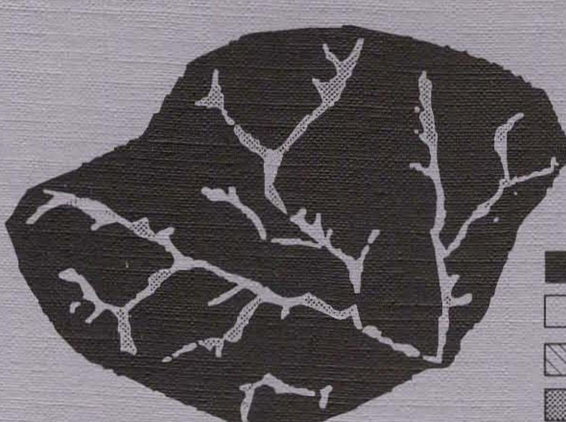
Inland Valley Characterization Report 1

Regional Characterization of Inland Valley Agroecosystems in Save, Bante, Bassila, and Parakou Regions in South central Republic of Benin

through Integration of Remote Sensing Global Positioning System, and Ground-Truth Data in a Geographic Information Systems Framework

Prasad S. Thenkabail and Christian Nolte



Inland valley watershed system highlighting the valley bottoms

- *Uplands*
- *Intensely cultivated valley bottoms*
- *Moderately cultivated valley bottoms*
- *Uncultivated valley bottoms*

International Institute of Tropical Agriculture
with Inland Valley Consortium

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Preface

The inland valley characterization report series of the Resource and Crop Management Division (RCMD) is intended for the wide dissemination of results of research about the inland valley agroecosystems of sub-Saharan Africa. These research reports will address issues relating to characterization and diagnosis concerning inland valley agroecosystems. The range of subject matter is expected to contribute to existing knowledge on improved agricultural principles, practices, and policies that affect the sustainable development of these potentially rich and productive agroecosystems of sub-Saharan Africa. These reports summarize results of studies by IITA researchers and their collaborators; they are generally more substantial in content than journal articles.

The research report series is aimed at scientists and researchers within the national agricultural research systems of Africa, the international research community, policy makers, donors, and international development agencies.

Individuals and institutions in Africa may receive single copies free of charge by writing to:

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I

Introduction and Background

The International Institute of Tropical Agriculture is currently conducting a characterization of inland valley agroecosystems in West and Central Africa (Izac et al. 1991). A macro-(subcontinental) scale stratification (level I) of West and Central Africa led to a map of 18 agroecological and soil zones. Each of these zones represents an area of more than 10 million ha (figure 1 and table 1). Overall, about 36 million ha spread across 11 countries of West and Central Africa are targeted for level II characterization. This will be mesoscaled (regional, semidetailed). For this purpose, 11 Landsat Thematic Mapper (TM) and 5 *Le système pour l'observation de la terre* (SPOT) high resolution visible (HRV) data bases were acquired in sample areas of level I (figure 1). Each satellite scene over a particular area will be referred to as a study area. Each study area covers one or more of IITA's level I agroecological and soil zones (figure 1 and table 1).

The objectives of level II (regional) characterization include inventorying and mapping inland valley bottoms; determining land use and land cover of inland valleys and their uplands; determining the cultivation intensities relative to settlements and the road network; mapping the spatial distribution of inland valley systems; testing hypotheses, such as relationships between upland/inland valley cultivation patterns, and cultivation patterns within and across agroecological zones; and determining the location of potential benchmark research sites for technology development activities.

The level II characteristics are reported with respect to subcontinental (level I) agroecological and soil zones and also with respect to the land regions of the wetland utilization research project in West Africa (Windmeijer and Andriesse 1993). The location of satellite images on the WURP map is shown in figure 2 (see also table 2). Results will be reported for two compartments of the toposequence of inland valleys (bottom and fringe) as defined in this study (see figure 3) as well as for surrounding uplands.

Readers of this inland valley agroecosystem report are referred to Thenkabail and Nolte (1995) for the background, definitions, rationale, objectives, approach, and methodology of level II characterization which remain consistent across the study areas. A brief overview of this methodology is described below:

1. The valley bottoms were delineated using image enhancement, display, and digitizing techniques.
2. The valley fringes were mapped by delineating the areas immediately adjoining valley bottoms, by using a search radius on either side of valley bottoms equivalent to the mean fringe width measured during the ground-truthing.
3. Land-use/land-cover studies were carried out separately for valley bottoms, valley fringes, and uplands using unsupervised classification of multiband data.
4. Several other characteristics, such as the percentage area of inland valleys cultivated at varying distances from roads and settlements, have been extracted through spatial data manipulation (e.g., boolean logic interpolation and contiguity analysis) of GIS datalayers.
5. A methodology for key site/key watershed selection was developed, based on expert knowledge and GIS modeling of various spatial datalayers.
6. Ground-truth data, GPS data, and other data sources were incorporated into digital image analysis.

Analyses were conducted using Earth Resources Digital Analysis System (ERDAS 1991).

Table 1 Parameters describing the level I agroecological and soil zones

Level I AEZ[a]	agroecological zone according to IITA's definition	LGP[b] (days)	major FAO soil grouping[c]	Area[d] (million ha)
1	Northern Guinea savanna	151–180	Luvisols	25.2
2	Southern Guinea savanna	181–210	Luvisols	18.4
3	Southern Guinea savanna	181–210	Acrisols	12.4
4	Southern Guinea savanna	181–210	Ferralsols	11.9
5	Southern Guinea savanna	181–210	Lithosols	10.7
6	Derived savanna	211–270	Ferralsols	47.2
7	Derived savanna	211–270	Luvisols	24.9
8	Derived savanna	211–270	Nitosols	14.2
9	Derived savanna	211–270	Arenosols	14.0
10	Derived savanna	211–270	Acrisols	11.7
11	Derived savanna	211–270	Lithosols	10.8
12	Humid forest	> 270	Ferralsols	150.1
13	Humid forest	> 270	Nitosols	27.2
14	Humid forest	> 270	Gleysols	19.2
15	Humid forest	> 270	Arenosols	18.9
16	Humid forest	> 270	Acrisols	18.0
17	Midaltitude savanna[e]		Ferralsols	45.4
18	Midaltitude savanna[f]		Nitosols	12.3

Notes:

a. AEZ: level I agroecological and soil zones

b. LGP: length of growing period

c. Names refer to the soil classification scheme of FAO/UNESCO (1974)

d. The area figures are for West and Central Africa and were determined using the AREA procedure of IDRISI (Eastman 1992)

e. Area distribution of LGP in AEZ 17 is: 151–180 days 11%; 181–210 days 9%; 211–270 days 59%; > 270 days 21%

f. Area distribution of LGP in AEZ 18 is: 151–180 days 2%; 181–210 days 5%; 211–270 days 53%; > 270 days 40%

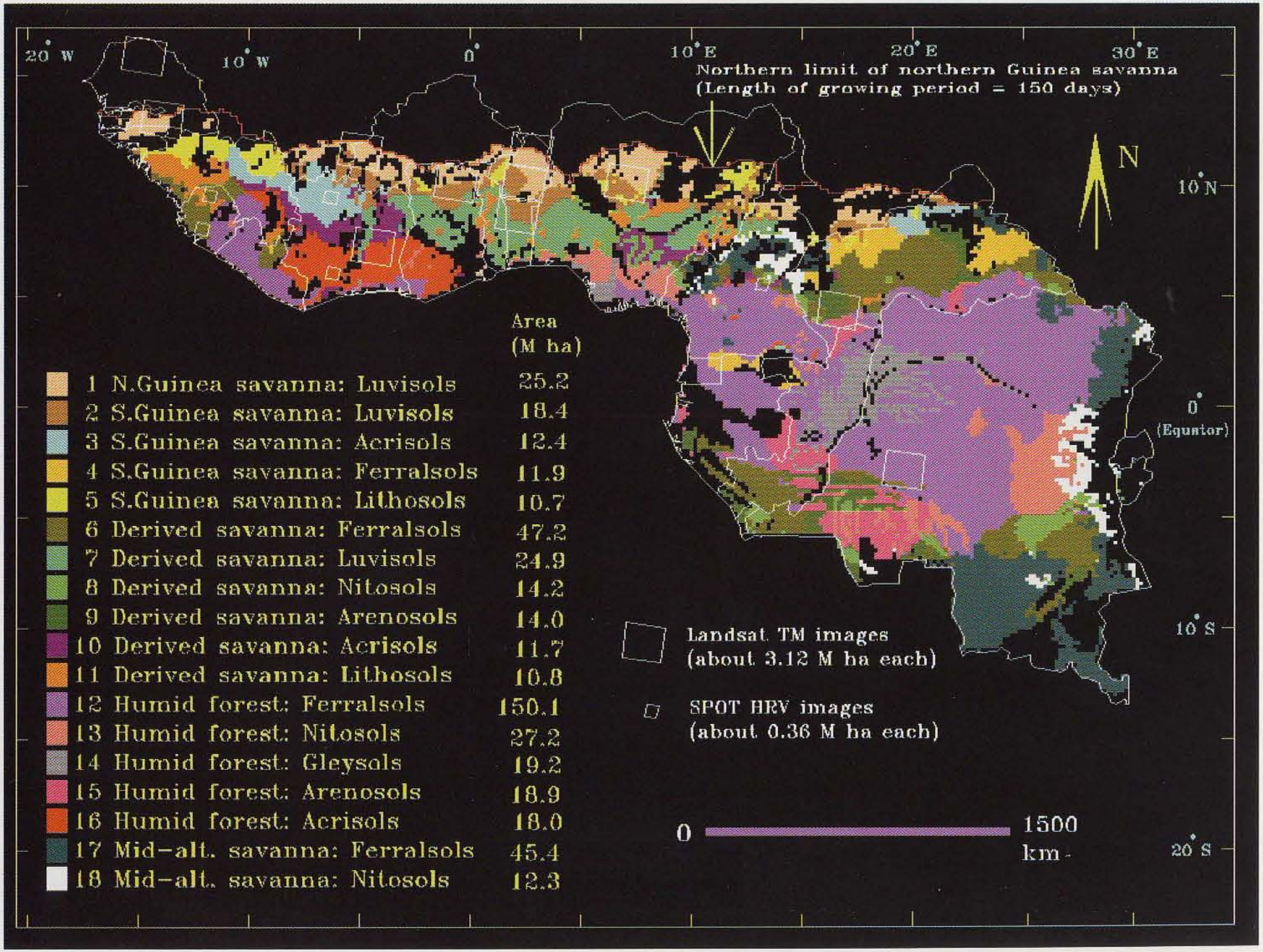

Figure 1. Landsat TM and SPOT HRV acquisitions for level II characterization of inland valley agroecosystems located in the level I map of agroecological and soil zones in West and Central Africa

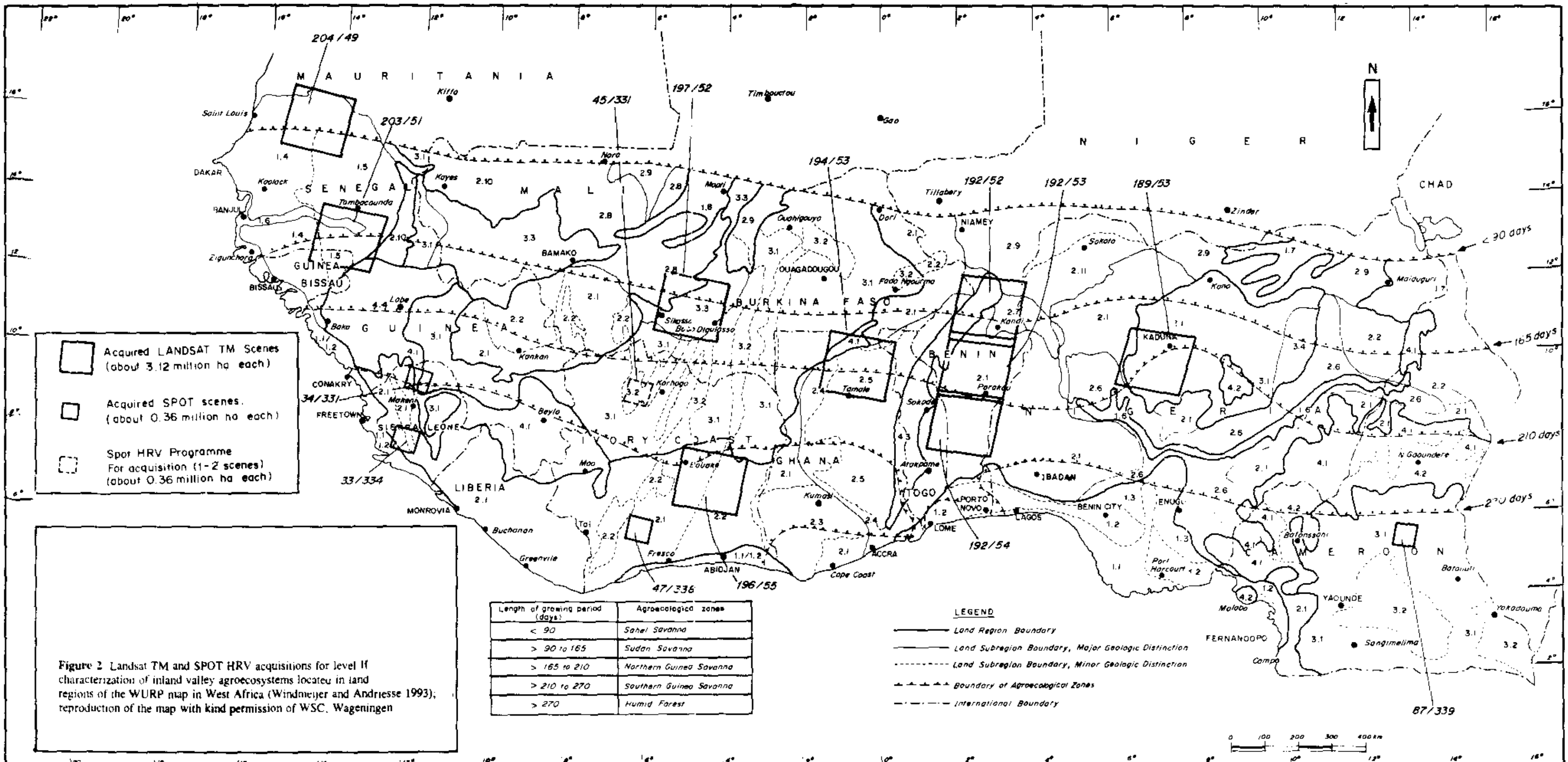

Figure 2 Landsat TM and SPOT HRV acquisitions for level II characterization of inland valley agroecosystems locateu in land regions of the WURP map in West Africa (Windmeijer and Andriesse 1993); reproduction of the map with kind permission of WSC, Wageningen

Figure 2 Landsat TM and SPOT HRV acquisitions for level II characterization of inland valley agroecosystems located in land regions of the WURP map in West Africa (Windmeijer and Andriesse 1993); reproduction of the map with kind permission of WSC, Wageningen

Table 2 Legend to the land-regions map of the WURP report - see figure 2 (adapted from Windmeijer and Andriesse 1993)

Map Unit	Geology	Geomorphology	Area (mha)*
1.	Land region : COASTAL AND ALLUVIAL PLAINS		
	recent coastal sands + alluvial silts and clays	nearly level to gently undulating	39.7
2.	Land region : INTERIOR PLAINS		
2.1	basement complex – lower Pre-cambrian: granites, migmatites, gneisses	slightly dissected, with inselbergs, mesas	
2.2	basement complex – middle Pre-cambrian: metamorphic rocks	slightly dissected, with inselbergs, mesas	85.2
2.3	basement complex – upper Pre-cambrian; and sedimentary and volcanic rocks	highly dissected, rolling to steep	
2.4	sediments – Paleozoic : sandstone	dissected and upwarded, gently rolling	
2.5	sediments – Paleozoic : sandstone, shale, mudstone	slightly dissected, nearly level	
2.6	sediments – Mesozoic : sandstone, shale	slightly dissected, level to gently rolling	
2.7	sediments – Pesozoic : sandstone, conglomerate	steeply dissected, undulating	66.3
2.8	sediments – Paleozoic : sandstone, tillite	slightly dissected, nearly level	
2.9	sediments – Tertiary : sandstone, mudstone, conglomerate	slightly dissected, level to gently rolling	
2.10	sediments – Paleozoic : schist, quartzite, sandstone	slightly dissected, with doloritic hills, and mesas	
2.11	sediments – complex of Tertiary, Mesozoic, Paleozoic	dissected, with mesas	
3.	Land region : PLATEAUX		
3.1	basement complex – lower Pre-cambrian: granites, migmatites, gneisses	slightly dissected, with inselbergs, mesas	74.5
3.2	basement complex – middle Pre-cambrian: metamorphic rocks	slightly dissected, with inselbergs, mesas	
3.3	sediments – Paleozoic sandstone	dissected, level to gently rolling	13.1
3.4	sediments – Tertiary sandstone	dissected, undulating to rolling	
4.	Land region : HIGHLANDS		
4.1	basement complex – lower Pre-cambrian : undifferentiated granites, migmatites	very steep mountain ranges	
4.2	basement complex of older (Pre-cambrian) + younger (Jurassic) rocks	rugged, rolling high plateaux	27.2
4.3	basement complex – middle + terminal Pre-cambrian; and sedimentary / extrusive formations	strongly faulted	
4.4	sediments – Paleozoic : sandstone, shale	steeply dissected	7.7

Note: Area figures are in million ha; for details refer to Windmeijer and Andriesse (1993) and Hekstra et al. (1983)

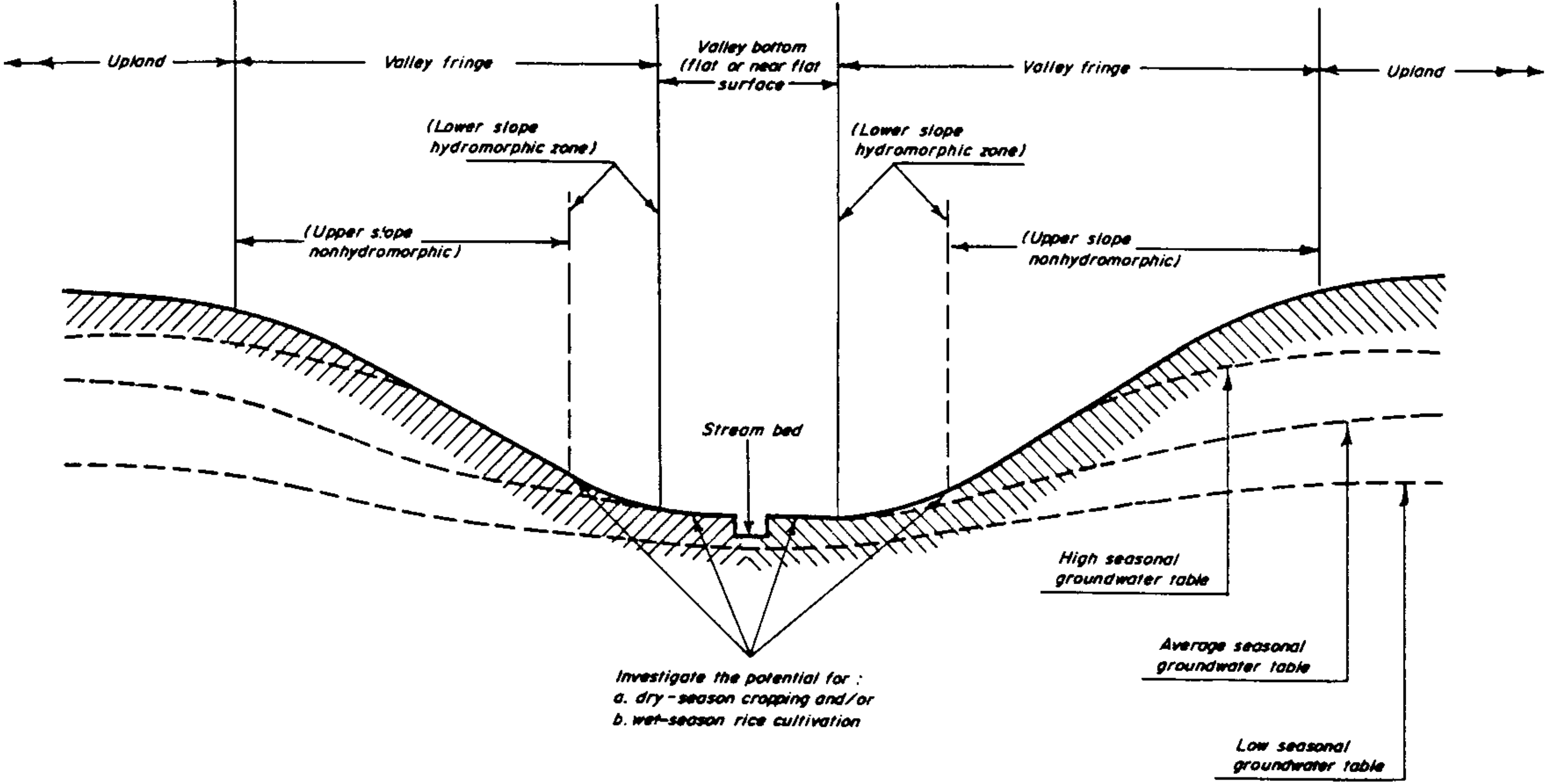

Figure 3 Cross-section showing a model inland valley as defined in this study

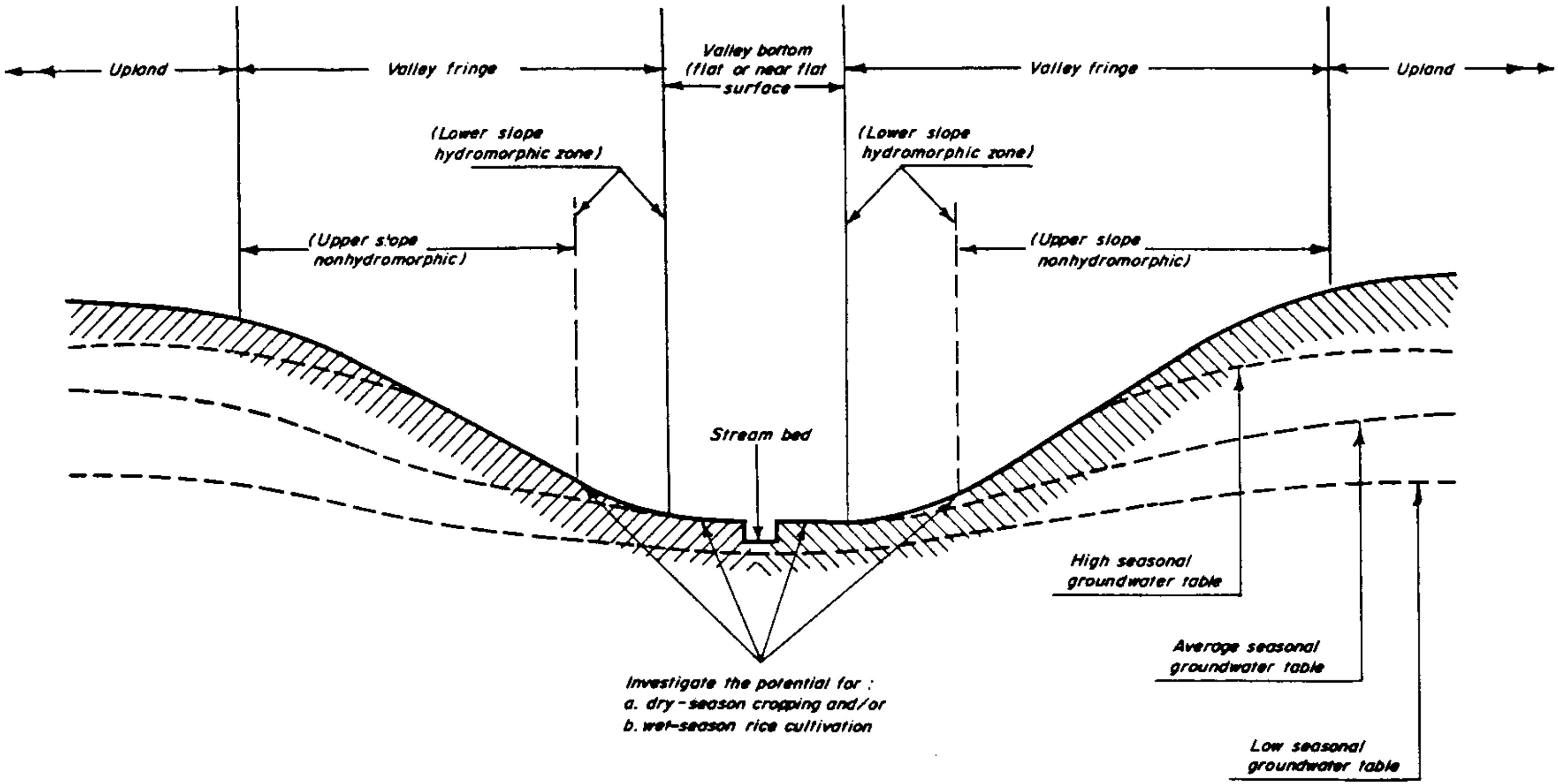

Figure 3 Cross-section showing a model inland valley as defined in this study

II

Study Area and Satellite Data Characteristics

This report is for the area covered by Landsat-5 TM data of path:192, row:54 of Landsat's world reference system. The study area is located in south-central Republic of Benin and covers 3.12 million ha of land. Major settlements in the study area are Save, Bante, Bassila, Parakou, and Tchaourou. Portions of the scene also fall into Togo and Nigeria. See figure 4 for the location of the study area and the ground-truth sites.

The study area covers two level I agroecological and soil zones (AEZ) (figure 5 and figure 1): AEZ 2 (southern Guinea savanna with Luvisols) and AEZ 7 (derived savanna with Luvisols). Characteristics of these zones are given in table 1. AEZ 2 occupies 49% and AEZ 7 46% of the study area (table 3). The two agroecological and soil zones differ only in terms of their length of growing period, which is 181–210 days for AEZ 2 and 211–270 days for AEZ 7. The major soil grouping throughout the study area is Luvisols according to the old FAO soil classification system (FAO/UNESCO 1974). The level II characteristics are reported with respect to these level I agroecological and soil zones of IITA and land regions of the WURP map. The entire study area falls within the WURP land region 2.1. Hence, the results of the entire study area can be taken as results for WURP land region 2.1. The characteristics of land region 2.1 are described in table 2.

According to the United Nations Environmental Program Global Resources Information Database (UNEP/GRID) all three agroecological zones have equal population densities (mean of 23 inhabitants/km^2). However, the estimates of population densities in the wetland utilization research project (WURP) report (Hekstra et al.1983; see figure 6) differ considerably from those of UNEP/GRID. Due to such variations in regional population estimates, it was considered more appropriate in this study to use settlement sizes mapped directly using high-resolution satellite imagery as a substitute for population data.

2.1 Physical characteristics of the study area

Geology. The study area is part of the Interior Plains region (figure 2 and table 2) which covers 61.7 million ha of land in West Africa (Hekstra et al. 1983). Uniform parent material underlaying the entire area is the Basement Complex with undulating relief. Raunet (1977) describes the summits of the uplands in this area as largely convex which are connected with inland valleys through long (convex) fringes with slopes varying between 2 and 5%. The difference in altitude between crests and valley bottoms is in the order of 20–40 m. Dubroeucq (1977) studied soils in the Benin territory between the 8th and 9th parallel (the region in which the major portion of this study area falls; see figure 2) at a scale of 1:200,000, and distinguishes three entities of particular relief:

1. A high peneplain which occurs northwest of the Bassila region, with exception of the river Ouémé trough; average altitude is 320 m; slopes are convex with differences in altitude of about 40 m; the hydrographic network is loose with orthogonal pattern;
2. A low peneplain which occurs southeast of the Save region; average altitude is 180 m; the relief is flat with almost unnoticeable short slopes; the hydrographic network is very dense and of dendritic pattern;

Table 3 Areas of level I agroecological and soil zones covered by Landsat TM path:192, row:54

Macroscale zones[a]	Area (ha)	Entire study area[b] %
AEZ 2	1,534,955	49
AEZ 7	1,440,193	46
Outside level I zone	153,229	5
Entire study area (full scene of TM)	3,128,377	100
Land region 2.1[c]	3,128,377	100

Notes:

a. AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the derived savanna with Luvisols; AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones

b. The percentages are rounded-off to the nearest integer

c. The entire study area falls into land region 2.1 (see figure 2)

3. A peneplain which occurs southwest and northeast around the Bante and Tchaourou regions; average altitude is 250 m; the relief is dissected, the peneplain changes into more and more flat depressions constituting the principal drainage ways of the rivers Zou, Otio, Beffa, Agbado; the hydrographic network is very hierarchical and of herringbone pattern.

The Basement Complex of Precambrian age in the study area consists of three principal rocks according to BRGM (1960): granites, migmatites, and gneisses of which granites and migmatites are most widespread (figure 7). Soils developed on these rocks are generally coarse textured with a relatively high content of gravels.

Soils. According to IITA's level I map, the soils on the uplands in the study area belong to the major FAO soil grouping of Luvisols (table 1). Figure 8 illustrates that 10 different map units according to FAO/UNESCO (1977) occur in the study area. Map units 1, 5, 6, and 7 dominate. Table 4 gives the distribution of soil units in each map unit according to the composition rules developed by FAO (1978). They allocate ≥ 20% of a map unit area to associated soils and ≤ 20% to soil inclusions. Thereby, the distribution of soil units in the study area, based on area measurements per map unit (figure 8), would be as follows:

Luvisols = 77%, of which 65% are Ferric Luvisols and 26% are Plinthic Luvisols
Nitosols = 8%
Lithosols = 10%
Others (Cambisols, Vertisols, and Planosols) = 5%

Luvisols are equal to *sols ferrugineux tropicaux lessivés* in the French classification system (Landon 1991). Dubroeucq (1977) gives data for different soil types in the Benin territory between the 8th and 9th parallel, the major part of the study area:

Table 4 Distribution of soil units in the study area (according to FAO/UNESCO 1977)[a]

Map unit	FAO-symbol	Extension in study area (ha)	Dominant soil	%[b]	Assoc. soils	%	Inclusions	%
1	Lf 32–a	500,540	Lf	90			I	10
2	Vc 8	62,568	Vc	70	Vp	30		
3	Ne–1a	31,283	Ne	100				
4	I-Lf–Rd	62,568	I-Lf–Rd	100				
5	Lf 25	500,540	Lf	50	Nd	30	Lp Be	10 10
6	Lp 3–a	250,270	Lp	60	Lf	30	Ne	10
7	Lf 26–a	1,407,770	Lf	50	Lp	30	I Lg	10 10
8	Lf 25	125,135	Lf	50	Nd	30	Lp Be	10 10
9	Lg 23–a	125,135	Lg	50	Lf We	20 20	Ws	10
10	I-Lf–Re	62,568	I–Lf–Re	100				

Notes:

a. Names of soil units according to FAO (1974); abbreviations:

B = Cambisol	R = Regosol	d = distric	g = gleyic
I = Lithosol	V = Vertisol	e = eutric	p = plinthic
L = Luvisol	W = Planosol	f = ferric	s = solodic
N = Nitosol			

b. Percentages according to the composition rules of FAO (1978)

a. *sols ferrugineux très lessivés ou appouvris* (very leached or impoverished ferruginous soils); principal soil characteristics related to their water regime are:

- sandy texture
- moderate field capacity
- rooting zone 1–2 m
- good drainage

b. *sols ferrugineux très lessivés, concrétionnés* (very leached and gravelly ferruginous soils); principal soil characteristics of their water regime are:

- sandy-clayey texture with gravels
- low field capacity
- rooting zone 1.5–2 m
- moderate drainage

c. *sols ferrugineux très concrétionnés ou indurés* (ferruginous soils with high amount of gravels that may form hardpans); principal soil characteristics of their water regime are:

- clayey-sandy texture with high amount of gravels
- low field capacity
- rooting zone 1–3 m
- average drainage

d. *sols ferrugineux lessivés peu concrétionnés* (leached ferruginous soils with low amount of gravels); principal soil characteristics of their water regime are:

- clayey-sandy texture
- average field capacity
- rooting zone 3 m
- average drainage

e. *sols ferrallitiques et ferrugineux profonds de plateaux* (deep ferrallitic and ferruginous soils of the uplands); principal characteristics of their water regime are:

- clayey-sandy texture
- average field capacity
- rooting zone > 4 m
- good drainage

Vegetation. The natural vegetation in this area is part of the dry continental zone according to FAO/UNEP (1980). The major part of the study area is covered with tree and shrub savanna (defined as having 2–20% woody cover) and savanna woodland (defined as having 20–50% woody cover). The dominant species are *Angoeissus leiocarpus, Butyrospernum paradoxum, Daniella oliveri, Isoberlinia doka,* and *Parkia biglosa.* Croplands and fallows dominate along major road networks and major settlements (Dassa-Zoumé, Save, Parakou, Djougou). Vegetation densities amongst different agroecological and soil zones were only slightly different (see mean values in table 5).

Farming systems. With respect to ground-truth observations outlined in section 3, it is of interest to give a broad overview of farming systems occurring in the study area. The following remarks are results of the study of Manyong et al. (in preparation). Four cropping systems, differing in terms of major crops grown, prevail on the uplands of the study area (figure 9):

a. yam/maize-based system in the northwestern part;
b. yam/sorghum-based system in the northeastern part;
c. maize/yam-based system in the southern part; and
d. maize/cassava-based system towards the southeast which has previously been intensively cropped with cotton.

These systems are currently undergoing rapid modifications because of changing driving factors, such as population density, infrastructure, and market conditions. Manyong et al. (in preparation) classified the agricultural systems in the study area as being population-driven (figure 10) because of poor infrastructure and access to markets. Agricultural systems in the major part of the study area are in the "population-driven expansion phase". One characteristic of this phase is the cultivation of new land, while a long fallow period on cultivated land is still practiced (Manyong et al. in preparation). For example, in the region with agricultural systems in the population-driven expansion phase (figure 10), where the maize/yam-based cropping system dominates (number 6 in figure 9), the mean cultivation period per piece of land was 3 years with an 8-year fallow period.

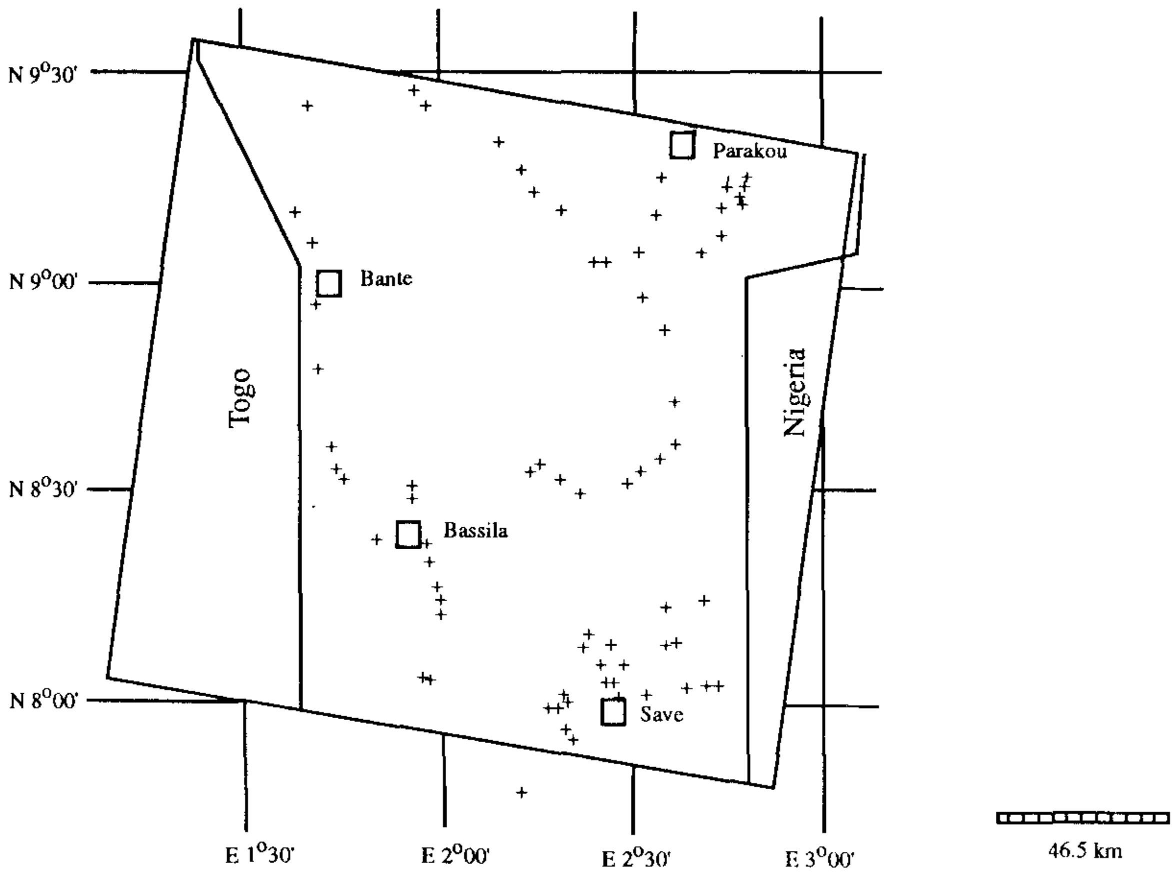

Figure 4 Location of the study area and the ground-truth sites

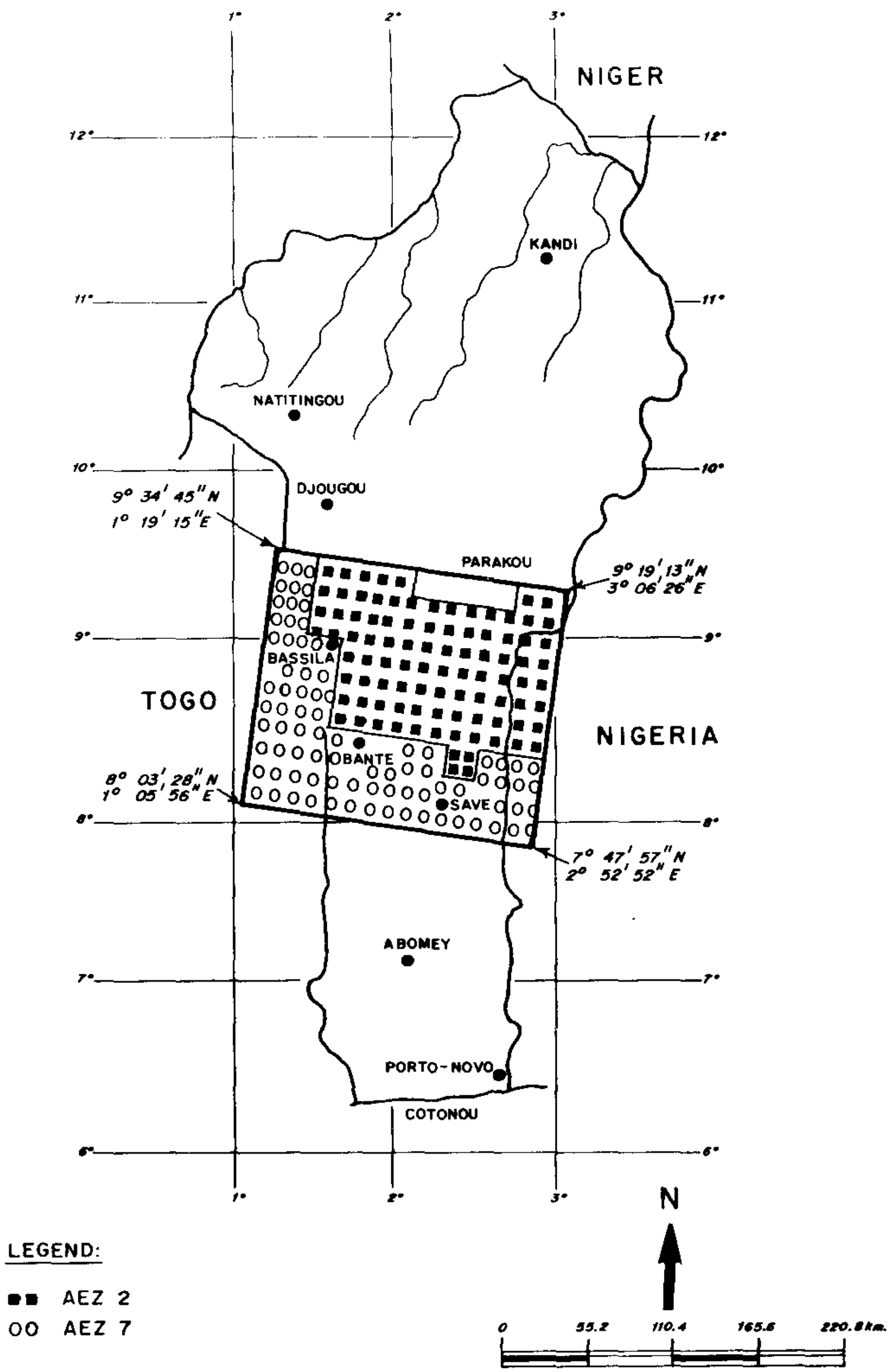

Figure 5 Spatial distribution of the level I agroecological and soil zones in this study area; the total study area covers about 3.2 million ha of which 49% fall into AEZ 2 and 46% into AEZ 7

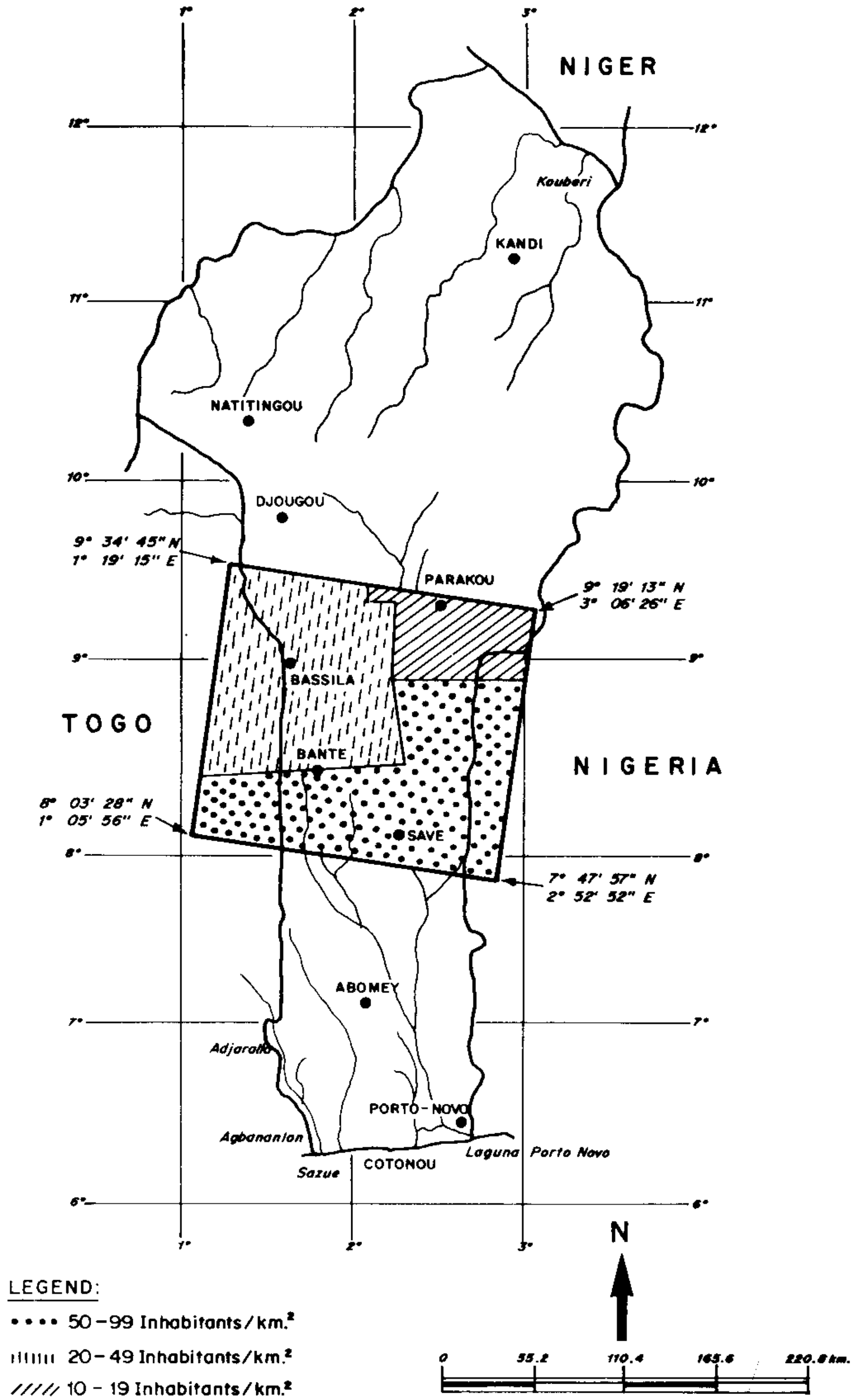

Figure 6 Population density in the study area

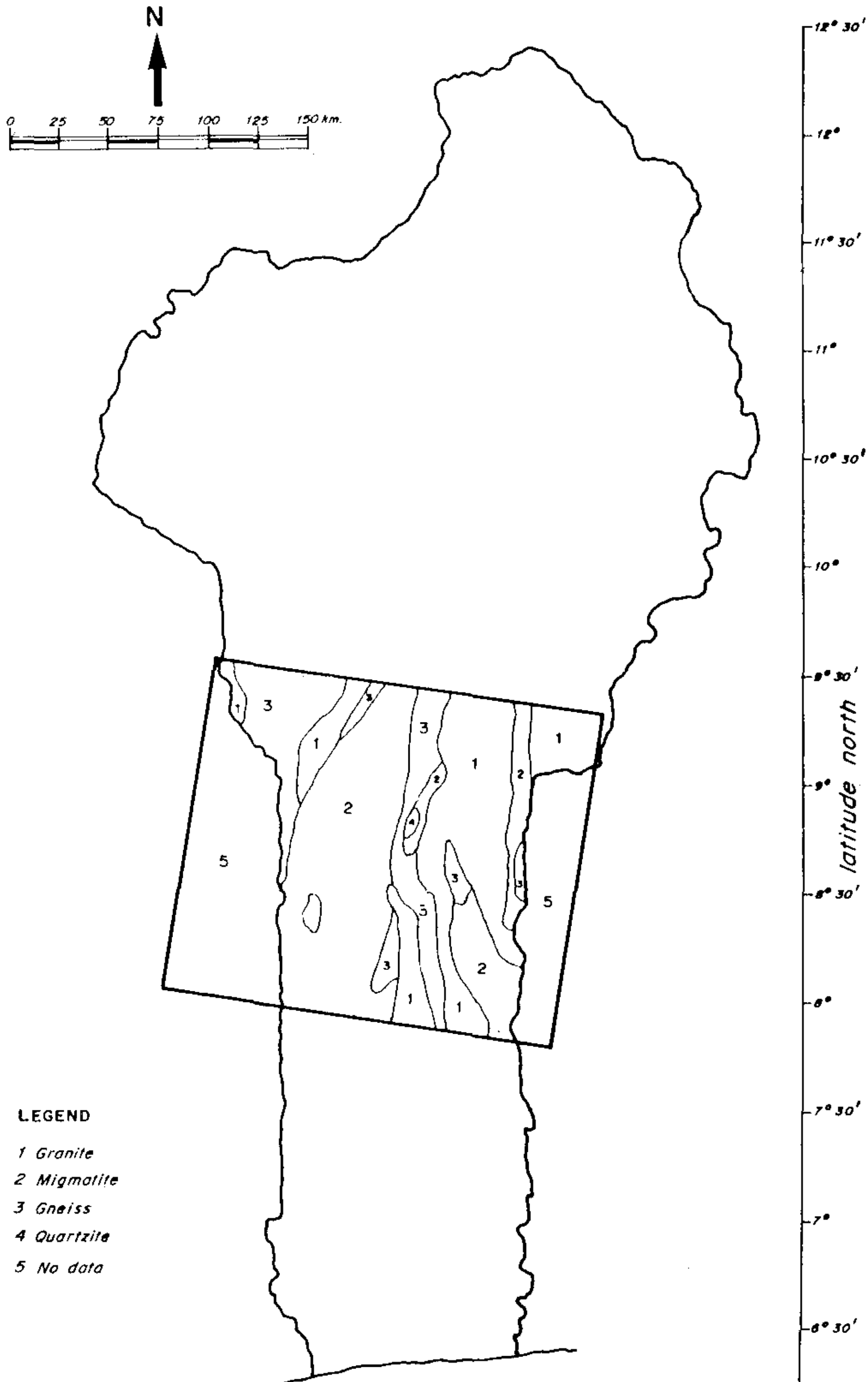

Figure 7 Geological formations in the study area

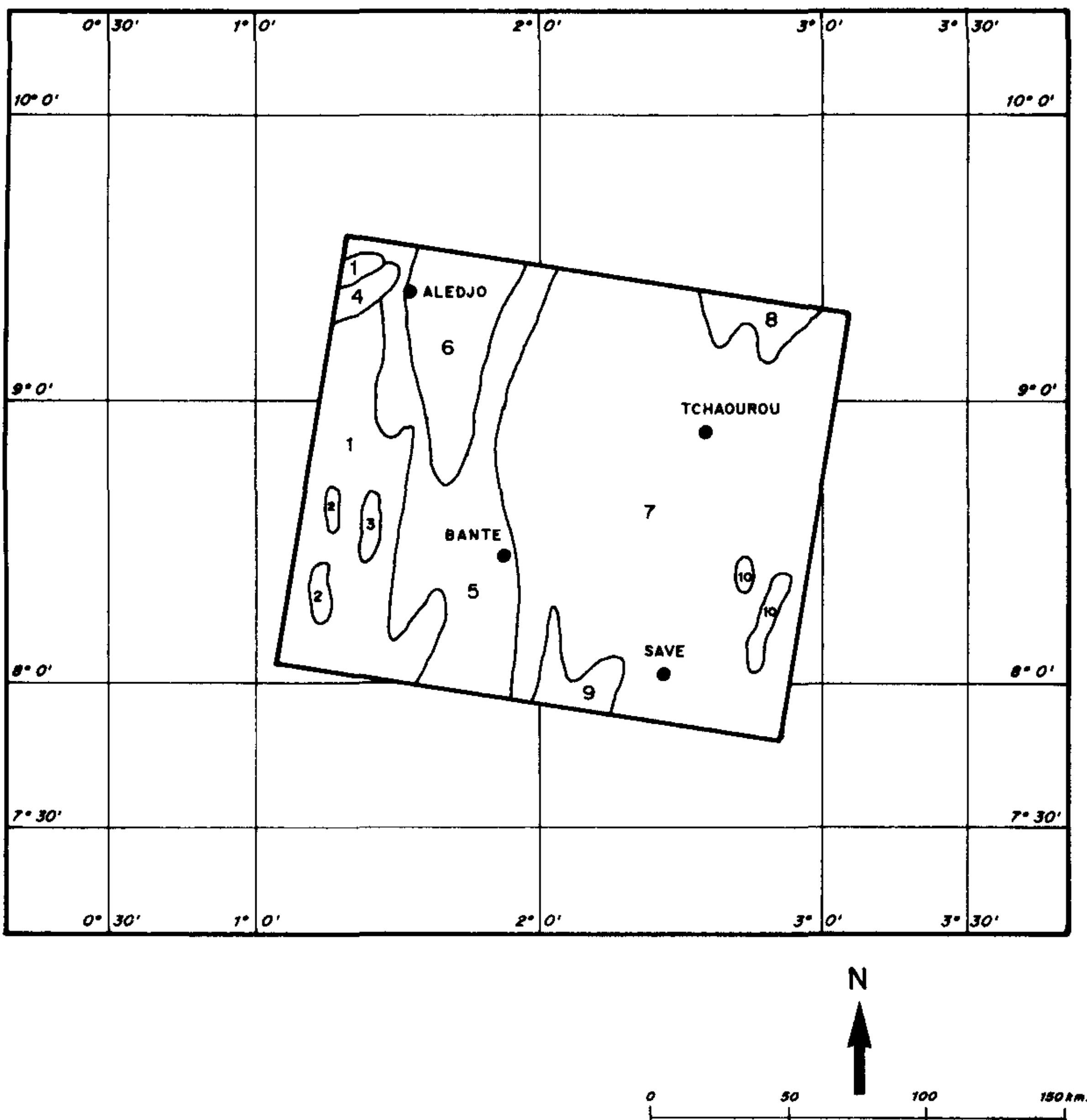

Figure 8 Soils distribution in the study area (for explanation of the map units see table 4)

South of Tchaourou, in the center-east of the study area, the agricultural system is moving towards a "population-driven intensification phase (early stage)" (figure 10). The mean cultivation period in the maize/cassava-based cropping system to be found here (figure 9) was 3 years with 4 years of fallow.

Rainfall and hydrology. Water dynamic is the major driving force in inland valleys. Any characterization of inland valleys, therefore, has to account for that factor. Although it is not of principal importance in the framework of this study, whenever data on water dynamic are available they will be summarized in these inland valley agroecosystem reports.

This section aims to give basic information about rainfall and the hydrologic regimes of rivers in the study area that is depicted by the quadrate in figure 11. The quality of information depends on the quality of available data and their analysis. This is especially true for rainfall and hydrologic data in West Africa because of factors such as very large variations in space and time, lack of quality control in data recording, no standardization of data collection, and wide variations in analyses and reporting.

Long-term raw data of the two parameters are available from the *Ministere de l'Energie, des Minéraux et de l'Hydrologie - Département de l'Hydrologie* (MEMH) of the Republic of Benin for 13 rain-gauge stations and 8 discharge stations that fall within the study area or are located very close to it (see figure 11). Data of these stations as well as data of all stations across the rest of Benin have recently been analyzed and published by Le Barbé et al. (1993). Their major results are reported here. An important characteristic of that study is the extensive and comprehensive statistical analysis of rainfall and discharge data which enabled the authors to extrapolate point data to create homogeneous regions.

The density of the rain-gauge network in Benin is about 1000-2000 km^2 per station. The rainfall in the study area varies on average between 975 mm and 1336 mm per year as analyzed by Le Barbé et al. (1993) for a reference period of 60 years (1925-1984). Based on a hierarchical clustering of the mean monthly rainfall profiles of each station, the country was divided into five rainfall zones as illustrated in figure 11. Most of the study area falls into zone 3 with a mean yearly rainfall of 1125 mm and shows a monomodal pattern. A minor portion in the northern part is included in zone 4, with a mean yearly rainfall of 1213 mm (table 6). In both zones, most rain falls from May through September with a sharp decline by the end of October. In zone 3, "productive rains" start earlier (in April) and last longer (October). The mean annual rainfall profile in zone 3 is flatter than in zone 4, as illustrated in figure 11. From May through September, the amount of rainfall is almost the same in zone 3 (with a slight difference in August and September). In zones 3 and 4, rainfall steadily increases from May through September in an average year.

Major watersheds in the study area are those of the rivers Ouémé, Okpara, and Zou. Discharge of subwatersheds has been measured at the outlets of rivers Wéwé, Agbado, Omini, and Klou (figure 12). The size of watersheds at the different stations ranged from 88 to 23,600 km^2. Data of these discharge stations have been calculated by Le Barbé et al. (1993) for a reference period of 45 years (1940-1984). Discharge data are characterized by their high variation. Therefore, only percentiles are able to illustrate the situation. They are depicted in table 7. In 1 out of 2 years, between 85 mm and 178 mm are discharged. That amount drops in dry years to 34-86 mm and rises in wet years to 155-302 mm, in both cases with a statistical 5-year recurrence period. Le Barbé et al. (1993) were able through a regionalization method to draw discharge isohyets which are shown in figure 11. They are valid for watersheds above 100 km^2. The major part of the study area covers the isohyets between 100 and 180 mm discharge per year. These are mean yearly data in mm and their coefficient of variation has been determined with 60% and 90%.

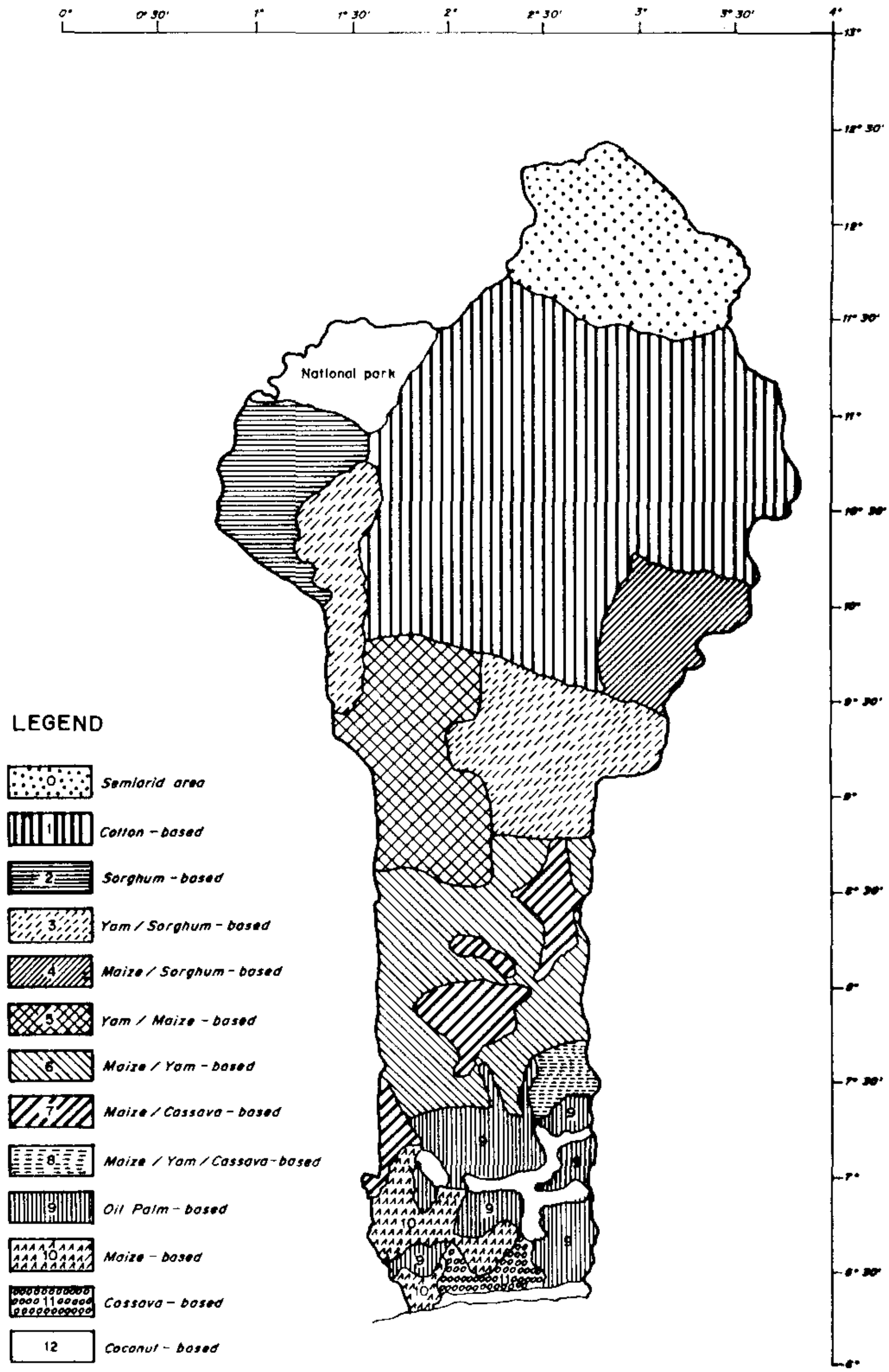

Figure 9 Characterization of cropping systems in the Republic of Benin (Manyong et al. in preparation)

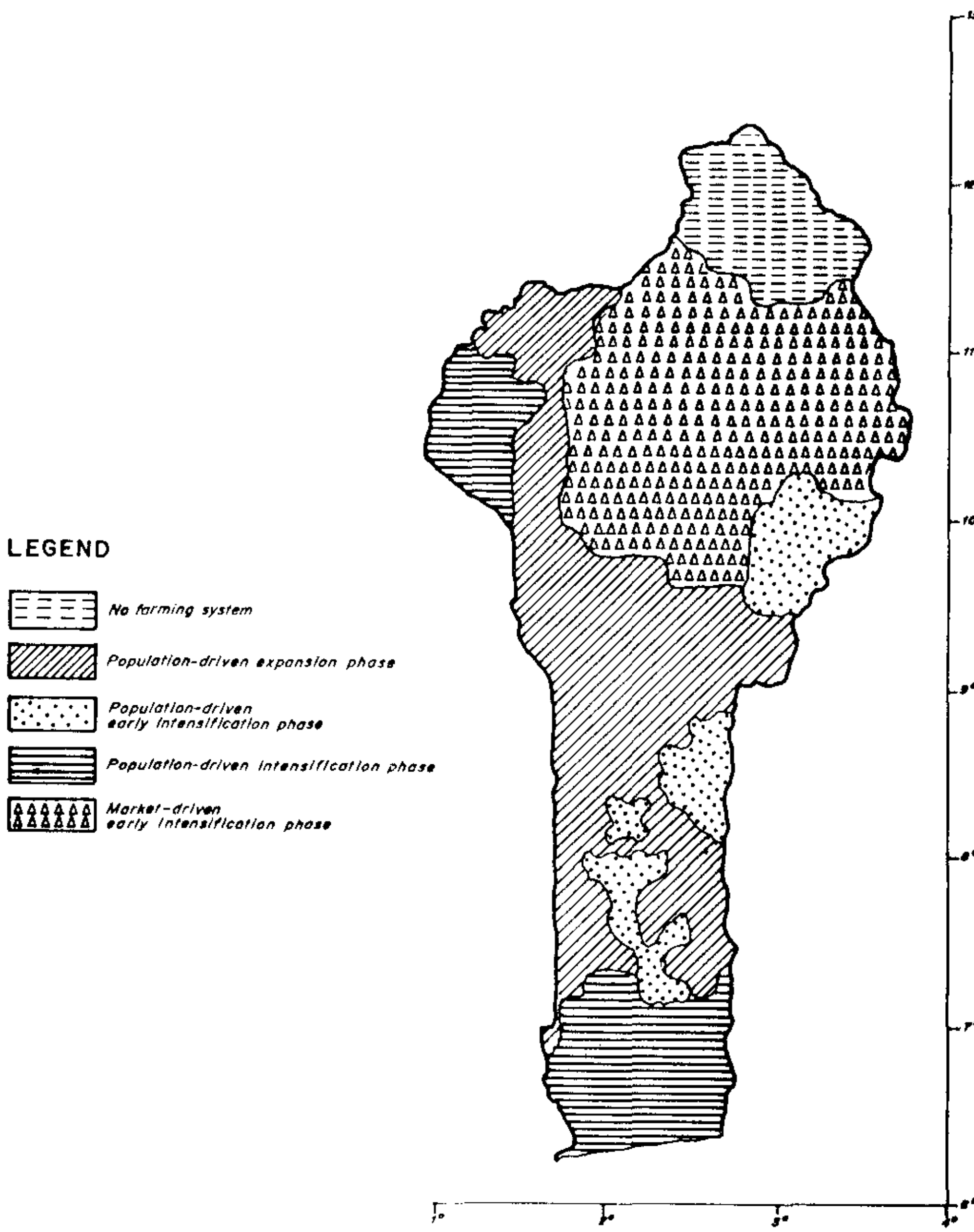

Figure 10 Characterization of agricultural systems in the Republic of Benin (Manyong et al. in preparation)

Table 5 Thematic Mapper vegetation indices for the agroecological and soil zones and the entire study area

Level I zone[a]	Percent of the entire study area	Vegetation Indices (VIs)			
		Ratio VI = $\frac{TM4}{TM3}$	Normalized VI = $\frac{TM4-TM3}{TM4+TM3}$	Midinfrared VI1 = $\frac{TM4}{TM5}$	Midinfrared VI2 = $\frac{TM4}{TM7}$
AEZ 2	49	1.07	0.03	0.61	1.33
AEZ 7	46	1.10	0.05	0.62	1.36
Entire study area[b]	100	1.08	0.039	0.60	1.31

Notes:

a. Level I agroecological and soil zones (see figure 1 and table 1). AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the Derived savanna with Luvisols. AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones.

b. Study area covered by the full scene of Landsat-5 path:192, row:54. Since the WURP land region 2.1 occupies this entire study area, the result of the full scene are equally applicable for land region 2.1.

Based on the rainfall and discharge data of table 7, it is possible to calculate a rough runoff coefficient that illustrates the relationship between rainfall and discharge for a watershed. It ranges between 8% and 15% in 1 out of 2 years, drops in dry years (1 out of 5) down to 3-7%, and rises in wet years (1 out of 5) to 14-25%. There is no relationship between the size of the watershed and its runoff coefficient. Le Barbé et al. (1993) determined at an experimental watershed of 45 km^2 size at Lhoto (see for its location figure 11), representative for the Zou watershed upstream of Atcherigbe, in 2 years annual runoff coefficients of 8% (1228 mm rainfall) and 16% (1200 mm rainfall). At Tero (size of the watershed 32 km^2), representative for the Djougou region, the annual runoff coefficient was 26% in a dry year with 1158 mm rainfall (5-year recurrence) and 32% in an exceptionally wet year with 1804 mm rainfall (50-year recurrence). If one compares the regional values (figure 11) of rainfall and discharge, 15-25% of rainfall is discharged in the northwestern part and 9% in the rest of the study area. That difference is a result of geology and geomorphology prevailing in these regions. Le Barbé et al. (1993) distinguished six units in Benin which are mainly characterized by their parent material and their geomorphology. The northwestern part of the study area belongs to unit II, encompassing the mountains of Djougou and the Atakora range (figure 11), whereas the rest of the country belongs to unit IV and V, the plain Basement Complex.

The time pattern of start and end of discharge as well as the duration of dry periods is also of interest in the scope of this report. These factors have also been analyzed by Le Barbé et al. (1993). Figure 12 illustrates the discharge distribution over a mean year for four high-order rivers with > 6000 km^2 watershed and 3 low-order rivers with ≤ 300 km^2 watershed. These figures have been drawn using data from Le Barbé et al. (1993). The waterflow starts in 1 out of 2 years at Atcherigbe and Logozohe between end of March and mid-April, at Bétérou, Save, and Kaboua in the first two weeks of May, at Wéwé at the end of May, and at Pira at the end of July. In dry years (3-year recurrence) the discharge starts about two weeks later at Atcherigbe, Bétérou, Pira, Wéwé, and Save, and 4-5 weeks later at Kaboua and Logozohe. In wet years (3-year recurrence) discharge starts about two weeks earlier at Atcherigbe, Bétérou and Logozohe, and 3-4 weeks earlier at Pira, Save, Wéwé, and Kaboua. All seven rivers dry out in the dry season, a phenomenon that has occurred at Save only since 1968 (Le Barbé et al.(1993).

Table 6 Rainfall in the study area (data from Le Barbé et al. 1993)

Station	Rainfall		Dry year 5 years[b] (mm)	Median 2 years[b] (mm)	Wet year 5 years[b] (mm)
	Mean (1925-1984)	Zone[a]			
Banté	1117	7	935	1110	1306
Dassa-Zoumé	1124	7	901	1101	1329
Ouessé	975	2	821	975	1146
Savalou	1153	7	962	1144	1348
Save	1108	7	876	1074	1306
Tchaourou	1153	2	939	1133	1363
Tchetti	1135	7	888	1093	1333
Toui	1128	2	906	1095	1332
Bassila	1207	7	1035	1207	1379
Bétérou	1187	2	992	1187	1383
Djougou	1336	7	1139	1315	1521
Okpara	1216	2	1019	1216	1414
Parakou	1171	2	989	1171	1352

Notes:
a. see figure 3
b. statistical recurrence in years

The authors analyzed a clear relationship between size of the watershed on one site, and the end-date of discharge, or the number of days without discharge, on the other site. The smaller the watershed, the earlier dry streams up and the longer they stay dry in the dry season.

Discharge ends in 1 out of 2 years at the end of November at Pira, in the first three weeks in January at Logozohe, Wéwé, and Atcherigbe, and from mid-February to the end of March at Bétérou, Kaboua, and Save. The drying up of streams is a result of two processes which are the impounding of water contained in the soil and subsoil and the cessation of groundwater supply to the rivers (Le Barbé et al. 1993). The impounding is dominating, irrespective of the parent material in the watershed and lasts 9-12 days in the study area. The second process is very fast in areas with basement complex as parent material. In the study area, Le Barbé et al. (1993) analyzed a period of 1-2 days for higher-order streams and 7 days at river Wéwé, a low-order stream. The high-order streams with watersheds above 6,000 km^2 stay dry for 2-3 months, whereas low-order streams ($\leq$ 300 km^2) are dry for for 4 months, the first-order stream Omini even for 9 months (Le Barbé et al. 1993).

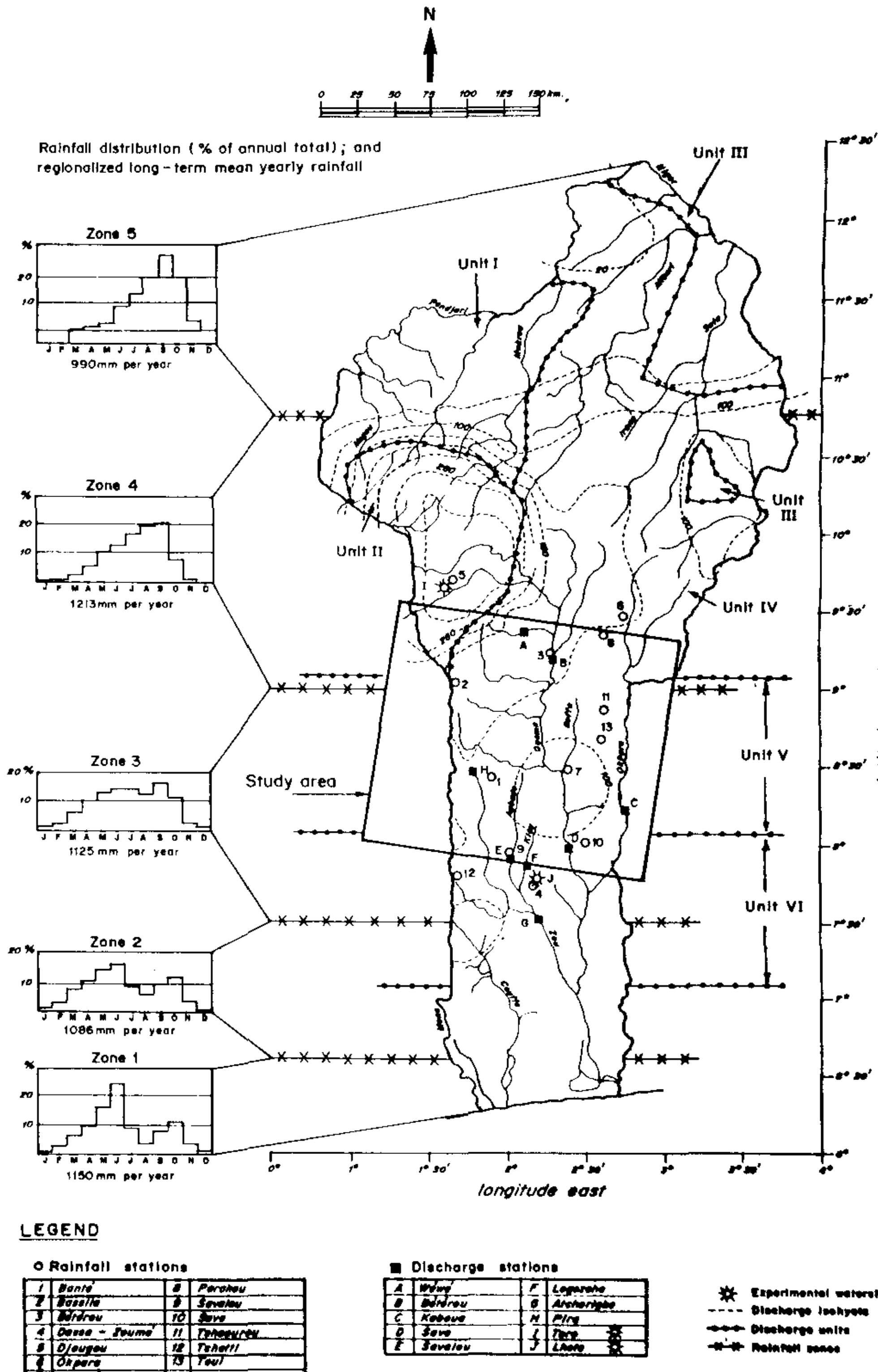

Figure 11 Rainfall zones, discharge units and isohyetes, and location of rainfall and discharge stations in the study area (adapted from Le Barbé et al. 1993)

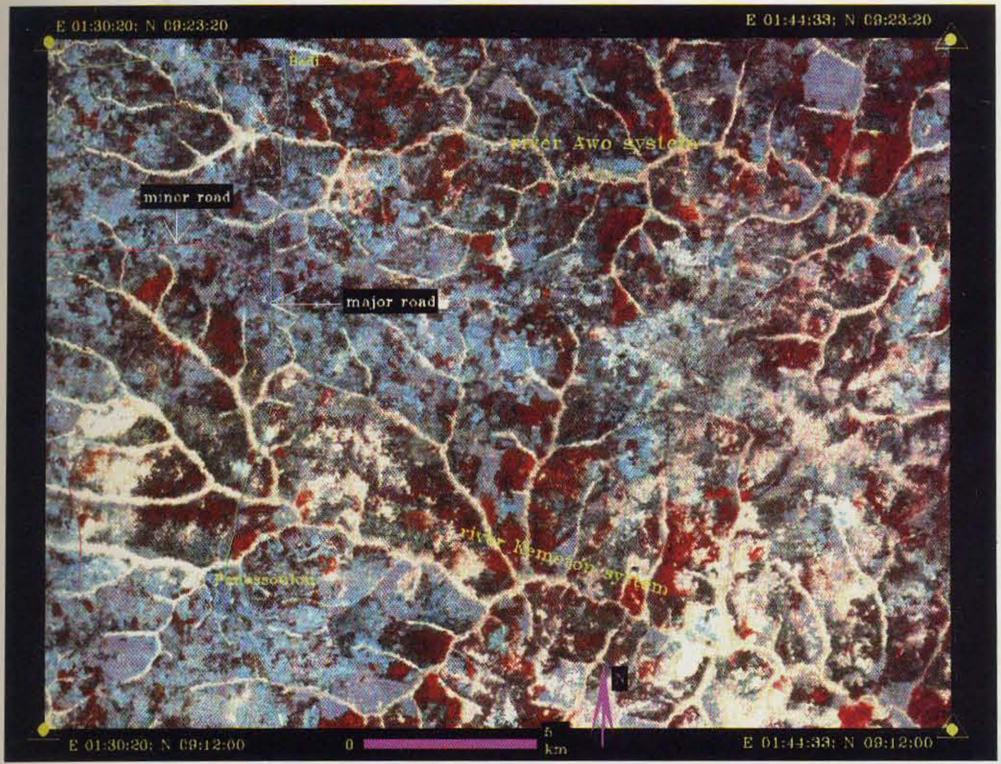

Plate 1 Ratio RGB image of Landsat TM bands: TM4/TM7 (red), TM4/TM3 (green), TM4/TM2 (blue) distinguishing the inland valley bottoms from fringes and uplands for a sub-area of Landsat Path: 192, Row: 54 in Save, Republic of Benin

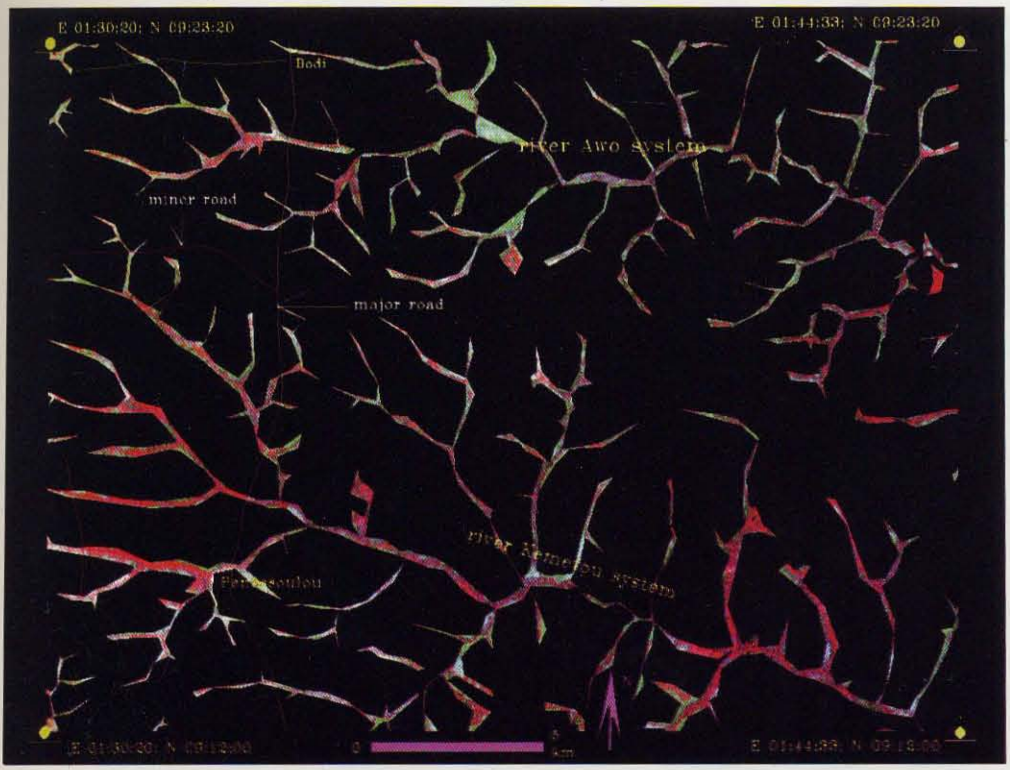

Plate 2 Inland valley bottoms delineated and displayed as a false color composite of TM bands: TM4 (red), TM3 (green), TM5 (blue). **Color key**: red (densest vegetation), shades of green and blue (very little and/or dry vegetation. The NDVI values were less than 0.10 for these areas)

Plate 3 Inland valley fringes for the same sub-area as shown in plate 1 and 2 displaying the false color image of TM4 (red), TM3 (green), TM5 (blue). **Color key**: red (densest vegetation), shades of green (lowest density and vigor of vegetation), and shades of blue and gray (intermediate vegetation)

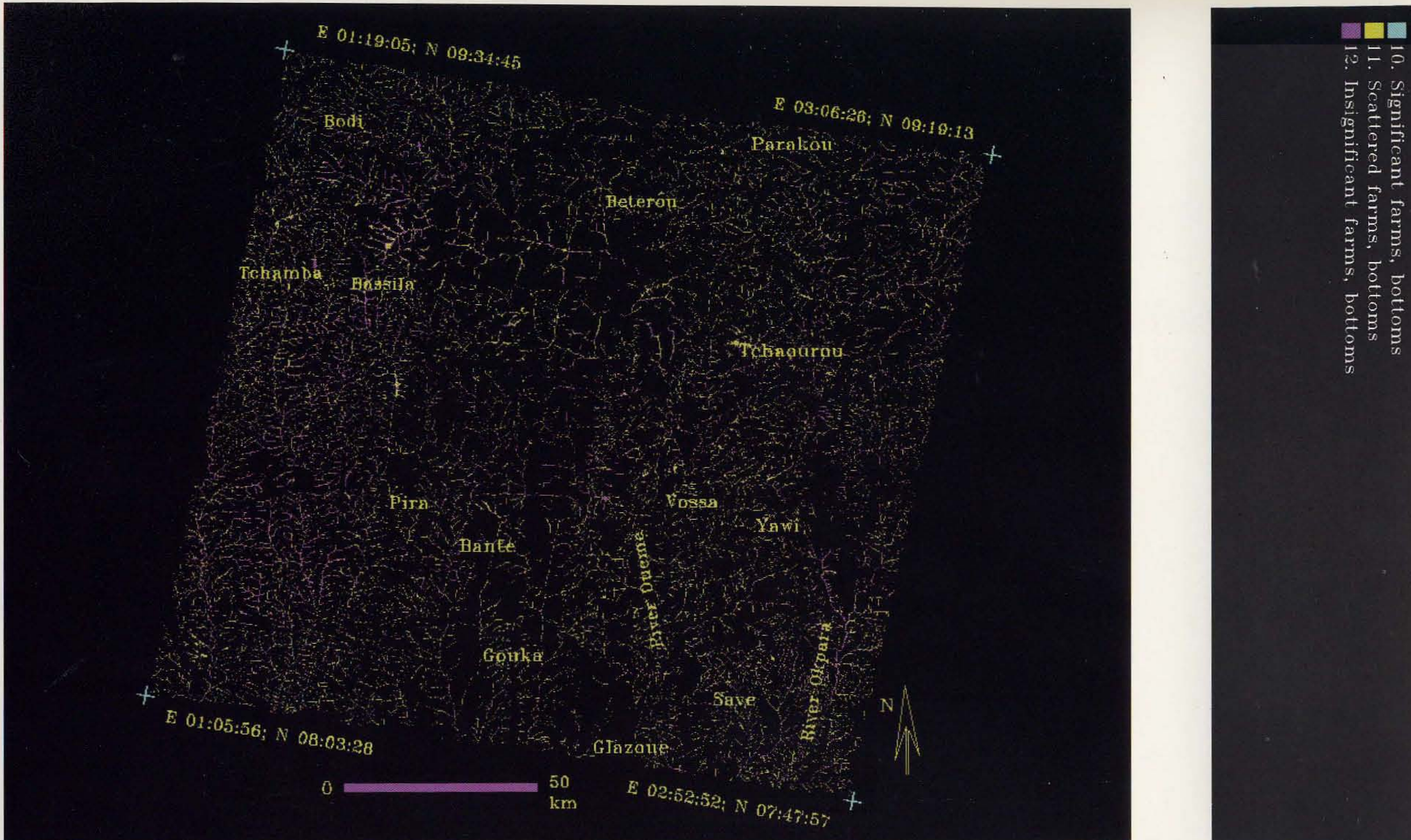

Plate 4 Inland valley bottoms and their land use delineated and mapped for the entire study area of Landsat Path: 192, Row: 54 (Save, Republic of Benin). The total valley bottom area was 9% (0.28 million ha) of the total area (see legend for color key)

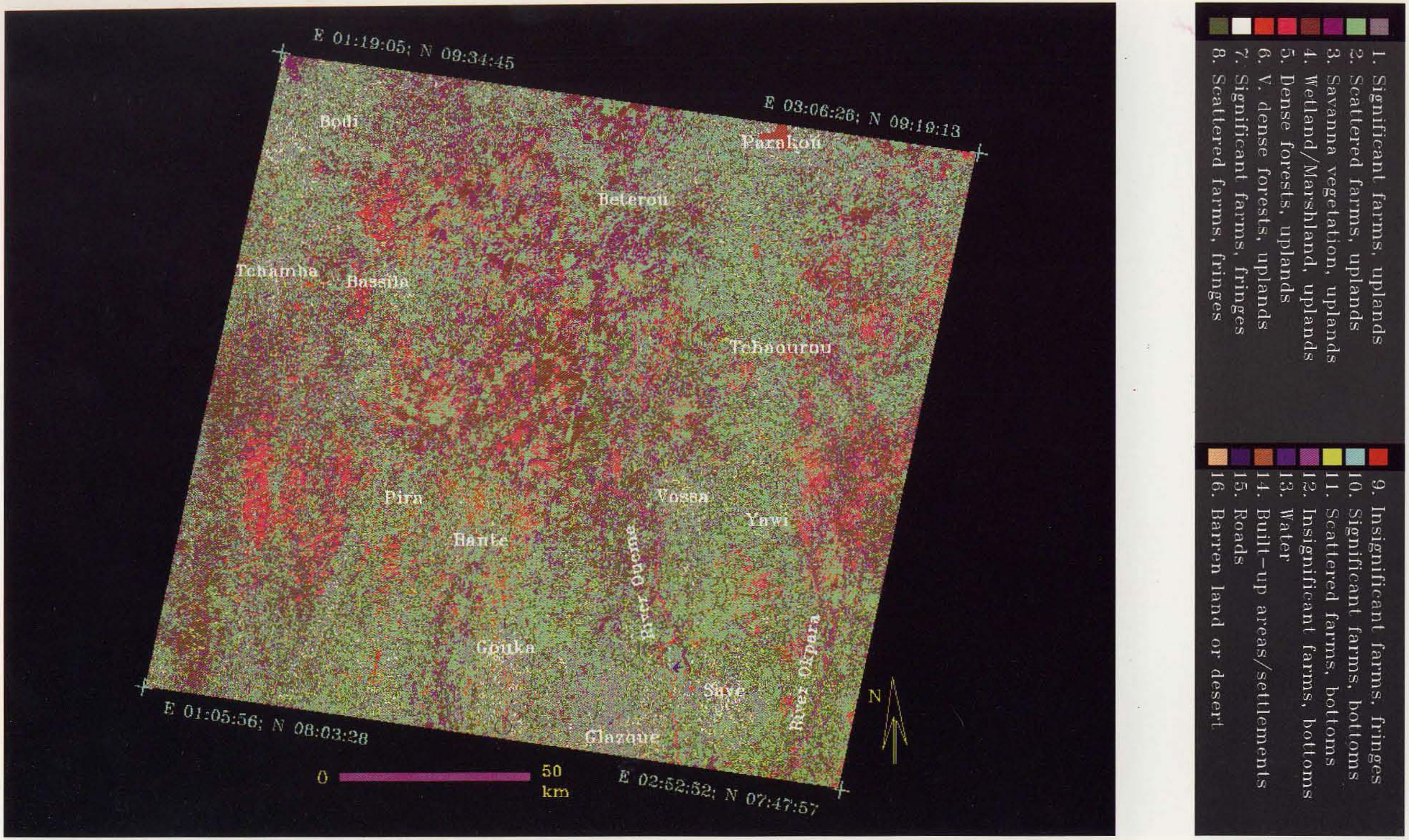

Plate 5 Land-use classes mapped for the different components of the toposequence (valley bottoms, valley fringes, and uplands) for the entire study area of 3.12 million ha covered by Landsat Path: 192, Row: 54 in Save, Republic of Benin (see legend for color key)

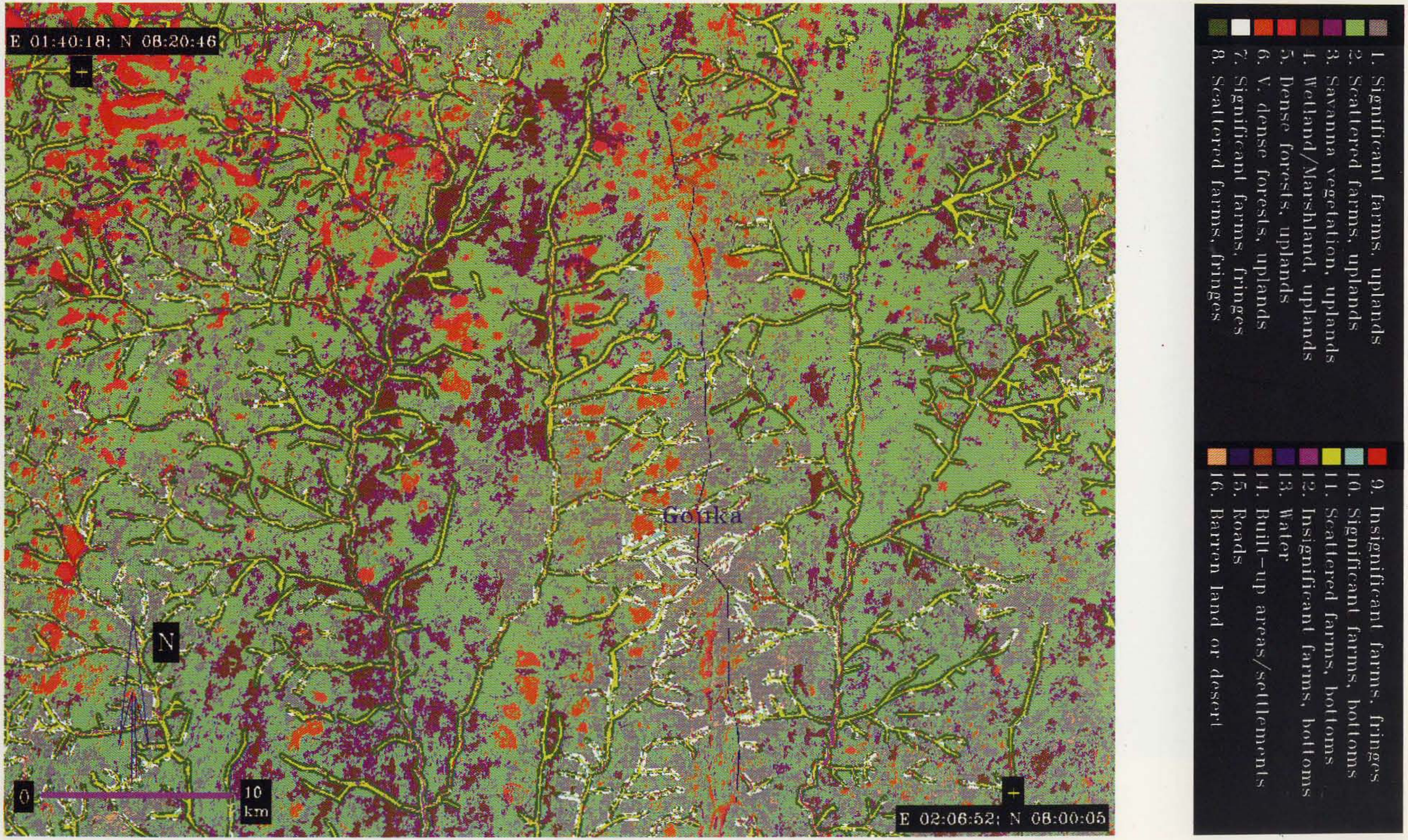

Plate 6 Land-use classes in a sub-area near Gouka, Republic of Benin. Note the relatively high density of cultivation across the toposequence in areas adjoining roads and settlements (see legend for color key)

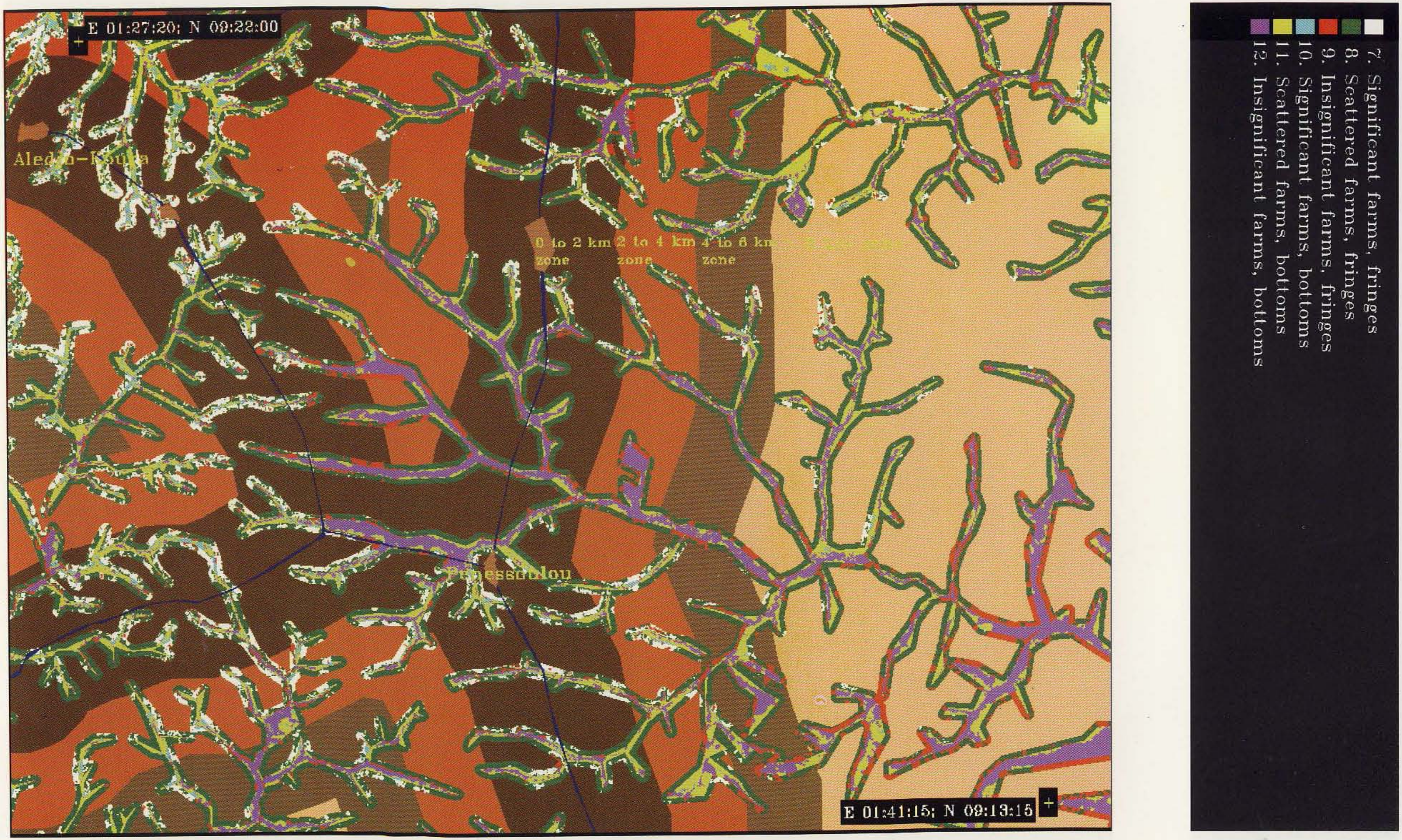

Plate 7 Cultivation intensities in inland valleys (valley bottoms plus valley fringes) relative to their distance from roads and settlements. Note the decreasing intensities of cultivation in inland valleys with increasing distances from roads and settlements

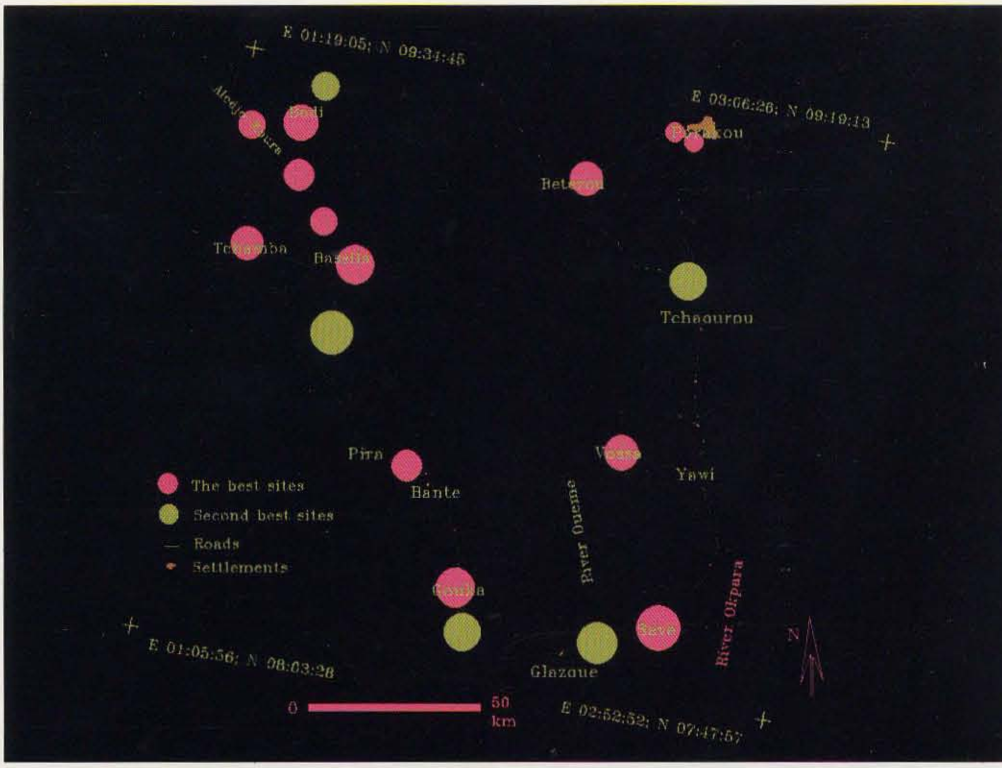

Plate 8 Location of potential benchmark research sites for technology development research activities in the study area of Landsat Path: 192, Row 54 (Save, Republic of Benin) determined through integration of Landsat TM, GPS, ground-truth, and expert opinion data in a GIS framework

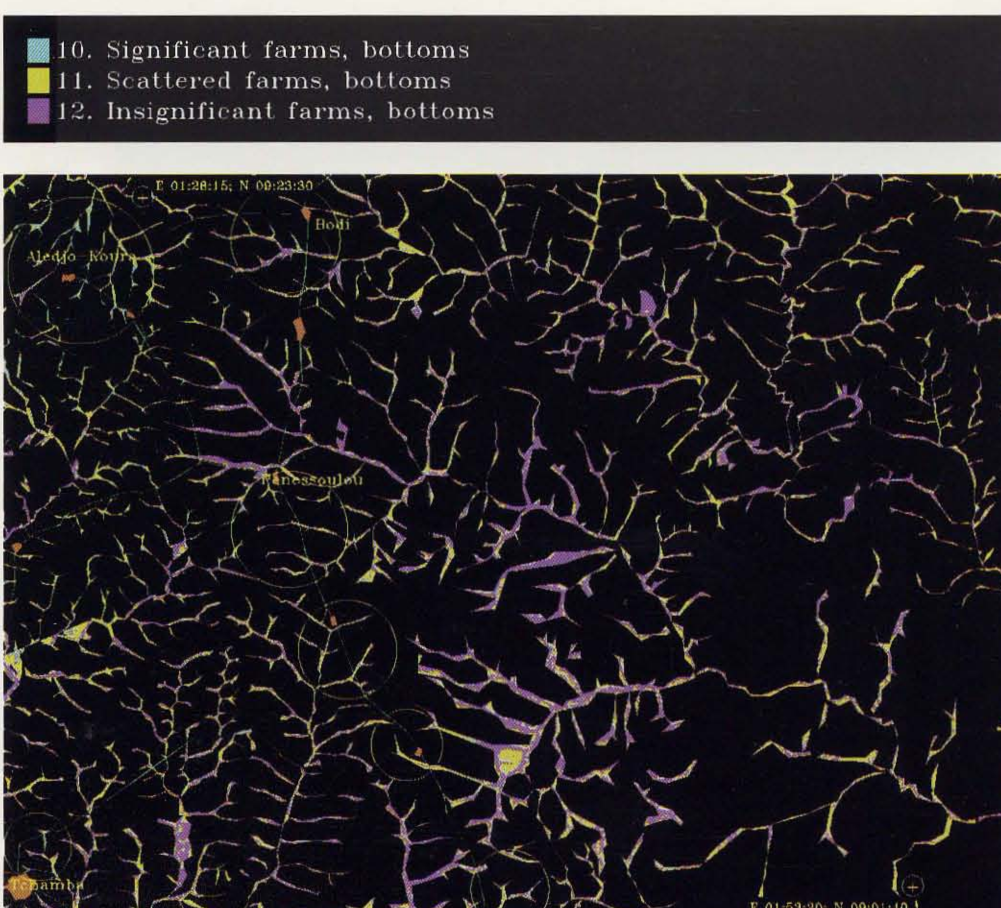

Plate 9 Land-use classes of valley bottoms in a sub-area (near Bassila, Republic of Benin) of Landsat Path: 192, Row 54. The encircled areas indicate the location of potential benchmark sites

Plate 10 Spatial distribution of areas of significant upland cultivation (see white color) in the entire study area. Areas encircled by the polygons 1, 2, 3 and 4 indicate insignificant cultivation

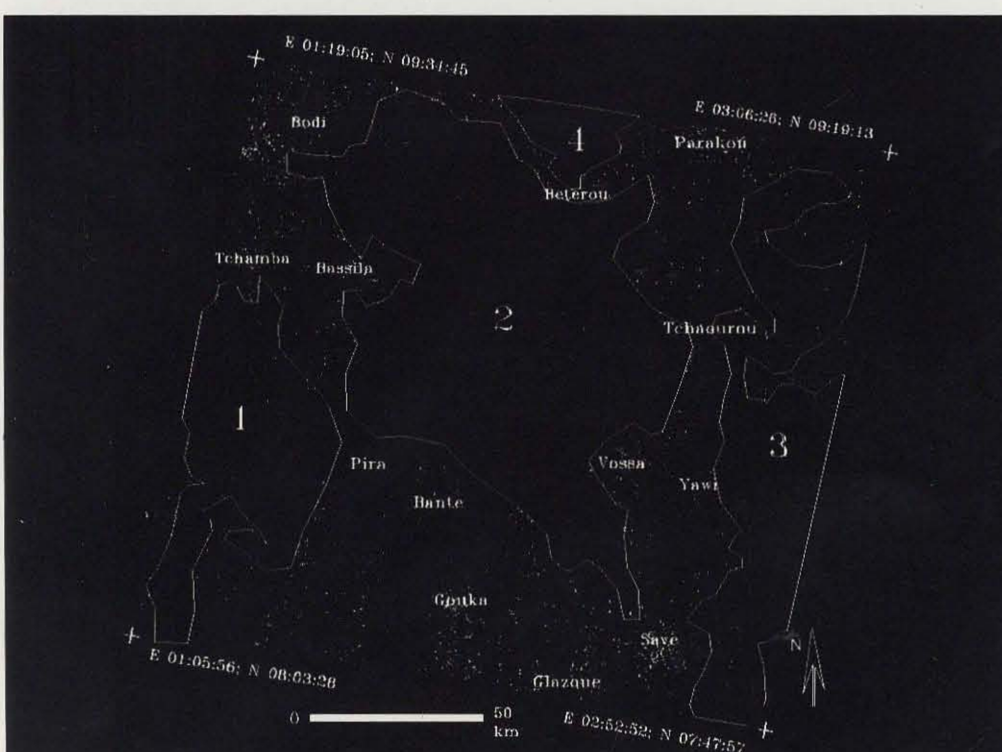

Plate 11 Spatial distribution of areas of significant cultivation (see white color) in inland valleys (valley bottom plus valley fringes) in the entire study area. Areas encircled by the polygons 1, 2, 3 and 4 indicate insignificant cultivation

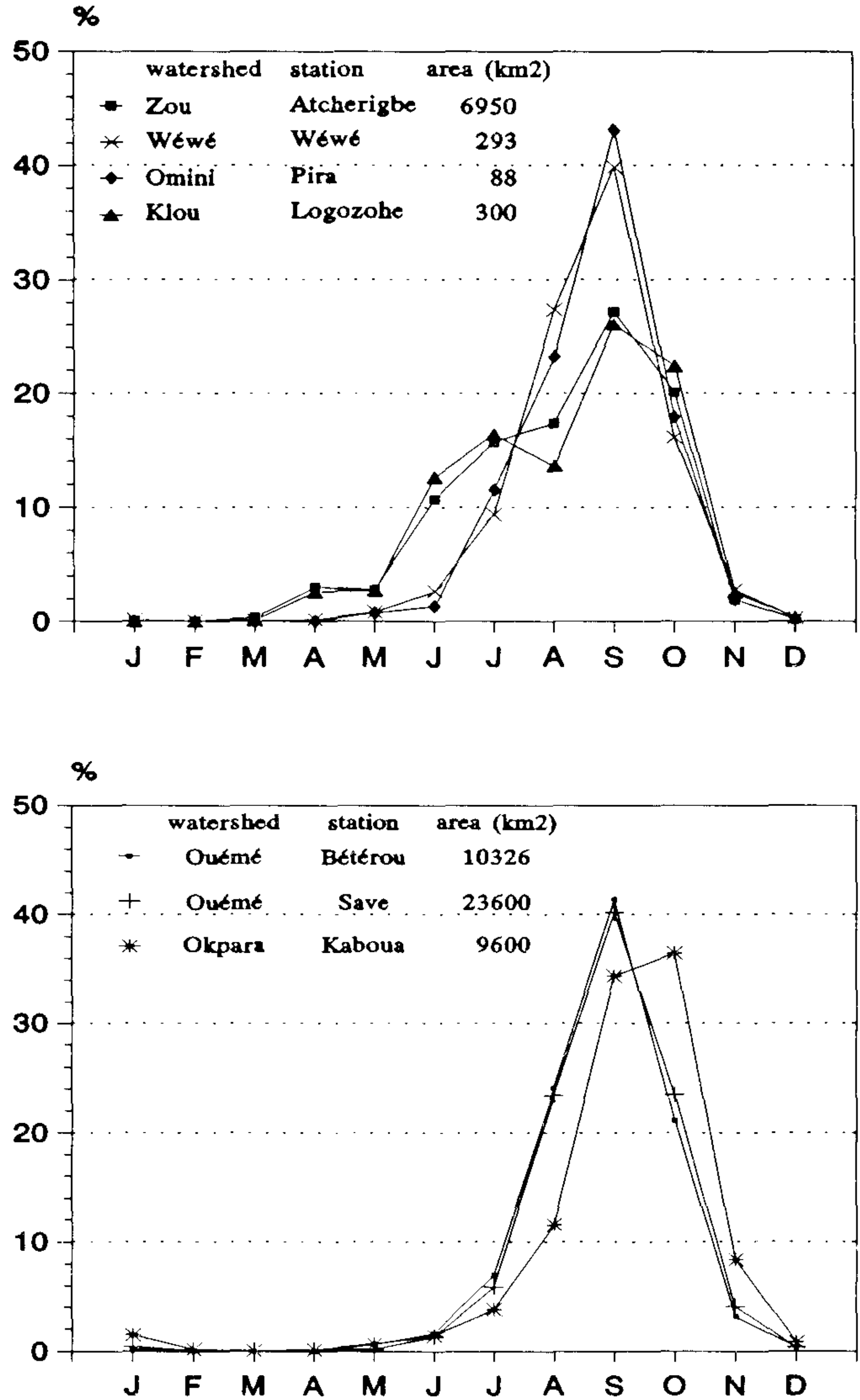

Figure 12 Mean monthly discharge in percent of the annual total (reference period 1960–1984) at 6 stations in the study area (drawn from data of Le Barbé et al. 1993)

Table 7 Discharge of sample watersheds in the study area (data from Le Barbé at al. 1993)

Watershed	Station	Area (km^2)	AEZ[a]	Rainfall[b] (mm)	Discharge per year (mm)		
					Dry year 5 years[c]	Median 2 years[c]	Wet year 5 years[c]
Agbado	Savalou	1,280	7	1125	43	117	223
Klou	Logozohe	300	7	1125	40	126	297
Okpara	Kaboua	9,600	2	1125	38	86	152
Omini	Pira	88	7	1125	34	85	155
Ouémé	Save	23,600	2	1125	61	127	215
Zou	Atcherigbe	6,950	7	1125	46	120	224
Oueme	Bétérou	10,326	2	1213	70	143	240
Wéwé	Wéwé	293	2	1213	86	178	302

Notes:

a. See figure 3

b. Regionalized mean yearly rainfall in rainfall zone

c. Statistical recurrence in years

It would be of interest to know the relationship between the water dynamic of first- or second-order streams, where inland valleys are mainly to be found, and higher-order streams. Le Barbé et al. (1993) restrict their findings to watersheds above 100 km^2. There are no data available for smaller watersheds, but Raunet (1977) gave an interesting view of the water dynamic of inland valleys in central Benin which should be quoted in this context (translation by authors of this report):

> A unique feature of the tropical peneplain Basement Complex is its enormous alteration layer (often tens of meters) above the bedrock. It acts like a sponge in absorbing precipitation. The fluctuating groundwater is embedded in this alteration layer. Under natural vegetation almost no (< 1%) surface flow will occur until the subsurface is saturated. Only late in the rainy season (end of August) water starts to run off above the surface. On the uplands the watertable is at 6–10 m below ground and mounts up to 2 m in the second half of the rainy season (August/September). However, only a minor part is free-flowing groundwater. Seventy five percent of the soil pores or 43% of the soil volume is constantly saturated with water. An amount of 550–600 mm of rainfall is required to saturate the great pores conducive for free-flowing groundwater. This is normally the case between end of July and beginning of August. Then inland valleys are filled with water through lateral flow at the lower slopes and by an emerging watertable in the valley bottom. Flash floods may occur after heavy rains at the end of the rainy season (September), when the alteration mantle of the uplands and upper fringes is completely water saturated. At the lateral parts of the valley bottom (with slopes of 1–2%) the groundwater table is heavily fluctuating but never goes beneath 2 m even in the dry season.

III

Ground-Truth Data

3.1 Methodology

Ground-truth data were collected from 62 valley bottoms, 61 valley fringes, and 25 uplands during the dry season, 21 through 29 March 1993. These data were expected to depict the dry-season characteristics of the satellite overpass date of 29 December 1991. Ideally, ground-truth data should be collected on or about the same date as the satellite data acquisition date. However, real- or near-real-time satellite data were not available. The implications of data collection at a later stage as well as the data-collection strategy, parameters measured or observed, and the methods and procedures used to collect and analyze these parameters have been discussed in detail in the monograph by Thenkabail and Nolte (1995).

The location of each ground-truth site was determined using a global positioning system (GPS) Garmin 100-SRVY^{R} (see figure 4 for precise location of the ground-truth sites). Locations noted were geographic co-ordinates (latitude/longitude) in degree, minutes and seconds, and universal transverse mercator (UTM) co-ordinates (x,y) in meters. The accuracy of these GPS readings was within ± 30 m. The GPS was also used to collect ground-control points to georeference the satellite image. A total of 19 ground-control points was recorded in prominent locations, such as a road crossing a river (over the center of the bridge) and railway lines crossing a road. These ground-control points were well spread across different portions of the image.

Land-use measurements were made in a 90 m by 90 m plot of the valley bottoms, valley fringes, and uplands. Its location was determined from the center with the GPS. The leaf area index of trees, shrubs, and grasses was measured in the same plot. Each land-use class has varying degrees of land cover types (table 8). A total of 10 land-cover types was recorded at each ground-truth site: water, trees, shrubs, grasses, cultivated farms, barren farms, barren lands, built-up areas or settlements, roads, and others (table 9). Different combinations of these land-cover types constitute specific land-use categories (table 10).

The measurements (in meters) of valley-bottom and valley-fringe width were taken at a transect covering the 90 m by 90 m plot for land-use measurements. Other characteristics recorded at each inland valley sample site included valley bottom width (in meters), valley fringe width, transversal slope (degree), stream order (number), and qualitative observations of the soil moisture status as well as the level of water management system prevailing in valley-bottom fields.

Table 8 Land-use classes, their vegetation distribution, and description in valley bottoms, at valley fringes, and on uplands in the study area

Spectral class no.	Land-use class	Vegetation description and distribution[a,b,c]
	Upland	
1	significant farmlands	total farmlands dominate in this area; trees (15%), shrubs (26%), grasses (16%), cultivated farms (20%), barren farms (17%), barren lands (5%)
2	scattered farmlands	savanna with scattered farmlands; trees (22%), shrubs (22%), grasses (39%), cultivated farms (5%), barren farms (7%), and barren lands (4%)
3	savanna vegetation	savanna with sparse or insignificant farmlands; trees (29%), shrubs (23%), grasses (40%) cultivated farms (2%), barren farms (2%), barren lands (2%)
4	wetland/marshland	short shrubs dominant with moist soils and/or flood plain; marshy vegetation; trees (15%), shrubs (28%), grasses (21%), cultivated farms (16%), barren farms (4%), and barren lands (2%)
5	dense forest	dense lush-green vegetation, mostly of forest type; trees (37%), shrubs (30%), grasses (29%), cultivated farms (0%), barren farmlands (2%), and barren lands (2%)
6	very dense forests	very dense lush-green forest vegetation dominated by trees; rarely another very dense lush-green vegetation; trees (44%), shrubs (39%), grasses (13%), cultivated farms (2%), and barren farms (1%)
	Valley fringe	
7	significant farmlands	region with significant cultivation in valley fringes; trees (21%), shrubs (20%), grasses (17%), cultivated farms (18%), barren farms (20%), and barren land (4%)
8	scattered farmlands	savanna with scattered cultivation at valley fringes; trees (26%), shrubs (24%), grasses (30%), cultivated farms (13%), barren farms (2%), and barren lands (5%)
9	insignificant farmlands	low cultivation at valley fringes; trees (32%), shrubs (32%), grasses (28%), cultivated farms (4%), barren farms (3%), and barren land (1%)
	Valley bottom	
10	significant farmlands	Region with significant cultivation in valley bottoms. Trees (15%), shrubs (25%), grasses (16%), cultivated farms (24%), barren farms (15%), and barren land (4%)
11	scattered farmlands	savanna with scattered cultivation in valley bottoms; trees (18%), shrubs (16%) grasses (48%), cultivated farms (2%), barren farms (9%), and barren land (4%)
12	insignificant farmlands	low or no cultivation; trees (28%), shrubs (40%), grasses (30%), farms (0.5%) and barren land (1.5%)
	Others	
13	water	water (100%)
14	built-up area/ settlements	Small and large settlements, including villages and townships. (100%)
15	roads	Major and minor roads. Include most motorable roads. (100%)
16	barren/desert area	open areas with rocks, sand, barren soil, etc. (100%)

Notes:

a. Percentage of land-cover type for each spectral class was derived from ground-truth data

b. Cultivated farms means cultivation during dry season; barren farm means the agricultural lands were left barren during the dry season, but were cultivated in the rainy season; total farmlands = cultivated farms + barren farms

c. When the total percentage of land use for each land-use class is less than 100%, then the rest constitutes other classes such as rocks, sand, and quarry

Table 9 Land-cover types identified in this study

Code	Land-cover type description	Code	Land-cover type description
1	water	6	barren farms
2	tree	7	barren lands
3	shrub	8	built-up area/settlement
4	grass	9	roads
5	cultivated farms	10	others

Table 10 Percentage distribution of land-cover types in the 16 land-use classes[a]

Code of land-use classes	Code of land-cover types									
	1	2	3	4	5	6	7	8	9	10
1		15	26	16	20	17	5			1
2		22	22	39	5	7	4			1
3		29	23	40	2	2	2			2
4		15	28	21	16	4	2			14
5		37	30	29	0	2	2			0
6		44	39	13	2	1	0			1
7		21	20	17	18	20	4			1
8		26	24	30	13	2	5			0
9		32	32	28	4	3	1			0
10		15	25	16	24	15	4			1
11		18	16	48	2	9	4			3
12		28	40	30	0	0.5	1.5			0
13	100									
14								100		
15									100	
16							100			

Note:

a. For the description of the 16 land-use classes refer to table 8 and for the 10 land-cover types refer to table 9

IV

Results and Discussion

4.1 Mapping valley bottoms and valley fringes

The bottoms and fringes of inland valleys were mapped for the entire study area using the methodology outlined in Thenkabail and Nolte (1995). The technique of mapping valley bottoms for a sample area is illustrated in plates 1 and 2. Plate 1 demonstrates:

1. An enhanced image using the ratio red-green-blue (RGB) image of TM bands TM4/TM7, TM4/TM3, and TM4/TM2. Valley bottoms show up in a white or cream network of streams which can be very easily distinguished from the neighboring fringes and uplands.
2. A magnified image displayed with a magnification factor of 2 so as to highlight inland valleys and to distinguish them from other neighboring features. This permits easy and exact digitizing of valley-bottom boundaries.
3. A digitized valley-bottom network (see the digitized polygons separating valley bottoms from fringes and uplands).

The valley bottoms enhanced, highlighted, and digitized as illustrated for a sample area in plate 1, were separated from the other components of the toposequence to obtain only the valley bottoms (see plate 2). Valley fringes adjoin valley bottoms and were mapped by a combination of image processing and GIS techniques (Thenkabail and Nolte 1995). The mean widths of the valley fringes, measured during the ground-truthing, were used to delineate valley fringes through digitizing on either side of the valley bottoms. The image area other than valley fringes was subsequently masked using the MASK procedure of ERDAS. The outcome is illustrated for a sample area in plate 3 (note that these are the fringes adjoining the bottoms shown in plate 2). In plate 3, both the valley bottoms and the uplands have been masked to highlight only the valley fringes. The same technique was adopted to map the valley fringes of the entire study area. The procedure explained above, adopted to delineate valley bottoms as in plate 2, is extrapolated for delineating the valley bottoms of the entire study area as depicted in plate 4.

4.2 Mapping settlements and road networks using TM data

The differences between UNEP/GRID data and data of the WURP report on population densities (table 11) reveal that consistent data were very difficult to obtain. As a result, Landsat TM data was used to interpret settlement areas with the presumption that there is a strong correlation between the size of a settlement and its population. Also, the absence of recent road networks on topographic maps (all of them from the 1960s) makes it more appropriate to extract this information from TM data. The following parameters were determined using the TM data for each agroecological zone (table 11):

1. presence or absence of major settlements;
2. number of major settlements;
3. area of settlements and percentage of settlement area to total area of study;
4. presence or absence of a major road network; and
5. density of the road network (km/km^2).

Table 11 Population, settlements, and major road networks in the study area

Agroecological Zone[a]	Population (number/km^2)		Major settlement (TM data)		Major road network (TM data)	
	UNEP/ GRID[b]	WURP[c]	major settlement presence and name (yes/no)	number of major settlements (#)	presence or absence (yes/no)	density of road network (km/km^2)
A. AEZ 2	23	42	yes Parakou	16	yes	0.018
B. AEZ 7	23	55	yes Tchaourou	28	yes	0.031
C. Entire study area	23	52	yes Parakou, Save, Bante, Bassila, Tchaourou	44	yes	0.023
D. Land region 2.1	23	52	yes Parakou, Save, Bante, Bassila, Tchaourou	44	yes	0.23

Notes:

a. AEZ 2 is southern Guinea savanna with Luvisols; AEZ 7 is Derived savanna with Luvisols. In the remaining study area AEZ 2 is 49% and AEZ 7 is 46%. The remaining 5% is outside level I zone or other zones.

b. United Nations Environmental Programme (UNEP)/GRID database on population (see Deichmann and Eklundh 1991)

c. Wetlands utilization research project (WURP); see Hekstra et al. (1983)

The number of settlements and the density of road networks were higher in AEZ 7 compared to AEZ 2. AEZ 2, however, has Parakou, a township of significant size with an area of about 3000 ha (representing about 90% of the area of all settlements in the AEZ 7 zone) and a population of nearly 90,000. AEZ 7 has several moderate-sized settlements including Save (390 ha), Bassila (160 ha), and Bante (80 ha). Apart from Parakou, the maximum size of any settlement in AEZ 2 was about 70 ha.

4.3 Land-use characterization of valley bottoms, valley fringes, and uplands

Land-use characteristics were mapped separately for valley bottoms, valley fringes, and uplands using the CLUSTR unsupervised classification algorithm of ERDAS. The classification process used six nonthermal bands of TM. The GPS data and the land-use/land-cover data were used along with the spectral vegetation indices to identify the spectral classes of unsupervised classification. The initial 70 spectral classes of unsupervised classification were reduced to the final 16 land-use classes mapped in this study (table 8). Each of these classes has a varying percentage of 10 land-cover types (table 9). Table 10 shows in a matrix format how the 10 land-cover types are related to the 16 land-use classes. These land-use classes consist of (see table 8):

a. 6 classes of uplands (classes 1, 2, 3, 4, 5, and 6);
b. 3 classes of valley fringes (classes 7, 8, and 9);
c. 3 classes of valley bottoms (class 10, 11, and 12); and
d. 4 classes of others (class 13, 14, 15, and 16).

Pure land-use classes (having a single land-cover type that occupies 100% of its area) are water, settlements, roads, and barren/desert areas. Three land-use classes are synonymous for each component of the toposequence (see table 8):

a. significant farmlands (classes 1, 7, and 10); farmlands (cultivated farms + barren farms) constitute > 30 % of the total land area of this class;
b. scattered farmlands (classes 2, 8, and 11); farmlands constitute > 10 % but ≤ 30 % of the total land area of this class; and
c. insignificant farmlands (classes 3,9, and 12); farmlands constitute ≤ 10 % of the total land area of this class.

The areas of each of the 16 classes in the 2 agroecological and soil zones and in the entire study area are given in table 12. These land use classes are designed on the lines of Anderson et al. (1976). Each land-use class contains a varying degree of land-cover types (table 10). Exact cultivated areas, for example, should be derived from table 12, based on the distribution pattern of land cover provided in table 10. The results for cultivated areas are presented in table 13. For example, the calculation procedure for cultivated valley bottoms in AEZ 2 is as follows:

1. read the areas of valley-bottom classes in AEZ 2 (table 12):
   class 10 (valley bottoms with significant farmlands) = 2012 ha
   class 11 (valley bottoms with scattered farmlands) = 78,174 ha
   class 12 (valley bottoms with insignificant farmlands) = 41,813 ha
2. add these areas up; total valley-bottom area = 121,999 ha
3. note: cultivated area = cultivated farms (land-cover type 5) + barren farms (land-cover type 6)
4. read the percentage of land-cover types 5 and 6 in each valley-bottom land-use class (table 10):
   class 10 = 24% + 15%; class 11 = 2% + 9%; class 12 = 0% + 0.5%
5. calculate cultivated area = Σ (total area × percentage of cultivated area):
   (2012 × 0.39) + (78,174 × 0.11) + (41,813 × 0.005) = 9593 ha
6. calculate cultivated valley-bottom area (9593 ha) as a percentage of total valley-bottom area (121,999 ha) = 7.86% (rounded off to 7.9%).

Table 13 provides the exact cultivated areas for different components of the toposequence.

Table 12 Distribution of land-use classes in the different agroecological and soil zones of the study area[a,b]

	Land-use class	AEZ 2		AEZ 7		Entire study area[b,c] Land region 2.1[c]	
		area (ha)	% of total AEZ 2	area (ha)	% of total AEZ 7	area (ha)	% of total area
	Uplands						
1	significant farmlands	57,853	3.8	148,609	10.3	221,399	7.1
2	scattered farmlands	547,694	35.7	492,119	34.2	1,099,828	35.2
3	savanna vegetation	233,120	15.2	155,091	10.8	407,026	13.0
4	wetlands/ marshland	129,808	8.5	78,665	5.5	218,185	7.0
5	dense forest	126,096	8.2	63,876	4.4	194,141	6.2
6	Very dense forest	30,498	2.0	28,445	2.0	60,052	1.9
	Valley fringes						
7	significant farmlands	12,550	0.8	32,452	2.3	47,861	1.5
8	scattered farmlands	234,627	15.3	250,003	17.4	507,711	16.2
9	insignificant farmlands	33,846	2.2	31,807	2.2	67,597	2.2
	Valley bottom						
10	significant farmlands	2,012	0.1	4,943	0.3	7,537	0.2
11	scattered farmlands	78,174	5.1	82,934	5.8	169,027	5.4
12	insignificant farmlands	41,813	2.7	59,160	4.1	103,895	3.3
	Others						
13	water	402	0.0	629	0.0	1,223	0.0
14	settlements/ built-up area	668	0.0	1,279	0.1	4,967	0.2
15	roads	1,856	0.1	1,858	0.1	3,929	0.1
16	barren/desert area	3,938	0.3	8,324	0.6	13,999	0.5
	Total	1,534,955	100.00	1,440,193	100.00	3,128,377	100.00

Notes:

a. For the composition of land-cover types and their distribution in each land-use class, see tables 8 and 10.

b. Level I agroecological and soil zones (see figure 1 and table 1). AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the Derived savanna with Luvisols. AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones.

c. 100% of the entire study area falls within the land region 2.1 of the WURP map (Windmeijer and Andriesse 1993) (see figure 2); hence the results of the entire study area are also those of land region 2.1.

Table 13 Distribution of valley bottoms, fringes, and uplands, and their cultivation pattern in the study area[a]

	Subarea	Level I agro-ecological and soil zones[b]	% of entire study area (% of full scene)	Valley-bottom Area		Valley-fringe Area		Upland Area	
				as a % of total geographic area[c] (%)	cultivated as a % of total valley-bottom area (%)	as a % of total geographic area[c] (%)	cultivated as a % of total valley-fringe area (%)	as a % of total geographic area[c] (%)	cultivated as a % of total upland area (%)
A.	Parakou and Tchaourou region of Rep.of Benin	AEZ 2	49	7.9	7.9	18.3	15.1	73.3	11.2
B.	Save/Bante/ Gonka/Bassila region	AEZ 7	46	10.2	7.7	21.8	16.6	67.1	14.3
C.	Entire study area	land region 2.1	100	9.0	7.9	19.9	15.9	70.3	13.2

Notes:

a. 100% of the study area falls in the WURP (Windmeijer and Andriesse, 1993) land region 2.1. Hence the results of the entire study area are applicable to land region 2.1.

b. AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the Derived savanna with Luvisols. AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones.

4.4 Discussion of results: valley bottoms, valley fringes, and uplands

Valley bottoms make up 10.2% of the geographical area of AEZ 7 (with a length of growing period of 211-270 days) compared with 7.9% of AEZ 2 (with length of growing period of 181-210 days (table 13). This proves one of the hypotheses that the percentage valley-bottom area is significantly higher in the wetter agroecological zones compared to the drier zones. The same was true for valley fringes which occupy 21.8% of the geographical area of AEZ 7 compared to 18.3% for AEZ 2. In the entire study area of 3128377 ha (path:192, row:54 of Landsat TM) valley bottoms were 9% (see plate 4). This plate provides the spatial distribution of inland valley bottoms and depicts their land-use characteristics. The poor density of inland valleys in the center of the image was caused by the presence of the major river Ouémé flowing north to south.

The intensity of valley-bottom cultivation increased slightly as the length of growing period decreased (table 13). Thereby, the hypotheses that the cultivation intensities decrease significantly in the valley bottoms of the drier zones in comparison with wetter zones was not correct. There was significantly higher cultivation intensity at valley fringes and uplands in AEZ 7 compared to AEZ 2 (table 13) which may be explained by a denser network of major roads and a greater number of major settlements for this zone (table 11). The higher intensity of valley-fringe and upland cultivation may also be a result of a wetter zone 7 (length of growing period 211-270 days). It should be noted that valley-fringe areas have significantly higher cultivation (15-17%) than uplands (11-14%).

The 16 land-use classes mapped for uplands, valley fringes, valley bottoms, and others (water body, settlements, roads, and desert lands) have been depicted in plate 5. Land-use intensities such as cultivation intensities described in previous paragraph can then be derived using land cover types as presented in section 4.3. The spatial view of the variability of land-use classes has been depicted in plate 5.

Class 12 of this study (valley bottoms with insignificant farmlands) is considered to be similar to USGS class 61 (forested wetland) since these are valley bottoms with dense natural vegetation. For a full comparison of both classification systems, see Thenkabail and Nolte (1995). The percentage of valley-bottom area with dense natural vegetation (class 12) was highest in AEZ 7 with 4.1% of the total geographic area or 40.2% of total valley-bottom area (classes 10, 11, and 12 comprise total valley bottoms) (table 12). Of this area 28% was covered by trees, 40% by shrubs, and 30% by grasses (see land-cover types 2, 3, and 4 for class 12 in table 10). The corresponding figures for class 12 in the AEZ 2 was 2.1% of the total geographic area or 34.2% of the total valley-bottom area (table 12). In addition, the scattered farmland class for valley bottoms (class 11) was mostly uncultivated (see table 10) in AEZ 7 and AEZ 2. This low cultivation in valley bottoms was a result of a road network with low density and also low population densities (with a concentration of settlements mainly along major roads (table 5). Valley bottoms with insignificant farmlands were concentrated mostly along the Benin/Togo border, along the banks of River Okpara (Nigeria/Benin border), and south of Bétérou along the banks of River Ouémé (see plate 4 and figure 4). This was mainly due to a poor road network, poor market access, and low population densities.

In general, the results in table 13 indicate a relatively low percentage of land utilization as farmland across the toposequence and agroecological and soil zones in terms of geographical area. No data could be obtained of the exact extent of the arable area in the region.

A very detailed map has been produced for a subarea around Gouka (plate 6). More farmlands occur around settlements (e.g., see around Gouka) and road networks than away from them. Valley-fringe cultivation in valleys around Gouka was very pronounced compared to areas elsewhere. The red-orange color around the road network depicts mainly cashew plantations (mapped as very dense forest).

Table 14 TM-derived vegetation indices for the final land-use classes

Land-use class[b]	Mean values[a]				
	TM3	TM4	TM5	RVI[c]	MSVI1[d]
1	40.54	46.03	85.78	1.13	0.53
2	38.34	42.70	75.22	1.11	0.56
3	36.71	38.03	62.66	1.03	0.60
4	34.97	32.18	47.85	0.92	0.67
5	34.16	42.10	57.29	1.23	0.73
6	35.37	45.58	65.05	1.28	0.70
7	40.07	45.93	85.95	1.14	0.53
8	36.73	38.62	64.15	1.05	0.60
9	34.36	44.11	60.53	1.28	0.72
10	39.50	45.68	83.64	1.15	0.54
11	36.17	39.46	64.28	1.09	0.61
12	33.77	45.84	58.6	1.35	0.78
13	32.43	26.52	24.55	0.81	1.08
14	44.36	47.63	89.55	1.07	0.53
15	42.39	44.09	84.55	1.04	0.52
16	43.17	48.52	98.43	1.12	0.49

Notes:

a. Data were obtained from 10 sample areas, each of 200 pixel by 200 pixel size for each of the 16 land-use classes; this was done using MASK and BSTATS option of ERDAS.

b. Names of the land-use classes are given in table 8.

c. RVI = ratio vegetation index; calculated by TM4/TM3.

d. MSVI1 = midinfrared simple vegetation index 1; calculated by TM4/TM5.

4.5 Spectral characteristics of land-use classes

The mean spectral characteristics of each of the 16 land-use classes (table 14 and figure 13) were determined based on spectral characteristics of sample areas, each with an area of 200 pixel by 200 pixel, randomly selected in the image. This was achieved by masking the image area (using the MASK routine of ERDAS) outside the class of interest and then generating the multispectral digital value statistics for the class of interest (using the BSTATS routine of ERDAS). Vegetation indices were subsequently derived using the digital values. Alternatively, cluster statistics generated by the unsupervised classification output can also be used to derive vegetation indices. Several inferences could be drawn from the results of the spectral signatures presented for the 16 classes in table 14. These were:

1. The ratio vegetation index (RVI = TM4/TM3) value of 1.35 for class 12 (insignificant farmlands) was significantly higher (at 0.05 level) when compared with the RVI value of the

other 15 classes. This was attributed to denser natural vegetation and greater plant vigor at valley bottoms because more moisture was available for plants during the dry season (period date of satellite overpass used in this study) when compared with the vegetation of fringes and uplands. During ground-truthing, the tree, shrub, and grass vegetation of valley bottoms was observed to be relatively more moist and green (qualitative estimates). This result suggests that valley bottoms are best delineated using remotely sensed data of dry seasons when the contrast between the wetter valley bottoms, and the drier uplands is known to peak (Turner 1985).

2. The densest vegetation at valley fringes (class 9 with a RVI value of 1.28) had spectral characteristics similar to the densest vegetation at uplands (class 6 with RVI value of 1.28). Also, RVI values for the classes with significant farming across the toposequence were of: 1.15 for valley bottoms (class 10), 1.14 for valley fringes (class 7), and 1.13 for uplands (class 1). These results clearly indicate the infeasability of separating these classes across the toposequence purely through spectral characteristics and the use of the approach outlined in section 4.1.

3. The mean RVI values of two diverse classes intermixed significantly; for example, class 11 (RVI = 1.09) versus class 14 (RVI = 1.07) and class 8 (RVI = 1.05) versus class 15 (RVI = 1.04). This indicates the need to use in such cases indices involving other spectral bands. One example has been provided by using the midinfrared simple vegetation index 1 (MSVI1) as shown in table 14. Unlike the RVI values, the MSVI1 values were significantly different between class 11 (MSVI1 = 0.61) and class 14 (MSVI1 = 0.53) and between class 8 (MSVI1 = 0.60) and class 15 (MSVI1 = 0.52). These results highlight the need to use multiple bands to extract diverse information through image classification and enhancement techniques. As depicted in figure 13, in the dry season the MSVI1 values had peaks for high vegetation densities (classes 5, 6, 9, and 12) and troughs for predominantly barren farmlands (classes 1, 7, and 10), barren lands (class 16), roads (class 15), and settlements (class 14). Classes with scattered farms (classes 2, 3, 8, and 11) fall in-between. The moisture sensitivity of the moisture-absorption band (TM 5) is depicted through high values of classes 1 and 2. RVI values generally were similar to MSVI1 values, forming the peak in classes with high vegetation densities. However, classes 8 and 11 form a trough in RVI values, unlike in MSVI1 values.

4.6 Cultivation intensities with respect to distance from settlements and road networks

Cultivation intensities of valley bottoms, valley fringes, and uplands were calculated relative to their distance from settlements and the road network through manipulation of relevant GIS spatial datalayers. Techniques such as boolean logic interpolation and contiguity analysis were used. Plate 7 illustrates land-use categories of valley bottoms, and valley fringes for a sample area at various distances from settlements and road networks. Four distance limits (0–2 km, 2–4 km, 4–5 km, and > 5 km) were considered since 5 km was thought to be the greatest distance for farmers to commute to their farms.

The cultivation intensities relative to roads and settlements for the two agroecological and soil zones (AEZ 2 and AEZ 7), and the entire study areas have been summarized in table 15. The results in this table indicate the following trends in AEZ 2, AEZ 7, and in the entire study area: (a) decreasing cultivation intensities across the toposequence with increasing distances from settlements and roads; (b) slightly greater percentage of cultivation across the toposequence relative to distance from settlements than from the road network; (c) about 3 to 4% higher cultivation in valley fringes compared to uplands and valley bottoms. Cultivation in AEZ 7 was generally higher at valley fringes (16.1% to 20.5%) and on uplands (13.7 to 18.3%) compared with valley-fringe (14.6% to 20.4%) and upland cultivation (10.5% to 16.9%) in AEZ 2. Cultivation of valley bottoms did not exceed 11.5% irrespective of the distance from settlements or road networks. Overall, the cultivation across the toposequence was modest with a maximum cultivation at the valley fringes (20.5% in the 0–2 km distance zone from settlements).

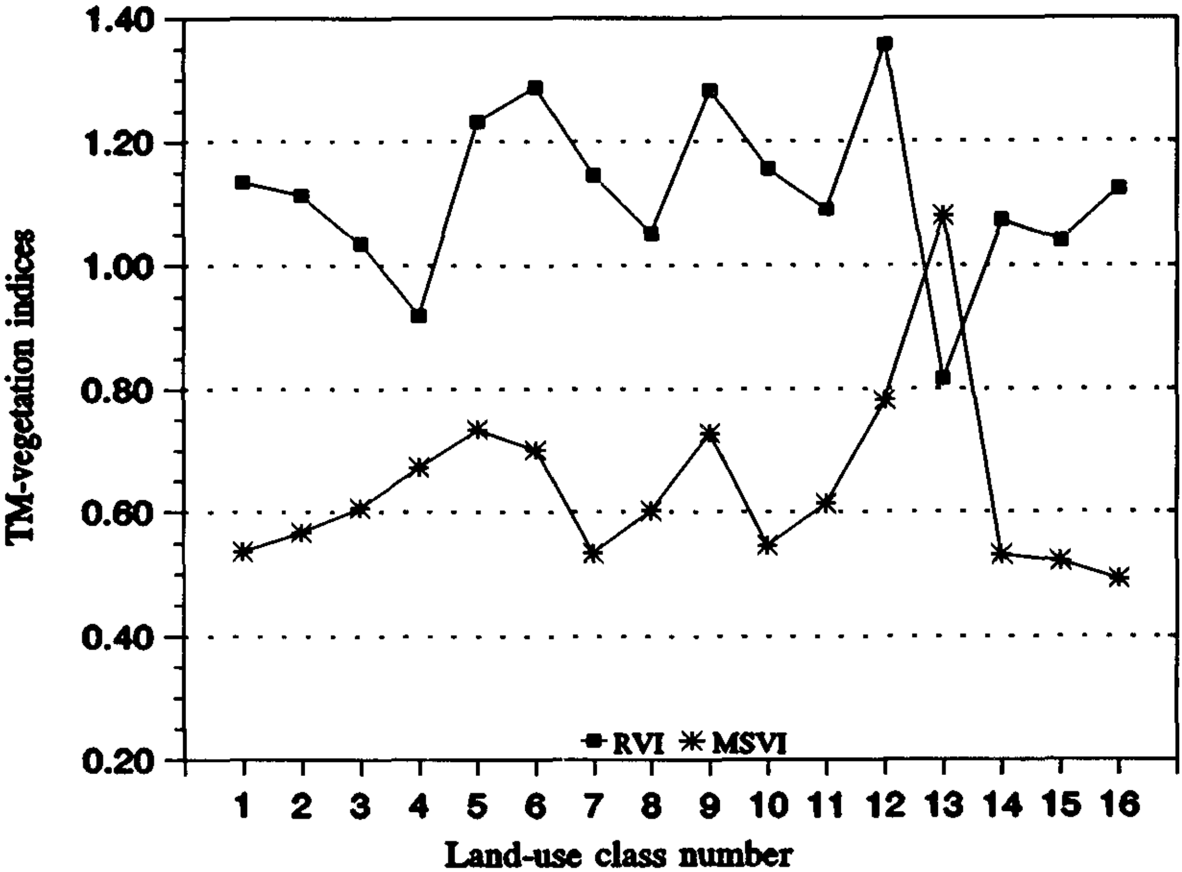

Figure 13 Selected vegetation indices for land-use class 1 through 16

4.7 Studying the cultivation pattern across the toposequence in the entire study area

The spatial distribution of significantly cultivated areas is illustrated for the uplands and valley fringes plus valley bottoms in plates 10 and 11, respectively, for the entire study area. It is clear from these plates that there is a high correlation between the cultivation pattern of uplands, valley fringes, and valley bottoms. This proves one of the hypotheses of Izac et al. (1991) that the degree of upland cultivation has a strong influence on the degree of lowland cultivation (valley bottoms and valley fringes). Also, settlements and roads influence these cultivation patterns. For example, the polygons 1, 2, 3, and 4, shown in plates 10 and 11 have insignificant cultivation as a result of lack of settlements and road networks in these regions.

4.8 Studying inland-valley characteristics from ground-truth data

Qualitative and quantitative data from 62 valley bottoms and 61 valley fringes were gathered at different stream orders. Nearly 50% of these inland valleys were first-order (table 16). When fewer than 3 inland valleys for a given stream order have been investigated, data were not used in the statistical analysis presented in table 16, resulting in the absence of any stream order higher than 2 for AEZ 2 and any stream order higher than 3 for AEZ 7. The results have been presented within and across agroecological zones. Within AEZ 2, the characteristics of inland valleys, such as bottom width, transversal slope, fringe width, and shape ratio, remained similar between two stream orders (table 16). Within AEZ 7, the mean bottom widths significantly increased for second-order valleys compared to the first-order valleys. But the valleys tended to have smaller bottom widths at third-order compared to second-order valleys. The third-order valleys had a lower shape ratio (table 16).

Table 15 Cultivation pattern of valley bottoms, fringes, and uplands with respect to their distance from settlements and road networks for different level I zones[a]

Distance limit (km)	Valley Bottom: Cultivated valley-bottom area as percentage of total valley-bottom area within the corresponding distance limit			Valley Fringe: Cultivated valley-fringe area as percentage of total valley-fringe area within the corresponding distance limit			Upland: Cultivated upland area as percentage of total upland area within the corresponding distance limit		
	AEZ 2	AEZ 7	entire study area	AEZ 2	AEZ 7	entire study area	AEZ 2	AEZ 7	entire study area
	%	%	%	%	%	%	%	%	%
Distance from settlements									
0–2	11.5	11.2	11.6	20.4	20.5	20.1	16.9	18.3	18.7
>2–4	10.4	8.7	9.6	17.2	18.4	18.1	14.7	17.0	17.1
>4–5	9.2	8.1	8.6	16.5	17.6	17.1	13.6	16.1	16.0
>5	7.6	7.5	7.6	14.8	16.3	15.6	10.8	13.9	13.2
Distance from road network									
0–2	10.3	9.2	9.8	17.3	18.9	18.3	14.9	17.5	16.0
>2–4	9.4	8.1	8.7	16.6	17.7	17.2	13.4	15.1	14.8
>4–5	8.7	7.4	8.1	15.7	17.0	16.3	12.2	15.4	14.0
>5	7.4	7.5	7.5	14.6	16.1	15.3	10.5	13.7	12.0

Notes:

a. AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the Derived savanna with Luvisols. AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones.

Table 16 Morphometric characteristics of inland valleys in the two agroecological and soil zones obtained through ground-truth data

AEZ	Stream order	Bottom width		Transversal slope		Fringe width		Shape ratio	
Within agroecological and soil zones		n	(m)	n	(degree)	n	(m)	n	(degree)
AEZ 2	1	18	81[a]	15	1.4[a]	16	156[a]	16	0.52[a]
	2	5	57[a]	5	2.0[a]	5	176[a]	5	0.42[a]
AEZ 7	1	9	45[a]	10	1.5[a]	9	327[a]	9	0.16[a]
	2	8	80[b]	8	1.3[a]	5	323[a]	5	0.25[a]
	3	8	40[a]	7	1.7[a]	6	472[a]	6	0.15[a]
Across agroecological and soil zones									
AEZ 2	1	18	81[a]	15	1.4[a]	16	156[a]	16	0.52[a]
AEZ 7	1	9	45[a]	10	1.5[a]	9	327[b]	9	0.16[b]
AEZ 2	2	5	57[a]	5	2.0[a]	5	176[a]	5	0.42[a]
AEZ 7	2	8	80[a]	8	1.3[a]	5	323[b]	5	0.25[a]
Entire study area and land region 2.1									
Entire study area	1	27	69[a]	25	1.5[a]	25	218[a]	25	0.39[a]
	2	13	71[a]	13	1.5[a]	10	250[a]	10	0.33[a]
	3	9	38[a]	8	1.8[a]	7	469[b]	7	0.13[a]

Notes:

AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the Derived savanna with Luvisols. AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones.

Within agroecological zones: Except valley bottom widths between first- and second-order valleys, and second- and third-order streamflow valleys, **none** of the other parameters were significantly different between first- and second-order streamflow valleys of AEZ 2 and first-, second-, and third-order streamflow valleys of AEZ 7. Significant differences are given at 0.05 level.

Across agroecological zones: The first-order streamflow valleys were significantly (at 0.05 level) different between AEZ 2 and AEZ 7 for fringe widths and shape ratio. The second-order streamflow valleys were significantly different between AEZ 2 and AEZ 7 for fringe widths.

In the entire study area: only fringe widths were significantly different between different orders of streamflow valleys.

Between the two agroecological and soil zones, fringe widths and shape ratios provided distinctive differences: there were significantly higher mean fringe widths for AEZ 7 over AEZ 2 for valleys along stream orders 1 and 2 and significantly lower shape ratios for the first-order valleys in AEZ 7 versus AEZ 2. This was not confirmed for the second-order valleys. In the entire study area (also for land region 2.1), fringe widths were significantly higher at third-order valleys versus the first- and second-order valleys. Good physical characteristics for the development of valleys were indicated by bottom widths (generally over 50 m) for the first-, second-, and third-order streams where inland valleys mostly occur. The mean widths of valley bottoms along first- to third-order streams were relatively small in the study area (40 to 81 m). Up to 90% of the inland valleys were U-shaped, meaning that the bottom had a substantial width (> 10-20 m) compared to the fringe. Only 17% of the investigated inland valleys had some improved water management features such as field leveling and bunding.

4.9 Establishing morphometric characteristics from ground-truth and TM data

Characteristics of watersheds, such as stream density (length of streams in a watershed to the area of watershed in km/km^2), stream frequency (number of streams to the area of watershed in streams/km^2), and the area of watersheds were computed from TM as well as from topographic map data (1:50,000 and 1:200,000), and are presented in table 17. In most cases, TM data slightly underestimated stream densities and stream frequencies compared to topographic maps. The stream densities were much higher for AEZ 7 (1.07 to 1.20 km/km^2), compared to AEZ 2 (0.9 to 1.0 km/km^2). The same was true for stream frequencies with AEZ 7 having 0.95-1.10 streamflow valleys/km^2 compared to 0.74 to 0.79 streamflow valleys/km^2 in AEZ 2. These results indicated higher density and frequency of streamflow valleys in the wetter zone (AEZ 7 with length of growing period of 211-270 days in a year) compared to relatively drier zones (AEZ 2) with length of growing period of 181-210 days in a year. With respect to the classification system of Hekstra et al. (1983), the drainage densities in this study area were medium (0.6-1.2 km/km^2) and stream frequencies were coarse (0.5-1.0 streams/km^2).

4.10 Determining the cropping pattern of inland valleys from ground-truth data

The spatial distribution of crops on farmland could not be determined by means of TM data because of their historical nature (date of overpass: 29 December 1991). However, the number of ground-truth observations at valley bottoms (n=62), valley fringes (n=61), and uplands (n=25) spread over the study area of 3.12 million ha offered a limited opportunity to interpret cropping patterns observed on farm fields.

The following remarks are exclusively based on the analysis of ground-truth data. The inland valleys chosen as ground-truth sites were randomly selected, limited only by accessibility. The upland readings were stratified according to striking features such as plantations, very dense canopy cover, or open areas. During ground-truthing, no specific distinction was made between uncultivated land and fallow land, (both having a canopy cover of trees, shrubs, and grasses) because such information could not be used with the historical TM data. Completely untouched land is most unlikely to exist in the study area, except in forest reserves. Therefore, trees and shrubs to be found on uncultivated land are secondary vegetation. However, there is land covered with long-term regrowth and land included in the rotational scheme of farmers covered with short-term (3-6 years) regrowth of trees and shrubs. Land with short-term regrowth fallow has fewer trees and shrubs.

Table 17 Characteristics of watersheds of inland valleys analyzed with Landsat-TM and ground-truth data

Characteristics relating to inland valley watersheds		Level I agroecological and soil zones (AEZ)[a]		
		AEZ 2	AEZ 7	entire study area
Mean drainage density (km/km^2)	TM	0.9	1.07	1.04
	GT[b]	1.0	1.20	1.11
Mean stream frequency (no/km^2)	TM	0.71	0.95	0.88
	GT[b]	0.79	1.10	0.92
Mean size[c] of watershed (km^2) of:				
second-order streams		11	11	9
third-order streams		28	35	32
fourth-order streams		82	79	78

Notes:

Hekstra et al. (1983) classified:

1. Drainage densities (km/km^2) as: very low (0–0.3); low (0.3–0.6); medium (0.6–1.2); high (1.2–2.4); and very high >2.4; and
2. Stream frequencies (number/km^2) as: very coarse (0–0.5); coarse (0.5–1.0); medium (1–2); fine (2–3); and very fine (>3).

a. AEZ 2 represents the southern Guinea savanna with Luvisols and AEZ 7 the Derived savanna with Luvisols. AEZ 2 occupies 49% and AEZ 7 46% of the entire study area. The remaining 5% are located outside the level I zones.

b. Determined using chartometer and counts on topographic maps

c. Determined using a planimeter on topographic maps

The relative distribution of species on uncultivated and fallow land in fringe position in inland valleys was 32% trees, 30% shrubs, and 38% grasses (table 18). On the upland, more trees (38%) and shrubs (34%) were observed. Two explanations are possible:

a. At the fringes of inland valleys, more land is covered with short-term fallow;
b. Given the exposure of soil on sloping terrain, regrowth of woody species may be slowed or inhibited by soil erosion occurring on the fringes of inland valleys.

The percentage of total farmland, cultivated and barren, determined on the fringes of inland valleys (18.3%) and on uplands (16.5%) showed no statistical difference. In the bottoms of inland valleys, grasses dominated strikingly with 53% of the canopy cover on uncultivated and fallow land (table 18). This is due to the seasonally waterlogged soil conditions, impeding the growth of most woody species (Menaut 1983). Land use as farmland was significantly lower in the bottoms of inland valleys (9.6%) compared to the fringes and uplands. Cultivation of farms differed according to the topographic position. Therefore, 35% of the farms in the bottoms of inland valleys were cropped, compared to 74% on the fringes, and 30 % on the uplands. Between 6 and 8% of the land was classified as barren land and others (rock outcrops, waterbodies, riverbeds, wastelands, abandoned areas of former settlements, roads or footpaths). Table 19 illustrates the cropping pattern on farms. About one-third of the 62 valley bottoms visited (38%) and 25 uplands (28%) were farmed, compared to two-thirds of the 61 valley fringes (67%). Most of the farms were barren, regardless of the topographic position (65% for valley bottoms, 59% for valley fringes, and 86% for uplands). This was caused by the dry condition of soils. Out of the 62 valley bottom soils investigated, 59 were dry. Only two had an accessible groundwater table within 1 m or 50–75 cm below the ground surface. Cassava and in some cases yam were the major crops to be found in the bottoms and at the fringes of inland valleys. Vegetables such as melon, pepper, and okra, were observed on 29% of the valley fringes but in hardly any valley bottoms.

Table 18 Land-use pattern in valley bottoms, at valley fringes, and on uplands of inland valleys the study area, determined using ground-truth data (collected at the end of dry season 21–29 March 1993)

Toposequence position	Observations	Uncultivated and fallow land			Subtotal (%)	Farmland		Subtotal (%)	Barren land and others	Total
		Trees (%)	Shrubs (%)	Grasses (%)		Cultivated (%)	Barren (%)		(%)	
A. Relative distribution of land-use patterns within a 90 × 90 m plot										
bottoms	62	21.0 (b/0.10)	18.6 (c/0.05)	44.4 (c/0.01)	84.0 (a)	3.4 (a/0.01)	6.2 (a)	9.6 (b/0.05)	6.0 (a)	100 %
fringes	61	24.4 (a)[1)]	23.3 (b/0.10)	29.5 (b/0.10)	77.2 (a)	13.6 (b/0.05)	4.7 (a)	18.4 (a)	4.5 (a)	100 %
uplands	25	28.6 (a)	26.0 (a)	20.9 (a)	75.5 (a)	5.1 (a)	11.4 (a)	16.5 (a)	7.9 (a)	100 %
B. Relative distribution of land-use types within a pattern										
bottoms	62	25 %	22 %	53 %	100 %	35 %	65 %	100 %		
fringes	61	32 %	30 %	38 %	100 %	74 %	26 %	100 %		
uplands	25	38 %	34 %	28 %	100 %	30 %	70 %	100 %		

Note:
Figures with a different letter are significantly different within their group at the given levels (0.01, 0.05, 0.10) using the LSMEAN procedure of SAS.

Table 19 Farmland cropping pattern at bottoms, fringes, and on uplands of inland valleys in the study area, determined using ground-truth data[a,b]

Toposequence position	Farms	Rice	Cassava/yam	Sorghum/Maize	Cotton	Vegetables	Bananas	Barren
				Observations in absolute figures				
bottoms (n=62)	20	2	10	0	0	1	1	13
fringes (n=61)	41	1	28	7	1	12	2	24
uplands (n=25)	7	0	1	1	0	0	0	6
				Observations in relative figures				
bottoms	32 %	10 %	50 %	0 %	0 %	5 %	5 %	65 %
fringes	67 %	2 %	68 %	17 %	2 %	29 %	5 %	59 %
uplands	28 %	0 %	14 %	14 %	0 %	0 %	0 %	86 %

Note:

a. Multiple cropping is common on farmland; therefore, relative figures may not total 100%.

b. Data are solely based on ground-truth observations; they only indicate crops observed and do not intend to give a spatial analysis. This was impossible due to the use of historical remotely-sensed data (date of overpass: 29/12/1991; date of ground-truthing 21–29/3/1993).

V

Key Site and Key Watershed Selection for Technology Development

The output spatial datalayers of level II study obtained from TM data (e.g., land use of valley bottoms, valley fringes, and uplands, road networks and settlements) were used in GIS modeling to select key sites for level III technology development research. The data obtained from ground truthing were incorporated in the above datalayers, also the location data of each ground-truth site.

Expert opinion was sought to rate each of the above spatial datalayers on a scale of 1 to 5 (5 being the best). This was done by weighing each factor of each datalayer according to its impact on inland valley cultivation according to the expert concerned. For a detailed discussion, see Thenkabail and Nolte (1995).

The modal value of expert opinion was taken for each variable pertaining to each spatial datalayer and incorporated into GIS modeling, using the GISMO routine of ERDAS. The expert opinion indicated the following:

1. Intensely cultivated uplands stimulate cultivation of nearby inland valleys (valley bottoms and valley fringes). Thereby, inland valley utilization should be focused in areas where there is already upland cultivation;
2. The farmers are more likely to exploit partially cultivated inland valleys more fully than embark on hitherto unexploited valleys;
3. The proximity of settlements to inland valleys stimulates their utilization for agricultural purposes;
4. The proximity of roads to inland valleys stimulates their utilization for agricultural purposes;
5. The greater the population density, the greater is the possibility of inland valley utilization; and
6. The shorter the growing period (that is, the drier the agroecological zones), the greater is the likelihood of inland valleys being used for cultivation.

The expert knowledge was used to weigh or rank data values in various spatial datalayers. Then, through GIS manipulation of these spatial datalayers, areas with high a potential for becoming benchmark research sites were indicated (see plate 8). Plate 8 highlights those inland valleys that have been rated best (rank 1 in a scale of 1 to 5). They represent the greatest potential for development and should be candidates for key sites or key watersheds. The final key-site selection would be based on a rapid appraisal of some of these inland valleys and their cultivation pattern. Detailed maps of the potential benchmark locations to be visited with roads, settlements, and valleys are important during field visits (see plate 9, for example). Plate 9 also provides information on the valley-bottom characteristics such as their spatial distribution, valley-bottom density, and land use. In addition, valley-bottom systems are well depicted.

A team of researchers representing varied expertise, such as agronomists, breeders, soil scientists, hydrologists, and remote sensing/GIS specialists will then visit the potential benchmark site locations for a rapid appraisal. The parameters assessed are moisture status of the valleys, issues of natural resource protection (flora and fauna inventory), accessibility to markets, socioeconomic and health issues, and cost and labor of clear-cutting. In addition, interest of national agricultural research systems (NARS) in these sites and interviews with farmers will be important. A final selection of a benchmark site or watershed is done only after the above appraisal of one or more of the potential benchmark sites.

VI

Summary and Conclusions

This study presents and discusses the results of regional (level II) mapping and characterization of inland valley agroecosystems in an area of 3.12 million ha in the Save, Bante, Bassila, and Parakou regions of the Republic of Benin (figure 4). The study involved using Landsat-5 Thematic Mapper (TM) data (path:192, row:54 of the Landsat world reference system) with 29 December 1991 as the date of overpass in conjunction with global positioning system (GPS) data and ground-truth data in a geographic information systems (GIS) framework. All spatial datalayers were georeferenced to Universal Transverse Mercator (UTM) co-ordinates obtained during ground-truthing using a GPS.

The study area encompassed two level I (macro or subcontinental) agroecological and soil zones: AEZ 2 (southern Guinea savanna with Luvisols) and AEZ 7 (derived savanna with Luvisols) (see table 1 and figure 5). AEZ 2 is representative of 18.4 million ha and AEZ 7 of 24.9 million ha in West and Central Africa (see spatial distribution of these zones in figure 1). Both these agroecological and soil zones have Luvisols as major soil grouping. The zones differ in their length of growing period, with AEZ 2 having 181-210 days and AEZ 7 having 211-270 days. The study area is part of a region that gets rainfall varying between 975 mm and 1336 mm per year. Most of the study area falls into a zone (zone 3 in figure 11) with a mean yearly rainfall of 1125 mm and a monomodal pattern. The total study area falls with 49% into AEZ 2 and with 46% into AEZ 7 while the remaining 5% are located outside the level I zones. The entire study area falls into the WURP land region 2.1 (see figure 2 and table 2) and hence the results reported for the entire study area are also applicable to land region 2.1.

The study demonstrated the strength of high-resolution remotely-sensed data in regional mapping and characterization of inland valley agroecosystems. The methodology used in this study allowed the rapid delineation of valley bottoms (see, for example, plate 1, 2, and 3) and characterization of an area as large as a full TM scene (about 3.12 million ha). The multiple bands of TM data involving visible, near- and midinfrared bands complemented and supplemented each other and made possible the discrimination between land-use classes. These were mapped across the toposequence (valley bottoms, valley fringes, and uplands) for the entire study area (see plate 5) and for subareas (see, for example, plate 6). TM data facilitated mapping the shape, size, spatial distribution, density, and frequency of inland valley bottoms occurring in the study area (see plates 4 and 9). They were also found to be very useful in detecting settlements (usually of sizes of > 15 ha) and the motorable road network (see, for example, plates 8 and 9). This was especially useful in mapping the recent spread of settlements and the road systems in the absence of such information on base maps, such as topographic maps (which were mostly available from the early 1960s). Furthermore, the cultivation pattern of inland valleys with respect to their distance from settlements and the road network could be studied (see, for example, plate 7).

A total of 9.0% (281,500 ha) of the entire study area (3.12 million ha) is occupied by valley bottoms (see plate 4 and table 13). The corresponding figures for the subzones were 7.9% in AEZ 2 and 10.2% in AEZ 7. Valley fringes accounted for 18.3% in AEZ 2, 21.8% in AEZ 7, and 19.9% in the entire study area, while uplands represented 73.3% in AEZ 2, 67.1% in AEZ 7, and 70.3% in entire study area. These results indicated a greater percentage of inland valleys in the wetter zone (AEZ 7) compared to the drier zone (AEZ 2).

The mapping of land-use classes across the land elements (valley bottoms, valley fringes, and uplands) of the toposequence involved determining their extent of cultivation. The cultivation intensity differed only marginally between the AEZs (table 13). A total of 7.9% of the valley bottoms in the entire study area was cultivated with 7.9% in AEZ 2 and 7.7% in AEZ 7. A total of 15.9% of the valley fringes was cultivated in the entire study area with 15.1% in AEZ 2 and 16.6% in AEZ 7. Compared to the valley fringes, less of the upland area was used as farmland, 13.2% across the entire study area, 11.2% in AEZ 2, and 14.3% in AEZ 7. These results indicated a low percentage of cultivation across the toposequence. This was attributed to: (a) a low density of the road network and (b) a low number of settlements, hence low population densities. In addition, socio-economical issues such as the traditional preference of farmers in cultivating uplands, debilitating diseases in lowlands, lack of appropriate technologies (e.g., low-cost water management techniques), lack of knowledge about lowland agriculture, lack of market access, and lack of governmental support for farmers imply less than optimal utilization of inland valleys for agriculture.

Vegetation of uncultivated and fallow land was dominated by grasses (53%) in valley bottoms and showed an almost equal proportion of grasses, shrubs, and trees at valley fringes and on uplands (table 18). At the time of ground-truthing (21 through 29 March 1993) the majority of farmlands in valley bottoms (65%) and on uplands (70%) were barren. Only 26% of farms at valley fringes were uncultivated. The dominating crop on cultivated farms was cassava in valley bottoms (50%) at valley fringes (68%) (table 19). Besides, maize was observed in 17% of the farms at valley fringes and cassava/yam (14%) or maize (14%) on upland fields.

There was a high spatial correlation in the cultivation pattern of valley bottoms and valley fringes (plate 11) when compared with the cultivation pattern of uplands (plate 10). Significantly cultivated areas as shown in plates 10 and 11 are mainly concentrated along major road networks and near settlements. The degree of cultivation decreased significantly as the distance from settlements or the road network increased (see, for example, plate 7). The results of cultivation intensities indicated the following trends in AEZ 2, AEZ 7, and in the entire study area: (a) a decreasing trend in the cultivation intensities across the toposequence with increasing distances from settlements and roads; (b) across the toposequence a slightly greater percentage of cultivation near settlements than in the vicinity of road networks; (c) about 3 to 4% higher cultivation at valley fringes compared to uplands and valley bottoms. The cultivation intensity at valley fringes (16.1% to 20.5%) and on uplands (13.7 to 18.3%) was generally higher in AEZ 7 than in AEZ 2, where cultivation intensities were 14.6% to 20.4% at valley fringes and 10.5% to 16.9% on uplands. Not more than 11.5% of the valley bottoms were cultivated in any distance zone from settlements or the road network. Overall, the cultivation intensity across the toposequence was modest with a maximum at fringes (20.5%) in the 0-2 km distance zone from settlements. However, this is in terms of the geographical area. No data could be obtained on the exact extent of the arable area in the region.

Stream drainage densities (km/km^2) were denser in the wetter zone (AEZ 7: 1.07 to 1.20 km/km^2) compared to the drier zone (AEZ 2: 0.9 to 1.0 km/km^2). The same was true for inland valley stream frequencies (number of streams per km^2): 0.95 to 1.10 streams/km^2 in AEZ 7; and 0.74 to 0.79 streams/km^2 in AEZ 2 (table 17). These figures differ from the estimates for the Guinea savanna given in the WURP report where drainage densities were classified as low to medium (0.3-0.6 km/km^2) and stream frequencies as very coarse (0-0.5 streams/km^2) (Windmeijer and Andriesse 1993).

About 90% of the inland valleys were classified as U-shaped. Only about 17% of those surveyed during ground-truthing had some improved water management schemes, such as field leveling and bunding. The valley bottom widths of first- to third-order valleys in AEZ 2 and AEZ 7 varied between 40 m and 81 m and hence provided considerable valley-bottom areas (7.7% to 9.0% of the geographic area). The valley bottoms are flat to near-flat. Most valley bottoms are characterized by grassy vegetation that could be easily cleared for cultivation.

Soil conditions in valley bottoms were not investigated in this study and the data presented in figure 8 and table 4 indicate only soil conditions on uplands and at nonhydromorphic valley fringes. The 1:5,000,000 scale of data in the FAO soil map of Africa (FAO/UNESCO 1977) is too small to capture inland valley locations. However, soils in valley bottoms do reflect the characteristics of soils of surrounding locations so that data of figure 8 and table 4 can be used for a first assessment. To characterize soil conditions in valley bottoms would require a detailed survey which was done by Kyuma et al. (1986) at 71 locations in West Africa.

Valley fringe widths of first- and second-order streams were significantly higher (at 0.05 level) in AEZ 7 (with 157 m and 176 m, respectively, see table 16) compared with 327 m and 323 m for first- and second-order streams, respectively, in AEZ 2. Hence, this provided the single distinctive physical parameter differentiating the valleys of AEZ 7 from those of AEZ 2.

This study integrated high-resolution remotely-sensed data with global positioning, ground-truth, expert knowledge and secondary data. GIS manipulation of these various spatial datalayers led to a selection of potential benchmark sites for technology development research activities (see plates 8 and 9). A final selection of a benchmark site or watershed can be done after a rapid appraisal of factors, such as moisture status of the valleys, issues of natural resource protection (flora and fauna inventory), accessibility to markets, socioeconomic and health issues, and cost and labor of clear-cutting. In addition, interest of national agricultural research systems (NARS) in these sites and interviews with farmers will be important. In this process one or more of the potential benchmark sites should be visited. The visiting team of researchers should comprise varies experts, such as agronomists, breeders, soil scientists, hydrologists, remote sensing/GIS specialists and should include NARS collaborators and farmers.

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INLAND VALLEY CHARACTERIZATION REPORTS

1. Regional Characterization of Inland Valley Agroecosystems in Save, Bante, Bassila, and Parakou Regions in South-Central Republic of Benin through Integration of Remote Sensing, Global Positioning System, and Ground-Truth Data in a Geographic Information Systems Framework. Prasad S. Thenkabail and Christian Nolte, 1995.

About IITA

The goal of the International Institute of Tropical Agriculture (IITA) is to increase the productivity of key food crops and to develop sustainable agricultural systems that can replace bush fallow, or slash-and-burn, cultivation in the humid and subhumid tropics. Crop improvement programs focus on cassava, maize, plantain and banana, cowpea, soybean, and yam. Research findings are shared through international cooperation programs, which include training, information, and germplasm exchange activities.

IITA was founded in 1967. The Federal Government of Nigeria provided a land grant of 1,000 hectares at Ibadan, for a headquarters and experimental farm site, and the Rockefeller and Ford foundations provided financial support. IITA is governed by an international Board of Trustees. The staff includes around 180 scientists and professionals from about 40 countries, who work at the Ibadan campus and at selected locations in many countries of sub-Saharan Africa.

IITA is one of the nonprofit, international agricultural research centers currently supported by the Counsultative Group on International Agricultural Research (CGIAR). Established in 1971, CGIAR is an association of about 50 countries, international and regional organizations, and private foundations. The World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP) are cosponsors of this effort.

About Inland Valley Consortium

The broad objectives of the Inland Valley Consortium (IVC) are: (i) to improve the competitiveness of crop production in sub-Saharan Africa; (ii) to reduce pressure on the fragile uplands by making it possible for farmers to intensify production in the more robust lowlands; (iii) to minimize environmental costs as inland valleys are brought into cultivation; and (iv) to strengthen the capacity of national research programs through collaboration, and technical, and financial assistance.

Three major research themes are adopted:
- Multiscale agroecological characterization
- *Aménagement* (development of low-cost water management systems)
- Transfer and testing of agronomic technologies

IVC was established in 1994. The present members of the Consortium are national institutes of Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Nigeria, and Sierra Leone, and five international research institutions, West African Rice Development Association (WARDA), International Institute for Tropical Agriculture (IITA), Winand Staring Center (SC-DLO), Wageningen Agriculture (IITA), DLO Winand Staring Center (SC-DLO), Wageningen Agricultural University (WAU), and Centre de Coopération Internationale en Recherche Agronomique pour le Dévelopement (CIRAD). New members are expected in the near future because the Consortium is an open structure for cooperation. The Consortium is based in Bouaké, Côte d'Ivoire, at WARDA headquarters.