost parts

of the Guinea Savanna Zone. As in the forest ecology, the differences in floristic composition of the savanna are determined by the range of total amounts of rainfall and its distribution, the soils, the hydrology, and the physiography.

The structure of the savanna is much more open than that of the forest and varies from a more or less closed savanna woodland in the more humid zone, to grasses with sparse trees in the drier parts (Figure 3.2). The sheer bulk of the savanna vegetation is only as high as 67,000 kg/ha (oven-dry weight), excluding roots (Nye and Greenland 1960).

Unlike the forests, the savanna vegetation is hardly arranged in different vertical layers, especially the more open vegetation in the northern part of the inventory area. The graminaceous layer is the most prominent element of the savanna ecological system. Almost all human and faunal activity is concentrated in this layer.

Because of its open structure, the savanna vegetation does not create its own microclimate and is not buffered against changes in temperature, relative humidity, and other climatological variables. As a result, sunshine and rains have a direct impact on the soil surface.

The water and nutrient cycles of the savanna ecological system are determined by the seasonality of water availability. Because of the prevailing short humid period in the Savanna Zones of West Africa and the open structure of their vegetation, the soils of the Savanna Zones dry up for a certain period during the dry season. This process is strengthened by the relatively shallow root system of the savanna vegetation, which is not as effective as the forest in pumping water from great depths. Water deficiency in the dry season has an inhibiting effect on the nutrient uptake by the vegetation. For that reason, the nutrient cycle is seasonal compared with the relative continuity under forest. These effects may be further strengthened where atmospheric water cannot be absorbed by the soil because of crust formation and surface sealing.
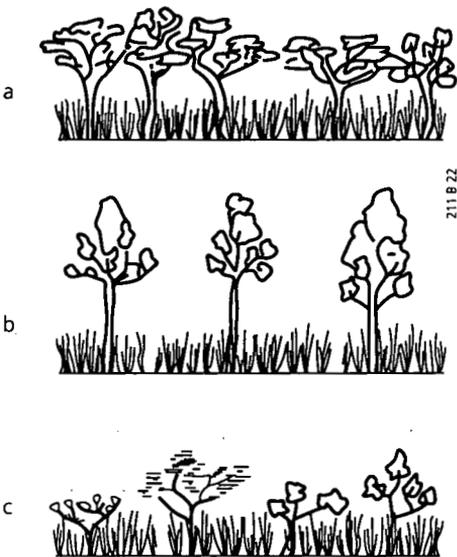

Figure 3.2 Different types of savanna: a: woodland savanna; b: tree savanna; c: shrub savanna (after: Trochain 1957; adapted)

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The lower rainfall in the Guinea Savanna and the Sudan Savanna Zones, as well as the capillary rise of groundwater prevailing during the dry season, is reflected in the general occurrence of less-leached soils in these Zones, as compared with the Equatorial Forest Zone. Consequently, inherent fertility levels in the Savanna Zones are somewhat higher too.

The natural plant-faunal relationships in the savanna are different from those in rain forest areas. The diversity of animal species in the savanna is less than in the forest, but the number of animals occurring per species is larger.

Nevertheless, livestock, which, over the years, has been kept in large numbers, has replaced the original herds of grazers with their associated predators. The predator food niches are nowadays occupied by man. This has an impact on the vegetation, both because of the cattle's food preferences for certain graminaceous species and because of the agricultural practices (i.e. the burning of grasslands at the beginning or end of the dry season). This concentration of interventions in the graminaceous element of the savanna ecological system has generally resulted in the degradation of the habitat.

3.1.3   Ecological Differences between Uplands and Bottomlands of Inland Valleys

Ecological differences between the different landscape elements of the inland valleys (i.e. the uplands, colluvial footslopes and valley fringes, and valley bottoms) are mainly the result of variations in hydrology.

The valley bottoms in the Equatorial Forest Zone are submerged for most of the year and have the watertable near the surface for the rest of the year. Because of this poor drainage, the vegetation of the valley bottoms contains species adapted to this wet environment, while the vegetation on the upland is more adapted to the well-drained conditions under high rainfall. In the uplands, however, as well as in the valley bottoms, the water and nutrient cycles are continuous throughout the year.

In the savanna areas, the valley bottoms and valley fringes represent environments that are distinctly different from those on the uplands. In the valley bottoms and fringes, the watertable fluctuates strongly, creating a wet environment in the rainy season and, in the dry season, dry conditions with a deep watertable. These ecological differences create habitats for very different plant species and animals.

In the uplands, with permanently deep groundwater, the growing period is determined strictly by the length of the rainy period. As a result, the water and nutrient cycles are seasonal too.

Because of the high watertable in the beginning of the dry season and the lateral groundwater flow from the uplands, the growing period in the valley bottoms and fringes is prolonged considerably, especially in the more humid areas (Guinea Savanna Zone). Because of lateral groundwater flow to the valley bottoms, nutrient cycling continues also after the rains have ceased. It remains seasonal, however, as in the uplands.

3.2 The Vegetation

3.2.1 General

The distribution of the natural vegetation of West Africa follows more or less the agro-ecological zonation as was distinguished in Section 2.1.5 and is shown in Figure 3.3. The climax vegetation (i.e. the state of the vegetation in equilibrium with the climate) grows progressively less dense from the south to the north. In the south, lowland rain forest forms the natural climax vegetation. To the north, this is replaced by woodland savanna, which in turn gives way to the less wooded tree savanna further north. Factors like soil and altitude account for local deviations from this general pattern.

It is not intended here to give a systematic account of all the species occurring in each vegetation zone. Rather, it is the aim to show the general characteristics of the different vegetation types, their distribution, and their relationship with other aspects of the environment. Also, a number of outstanding vegetation types will be described.

3.2.2 The Vegetation of the Equatorial Forest Zone

The Equatorial Forest Zone comprises the forests of the salt and fresh water swamps, the actual lowland rain forest, the derived savanna, and the montane vegetation. The Zone stretches from the coastal areas of Guinea Bissau through southeastern Ghana and from southwestern Nigeria eastward (see Figure 3.3).
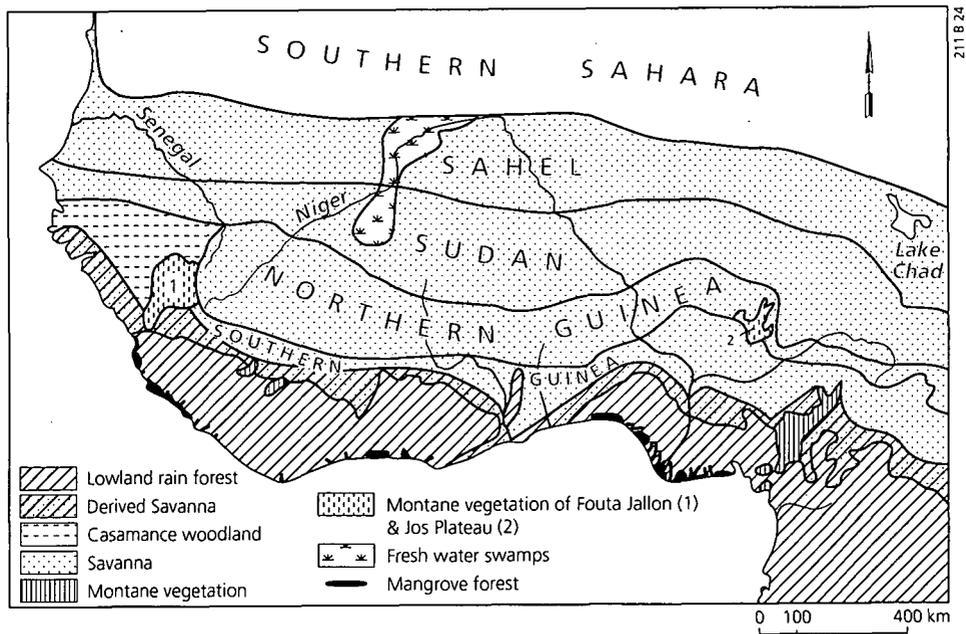

Figure 3.3 The vegetation zones of West Africa (after: Harrison Church 1974; adapted)

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The **salt-water swamp forest** is the vegetation that occurs along the coast and estuaries which are under tidal influence. During high tides, the muddy soils prevailing in these areas become saturated with saline or brackish water. In this physical environment, the vegetation is mainly formed by mangroves, with their characteristic stilt roots. In the areas close to the sea, which are flooded every high tide, *Rhizophora racemosa* and *Rhizophora mangle* occur. On the landward, higher, and less frequently flooded margins of the salt-water swamps, the rhizophora gives way to avicennia mangroves (*Avicennia africana* and *A. nitida*) and, higher still, to herbaceous plant species like *Sesuvium, Philoxerus, Eleocharis*, and *Paspalum* (Dent 1986; Langenhoff 1986; Chapman 1977).

The combination of mangrove vegetation, with its high production of organic matter, and the regular flooding with saline water results in the formation of sulphides in the soils (potential acid sulphate soils). In West Africa, as in other regions of the world, no clear relation has been found between the type of mangrove vegetation and the amount of sulphide production (van der Kevie 1973; Thomas et al. 1979; Dent 1986; Janssen et al. 1993). Upon aeration (e.g. through artificial drainage), the sulphides in these soils oxidize to form sulphuric acid, rendering the soils extremely acid (pH < 3.5; actual acid sulphate soils).

In the least saline areas of Senegal, Guinea Bissau, Sierra Leone, and Nigeria, the mangrove vegetation has been eliminated to enable rice cultivation. The heavy rainfall and/or flooding by rivers in these areas is used to flush salt and free acids from the soil.

Fresh-water swamp forest is found under swampy conditions further inland, where there is no longer a tidal influence. It is widespread in the lower Niger Delta in Nigeria. The vegetation is dominated by raphia palms (*Raphia vinifera* and *R. hookeri*) and has an open canopy in which tangled shrubs and lianes with hooked spines form a dense undergrowth.

The West African **lowland rain forests** are located within two blocks, the first covering parts of Sierra Leone, Liberia, Ivory Coast, and Ghana, and the second, parts of Nigeria and Cameroon. They are separated by the tongue of the Guinea Savanna which comes down in the Togo Gap. This separation is mainly due to lower rainfall and the action of man within the Gap.

The semi-evergreen or evergreen lowland rain forest vegetation is vertically arranged in different distinct layers or storeys. White (1983) distinguishes the following stratification:
– Lower storey: dense undergrowth (3 – 5 m high), made up of low plants, shrubs, and ferns;
– Middle storey: huge trees (20 – 30 m high), with dark green and dense foliage, and many branches which grow on thick woody trunks;
– Upper storey: very tall and straight trees (30 to 50 m or more in height), which have few leaves, grey trunks, and buttressed roots.
The canopy of the upper storey is usually discontinuous, whereas the lower storeys have a more continuous canopy.

Moss (1969) gives a slightly different subdivision. He distinguishes a shrub layer, an understorey (up to 20 m high), the main canopy (up to 30 m high), and emergents (up to 45 m high) (see Figure 3.1).

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The lowland rain forest comprises many different species. The hard woods/timber species are the most famous, e.g. *Khaya ivorensis* and *K. anthotheca* (both mahoganies), *Entandrophragma cylindricum* (sapele), *Guarea cedrata* (guarea), and *Lovoa trichiloides* (African walnut).

Variations in the species composition of the lowland rain forests are mainly caused by differences in the physical environment (variations in relief, soil, slope, and drainage).

The area covered by virgin rain forest in West Africa has severely decreased during the last decades. In the first half of the 1980s, an annual forest loss of 7,200 km² was recorded in the countries along the Gulf of Guinea (Martin 1991). Table 3.1 lists the estimated areas of existing closed rain forests and degraded forest lands in the various countries of West Africa.

Table 3.1 shows that, by 1985, only about 43% of the original rain forest remained. This percentage, however, is strongly influenced by the large area covered by undisturbed rain forests in Cameroon. If the figures for Cameroon are excluded, only 28% of the original forest area in West Africa is covered by natural vegetation.

To preserve the tropical rain forests in West Africa from continuing destruction, a number of rain forest national parks have been established. The most important of these is the Taï National Park, which covers an area of 3,300 km² in Ivory Coast (Martin 1991).

In the forests, a patchwork arrangement of primary or secondary species often occurs. The secondary species result from the cutting or burning of the forest by shifting cultivators. The resulting differences in light and humidity stimulate the germination and/or growth of light-tolerant species. These grow faster and develop into a much simpler structure than that of primary forest. The number of species inhabiting secondary patches is also less (Harrison Church 1974).

If a patch is frequently burned, grasses may invade the area and fire-tolerant tree species may take over to form the so-called derived savanna. The forest patches within can be seen as remnants of the former lowland rain forest.

Table 3.1 Estimated areas of closed rain forests and degraded forest lands (in km² and %) in West Africa in 1985 (source: Martin 1991).

Country	Closed rain forests		Degraded forest lands	
	km²	%	km²	%
Benin	410	85	70	15
Cameroon	175,200	77	52,800	23
Ghana	16,080	20	65,900	80
Guinea	18,700	52	17,500	48
Guinea Bissau	5,750	71	2,300	29
Ivory Coast	30,080	24	97,150	76
Liberia	17,700	24	56,700	76
Nigeria	44,500	33	90,000	67
Sierra Leone	7,100	15	38,800	85
Togo	2,940	55	2,400	45
Total West Africa	318,460	43	423,620	57
Idem without Cameroon	143,260	28	370,820	72

The occurrence of **montane vegetation** is determined by the altitude. Altitude may modify vegetation because of the lower temperature, increased and more constant humidity and cloudiness, less solar radiation, and less evaporation. Consequently, in the Guinean Highlands, on Mount Cameroon, and in the Cameroon Highlands, a tall canopied montane rain forest is found at elevations above 1,000 m. From approximately 1,200 m, the forests are saturated in mists, and temperate tree species are quite common. Above 1,500 m, montane woodland occurs with abundant grasses. Grassland may also occur at lower altitudes as the result of frequent burning.

3.2.3   The Vegetation of the Guinea Savanna Zone

The vegetation of the Guinea Savanna Zone comprises the casamance woodland (Guinea Bissau, The Gambia, and southern Senegal), the guinea savanna, and the vegetation types of the Fouta Jallon (Guinea) and Jos Plateau (Nigeria). This Zone stretches from Guinea Bissau eastward to Nigeria, including the Togo Gap (see Figure 3.3).

Characteristic of this Zone is the woodland savanna, which consists of an open stand of trees, the crowns of which form a canopy from 8 – 20 m or more in height and cover at least 40% of the surface (White 1983). The crowns of adjacent trees are often in contact but are not densely interlocking as in the Equatorial Forest climax vegetation (see Figure 3.2). There is a groundcover of herbaceous tussock grasses, up to 2 m high.

The **casamance woodland** is the woodland savanna around the Casamance River in Guinea Bissau, The Gambia, and southern Senegal. The structure of the vegetation consists of two storeys. The upper storey (up to 15 – 20 m high) consists dominantly of only four tree species: *Parinari excelsa, Erythrophleum guineense, Detarium senegalense*, and *Afzelia africana*. The trees are low-branching and spreading. The lower storey (up to 3 – 6 m high) consists of bushes, lianes, and herbaceous plants.

The **guinea savanna** covers the most extensive region of the West African savanna. This woodland savanna can be divided into two types:
– The southern guinea savanna, with a tree cover that varies from forest in the south to a woodland savanna in the north. The main tree species are *Daniellia oliveri, Lophira alata*, and *Terminalia glaucescens*. Significant grass genera are *Andropogon, Cymbopogon, Hyparrhenia, Pennisetum*, and *Setaria*.
– The northern guinea savanna, a more open woodland savanna, which is characterized by *Isoberlinia spp.*, in association with the perennial grass *Hyparrhenia spp.* Its physiognomy is rather similar to that of the southern guinea savanna, although poorer and more distinct in its species composition. Common trees are: *Isoberlinia dalzielii* and *Monotes kerstingii*. Common grass genera are more or less the same as in the southern guinea savanna. *Brachiaria spp.*, however, takes the place of *Setaria*.

On the plateaux of **the Fouta Jallon** (Guinea), with an altitude of up to 1,500 m, no altitudinal gradations of the vegetation occur; nor is there a true montane vegetation. The original climax vegetation may have been lowland rain forest. If it was, however,

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it must have been exceedingly frail owing to the marginal position of the Fouta Jallon in both latitude and altitude. Another option for the climax vegetation could be casamance woodland, with some lowland rain forest additions. The presence of *Parinari excelsa*, a typical casamance woodland species, supports this. The original vegetation cover, however, has been almost completely eliminated, leaving lateritic exposures behind, almost bare of soil and vegetation.

The **Jos Plateau** (Nigeria) is covered by northern guinea savanna at its foothills, to poor woodland savanna above. The original vegetation, whether montane or northern guinean in character, has been thoroughly destroyed. The people living on the Jos Plateau have lost almost 15% of their land to tin-mining activities. This has resulted in an increased pressure on the remaining land. At present, the most accessible areas are almost treeless and are under grass. The mining activities have also impaired the vegetation and drainage. What is left is a highly degraded northern guinea savanna vegetation with some montane additions.

3.2.4   The Vegetation of the Sudan Savanna Zone

In the Sudan Savanna Zone, sudan savanna and fresh-water swamp vegetation of the inland Niger Delta occur. This Zone stretches north of the Guinea Savanna Zone (see Figure 3.3).

The zonal **sudan savanna** changes from open woodland in the south to tree savanna in the north. The sudan savanna trees have very wide geographical ranges, both longitudinal and latitudinal, and wide ecological tolerances. According to White (1983), too few species occur in sufficiently constant association with others over sufficiently extensive areas to permit the recognition of well-defined ecological elements.

Some authors – e.g. Keay (1949), Aubréville (1950), and Chevalier (1951) – have suggested that a dry forest was the original climax vegetation of the Sudan Savanna Zone. On the sandstone plateaus of western Mali, some relics of dry evergreen forest still persist (Jaeger 1968). Because of its favourable climate and soils, this Zone is heavily populated by both man and animals.

Trees, almost always occurring singly, have wide-spreading crowns. The natural vegetation includes tree species of *Guiera senegalensis, Combretum glutinosum, Piliostigma reticulata*, and, in association with water courses, *Hyphaene thebaica* (doum palm). Most vegetational cover is found in various stages of regeneration following periods of cultivation. Where the fallow period is short and fires are frequent, the trees are often represented by coppice shoots and mature trees of specially preserved species of economic importance. These trees include *Parkia spp., Butyrospermum parkii* (karité), *Acacia albida, Tamarindus indica* (tamarind), and *Ceiba pentandra* (kapok).

The grasses are shorter than in the Guinea Savanna Zone, and they have a different character. Most grasses are annuals because of drought-stress in the long dry period. Commonly occurring annuals include *Andropogon pseudapricus, Hyparrhenia*, and *Loudetia spp.* A number of perennials grow vigorously: *Andropogon gayanus, Anthrophora nigritane, Aristida stipoides, Pennisetum setosum*, and *Hyparrhenia spp.*

More to the north, trees with thorns (e.g. *Acacia spp.*) become more common and the grasses become shorter, less tussocky, and more feathery.

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The **fresh-water swamp vegetation** is an azonal type of vegetation which occurs in the inland Niger Delta in Mali. Differences in the vegetation composition are dictated mainly by the hydrological conditions, such as the frequency and duration of flooding and the depth of the water level, and by physiography.

Andropogon and *Chloris* occur on the infrequently flooded transition zones between the floodplains and the *toguéré* (i.e. non-flooded areas like dunes and ancient levees). On the shallow and moderately deep flooded parts of the floodplains, an association of *Panicum* and *Eragrostis* occurs, and on the flooded levees near the main rivers, *Echinochloa* and *Oryza*. On places where the flooding is deep, *Vetivera* and *Mahinot* are found.

The vegetation of the non-flooded areas is characterized by *Borassus, Ficus, Diospyros, Guaera* or *Acacia*, and *Cenchrus* (Drijver and Marchand 1985, Gallais 1967).

3.3   Uses and Interventions in the Ecological Systems

3.3.1   General

Agricultural ecology in West Africa has been extensively treated by Kowal and Kassam (1978), Harrison Church (1974), and Thomas and Whittington (1969). Farming systems have been described by Fiselier (1990), Jansen and Diarra (1990), de Rouw et al. (1990), Turner (1986), Smaling et al. (1985a,b), Broekhuyse and Allen (1984), Kessler and Ohler (1983), and Gleave and White (1969).

3.3.2   Uses and Interventions in the Ecology of the Equatorial Forest Zone

The inland valley bottoms in the Equatorial Forest Zone are flooded for most of the year. Because the environment is unhealthy owing to water-borne diseases (see Chapter 4) and because of the high labour demand for clearing, the valley bottoms are not extensively used for crop production.

If not used for crop production, the inland valleys are traditionally used for gathering fruits and nuts, as a source of firewood, and as waterways for transport. Fish, caught in the valley streams or swamps, form an important source of protein.

Often, the wet parts of the inland valleys or parts thereof (mostly the peripheries) are used for growing some vegetables or staples (including rice), crops not much different from those grown on the uplands.

In the last decades, more and more attention has been given to the potential of the inland valley bottoms for rice production, especially in Sierra Leone and Liberia. It is assumed that, in Sierra Leone, about 40% of the inland valley bottoms are used for rice production in the rainy season.

The uplands in the rain forest zone are used for arable crop production. The most common farming system is shifting cultivation and, to a lesser extent, the bush fallow system. The bush fallow can be seen as an intensive form of shifting cultivation (Ruthenberg 1980). In this farming system, a new field is required nearly every year. In choosing the location of the field, farmers consider the soil, physiography, and condition of the forest. In case of a secondary forest, this encompasses the age (i.e. the

time since last cutting), the structure, and the floristic composition. These factors are important because, owing to the low inherent fertility of the upland soils, the crop thrives on the nutrients present in the ash of the burned forest.

Because of the activities of man, the vegetation pattern of the uplands has been modified in such a way that mosaics of forest regrowth, secondary forest, and derived savanna cover much of the area.

A decrease in yields on the uplands, the higher agricultural potential of the valley bottoms, and the increasing need to spread the risks of crop failure, were reasons for farmers in, for instance Sierra Leone and Liberia, to involve the hydromorphic and wet parts of the inland valleys (i.e. the footslopes and valley bottoms) in their farming system (FAO 1979; Richards 1985 and 1986). The moist conditions of the footslopes and valley bottoms allow flexibility in the period of planting. The fallow periods in the hydromorphic and wet parts of the inland valleys are generally shorter than on the uplands.

Some farmers in Ivory Coast are accustomed to growing rice, mainly on the lower slopes and part of the valley bottoms. The dominant occurrence of raphia palms in the valley bottoms is often an indication of former human activity (de Rouw et al. 1990).

Farming systems in the Equatorial Forest Zone are extensively discussed in Chapter 5.

3.3.3   Uses and Interventions in the Ecology of the Savanna Zones

In the Savanna Zones of West Africa, the inland valleys differ significantly in their ecology from the adjacent uplands. Along the streams, gallery forest occurs with its specific vegetation and animal population. This type of forest forms an important corridor for certain animal species and it offers shelter and roosting places for birds. At places, a so-called holy forest occurs near the stream, where the local population buries its deceased or holds certain rituals.

During and after the rainy season, inland valleys offer conditions and habitats that resemble those of the larger floodplains: shallow inundated land, temporary marshes, and receding flood waters that leave a waterbird and wader habitat behind, such as small natural or artificial lakes with drawdown zones that remain attractive to birds (Fiselier 1990).

Regionally, the combination of inland valleys and larger floodplains, as found in the inland Niger Delta in the Sudan Savanna Zone, provides a continuous food supply to palearctic waterbirds and waders. In periods of prolonged drought, the inland Niger Delta also serves as a refuge for birds from the Senegal and Guinea Bissau coastal wetlands (de Bie 1990).

Most inland valleys in the Sudan Savanna Zone dry out completely in the dry season. They therefore contain no fish, except for lung fish.

The presence of any wildlife depends on hunting pressure. Many inland valleys contain dry-season pastures that are attractive for grazers, whether these be wild animals or domestic cattle. Drinking water is crucial for mammals and, in the semi-arid regions, its occurrence is largely restricted to river valleys. The combination of drinking water and food makes inland valleys ideal as corridors for migrating animals.

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Traditionally, arable farming in the Savanna Zones was mainly concentrated on the uplands, and to a lesser degree on the valley bottoms (e.g. *fadama* cultivation in Nigeria). The traditional upland arable farming systems in the Guinea Savanna and Sudan Savanna Zones form an arrangement of different uses in a number of concentric zones centred around the village (Broekhuyse and Allen 1984, for the Mossi Plateau in Burkina Faso; Gleave and White 1969, for Zaria Province in Nigeria; Jansen and Diarra 1990, for southern Mali; Manshard 1961, for the Kumasi District in Ghana). Three principal zones can be distinguished. The first zone, immediately outside the village, is used for permanent cultivation. The second zone is used in a cultivation/fallow production. The third zone is sylvo-pastoral or unfarmed bush. Sometimes the uses are arranged in a slightly different order. Where population densities get higher and/or cash crops are introduced, this zonation of uses breaks down. With the break-down of the land-use pattern in concentric zones, the inland valleys with their relatively more fertile and wetter soils became more important.

More information about the farming systems in the Savanna Zones is given in Chapter 5.

Unlike the inland valleys in the Equatorial Forest Zone, most of the inland valleys of the Guinea Savanna and Sudan Savanna Zones are already part of the actual arable and livestock farming systems.

Seasonally-flooded grasslands have always been key elements in the grazing cycle of cattle herds; the forests have always acted as a wood resource, and perennial streams and groundwater seepage have provided drinking water and a sustained water supply to vegetable gardens.

In the western part of West Africa, rice has been grown by smallholders in the inland valleys for a long time, especially in the Guinea Savanna Zone, where rice has been an important staple crop. According to Mohr (1969), this area comprises the upper catchments of the Casamance and Gambia Rivers, south Mali, Burkina Faso, north and west Ivory Coast (Korhogo and Man), Guinea, north Liberia, Sierra Leone, and Guinea Bissau. In this region, valley rice cultivation is still widespread.

The inland valleys in the northern parts of the Savanna, especially the valley slopes, are important areas of staple crop production, e.g. sorghum and millet (Broekhuyse and Allen 1984; Vierich and Stoop 1990). Here, the soils of the valley slopes are used according to their texture and water balance. If rainfall is late or irregular, the crops grown on the valley bottoms will provide the food supply because the slopes remain too dry for good crop production. If rains are excessive, the harvest of the crop culti-vated on the slopes provides the food supply, while in the valley bottom the crop fails.

The spread of risks is an important element of the farming systems in areas with unpredictable rainfall.

The reclamation of inland valleys implies the removal of the natural vegetation and the loss of habitat for certain animals. The protective vegetational cover is lost for the benefit of crop production during the wet season. In the dry season, the soils are unprotected and susceptible to erosion at the beginning of the rains.

Without vegetational cover, the passage of animals causes damage at the crossings. In Bida, central Nigeria, erosion processes have turned some of these crossings into

wastelands (Smaling et al. 1985a). The resource availability to transhumance herders (i.e. drinking water and food for their cattle) will be reduced. Excessive grazing in the areas left will cause compaction of the soil by trampling. This, in turn, reduces the soil permeability and increases the amount of runoff, thus contributing to further soil erosion (Ingram 1991).

Man's activities in the upland areas disturb the hydrological balance of the inland valleys. Interventions like the removal of vegetation will further aggravate the hydrological disbalance and will change the ecology. Infiltration of water will decrease and overland flow will be enhanced. Peak flows will become more intensive and destructive. Reduced groundwater recharges will result in less seepage and base flow, thus provoking drying out of the soils and water shortages earlier in the dry season.

4   Water-Borne Diseases in West Africa

4.1   Distribution and Transmission Mechanisms of Water-Borne Diseases

For long periods, inland valley bottoms have not been used for agriculture because of the occurrence of water-borne diseases. Nowadays, however, with the declining yields on the uplands, the increasing population pressure on the available agricultural land, and the agricultural potential of the inland valley wetlands, they are being used more and more within the different farming systems.

The main water-borne diseases that are a major public-health problem in West Africa are malaria, schistosomiasis (bilharzia), trypanosomiasis (sleeping sickness), onchocerciasis (river blindness), and dracontiasis (guinea worm). Malaria is common
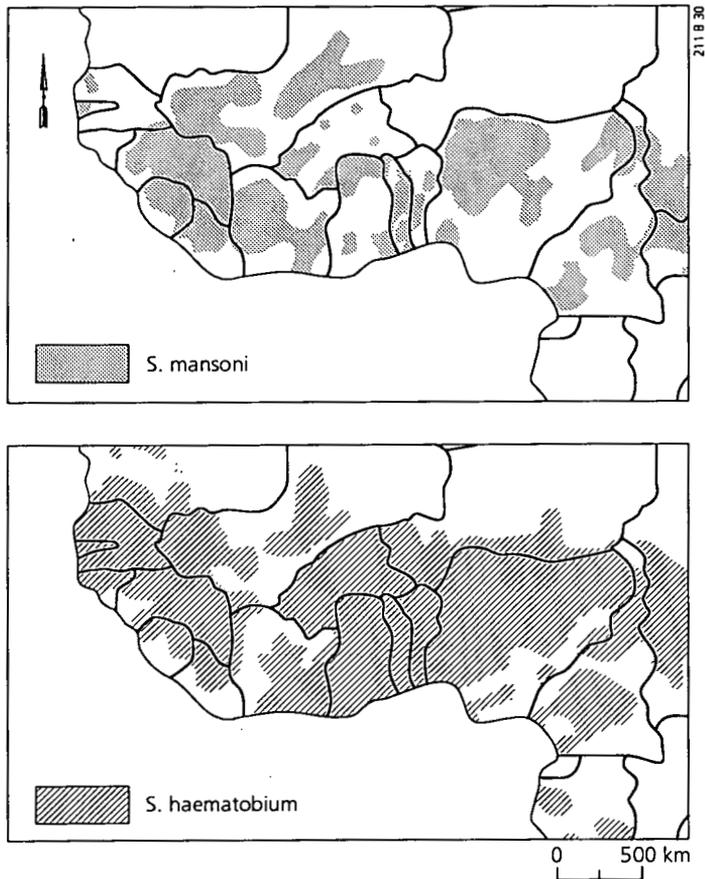
Figure 4.1 Distribution of schistosomiasis (bilharzia) by *Schistosoma mansoni* and *S. haemotobium* in West Africa (after: Doumenge et al. 1987; adapted)

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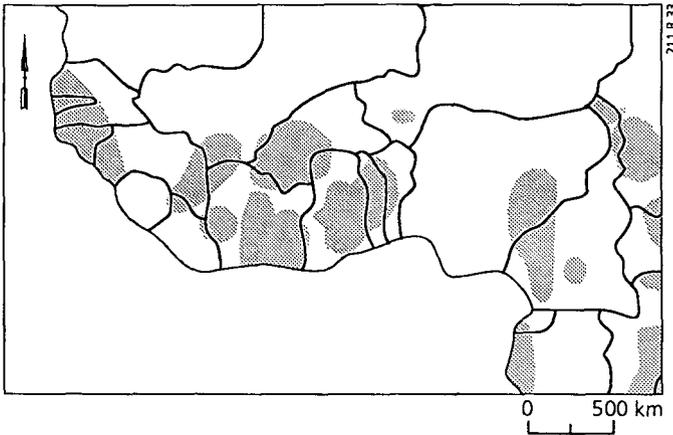
Figure 4.2 Distribution of trypanosomiasis (sleeping sickness) in West Africa (after: Mollyneux and Janssens 1980; adapted)
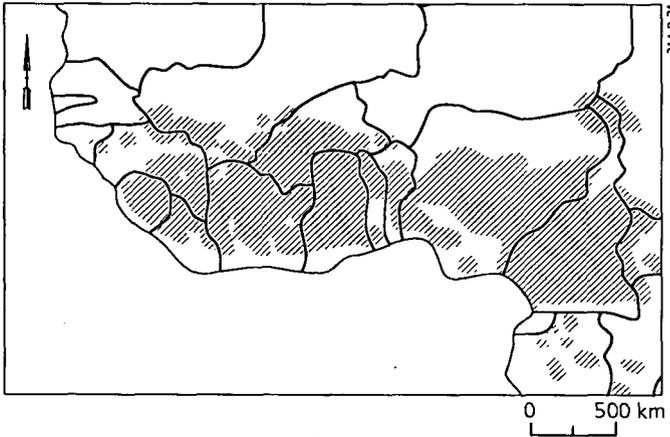
Figure 4.3 Distribution of onchocerciasis (river blindness) in West Africa (after: Muller 1980; adapted)

throughout the inventory area. The distribution of the other diseases is shown in Figures 4.1, 4.2, 4.3, and 4.4.

All these diseases are vector-borne. This means that, for their transmission, at least one intermediate host (vector) is required. The hosts may be insects or aquatic animals. If the host is an insect (mosquito or fly), it will acquire disease parasites by stinging an infected man or animal and may transmit these parasites to any man or animal it stings afterwards (mechanical transmission). If the host is an aquatic animal (snail), it acquires the parasites from infected water. After the parasites have completed a part of their life cycle within the host's body, they are released back into the water. There, they may penetrate the skin of any new host – man or animal – present in the water (biological transmission) (Oomen et al. 1990).

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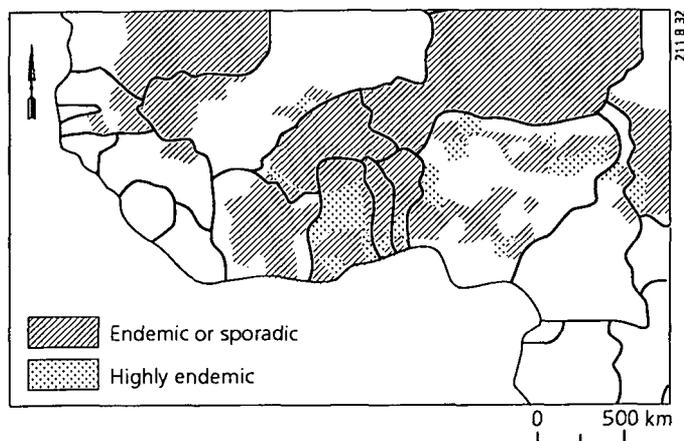
Figure 4.4 Distribution of dracontiasis (guinea worm) in West Africa (after: Watts 1987; adapted)

Ecological changes brought about by the development of wetlands, including valley bottoms, can lead to the explosive propagation of these vectors. The health infrastructure in many countries of West Africa is unable to cope with any increased burden of diseases. Therefore, from the very beginning of the development of water resources, one has to incorporate environmental safeguards to fight these diseases (Oomen et al. 1990; van der Laar 1985).

The distribution and incidence of water-borne diseases are influenced not only by water management for agricultural production but also by the quality of community water supplies, sanitation and housing facilities, and by the degree of settlement and migration of the population. Improvements in drinking-water supplies, in excreta disposal, and in nutrition and nutritional hygiene can reduce the transmission of many infections.

Table 4.1 lists various kinds of mechanisms of disease-transmission and the design components that can reduce such transmissions. These components of environmental health engineering should be kept in mind when rural development programs are being planned for wetland areas.

The burden of infectious diseases in a community can be reduced by the partial or complete disruption of their transmission mechanism. There are three ways in which this can be done (Oomen et al. 1990):
– By interfering with the transmission mechanism;
– By protecting the susceptible hosts;
– By reducing the reservoirs of infection.

Environmental management can disrupt transmission by eliminating the breeding places of the vectors. This might be supplemented by the use of chemicals, to kill either the disease agents by disinfection or the vectors with insecticides or molluscides. Bio-technological measures, such as genetic manipulation or the introduction of or-

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Table 4.1 Transmission mechanisms of diseases and design components for environmental health engineering that contribute to integrated control (source: Oomen et al. 1990)

Design component	Transmission mechanism	Design feature	Related diseases
Occupation	Insect-vector breeding in water/biting near water	Dam construction Irrigation network	Malaria, onchocerciasis, trypanosomiasis, other vector infections
	Water-based	Agriculture	Schistosomiasis
Water supply	Water-borne Water-washed	Quality and/or quantity of water	Diarrhoeas & dysenteries Enteric fevers Enteric virus ingections
		Quantity only	Skin & eye infections Louse-born fevers
	Water-based	Protection of water source	Guinea worm infections
Excreta disposal	Person-person contact Domestic contamination Water contamination Field contamination Crop contamination	Latrine construction Excreta treatment Hygiene environment	Diarrhoeas & dysenteries Enteric fevers Soil transmitted helminths Beef and pork tapeworms Water-based helminths (Schistosomiasis) Filariasis
Housing	Siting near habitat	Siting/screening of houses	Malaria, filariasis, onchocerciasis, trypanosomiasis
	Overcrowding Air pollution	Space and ventilation	Epidemic meningitis Acute & chronic respiratory infections Respiratory malignances
	Vector breeding	Water storage	Arbo-viral infections (denque, yellow fever)
	Refuse Construction Fire	Refuse disposal Construction materials Burns	Chagas disease, leishmaniasis Soil transmitted helminths Fire hazards
Nutrition	Lack of calories Lack of proteins Lack of vitamins	Staple crops Home-gardens	Under nutrition Protein-caloric malnutrition Vitamin deficiencies
	Food storage Food preparation	Storage facilities	Food poisoning: diarrhoeas
Energy	Use of fire-wood Open fire Storage of kerosene	Kitchen stoves Chimneys	Food poisoning: diarrhoeas Burns see: Air polution
Village infrastructure		Immunizations	Childhood infections, poliomyelitis, yellow fever
Health care		Mother-child care Education and communication	Perinatal/infant mortality Treatment endemic diseases: malaria, diarrhoea, repiratory infections, helminths, schistosomiasis etc. Birth regulation

ganisms that compete ecologically with the disease agents or vectors, can also be taken.

Hosts can be made less susceptible through the use of prophylactic drugs (e.g. in the case of malaria) or by reducing their contact with the vector by using mosquito-nets, by applying repellants, or by screening their houses.

Reservoirs of infection can be reduced by treating infected and ill people, and by treating or eliminating infected animals (e.g. in the case of trypanosomiasis).

The integrated control of infectious diseases is a control strategy that combines, if relevant, the above-mentioned approaches (WHO 1983).

4.2   The Main Water-Borne Diseases

4.2.1   Malaria

Malaria is the most widespread water-borne disease in West Africa and is clinically characterized by high fever, which may have a characteristic periodicity, and anaemia, which results from the destruction of red blood cells and enlargement of the spleen.

The disease is caused by a number of protozoan organisms of the genus *Plasmodium*, especially *P. falciparum, P. vivax*, and *P. malariae*. Malaria is transmitted by mosquitoes (*Anopheles spp.*), which breed in stagnant or slowly flowing water in streams and rivers, in small pools, and in standing water in, for instance, cans and barrels.

Malaria control aims at reducing the reservoirs of infection in the community and/or reducing the number of malaria vectors biting man. Depending on environmental and socio-economic conditions in the community, a control strategy could be (Oomen et al. 1990):
- To prevent mosquitoes from feeding on man;
- To prevent or reduce mosquito breeding;
- To destroy mosquito larvae;
- To destroy adult mosquitoes;
- To eliminate malaria parasites in the human host.

The inland valleys seem to be excellent breeding sites for different *Anopheles* species. If water management results in a prolonged wet season (double cropping of rice), the increased water availability provides extra breeding potential. With intensified swamp labour, the transmission of malaria can be promoted by the increased intensity of man-mosquito contact (van der Laar 1985).

In the cultivation of rice, intermittent water application and field drainage will reduce breeding facilities.

4.2.2   Schistosomiasis (Bilharzia)

Schistosomiasis is a complex parasitic infection that is caused by five species of parasitic worms of the genus *Schistosoma* which affect different organ systems. The different stages of this disease are (Oomen et al. 1990):
- Invasion: cercarial skin reaction and possibly some fever;
- Development: acute febrile illness, which is not always recognized;

– Established infection: early chronic disease with haematuria or intestinal symptoms;
– Late infection: chronic disease of the bladder/kidneys, intestinal tract, and liver.

Schistosomiasis is transmitted to man in a variety of freshwater habitats. Aquatic snails (*Bulinus spp., Biomphalaria spp.*, and *Oncomelania spp.*) are the intermediate host in the life cycle of the parasites *S. haematobium, S. mansoni*, and *S. japonicum*, respectively. The reservoir of infection of *S. haematobium* appears to be in humans, whereas *S. mansoni* infections are found in monkeys, baboons, and rodents. There is no evidence, however, that these animals play a role in transmitting *S. mansoni* to humans. Domestic and wild animals contribute significantly to the transmission of *S. japonicum* to humans.

The snails also provide a transport function in spreading the disease.

Opportunities to control transmission are offered by the human host, the snail host, and the free-swimming stages of the parasite.

Human behaviour is important in the transmission of the disease. Good excreta treatment and hygiene (latrine construction) will reduce the release of schistosome eggs into the environment. Reducing the exposure of humans to infected water will lower the transmission too (Oomen et al. 1990).

Snail populations can be reduced through chemical control, but this is expensive and must be repetitive (McJunkin 1975).

The snails prefer standing water with a constant depth. Constructing and maintaining irrigation canals to increase the velocity of stream flow and to fluctuate the water level may reduce the snail populations and would seem to be the most beneficial measure. Vegetation in the drainage network lowers the stream velocity and should not be allowed to develop.

The ability of the snails to survive in the absence of free water varies with the species. If periods of drought are sufficiently prolonged or frequent, the snail population may be reduced or eliminated.

Since some snail species are drought-tolerant, they enable the parasites to survive a drying out of irrigation canals or the entire dry season, even in the savanna areas.

The cultivation of inland valleys increases the exposure of humans to infected water. On the other hand, clearing and cultivating the valley bottoms will probably lead to an increase in the stream velocity and the use of pesticides and anorganic fertilizers. This will change the environment required by the snails and will lower their numbers (van der Laar 1985).

4.2.3   Trypanosomiasis (Sleeping Sickness)

Trypanosomiasis is a fatal disease caused by protozoan parasites of the genus *Trypanosoma*. In West Africa, *Trypanosoma brucei gambiense* and *T.b.rhodesiense* are the causative agents of sleeping sickness in man, while *T.b.brucei* affects domestic animals. The different stages of this disease in man are (Oomen et al. 1990):
– The onset of the disease is characterized by recurrent bouts of fever;
– During the first stage, essential trypanosomal activity is in the lymph glands and the spleen;
– During the second stage, the central nervous system and the heart are affected, which

results initially in irritability and sleeplessness, followed by apathy and drowsiness;
– Death follows, usually because of an intercurrent infection like pneumonia.

Trypanosomiasis is transmitted by tsetse flies. In West Africa *T.b. gambiense* is transmitted by *Glossina palpalis spp.* and *G. tachinoides*, and *T.b. rhodesiense* by *G. morsitans morsitans, G.m. centralis, G. pallidipes*, and *G. swynnertoni.* All these vector species need shady (forested) and relatively humid conditions. The distribution and ecology of the different species are closely linked with vegetation. Any modification in vegetational cover may affect the dynamic behaviour of the tsetse fly populations and the transmission of trypanosomiasis.

The reservoir of infection was believed to be man, but recently it has been isolated from domestic pigs, dogs, and forest antelopes, suggesting that a reservoir exists in the wild. The disease occurs in distinct isolated foci scattered over the 'tsetse belt'. Most foci are known and are geographically stable (Oomen et al. 1990).

The disease remains a problem despite its low incidence. Changes in climate, vegetation, and land use, population movements, or interruptions in medical surveillance may cause the outbreak of an epidemic.

Animal trypanosomiasis affects cattle, goats, sheep, and camels, and is one of the main obstacles to rural development in Africa.

Medical surveillance and treatment have proven to be effective in controlling trypanosomiasis. Removing the habitats of the tsetse flies and eliminating their hosts (e.g. by clearing the vegetation and destroying any infected wild animal) are other effective methods of vector control.

Land-use patterns can restrict the transmission of trypanosomiasis. If wetlands occur near villages, a buffer zone, cleared around the village and restricted to the cultivation of dryland crops, functions as an obstacle for the movement of tsetse flies between the village and the wet areas.

The development of inland valleys can result in a decrease in sleeping sickness if land clearing includes the removal of the habitat of the tsetse fly (gallery forests).

If the present habitat of the inland valleys is already unfavourable for the tsetse flies, sleeping sickness is not expected to increase through more intensive swamp farming and water management (van der Laar 1985).

4.2.4   Onchocerciasis (River Blindness)

Onchocerciasis is a vector-borne filarial infection caused by *Onchocerca volvulus*, a nematode worm. The most common symptoms are itching, changes in pigmentation, and the development of nodules containing adult worms. Microfilariae produced by these worms can invade the eyes and damage the eye structure, which results in blindness in the patients.

In endemic areas (e.g. the Volta River basin), the general pattern of infection shows an increasing prevalence and severity with age. Also, while the incidence of infection in males and females is similar, men have heavier infections than women because of the nature of their work (Oomen et al. 1990).

The infection is transmitted by species of *Simuliidae* (blackflies), in West Africa mainly *Simulium damnosum*. The *Simulium* vector breeds in rapidly flowing and well-

aerated water. The World Health Organization (WHO 1980) indicates that the most commonly tolerated velocities range from 0.7 to 1.2 m/s. The adult fly is usually found near its breeding site, but it can fly considerable distances. This has important consequences for the spread of this disease.

Onchocerciasis can be controlled by campaigns against the parasite, the vector, or both. Since *S. damnosum* can disperse over long distances, control efforts must cover large areas to avoid re-invasion from adjacent foci.

Environmental management for vector control is focussed on turbulent water sites. These conditions may occur at spillways, rapids, bridges, or wherever streams face a temporary obstruction (e.g. from debris). The breeding sites are thus very specific and isolated. They may even occur at unanticipated locations. This remains a problem, especially because of the rapid development of *Simulium*, sometimes within five days.

There are also drugs available to control the parasite. Ivermectine has proven effective against microfilaria in the body, and needs to be taken only once a year (TRD 1988).

Inland valley development will not change the habitat of the present foci where the blackflies occur. Blackflies prefer to breed in high-velocity streams. If these are avoided in drainage and irrigation canals, river blindness is not expected to increase because of water-management measures (van der Laar 1985).

4.2.5 Dracontiasis (Guinea Worm)

Dracontiasis concerns infection with the helminth *Dracunculus medinensis* (guinea worm), which inhabits the subcutaneous tissues of the human host. Dracontiasis sores are painful and often give rise to abscesses, or they affect joints. Without other complications (e.g. tetanus), dracontiasis is not a killing disease but disables the infected for prolonged periods.

Infection occurs when water infested with *Cyclops*, a crustacean, is ingested. The time required to mature in the human host is one year. When an infected human steps into a well or pond from which others may draw drinking water, larvae are liberated from the sores to renew the cycle.

Infection is markedly seasonal because of the influence of the weather on the occurrence of water sources and on the development cycle of the parasite. The periods of the patients' incapacity therefore occur during the farming seasons.

The transmission of guinea worm infection can be totally stopped by the provision of safe drinking water. Effective control should therefore be based on improving drinking-water facilities (e.g. closed wells). Chemicals (e.g. Abate) can be used as well (Lyons 1973).

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5 Farming Systems and Rice-Cropping Systems in West Africa

5.1 General

This chapter describes the main farming systems of West Africa. As, under the influence of climate and soils, the farming systems are area specific, they are described only in general terms. Rice-cropping systems within these farming systems are discussed in the second part of this chapter.

Many authors give information, at various levels of detail, about the farming systems in West Africa. The information compiled here is mainly derived from Webster and Wilson (1980), Ruthenberg (1980), Okigbo (1981), Moormann and Juo (1986), Harrison Church (1968), Morgan (1969), Gleave and White (1969), and Kowal and Kassam (1978).

Rice-cropping systems are described by, among others, Moormann and Juo (1986), Luning (1984), Buddenhagen (1978), Becker (1990), WARDA (1991), Bindraban (1991), Andriesse and Fresco (1991), de Rouw (1991), and Richards (1985, 1986, 1987).

A farming (or farm, or agricultural) system is defined by Okigbo (1979) as an enterprise or business in which sets of inputs or resources are uniquely orchestrated by the farmer in such a way as to satisfy needs and to achieve desired objectives in a given environmental setting. In West Africa, the farming system comprises the activity of one or more individuals, usually a family unit, with some or all members of the family participating for some or most of their time in farm work.

According to de Rouw (1991), the farming system functions as a decision-making unit as it transforms land, capital, and knowledge into useful products that can be consumed or sold.

A (rice-)cropping system refers to the kinds, combinations, and/or sequences of activities in time and space, in addition to the practices and technologies used in the production of the crop in a specific area to satisfy the needs of growers and users (Okigbo 1979).

The function of the cropping system is the transformation of plant material and soil nutrients into useful biomass. A cropping system is a component of the farming system (de Rouw 1991).

5.2 Farming Systems

Okigbo (1981) and de Jong (1989) summarize the main characteristics of the traditional farming systems in West Africa as follows:
- Crop production is mainly for home consumption;
- Farming systems are diverse and range from true shifting cultivation to permanent cultivation;
- Levels of mechanization, as well as of capital input, are low and the possibilities of external inputs are restricted;

- Farms are small but have a high diversity of crops;
- There is a clear division of labour and income between the sexes;
- Cropping patterns are strongly dependent on the prevailing rainfall regime. Rotational and mixed cropping are practised to spread the risk of crop failure;
- Traditional cropping systems take advantage of local topographic features and hydrological circumstances. There is much indigenous knowledge;
- In the humid areas (Equatorial Forest Zone) and in the tsetse-infested areas, farming is predominantly based on human labour and simple tools. Only goats, chickens, sheep, and pigs are kept as livestock;
- In the drier Savanna Zones, arable cropping and livestock production are integrated within the farming system. Oxen are used to work the fields, as a source of manure, etc.

Farming systems can be subdivided on the basis of the types of crops cultivated. Webster and Wilson (1980), for instance, distinguish four main types of crop-based or livestock-based farming systems. These are:
- Rain-fed arable farming systems other than those involving wetland rice;
- Rain-fed and irrigated systems based on wetland rice;
- Monoculture of perennial crops;
- Predominantly livestock systems (e.g. nomadic pastoralism and ranching).

Because rice cultivation in West Africa is the main subject of the present study, a more convenient subdivision of farming systems is given by Ruthenberg (1980). He distinguishes three main arable farming systems, based on the length of the fallow period and the input of labour, capital, and technology. These are:
- **Shifting cultivation:** Short periods of cropping are followed by long fallow periods. Less than 33% of the potential cropping area is under cultivation at any one time;
- **Fallow system:** Periods of cropping are followed by relatively short fallow periods. More than 33%, but less than 66% of the potential cropping area is under cultivation at any one time;
- **(Semi-)permanent cultivation:** Fallow periods are very short or do not occur at all. More than 66% of the potential cropping area is under cultivation at any one time.

In practice, the farming systems distinguished above are not distinctly separated. Within a certain area, different farming systems occur. Fields or gardens near the farmsteads are generally more permanently cultivated (short fallow periods) and more intensively than the fields further away from the villages (long fallow periods). Large floodplains, coastal plains, and inland valley bottoms can be cultivated more intensively, whereas the adjacent uplands are cultivated with short to long fallow periods.

5.2.1   Shifting Cultivation

Shifting cultivation is the characteristic agricultural practice in much of the humid part of West Africa (i.e. the Equatorial Forest Zone). This farming system is based on the natural soil fertility and the input of manual labour only. There is no input of capital, technology, manure, or fertilizers. It is characterized by short periods of

cropping (one to three years), alternating with long fallow periods which serve to re-store the fertility of the soil. The fields under shifting cultivation are cleared by slashing and burning. Shifting cultivators, in general, have only a few domestic animals like goats, sheep, chickens, or pigs, which are kept near the farm yards. During the fallow period, the fields are not used for grazing.

Shifting cultivation is mainly associated with subsistence agriculture. The length of the fallow period is strongly correlated with the distribution and the density of the population (generally less than 10 per km²). The shifting cultivator is skilled in adapting cropping practices to the environment in which he is working. Important aspects of adaptation are the selection of the field to be cultivated, the choice of crops, the organization of intercropping, mixed cropping, or phased planting, and the arrangement of short-, middle-, and long-term fallows.

Shifting cultivation creates only temporary boundaries between cultivated and non-cultivated land. The fields are well defined during the growing period, but they are lost in the subsequent fallow period.

Under shifting cultivation, the staple crop is of primary importance. These crops, however, differ per country. In Liberia, Sierra Leone, and parts of Ivory Coast, upland rice is the staple crop. In the other parts of the Equatorial Forest Zone, the main staple crops are maize and tubers, including cassava, yam, sweet potato, and taro.

The main problem of shifting cultivation lies in the fact that the productivity of labour and natural resources can hardly be increased. Shifting cultivation cannot absorb a growing population and does not allow increased cash production or the introduction of technical innovations (Ruthenberg 1980).

5.2.2   Fallow Systems

Under increasing population pressure and expanding cash production, shifting culti-vation will be replaced by the fallow farming system. Within that system, the period of fallow is shorter than that under shifting cultivation, but in general the time in fallow still exceeds the time during which the land is cultivated. Ruthenberg (1980) defines the fallow system by the fact that between 33% and 66% of the potential area is under cultivation at any one time.

This farming system is widespread in the Guinea Savanna and Sudan Savanna Zones of West Africa and, to a much lesser extent, in the Equatorial Forest Zone. Based on the vegetational zonation, different names are used for this system (e.g. savanna fallow and bush fallow).

Under fallow systems, a regular system of fallows is created which are never permit-ted to revert to savanna woodland or equatorial forest. After several years of arable cropping, the field can be used for the cultivation of grasses and legumes and utilized for livestock production. This can be the natural fallow vegetation without manage-ment, or a more regulated fallow vegetation involving the planting of certain grasses, the application of manure, etc. More or less regulated fallow cultivation is called the ley system (Ruthenberg 1980).

Fallow farming is usually characterized by clearly defined farms with largely perma-nent field divisions and more or less permanent farm yards. Land occupied by fallow

cultivators is substantially modified by man's efforts to maintain and improve his living.

The most common staple crops cultivated in this way are rice, roots and tubers (cassava, yam, sweet potato) and mixed grains (maize, sorghum, millet).

Along the toposequences of the inland valleys, each (physio-hydrologic) segment has its specific agricultural potential and is used accordingly by the farmers (Ruthenberg 1980; Richards 1987).

In the West African Savanna Zones, for instance, the more drought tolerant crops are grown on the relatively dry uplands (millet, groundnut, cowpea, and cotton), while maize, sorghum, sweet potato, and rice are cultivated in the wetter lower parts of the slopes and in the valley bottoms. This strategy spreads the risks of crop failure from both droughts and floods (Vierich and Stoop 1990).

In a bush fallow farming system in Nigeria, described by Gembremeskel and de Vries (1985), almost all farmers cultivate fields in both the uplands and the valley bottoms. The upland farms are cultivated for about five years, followed by a fallow period of about ten years. During the rainy season, the most important upland crops are Guinea corn (sorghum), melon, maize, and yam, while on the valley bottoms only rice is cultivated. In the dry season, the valley bottoms are cultivated with cassava, sweet potato, okra, and sugarcane.

In addition to these physiographically-induced differences in land use, the distance from the village or houses to the fields also influences the cropping practices. The most intensive land use is found near the houses, and consists of permanent gardens with fruit trees and perennial crops, and on the dungland, the arable land close to the village. Both are permanently cultivated, with the use of household and farmyard manure.

Adjoining the dungland, intensive fallow systems occur in concentric circles of varying sizes. These fields are often used for staple-food and cash-crop production. The fallow is mostly used as pasture.

The intensity of the cropping cycle decreases proportionally with the distance from the farmstead. The fallow periods are of long duration far away from the village and are under regenerating natural vegetation (Ruthenberg 1980).

Because of the more intensive land use of the fallow system, as compared with shifting cultivation, the soils are more frequently fertilized with manure, green manure, and, in the case of cash crops, with mineral fertilizers. The fallow system also uses more advanced cultivation techniques.

Large stocks of cattle are integrated into the fallow farming systems, especially in the Savanna Zones outside the tsetse belt. The cattle are kept for traction power, for ox-plough cultivation, for meat and milk, to cover the risks of harvest failure, and for social functions (bride price). The manure is used to fertilize the fields.

A major problem in fallow farming systems is the declining fertility status of the soils because the fallow periods are too short generally, and the manure applications are insufficient to maintain the soils' natural fertility. Furthermore, fallow farming can cause a degradation of the soil structure, resulting in the sealing of the soil surface and the compaction of subsurface layers. This, in turn, leads to increased soil erosion.

Another problem of the fallow farming system, rather specific for West Africa, is

the labour shortage, especially in the rainy season. Because of the lack of means to pay hired workers and the general shortage of labour in the rural areas of West Africa (Kowal and Kassam 1978), most of the work has to be done by family labour. This is often too little to plant and weed according to a timetable that would optimize the yields.

A third problem occurs in the Savanna Zones where livestock is present. The increase of the area used for arable farming creates conflicts of interest between arable farmers and livestock herders. This can result in overgrazing of the lands and may cause severe soil degradation and erosion.

5.2.3   (Semi-)Permanent Farming Systems

Any intensification of the fallow farming system results in a further shortening of the fallow period, or, eventually, its absence. The farming system becomes more or less permanent. This is particularly the case in densely populated areas like the Mossi Plateau (Burkina Faso), Kano (north Nigeria), and the Ibo and Ibilio lands (east Nigeria). As early as 1969, Morgan had already described great problems of overcultivation, soil degradation, and soil erosion occurring in these areas. Vierich and Stoop (1990) found severe degradation of the soils along some toposequences in Burkina Faso, due to increased population pressure and protracted periods of low rainfall.

Ruthenberg (1980) distinguishes three different types of farming systems within permanent farming systems. These are:
– Permanent cropping of annual crops;
– Planting of perennials, especially tree crops;
– Irrigated farming.

Because of the strong leaching of the nutrients and the very fast alteration of organic matter under humid tropical conditions, permanent upland cultivation of annual crops may result in a severe decline in soil fertility and in very low yields. Technically-feasible solutions to these problems exist, but the economic returns are as yet still marginal. For these reasons, permanent annual crop production is hardly found in the Equatorial Forest Zone. In the drier parts of West Africa (i.e. the Savanna Zones), permanent cultivation is more common, but the major part of agricultural production is done in fallow farming systems.

In the humid areas of West Africa, perennial crops like oil palm, cacao, and coffee have long been cultivated on the uplands. If these crops are intensively cultivated, the requirements of fertilizer, management, capital, and technical knowledge are high. Generally, in West Africa, these crops are produced for the export market.

Irrigated farming must be divided into traditional and modern irrigation. Traditional irrigation is found in various parts of the inventory area. Mainly along the main rivers (Senegal, Niger, Benué), the annual flooding of the floodplains is used for the cultivation of (floating) rice and the production of flood-recession cereals (millet, sorghum). In the inland delta of the Niger River (Mali), an area of some 60,000 ha is cultivated

with rice (FAO 1986). All along the West African coast – from The Gambia to Liberia and, to a lesser extent further east (from Benin through Cameroon) – coastal swamps and estuaries are used for tidal rice production.

In the western part of West Africa, rice has long been grown by smallholders in the inland valleys, especially in the Guinea Savanna Zone, where rice is an important staple crop. According to Mohr (1969), this area comprises the upper catchments of the Casamance and Gambia Rivers, in south Mali, Burkina Faso, north and west Ivory Coast (Korhogo and Man), Guinea, north Liberia, Sierra Leone, and Guinea Bissau. In this region, valley rice cultivation is still widespread.

In Nigeria, smallholder traditional *fadama* development has taken place in the middle belt of the Guinea Savanna Zone, where it is estimated to have expanded from 100,000 ha in 1958 to 800,000 ha at present. Here, vegetables are an important crop, supplementing rain-fed cereals in the wet season (FAO 1986).

Over the last 50 years, large, modern irrigation schemes have been developed in several countries of West Africa: in Senegal, Mali, Nigeria, Ivory Coast, and Cameroon. Owing to the low yields, the high implementation costs, or the remote location of these projects, their performance has been disappointing and incommensurate with the large investments made (FAO 1986).

In recent years, small- and medium-scale irrigation schemes have been implemented, such as village irrigation schemes along the main rivers (e.g. the Senegal River) and schemes based on small dams in Burkina Faso. The success of some of these schemes has often been the result of good prices for rice or the impossibility of farmers obtaining their food requirements from rain-fed crops (FAO 1986).

Permanent rice production by irrigated farming, with or without water control, is mainly practised in the large floodplains and in the coastal areas. Recently, more attention has been given to rice production in the valley bottoms of the inland valleys (WARDA 1988; IITA 1990).

5.3   Rice-Cropping Systems

In literature, different kinds of rice-cropping systems have been defined. Buddenhagen (1978) distinguishes four main types of African rice culture, subdivided into several sub-types: upland rice (dryland and hydromorphic), irrigated rice, inland swamp rice, and flooded rice (riverine deep, riverine shallow, boliland, mangrove).

Nyanteng (1986) gives a slightly different subdivision:
– Upland rice;
– Inland swamp rice (including boliland);
– Mangrove swamp rice;
– Irrigated rice;
– Deep-water rice.

Table 5.1 shows the distribution of these categories of rice-cropping systems over the different countries of West Africa.

From these data, it can be concluded that, in the humid zone of West Africa, most

Table 5.1 Rice-cropping systems and their distribution (in % of total rice area) in West Africa, 1980-1985 (Source: Nyanteng 1986)

	Upland	Inland swamp (+ boliland)	Mangrove swamp	Irrigated	Deep-water floating riverine
Benin	6.7	92.0	–	1.3	–
Burkina Faso	0.3	85.9	–	13.8	–
The Gambia	15.4	63.7	14.2	6.7	–
Ghana	85.2	7.4	–	7.4	–
Guinea	47.0	30.0	15.0	5.0	3.0
Guinea Bissau	20.3	23.0	54.6	2.1	–
Ivory Coast	87.1	7.1	–	5.8	–
Liberia	94.0	6.0	–	–	–
Mali	5.0	–	–	34.4	60.6
Niger	–	–	–	27.9	72.1
Nigeria	60.0	10.0	5.0	5.0	20.0
Senegal	–	72.7	11.8	15.5	–
Sierra Leone	67.1	26.2	5.7	–	1.0
Togo	77.2	18.5	–	4.3	–

of the rice cultivation takes place on the uplands (Ivory Coast, Ghana, Liberia, Nigeria, Togo, and Sierra Leone). Inland swamp rice is prominent in Benin, Burkina Faso, The Gambia, and Senegal. In Niger and Mali, irrigated and deep-water floating riverine rice are the most important rice-cropping systems.

More recently, for its research programme in West Africa, the West Africa Rice Development Association distinguished four main types of rice cultivation (WARDA 1991, Becker 1990). This subdivision is based mainly on ecological/environmental differences, as follows:
– Irrigated Sahel;
– Coastal mangrove swamp;
– Deep-water floodplains of inland rivers and lakes;
– Upland/inland swamp continuum.

The upland/inland swamp continuum represents the diversity of ecosystems from – at the lower end – the valley bottoms, which are often seasonally submerged, to – at the higher end of the continuum – the uplands, comprising the rain-fed zones. The upland/inland swamp continuum is the characteristic toposequence of the inland valleys (see Section 2.3). As the inland valleys are the main subject of the present inventory, the rice cropping systems of the upland/inland swamp continuum will be described here in more detail.

The basic differences between the various rice-cropping systems of the upland/inland swamp continuum are the hydrological conditions in the rice fields. On the uplands (crests, upper and middle slopes), the only source of water for agriculture is precipitation. This is the pluvial zone, described in Section 2.4. In general, the soils drain freely and there is no saturation of the soil, even during the rainy season. The lowest parts of the slopes are characterized by a temporary saturation of the soils

due to subsurface groundwater inflow and runoff from the uplands (the phreatic zone) while the valley bottom soils are annually flooded for a certain period (the fluxial zone).

On the uplands, the rice-cropping system is defined as upland (or pluvial), on the temporarily-saturated footslopes as hydromorphic (or phreatic), and in the flooded valley bottoms as wetland (or fluxial) rice cultivation.

5.3.1   Upland (Pluvial) Rice-Cropping Systems

Traditionally, upland rice cultivation in West Africa is mainly found in the Equatorial Forest Zone and, because of the lower rainfall and the limited water retention, to a lesser extent in the humid parts of the Guinea Savanna Zone (see Table 5.1). In the Sudan Savanna Zone, rice cultivation is hardly found on the uplands because of the small amount of precipitation and its irregularity (Andriesse and Fresco 1991).

In the Equatorial Forest Zone, it is practised mainly within the shifting cultivation farming system, and it is one of the components of the bush fallow farming system in the Guinea Savanna Zone. Rice is not cultivated in permanent farming systems on the uplands.

Upland rice is mostly cultivated as part of a mixed cropping system. Combinations with maize, millet, sorghum, cassava, yam, and various kinds of vegetables and spice plants are frequently found. In some regions, upland rice is intersown in the first two years after the establishment of perennial crops like coffee, cocoa, and banana. Mixed cropping systems are practised for various reasons: to ensure the farmers of some cash income from crops other than rice, to meet the family needs for vegetables, spices, etc., and to spread the risk of crop failure.

In the second year of the cultivation cycle, a second rice crop is sometimes grown, but it is more common to grow other food crops (groundnut, maize, yam, sweet potato). Cassava is very often planted as the final crop of the cultivation cycle.

In West Africa, 75 to 95% of the rice area is used to grow traditional varieties. According to the farmers, traditional varieties are tastier and more resistant to drought and to storage pests than the improved varieties. In general, the traditional varieties are preferred for home consumption while the improved varieties are grown for the market (WARDA 1984).

Nearly all farm operations, from land clearing to harvesting, are performed manually with the help of simple tools. The use of animal power is very rare, as the presence of the tsetse fly prohibits the keeping of cattle. Most of the work is done by family labour. Hired labour, if available, is usually employed seasonally at times of peak labour demand. Labour scarcity is often a bottleneck in improving yields.

Towards the end of the dry season, the farmer begins to clear the land. After the first rains, the rice is sown broadcast and hoed into the soil. Soil preparation work is practically non-existent in the Equatorial Forest Zone, and is very superficial in the Savanna Zones, where only a little hoeing is done (Courtois and Jacquot 1988). Crops that are grown with rice on the same plot are sown by mixing the seeds with the rice (millet, sorghum, maize, various vegetables) or by interplanting them in the rice field (cassava, yam, etc.). The proper time for sowing depends on the rainfall

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and varies considerably. Sowing generally takes place between early April and mid-June. The harvest is usually between July and October. Where the rainfall pattern is bimodal, upland rice is cultivated during the major rainy period (WARDA 1984).

Weeding is a labour-intensive and time-consuming operation. It is one of the main bottlenecks in the cropping calendar and, together with pests, diseases, and damage caused by birds and rodents, results in very low yields.

Table 5.2 shows the labour requirements of the various operations in the different upland rice cropping systems under shifting cultivation.

Table 5.2 Labour requirements (man-days/ha) of various operations in shifting upland rice cultivation in West Africa (source: Courtois and Jacquot 1988)

	Central Ivory Coast	Western Ivory Coast	Liberia	Western Nigeria	Sierra Leone
Land management					
Clearing, cutting, and burning*	25	50	79	49	37
Fencing	20	8	20	26	27
Rice cultivation					
Planting	20	24	37	30	42
Weeding	15-30	49	32	53	31
Harvest and transport	30	36	47	82	84

* including soil preparation

The yield of traditional upland rice is generally very low. The average yield in West Africa is about 900 kg/ha, with a range of 100 to 3,400 kg/ha (Bindraban 1991). In Sierra Leone, average yields of 1,100 kg/ha, with a variation from 200 kg/ha to 2,660 kg/ha, were reported by Ay et al. (1985), whereas Richards (1986) mentioned 1,350 kg/ha. In the Tai Region (Ivory Coast), yields vary between 750 and 1,000 kg/ha (de Rouw 1991).

Yield-increasing inputs like mineral fertilizers and pesticides are rarely applied. If used, they are leached by the intensive rains (FAO 1982).

Technical innovations will not always result in higher net economic returns for the farmer. Studies on mechanization in Nigeria have revealed that mechanical weed control for upland rice is not as efficient as hand and hoe weeding. In Ivory Coast, too, the net farm income was found not to increase with the introduction of mechanized farming (FAO/WAU 1976).

An advanced upland rice cropping system is described by Olagoke (1989), in the Anambra State, Nigeria. The studied area is situated in the derived Savanna Zone. Here, land use is rather intensive, with relatively short fallow periods of one to two years only. Fertilizer, herbicides, and insecticides are applied and a part of the soil preparation and weeding is done with machinery. Rice yields during the 1987-88 survey were up to 1,710 kg/ha.

5.3.2   Hydromorphic (Phreatic) and Wetland (Fluxial) Rice-Cropping Systems

In many ways, hydromorphic and wetland rice-cropping systems in West Africa resemble those of the uplands: most of the work is done manually and there is a low input of technology and capital. The main differences between these systems and the upland rice-cropping system will be explained below.

In the wet parts of the inland valley/swamp continuum (i.e. the lower footslopes and the valley bottoms), precipitation is not the only source of water for the crops. The precipitation and the lateral groundwater flow from the adjacent uplands cause the lower footslopes and valley bottoms to be saturated or flooded for a certain period. Because, in the Equatorial Forest Zone and the Guinea Savanna Zone, the groundwater flow continues for some time after the rains have ceased, the potential cropping period is longer than the rainy season (see Section 2.4.7).

On the footslopes and the valley bottoms in the Equatorial Forest and Guinea Savanna Zones, rice is cultivated during the rainy season as a single crop because of the wet growing environment. In the first part of the dry season, different kinds of vegetables and root crops are cultivated. On the wettest parts of the valley bottoms, these crops are planted on heaps or ridges made by the farmers. On the valley bottoms, double cropping of rice can be practised, with or without additional water management.

In the relatively dry Sudan Savanna Zone, with its highly irregular precipitation, the growing season is hardly prolonged by lateral groundwater flow. During the rainy season, rice is often intersown with maize on the valley bottoms. In dry years, the maize will perform best, whereas in wet years the rice will grow best and will be harvested. This is an example of spreading the risk of crop failure (Vierich and Stoop 1990).

The farmers treat the footslopes and the valley bottoms similarly to the upland areas, allowing the land to revert to bush or grass fallow after one to two cycles of rice cropping.

Despite the higher natural fertility of the bottomlands, farmers prefer to cultivate the uplands. This is because of the difficulties in the initial clearance of the wetland vegetation, the preference for upland rice in the local diet, the possibility of mixed cropping on the uplands, and the unhealthy working conditions in the wetlands.

Clearing the vegetation is hard work, even with effective tools. It is estimated that land clearing may require as many as 100 working days per ha, depending on the character of the vegetation. Ideally, land clearing should be rapidly followed by land preparation, in order to minimize the regrowth of the vegetation. Labour, however, is a serious constraint.

Rice is sown broadcast or it is transplanted. In areas where farmers cultivate crops on both uplands and bottomlands, rice on the footslopes and valley bottoms is generally transplanted during the later part of the rainy season, or after the harvest of most of the upland crops. This is the consequence of the farmers' greater interest in upland crops and of the shortage of labour, especially in the rainy season. Because the farmers cannot follow the ideal cropping calendar for the wetland rice, weeds, pests, and diseases are serious problems.

Yields are generally low. In Sierra Leone (Equatorial Forest Zone), average yields

are about 625 kg/ha, with variations from 100 to 2,330 kg/ha (Ay et al. 1984). Gebre-meskel and de Vries (1985) found yields up to 2,700 kg/ha for wetlands in Nigeria (Guinea Savanna Zone). In Burkina Faso (Sudan Savanna Zone), yields vary from 270 to 1,000 kg/ha (Vierich and Stoop 1990).

An advanced wetland rice-cropping system is described by Olagoke (1989) in the Anambra State, Nigeria. In the same study area as was mentioned earlier (Section 5.2.1), and with similar inputs, yields during the 1987-88 survey were up to 1960 hg/ha, about 250 kg/ha more than the yields of the upland rice-cropping system.

The use of tractors for land preparation, harvesting, and threshing will increase the yields and the net return of wetland rice. Okereke (1990) reports that, under condi-tions similar to those in the study by Olagoke, yields during the 1988-89 survey varied from 2,540 kg/ha on farms without the use of tractors to 3,430 kg/ha on farms where tractors were used.
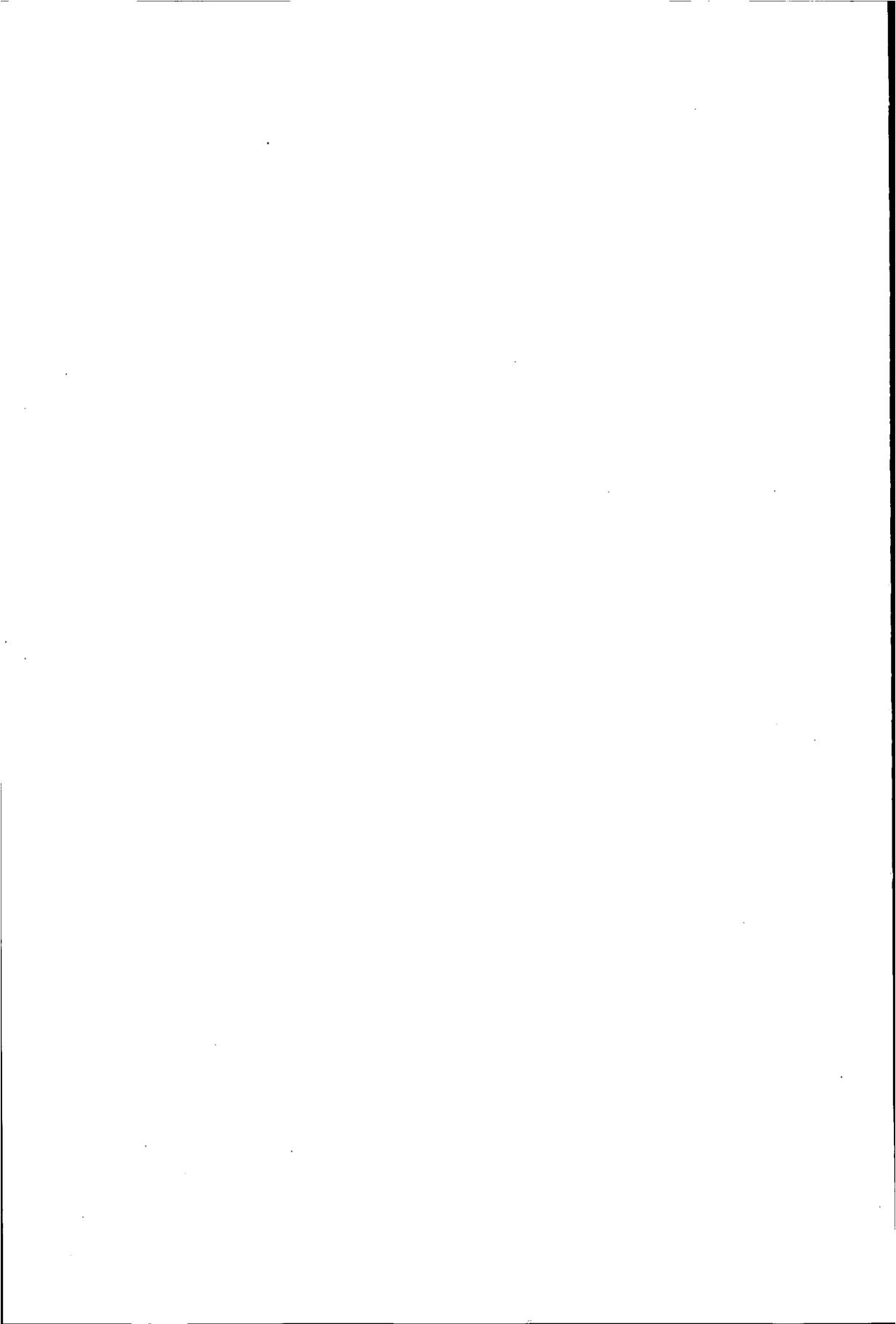
6 Socio-Economic Aspects

6.1 Demography

6.1.1 Population

The population of the inventory area consists of a great variation in people, in terms of numbers, ethnology, and customs. The population figures for the various countries in 1975, 1980, 1985, 1988, 1989, and 1990 are given in Table 6.1. Figure 6.1 shows the regional variations in population densities.

The overall population density in West Africa is low (65 persons/km^2). The distribution of the population, however, is strongly determined by the economic strength and stability of the individual countries or parts thereof. Changes in the economic situation often result in movements of large numbers of people.

Within the inventory area, Nigeria is by far the most populous country (117 persons/km^2), and Niger and Mali the least (6 and 7 persons/km^2 respectively). Generally, the eastern part of the inventory area is more densely populated than the western part, and the coastal areas are more populous than the inland areas.

The highest population densities (20 to more than 200 persons/km^2) are found in the Equatorial Forest Zone and the southern parts of the Guinea Savanna Zone, especially around the capitals and other centres of administration. In the northern part

Table 6.1 Population of West Africa (source: FAO Production Yearbook, several editions)

| | Population (x 1000) | | | | | | Density (p/km^2) |
	1975	1980	1985	1988	1989	1990	1990
Benin	3,033	3,459	3,985	4,357	4,491	4,630	41
Burkina Faso	6,202	6,957	7,877	8,520	8,753	8,996	33
Cameroon	7,520	8,653	10,051	11,071	11,444	11,833	25
The Gambia	548	641	745	813	837	861	76
Ghana	9,831	10,736	12,839	14,121	14,561	15,028	63
Guinea	4,149	4,461	4,987	5,421	5,584	5,755	23
Guinea Bissau	672	795	873	926	945	964	27
Ivory Coast	6,755	8,149	9,933	11,124	11,552	11,997	37
Liberia	1,609	1,876	2,199	2,417	2,494	2,575	23
Mali	6,169	6,863	7,915	8,661	8,930	9,214	7
Niger	4,771	5,586	6,608	7,263	7,493	7,731	6
Nigeria	66,346	78,430	92,016	101,592	105,019	108,542*	117
Senegal	4,806	5,538	6,375	6,930	7,126	7,327	37
Sierra Leone	2,931	3,236	3,665	3,945	4,046	4,151	58
Togo	2,285	2,615	3,028	3,318	3,422	3,531	62

* The figures for Nigeria may be too high. In the 1991 census in Nigeria, only 88.5 million people were counted (Onze Wereld 1992).
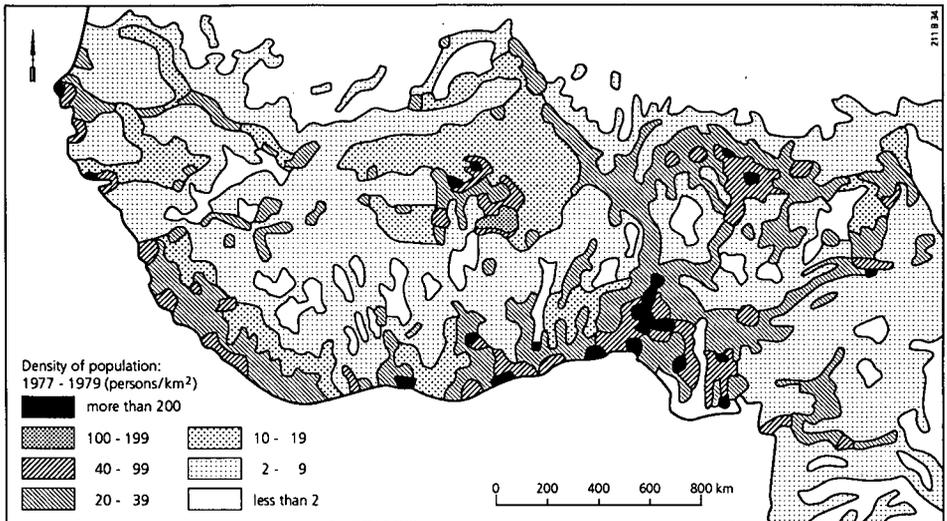
Figure 6.1 Population distribution and density in West Africa (source: The Times Atlas of the World 1981; adapted)

of the inventory area, the population density is mainly below 20 persons/km^2. Some areas, however, have higher densities. This refers in particular to the region of southern Burkina Faso and northern Ghana, with 20 to more than 200 persons/km^2, and northern Nigeria, with over 50 persons/km^2 in the Sokoto-Zaria-Bauchi region, to more than 200 persons/km^2 near Kano. Also the Fouta Jallon has a density of more than 20 persons/km^2.

Obviously, in those densely populated areas, not all the people are employed in agriculture, thereby exerting little pressure on the land. In Nigeria, Benin, and Ghana, the rural population is roughly half of the total population. In the other countries, about three-quarters of the population lives in and off the rural areas.

The population growth in West Africa is high. Table 6.2 gives the annual population growth, and the total growth between 1975 and 1990. The highest growth rates in 1990 are found in Ivory Coast (3.8%), Cameroon (3.4%), and Nigeria (3.4%). They are relatively low in Guinea Bissau (2.0%), Sierra Leone (2.6%), and Senegal (2.8%). The total increases in population between 1975 and 1990 in the different countries of West Africa vary from 38.7% in Guinea to 77.0% in Ivory Coast.

Table 6.2 also demonstrates that, in several countries, the growth rates are still increasing. Only in The Gambia, Ivory Coast, Nigeria, and Senegal was there a decline in growth rates in the late eighties. In Africa, peak growth is occurring at a higher level and the period will last longer than in other parts of the world. For several countries, the period of peak growth will not be reached before 1995 (FAO 1986).

High population growth rates affect many aspects of African society. Agricultural production has to expand rapidly just to keep per caput food production at the present level. High pressure on agricultural development results in environmental degradation. The demand for increased food production is causing African farmers to shorten the

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Table 6.2 Population growth in West Africa (source: FAO Production Yearbook, several editions)

	Population growth per year (%)					Total (%)
	1975-80	1980-85	1985-88	1988-89	1989-90	1975-90
Benin	2.8	3.0	3.1	3.1	3.1	52.7
Burkina Faso	2.4	2.6	2.7	2.7	2.8	45.0
Cameroon	3.0	3.2	3.4	3.4	3.4	57.4
The Gambia	3.4	3.2	3.0	3.0	2.9	57.1
Ghana	1.8	3.9	3.3	3.1	3.2	52.8
Guinea	1.5	2.3	2.9	3.0	3.1	38.7
Guinea Bissau	3.6	2.0	2.0	2.1	2.0	43.5
Ivory Coast	4.1	4.4	4.0	3.8	3.8	77.0
Liberia	3.3	3.4	3.3	3.2	3.3	60.0
Mali	2.2	3.0	3.1	3.1	3.2	49.4
Niger	3.4	3.6	3.3	3.2	3.2	62.0
Nigeria	3.6	3.5	3.5	3.4	3.4	63.6
Senegal	3.0	3.0	2.9	2.8	2.8	52.5
Sierra Leone	2.1	2.6	2.5	2.6	2.6	41.6
Togo	2.9	3.2	3.2	3.1	3.2	54.5

fallow periods and to grow unsuitable crops on marginal lands. Where livestock populations are increasing, there is a danger of overgrazing, especially where the loss of traditional grazing land to crop production intensifies the pressure on the remaining area (FAO 1986).

High growth rates lead to a greater demand for social facilities such as health care, schooling and training, housing, and the infrastructure. As a result of insufficient national budgets, agriculture may be starved of both the finance and the trained manpower it needs (FAO 1986).

6.1.2   Migration

West Africa is one of the few regions in the world where a relatively large-scale free movement of people across international borders still takes place. Where once movement was compulsory because of wars, the slave trade, and forced labour, over the last decades it has become a free migration of individuals and families as part of an effort to improve their economic conditions.

For West Africa, Zacharia and Condé (1981) report that, expressed as a percentage of the national population, Ivory Coast (21.3%) and The Gambia (10.6%) have the highest numbers of foreign nationals, whilst Mali (1.7%) and Burkina Faso (1.9%) have the lowest.

Nevertheless, the external migration is only half of the internal migration. The general direction, however, is the same: towards the south, from the interior to the coastal areas. There is a negative relationship between emigration and internal migration and a positive relationship between immigration and internal migration. Immigration rates have been high in Ghana and still are in Ivory Coast. More recently, these rates have

increased for Nigeria, at the expense of those for Ghana. They are low for Benin, Togo, Guinea, and Guinea Bissau.

The principal areas of immigration are the capital cities, which are mainly located along the coast. Secondary areas of immigration are usually the other main administrative and business centres.

Differences in population density do not explain the migration movements. These movements are mainly caused by the economic differences between or within countries. People move from countries or regions with weak economies to those with a stronger one. The number of people involved in these movements is relatively large and the economic and social consequences are substantial. In Ivory Coast, for example, only 35% of the population is living in the localities where they were born.

Iloeje (1982) gives some examples of migrations. Seasonally, many people from Mali move to the groundnut fields of Senegal. The cocoa and coffee plantations of Ivory Coast annually absorb thousands of people from Mali and the Mossi Plateau in Burkina Faso. Some Mossis also travel to the mining districts of Ghana. Mining areas of Fria in Guinea and Nimba in Liberia have attracted populations from distant districts. People from the eastern states of Nigeria and Ishan Plateau moved to the rubber plantations of the Bendel state in south Nigeria to work as tappers.

In addition, there are migrations due to disasters. The drought in 1972-74, for example, caused a wholesale emigration from the Sahelian countries to southerly areas where conditions were wetter.

The economic impact of these movements is most evident from the size of the migrant labour force in the destination countries, and from the amount of migrant workers' remittances sent to their countries of origin. In 1975, about 11% of the total labour force in West Africa were immigrants, whilst 17.5% were internal migrants. The total external remittances between 1970 and 1974 amounted to 7.4% of the average annual export earnings of the receiving countries.

Migrants include a relatively large proportion of young adults. Women are more inclined to migrate when they are young or when the distance is short. The overall age differential is larger with the external migrants than with the internal migrants, whilst unmarried persons are usually more mobile than married ones.

Ay (1981) states that, in the rural areas of West Africa, because of the migration to urban centres, the age group between 15 and 30 years is lagging behind the normal demographic distribution, somewhat more for males than for females. Owing to this rural-urban migration, the population growth in Sub-Saharan Africa was almost three times as rapid in urban areas as in rural ones. This migration has produced the paradox of a shortage of agricultural labour (mainly seasonal) at a time of high population growth. Furthermore, the local food production was not enough – and not adapted to the changing food preferences – to feed the urban population. Food imports have increased, leading to worsening balances of payment and other economic problems (FAO 1986).

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6.2 The Role of Rice in the Food Supply

6.2.1 Total Agricultural Crop Production

Tables 6.3 and 6.4 show the total crop production indices and crop production indices per caput for 1975, 1979-81, 1985, 1988, 1989, and 1990. The average crop production index for 1979-81 has been set at 100.

From Table 6.3, it can be concluded that, in several countries of West Africa, the total agricultural crop production has sharply increased during the last decade. The highest increases occurred in Nigeria (63%) and in Mali (61.8%). A slight increase is found in Sierra Leone (5.8%) and a slight decrease in Niger (1.7%). A strong decline in crop production is found in Liberia for 1990. This must be imputed to the civil war, which makes normal agricultural production impossible.

The data from Table 6.4, the crop production indices per caput, give a much less positive image of the development of agricultural production. In the last ten years, the crop production indices per caput in Nigeria and Mali increased by only 17.8% and 20.6% respectively. In the same period, the per caput crop production declined by almost 10% or more in Cameroon, Guinea, Ivory Coast, Liberia, Niger, Senegal, Sierra Leone, and Togo.

These figures reflect one of the main problems of agricultural development in West Africa: most of the efforts to improve the food situation will be annulled by the high population growth rates.

Table 6.3 Total crop production indices in West Africa (1979-81 = 100) (source: FAO Production Yearbook, several editions)

	Total crop production indices					
	1975	79-81	1985	1988	1989	1990
Benin	80.7	100.0	129.1	145.8	162.1	151.1
Burkina Faso	97.4	100.0	131.3	163.8	152.7	147.4
Cameroon	101.5	100.0	107.8	120.7	112.8	115.6
The Gambia	137.6	100.0	122.6	122.9	138.7	138.7
Ghana	111.5	100.0	136.6	156.2	154.8	142.5
Guinea	97.9	100.0	103.1	107.7	103.7	112.7
Guinea Bissau	101.5	100.0	114.7	128.4	132.4	132.4
Ivory Coast	73.2	100.0	118.2	134.2	133.5	129.9
Liberia	86.9	100.0	113.2	118.9	117.6	83.5
Mali	85.8	100.0	139.1	168.9	168.7	161.8
Niger	61.5	100.0	93.7	124.6	105.7	98.3
Nigeria	84.7	100.0	122.1	148.3	162.3	163.0
Senegal	131.8	100.0	126.3	114.2	134.2	118.7
Sierra Leone	99.2	100.0	99.5	101.7	102.5	105.8
Togo	88.3	100.0	107.4	118.7	130.7	123.4

Table 6.4 Total crop production indices per caput in West Africa (1979-81 = 100) (source: FAO Production Yearbook, several editions)

	Crop production indices per caput					
	1975	79-81	1985	1988	1989	1990
Benin	93.3	100.0	111.9	115.6	124.7	112.7
Burkina Faso	107.7	100.0	116.0	133.7	121.4	114.0
Cameroon	115.1	100.0	92.9	94.4	85.3	84.5
The Gambia	164.4	100.0	105.9	97.3	106.7	103.8
Ghana	141.6	100.0	114.5	119.0	114.4	102.0
Guinea	114.5	100.0	92.3	88.7	82.9	87.4
Guinea Bissau	140.1	100.0	104.2	109.9	111.1	108.9
Ivory Coast	93.2	100.0	97.6	99.0	94.8	88.8
Liberia	104.8	100.0	96.6	92.4	88.5	60.9
Mali	110.8	100.0	120.6	133.9	129.7	120.6
Niger	65.1	100.0	79.2	95.8	78.8	71.0
Nigeria	105.6	100.0	104.1	114.5	121.2	117.8
Senegal	176.6	100.0	110.2	91.7	104.8	90.1
Sierra Leone	109.1	100.0	88.6	84.3	82.7	83.2
Togo	100.5	100.0	92.8	93.6	99.8	91.4

6.2.2   Production of, and Trends in, Staple Food Crops

Table 6.5. shows the relative importance of the production of the major staple food crops in the countries of the inventory area. Rice is a main staple crop in Sierra Leone, Liberia, Guinea Bissau, Guinea, and Ivory Coast. In 1990, the relative importance of rice production was greatest in Sierra Leone (72.0%), followed by Guinea Bissau (55.4%), Liberia (55.1%), Guinea (47.8%), Ivory Coast (24.6%), Mali (16.3%), and The Gambia (11.3%). In the other countries, its relative importance was less than 10%.

Between 1975 and 1990, however, the relative importance of rice decreased in all the important rice-producing countries, except for Guinea and Guinea Bissau.

6.2.3   Trends in Rice Production, Imports, and Consumption

The development of rice production in the various countries of West Africa is reflected in the trends in total rice production, cultivated area, yields, imports, supply, consumption, and rates of self-sufficiency. Figures for rice production, yields, imports, and consumption are given by Nyanteng (1983, 1986), WARDA (1980, 1986), the FAO Production Yearbook, and the FAO Trade Yearbook (several editions). The data presented in the following sections for the period 1975 to 1990 have been derived from the FAO Production Yearbooks and FAO Trade Yearbooks because they offer the most recent data.

The general trend is that total rice production during this period has strongly

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Table 6.5 Importance of rice production in relation to other food crops in West Africa (× 1000 ton) (source: FAO Production Yearbook, several editions).

	Rice		Maize		Millet		Sorghum		Tubers (total)		Pulses (total)		Groundnut		Total		% rice	
	1975	1990	1975	1990	1975	1990	1975	1990	1975	1990	1975	1990	1975	1990	1975	1990	1975	1990
Benin	13	10*	217	407*	15	21*	52	110*	230	615	14	57^F	35	79	568	1299	2.3	0.8
Burkina Faso	40	42	84	217*	383	597*	738	917*	39^F	38^F	180^F	172^F	90	140	1554	2123	2.6	2.0
Cameroon	16*	39^F	350*	350*	386	50^F	–	380^F	672	833^F	84^F	135^F	165*	100^F	1673	1887	1.0	2.1
The Gambia	31*	20^F	10	15*	47	50^F	–	11^F	3^F	2^F	3^F	4^F	150^F	75	244	177	12.7	11.3
Ghana	71	81	343	553	122	75	135	126	1402	1733	17	20^F	111	180^F	2201	2778	3.2	2.9
Guinea	300*	500^F	310^F	100^F	–	60^F	5^F	34^F	202^F	239	27^F	60^F	28^F	52*	872	1045	34.4	47.8
Guinea Bissau	67	160	4^F	24	7^F	20	5^F	40^F	10^F	13^F	2^F	2^F	37	30*	132	289	50.8	55.4
Ivory Coast	461	687	131^F	484	46	44	32	24	907	1415	8^F	8^F	48	134	1633	2796	28.2	24.6
Liberia	229	150^F	–	–	--	–	--	–	102^F	116	3^F	3^F	3^F	3^F	337	272	70.0	55.1
Mali	218	376*	71	214*	696	695*	–	754*	28^F	46^F	33^F	67^F	227	160^F	1273	2312	17.1	16.3
Niger	29	73	5	8^F	581	1133	254	415	64	83	231	368^F	42	60*	1206	2140	2.4	3.4
Nigeria	515	1900^F	1265	1832	3000^F	4000^F	3590*	4000^F	9173^F	16534^F	902^F	1463	280^F	1166	18725	30895	2.8	6.1
Senegal	116	156	49	133	621	514	–	147	39	29	21	25^F	1476	698	2322	1702	5.0	9.2
Sierra Leone	524	430^F	13^F	12*	8^F	23*	11^F	21*	35^F	53	26^F	38^F	18^F	20*	635	597	82.5	72.0
Togo	15	26*	135	220	119	50*	–	106*	299	306	21	30^F	20	28^F	609	766	2.5	3.4

* unofficial figure
^{F} FAO estimate

increased in almost all countries. This is the result of the expansion of the cultivated area, increased average yields, or both.

The higher production, however, has been too little to cover the increase in consumption resulting from the growth of the population and the change in food preference. This has caused decreasing self-sufficiency rates and increasing quantities of rice imports. This situation is observed in all countries of West Africa.

Total Rice Production

Table 6.6 shows that, between 1975 and 1990, the total rice production in the inventory area increased by about 75%. This increase was mainly achieved between 1975 and 1988. Since 1988, the total rice production in the area has remained stable, except for Liberia, which showed a drastic decrease in 1990 due to the raging civil war.

The individual countries, however, show deviating figures of total rice production. Between 1975 and 1990, it more than doubled in Nigeria (268.9%), followed by Niger (151.7%), Cameroon (143.8%), and Guinea Bissau (138.8%). In four countries, the production decreased in this period: The Gambia (-35.5%), Liberia (-34.5%), Benin (−23.1%), and Sierra Leone (−17.9%).

Rice Cultivation Areas

Table 6.7 gives the areas under rice cultivation in the different countries of West Africa. Although the total area under rice increased by 47.9%, there are large differences between the individual countries. In Nigeria, the rice area tripled between 1975 and 1990,

Table 6.6 Total rice production in West Africa (source: FAO Production Yearbook, several editions)

	Rice production (x 1000 ton paddy)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	13	9	6	10	9	10*	−23.1
Burkina Faso	40	29	50	39	42	42	5.0
Cameroon	16*	55	107	40^F	35^F	39^F	143.8
The Gambia	31*	34^F	43*	29	21	20^F	−35.5
Ghana	71	62	80	84	67	81	14.1
Guinea	300*	350^F	437	521	426*	500^F	66.7
Guinea Bissau	67	23^F	115	146*	162*	160	138.8
Ivory Coast	461	511	541*	610	635	687	49.0
Liberia	229	243	288	298	280	150^F	−34.5
Mali	118	125*	195*	288	338	376*	72.5
Niger	29	31	57	63	79	73	151.7
Nigeria	515	1090*	1515*	2000	2000^F	1900^F	268.9
Senegal	116	65	147	146	168	156	34.5
Sierra Leone	524*	513	416*	420*	430^F	430^F	−17.9
Togo	15	24	15	27	29	26*	73.3
Total	2645	3164	4012	4721	4721	4650	75.8

* unofficial figure
^{F} FAO estimate

Table 6.7 Area under rice cultivation in West Africa (source: FAO Production Yearbook, several editions)

	Area under rice cultivation (x 1000 ha)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	7	9^F	6	7	7	7^F	0.0
Burkina Faso	41	40^F	28	22	20	20	−51.2
Cameroon	20^F	23	23	14	13	13^F	−35.0
The Gambia	22^F	26^F	25*	19	14	14*	−36.4
Ghana	79	80	87	52	72	49	−37.9
Guinea	400^F	400^F	561	578	585*	590^F	47.5
Guinea Bissau	42^F	73^F	97	100^F	100^F	73	73.8
Ivory Coast	361	461	420*	519	545	572	58.4
Liberia	191	197	234*	233	235*	150^F	−21.5
Mali	129	140^F	170*	214*	219	250^F	93.8
Niger	17	21	21	28	35	32^F	88.2
Nigeria	300*	550*	700*	871	870	900^F	200.0
Senegal	87	67	78	79	79	73	−16.1
Sierra Leone	385^F	410	340	300*	330^F	330^F	−14.3
Togo	11	20^F	22	25	20	22*	100.0
Total	2092	2517	2812	3061	3144	3095	47.9

* unofficial figure
^{F} FAO estimate

and in Togo it doubled. In several countries, however, the rice area declined: for example in Burkina Faso (−51.2%), Ghana (−37.9%), The Gambia (−36.4%), Cameroon (−35%), and Sierra Leone (−14.3%).

Rice Yields
Table 6.8 shows the average rice yields during the period 1975-1990. Over this period, the average yield increased substantially in a number of the countries: Cameroon (286.6%), Burkina Faso (133.3%), Mali (64.6%), Senegal (61.1%), Guinea Bissau (37.9%), Niger (32.2%), and Nigeria (22.9%). In the other countries – Sierra Leone, Liberia (except 1990), The Gambia, and Ivory Coast – the average yield remained more or less the same, although variations between the individual years can be considerable.

From Tables 6.6, 6.7, and 6.8, some conclusions can be drawn about the way the rice production in the inventory area has increased over the last decades. In Cameroon, for example, even though the rice area declined by 35%, the total rice production increased strongly (+ 143.8%) as the result of higher yields per unit area (+ 286.6%). Most of the rice in Cameroon is produced under modern irrigation schemes in the dry northern part of the country. In Burkina Faso, where the rice area has halved, the total rice production did not decrease because of the higher yields.
  Niger and Nigeria achieved the highest increase in the total rice production as a result of both an expansion of the rice area and higher yields. The increased rice pro-

Table 6.8 Rice yields in West Africa (source: FAO Production Yearbook, several editions)

	Rice yields (kg paddy/ha)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	1742	1071	1080	1364	1288	1400	−19.6
Burkina Faso	966	716	1814	1787	2054	2100	133.3
Cameroon	776	2391	4737	2857	2692	3000	286.6
The Gambia	1391	1308	1720	1535	1473	1429	2.7
Ghana	904	781	919	1622	929	1641	81.5
Guinea	750	875	778	900	728	847	12.9
Guinea Bissau	1595	622	1187	1455	1620	2200	37.9
Ivory Coast	1278	1108	1288	1175	1165	1201	−6.0
Liberia	1199	1234	1231	1277	1191	1000	−16.6
Mali	914	891	1147	1345	1541	1504	64.6
Niger	1725	1499	2752	2266	2257	2281	32.2
Nigeria	1717	1982	2164	2296	2299	2111	22.9
Senegal	1328	963	1881	1858	2121	2139	61.1
Sierra Leone	1361	1251	1224	1400	1303	1364	0.2
Togo	1403	1200	700	1064	1420	1182	−15.8

duction in Guinea and Ivory Coast is mainly the result of the expansion of the rice area. Finally, the decreased rice production in The Gambia, Liberia, and Sierra Leone is mainly due to the decrease in the rice area.

Rice Imports
Rising food imports are attributed to many factors, such as population growth, lagging domestic production, availability of food aid, overvalued local currency exchange rates – which often make imported cereals cheaper than domestic supplies – increasing urbanization, and the accompanying shift of consumer preference from cassava, yams, millet, and sorghum to rice and wheat.

Table 6.9 gives the rice imports for the countries of the inventory area from 1975 to 1990. Rice imports have increased tremendously in almost all countries of West Africa. For the countries of the inventory area, the total imports increased from 381,000 tons (paddy equivalent) in 1975 to 2,268,000 tons in 1990: an increase of 590%! In the same period, the total domestic rice production increased only by 75.8%. In 1990, of all West African countries, Senegal imported the largest amount of rice (549,000 tons), followed by Ivory Coast (416,000 tons), Nigeria (385,000 tons), Guinea (172,000 tons), and Burkina Faso and Sierra Leone (both 169,000 tons).

More alarming is the fact that, for most countries, the rice imports are still increasing. Only in Mali and Niger have rice imports decreased in the last few years. During the period 1988-1990, Nigeria imported smaller amounts of rice than in the early eighties. In 1986, the Nigerian Government restricted the imports of rice. Because of the strong consumer demand, the market prices of rice were pushed upward. This stimulated the expansion of the cropped area and the total rice production (IITA 1989).

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Table 6.9 Rice imports in West Africa (source: FAO Production Yearbook, several editions)

	Rice imports (x 1000 ton paddy)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	7	47	29	69	92	62	786
Burkina Faso	15	47	160	132	131	169	1026
Cameroon	3	32	74	77	88	139	4533
The Gambia	21	41*	100	109*	92*	102*	386
Ghana	1	46*	92	106	123*	154*	15300
Guinea	56*	197*	107*	131	300	172	207
Guinea Bissau	22	18	30*	72	77*	66*	200
Ivory Coast	3	389	527	326	570*	416*	13767
Liberia	47	133	131	122	200*	100*	113
Mali	31	82	176	108	79	31	0
Niger	2	55	49	92*	89*	59*	2850
Nigeria	10	616	548	308*	308*	385*	3750
Senegal	160	430	517	477	527	549	243
Sierra Leone	1	96	142	149*	154	169	16800
Togo	2	33	27	46	59	55	2650
Total	381	2262	2709	2324	2889	2628	590

* unofficial figure

Rice Supply

The rice supply, comprising domestic production and imports, and its changes during the period 1975 to 1990, are presented in Table 6.10.

The rice supply for the inventory area increased by 150% between 1975 and 1990. Because of the increased production and/or imports, the rice supply in all countries increased too. Only in Liberia did a decrease occur, as a result of the decline in production and imports in 1990. Rice supply enters in the estimate of the self-sufficiency.

Rates of Self-Sufficiency in Rice

The rate of self-sufficiency is the ratio between domestic rice production and the rice supply. Table 6.11 shows the self-sufficiency rates of the various countries in West Africa.

In all countries except Mali, the rate of self-sufficiency declined between 1975 and 1990. In Mali, the self-sufficiency rate in 1990 was 5% higher than in 1975, although, in the period in between, it was much lower.

In 1990, the highest self-sufficiency rates were achieved in Mali (91%), followed by Nigeria (81%), Guinea (71%), Sierra Leone (68%), Guinea Bissau (67%), Ivory Coast (58%), Liberia (56%), and Niger (51%). All the other countries have self-sufficiency rates below 50%.

The most severe decreases in self-sufficiency between 1975 and 1990 are found in Ghana (–68%), Cameroon (–61%), Togo (–56%), and Burkina Faso (–52%). The lowest values are found in Guinea Bissau (–5%), Guinea (–11%), Nigeria (–17%), and Senegal (–19%).

Table 6.10 Rice supply* in West Africa (calculated from Tables 6.6 and 6.9)

	Rice supply (x 1000 ton paddy)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	18	55	34	78	99	71	294
Burkina Faso	49	72	203	165	167	205	318
Cameroon	17	79	165	111	118	172	912
The Gambia	47	70	137	134	110	119	153
Ghana	61	99	160	177	180	223	266
Guinea	311	495	479	574	662	597	92
Guinea Bissau	79	38	128	196	215	202	156
Ivory Coast	395	823	987	846	1110	1000	153
Liberia	242	340	376	375	428	227	−6
Mali	216	188	342	353	366	351	62
Niger	27	81	98	146	156	121	348
Nigeria	448	1543	1836	2008	2008	2000	346
Senegal	259	485	642	601	670	682	163
Sierra Leone	446	532	469	506	520	535	20
Togo	15	53	40	69	84	77	413
Total	2630	4953	6123	6339	6903	6582	150

* Rice supply is the domestic rice production, less 10% post-harvest losses (FAO 1977b) and 5% seed, plus import. Export is negligible.

Table 6.11 Rates of self-sufficiency* in rice production in West Africa (calculated from Tables 6.6 and 6.10)

	Rates of self-sufficiency (%)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	61	14	15	11	8	12	−49
Burkina Faso	69	34	20	20	21	17	−52
Cameroon	80	59	55	31	25	19	−61
The Gambia	56	41	27	18	16	14	−42
Ghana	99	53	43	40	32	31	−68
Guinea	82	60	77	77	55	71	−11
Guinea Bissau	72	51	76	63	64	67	−5
Ivory Coast	99	53	47	61	49	58	−41
Liberia	80	61	65	68	54	56	−24
Mali	86	56	48	69	78	91	5
Niger	91	32	49	37	43	51	−40
Nigeria	98	60	70	85	85	81	−17
Senegal	38	11	19	21	21	19	−19
Sierra Leone	99	82	71	71	70	68	−31
Togo	85	38	32	33	29	29	−56

* Rate of self-sufficiency is the domestic rice production, less 10% post harvest losses (FAO 1977b) and 5% seed, divided by the rice supply.

It should be noted that, since 1988, the rates of self-sufficiency have stabilized in most countries, although at different levels for individual countries.

Rice Consumption

Rice consumption per caput per annum is an indication of whether the higher production and imports of rice will result in its greater availability for the people in West Africa. Table 6.12 shows the rice consumption over the period 1975-1990.

In most West African countries, rice consumption is fairly low. The main staples in the inventory area are cassava, yam, or maize in the humid zone, and millet and sorghum in the arid area. Rice is a staple food only in Sierra Leone, Liberia, and Guinea Bissau, while in The Gambia it shares its position with millet and groundnut, in Guinea with cassava, and in Ivory Coast with maize and cassava.

In all countries, rice consumption increased between 1975 and 1990, except for Liberia, because of the low rice supply in 1990. Generally, however, the sharpest rise occurred in the early eighties, and rice consumption per caput has been more or less steady since.

6.3   Rice Marketing and Price Policies

In order to increase the self-sufficiency in food production, many governments are stimulating the domestic crop production by guaranteeing fixed prices for the crops produced and by controlling retail and wholesale prices.

Table 6.12 Rice consumption in kg milled rice* per caput per year in West Africa (calculated from Tables 6.1 and 6.10)

	Rice consumption (kg milled rice/capita/ year)						Increase (%)
	1975	1980	1985	1988	1989	1990	1975-90
Benin	3.8	10.3	5.5	11.6	14.3	10.0	163
Burkina Faso	5.1	6.7	16.7	12.6	12.4	14.8	190
Cameroon	1.5	5.9	10.6	6.5	6.7	9.5	533
The Gambia	55.8	70.9	119.5	107.1	85.4	89.8	61
Ghana	4.0	6.0	8.1	8.1	8.0	9.6	140
Guinea	48.8	72.2	62.4	68.8	77.1	67.4	38
Guinea Bissau	76.4	31.1	94.9	137.6	147.9	136.2	78
Ivory Coast	38.0	65.5	64.6	49.4	62.5	54.2	43
Liberia	97.8	117.8	111.1	100.8	114.2	57.3	–41
Mali	22.8	17.8	28.3	26.5	26.6	24.8	9
Niger	3.7	7.7	8.1	10.9	13.5	10.2	176
Nigeria	4.4	12.8	13.0	12.8	12.4	12.0	173
Senegal	35.0	56.9	65.5	56.3	61.1	60.5	73
Sierra Leone	60.3	106.9	87.9	83.3	83.5	83.8	39
Togo	4.3	13.2	8.6	13.5	16.0	14.2	230

* 1 ton paddy = 650 kg milled rice

In most countries, government policies to promote domestic rice production include a subsidy to rice producers, adding to the diversity of rice prices in the various West African countries, as is shown in Table 6.13.

Table 6.13 Average producer prices in West Africa 1983-85 in U.S.$ per ton paddy (source: WARDA 1986)

Benin	134	Liberia	400
Burkina Faso	183	Mali	154
Cameroon*	143	Niger	209
The Gambia	168	Nigeria	611
Ghana	2468	Senegal	166
Guinea	559	Sierra Leone	281
Guinea Bissau	346	Togo	249
Ivory Coast	157		

* after Baudet 1981, prices for 1975-77

Between 1983 and 1985, the lowest producer price for paddy was paid in Benin (U.S.$ 134/ton), followed by Mali, Ivory Coast, and Senegal. The highest price was paid in Ghana (U.S.$ 2,468/ton) and Nigeria (U.S.$ 611/ton). These high figures are largely explained by the overvalued local currency.

In order to compare the producer's price for paddy with the world market price for rice, the following calculation was made. The producer's price for paddy in Benin (U.S.$ 134/ton) is equivalent to a rice price of U.S.$ 207/ton (out-turn 65%), milling and distribution costs not included.

During the period 1983-85, the average world market price for Thai white long grain 5% broken f.o.b. Bangkok was U.S.$ 249/ton and Thai white 100% broken was available for U.S.$ 187/ton. Including the milling and distribution costs, which, however, vary strongly between the different countries and regions, it will be clear that none of the countries of West Africa was able to compete with the world market. At the national level, it appears that importing rice is cheaper than producing domestically.

From 1986 onwards, however, national market liberalization policies resulted in a dominance of unofficial market prices in almost all countries of West Africa.

Another policy to stimulate rice production was the fixing of the consumer price of rice at levels below the total production costs. In this way, milling and distribution costs were strongly subsidized. In 1986, the differences between cost price and the consumer price of local rice per kilo were 100 FCFA in Senegal, 10 FCFA in Cameroon, and 85 FCFA in Ivory Coast (Phelinas 1990). Because of the recent liberalization of rice production and marketing, under pressure from the World Bank and IMF, subsidies on the consumer price of rice have been partly or completely abandoned (Phelinas 1990).

Inputs, too, are generally subsidized. Inputs such as improved seed, fertilizers, and insecticides, along with extension services and the maintenance of water distribution systems, are delivered as a package. Mechanization is delivered as a service. Investments for oxen and implements are subsidized by the government. In return, the farmer is charged a fixed fee for the input package or service. Table 6.14 shows farm-level subsidies on inputs in Ivory Coast.

Another governmental policy providing incentives for domestic paddy production

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Table 6.14 Farm level subsidies on inputs in Ivory Coast, in FCFA (1975-76) (source: Lang 1979)

	Market costs per ha	Net farm-level subsidy			Subsidy rate
		per ha	per ton paddy	per ton rice	(%)
Modern inputs	37,129-63,119	17,745	7,094	10,748	33-40
Power tillers	24,170	6,580	1,645	2,492	28
Animal traction	9,165	1,885	1,047	1,586	21
Tractors and harvesters	43,600-72,929	14,940	5,975	9,053	18-30

is the public financing of land development. According to Pearson et al. (1981), investment costs in such projects in Ivory Coast are subsidized at rates ranging between 52% and 100%.

For Ivory Coast, Pearson et al. (1981) conclude that the heavy subsidies on improved rice production reduce national growth. Compared to the price of imported rice, the costs of domestic production are too high, resulting in a waste of resources and in a potential loss of foreign exchange. The apparent failure of the government policy has two main causes: the rice sector cannot compete efficiently with imports, and wage rates are too high in relation to the low population density and the area of unused arable land. It was concluded that in Ivory Coast, from the viewpoint of net social profitability (= profitability on national level), domestic rice production is only justified for on-farm and in-village consumption.

Asuming-Brempong (1989) studied the rice policy in Ghana. Here, the situation is comparable with that in Ivory Coast. The analysis has shown that even though Ghana has no comparative advantage in rice production at wholesale level, government policies have highly favoured domestic rice production. This resulted in high domestic rice prices as compared to border prices (sometimes more than 10 times higher) and subsequent high consumer welfare losses. High subsidies on inputs resulted in a gross misallocation of resources, as large area expansion and large-scale rice farming were undertaken, along with expensive irrigation projects. Nevertheless, the slight increase in rice production achieved over the years could not compensate for the huge investments incurred by the government in pursuing a programme of self-sufficiency in rice.

Asuming-Brempong studied the Net Economic Profit (NEP) of three different rice cropping systems, i.e. the traditional system, the improved and partially mechanized system, and the irrigated, fully mechanized system. The NEP is negative for all three systems, but least for the traditional system.

It was concluded that it seems appropriate to discourage rice production in Ghana for reasons of economic inefficiency. However, taking into account other issues such as food security and income distribution, it will be more economical and socially beneficial for the government to direct attention towards the traditional small-scale rice farmers where a relative comparative advantage in rice lies.

6.4   Economic Returns of Rice-Cropping Systems

National price and market policies of the governments (e.g. subsidies on land clearing,

inputs, etc., and wages, availability of labour, and the type of rice cultivation) are all factors that influence the net economic returns of the farms.

The management aspects of smallholder farms have been studied by Ruthenberg (1980) for cases in Sierra Leone, Liberia, and Ivory Coast. Paddy prices were U.S.$ 110/ton in Liberia, U.S.$ 94/ton in Sierra Leone, and U.S.$ 254/ton in Ivory Coast. Total agricultural work was 5 hours/day in Liberia and 6 hours/day in Sierra Leone and Ivory Coast.

Table 6.15 demonstrates the resulting low return from rice production to labour and its low contribution to farm income. In Sierra Leone, where (upland) rice constituted over 90% of the cropping systems, the average family income was U.S.$ 205 and the return to labour only U.S.$ 0.11 per man-hour. In Ivory Coast, where (upland) rice constituted only 32% of the cropping system, these values were U.S.$ 1,518 and U.S.$ 0.65 respectively.

Table 6.15 Farm management data on rice cultivation in Sierra Leone, Liberia, and Ivory Coast (source: Ruthenberg 1980)

Year	Sierra Leone 1971-72	Liberia 1972	Ivory Coast 1974-75
Rainfall (mm)	2500	1900	1750
Number of samples	22	20	30
Persons per household	8.4	7.2	6.9
Labour force (ME)*	5.2	2.7	3.2
Labour input (man-hours)	1919	1975	2340
Land reclaimed (ha)	25	16	12.20
Upland rice (ha)	1.74	1.34	1.74
Swamp rice (ha)	n.a.	0.40	n.a.
Other food crops (ha)	0.16	0.68	0.40
Sugarcane (ha)	n.a.	0.12	n.a.
Coffee and cacao (ha)	n.a.	0.20	3.30
Total crop area (ha)	1.90	2.74	5.44
Cropping index (%)	8	17	25
Yield (ton/ha), rice	1.23	1.12	1.74
Yield (ton/ha), coffee	n.a.	0.20	0.22
Economic returns			
(U.S.$ per holding)			
Gross return from crops	220	480	1580
Purchased inputs	15	12	62
Income	205	468	1518
Productivity			
Gross return U.S.$/ha total land	9	30	130
Gross return U.S.$/ha crop land	116	175	290
Gross return U.S.$/ME	42	178	494
Income U.S.$/ha crop land	108	171	279
Income U.S.$/ME	39	173	474
Income U.S.$/man-hour	0.11	0.24	0.65

* ME = man equivalent
  n.a. = not applicable

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The low farm-level profitability of rice cultivation is also described by von Braun et al. (1989). During the wet-season crop production of 1985 in The Gambia, the average gross margin for swamp rice, calculated as the difference between the value of (marketable) output minus variable costs, was only U.S.$ 1.48 per person/day of family labour, while the net return for maize was U.S.$ 1.71, for groundnuts U.S.$ 2.25, and for millet and sorghum U.S.$ 2.33 per person/day of family labour. Only cotton had a lower net return than rice, U.S.$ 0.83 per person/day.

In the Bida area, Nigeria, Ward (1981) compared the crop budgets of rice grown in an unimproved inland valley with traditional farming methods, and in an improved inland valley with improved cropping techniques. He found that, when improved techniques were applied, the rice yield increased by about 30% to 3.5 ton/ha. The net family income and the return to labour, however, increased only by 9% to 1314.2 and 11.6 Naira respectively. Obviously, the production of rice was raised, but the return to family income and labour did not rise proportionally, and they do not sufficiently warrant the added risks of higher inputs in bad years.

Okereke (1990) studied the effects of using tractors on the economic returns of wetland rice cultivation in inland valleys in Anambra State, Nigeria, for the 1988 season. Here, rice was produced in a rather sophisticated manner. IR8 and IR1416 were the most widely cultivated varieties and fertilizer was applied on almost all farms. Herbicides and insecticides were mainly applied by farmers using tractors. Because of the short supply of fertilizers, their actual prices were above the official levels. Pesticides and herbicides were subsidized by the government only for the farmers who had adopted modern innovations such as tractors. The most important tractor services in the study area could be hired from private enterprises.

It appeared that the net return per hectare was significantly higher for farmers using tractors than for non-tractor farmers: 3,171 Naira per hectare, as against 1,151 Naira. Labour was more productive on farms that used tractors, where each worker-day of labour produced 17.6 Naira. On farms without tractors, this was only 4.3 Naira (average wage rate was 15.00 Naira per worker day). Similarly, 100 Naira invested in production yielded 204 Naira for farmers using tractors and 133 Naira for traditional farmers.

Olagoke (1989) examined the efficiency of resource use for the 1987-88 crop year in Anambra State, Nigeria, in three different rice cropping systems (i.e. irrigated, swamp, and upland rice production; see Table 6.16). Rice yields were highest on the irrigated fields (2.19 ton/ha), followed by the swamps (1.96 ton/ha), and they were lowest on the uplands (1.71 ton/ha). Because of different production costs, however, net returns were highest for the swamp fields (567.68 Naira/ha). Under irrigation, net returns were 413.25 Naira/ha, and for the upland rice they were 248.89/ha.

From the different examples given above, it can be concluded that improving rice-based smallholder farming systems should be approached cautiously. Higher inputs aiming at higher yields are justified only if the consequently higher risks are financially, economically, and socially acceptable to the farmer, and if the net family income and the net return to labour are substantially increased.

Table 6.16 Comparison of average production costs, input usage and net returns per hectare for irrigated rice, swamp rice and upland rice (Olagoke 1989).

Item	Unit price (Naira)			Units/ha			Value/ha (Naira)		
	Irrigated	Swamp	Upland	Irrigated	Swamp	Upland	Irrigated	Swamp	Upland
Rice output (RO) (ton paddy)	1213.33	1207.33	1151.33	2.187	1.964	1.711	**2653.55**	**2371.20**	**1969.93**
Capital operating inputs									
Seed (kg)	1.05	1.05	1.09	99.87	98.38	112.08	104.86	103.30	122.17
Fertilizer (kg)	0.22	0.22	0.22	333.95	368.36	281.95	73.47	81.04	62.03
Machine-hire costs							307.62	185.31	212.55
Irrigation costs							197.02		
Other capital operating costs							101.20	96.28	71.52
Total capital operating costs (TCOC)							**784.17**	**465.93**	**468.27**
Labour input (man-hours)									
Land preparation	1.04	1.11	1.11	234.78	268.82	189.33	244.17	298.39	210.16
Nursery	1.30	1.31		60.92	46.54		79.81	60.97	
planting	1.21	1.25	1.21	184.86	130.55	110.03	223.68	163.19	133.14
Weeding	1.25	1.28	1.24	305.53	222.55	333.31	381.91	284.86	413.30
Bird scaring	0.40	0.42	0.37	162.89	121.31	120.98	65.16	50.95	44.76
Harvesting	1.12	1.16	1.17	229.44	216.68	243.77	256.97	251.35	285.21
Threshing/winnowing	1.08	1.06	1.09	10.47	73.76	39.95	11.31	78.19	43.55
Packaging	0.69	0.67	0.74	62.17	48.55	32.68	42.90	32.53	24.18
Other	1.08	1.11	1.06	69.65	27.71	16.06	75.22	30.76	17.02
Total labour input (TLI)							**1381.13**	**1251.19**	**1171.32**
Total variable costs (TVC=TCOC+TLI)							**2165.30**	**1717.12**	**1639.59**
Gross margin (RO-TVC)							**488.25**	**654.08**	**330.34**
Fixed costs									
Depreciation							48.60	52.93	45.15
Land rent							26.40	33.47	36.30
Total fixed costs (TFC)							**75.00**	**86.40**	**81.45**
Total costs (TC=TVC+TFC)							**2240.30**	**1803.52**	**1721.04**
Net return (RO-TC)							**413.25**	**567.68**	**248.89**

7   Inland Valley Suitability for Rice Cultivation

7.1   General

The suitability of inland valleys for rice cultivation depends on parameters that are valley-related and non-valley-related. Non-valley-related parameters include climatological conditions, socio-economic factors, and cultivation methods.

In the Savanna Zones, the main climatological constraints are the rainfall distribution and its irregularity, high temperatures during the second crop cycle, and the seasonally low night temperatures. In the Equatorial Forest Zone, the main climatological constraints are the high air humidity and the low solar radiation.

The socio-economic conditions at present prevailing in West Africa have a strong negative impact on agricultural production. The rapid population growth, rural-urban migration, and changing food preferences, especially in the urban areas, result in labour shortages in the rural areas and decreasing rice production per caput. The shortage of labour also results in inappropriate farming and cropping methods because the optimum cropping calendar cannot be followed.

Furthermore, compared with crops like maize and millet, the low net return of the rice-cropping systems to labour does not stimulate the farmers to increase their rice production.

Some of these factors cannot be improved at all (the climate), will change only in the long term (the increasing population), or will change only when supported by political decision-making in the individual countries or at a supra-national level (price policies). For these reasons, these constraints will not be discussed in more detail here, even though they strongly affect the potential improvements that could be made in the production of rice in West Africa.

At valley scale, the main constraints to rice production result from the soils, hydrology, and valley shape. If these constraints are not too severe, they can be improved by relatively simple technical interventions.

For such improvements to have a distinct and sustainable impact, they have to aim at a substantial increase in the farmers' net return to rice.

In the following sections, the constraints of the inland valleys in West Africa on smallholder rice production are divided into agronomic aspects (soils and hydrology) and engineering aspects (water control). Also presented is a suitability classification of inland valleys for rice production. This is followed by a discussion of possible improvements. Finally, summary descriptions of the main rice-growing environments in West Africa are given, with their main constraints and their potentials.

The agronomic and engineering aspects of the inland valleys have been studied, either singularly or combined, by, among others, IITA (1973, various annual reports), Moormann et al. (1974, 1977), Veldkamp (1979), Okali et al. (1979, 1980), Juo and Moormann (1980), Savvides (1981), Barraud (1963), Stiemer (1968), SODERIZ (1976), Glemet (1975), Arrivets (1973), AVV (1981), Raunet (1982), Oosterbaan et al. (1987), Spencer (1991), and Andriesse and Fresco (1991).

7.2 Main Constraints to Rice Cultivation

7.2.1 Soil Constraints

Upland (pluvial) rice is mainly cultivated in the Equatorial Forest Zone and in the humid parts of the Guinea Savanna Zone. The soils of these uplands are characterized by strong weathering and leaching. They have a (very) low pH, base saturation, and cation exchange capacity. Furthermore, they show Al toxicity, P fixation, and K deficiency. The very low soil fertility of the uplands is one of the main constraints to agriculture in general. In addition, in the Guinea Savanna Zone, the soils are often coarse-textured and shallow, which results in a low water-holding capacity (Andriesse and Fresco 1991).

Hydromorphic (phreatic) and wetland (fluxial) rice cultivation require specific characteristics of the soils of the colluvial footslopes and the valley bottoms. Rice being a semi-aquatic plant, poor to moderately-well drained conditions are best suited for hydromorphic and wetland rice cultivation. Well-drained and excessively well-drained soils carry a drought risk. Such a risk may be overcome by levelling and by constructing bunds around the fields to retain the water. Continuous saturation is not suitable for rice because some alternating oxidation and reduction of the (top)soils is required for good rice growth.

Coarse-textured soils generally are less productive than soils with a fine texture. This is due to the lower inherent fertility of the former, but also to their higher percolation rates, by which nutrients (including fertilizers) are easily leached beyond the root-zone. On sandy soils, therefore, fertilizers should be applied in several small doses rather than in one or two large applications.

The higher percolation of sandy soils implies that it is difficult to retain water on the field. Also, coarse-textured soils lend themselves less well for the construction of bunds, dikes, and drains than do loams or clays.

The inherent fertility of sandy soils in general is very low. In such soils, the cation exchange capacity/CEC depends largely on the organic matter. This serves as storage for plant nutrients, but it is a source of nutrients too, mainly of nitrogen. In clayey soils, the fertility is generally higher. Here, the CEC depends not only on the organic matter and clay content, but also on the clay mineralogy.

Kaolinitic clays, which dominate the clay fraction of alluvium derived from granitic Basement Complex rocks and which prevail in the humid parts of West Africa, have a low CEC compared with illite, vermiculite, and smectite. The latter clay minerals are slightly more abundant in alluvium derived from the metamorphic Basement Complex rocks (schists, greenstones, and amphibolites). Alternatively, they are formed in situ in the drier zones of the inventory area.

In general, a high base saturation is favourable for plant growth. It is of limited relevance, however, if the total amount of bases available to the plant is low (i.e. if the CEC is low), as is the case in many valley bottom soils.

Soil reaction (pH) in the valley bottoms of West Africa ranges from extremely acid (pH 4.0 to 4.5) to slightly acid (pH 6.1 to 6.5). For rice production, this is a suitable range, considering that, upon reduction of the (top)soil following submergence, the pH tends to change towards neutral (pH 6.5 to 7.0). Most plant nutrients are most readily available for uptake by roots in a slightly-acid to near-neutral environment (IRRI 1978).

In wetland rice cultivation, puddling (i.e. the destruction of the soil structure through intensive ploughing of the wet soil) is often practised. The advantages of puddling are that a soft bed is created for seeding and/or transplanting, percolation losses are reduced, weeds can be better controlled, and the fields are slightly levelled. Puddling is more difficult in fine-textured soils, which generally have a stronger structure than soils with a less fine texture, but it is more effective in decreasing losses.

A disadvantage of puddling is that the soil structure becomes less favourable for dryland cropping after rice cultivation.

Valley bottom soils in the northern part of the inventory area (Sudan Savanna Zone) may have salinity problems in the dry season, due to the capillary rise of groundwater. Upon evaporation of the water, salts may accumulate to harmful concentrations at the soil surface or in the rootzone. In the Equatorial Forest and Guinea Savanna Zones, these salts are usually leached with the first rains of the subsequent rainy season, before cultivation.

In the Equatorial Forest and Guinea Savanna Zones, wetland and hydromorphic rice cultivation faces the problem of iron toxicity. Iron toxicity is mostly found in the lower parts of the colluvial footslopes and in the adjacent parts of the valley bottoms. This problem, which has been reported from many West African countries, appears to be most severe in areas where Ferralsols dominate (Sierra Leone, Liberia, southeastern Nigeria, and Cameroon).

Ferrous iron (Fe^{2+}) is either formed in the soil by the reduction under acid conditions of ferric iron (Fe^{3+}), already present in situ, or it is brought into the rootzone by subsurface flow from the uplands. Under reduced conditions, ferrous iron affects the development of the rice crop in two ways:
- By coating the plant roots with iron oxide and thus reducing the absorption capacity of the plant for other nutrients, such as P, K, Ca, and Mg (Fe^{2+}-induced deficiency), or
- By direct iron toxicity through excessive Fe^{2+} absorption by the plant.

Iron toxicity in rice plants shows as a characteristic orange discoloration (bronzing) of the leaves (Howeler 1973). Possible remedies, apart from the use of tolerant rice varieties, include seasonal drying of affected fields (oxidation of Fe^{2+} to insoluble Fe^{3+}) or interception of the subsurface water flow containing ferrous iron (IITA 1982).

7.2.2   Hydrological Constraints

For a valley to be suitable for rice production under smallholder farming, it should meet a number of hydrological conditions, as will be discussed below.

The crop water requirement should be covered during the entire growth period. On the uplands, the crops depend entirely on the precipitation. On the footslopes and in the valley bottoms, a shortage of precipitation may be compensated by groundwater, by lateral water inflow, or both. The lateral inflow is basically maintained by upland surface runoff and groundwater flow. The latter forms the core of the base flow in the valley stream. The minimum size of this flow is strongly related to the amount and distribution of the precipitation and the size of the catchment area. In

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the Guinea Savanna Zone, about 1 km^2 of catchment is needed to provide a minimum flow sufficient to cover crop water requirements for rice on a cultivated area of 0.8 to 3.0 ha in the valley. For the Equatorial Forest zone, this ratio is 1 km^2 for 2.0 to 5.0 ha.

Peak discharges in the valleys, especially in the river inland valleys have a devastating nature. Floods submerging the crop for long periods cause crop failure. To avoid such failures, rice should not be submerged for longer than 48 hours. Peak discharges are related to the adsorption capacity of the catchment, the amount of rainfall, rainfall intensity, and slope. The effects of the individual factors diminish with increasing size of the catchment area.

Rice being a shallow-rooting crop, it is very sensitive to drought, the wetland varieties in particular. The latter prefer soils which are submerged for an adequately long time during the growth period. Submergence is the result of rising groundwater levels and/or surface water accumulation during the rainy period.

In the Sudan Savanna Zone, the groundwater level is deep and generally remains below the soil surface, even in the rainy season. Here, throughout the year, flooding of the valley bottoms is mainly the result of the accumulation of rain water and upland runoff causing a perched watertable. Soil permeability therefore strongly determines the length of the flooding period. As permeability depends on soil texture, the sandy soils prevailing in this Zone are only briefly saturated or submerged during the rainy season.

In the Guinea Savanna Zone, the annual fluctuation of the groundwater level in the valleys is considerable, ranging between 1 and 5 m, and sometimes more. During the rainy season, the groundwater level may be at, or above, the soil surface, but this is not always so for every valley. Locally, the groundwater level falls before the end of the rainy season and may fall to such a depth that crop production on residual moisture is impossible during (a part of) the dry season.

In the Equatorial Forest Zone, annual fluctuations of the groundwater level in the valleys are relatively small, ranging from 0.5 to 1.5 m. During the rainy season, the groundwater level is at or above the soil surface, without many exceptions. This level starts to fall roughly 0.5 to 1.5 months after the rains have ceased. Crop production on residual moisture is possible throughout the dry season, which is short anyway.

7.2.3   Engineering Constraints

If a water control and distribution system is being designed, the size of the catchment areas, peak discharges, soil texture, and valley morphology have to be considered.

The size of the catchment co-determines the size of the base flow and the peak discharge. To secure a reasonable amount of water in the distribution system on the basis of the factors discussed in Section 7.2.2, the catchment area should be larger than 10 to 30 km^2 in the Guinea Savanna Zone and larger than 5 to 15 km^2 in the Equatorial Forest Zone, corresponding roughly with 15 to 50 ha of valley bottom cultivation; if catchments are smaller, contour bunding should be applied to conserve water on the field. These figures should be treated with caution, however, because hardly any information on this subject was found in the reviewed literature.

The risk of floods and inundation/submergence damaging the crops and/or the

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water distribution system depends on the size of the catchment and the precipitation. In Burkina Faso (Sudan Savanna Zone), it has been observed that, in valleys with catchments greater than 250 km², peak discharges and durations of inundation/submergence become prohibitive for rice cultivation unless dam reservoirs are envisaged. In central Ivory Coast (Guinea Savanna Zone), it has been reported that catchments should not exceed 100 km² to allow for safe rice cultivation. Generally, the optimum size of catchments in northern Togo (Guinea Savanna Zone) varies between 5 and 70 km² (Kilian and Teissier 1973).

Besides the size of the catchment area, Kilian and Teissier (1973) mention three other morphological criteria important for designing water control systems. The valleys must be at least 2 km long and at least 100 m wide, with a cross-sectional slope of less than 2%, whereas the longitudinal slope of the valley bottom may vary from 0.1% to 0.2%.

The shape of the valley (i.e. the ratio between length and width) determines the optimum size of the scheme that can be obtained and can be operated and maintained by the farmers or the community. Very long and narrow valleys have the disadvantage of having an unfavourable ratio between the length of the channels and the cultivated area (high costs of construction and maintenance). The longitudinal slope should allow for adequate drainage, but should not exceed 0.2% to avoid heavy levelling and over-drainage in sandy soils.

The interaction of the various hydrological processes results in a flow pattern that can be used to qualify the valley stream:
- A stream with an open outlet, a regular flow, and slight inundation only, does not present any hydrological restrictions to the construction of water control and distribution systems;
- A stream with a small flow or one that often falls dry is restrictive in that valley bottoms need to be bunded along the contours;
- A stream with an obstructed outlet or a very irregular flow and severe and prolonged inundations presents many hydrological restrictions.

The soil texture and structure are of great importance for the water control (seepage) and the stability of the water control structures. Limitations due to soil texture can be indicated as follows:
- Fine to very fine texture: No limitation
- Medium texture: Moderate limitation
- Coarse texture: Severe limitation

7.3   Suitability Classification of Inland Valleys for Rice Cultivation

Some suitability classification systems of inland valleys for rice cultivation are found in literature. They are based on studies in rather small areas. Further research is needed for the extrapolation of these systems to larger areas.

Killian and Teissier (1973), in their study in northern Benin, give two suitability classifications. The first is for rice cultivation without water control, the second for rice cultivation with water control.

Rice Cultivation without Water Control

The depth of the groundwater level and its fluctuation are of great influence on the crop performance. Several researchers have endeavoured to make a suitability classification for rice incorporating these parameters, with or without soil characteristics.

Kilian and Teissier (1973) developed a classification system based on the groundwater regime and soil texture. They distinguish four classes:

Class I: Very good soils for rice. Shallow groundwater table or slightly flooded throughout vegetative cycle. The soil texture is variable, but mainly medium to fine, locally with a shallow (20-30 cm) coarse-textured surface layer.

Class II: Good soils for rice. Deeper groundwater table than Class I or temporary inundation (at least during the critical periods of plant life such as seeding and flowering). The soil texture is variable, but mainly medium to very fine.

Class III: Marginal soils for rice. Deep or perched groundwater table with large fluctuations (risks of temporary drying out). The soil texture is variable but mainly coarse, locally with a thin clayey surface layer.

Class IV: Very marginal soils for rice. Temporary perched groundwater table, inadequate water influx, risks of drought. The soil texture is coarse.

This system was tested for the soils of valleys in northern Benin. Though the system is provisional, it is considered applicable for the Sudan Savanna and the Guinea Savanna Zones, which have ecological conditions comparable to those of northern Benin. It is recognized, however, that the scope of its applicability might be restricted.

Apparently, this suitability classification does not provide for soils not suitable for rice cultivation and does not comprehend all soils of the toposequence.

Veldkamp (1979) developed a classification system which is based on the fluctuation of the groundwater table. The different classes differ in the variations of these fluctuations (i.e. by the average highest and the average lowest groundwater tables). Suitability classes can be determined by the average high and low groundwater tables per year (for perennials) or per growing season (for annual crops).

To evaluate the suitability of the footslopes and the valley bottoms for hydromorphic and wetland rice cultivation, yearly average high groundwater tables (i.e. the groundwater tables in the rainy season) are used to distinguish several groundwater classes:

Class I: Soils that are permanently flooded (Class Ia) or temporarily flooded (Class Ib).

Class II: Soils that have an average high groundwater table within a depth of 20 cm.

Class III: Soils with an average high groundwater table between 20 and 40 cm; etc.

With increasing depth of the average high groundwater table, the conditions become increasingly less suitable for rice cultivation. For wetland rice cultivation, the most suitable hydrological conditions are found in the soils of Class Ib and, for hydromorphic rice cultivation, in those of Class II.

Rice Cultivation with Water Control

For the development of valleys in north Benin, Kilian and Teissier (1973) developed

an inland valley suitability classification for rice cultivation with water control, consisting of six classes:

Classes I + II: There are no morphological restrictions. The hydrological regime is favourable. The soil texture is fine to very fine (Class I) or medium (Class II). Usually the valleys are situated over schists (Class I) or largely over schists and partly over granites (Class II).

Classes III + IV: There are no morphological restrictions. The hydrological regime is slightly unfavourable but soils have a fine to very fine texture (Class III), or is favourable with coarse-textured soils (Class IV). These valleys are situated over fine-textured granites with micas (Class III), or they are situated over granites and many rock outcrops are found (Class IV).

Class V: There are no morphological restrictions, but the unfavourable hydrological regime in combination with medium-textured soils renders these valleys unsuitable for development. These valleys are situated over schists-granite contact zones.

Class VI: Either the morphological conditions are unfavourable or the hydrological regime is unfavourable in combination with coarse-textured soils. These valleys cannot be developed.

The applicability and the usefulness of this classification for all inland valleys in the inventory area have to be tested. Most probably, this classification will have to be adapted to cater for inland valleys formed in sedimentary deposits. This qualitative classification system could be developed into a quantitative system by including parameters related to cropping intensities, crop yields, and economic returns with respect to construction and maintenance costs.

7.4   Fertilizer and Water Management

In spite of the constraints described above, the potential for rice production in the inland valleys in West Africa is high. With proper management practices, rice yields could be improved considerably. Some general comments about fertilizer management and improved water management systems are given in the sections below.

7.4.1   Fertilizer Management

The chemical characteristics of the soils of the inland valley toposequences were described in Section 2.5. From these data, it would appear that most inland valley soils in West Africa have a (very) low inherent fertility. Generally, the fertility is to a large extent governed by the organic matter content of the topsoils. Depending on variations in texture and organic matter content, the upland soils have a low to moderate fertility, the footslopes a very low to low fertility, and the soils of the valley bottoms a low to moderate inherent fertility. In the valley bottoms, however, the fertility of the soils is also governed by the hydrology of the valley. Because of submergence, the pH becomes near neutral, and phosphate, for instance, becomes more readily available.

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To increase the productivity of these soils, fertilizer applications are necessary. The efficiency of the fertilizers depends on the management level of the farms.

Soil and fertilizer nutrients are lost by different processes. On the uplands, large amounts of nutrients are lost by leaching, erosion, or fixation (phosphate). The extent of these losses depends on the soil texture and the content of sesquioxides in the soil. On the (colluvial) footslopes, besides leaching (N and K) and fixation (P), losses of nitrogen by volatilization and denitrification are high. In the valley bottom, loss of nitrogen by denitrification and volatilization is the main problem.

Nitrogen in the soil is susceptible to various loss mechanisms, including leaching, denitrification, and volatilization. These loss mechanisms act most severely in strongly alternating wet and dry environments, as occur in the (colluvial) footslopes. Moormann et al. (1977) found that nitrogen deficiency was highest in these phreatic zones of the inland valleys.

On the uplands, nitrogen is lost mainly by leaching. Leaching is highest in the most humid zone of West Africa (i.e. the Equatorial Forest Zone). In the drier Guinea Savanna and Sudan Savanna Zones, the recovery of nitrogen is higher.

In lowland rice cultivation, the major loss of nitrogen is due initially to NH_3-volatilization, followed by denitrification. Any management techniques aiming at a more efficient use of nitrogen fertilizer and a reduction of N-loss must necessarily look for ways to delay nitrification (Goswami et al. 1986).

On the uplands, urea and NO_3-fertilizer applications are effective, while, on the footslopes, urea gives a higher response than NO_3-fertilizers. Also, topdressing is more efficient than a basal application of fertilizers at planting time.

In the valley bottoms, under waterlogged conditions, the application of urea is recommended whereas NO_3-fertilizer gives a higher response when the groundwater table is below the soil surface. High nitrogen response was found when urea (as urea supergranules) was applied in one deep placement during land preparation or at planting. In other cases, higher nitrogen efficiency was found when half of the urea was applied as basal dressing and incorporated into the soil and the other half was topdressed five days before panicle initiation. The recovery of nitrogen under this system was better than when urea was all basal and surface broadcast (Goswami et al. 1986).

The efficiency of nitrogen fertilizer is highly dependent on adequate water management. Without water control, rice fields can undergo frequent drying and reflooding, resulting in considerable N-losses through sequential nitrification-denitrification.

Phosphate is strongly fixed in the upland soils because of their high content in sesquioxides. In these well-drained and acid soils, phosphate is hardly soluble and therefore leaching of phosphates does not occur. In the footslopes, phosphate fixation can be high too. To avoid high losses by fixation, phosphate fertilizers should be applied in point placements.

In soils with very low contents of available nitrogen, response to phosphate fertilizer is nil unless nitrogen is applied as well.

The availability of phosphorus in the soils of the valley bottoms is strongly related to the actual hydrology. During flooding, the availability of phosphorus increases as the subsequent rise in pH results in the higher solubility of various phosphates like variscite ($AlPO_4$) and strengite ($FePO_4$). The increased availability of phosphorus ceases once the soil becomes dry. The application of farmyard manure might help

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in keeping phosphorus more readily available under alternate wetting and drying. Another possibility is the split application of phosphorus, half at transplanting and half topdressed along with N at tillering and mixed with the soil (Goswami et al. 1986).

Potassium availability is low in most soils of the inland valleys because they are strongly weathered and often strongly leached, resulting in soils with low cation exchange capacity and base saturation. Soils with a high CEC generally do not show any potassium deficiencies (von Uexkull 1985).

Flooding of the valley bottom soils enhances the release of soil potassium from the exchangeable and not exchangeable forms to the soil solution, resulting in a higher availability of potassium during submergence (von Uexkull 1985).

Even though only little is known about K-deficiencies, basal applications of potassium often result in higher yields. Applications of about 30 to 60 kg K/ha were found to be effective in significantly increasing the yield (von Uexkull 1985; de Datta and Kundu 1991). The response was much higher when potassium was applied in three equal splits: at transplanting, active tillering, and panicle initiation. Furthermore, K application was found to be essential for better nitrogen use by lowland rice (de Datta and Kundu 1991).

Potassium is also known to have a beneficial effect in cases of drought and diseases. For instance, Fe^{2+}-toxicity is likely to be reduced with adequate K in soil and plant (de Datta and Kundu 1991).

7.4.2   Water Management

The duration and the depth of flooding and fluctuations of the water level determine the potential of inland valleys for wetland rice production. Without water management, the periods and depths of flooding vary strongly with the climatic conditions in a certain period, but also with the topography. In wet years, the flooding can be too long for the rice crop to mature; in dry years, the crop water requirements will not be met.

In Sierra Leone, Oosterbaan et al. (1987) found that yields of rice grown on the valley fringes, with shallow and irregular submergence, were lower than on the wetter parts of the valley bottom. By improving water management, the rice production on the valley fringes could be increased.

Water-control methods for agricultural production in inland valleys in West Africa have different aims, depending on the agro-ecological zone. In the Sudan Savanna Zone and in the dry areas of the Guinea Savanna Zone where water is in short supply, the main goal is water conservation. In the humid part of the Guinea Savanna Zone and in the Equatorial Forest Zone, flood control and drainage improvement are the main objectives.

Water-management systems for rice cultivation are described by Savvides (1981), Zeppenfeldt and Vlaar (1990), Scoones (1991) and Oosterbaan et al. (1987).

Besides describing the traditional random-basin system, Oosterbaan et al. (1987) describe four improved water-management systems for wetland rice. These are:
– The central-drain system;

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- The interceptor-canal system;
- The head-bund system;
- The contour-bund system.

The traditional **random-basin system** is widely practised in inland valleys all over West Africa. In this system, small bunds divide the valley bottom and the lower parts of the valley fringes into approximately rectangular blocks. In the Equatorial Forest Zone, this bunding is locally rudimentary or not done at all. Because of the high prevailing precipitation, there is no need to conserve water. Within the basins, the rice is planted on ridges or small mounds of variable height. The plots are more or less levelled. The farmers regulate the water levels inside the basins by opening the bunds.

The **central-drain system** (Figure 7.1), which is locally used in the Equatorial Forest Zone, is based on improving the drainage of the inland valley by excavating and bunding the central drain. The advantage of this system is that the water levels in the rice fields, especially those near the central drain, can be controlled at a lower level than before.

In the **interceptor-canal system**, two interceptor canals are dug along the valley sides. At regular intervals along the stream, contour drains carry the axial discharge from the stream to the interceptor canals. Along the canals, take-off structures or small spillways distribute the water over the rice fields (Figure 7.2).

In periods of high rainfall, the fields are better protected from any rapid overflow
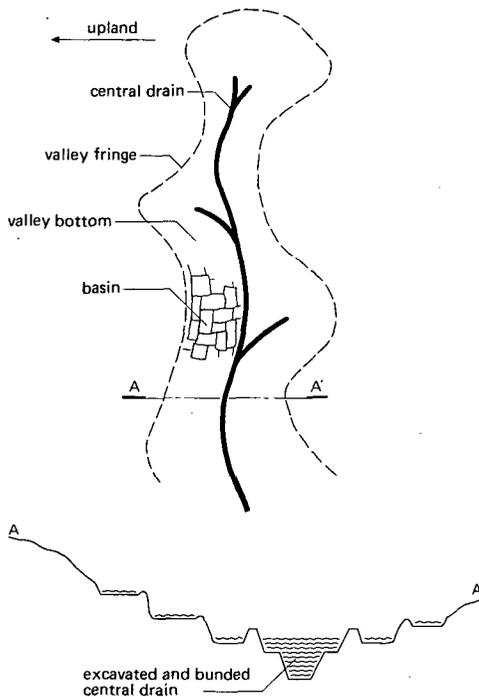
Figure 7.1 A central-drain system in inland valleys (source: Oosterbaan et al. 1987)

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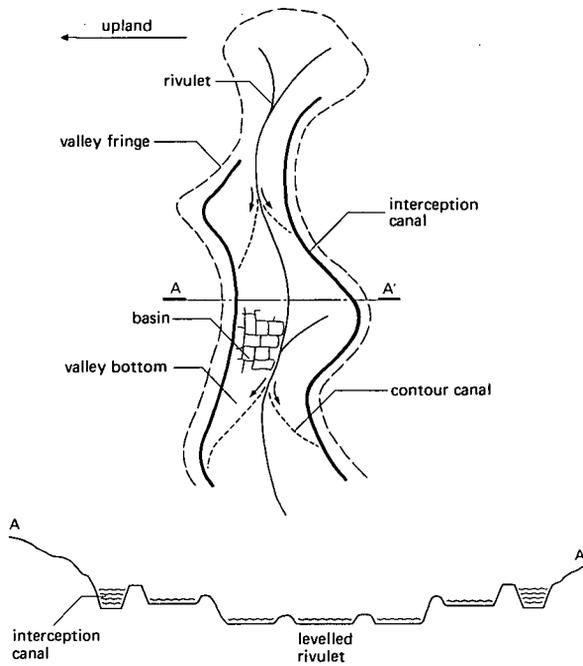
Figure 7.2 An interceptor-canal system in inland valleys (source: Oosterbaan et al. 1987)

of water from the stream and from the lateral runoff from the uplands. During dry spells in the rainy season, the interceptor-canal system can be used to irrigate the rice fields.

In the **head-bund system**, which is locally applied in the Savanna Zones, a series of head bunds are built across the stream, so that behind the bunds the water level in the stream is raised and small reservoirs or ponds are created (Figure 7.3). Contour canals lead the water from the ponds to the valley sides. Sometimes the water is led directly from the reservoirs to canals dug in the valley sides (Savvides 1981). The contour and valley side canals are used for irrigation. One of the advantages of this system is the water conservation in the reservoirs. Because the ponds are small compared with the total water inflow and the water stored in the rice fields, relatively small amounts of water are conserved and are used for additional irrigation during dry spells only.

The **contour-bund system** consists of a number of bunds laid across the valley stream, following the contour lines of the valley bottom (Figure 7.4). If necessary, land levelling can be done to obtain flat fields. The bunds are spaced at distances that depend mainly on the longitudinal slope of the valley.

In this system, the stream is obliterated. In order to drain, each individual field is provided with an outlet or spillway to the next field. If, especially in the lower parts, the flow from field to field becomes too great or the drainage of the fields by these outlets is not sufficient, interceptor canals can be dug along the valley slopes to transport the surplus water directly to a stream or river more downstream.

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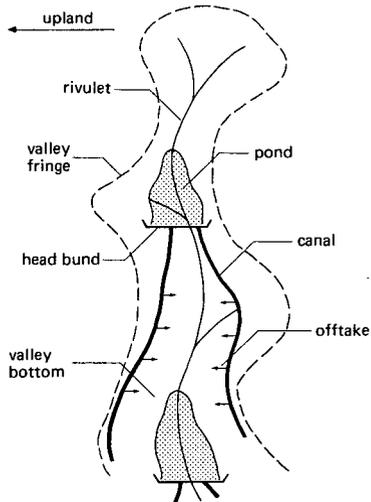
Figure 7.3 A head-bund system in inland valleys (source: Oosterbaan et al. 1987)
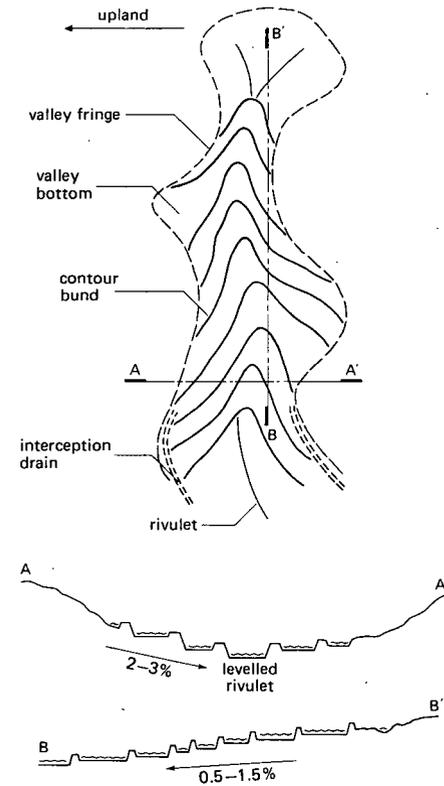
Figure 7.4 A contour-bund system in inland valleys
(source: Oosterbaan et al. 1987)

The main advantages of the improved water-management systems are that the water levels in the rice fields can be controlled more accurately and that more homogeneous conditions are created over larger areas.

There are disadvantages too: the canals and bunds require additional investment, maintenance, and operational care; farm fields may have to be re-allocated; and bunds, canals, and ponds take up valuable agricultural land. Also, improving the drainage in the upstream parts of inland valleys may increase the flood hazard downstream.

The contour-bund system was tested on a limited scale in Sierra Leone. Water levels in the terraced rice fields varied only a few centimetres during the growth period. Outside the bunded area, they varied by as much as 20 to 40 cm. The ponded water between the bunds could be drained in three days. After the outlets were closed, the water could be ponded in two days. The costs of bund and spillway construction could be covered by an increased rice yield of about 15%, based on 1986 prices for labour and rice (Oosterbaan et al. 1987).

7.5 Rice-Growing Environments

As was discussed in Chapter 1, the rice-growing environments in West Africa differ widely and a thorough investigation of these environments is required to get a better understanding of the ways in which rice production could be improved.

On the basis of ecological and agronomic parameters and by introducing the toposequence concept, Andriesse and Fresco (1991) described the rice-growing environments in West Africa. Tables 7.1, 7.2, and 7.3 present their findings for the inland valleys in the Equatorial Forest Zone, the Guinea Savanna Zone, and the Sudan Savanna Zone respectively.

The results of the combined use of ecological and agronomic parameters, the toposequence concept, and rice-cropping systems in characterizing rice-growing environments, confirm the diversity and complexity of the conditions under which rice is grown in West Africa.

These descriptions of the various rice-growing environments are small-scale characterizations. More detailed information about soils, climate, hydrology, cropping systems, etc., is needed to develop a comprehensive and quantitative classification framework.

One conclusion that can be drawn is that, for the characterization of the rice-growing environments in West Africa, the existing broad agro-ecological classifications, which are mainly based on the length of the rainy season, are inadequate because the length of the growth period for wetland rice is a function of physiography (toposequence) as much as of the rainfall pattern (Andriesse and Fresco 1991).

Table 7.1 Characteristics, limitations, and potential of rice-growing environments in the Equatorial Forest Zone of West Africa (source: Andriesse and Fresco 1991; adapted)

	Crests, upper slopes	Middle slopes	Lower slopes	Valley bottoms
Hydrological regime	Pluvial	Pluvial	Phreatic (groundwater flow), pluvial	Fluxial (seasonal)
Main soils (descriptive)	Well drained, deep to very deep, coarse- to medium-textured soils of very low fertility; in places gravelly and/or moderately deep over (petro-) plinthite; in places with acid humic top-soil	Moderately well to well drained, deep, coarse- to medium-textured soils of very low fertility; in places gravelly	Imperfectly to poorly drained, deep, coarse-textured soils of very low fertility; in places over soft plinthite	Poorly drained, deep, coarse-textured soils of low fertility; in places with acid humic or peaty topsoil
Main rice yield limitation	Solar radiation and air humidity (blast) Soil fertility (very low pH, BS, CEC; Al toxicity, P fixation, K deficiency)	Solar radiation and air humidity (blast) Soil fertility (like in crests and upper slopes)	Solar radiation and air humidity (blast) Soil fertility (like in crests and upper slopes but also Fe toxicity) 'Sandiness' for tillage	Solar radiation and air humidity (blast) Flooding Soil fertility (like in lower slopes but also N flushing) 'Sandiness' for tillage
Required (water) management	Erosion control; contour cropping, terracing		Erosion control, bunding, levelling, drainage	Flood control, contour bunding, levelling, drainage
Actual rice cropping system	Shifting cultivation and fallow systems (maize) (rice) (yam)-cassava		Single-cropped wet rice, sometimes rice-(taro) (vegetables) on bunds; cassava	Single-cropped wet rice, sometimes rice-(taro) (vegetables)
Potential rice cropping system	Perennial cropping with rice and other food crops under young trees	Perennial and alley cropping with rice as possible food crop	Single-cropped rice with improved water management, followed by other food crops	Single-or double-cropped rice with improved water management, followed by other food crops
Representative areas	Interior plains and plateaux in Sierra Leone, Liberia, Ivory Coast and Ghana; southern Nigeria and Cameroon			

BS = Base Saturation
CEC = Cation Exchange Capacity

Table 7.2 Characteristics, limitations, and potential of rice-growing environments in the Guinea Savanna Zone of West Africa (source: Andriesse and Fresco 1991; adapted)

	Crests, upper slopes	Middle slopes	Lower slopes	Valley bottoms
Hydrological regime	Pluvial	Pluvial	Phreatic (groundwater flow), pluvial	Fluxial (seasonal)
Main soils (descriptive)	Well drained, moderately deep to deep, gravelly, coarse- to medium-textured soils of low fertility; in places shallow, overlying petroplinthite or rock	Moderately well to well drained, moderately deep to deep, gravelly, coarse- to medium-textured soils of low fertility	Imperfectly to poorly drained, moderately deep to deep, coarse- to medium-textured soils of low fertility; in many places over soft plinthite	Poorly drained, deep, coarse- to medium-textured soils of low to moderate fertility
Main rice yield limitation	Water retention on coarse-textured and/or shallow soils Soil fertility Foothold on shallow soils	Water retention on coarse-textured soils Soil fertility	Soil fertility	Flooding Soil fertility (N flushing)
Required (water) management	Erosion control, (single-tree) terracing, contour cropping		Bunding, levelling, drainage	Flood control, contour bunding, levelling, drainage
Actual rice cropping system	Fallow systems; rice marginal with fallow rotation; maize/cowpea; (rice)/cassava; (rice)/maize or sorghum intercropping		Single-cropped wet rice, followed by vegetables (cowpea) (cassava)	Single- or double- cropped transplanted wet rice
Potential rice cropping system	Perennial tree cropping with food crops (rice) under young trees		Single cropped wet rice under improved management	Double cropped wet rice under pump irrigation and improved management
Representative areas	Interior plains and plateaux in Guinea Bissau, Guinea, southern Mali and Burkina Faso, north-central Ivory Coast and Ghana, Togo, central Benin and Nigeria			

Table 7.3 Characteristics, limitations, and potential of rice-growing environments in the Sudan Savanna Zone of West Africa (source: Andriesse and Fresco 1991; adapted)

	Crests, upper slopes	Middle slopes	Lower slopes	Valley bottoms
Hydrological regime	Pluvial	Pluvial	Phreatic (groundwater flow), pluvial	Fluxial (seasonal)
Main soils (descriptive)	Well drained, moderately deep, coarse- to medium- textured soils of low to moderate fertility; in many places shallow and/or gravelly over petro-plinthite	Moderately well to well drained, moderately deep to deep, medium- textured soils of low to moderate fertility; in places gravelly	Imperfectly drained, moderately deep, coarse- to medium-textured soils of low to moderate fertility; in places over soft plinthite	Imperfectly to poorly drained, deep, medium- textured soils of moderate fertility; in places coarse textured; in places saline
Main rice yield limitation	Rainfall Water retention on shallow soils Surface sealing Foothold on shallow soils (Soil fertility)	Water retention on moderately deep soils Surface sealing Dense, impermeable subsoil	Surface sealing Dense impermeable subsoil	Flooding Availability of (irrigation) water High temperature (2nd crop) and/or low winter temperature (Dec.-Feb.)
Required (water) management	Erosion control, water harvesting	Erosion control, water harvesting	Bunding, levelling, supplementary irrigation	(Pump) irrigation for 2nd crop
Actual rice cropping system	Rice exceptional; only in highest rainfall areas (> 900 mm) and on soils with high water retention capacity; rice-food crop rotation		Single-cropped wet rice, sometimes rice-(vegetables)	Single-cropped wet rice, broadcast or transplanted
Potential rice cropping system	Little potential outside favourable areas		Rice followed by vegetables or beans under improved management	(Double-cropped) rice under pump irrigation and improved management
Representative areas	Aggradational plains, interior plains and plateaux in Senegal, Gambia, southern Mali, Burkina Faso, Niger, northern Benin and Nigeria			

8 Summary and Main Topics for Further Research

8.1 Summary

The present inventory of West Africa is confined to the area with a growing period ranging from 90 days to year-round. This area comprises the Sudan Savanna Zone with a growing period of 90-165 days, the Guinea Savanna Zone with a growing period of 165-270 days, and the Equatorial Forest Zone with a growing period of more than 270 days. Precipitation in the latter two zones allows rain-fed double cropping, or more.

The total inventory area is approximately 3.14 million km², of which the Sudan Savanna Zone covers about 0.92 million km², the Guinea Savanna Zone about 1.35 million km², and the Equatorial Forest Zone about 0.87 million km².

The climate of West Africa imposes restrictions on agriculture. In the northern part, the Sudan Savanna Zone, where the rainfall distribution is monomodal, the rainy season is short, the precipitation can be irregular, and the diurnal variations in temperature are great. In the southern part of the monomodal rainfall area, the humid period varies from five to eight months. In the zone with only five humid months, the main limitation to crop production is the deficiency in soil moisture for the remaining period of the year. Solar radiation is high, however, favouring high photosynthetic energy conversion. In the area with up to eight humid months, the main limitations to crop production are sub-optimum solar radiation and high air humidity.

The bimodal rainfall area is characterized by two rainfall periods, separated by a short dry season in August. In this area, the main constraints are the irregular precipitation within the rainy seasons and the sub-optimum solar radiation.

The pseudo-bimodal rainfall area has a continuous rainy season from March/April to October/December. Here, the main limitations to crop production are the sub-optimum solar radiation and high air humidity. This combination causes a high incidence of pests and diseases.

Four land regions, based on differences in their morphology, have been distinguished in the inventory area. These land regions are broad landscape units with recurrent physiography:
- Coastal and alluvial plains   397,000 km² (12.6%);
- Interior plains   1,515,000 km² (48.3%);
- Plateaux   876,000 km² (27.9%);
- Highlands   349,000 km² (11.2%).

The interior plains and the plateaux, comprising 76.2% of the inventory area, are the most extensive land regions. Within these two land regions, the geological formations belonging to the Basement Complex cover about 1,597,000 km² (66.8%) and sedimentary deposits cover some 794,000 km² (33.2%). In the Sudan Savanna Zone, however, sedimentary deposits are more abundant than the rocks of the Basement Complex.

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Inland valleys are found in all four land regions, but most commonly in the interior plains and the plateaux. Physiographically, inland valleys can be subdivided into three main units, each with its own particular hydrological conditions:
- The uplands, crests, and side slopes occupy the highest parts of the inland valley toposequences. Generally, these parts are well-drained. Hydrologically, this unit belongs to the pluvial zone; precipitation is the only source of water for crops;
- The footslopes are less well-drained, and an important additional source of water is the seepage of groundwater flowing from the uplands to the valley bottoms (the phreatic zone). The lowest parts of the footslopes are flooded during the rainy season;
- The valley bottoms, naturally, occupy the lowest parts of the inland valleys. They are poorly drained and are flooded during the rainy season and at the beginning of the dry season (the fluxial zone).

On the basis of their morphological features and their flooding regime, the inland valleys are divided into river inland valleys and stream inland valleys.

Generally, the upland soils in the inventory area are gravelly and coarse to medium-textured, have a low water-holding capacity, and low inherent fertility. The best soils are formed over basic metamorphosed rocks of the Basement Complex (schists, amphibolites, greenstones, etc.), or on fine-grained sedimentary deposits (shales and claystones). As the processes of soil weathering and leaching increase toward the southeast and the southwest, the most depleted soils are found in those parts of the inventory area. On the uplands, three main soil groups are distinguished:
- Ferralsols in the Equatorial Forest Zone. These are very strongly weathered acid soils with a ferralitic B-horizon and a very low CEC. Most Ferrasols in the inventory area have a low base saturation;
- Acrisols in the transition between the Equatorial Forest Zone and the Guinea Savanna Zone. These soils are strongly weathered and acid, and have an argic B-horizon with a low CEC and a base saturation of less than 50%;
- Lixisols in the dryer parts of the Guinea Savanna Zone and in the Sudan Savanna Zone. These are strongly weathered soils that are slightly acid to near neutral, and have an argic B-horizon with a low CEC but a base saturation of more than 50%.

The soils of the valley bottoms vary widely in their characteristics – in their texture as well as in their fertility status. The mineral part of these soils generally reflects the characteristics of the soils of the surrounding upland and their parent material. Because of poor drainage, however, the topsoils have a higher organic-matter content and consequently a better inherent fertility. Flooding influences the fertility too, because, upon flooding, the pH of the soil rises and the availability of several nutrients increases.

The total area of wetlands in the inventory area is estimated somewhere between 375,000 and 842,910 km², or between 11.9 and 26.8%. Four categories of wetland are distinguished:
- Deltas, tidal lands, and large inland swamps (including *bolis*) cover about 42,000 to 84,940 km², or 1.3 to 2.7% of the inventory area;

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- Large river floodplains cover between 123,000 and 247,970 km^2, or 3.9 to 7.9% of the inventory area;
- River inland valley bottoms and footslopes cover approximately 100,000 to 230,000 km^2, or 3.2 to 7.3 % of the inventory area;
- Stream inland valley bottoms and footslopes cover between 110,000 and 280,000 km^2, or 3.5 to 8.9% of the inventory area.

In any place in the inventory area with favourable vector habitats, five major water-borne human diseases occur: malaria, schistosomiasis (bilharzia), trypanosomiasis (sleeping sickness), onchocerciasis (river blindness), and dracontiasis (Guinea worm). They form a great menace to the health of the population, especially in the rural areas.

In West Africa, the major part of the rice production occurs on the uplands, but in the last decades an increasing amount of rice is being grown on the valley bottoms. Large parts of the valley bottoms are cultivated without any water management being applied.

Most of the upland rice is produced in shifting-cultivation farming systems (especially in the Equatorial Forest Zone) or in fallow systems. Permanent rice cropping is hardly found in the inland valleys.

West Africa as a whole is not densely populated, the average being 65 persons/km^2. Within the inventory area, however, there are great differences in population densities. Generally, the eastern part is more densely populated than the western part, and the coastal zone is more densely populated than the inland area. Nigeria, with 117 persons/km^2, has the highest population density.

Rural-urban migration is a common phenomenon, which results in overpopulated urban areas and (seasonal) labour shortages in the rural areas.

Population growth rates are high in almost all countries of West Africa. In the period 1975-1990, the population of Ivory Coast, for example, increased by 77%, followed by Nigeria (64%), Niger (62%), and Liberia (60%). The lowest population growth during this period was found in Guinea (39%). The annual population growth rates in 1990 varied from 2.0% in Guinea Bissau to 3.8% in Ivory Coast. In several countries, the highest growth rates are not expected to occur before 1995.

Although the total agricultural crop production increased substantially between 1975 and 1990, the high rates of population growth are the main reason why production per caput has decreased, or has increased only slightly.

For the whole inventory area, the total rice production increased by some 75% between 1975 and 1990. This was mainly due to the expansion of the rice-cultivated area rather than to increased yields. There are, however, large differences between the various countries. The highest increases in rice production are found in Nigeria (270%) and Niger (150%). Rice production decreased in The Gambia (–35%), Liberia (–35%), Benin (–23%), and Sierra Leone (–18%).

The highest increase in rice production was achieved between 1975 and 1985. Since 1985, the production of rice has more or less stabilized.

Because of the population growth and changing food preferences in West Africa, espe-

cially in the urban centres, rice consumption has increased tremendously, resulting in high imports of rice and in declining self-sufficiency rates. For the whole inventory area, rice imports increased by 590% between 1975 and 1990. Only in Mali was the self-sufficiency rate higher in 1990 (5%) than in 1975. In all the other countries, it diminished between some 5% (Guinea Bissau) and 70% (Ghana).

Government policies in West Africa are directed towards self-sufficiency in rice production. These policies are sustained not only by research, agricultural extension, and development programs, but in most countries of the inventory area also through subsidies on inputs, outputs, transport, processing, storage, and marketing, or by levy or quota systems on rice imports.

These policies have saved foreign currency. The negative impact of subsidies, however, is that they increase the cost price at the national level, while the levy and quota systems increase the consumer price.

On the other hand, large investments are made – in foreign currency – for the introduction of modern rice-cropping systems: for fertilizers, insecticides, pesticides, improved varieties, and improved technology. The results of large, modern irrigation schemes, however, have been particularly disappointing, and are incommensurate with the large investments made. Small-scale irrigated/water-controlled rice cultivation seems to be economically the most profitable method of increasing the rice production.

Advanced rice-cropping systems give the highest yields, but they do not result in the highest net return per unit area. On the other hand, in the traditional rice-cropping systems, yields and net return per ha are both low. The introduction of adapted technology will raise these yields and net return/ha, while the high production costs of advanced rice-cropping systems result in a net return/ha at an intermediate level between those of the traditional and the partly improved cropping system.

8.2 Research Programs and Strategies

Rice research in West Africa began in the 1920's with the Moor Plantation in Ibadan, Nigeria. The oldest rice research station in West Africa is Rokupr in Sierra Leone, which started in 1934. The rice research station at Badeggi in Nigeria was established in 1953. Rice research was conducted in Kumasi and Kpong in Ghana, in Harbel and later in Suakoko in Liberia, and in Spu in The Gambia.

Rice research in West Africa benefitted from the findings of the International Rice Research Institute/IRRI in The Philippines, the International Institute of Tropical Agriculture/IITA, established in 1967 in Ibadan, Nigeria, and the West Africa Rice Development Association/WARDA, established in 1971 in Monrovia, Liberia, but now (since 1988) in Bouaké, Ivory Coast.

For the past three or four decades, research on West African inland valleys has been conducted by several institutions and scientists. This research, however, was mainly focussed on rice-cropping systems in the inland valleys, was largely monodisciplinary and site-specific, and was largely based on the 'Asian experience' with rice-cropping systems (Izac et al. 1990). In view of the complexity of the West African inland valleys, these investigations contributed only to partial insights into some of their ecological and economic aspects, and did not result in a systematic classification

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system of these agro-ecosystems.

It is only in the last decade that multidisciplinary research has been started to gain a deeper understanding of the complexity of the agro-ecological characteristics of inland valleys. This type of research now constitutes the major theme in several national and international research programs in West Africa.

In 1980, IITA initiated the Wetland Utilization Research Project/WURP, which was undertaken in collaboration with (in The Netherlands) the International Institute for Land Reclamation and Improvement/ILRI, what was then known as The Netherlands Soil Survey Institute/*STIBOKA* (now merged into the Winand Staring Centre), and the Royal Institute for the Tropics/*KIT*. Also collaborating in WURP were the Land and Water Development Division/LWDD in Sierra Leone and the National Cereals Research Institute/NCRI in Nigeria.

In the first phase of WURP, secondary information was compiled on key physical and socio-economic aspects of wetlands in the Equatorial Forest Zone and the Guinea Savanna Zone (Hekstra et al. 1983: the WURP Reports, of which the present publication is an update). Subsequently, the Project focussed on detailed soil survey and land evaluation, agro-socio-economic surveys, and water-management studies in selected inland valleys near Makeni, Sierra Leone, and Bida, Nigeria. The Project came to an end in 1987.

In 1990, IITA started its research on inland valley agro-ecosystems. The general objective of this research is 'to evaluate existing natural resource- and crop-management systems in inland valleys in West and Central Africa in terms of their economic and ecological sustainability and farmers' welfare, and to design feasible improvements in these systems on the basis of this evaluation' (Izac et al. 1990; Spencer 1991).

To fulfil the research objectives, three major sets of activities are being undertaken:
- First, an inventory and classification of inland valley agro-ecosystems is being made. This includes measuring the land and catchment areas of the inland valleys, identifying their distribution and their land-use patterns, relating them to ecological and economic environments, and, last but not least, identifying the different categories of inland valleys and sites representative of these categories;
- The second set of activities concerns the quantification of constraints to sustainable and increased food production. These activities include identifying the principal components and functions of the inland valley agro-ecosystems, quantifying the constraints to food production, and building integrated and ecological-economic models of the different types of inland valleys;
- The last set of activities involves the design, evaluation, and testing of improved technologies.

All these activities are being undertaken in close collaboration with National Agricultural Research Systems/NARS – an essential component for their successful completion.

WARDA (1987, 1988) outlined the strategy for its rice research program within the three major West African rice ecologies, i.e. the upland/inland swamp continuum (inland valleys), the Sahel Zone (irrigated rice production), and the mangrove swamps (tidal rice cultivation).

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For the upland/inland swamp continuum, the research is directed to germplasm improvement, to environment-, crop-, and resource-management, and to on-farm research. In 1990, WARDA started its research into the characterization of rice-growing environments in Ivory Coast. An agro-socio-economic inventory of rice-cropping systems was made through interviews with regional site officials, followed by visits to farmers all over the country (Becker and Diallo 1992). At each location, survey teams identified rice varieties, weeds, bird pests, and the plants occupying the ecological niches suitable for rice. Farmers described their rice-growing practices, farming objectives, crop rotations, labour allocation, and major problems.

At the same time, at its headquarters near Bouaké, Ivory Coast, WARDA initiated research on soil-fertility management, weed control, varietal improvement, and rice-cropping practices along a toposequence in the M'Be valley (WARDA 1991).

Currently, WARDA, IITA, the Winand Staring Centre, and the Wageningen Agricultural University are collaborating on the development of a regional research program 'Sustainable Use of Inland Valley Agro-Ecosystems in Sub-Saharan Africa'. Under this program, a consortium approach is being developed between National Agricultural Research Systems, initially from the West African regions, and International Institutes. This will lead to a structure of cooperation for the agro-ecological characterization of inland valleys. In a later stage, on the basis of this characterization, technology packages will be developed for the improved and sustainable use of inland valleys for rice-based farming systems.

In Burkina Faso, the Institut d'Etudes et de Recherches Agricoles is conducting research on the improvement of rice cultivation in inland valleys. As a first step, the rice agro-ecology has been characterized. The study has shown that, south of the 800 mm/year isohyet, upland rice can be cultivated on soils with a high water-retention capacity. Rice varieties with a short growing period are better adapted to the short rainy season prevailing there. Further research will focus on the selection of adapted varieties and the improvement of the cropping system.

In the bottoms and footslopes of the inland valleys, a study is being made of the relationships between topography and hydrology in the phreatic and fluxial zones. Also being studied are the selection of varieties, the possibilities of fertilizing with green manures and natural phosphates, and improvements in the rice-cropping system. Taken into account in these studies are technical and socio-economic aspects of exploiting the inland valleys.

In the near future, the research in Burkina Faso will address the agro-climatological zonation of pluvial rice cultivation (upland and wetland) in the area with a precipitation of more than 800 mm/yr. Also, in inland valleys where rice-growing has been discontinued, hydrological studies will be conducted with the aim of re-introducing (irrigated) rice cultivation by lowering the production costs through a more efficient use of irrigation water, fertilizers, etc. Finally, pilot farms will be established to enhance the transfer of improved technology (Sie and Dembele 1991).

In the northern part of Benin, between 1960 and 1970, extensive research was done on several morphological, pedological, and hydrological characteristics of the inland valleys. In the period 1970-1986, however, the Government of Benin invested heavily

in large-scale irrigated rice cultivation. During these years, no investments were made to support the smallholder farmers cultivating the inland valleys.

After the failure of introducing large irrigation schemes, Governmental policy changed so as to stimulate and develop smallholder rice-cropping systems in inland valleys. In 1986, the Direction de la Recherche Agronomique started an inventory and classification of the different types of inland valleys in Benin. The project resulted in the distinction of four major categories of inland valleys. This classification will be the basis for further research into the rice-cropping systems and the agro-ecological systems in the country (Assigbe 1991).

For Nigeria, Ajayi (1991; National Cereals Research Institute/NCRI, Nigeria) gives some proposals on the characterization and management of inland valleys for rice-based cropping systems. The different proposed projects include: The characterization and fertility-capability classification of inland valley soils; Research into the potential of green manuring of inland valley soils, and; The screening of rice varieties that will fit into rice-based cropping systems in inland valleys.

For the study of the potential of green manuring, Ajayi proposes three possible experiments: A survey of indigenous legumes in inland valleys and river floodplains; The integrated use of inorganic and organic fertilizers, and; The effect of different green manures on grain yield and soil fertility.

In the Savanna Zone of northern Ghana, research on rice-growing environments is being done by the Nyankpala Agricultural Experiment Station, Tamale. There, the climatic variables of the area are being characterized, as are the soils of the inland valleys. This research, however, is only in its initial phase. Also, because of limited resources, little attention has been given so far to the collection and interpretation of socio-economic data, hydrological data, rice production systems, and the main constraints to rice production (Dekuku et al. 1991).

Another research program on inland valleys in Ghana is being implemented by the Crops Research Institute, in collaboration with several other institutes. The main objectives of this program are to set up pilot project sites, where detailed studies will identify the constraints to utilizing the inland valleys for rice and rice-based cropping systems, and, after that, to devise systems to overcome these constraints. Four sites have been selected on the basis of their proximity to sources of technology generation, accessibility of the site throughout the year, and the presence of smallholder rice farmers.

The main constraints to rice-growing found during the inventory of these sites were the lack of improved varieties, inappropriate cropping practices, (very) low to medium fertility, and, locally, the coarse texture of the soils. Added to these are weed growth and several pests; the control of birds and rodents is difficult and time-consuming. Further constraints are the lack of water control and the lack of credit facilities for farming operations (Otoo 1991).

8.3   Recommendations for Further Research

Research on rice-based smallholder farming systems in inland valleys in West Africa

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is urgently required. The reasons for this urgency are the sharp increase in the demand for rice, the continuing decrease in self-sufficiency in rice and in food supplies in general, and the high costs of food imports.

The research should aim at maximizing the returns to scarce production factors such as labour (which, at present, is characterized by high costs and low productivity) and other inputs.

It is strongly emphasized that this research be directed to developing appropriate techniques at costs that fall significantly below the current costs of rice production. This should effectively increase the rice production by smallholder farmers.

Because of the large total area occupied by stream inland valley bottoms and foot-slopes in West Africa – more than 11 million ha, most of which, at present, are only being marginally used – the research will contribute considerably to alleviating the precarious food situation in the region.

The research should include aspects of land and water management and of agro-socio-economy. The latter form the basis for the proper identification of research and, later, for the application of its results. To find solutions to the constraints in small-holder farming systems, existing farming/cropping systems should be studied thoroughly, with an interlinking of valley-bottom resources and upland resources.

Because of the great heterogeneity in the physical, agronomic, and socio-economic conditions in West Africa, research on inland valleys must give first priority to characterizing the inland valleys' agro-ecology. With the agro-ecology characterized, it will be possible to develop a classification system for the inland valleys. This will allow data from different locations to be compared and interpreted, and results of research to be extrapolated and transferred from one area to another.

From a socio-economic point of view, in need of study at farm level are the following:
– The size of the farm households and the labour availability (men, women, and children);
– The role of women in producing rice in the valley bottoms, and in its processing and marketing;
– The off-farm labour supplement to family labour, and the wages paid.

Other socio-economic parameters that need study at a higher aggregation level are:
– The presence of processing and marketing facilities, including the infrastructure;
– The availability of modern farm inputs such as improved rice varieties, fertilizers, pesticides, herbicides, and improved technologies;
– The accessibility to credit facilities;
– The subsidies on production and processing costs, and the stability of farm prices.

Before improved farming and cropping systems can be developed, an inventory of the existing systems needs to be made. This inventory should cover:
– Assessing farm sizes and identifying the crops and livestock components of the farming system, including their relative importance in terms of land area, production, home consumption, and market sales;
– Describing existing production techniques for the major crops, including quantities and costs of inputs, yields, total outputs, post-harvest losses, and returns;
– Analyzing the agricultural calendar and identifying peak demands for labour;

– Identifying the major production constraints for the principal crops, as viewed by the farmers.

The characterization of the physical parameters will have to be related to the entire valley toposequence. It should comprise:
– A physical characterization of the sites, including valley morphology (slope shape and slope angle; location of the stream), hydrology (catchment size, runoff rate, groundwater fluctuation, flooding pattern, water retention and depletion), erosion status, and soil conditions (texture, drainage class, clay mineralogy, organic-matter content, nutrient status, salinity, and toxicities);
– Climatic parameters, including rainfall pattern and reliability, temperature, radiation, and air humidity;
– Existing infrastructure for land and water development;
– Health aspects.

All these research activities will result in:
– An identification and understanding of the main constraints to crop production in these valleys;
– Systems for the characterization and classification of inland valleys that will enable newly-developed technologies to be transferred to areas with similar valley characteristics.

To develop and test packages of improved technology, research projects will have to be formulated. Tentatively, these in-depth projects should focus on:
– The monitoring of (surface and subsurface) water regimes, soil erosion, soil degradation, and agro-climatological parameters;
– Land and water development, including low-cost technologies for bush clearing, drainage, and irrigation;
– Land and water management, including systems of water control and distribution with simple structures, field layout, and land levelling;
– Soil management, including soil tillage, fertilizer application (including green manuring), and toxicity control;
– Crop management, including the use of improved varieties, integrated pest management (including biological and chemical control), weed control; optimizing the cropping calendar and crop rotation schemes;
– Health aspects: improving health care, drinking-water supplies, and excreta disposal; interfering with the transmission mechanisms of diseases (by eliminating the breeding places of vectors, killing the vectors, bio-technical measures, developing prophylactic drugs);
– Improving the infrastructure and the facilities for processing, marketing, and credit; stabilizing prices, etc.;
– Assessing the environmental impact.

The reclamation of inland valleys will undoubtedly have an impact on the environment. Reclamation implies the removal of the natural vegetation (e.g. gallery forests) and the loss of habitats for certain animals. The result will be a decreased bio-diversity in the inland valleys.
Reclamation will also affect the nutrient balances in the soils of the uplands and

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valley bottoms. Soil physical characteristics will be affected; soils may become compacted which results in increased soil erosion. The hydrological regimes of the various land subelements of the inland valleys will be changed. Erosion in the uplands will lead to the deposition of materials in the valley bottoms; increased runoff will result in higher peak discharges; and improving the drainage in the upstream part of a valley may increase the flood hazard downstream.

References

Andriesse, W. 1986. Area and Distribution. In: *The Wetlands and Rice in Sub-Saharan Africa.* pp. 15-30. A.S.R. Juo and J.A. Lowe (Eds.). IITA, Ibadan, Nigeria.

Andriesse, W., and L.O. Fresco. 1991. A Characterization of Rice-Growing Environments in West Africa. *Agric. Ecosys. and Environ.* 33: 377-395.

Ahn, P. 1970. *West African Soils.* Oxford Univ. Press, London, England.

Ajayi, E.O. 1991. Proposals on Characterization and Management of Inland Valleys for Rice-Based Cropping Systems. Paper presented at the Workshop on the Collaboration in the Characterization of Continuum Environments in West Africa. WARDA, Bouaké, Ivory Coast.

Argoulon, J. 1972. Les surfaces potentielles pour le développement de l'irrigation dans la vallée supérieure du Niger. SCET, Internationale, France. Séminaire international sur les perspectives pour l'irrigation en Afrique de l'Ouest. Univ. d'Ibadan, Nigeria.

Arrivets, J. 1973. Résultats de riziculture sans aménagement en zone Soudanienne. L'example de bas-fonds du centre d'Haute-Volta. *Agron. Trop.* 28(1): 34-53.

Assigbe, P. 1991. Atelier sur la caractérisation et la classification des bas-fonds en Afrique de l'Ouest et en Afrique Central. Paper presented at the Workshop on the Collaboration in the Characterization of Continuum Environments in West Africa. WARDA, Bouaké, Ivory Coast.

Asuming-Brempong, S. 1989. Ghana Rice Policy : The Cost of Self-Sufficiency. *Africa Devel.* 14(4): 67-82.

Atavion, K. 1979. Les ressources en eau de l'Afrique de l'Ouest et leur disponibilité pour l'agriculture. Seminaire sur la gestion de l'eau. CIEH-Ouagadougou, WARDA, Monrovia, Liberia.

Atlas de la Haute-Volta. 1975. Editions Jeune Afrique. *Les atlas Afrique.* Paris, France.

Aubréville, A. 1950. Le concept d'association dans la forêt dense équatoriale de la basse Côte d'Ivoire. *Mém. Soc. Bot. Fr.* 1950-1951: 145-158.

Avenard, J.M. 1971. Aspects de la géomorphologie. In: *Le milieu naturel de la Côte d'Ivoire.* Mém. 50: 7-81, ORSTOM, Paris, France.

AVV. 1981. *Synthèse des résultats de l'étude sur les possibilités de mise en valeur de la vallée de la Koulipele dans le bloc de Kaibo sud, 1977 à 1980.* Autorité des Aménagements des Vallées de Volta, Service d'expérimentation. Min. de Dév. Rural, Haute Volta.

Ay, P. 1981. *Rural Population Crisis and Research Priorities.* IITA, Ibadan, Nigeria.

Ay, P., T. Gebremeskel, M. Jalloh, and C.A. de Vries. 1984. *Report on the Agro-Socio-Economic Survey of Two Sites in Sierra Leone.* WURP, Phase II, Pre-Implementation Stage. ILRI, Wageningen, and KIT, Amsterdam, The Netherlands.

Barraud, J. 1963. *Rapport au gouvernement du Togo sur les aménagements hydro-agricoles au Togo.* Progr. Elargi d'Assistance Technique 1609. FAO, Rome, Italy.

Barrère, J., and M. Slansky. 1965. *Notice explicative de la carte géologique au 1:2,000,000 de l'Afrique occidentale.* Mém. du Bur. de Recher. Géol. et Min. 29, Paris, France.

Baudet, J.L. 1981. Cameroon : Towards Self-Sufficiency in Rice. *The Courier* 66 (March-April): 75-77.

Becker, L. 1990. Classifying the Spatial Distribution of Rice-Based Agro-Ecosystems in West Africa. Paper presented at the Rockefeller Foundation Social Research Fellows' Workshop on Space and Time : Social Perspectives on Agricultural Development. IITA, Ibadan, Nigeria.

Becker, L., and R. Diallo. 1992. *Characterization and Classification of Rice Agroecosystems in Côte d'Ivoire.* WARDA, Bouaké, Ivory Coast.

Bertrand, R. 1973. Contribution à l'étude hydrologique, pédologique et agronomique des sols gris sableux hydromorphes du Casamance (Sénégal). *Agron. Trop.* 28(12): 1145-1192.

Bertrand, R., P. Sibaud, F. Garuy, and S. Guillobez. 1978. Rice Cultivation under Hydromorphic Conditions on the Sandy Grey Soils of the Lower Slopes in Senegal. In: *Rice in Africa.* pp. 249-256. I.W. Buddenhagen and G.J. Persley (Eds.). Acad. Press, New York, San Francisco, London.

Beven, K.J., and P.E. O'Connell. 1985. General Report on Water Balance Computation Techniques. In: *New Approaches in Water Balance Computations.* A. van der Bekem and A. Herrmann (Eds.). Publ. 148. Int. Ass. Hydrol. Sci. pp. 41-46.

Bindraban, P.S. 1991. *Rice Cultivation on the Upland/Inland Swamp Continuum in West Africa.* Internal Communications 126, Winand Staring Centre, Wageningen, The Netherlands.

147

Birie-Habas, J., J.P. Aubin, D. Sene, and C. Posson. 1970. Les recherches rizicoles au Sénégal. Doc. IRAT/IITA Seminar on Rice. IITA, Ibadan, Nigeria.

Blanchot, A., J.P. Dumas, and A. Papon. 1973. *Carte géologique de la partie meridionale de l'Afrique de l'Ouest à 1:2,000,000.* Bur. de Recher. Géol. et Min., Paris, France.

Boulet, R. 1978. *Toposéquences des sols tropicaux en Haute Volta. Equilibre et déséquilibre pédobioclimatique.* Mém. 85, ORSTOM, Paris, France.

Bourges, J. 1991. *Hydrologie d'un bassin représentatif des Hauts Plateaux du sud Togo.* Etudes et Thèses, ORSTOM, Paris, France.

Braun, J. von, D. Puetz, and P. Webb. 1989. *Irrigation Technology and Commercialization of Rice in The Gambia : Effects on Income and Nutrition.* Res. Report 75. Inter. Food Policy Res. Inst., Washington, D.C.

Breemen, N. van, and F.R. Moormann. 1978. Iron-Toxic Soils. In: *Soils and Rice.* IRRI, Los Baños, The Philippines.

Brouwers, M., and M. Raunet. 1976. *Etude morphopédologique du Plateau Mandingue.* IRAT, Pédologie. Min. du Dév. Rural, Mali.

Broekhuyse, J.T., and A.M. Allen. 1984. Farming Systems Research on the Northern Mossi Plateau. *J. Hum. Organ.* 47: 330-342.

Buanec, B. le. 1975. La riziculture pluviale en terrain drainé. Situation, problèmes et perspectives. *Agron. Trop.* 30(4): 350-381.

Buddenhagen, I.W. 1978. Rice Ecosystems in Africa. In: *Rice in Africa.* pp. 11-27. I.W. Buddenhagen and G.J. Persley (Eds.). Acad. Press, London, England.

Casenave, A. 1978. Etude hydrologique des bassins de Sanguéré. *Cah. ORSTOM, Série Hydrol.* XV(1 + 2): 3-209.

Chapman, V.J. (Ed.). 1977. Wet Coastal Ecosystems. In: *Ecosystems of the World.* Vol. 1. D.W. Goodall (Ed. in Chief). Elsevier, Amsterdam, The Netherlands.

Chauméni, J. 1972. The Irrigation Potential of the Senegal River Basin. UNDP-Senegal. International Seminar on Prospects for Irrigation in West Africa. Univ. of Ibadan, Nigeria.

Chevalier, A. 1951. Sur l'existence d'une forêt vierge sèche sur de grandes étendues aux confins des bassins de l'Oubangui, du Haut-Chari et du Nil (Bahr-el Ghazal). *Rev. Int. Bot. Appl. Agric. Trop.* 31: 135-136.

Chevalier, P. 1990. *Complexité hydrologique du petit bassin versant; example en savane humide Booro-Borotou (Côte d'Ivoire).* Etudes et Thèses, ORSTOM, Paris, France.

Collinet, J., and C. Valentin. 1979. Analyse des différents facteurs intervenant sur l'hydrodynamique superficielle. Nouvelles perspectives – applications agronomiques. *Cah. ORSTOM, Série Géol.* XVII(4): 283-329.

Courtois, B., and M. Jacquot. 1988. *Upland Rice Cropping Systems.* Mém. & Travaux de l'IRAT 16. IRAT, Montpellier, France.

Datta, S.K. de, and D.K. Kundu. 1991. Fertility Management of Acid Rice-Growing Soils in Tropical Asia : A Review. In: *Rice Production on Acid Soils of the Tropics.* pp. 147-160. P. Deturck and F.N. Ponnamperuma (Eds.). Proc. of an Inter. Symp., 26-30 June 1989. Inst. of Fundamental Stud., Kandy, Sri Lanka.

Dekuku, R.C., C.N. Casei, P. Rebuffel, W. Dogbe, and A.L. Nyamekye. 1991. Attempts at Characterization of Rice-Growing Environments in the Northern Savanna of Ghana. Paper presented at the Workshop on the Collaboration in the Characterization of Continuum Environments in West Africa. WARDA, Bouaké, Ivory Coast.

Dent, D. 1986. *Acid Sulphate Soils : A Baseline for Research and Development.* Publ. 39. ILRI, Wageningen, The Netherlands.

D'Hoore, J.L. 1965. *Explanatory Monograph of the Soil Map of Africa.* (Map scale 1:5,000,000). Comm. for Tech. Coop. in Africa, Joint Project 11, Publ. 93. Lagos, Nigeria.

Dir. des Mines et de la Géologie. 1953-59. *Carte géologique du reconnaissance du Cameroun, à 1:500,000.* Paris, France. (7 sheets available; no complete coverage of country).

Dir. Geological Surveys. 1962. *Nigeria 1:250,000.* Geological series (6 sheets available; no complete coverage of country).

Dir. Overseas Surveys. 1960. *Geological Map of Sierra Leone.* (Map scale 1:1,000,000).

Doumenge, J.P., K.E. Mott, C. Cheung, D. Villenave, O. Chapuis, M.F. Perrin, and G. Reaud-Thomas. 1987. *Atlas of the Global Distribution of Schistosomiasis.* WHO/Univ. of Bordeaux, France.

Driessen, P.M., and R. Dudal (Eds.). 1989. *Lecture Notes on the Geography, Formation, Properties, and Use of the Major Soils of the World.* Wageningen, The Netherlands/Leuven, Belgium.

Drijver, C.A., and M. Marchand. *1985. Taming the Floods : Environmental Aspects of Floodplain Development in Africa.* Centre for Environ. Stud., Univ. of Leyden, The Netherlands.

Dubreuil, P. 1966. Les caractéristiques physiques et morphologiques des bassins versants. Leur détermination avec une précision acceptable. *Cah. ORSTOM, Série Hydrol.* 5. Paris, France.

FAO. 1977a. *FAO/UNESCO Soil Map of the World 1:5,000,000.* Vol. VI: *Africa.* UNESCO, Paris, France.

FAO. 1977b. *Analyses of an FAO Survey of Post-Harvest Crop Losses in Developing Countries.* AGPP:MISC/27. FAO, Rome, Italy.

FAO. 1978. *Report on the Agro-Ecological Zones Project.* Vol. I: *Methodology and Results for Africa.* FAO World Soil Resources Report 48. FAO, Rome, Italy.

FAO. 1979. *Land in Sierra Leone : A Reconnaissance Survey and Evaluation for Agriculture.* Tech. Report 1. FAO, Rome, Italy.

FAO. 1982. *Rice Development and Rain-Fed Rice Production.* Plant Prod. and Protec. Paper 41. FAO, Rome, Italy.

FAO. 1986. *African Agriculture : The Next 25 Years* (8 Vols.). FAO, Rome, Italy.

FAO. *Production Yearbook.* Several editions. FAO, Rome, Italy.

FAO. *Trade Yearbook.* Several editions. FAO, Rome, Italy.

FAO/WAU. 1976. *Mechanization of Rice Production : India-Nigeria-Senegal : An International Coordinated Research Project: 1970-1976.* Agric. Univ., Wageningen, The Netherlands.

FAO/UNESCO/ISRIC. 1990. *Revised Legend of the FAO-UNESCO Soil Map of the World (Reprint with Corrections).* World Soil Resources Report 60. FAO, Rome, Italy.

Fiselier, J.L. 1990. *Living Off the Floods : Strategies for the Integration of Conservation and Sustainable Resource Utilization in Floodplains.* Environ. Database on Wetland Interv/EDWIN. Centre for Environ. Stud., Univ. of Leyden, The Netherlands.

Furron, R. 1963. *Geology of Africa.* Oliver and Boyd, London, England.

Gallais, J. 1967. *Le delta intérieur du Niger : Etude de géographie régionale.* Mém. de l'Inst. Fond. d'Afrique Noire. Dakar, Sénégal.

Gebremeskel, T., and C.A. de Vries. 1985. *Report on the Agro-Socio-Economic Survey of Two Sites in Central Nigeria.* WURP, Phase II, Pre-Implementation Stage. ILRI, Wageningen, The Netherlands.

Geological Survey Division. 1964. *Geological Map of Nigeria.* (Map scale 1:2,000,000).

Gillet, N. 1973. Caractérisation et mise en valeur des petites vallées ou bas-fonds pour l'agriculture irriguée. *Agron. Trop.* 28(11): 1089-1099.

Girard, G., J. Sircoulon, and P. Touchebeuf. 1971. Aperçu sur les régimes hydrologiques. In: *Le milieu naturel de la Côte d'Ivoire.* Mém. 50, ORSTOM, Paris, France.

Gleave, M.B., and H.P. White. 1969. Population Density and Agricultural Systems in West Africa. In: *Environment and Land Use in Africa.* pp. 273-300. M.F. Thomas and G.W. Whittington (Eds.). Methuen & Co. Ltd., London, England.

Glemet, D. 1975. *l'Aménagement des bas-fonds, 1969-1976.* SATEC, Min. du Dével. Rural, Comité de Coordination des ORD, Haute Volta.

Goswami, N.N., S.K. de Datta, and M.V. Rao. 1986. Soil Fertility and Fertilizer Management for Rain-Fed Lowland Rice. In: *Progress in Rain-Fed Lowland Rice.* pp. 275-284. IRRI, Los Baños, The Philippines.

Gunneweg, H.A.M.I., A. Evers, and A. Huizing. 1986. A Model to Assess Proposed Procedures for Water Control : Application and Results for Two Small Inland Valleys. In: *The Wetlands and Rice in Sub-Saharan Africa.* pp. 87-96. A.S.R. Juo and J.A. Lowe (Eds.). IITA. Ibadan, Nigeria.

Hakkeling, R.T.A., S. Diatta, and E.M.A. Smaling. 1993. Response of Upland Rice to Soil and Hydrological Conditions on a Footslope in Central Ivory Coast. *Geoderma.* In press.

Hakkeling, R.T.A., E.M.A. Smaling, and S. Diatta. 1989. *Detailed Survey and Land Evaluation of the WARDA Experimental Area, Bouaké, Côte d'Ivoire.* Report 22, Winand Staring Centre, Wageningen, The Netherlands.

Harrison Church, R.J. 1974. *West Africa : A Study of the Environment and of Man's Use of It.* Longman Group Ltd., London, England.

Hayward, D.F., and J.S. Oguntoyinbo. 1987. *The Climatology of West Africa.* Hutchinson, London, England.

Hekstra, P., W. Andriesse, C.A. de Vries, and G. Bus. 1983. *Wetland Utilization Research Project, West Africa. Phase I, The Inventory* (4 Vols.). ILRI, Wageningen, The Netherlands.

Howeler, R.H. 1973. Iron-Induced Oranging Disease of Rice in Relation to Physico-Chemical Changes in a Flooded Oxisol. *Soil Sci. Soc. Am. Proc.* 37: 898-903.

HYPERBAV. 1990. *Structure et fonctionnement hydropédologique d'un petit bassin versant de savane humide.* Etudes et Thèses, ORSTOM, Paris, France.

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Institute for Agricultural Research, Samaru. 1972. *The Hydrology of a Small Catchment Basin at Samaru, Nigeria*. Samaru Res. Bull. 149. Ahmado Bello Univ., Zaria, Nigeria.
  I   Kowal, J., and A.O. Omolokum. *Seasonal Fluctuations in the Height of the Groundwater Table*.
  II   Kowal, J. *Assesment of the Main Components of the Water Budget*.
  III Kowal, J. *Assesment of Surface Runoff under Varied Land Management and Vegetation Cover*.
  IV Kowal, J. *Assesment of Soil Erosion under Varied Land Management and Vegetation Cover*.
IITA. 1973. *Farming Systems Programme : Study on Major Soils in West Africa. Land Suitability Classification Studies of a Toposequence*. IITA, Ibadan, Nigeria.
IITA. 1972, 1974, 1976, 1978, 1979, 1980. *Annual Reports*. IITA, Ibadan, Nigeria.
IITA. 1982. Source and Dynamics of Iron Toxity in Inland Valley Swamps. *IITA Research Highlights*, pp. 34-38. Ibadan, Nigeria.
IITA. 1989. Rice Production Gains in Nigeria. *IITA Research Briefs* 9(3): 4-7.
Iloeje, N.P. 1982. *A New Geography of West Africa*. New revised edition. Longman, Essex, England.
Ingram, J. 1991. Soil and Water Processes. In: *Wetlands in Drylands : The Agro-Ecology of Savanna Systems in Africa*. I. Scoones (Ed.). International Institute for Environment and Development/IIED, Drylands Programme, London, England.
IRRI. 1978. *Soils and Rice*. IRRI, Los Baños, The Philippines.
Iwata, S., S. Hasegawa, and K. Adachi. 1986. Water Flow, Balance, and Control in Rice Cultivation. In: *The Wetlands and Rice in Sub-Saharan Africa*. pp. 69-86. A.S.R. Juo and J.A. Lowe (Eds.). IITA. Ibadan, Nigeria.
Izac, A.M.N., M.J. Swift, and W. Andriesse. 1990. *A Strategy for Inland Valley Agro-Ecosystems Research in West and Central Africa*. RCMP Research Monograph 5. IITA, Ibadan, Nigeria.
Jaeger, P. 1968. Mali. In: *Conservation of Vegetation in Africa South of the Sahara*. pp. 51-53. J. and O. Hedberg (Eds.). Almqvist and Wiksells Boktryckeri, Uppsala, Sweden.
Jansen, L., and S. Diarra. 1990. *Le Mali-Sud vu 'superficiellement'. Quantification des superficies agricoles et la dégradation pour quatre terroirs villageois entre 1952 and 1987*. IER/KIT/WAU, Amsterdam, The Netherlands.
Janssen, J.A.M., W. Andriesse, Hendro Prasetyo, and A. Bregt. 1992. *Guidelines for Soil Surveys in Acid Sulphate Soils in the Humid Tropics*. Research Programme on Acid Sulphate Soils in the Humid Tropics. AARD, Indonesia, and LAWOO, The Netherlands.
Jones, R.A.D., and A. Wild. 1975. *Soils of the West African Savanna*. Tech. Comm. 55. Commonwealth Agricultural Bureaux, Commonwealth Bureau of Soils, Harpenden, England.
Jong, L. de. 1989. *De regenafhankelijke landbouw in de Sahel- en Sudan Zone van West Africa*. Organisatie voor ontwikkelingssamenwerking en bewustwording, Den Haag, Nederland.
Juo, A.S.R., and F.R. Moormann. 1980. Characteristics of Two Soil Toposequences in Southeastern Nigeria and Their Relation to Potential Agricultural Land Use. *Soil Sci. Nig. J.* 1(1): 47-61.
Keay, R.W.J. 1949. An Example of Sudan Zone Vegetation in Nigeria. *J. Ecol.* 37: 335-364.
Kessler, J.J., and F.M. Ohler. 1983. *Interventies in Sahellanden : een ecologische benadering*. Mededelingen Vakgroep Natuurbeheer 236. LUW, Wageningen, The Netherlands.
Kevie, W. van der. 1973. Physiography, Classification and Mapping of Acid Sulphate Soils. In: *Proc. of the Int. Symp. on Acid Sulphate Soils, in Wageningen*. pp. 204-222. Publ. 18 (2 Vols.), ILRI, Wageningen, The Netherlands.
Kilian, J. 1972. Contribution à l'étude des aptitudes des sols à la riziculture des bas-fonds sans aménagement dans le Nord-Dahomey (bas-fonds de Sirarou et Bagou). *Agron. Trop.* 27(3): 323-375.
Kilian, J., and J. Teissier. 1973. Methodes d'investigation pour l'analyse et le classement des bas-fonds dans quelques régions de l'Afrique de l'Ouest. Propositions de classification d'aptitudes de terres à riziculture. *Agron. Trop.* 28(2): 156-171.
King, L.C. 1967. *Morphology of the Earth*. Oliver and Boyd, Edinburgh, Scotland.
Kowal, J.M., and A.H. Kassam. 1978. *Agricultural Ecology of Savanna : A Study of West Africa*. Clarendon Press, Oxford, England.
Laar, M.J.W. van de. 1985. *Health Consultancy Sierra Leone*. WURP, Phase II. ILRI, Wageningen, The Netherlands.
LaBaugh, J.W. 1986. Wetland Ecosystems Studies from a Hydrologic Perspective. *Water Res. Bull.* 22(1): 1-10.
Landsberg, H.E., and J.F. Griffith. 1972. *Climates of the World : World Survey of Climatology*. Vol. 10: *Africa*. Elsevier Publishing Co., Amsterdam, London, New York.
Lang, H. 1979. *The Economics of Rain-Fed Rice Cultivation in West Africa : The Case Study of the Ivory Coast*. Socio-Economic Studies on Rural Development 35.

150

Langenhoff, R. 1986. *Distribution, Mapping, Classification, and Use of Acid Sulphate Soils in the Tropics.* Internal Comm. 74. STIBOKA, Wageningen, The Netherlands.

Lauer, W., and P. Frankenberg. 1981. *Untersuchung zur Humidität und Aridität von Afrika. Das Konzept einer potentiellen Landschaftverdünstung.* Bonner Geographischer Abhandlungen, Heft 66. Fred. Dümmlers Verlag, Bonn, Germany.

Lawson, T.L., J.S. Oguntoyinbo, and O. Ojo. 1979. Agroclimatic Conditions of West Africa. Paper presented at the IITA Annual Research Conference on Soil and Climatic Resources and Constraints in relation to Food Crop Production in West Africa. IITA, Ibadan, Nigeria.

Ledger, D.C. 1975. The Water Balance of an Exceptionally Wet Catchment Area in West Africa. *J. of Hydrol.* 24: 207-214.

Lenoir, F. 1978. Relations entre le dynamique et la composition chimique d'une nappe d'arène en Côte d'Ivoire. *Cah. ORSTOM, Série Géol.* X(2): 209-236.

Luiten, T., and R.T.A. Hakkeling. 1991. *Fertility Parameters of Soils in 86 Selected West African Toposequences.* Internal Communication 135. Winand Staring Centre, Wageningen, The Netherlands.

Luning, H.A. 1984. Rice Research and Development in West Africa : Problems and Perspectives. *Neth. J. of Agric. Sci.* 305: 193-204.

Lyons, G.R.L. 1972. *Guinea Worm Infections in the Wa District of North-western Ghana.* Bull. 47. WHO, Geneva, Switzerland.

MacJunkin, F.E. *1975. Water, Engineers, Development, and Diseases in the Tropics.* USAID, Washington, D.C., USA.

Manshard, W. 1961. *Die geographischen Grundlagen der Wirtschaft Ghanas unter Berücksichtigung der agrarischen Entwicklung.* Wiesbaden, Germany.

Martin, C. 1991. *The Rainforests of West Africa : Ecology, Threats, Conservation.* Birkhäuser Verlag, Basel, Switzerland.

Martin, J, and D. Thiery. 1987. Analyse d'une longue série piézométrique au Burkina Faso. *Hydrogéol.* 2: 137-145.

Matthieu, Ph. 1971. Erosion et transport solide sur un bassin versant forestier tropical (Bassin de l'Amitioro, Côte d'Ivoire). *Cah. ORSTOM, Série Géol.* III(2): 115-144.

Mensvoort, M.E.F. van, R.S. Lantin, R. Brinkman, and N. van Breemen. 1984. Toxicities of Wetland Rice Soils. In: *Wetland Soils : Characterization, Classification, and Utilization.* pp. 123-138. S.J. Banta (Ed.). IRRI, Los Baños, The Philippines.

Mitchel, P. 1973. *Les bassins des fleuves Sénégal et Gambie : étude géomorphologique.* Mém. 63. ORSTOM, Paris, France.

Ministry of Overseas Development. 1976. *The Agricultural Development of The Gambia : An Agricultural, Environmental, and Socio-Economic Analysis.* Land Res. Div. Tolworth Tower, Surrey, England.

Millington, A.C., F. Helmisch, and G.J. Rhebergen. 1985. Inland Valley Swamp and Bolis in Sierra Leone : Hydrological and Pedological Considerations for Agricultural Development. *Zeitschrift für Geom.,* Suppl. Band 52: 201-222.

Molinier, M. 1976. Qualité des eaux de surface en zone forestière équatoriale de Côte d'Ivoire. *Cah. ORSTOM, Série Hydrol.* VIII(1): 7-24.

Molyneux, D.H., and P.G. Janssens. 1980. In: *African Trypanosomiases.* H.R. Folmer and W. Peters (Eds.). Serie Meddia. KIT, Amsterdam, The Netherlands.

Moniod, F. 1973. Régime hydrologique de l'Ouémé (Dahomey). *Cah. ORSTOM, Série Hydrol.* X(2): 171-183.

Moormann, F.R. 1973. General Assessment of Lands on which Rice is Grown in West Africa. Seminar on Rice Soil Fertility and Fertilizer Use. WARDA, Monrovia, Liberia.

Moormann, F.R. 1981. Representative Toposequences of Soils in Southern Nigeria and Their Pedology. In: *Characterization of Soils in Relation to Their Classification and Management for Crop Production : Examples from Some Areas in the Humid Tropics.* pp. 10-29, 284-421. D.J. Greenland (Ed.). Oxford Sci. Publ., England.

Moormann, F.R., and N. van Breemen. 1978. *Rice, Soil, Water, and Land.* IRRI, Los Baños, Philippines.

Moormann, F.R., and W.J. Veldkamp. 1978. Land and Rice in Africa : Constraints and Potentials. In: *Rice in Africa.* pp. 29-43. I.W. Buddenhagen and G.J. Persley (Eds.). Acad. Press, London, England.

Moormann, F.R., and A.S.R. Juo. 1986. Present Land Use and Cropping Systems in Africa. In: *The Wetlands and Rice in Sub-Saharan Africa.* pp. 187-194. A.S.R. Juo and J.A. Lowe (Eds.). IITA, Ibadan, Nigeria.

Moormann, F.R., H.P.F. Curfs, and J.C. Ballaux. 1974. Classification of Conditions under which Rice

151

is Grown in the Tropics, with Special Reference to Mechanization in West Africa. IITA/FAO/Neth. Govt.: Exp. Consultative Meeting on the Mechanization of Rice Production. IITA, Ibadan, Nigeria.

Moormann, F.R., A.T. Perez, and W.J. Veldkamp. 1976. *Potential of Hydromorphic Rice Cultivation in Nigeria.* NAFPP Workshop Paper. IITA, Ibadan, Nigeria.

Moormann, F.R., W.J. Veldkamp, and J.C. Ballaux. 1977. The Growth of Rice on a Toposequence: A Methodology. *Plant and Soil* 48: 565-580.

Morgan, W.B. 1969. Peasant Agriculture in Tropical Africa. In: *Environment and Land Use in Africa.* M.F. Thomas and G.W. Whittington (Eds.). Methuen & Co. Ltd., London, England.

Mohr, B. 1969. *Die Reiskultur in West Africa.* IFO-Inst. für Wirtschaftsforschung, Afrika Studien 44, Weltforum Verlag, München, Germany.

Moss, R.P. 1969. The Ecological Background to Land Use Studies in Tropical Africa, with Special Reference to the West. In: *Environment and Land Use in Africa.* pp. 193-240. M.F. Thomas and G.W. Whittington (Eds.). Methuen & Co. Ltd. London, England.

Muller, R. 1980. In: *Fylariasis.* H.R. Folmer and W. Peters (Eds.). Serie Meddia. KIT, Amsterdam, The Netherlands.

Murdoch, G., J. Ojo-Atere, E.I. Olomu, and E.M. Odugbesan. 1976. *Soils of the Western State Savanna in Nigeria.* (Land facets map at scale 1:125,000). Land Res. Study 23. Land Res. Div., Surbiton, England.

Nahon, D. 1976. *Cuirasses ferrugineuses et encroutements calcaires au Sénégal occidental et en Mauritanie.* Thèse. Marseille, France.

Nicklès, M., and V. Hourcq. 1952. *Notice explicative de la carte géologique de l'Afrique Equatorial Francaise et du Cameroun au 1:2,000,000.* Dir. des Min. et de la Géol., Paris, France.

Nyanteng, V.K. 1983. *Some Recent Policies and Programmes Related to Rice Production, Consumption, and Trade in West Africa.* Occasional Paper 6. WARDA, Monrovia, Liberia.

Nyanteng, V.K. 1986. *Riceland in West Africa : Distribution, Growth, and Limiting Factors.* Occasional Paper 7. WARDA, Monrovia, Liberia.

Nye, P.H., and D.J. Greenland. 1960. *The Soil under Shifting Cultivation.* Tech. Communication 51. Commonwealth Agricultural Bureau, Farnham Royal, Bucks, England.

Odell, R.T., J.C. Dijkerman, W. van Vuure, S.W. Melsted, A.H. Beavers, P.M. Surron, L.T. Kurtz, and R. Miedema. 1974. *Characteristics, Classification, and Adaptation of Soils in Selected Areas in Sierra Leone.* Coll. Bull. 4. Njala Univ. Njala, Sierra Leone.

Ojo, O. 1969. Potential Evaporation and the Water Balance in West Africa : An Alternative Method of Penman. *Arch. Met. Geom. Biokl.*, Serie B, 17: 239-260.

Ojo, O. 1977. *The Climate of West Africa.* Heineman Educational Books Ltd., London, Ibadan.

Ojo, O. 1983. Recent Trends in Aspects of Hydroclimatic Characteristics in West Africa. In: *Hydrology of Humid Tropical Regions.* pp. 97-104. R. Keller (Ed.). Publication 140. Int. Ass. of Hydrol. Sci.

Ojo, O. 1985. Water Balance Computations in West Africa : Problems and Prospects. In: *New Approaches in Water Balance Computations.* pp. 159-167. A. van der Beken and A. Herrmann (Eds.). Publ. 148. Int. Ass. of Hydrol. Sci.

Ojo, O. 1987. Rainfall Trends in West Africa, 1901 – 1985. In: *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources.* pp. 37-48. S.I. Solomon, H. Beran, and W. Hogg (Eds.). Publ. 168. Int. Ass. of Hydrol. Sci.

Okali, C., D. Obeng, T. Ojo-Atere, and T. Lawson. 1979. *An Evaluation of Farmer's Knowledge and Use of Hydromorphic Toposequences in the Western State of Nigeria : Findings from Selected Areas in Oshun River Basin.* Disc. Paper 4/79. Agric. Economics, IITA, Ibadan, Nigeria.

Okali, C., D. Obeng, and T. Ojo-Atere. 1980. *The Management and Use of Hydromorphic Toposequences in the Ogun River Basin : The Case of Traditional Farmers in the Ofada Area of Ogun State.* Disc. Paper 5/80, Agric. Economics, IITA, Ibadan, Nigeria.

Okereke, O. 1990. *Increasing Rice Output through Tractor Use in Anambra State, Nigeria.* Research Report 14. Afr. Rur. Soc. Sci. Ser., Winrock Int. Inst. for Agri. Dev., University of Nigeria, Nigeria.

Okigbo, B.N. 1979. Cropping Systems in the Humid Tropics of West Africa and Their Improvement. Paper presented at the IITA Research Review 1979. IITA, Ibadan, Nigeria.

Okigbo, B.N. 1981. Farming Systems and Crops of the Humid Tropics in relation to Soil Utilization. In: *Characterization of Soils in relation to Their Classification and Management for Crop Production : Examples from Some Areas in the Humid Tropics.* pp. 278-283, 422-432. D.J. Greenland (Ed.). Clarendon Press, Oxford, England.

Olagoke, M.A. 1989. *Efficiency of Resource Use in Rice Production Systems in Anambra State, Nigeria.* Research Report 7. Afr. Rur. Soc. Sci. Ser., Winrock Int. Inst. for Agri. Dev., University of Nigeria, Nigeria.

Olivry, J,C. 1976. Régimes hydrologiques en pays Bamiléke (Cameroun). *Cah. ORSTOM, Série. Hydrol.* VIII(1): 37-71.

Onze Wereld. 1992. Dertig miljoen Nigerianen zoek. *Onze Wereld* 6: 3.

Oomen, J.M.V., J. de Wolf, and W.R. Jobin. 1990. *Health and Irrigation : Incorporation of Disease-Control Measures in Irrigation, a Multi Faceted Task in Design, Construction, Operation.* Publication 45 (2 Vols.). ILRI, Wageningen, The Netherlands.

Oosterbaan, R.J., H.A.M.I. Gunneweg, and A. Huizing. 1987. Water Control for Rice Cultivation in Small Valleys of West Africa. *Annual Report 1986.* pp.30-49. ILRI, Wageningen, The Netherlands.

ORSTOM. 1970. *Monographie hydrologique du Basin du Niger* (3 part.). CIEH, Série Hydrol., Ouagadougou, Haute Volta.

Otoo, E. 1991. Studies on Characterization of Selected Valley Bottom Areas for Rice and Rice-Based Cropping Systems in Ghana. Paper presented at the Workshop on the Collaboration in the Characterization of Continuum Environments in West Africa. WARDA, Bouaké, Ivory Coast.

Papadakis, J. 1966. *Crop Ecologic Survey in West Africa* (2 Vols.). FAO. Rome, Italy.

Pearson, S.R., J.D. Stryker, and C.P. Humphreys (Eds.). 1981. *Rice in West Africa : Policies and Economics.* Univ. Press, Stanford, California, U.S.A.

Perez, A.T., and I.C. Mahapatra. 1978. Technology Transfer in Nigeria and Sierra Leone. In: *Rice in Africa.* pp. 231-241. I.W. Buddenhagen and G.J. Persley (Eds.), Acad. Press, London, England.

Phelinas, P. 1990. Le riz: politique des prix et relance de la production (Cameroun, Côte d'Ivoire, Madagascar, et Sénégal). *Politique Africaine* 37: 31-75.

Pieri, C. 1989. *Fertilité des terres de savanes.* Min. de la Coop. et CIRAD-IRAT. 444 pp.

Pol, F. van der 1992. *Soil Mining : An Unseen Contributor to Farm Income in Southern Mali.* Bulletin 325. KIT, Amsterdam, The Netherlands.

Quartey-Papafio, H.K., and E.D. Kemevor. Undated. Land and Water Resources for Irrigation in the Volta Basin.

Raunet, M. 1982. *Les bas-fonds en Afrique et a Madagascar.* IRAT, Service de Pédologie, Montpellier, France.

Raunet, M. 1984. Les potentialités agricoles des bas-fonds en régions intertropicales : l'example de la culture du blé de contre-saison a Madagascar. *Agron. Trop.* 39(2): 121-135.

Raunet, M. 1985. Bas-fonds et riziculture en Afrique: approche structurale comparative. *Agron. Trop.* 40(3): 181-201.

Reichold, W., E.G. Bleckman, R. Mayer, and J. Paris-Teynac. 1978. *Der Senegalstrom, Lebensader dreier Nationen.* Afrika Studien 102. IFO-Inst. für Wirtschaftsforschung, Weltforum Verlag, München, Germany.

Ribstein, P. 1990. *Modèles de crues et petits bassins versants au Sahel.* Etudes et Thèses, ORSTOM, Paris, France.

Richards, P. 1985. *Indigenous Agricultural Revolution : Ecology and Food Production in West Africa.* Hutchinson, London, England.

Richards, P. 1986. *Coping with Hunger : Hazards and Experiments in an African Rice Farming System.* Allen & Unwin, London, England.

Richards, P. 1987. Spreading Risks Across Slopes : Diversified Rice Production in Central Sierra Leone. *Ileia* 3(2): 8-9.

Rodier, J. 1964. *Régimes hydrologiques de l'Afrique noire à l'Ouest du Congo.* Mém. 6. ORSTOM, Paris, France.

Rodier, J. 1976a. Estimations des débits de crues décennales pour les petits bassins forestiers en Afrique tropicale. Etude préliminaire. *Cah. ORSTOM, Série Hydrol.* VIII(4): 243-268.

Rodier, J. 1976b. Evaluation de l'écoulement annuel dans les régions tropicales sèches de l'Afrique occidentale. *Cah. ORSTOM. Série Hydrol.* VIII(4): 269-306.

Rodier, J., and C. Auvray. 1965. *Estimation des débits de crues décennales pour des bassins versants de superficie inférieure à 200 km² en Afrique occidentale.* ORSTOM, Paris, and CIEH, Ouagadougou. (This paper has been translated into English by W.E. Herridge, 1965, Publ. Works Dept., Ghana).

Rodier, J., and J. Sircoulon. 1963. *Monographie de l'Ouémé supérieure* (2 Vols.). ORSTOM, Paris, France.

Rouw, A. de. 1991. *Rice, Weeds, and Shifting Cultivation in a Tropical Rain Forest : A Study of Vegetation Dynamics.* Thesis. Agric. Univ., Wageningen, The Netherlands.

Rouw, A. de, H.C. Vellema, and W.A. Blokhuis. 1990. *Land Unit Survey of the Taï Region, South-West Côte d'Ivoire.* The Tropenbos Foundation, Ede, The Netherlands.

Ruthenberg, H. 1980. *Farming Systems in the Tropics.* 3rd Ed. Oxford University Press, London, England.

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Sanchez, P.A., J.H. Villachica, and D.E. Bandy. 1983. Soil Fertility Dynamics After Clearing a Tropical Rain Forest in Peru. *Soil Sci. Soc. Am. J.* 47: 1171-1178.

Savvides, L. 1981. *Guidelines to Improving Valley Swamps (fadamas)*. Bida Agricultural Development Project, Nigeria.

Scoones, I. (Ed). 1991. *Wetlands in Drylands : The Agroecology of Savanna Systems in Africa* (3 Vols.). Int. Inst. for Eviron. Dev., Dryland Programme, London, England.

Sie, M., and Y. Dembele. 1991. La riziculture de bas-fond au Burkina Faso. Paper presented at the Workshop on the Collaboration in the Characterization of Continuum Environments in West Africa. WARDA, Bouaké, Ivory Coast.

Silva Teixeira, A.J. da. 1962. *Os solos da Guine Portuguesa.* (Map scale 1:500,000). Luanda.

Sivakumar, M.V.K. 1989. Agroclimatic Aspects of Rain-Fed Agriculture in the Sudano-Sahelian Zone. In: *Soil, Crop, and Water Management in the Sudano-Sahelian Zone.* pp. 17-38. T. Gaillard and V. Sadhana (Eds.). ICRISAT, Sahelian Centre, Niamey, Niger.

Smaling, E.M.A. 1985. *Characterization and Classification of Soils of Various SAFGRAD Trial Fields in West, North, and Central Burkina Faso.* IITA, Ibadan, Nigeria.

Smaling, E.M.A., E. Kiestra, and W. Andriesse. 1985a. *Detailed Soil Survey and Qualitative Land Evaluation of the Echin-Woye and the Kunko Benchmark Sites, Bida area, Niger State, Nigeria.* WURP, Phase II, Pre-Implementation Stage. ILRI, Wageningen, The Netherlands.

Smaling, E.M.A., T. Dyfan, and W. Andriesse. 1985b. *Detailed Soil Survey and Qualitative Land Evaluation in the Rogbom-Mankane and Matam-Romangoro Benchmark Sites, Sierra Leone.* WURP, Phase II, Pre-Implementation Stage. ILRI, Wageningen, The Netherlands.

Small, R.J. 1972. *The Study of Land Forms : A Textbook of Geomorphology.* Univ. Press, Cambridge, England.

SODERIZ. 1976. *Project Bouaké-Nord.* Rapport de synthèse prévenu dans le cadre du contract d'Assistance Technique TA/984 entre le Fond Européen de Développement et Grontmij International, Ivory Coast.

Sommen, J.J. van der, and W. Geirnaert. 1988. On the Continuity of Aquifer Systems on the Crystalline Basement of Burkina Faso. In: *Estimation of the Natural Groundwater Recharge.* pp. 29-48. I. Simmers (Ed.). NATO ASI Series: Mathem. and Phys. Sci., Vol. 222.

Spencer, D.S.C. 1991. A Farming System Research Strategy for the Development of Inland Valleys for Increased Food Production in West Africa. *Agric. Systems in Africa* 1(2): 5-14.

Staveren, J.Ph., and W.A. Stoop. 1986. Adaptation aux types de terroirs des toposéquences de l'Afrique de l'Ouest de différents génotypes de sorgho par rapport aux cultivars locaux de sorgho, de mil et de maïs. *Agron. Trop.* 41(3-4): 203-217.

Stiemer, D. 1968. *Aménagement hydro-agricole dans le nord de la Côte d'Ivoire.* FAO/SATMACI, Opération Riz, Korhogo, Ivory Coast.

Stoop, W.A. 1987. Variations in Soil Properties Along Three Toposequences in Burkina Faso and Implications for the Development of Improved Cropping Systems. *Agric. Ecosys. and Environ.* 19: 241-264.

Stoorvogel, J.J., and E.M.A. Smaling. 1990. *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa, 1983-2000.* Report 28, Winand Staring Centre, Wageningen, The Netherlands.

TAMS/CIEH. 1976-1978. *Savanna Regional Water Resources and Land Use.* CIEH, Ouagadougou, Haute Volta.

TDR. 1988. UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases. *TDR News.* WHO, Geneva, Switzerland.

The Times Atlas of the World : Comprehensive Edition. 1981. John Bartholomew & Son Limited, Edinburgh, Scotland.

Thomas, M.F., and G.W. Whittington (Eds.). 1969. *Environment and Land Use in Africa.* Methuen & Co. Ltd., London, England.

Thomas, P., J.A. Varley, and J.E. Robinson. 1979. *The Sulphidic and Associated Soils of the Gambia Estuary above the Proposed Barrage at Yelitenda, The Gambia.* Project Report 89, Overseas. Dev. Min., Land Resources Dev. Centre, Tolworth, England.

Trochain, J. 1957. Accord Interafricain sur la définition des types de végétation de l'Afrique Tropicale. *Bull. Inst. Etud. Centrafr.* (13-14): 55-93.

Turner, B. 1985. The Classification and Distribution of Fadamas in Central Northern Nigeria. *Zeitschrift für Geom.*, Suppl. Band 52: 87-114.

Turner, B. 1986. The Importance of Dambos in African Agriculture. *Land Use Policy* (October): 343-347.

UNESCO. 1976. *Atlas géologique du monde au 1:10,000,000.* Paris, France.

Veldkamp, W.J. 1979. *Land Evaluation of Valleys in a Tropical Rain Area : A Case Study.* Thesis, Agric. Univ., Wageningen, The Netherlands.

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Vermani, S.S., J.O. Olufowoto, and A.O. Abifarin. 1978. Rice Improvement in Tropical Anglophone Africa. In: *Rice in Africa*. pp. 101-116. I.W. Buddenhagen and G.J. Persley (Eds.). Acad. Press, London, England.

Uexkull, H.R. von. 1985. Availability and Management of Potassium in Wetland Rice Soils. In: *Wetland Soils : Characterization, Classification, and Utilization*. pp. 293-305. S.J. Banta (Ed.) IRRI, Los Baños, The Philippines.

Vierich, H.I.D., and W.A. Stoop. 1990. Changes in West African Savanna Agriculture in Response to Growing Population and Continuing Low Rainfall. *Agric. Ecosys. and Environ*. 31: 115-132.

Wall, J.R.D. (Ed.). 1979. *Land Resources of Central Nigeria*. (Land Systems maps at 1:250,000). Land Res. Study 29 (6 Vols.). Land Res. Div., Surbiton, England.

Walter, H., and H. Lieth. 1960. *Klima diagramm – Welt Atlas*. VEB-Gustav Fischer Verlag, Jena, Germany.

Ward, K. 1981. *A Profile of Rice Cultivation within the Bida A.D.P. Area*. Bida A.D.P. Monitoring and Evaluation Section, Nigeria.

WARDA. 1975. *Rice Statistics Yearbook 1975*. WARDA, Monrovia, Liberia.

WARDA. 1980. *Prospects of Self-Sufficiency in Rice in West Africa*. Occasional Paper 1. WARDA, Monrovia, Liberia.

WARDA. 1984. *Activities Highlights*. WARDA, Monrovia, Liberia.

WARDA. 1986. *Rice Statistics Yearbook*. 6th edition, revised. WARDA, Monrovia, Liberia.

WARDA. 1987. *WARDA's Strategy for Rice Research in West Africa*. WARDA, Monrovia, Liberia.

WARDA. 1988. *Strategic Plan 1990-2000*. WARDA, Monrovia, Liberia.

WARDA. 1991. *Annual Report 1990*. WARDA, Bouaké, Ivory Coast.

Watts, J. 1987. Dracunculiasis in Africa in 1986 : Its Geographic Extent, Incidence, and At-Risk Population. *Am. J. Trop. Med. Hyg*. 37(1): 119-125.

Webster, C.C., and P.N. Wilson. 1980. *Agriculture in the Tropics*. Longman Group Ltd., London, England.

White, F. 1983. *The Vegetation of Africa : A Descriptive Memoir to accompany the UNESCO/AETFAT/ UNSO Vegetation Map of Africa*. UNESCO, Switzerland.

WHO. 1980. *Environmental Management for Vector Control*. Technical Report 649, WHO, Geneva, Switzerland.

WHO. 1983. *Integrated Vector Control*. Technical Report 668. WHO, Geneva, Switzerland.

Will, H. 1978. The Research Programme of the West African Rice Development Association/WARDA. In: *Rice in Africa*. pp. 215-223. I.W. Buddenhagen and G.J. Persley (Eds.). Acad. Press, London, England.

Zacharia, K.C., and J. Condé. 1981. *Migration in West Africa : Demographic Aspects*. A Joint World Bank – OECD Study. Univ. Press, Oxford, England.

Zeppenfeldt, T., and J.C.J. Vlaar. 1990. *Mise en valeur des bas-fonds en Afrique de l'Ouest*. CIEH, Ouagadougou, Burkina Faso.

References Not Cited in Text

Ahn, P. 1961. *Soils of the Lower Tano Basin, Southwestern Ghana.* (Map scale 1:250,000). Min. of Food and Agric., Kumasi, Ghana.

Asamao, G.K. 1968. *Soils of the Ochi-Nakwa Basin, Ghana.* (Map scale 1:25,000). Soil Res. Inst. Mem. 4. Acad. of Sci., Kumasi, Ghana.

Barneveld, G.W. van. 1980. *Soils and Soil Conditions of the Zapi-est Area, Eastern Province, Cameroon, and Their Capabilities and Constraints to Crop Production.* Prelim. Working Paper 6, FAO Soil Resources Project, Ekona, Cameroon.

Bawden, M.G., and P. Tuley. 1966. *The Land Resources of Southern Sardauna and Southern Adamawa Provinces, Northern Nigeria.* (Land system map at scale 1:500,000). Land Res. Study 2. Land Res. Div., Tolworth, England.

Bawden, M.G., D.M. Caroll, and P. Tuley. 1972. *The Land Resources of N.E. Nigeria.* (Land system map at scale 1:500,000; Geomorphological map and soil map at 1:1,000,000). Land Res. Study 9, Vol. I: *The Environment*, and Vol III: *The Land Systems.* Land Res. Div., Surbiton, England.

Boutrais, J. 1978. *Deux études sur l'élevage en zone tropicale humide, Cameroun.* ORSTOM, Paris, France.

Brammer, H. 1962. Soils. In: *Agriculture and Land Use in Ghana.* pp. 88-126. J.B. Wills (Ed.). Oxford Univ. Press, London, England.

Brammer, H. 1967. *Soils of the Accra Plains, Ghana.* (Map scale 1:25,000). Soil Res. Inst. Mem. 3. Acad. of Sci., Kumasi, Ghana.

Byerlee, J., and H. Fatoo. 1976. *Rural-Urban Migration in Sierra Leone : Determinants and Policy Implications.* Afr. Rur. Econ. Paper 13.

Chabrolin, R. 1977. Rice in West Africa. In: *Food Crops of the Lowland Tropics.* C.L.A. Leakey and J.B. Wills (Eds.). Univ. Press, Oxford, England.

Dabin, B., N. Leneuf, and G. Riou. 1960. *La carte pédologique de la Côte d'Ivoire au 1:2.000.000.* ORSTOM, Paris, Abidjan.

Diepen, C.A. van. 1980. *La dégradation des sols en la République Populaire du Bénin.* Etude 229. Proj. Agro-pédologique, Cotonou, Bénin.

Djibril, A.W. 1978. Rice Development Strategies in Africa. In: *Rice in Africa.* pp. 69-74. I.W. Buddenhagen and G.J. Persley (Eds.), Acad. Press, London, England.

Due, J.M., and L. Karr. 1973. Strategies for Increasing Rice Production in Sierra Leone. *Afr. Stud. Rev.* XVI(1) April.

Eschenbrenner, V., and L. Badarello. 1978. *Etude pédologique de la région d'Odiénné, Côte d'Ivoire.* (Map scale 1:200,000). Notice Explicative 74. ORSTOM, Paris, France.

FAO. 1965. *Land Use Survey in the Western Region of Nigeria.* FAO/EPTA Rep. 2108, Vol. II, Rome, Italy.

FAO. 1968. *Land and Water Survey in the Upper and Northern Regions of Ghana.* (Map scale 1:500,000). FAO, SF:31/GHA. Vol. I: *General*; Vol. III: *Soil Survey.* Rome, Italy. (Report includes semi-detailed maps of selected areas at scales 1:30,000 and 1:50,000).

FAO. 1969a. *Soil and Water Resources Survey of the Sokoto Valley, Nigeria :Final Report.* Vol. V. *Soil Survey and Land Classification.* (Reconnaissance soil map at scale 1:250,000; semi-detailed maps at scale 1:20,000). FAO/SF: 67/NIR 3. Rome, Italy.

FAO. 1969b. *Report to the Government of Sierra Leone : Problems related to Land Use.* FAO, Rome, Italy.

FAO. 1971. *The Evaluation of Soil Resources in West Africa.* World Soil Resources Report 40. FAO, Rome, Italy.

FAO. 1981. *Fourth Meeting of the West African Sub-Committee for Soil Correlation and Land Evaluation, Banjul, The Gambia.* World Soil Resources Report 53, FAO, Rome, Italy.

Fanfant, R. 1970. *Report to the Government of Liberia on Soil Survey.* FAO, TA/2845, Rome, Italy.

Fressons, S. 1978. *Public Participtation on Village-Level Irrigation Perimeters in the Matam Region of Senegal.* Occ. Papers 4. OECD.

Gigou, J. 1972. Régularité des précipitations et cycles culturaux en Côte d'Ivoire. (Première esquisse). Séminaire international sur les perspectives pour l'irrigation en Afrique de l'Ouest. Univ. d'Ibadan, Nigeria.

Gigou, J., and P.F. Chabalier. 1987. L'utilisation de l'engrais azoté par les cultures annuelles en Côte d'Ivoire. *Agron. Trop.* 42(3): 171-179.

Haas, A.W. 1974. *Diffusion of Innovations in Sierra Leone, W. Africa.* First report of the introduction and diffusion of a new rice-farming method among Koranko farmers in Alikalia, Koinadugu District. A study of human communication. Inst. of Cult. and Soc. Stud., Leyden State Univ., The Netherlands.

Hawkins, P., and M. Brunt. 1965. *The Soils and Ecology of West Cameroon.* Report to the Government of Cameroon. (Map scale 1:200,000). Report 2083. FAO/PTA, Rome, Italy.

Howard Humphries and Sons. 1975. *Project Sucrier, Etude de pré investissement.* Guinea.

IRAT, 1981. Rice Research in the ACP Countries. *The Courier* 66, (March/April): 65-68.

ITC. 1977. *Project de développement rural intégré de la région du Kaarta, République du Mali.* Enschede, The Netherlands.

Jordan, H.D. 1964. The Relation of Vegetation and Soil to Development of Mangrove Swamps for Rice Growing in Sierra Leone. West African Rice Research Station, Rokupr, Sierra Leone. *J. of Appl. Ecol.* 1: 209-212.

Jungerius, P.D. 1964. The Soils of Eastern Nigeria. (Map scale 1:1,000,000). *Publ. Serv. Géol. du Luxembourg* XIV: 185-198.

Kang, V.T., and A.S.R. Juo. 1981. Management of Low Activity Clay Soils in Tropical Africa for Food Crop Production. Paper presented at the Fourth Int. Soil Class. Workshop, Kingali, Rwanda.

Kassam, 1976. *Crops of the West African Semi-Arid Tropics.* ICRISAT, Hyderabad, India.

Klinkenberg, K., and P.N. de Leeuw. 1967. *The Soils of the Lau-Kaltungo Area, Nigeria.* (Map scale 1:100,000). Soil Sur. Bull. 36, Zaria, Nigeria.

Kortenhorst, L.F. 1980. *Factors Affecting the Viability of Smallholders' Irrigation.* ILRI, Wageningen, The Netherlands.

Kosaki, T., and A.S.R. Juo. 1982. *Selected Profile Data of Hydromorphic Soils from Central and Southeastern Niger.* IITA, Farming Systems Program, Mimeograph, Ibadan, Nigeria.

Lamouroux, M. 1969. *La carte pédologique du Togo à 1:1.000.000.* Not. Expl. 34. ORSTOM, Paris, France.

Lawson, T.L., A.S.R. Juo, and P. Ay. 1982. *Methodology for Farming System Research : Environmental Description and Resource Evaluation.* IITA, Ibadan, Nigeria.

Lévèque, A. 1969. Les principaux événements géomorphologiques et les sols sur le socle gneissique au Togo. *Cah. ORSTOM, Série Géol.* 8(2): 203-223.

Lévèque, A. 1979. *Pédogénèse sur le socle granito-gneisique du Togo.* Trav. et Doc. 108. ORSTOM, Paris, France.

Maiga, I.D. 1979. Organization paysanne et gestion de périmètre. Le riz en Afrique de l'Ouest, perspectives de l'autosuffisance. In: *Séminaire sur la gestion de l'eau, sept. 1979.* WARDA, Monrovia, Liberia.

Maignien, R. 1953. Etudes pédologiques en Guinée Française. *Ann. Inst. des Fruits et Agrumes Col.* 5: 1-48.

Maignien, R. 1956. *Le cuirassement des sols en Guinée.* ORSTOM, Dakar, Sénégal.

Maignien, R. 1965. *La carte pédologique du Sénégal au 1:1,000,000.* Not. Expl. ORSTOM, Paris, France.

Martin, D. 1967. Géomorphologie et sols ferralitique dans le centre Cameroun. *Cah. ORSTOM, Série Pédol.* V(2): 189-218.

Martin, D., and P. Segalen. 1966. *La carte pédologique du Cameroun oriental au 1:1,000,000.* Not. Expl. ORSTOM, Paris, France.

May-Parkers, I. 1974. Problems of Rice Marketing in Sierra Leone. *The Sierra Leone Agri. J.* 3(1).

Milette, G., and J. Vieillefon. 1965. Les sols de la région maritime et de la région des savanes. (Map scale 1:50,000). In: *Etudes pédohydrologiques au Togo.* FAO/SF: 13/50, Vol. II. Rome, Italy.

Moormann, F.R., R. Lal, and A.S.R. Juo. 1975. *The Soils of IITA, Ibadan.* Techn. Bull. 3. IITA, Ibadan, Nigeria.

Morgan W.B., and J.C. Pugh. 1969. *West Africa.* Methuen and Co., London, England.

Mourik, D. van. 1979. *Land in Western Liberia : A Reconnaissance Agricultural Land Evaluation of the Mano River Union Project Area.* (Land system map at scale 1:500,000). Mano River Union Project, Freetown, Sierra Leone.

Nelson, N. 1981. African Women in the Development Process. *J. Dev. Stud.* 17(3): 152.

Okusami, T.A. 1981. *Land and Pedogenetic Characterization of Selected Wetlands in West Africa with Emphasis for Rice Production.* Thesis, Univ. of Minesota, United States.

Okusami, T.A., R.H. Rust, and A.S.R. Juo. 1982. *Properties, Genesis, and Classification of Selected Alluvial Soils in the Niger-Benue Trough, Central Nigeria.* IITA, Mimeographs, Ibadan, Nigeria.

ORSTOM. 1970-78. *Notices explicatives des cartes pédologiques de reconnaissance de la République Populaire du Bénin.* Not. Expl. 66(1-9). Paris, France.

ORSTOM. 1974-76. *Notices explicatives des cartes pédologiques de reconnaissance du Cameroun.* (Map scale 1:200,000; no complete coverage of country). Not. Expl. 51, 53, 62. Paris, France.

Perraud, A. 1971. Les sols. In: *Le milieu naturel de la Côte d'Ivoire*. pp. 265-392. Mém. 50. ORSTOM, Paris, France.

Poss, R. 1982. *Etude morpho-pédologique de la région de Katiola, Côte d'Ivoire.* (Map scale 1:200,000). Not. Expl. 94, ORSTOM, Paris, France.

Pullan, R.A. 1969. The Soil Resources of West Africa. In: *Environment and Land Use in Africa.* pp. 147-191. M.F. Thomas and G.W. Whittington (Eds.). Methuen & Co. Ltd., London, England.

Reed, W.E. 1951. *Reconnaissance Soil Survey of Liberia.* (Map scale 1:3,300,000). Agric. Inf. Bull. 66, USDA, Washington, D.C.

Roose, E., and M. Chéreux. 1966. Les sols du bassin sédimentaire de Côte d'Ivoire. *Cah. ORSTOM, Série Pédol.* IV(2): 51-92.

Segalen, P. 1967. Les sols et la géomorphologie du Cameroun. *Cah. ORSTOM, Série Pédol.* V(2): 137-188.

Sivakumar, M.V.K., and F. Gnoumou. 1987. *Agroclimatology of West Africa : Burkina Faso.* Information Bulletin 23. ICRISAT, India.

Sivakumar, M.V.K., M. Konate, and S.M. Virmani. 1984. *Agroclimatology of West Africa : Mali.* Information Bulletin 19. ICRISAT, India.

Sivarajasingham, S. 1968. *Soil and Land Use Survey in the Eastern Province, Sierra Leone.* (Map scale 1:200,000). FAO TA 2684, Rome, Italy.

Smith, G.K. 1962. *Report on Soil and Agricultural Survey of Sene-Obosum River Basins, Ghana.* (Map scale 1:800,000). USAID, Washington, D.C., USA.

Smyth, A.J., and R.F. Montgomery. 1962. *Soils and Land Use in Central Western Nigeria.* (Map scale 1:250,000). Min. of Agric. and Nat. Res., Ibadan, Nigeria.

Somasiri, S., R.L. Tinsley, C.R. Panabokke, and F.R. Moormann. 1978. Evaluation of Rice Lands in Mid-Country Kandi District, Sri Lanka. In: *Soil Resource Inventory and Development Planning.* pp. 97-122. Proc. on a Workshop held at Cornell University, USA.

Sombroek, W.G., and I.S. Zonneveld. 1971. *Ancient Dune Fields and Fluvial Deposits in the Rima-Sokoto River Basin (N.W. Nigeria).* Soil Survey Paper 5, STIBOKA, Wageningen, The Netherlands.

Sow, N.A. 1981. *Range Inventory and Evaluation for Domestic Livestock and Wildlife : Case-study in Mali, around Dyoumara (Kaarta).* ITC, Enschede, The Netherlands.

Stern, R.O., M.D. Dennett, and D.J. Garbutt. 1981. The Starts of the Rains in West Africa. *J. of Climat.* 1: 59-68.

Sutcliffe, J.V., and B.S. Piper. 1986. Water Balance in Guinea and Togo-Benin. *Hydrol. Contin.* 1(1): 51-61.

Teissier, J. 1974. Terroir de Mogtélo (Haute-Volta). Etude morpho-pédologique en vue de la mise en valeur des terres. *Agron. Trop.* 29(2-3): 312-363.

Thomas, M.F. 1974. *Tropical Geomorphology : A Study of Weathering and Land Form Development in Warm Climates.* MacMillan Press, London, England.

USAID & FAC. 1978. *Resource Inventory of North Cameroon.* (Land system map at scale 1:1,000,000). Washington, D.C.

Vallerie, M. 1971. *La carte pédologique du Cameroun occidental au 1:1,000,000.* Not. Expl. 29, ORSTOM, Paris, France.

Vallee, G., and H.H. Vuong. 1978. Floating Rice in Mali. In: *Rice in Africa.* pp. 243-248. I.W. Buddenhagen and G.J. Persley (Eds.). Acad. Press, New York, San Francisco, London.

Valtleon, A.P. 1979. *Evaluation of a Rice Farming Project in Alikalia, Sierra Leone, W. Africa.* Research Report, Inst. of Cult. and Soc. Stud., Leyden State Univ., The Netherlands.

Veldkamp, W.J. 1980. *Soil Survey and Land Evaluation in the Mano River Union Area, E. Sierra Leone and W. Liberia.* (Various small-scale maps). Mano River Union Project, Freetown, Sierra Leone.

Vernon, R.D., and L. Barry. 1979. *Essays on the Economic Anthropology of Liberia and Sierra Leone.* Philadelphia Inst. for Liberian Stud., USA.

Volkhoff, B., and P. Willaime. 1963. *La carte des sols de la République du Dahomey.* (Map scale 1:1,000,000). Not. Expl., ORSTOM, Paris, France.

Vuure, W. van, and R. Miedema. 1973. *Soil Survey of the Makeni Area, Northern Province, Sierra Leone.* (Semidetailed soil association maps at scales 1:50,000, 1:25,000 and 1:5,000). Njala Univ. Coll., Sierra Leone.

Wade, R. 1979. The Social Response to Irrigation : An Indian Case Study. *J. Dev. Stud.* 16(1): 3-26.

WARDA. 1981. Rice Development in West Africa. *The Courier* 66, (March/April): 70-72.

WARDA/ADRAO. 1979. *La politique rizicole en Sierra Leone.* ADRAO/SD/79/8 Rice Development Strategies, WARDA, Monrovia, Liberia.

Weintraub, L. 1973. Introducing Agricultural Change : The Inland Valley Swamp Rice Scheme in Sierra Leone. Unpublished thesis Univ. of Wincosin, Madison, U.S.A.

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Westphal, E. 1981. *l'Agriculture autochtone au Cameroun. Les techniques culturales, les séquences de culture, les plantes alimentaires et leur consommation.* Misc. Papers 20, Agri. Univ. Wageningen. Veenman & Zonen, Wageningen, The Netherlands.

Whittaker, V.A. 1971. *The Economics of Mechanical Cultivation of Rice Lands in Sierra Leone.* Univ. Microfilm Int., Ann Arbor, Michigan, U.S.A.

Winch, F.E., and C.D. Kivunja. 1978. Relative Importance of Rice in Tropical Africa and the Need to Increase the Farm Level Economic Data Base. In: *Rice in Africa.* pp. 75-98. I.W. Buddenhagen and G.J. Persley (Eds.), Acad. Press, London, Engeland.

Yoshida, S.M. 1981. *Fundamentals of Rice Crop Science.* IRRI, Los Baños, The Philippines.