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Multi-scale characterization of inland valley agro-ecosystems in West Africa

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Abstract

Inland valleys are the upper reaches of river systems, comprising valley bottoms and minor floodplains which may be submerged for part of the year, their hydromorphic fringes, and contiguous upland slopes and crests. Valley bottoms and hydromorphic fringes are estimated to occupy between 22-52 million ha of land in West Africa. In spite of their potential for agricultural use, they are only marginally used and with limited success. The high physical and biotic complexity and heterogeneity of inland valleys explain why little progress has been made in the systematic characterization of inland valley systems.

We propose a multi-scale agro-ecological characterization with increasing detail at four levels: macro level (scales between 1:1,000,000 and 1:5,000,000), reconnaissance level (1:100,000-1:250,000), semi-detailed level (scales 1:25,000-1:50,000), and detailed level (1:5,000-10,000). Methods of characterization at each of these levels are discussed, and examples of actual applications are given, as well as the mechanisms applied in desaggregation (scaling down) and aggregation (scaling up) between characterization levels. This approach allows (i) a systematic description of (different) inland valley agro-ecosystems; (ii) identification of constraints to sustainable agricultural use; (iii) targeting and implementation of research; and (iv) extrapolation of research results and transfer of newly developed technologies to other areas with similar agro-ecological conditions.

Agro-ecological characterization of inland valleys carried out so far, shows that variation in (bio)physical and land use factors is considerable, both between levels and within valleys. The set of descriptors now developed, allows for extrapolation in particular of the relation between biophysical driving factors and actual land use. Besides, it allows the identification of geographic areas where improved management is promising, as well as indications on the types of improvement required to overcome constraints.

Keywords: inland valleys, agro-ecological characterization, agro-ecosystems, multiple scales, (des)aggregation, West Africa, Côte d'Ivoire

Introduction

The bottom lands *(bas-fonds, fadamas, inland swamps)* of inland valleys in West Africa show considerable potential for intensified and sustainable land use (Izac et al., 1991; Windmeijer and Andriesse, 1993). This is mainly due to better water availability as compared to the adjacent uplands. Presently, however, they are only marginally used, and with limited success: only 10 to 25% of the total valley bottom area in West Africa is under cultivation (mainly rice), and yields are generally low (0.8-1.2 ton paddy per ha). The constraints to bring land into cultivation include: extensive weed growth, lack of appropriate water management technologies, labour shortage (clearing of natural vegetation), prevalence of water-related diseases (e.g. bilharzia, malaria) and an unfavourable infrastructure (e.g. markets, accessibility).

Inland valleys occur all over West Africa, where valley bottoms and hydromorphic fringes are estimated to occupy between 22-52 million ha of land (Windmeijer and Andriesse, 1993). The wide area-range indicated here is a reflection of the high complexity and heterogeneity of the inland valleys and the lack of international agreement on what exactly constitutes an inland valley. These factors partly explain why, to date, little progress has been made in the systematic characterization of inland valley systems. Moreover, complexity and heterogeneity are compounded if not only the physical component of inland valleys is included, but also the biotic component (land cover and land use).

This paper presents a description of a comprehensive characterization system for inland valley agro-ecosystems in West Africa. The study area is confined to the part of West Africa with a growing period of more than 90 days, allowing for rainfed cultivation of one (rice) crop. A multi-scale approach has been developed in view of the need for applicability at different levels in terms of inventory, interpretation and implementation.

The present system for multi-scale agro-ecological characterization has been developed as part of a collaborative research approach to the development of sustainable rice-growing ecosystems in West Africa, involving the West Africa Rice Development Association in Côte d'Ivoire, the International Institute of Tropical Agriculture in Nigeria, and the Wageningen Agricultural University and the DLO-Winand Staring Centre for Integrated Land, Soil and Water Research, both in The Netherlands. Results used in this paper to illustrate the characterization method at semi-detailed level originate from field work which was carried out within this project, in Côte d'Ivoire. Detailed characterization using the present method has not yet been implemented. Presently, a follow-up to the initial characterization activities is implemented under a regional Consortium Programme, incorporating the full participation of national research institutes in West Africa (WARDA, 1993). Both activities are co-financed by the Netherlands' Directorate General for International Cooperation.

Agro-ecological characterization has gained much interest among various international and national research institutes and organizations (IRRI, 1984; Bunting, 1987; WARDA, 1988; CIAT, 1991; TAC, 1991; IITA, 1993). Also, several attempts were made at the characterization of inland valleys. So far, the systems developed were either litho-morphologic (Moormann, 1981; Raunet, 1985), or morpho-hydrologic (Killian and Teissier, 1973; Moormann and Van Breemen, 1978; Veldkamp, 1979). To a lesser extent, rice cropping systems were defined in relation to (surface) hydrology (Buddenhagen, 1978; WARDA, 1980; Khush, 1984). Bowles and Garrity (1988) initiated the development of a comprehensive classification of rice ecosystems. None of these studies, however, take into account the specific conditions along the inland valley toposequences, and only the classification system of Bowles and Garrity (op. cit.) deals, to some extent, with multiple aggregation levels.

Over the past fifteen years, considerable research has been conducted on inland valley agro-ecosystems. Hekstra et al. (1983) carried out a macro characterization of inland valley systems in the major agro-ecological zones in West and Central Africa (scale 1:5,000,000). More-detailed inventories and studies involving soils, hydrology, agronomy and socio-economics were executed by for instance Raunet (1982), Smaling et al. (1985), Gebremeskel and De Vries (1985), Gunneweg et al. (1986), Oosterbaan et al. (1987), Hakkeling et al. (1989), Albergel et al. (1993), Izac and Tucker (1993) and Leplaideur (1993). An overview of rice-growing environments in relation to both, broad agro-ecological zones and inland toposequences in West Africa was elaborated by Andriesse and Fresco (1991). Recently, a nation-wide socio-agronomic description of agro-ecosystems was completed in Côte d'Ivoire, (scale 1:1,000,000; Becker and Diallo, 1992). Windmeijer and Andriesse (1993) provided a general state of the art on inland valley agro-ecosystems in West Africa.

Materials and methods

Definitions of central concepts

Inland valleys

Inland valleys are defined as the upper reaches of river systems, inland in respect of the main rivers and tributaries, in which river alluvial sedimentation processes are absent or of minor importance: inland valleys have only a minor floodplain and levee system (Windmeijer and Andriesse, 1993). Inland valleys comprise the toposequence, or continuum, of valley bottoms and minor floodplains which may be submerged for part of the year, their hydromorphic fringes, and contiguous upland slopes and crests, extending over an area that contributes runoff and seepage to the valley bottom (Fig. 1). Longitudinally, inland valleys may be continuous and smooth, or interrupted and stepped, depending on the underlying rock formations. Individual inland valleys (land elements) and their sub-elements (i.e. crests, slopes, hydromorphic fringes and valley bottoms) are part of a differentiated valley system of first and higher-order streams (segments).

Land cover and land use

Land cover is the vegetation (natural or planted) or the human constructions covering the land surface, including water bodies and bare soil (Mücher et al., 1993). Land use is defined as the human activities that are directly related to land, making use of its resources or having an impact on it. Land use is reflected in the land cover, which changes with time. The description of land use includes the sequence of oper-

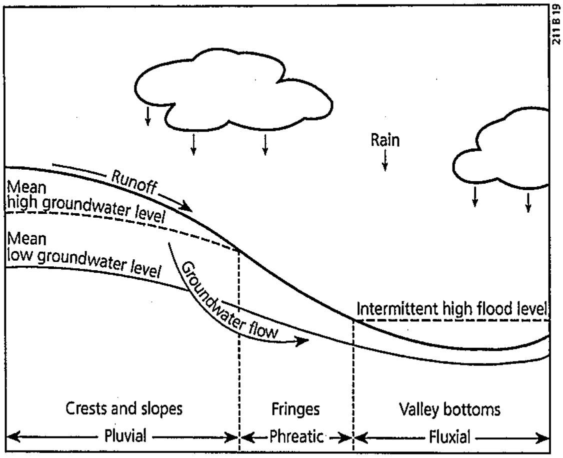


Figure 1. Schematic cross-section of an inland valley, showing the various land sub-elements with their specific hydrologic regimes.

ations, their timing, the applied inputs, the implements and traction sources used, and the type of output (Stomph et al., 1994).

Agro-ecosystems
Agro-ecosystems are ecosystems with an agricultural component in their primary production compartment. The concept is scale-neutral and may be used in reference to valley systems, individual valleys or parts thereof. Inland valley agro-ecosystems are highly complex and heterogeneous, due to the high spatial variability of the biophysical factors along the toposequences, and because of the temporal and spatial changes in cropping systems (rotations).

The high diversity strongly influences the type of agricultural practices predominating in each agro-ecological zone. Within the major agro-ecological zones of West Africa, various crops are grown under a range of distinct ecological conditions that are determined both by topography (position on the toposequence) and by human modifications. Overlaid on these ecosystems, farmers have developed a variety of distinct cropping systems that can differ across, as well as within, ecosystems. The cropping systems actually applied by farmers are also determined by factors endogenous to the farm unit (e.g. household demographic composition, assets, labour availability).

Agro-ecological characterization
Agro-ecological characterization implies the comprehensive description of agro-ecosystems on the basis of physical (climate, lithology, landform, soils and hydrology) and biotic parameters (vegetation and land use). Land use (primary and secundary production) is described including its socio-economic identifiers (labour, capital input and management). The degree of detail of the information gathered in agro-ecological characterization is strongly related to the scale of characterization.

Multi-scale approach
A multi-scale approach has been developed because data collection, interpretation

and, later on, planning always take place at various levels. Scaling down to a lower level of characterization (desaggregating), implies greater detail of increasingly dynamic parameters, while at the same time certain macro-level parameters are more or less static (e.g. climate and lithology at detailed level). On the other hand, while scaling up (aggregating), details distinguished for variables at lower level (e.g. crop rotations) are disregarded at higher level. Compared to soils and climate, land use involves the most dynamic set of variables: cropping and farming systems are highly dynamic, both spatially (land elements, rotations, intercropping) ánd temporally (rotations, cultivation practices, labour inputs).

The multi-scale characterization consists of four levels, from high to low, with their respective scales. They are presented schematically in Table 1, and they are described in detail in the next sections.

Multi-scale agro-ecological characterization

Macro characterization

The macro characterization (scale 1:1,000,000 to 1:5,000,000) aims at the distinction and the description of the major agro-ecological zones in West Africa, based on existing sources of information. These agro-ecological zones were defined on the basis of the length of the growing period, i.e. the period in which the rainfall exceeds half of the potential evapotranspiration, plus a period to evapotranspire an assumed 100 mm of water from excess rainfall stored in the soil profile. A normal growing period must exhibit a humid period, i.e. a period with an excess of rainfall over potential evapotranspiration (FAO, 1978). Additional general data on lithology and landform (land regions) were collected from national and regional multi-scale studies. Based on this information the agro-ecological zones were subdivided into agro-ecological units, each with their specific physical characteristics. The descriptions of the units include general information on valley density and on the main yield limitations.

Reconnaissance characterization

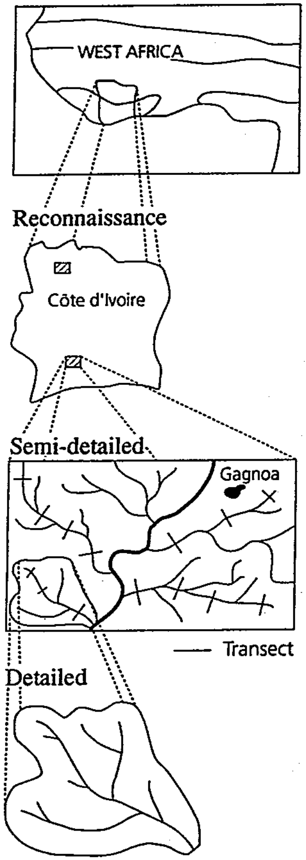
The reconnaissance characterization (scale 1:100,000 to 1:250,000) aims at subdivision of agro-ecological units into agro-ecological sub-units at country level. National sources of secondary information on landform, lithology, soils, climate, hydrology, major land use, morphology, population density and socio-economics were consulted. Information on the distribution and extent of inland valleys in (parts of) the country was obtained from satellite imagery, if available. Additional information on main land use was collected by means of rapid rural inventories.

Within the most extensive sub-units representative key areas were selected for more-detailed characterization activities. The concept of key areas enables the inventory of all characteristics of agro-ecological sub-units in a confined area and, thus, in a restricted time period. The size of the key areas was set at about 2500 km^2 to cover a number of inland valley systems.

Semi-detailed characterization

The semi-detailed characterization (scale 1:25,000 to 1:50,000) focusses on the col-

Table 1. The different levels and scales in agro-ecological characterization of inland valleys, units of analysis, objectives and main information sources.

Characterization level	Scale	Unit of analysis	Objectives	Information sources
Macro 	1:1,000,000 to 1:5,000,000	Agro-ecological zone	Characterization of agro-ecological zones subdivided into agro-ecological units on the basis of landform and major lithology (i.e. land regions)	Secondary information
Reconnaissance	1:100,000 to 1:250,000	Country	Characterization of agro-ecological sub-units on the basis of rainfall, length of humid period, landform, lithology, drainage density, major upland soils, major land use, and population density; Selection of key areas	Secondary information, rapid inventories (soils, land use) and satellite imagery
Semi-detailed	1:25,000 to 1:50,000	Key area	Characterization of valley systems based on soils and valley morphology, periods of flooding and shallow groundwater, size of watersheds, land use ratios (per land subelement and at valley level), crops and crop rotations, socio-economics (e.g. market, credit), and infra-structure; Selection of inland valleys	Satellite imagery, aerial photographs, transect surveys, farmer interviews
Detailed	1:5,000 to 1:10,000	Inland valley	Characterization of inland valleys on the basis of variation of soils and valley morphology, soil fertility and toxicities, soil physics (infil-tration, permeability), flooding and groundwater dynamics, farming systems and cropping intensities, inputs-outputs, crop varieties, crop-ping calendar; Quantification of constraints	Aerial photographs, detailed surveys, farmer interviews, monitoring, experiments and simu-lation modeling

lection of information, through field surveys by transects, on the physical environment and land cover/use of inland valley systems by agro-ecological sub-units. The inventory started with the interpretation of recent aerial photographs (scale 1:25,000 or 1:50,000) of the key areas, with emphasis on the distribution of inland valleys and their shape, the extent of their watersheds, land cover and infrastructure. The interpretation was used to select four representative valleys per agro-ecological sub-unit. In each of these valleys some four to five transects were selected for field description. The transects cut across different segments of the valleys, from one top of the crests to the other. Along with the various land sub-elements occurring in the transect, a number of physical characteristics was described or measured. These include: gradient, soils and hydrology. As for the latter, special attention was given to the hydromorphic fringes and the valley bottoms. Soils were sampled, by land sub-element, for chemical analysis.

Land cover and use were described for a strip of land of 200 to 400 m width along the transect line. Actual strip width depended on the density of the natural vegetation. The minimum size of individual land cover/use units to be described, was set at 250 m^2. Crops, fallow and natural vegetation were described in terms of type, species, land and crop management and structure. Information on animal husbandry was also noted, but their roaming presence did not lend itself to interpretation at this level of characterization. Subsequently, the land use units were classified: land with annual crops, land with perennial crops, prepared land, young fallow (<10 years old), old fallow (10-30 years old), managed grazing land, grassland & forbland, savanna & shrubland, woodland & forest, infrastructure or wasteland. Farmers were interviewed for additional information on flooding features of the valley bottoms, crops and crop rotations, production levels, land tenure, inputs (e.g. labour, fertilizer), and constraints.

The results obtained per transect were processed into an agro-ecological diagram showing the physical parameters in a cross-section, in combination with a map showing the land use. Accompanying descriptions highlighted the variability of valley characteristics within agro-ecological sub-units, as well as the differences between inland valleys in different agro-ecological sub-units, if applicable. Processing at this level of characterization also involved establishing databases linked with a geographic information system.

A number of valley characteristics was quantified to facilitate the comparison of different valleys or different land sub-elements within valleys. For example, the Valley Bottom Ratio (*VBR*, no dimension) is the ratio of the area occupied by the higher parts of the valley (crests, slopes and fringes) over the area of the valley bottom. It is a possible measure of the potential amount of water, related to the total rainfall, that may flow as runoff or as groundwater from the higher parts of the valley into the valley bottom. A high value indicates a relatively narrow valley bottom and a potentially large amount of water that may accumulate in the valley bottom.

Land use class ratios, as another example, express the relative area of the individual land use classes over the total area of the land sub-element. From these individual land use class ratios, the Land Use Ratio (*LUR*, in %) can be calculated as the sum of cropped area, prepared land, grazing land and young fallow, over the total area of the land sub-element. As this ratio excludes the area under old fallow, it reflects land use intensity over the past ten years. By excluding the grazing and young fallow components from the *LUR*, the rate of actual crop cultivation is expressed in the Actual Production Ratio (*APR*, in %). The Fallow Index (*FI*, no dimension) is the quotient of the area under young and old fallow over the total area used for agriculture in the past 30 years (including prepared land and managed grazing land). An *FI* of zero indicates the absence of fallow, an *FI* of 0.5 shows that fallow and cropped land are equal in acreage, and an *FI* of 1 stands for fallow only. Finally, the Soil Preparation Intensity (*SPI*, in %) is used as a measure to assess the spread of implementation of soil preparation activities. It is defined as the ratio between the area that has been tilled (ploughing or the construction of mound or beds) over the total of cropped land (annual and perennial crops) and prepared land. Because land preparation has a distinct effect on the land and on the production level of the crop, the *SPI* is regarded as an important parameter.

Detailed characterization

The last step of the multi-scale approach is the detailed characterization of valleys and the delimitation of the land sub-elements, at scales between 1:5.000 and 1:10.000. Detailed characterization, however, has not yet been implemented and therefore, data are not available for interpretation. They will be reported separately in due course.

Detailed characterization will be done in one or two representative inland valleys within an agro-ecological sub-unit. At this level, the characterization aims at the classification of the inland valleys and their land use, including the quantification and ranking of the constraints to sustainable production. The required information will be collected in detailed field surveys, farmer interviews, monitoring programmes and research, including simulation modelling. Field surveys will start with the further interpretation of aerial photographs, linking the transect information on both the physical and the agronomic characteristics, as gathered during semi-detailed fieldwork, to geographically-defined map units.

The increase in level of detail allows the quantification of the spatial and temporal variability of physical, agronomic and socio-economic variables. For instance, the dynamics of farming and cropping systems within valleys will be studied in relation to the dynamics of the physical and socio-economic conditions. Subsurface water flow, water availability in the valley fringes and flooding regimes in the valley bottoms, their effect on nutrient availability (N, P, K) and (iron) toxicity, as well as nutrient balances of cropping systems and soil erosion processes will be subject of study, too.

Also at this level of characterization, new parameters are defined. Total Land Use Intensity (*TLI*, in %), for example, describes the intensity of agricultural exploitation in the last 30 years (sum of the areas of prepared, cropped and fallow land) relative to the total area that can be cropped (total area minus areas occupied by infrastructure and wasteland). The Actual Land Use Intensity (*ALI*, in %) excludes the area under old fallow, thus expressing the level of exploitation over the past ten years.

Results

Application of macro characterization

In the study area, three major agro-ecological zones were distinguished: the Equatorial Forest Zone (growing period more than 270 days), the Guinea Savanna Zone (165-270 days) and the Sudan Savanna Zone (90-165 days). They are shown in Figure 2, and their main characteristics are summarized in Tables 2 and 3.

Figure 2 also shows the valley density in the different agro-ecological units. In general, this density increases from the dry Sudan Savanna Zone in the north to the humid Equatorial Forest Zone in the south. The lithology, however, has a distinct impact on the valley density: formations of the Basement Complex have a higher valley density than the more-permeable sedimentary deposits. In Table 3 the valley density is given as the weighed average for the whole land region. It was estimated that between 7 and 17% of the study area is occupied by the hydromorphic parts of the inland valleys (i.e. the valley bottoms and fringes), which means that an area between 221,000 to 523,000 km^2 consists of these land sub-elements.

Application of reconnaissance characterization

The major agro-ecological units in Côte d'Ivoire are the Plateaux, which are formed over Basement Complex formations in the Guinea Savanna Zone, and the Interior Plains, which are also formed over Basement Complex formations, in the Equatorial Forest Zone. On the basis of information from secondary sources (e.g. Avenard et al., 1971; Beaudou and Sayol, 1980), and data from the rapid inventory of the main land use in inland valleys in this country (Becker and Diallo, 1992), four agro-ecological sub-units were distinguished within the two major agro-ecological units.

In both major units key areas were selected, near Boundiali (Plateaux, Guinea

Table 2. Main characteristics and extent of the major agro-ecological zones in West Africa.

Agro-ecological zone	Length of growing period (days)	Annual rainfall (mm)	Rainfall pattern	Area (estimated)*	
				(10^3 km^2)	(%)
Equatorial Forest	>270	>1500	Monomodal (west) Pseudo-bimodal (east) Bimodal (central-south)	870	27.7
Guinea Savanna	160-270	1100-2500 (west) 900-1500 (east)	Monomodal (north) Bimodal (central-south) Pseudo-bimodal (elsewhere)	1350	42.9
Sudan Savanna	90-160	550-1500	Monomodal	920	29.4

* Estimates based on maps at scale 1:5,000,000

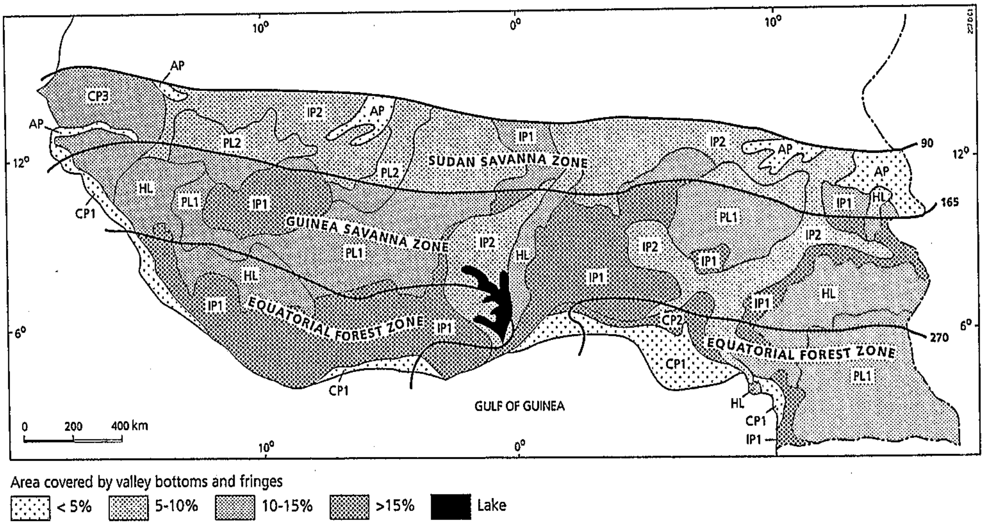


Figure 2. Major agro-ecological zones and land regions, and density of inland valley bottoms and fringes by agro-ecological units in West Africa (for explanation of symbols, see Tables 2 and 3).

Savanna Zone), and near Gagnoa (Interior Plains, Equatorial Forest Zone). The key areas were selected in such a way, that each of them covered two different agro-ecological sub-units. The latter were distinguished mainly on the basis of a further differentiation of the prevailing lithology (i.e. granites and schists in Boundiali, and migmatites and schists in Gagnoa), and the (related) drainage density. Further details of the agro-ecological sub-units are given in Table 4.

Application of semi-detailed characterization

In the semi-detailed characterization that was carried out in Côte d'Ivoire, fourteen valleys were studied. Eight valleys were in the Boundiali key area and six in Gagnoa. Figure 3 shows, as an example, the schematic cross-section and the land use map of a valley formed in migmatite near Gagnoa. The main physical and land use characteristics of the valleys studied in Côte d'Ivoire are summarized in Table 5 .

This table shows clear differences between the valley systems. In the Boundiali key area, the valleys are much wider than in Gagnoa, in accordance with the various drainage densities that were observed at reconnaissance level. The valley bottoms, however, are much wider in Gagnoa than in Boundiali: the *VBR* for Gagnoa is 5 and 13, in schists and migmatites, respectively, whereas in Boundiali the *VBR* is 64 and 83, in schists and granites, respectively. Also, valley slopes are steeper in Gagnoa (4-12%) than in Boundiali (1-7%). Differences between agro-ecological sub-units are much less pronounced than between units. This may point at a major effect of climate on the morphology of inland valleys.

The high standard deviations of the widths of the various land sub-elements indicate highly variable conditions along the slope in all four valley systems.

Table 3. Main characteristics and extent of major land regions, and areas occupied by valley bottoms and fringes in West Africa.

Land region/ map symbol	Description	Area (estimated)*			
		Total map unit		Valley bottoms and fringes	
		(10^3 km^2)	(%)	(10^3 km^2)	(%)
Alluvial Plains					
AP	Major river floodplains; slope 0-5%	101	3.2	--	--
Coastal Plains, Lacustrine Plains and Terraces					
CP1	Beach ridges, minor river floodplains, tidal flats, lacustrine plains and slightly dissected terraces; slope 0-5%	100	3.2	2–7	2–7
CP2	Strongly dissected older coastal terraces with distinct dipslopes and steep scarps; slope 0-5%	40	1.3	6–10	15–25
CP3	Slightly dissected aggradational coastal plains; slope 5-15%	156	5.0	11–23	7–14
Interior Plains					
IP1	(Slightly) dissected peneplains with inselbergs and mesas, over Basement Complex formations; slope 2-10%, locally 10-20%	855	27.3	85–214	10–25
IP2	Slightly dissected peneplains with mesas and basalt cones, over sedimen tary formations; slope 2-5%, locally 10-15%	650	20.7	26–65	4–10
Plateaux					
PL1	Slightly dissected plateaux with inselbergs, hill ridges and mesas, over Basement Complex formations; slope 2-5%, locally 10-20%	745	23.9	52–119	7–16
PL2	Dissected, locally strongly dissected plateaux with mesas, steep scarps and deep valleys, over sedimentary formations; slope 5-20%	131	4.2	8–22	6–17
Highlands					
HL	Strongly dissected mountain ranges and high plateaux, not differentiated; slope 35-50%, locally > 50%	349	11.1	31–63	9–18
Lake		13	0.1	--	--
Total study area		3140	100.0	221–523	7–17

* Estimates based on maps at scale 1:5,000,000.

Differentiation that does occur in the longitudinal direction of the valleys is not reflected in these values and they are not discussed here.

Also with respect to land use a number of differences between the valley systems stands out. For example, land use in the Gagnoa key area is much more intensive (average *LUR*: 76% on schists and 65% on migmatites) than in Boundiali (*LUR*: 28% on schists, 33% on granites). Differences between the sub-units are less pronounced. If expressed by land sub-elements, however, it is clear that, regardless of lithology, slopes and fringes are more intensively used in Gagnoa (*LUR* range: 68-83%) than in Boundiali (12-45%). Farmers in Boundiali appear to give relative preference to cultivation of the valley bottoms, as compared to those in Gagnoa. This is particularly apparent from the *APRs*. The latter also show low values for the crests, most clearly in the Boundiali area (*APR*: 4% on schists, and 2% on granites).

Due to the higher land pressure in Gagnoa, as reflected in high *LURs* and *APRs*, less land remains under fallow as compared to Boundiali: *FIs* are 0.30 to 0.51 and 0.71 to 0.75, respectively. *FIs* are particularly low on the slopes and fringes in the schists of Gagnoa (0.21-0.25), where the shortage of fallow land and, as a consequence, the decreasing periods of fallow, become possible limiting factors to sustained agricultural production, being aggravated by the absence of fertilizers. The

Table 4. Characteristics of the agro-ecological sub-units covered by the Boundiali and Gagnoa key areas in Côte d'Ivoire.

Characteristics	Boundiali	Gagnoa
Macro characterization		
Major agro-ecological zone	Guinea Savanna Zone	Equatorial Forest Zone
Length of growing period (days)	165 - 270	> 270
Land region/landform	Plateaux	Interior Plains
Land region/lithology	Basement Complex	Basement Complex
Reconnaissance Characterization		
Coordinates	6.10-6.30WL/9.20-9.35NL	5.50-6.20WL/5.40-6.10NL
Rainfall pattern	Monomodal	Bimodal
Humid period	May-September	March-July/September-November
Annual rainfall (mm)	1400	1500
Annual temperature (∞C)	26	26
Annual evapotranspiration (mm)	1850	1450
Lithology	Schists, granites	Schists, migmatites
Major soil associations	Lixisols, Acrisols, Gleysols	Acrisols, Cambisols, Gleysols
Drainage density (km/km^2)	0.53 (schist), 1.16 (granite)	1.40 (schist), 1.32 (migmatite)
Rural population density (persons/km^2)	<16	26-35
Major food crops	Rice, maize	Rice, maize
Major cash crops	Cotton	Coffee, cacao
Area under rice cultivation (ha/km^2)	1-2	2-3

* In both Boundiali and Gagnoa about 80% of the rice is grown on the uplands.

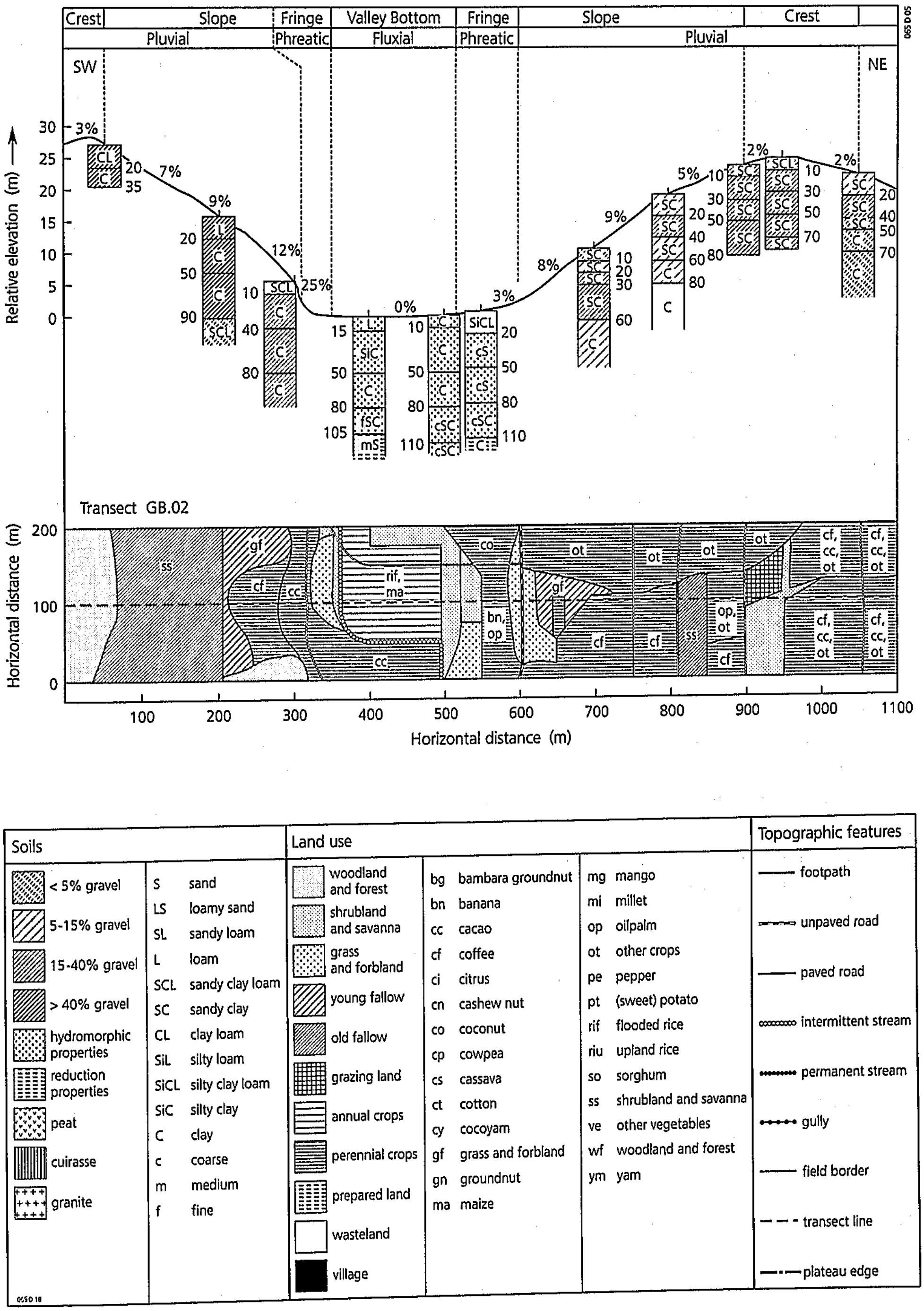


Figure 3. Schematic cross-section and land use map of a valley formed in migmatite near Gagnoa.

same holds, to a lesser extent, for the fallow in the valley bottoms in Boundiali.

A considerable difference in the soil preparation intensity (SPI) occurs between the two agro-ecological units. In the Boundiali key area more than half of the land is prepared (ridging or ploughing), while in the Gagnoa key area almost no land is prepared (Table 5). In the Boundiali key area, soil preparation is required due to prevailing very high soil compaction.

It should be noted that the figures on land use in Table 5 are the weighed averages of data from individual transects. As such, these figures do not reflect the very high spatial variability and the high temporal dynamics of land use. A detailed discussion of these aspects is beyond the scope of the present article on methodology.

The major food crops grown in the different sub-units are about the same, but their relative importance is different, as indicated by the order in which they are presented in Table 5. Reported production levels of the various crops differ considerably. For rice in the Gagnoa key area, for example, they range from 1000 kg ha^{-1} under rainfed and manual cultivation, to 2700 kg ha^{-1} when irrigated and manually cultivated, up to 4700 kg ha^{-1} when irrigated and mechanized. The kinds of cash crops grown (cotton, coffee and cacao) differ distinctly between the sub-units. Generally, levels of fertilizer and pesticide inputs are low.

Application of detailed characterization

The parameters defined for the detailed characterization will be calculated over the total valley, as well as for individual land sub-elements, similar to the data presented in Table 5 for the semi-detailed characterization. As the data will be collected on the basis of individual farmers fields, through field surveys and detailed aerial photograph interpretation, simultaneously insight is generated on the actual farming systems applied in the respective inland valleys under study. Thus, complete information becomes available on how farmers actually distribute their cultivation activities over the different land sub-elements of the toposequences. This enables developing of improved management technologies adapted to the local agro-ecological conditions. After on-farm testing, these improved practices can be extrapolated to other areas with similar agro-ecological characteristics.

Discussion

The multi-scale agro-ecological characterization elaborated here, involves a number of issues with respect to scale, spatial and temporal dynamics, and the extrapolation and transfer of results that are discussed below.

Scale, aggregation and desaggregation

Four aspects related to scale are highlighted. First, data and characterization criteria are scale-dependent. They refer to determinants (e.g. solar radiation) or processes (crop growth) at well-defined levels of analysis. Throughout the characterization process, data collected at one level were used to construct classes (i.e. criteria) at the next-higher level. In fact, the class boundaries at each level are quantified on the basis of more-detailed measurements at the next-lower level. For example, the length of the growing period of agro-ecological zones was calculated on the basis of various weather (rainfall and evapotranspiration) and soil (moisture retention capacity) data observed at semi-detailed and detailed levels. This implies that any agro-ecological characterization must define characterization variables at the appropriate level of analysis.

Secondly, the importance of certain variables for agro-ecological characterization is scale-dependent. The length of the growing period, for example, is a determinant at macro level, applying to upland conditions. At semi-detailed level, it is differentiated in order to cater for the effects of seepage or flooding which effectively prolong the lengths of the growing periods in the hydromorphic fringes and valley bottoms, respectively. Also, lithology, which is a variable at reconnaissance level, is a constant factor at lower levels of characterization. Thus, lithology of valley systems (i.e. semi-detailed level) and of individual valleys (detailed level) is homogeneous.

Thirdly, and following directly from the previous points, multi-scale agro-ecological characterization seeks to deal adequately with variability in a dual way, i.e. at the level studied and at the next-lower level. At each level of characterization, the variability occurring within the units distinguished, is described on the basis of the differentiation applied at the next-lower level. Such a differentiation is done appropriately by studying (i.e. characterizing) that next-lower level. For example, variability in lithology as described at the reconnaissance level for Côte d'Ivoire (i.e. schists/granites and schists/migmatites, see Table 4) is used to distinguish four different valley systems, one in each of these lithologies, at semi-detailed level. Characterization is often an iterative process whereby differentiation between units at a certain level leads to a better description of variability within units at the next-higher level and, subsequently, to a better definition, and selection, of representative sub-units, key areas or valley systems.

Fourthly, multi-scale characterization involves aggregation of variables in upward direction (i.e. when going from large-scale to small-scale characterization), and desaggregation of variables when going down the scale ladder. In aggregation certain detail of information, including the variability in space and time, is lost. This loss may take the form of replacement of detailed observations by average values, preferably with an indication of their distribution (e.g. standard deviations), or their uncertainties (probabilities of occurrence). In other cases, certain variables are eliminated entirely at a next-higher level, because they are not considered distinctive for the characterization at that level. Replacement by average values applies, for example, to values for soil characteristics (e.g. texture, depth) for map units as distinguished at detailed characterization, which are replaced by average values for land sub-elements at semi-detailed level. The same is true for the *LURs*, *APRs*, *FIs*, used to characterize land use at semi-detailed level (Table 5). Elimination of variables occurs, for example, where at semi-detailed level land use is described in terms of major crops, *LURs* and crop rotations (Table 5), whereas at reconnaissance level only the major crops are described (Table 4). Also, the incorporation of individual quantitative data

Table 5. Selected physical and land use characteristics of valley systems in the Boundiali and Gagnoa key area in Côte d'Ivoire.

	Boundiali				Gagnoa			
	Schist (n = 14)		Granite (n = 9)		Schist (n = 3)		Migmatite (n = 13)	
Physical characteristics								
Average width (m):								
total valley	1646	(± 477)	1383	(± 354)	842	(± 104)	980	(± 249)
crests and slopes	704	(± 189)	571	(± 238)	309	(± 124)	390	(± 189)
fringes	32	(± 37)	33	(± 33)	46	(± 42)	54	(± 54)
valley bottom	42	(± 27)	31	(± 34)	157	(± 58)	105	(± 60)
Valley Bottom Ratio (*VBR*, -)	64	(± 51)	81	(± 55)	5	(± 3)	13	(± 15)
Slope gradient (%)	1-4		2-7		4-10		4-12	
Slope form	rectilinear		concave/convex		concave/convex		concave/convex	
Soil depth:								
crests and slopes	shallow-mod. deep		deep-mod. deep		shallow-mod. deep		deep	
fringes	shallow-mod. deep		deep-mod. deep		deep		deep	
valley bottoms	deep		deep		deep		deep	
Soil fertility:								
crests and slopes	very low-medium		low-very low		low		low-very low	
fringes	low-medium		very low		low-very low		very low-low	
valley bottom	low-medium		very low-low		very low-low		very low	
Land use characteristics								
Land Use Ratio (*LUR*, %):								
total	28		33		76		65	
crests	17		24		75		46	
slopes	30		32		82		68	
fringes	12		45		83		77	
valley bottoms	26		40		51		51	
Actual Production Ratio (*APR*, %):								
total	11		11		53		34	
crests	4		2		24		26	
slopes	11		11		65		37	
fringes	10		8		63		34	
valley bottoms	19		22		21		28	
Fallow Index (*FI*, -):								
total	0.75		0.71		0.30		0.51	
crests	0.89		0.96		0.68		0.42	
slopes	0.74		0.71		0.21		0.52	
fringes	0.53		0.86		0.25		0.57	
valley bottoms	0.28		0.44		0.59		0.46	
Soil Preparation Intensity (SPI, %):								
total	75		62		0		5	
crests	62		100		0		1	
slopes	79		74		0		4	
fringes	19		76		0		9	
valley bottoms	50		13		0		9	
Major food crops	rice, maize, yam		yam, maize, rice		yam, cassava, rice		rice, cassava	
Major cash crops	cotton, cashewnut		cotton, cashewnut		coffee, cacao		coffee, cacao	
Crop rotation (years)	5-8 (annuals), 8-30 (fallow)		6-8 (annuals), 7-11 (fallow)		2-7 (annuals), 20-25 (perennials), 3-10 (fallow)		2-7 (annuals), 20-25 (perennials), 2-6 (fallow)	

Table 5. Continued.

	Boundiali		Gagnoa	
	Schist (n = 14)	Granite (n = 9)	Schist (n = 3)	Migmatite (n = 13)
Other characteristics				
Main ethnic group	Sonoufo	Dioula	Baoulé	Bété
Persons per household	9 (4-16)	23 (11-32)	16 (7-30)	11 (6-15)
Total field size (ha):				
uplands	men, 7 (3-15)	men, 16 (10-24)	men, 17 (1-32)	men, 5 (1-10)
valley bottoms	women, 1.8 (0.2-3)	women, 3.5 (3-4)	–	–

n: number of transects; (± 477): standard deviation; (4-16): range.

into semi-quantitative classes at the next-higher level of characterization involves elimination of detail. As an example may be used the ratings of soil fertility (e.g. low, medium, high; see Table 5). These are derived from data on for example organic matter content, pH, available P, CEC and exchangeable K.

Desaggregation requires judgements about the spatial distribution of variables within lower-level units. The key issue here is to assess to what extent justice can be done to variability at lower levels, which is not yet known, but only assumed. One way of dealing with this problem is through variable correlations. For example, a known relationship between soil fertility and toposequence position may be used to distribute soil fertility indicator values in valleys where these measurements have not been taken. Also, a 'transfer function' may be defined to derive details from higher-level data (e.g. land use intensity from lithology, climate and slope). Alternatively, (geo-)statistical methods (e.g. analysis of covariance, principle component analysis, cluster analysis, kriging) can be applied to quantify spatial dependence within, and correlations between, scales.

Data sets in relation to scale and time

The decision as to what variables are relevant at a specific level is based on previous characterization work, as well as on the skill of the scientist. The art of agro-ecological characterization, obviously, is to determine minimal data sets for each level. The method presented here distinguishes relevant variables at each level. The volume of actual data to be collected depends on the variability within each unit of analysis. Various statistical methods are available to select samples as function of the known or unknown variability.

Data sets may be widely different in origin, accuracy and scale. This applies to direct observations on individual variables (e.g. soil survey data based on physiographic, grid, or probability surveys as opposed to climate data from (few) fixed stations), as well as to secondary data, which in itself may be compilations of primary data at lower levels of characterization. Compatibility of data sets therefore needs to be assessed before combinations of data can be made. Ultimately, data may be of incomparable origin, scale and accuracy. As an example, data on farm sizes, production levels and inputs from local statistics could be mentioned.

Preferably, aggregation and desaggregation are to be carried out in combination with a sensitivity analysis indicating to what extent the results at higher levels are influenced by the full exclusion, or the inclusion of average values only, of variables included in the data sets at lower levels. On this basis minimal data sets may have to be adjusted.

With few exceptions, semi-detailed and detailed data refer to limited time frames. They are collected for a relatively short period of three to five years. For higher level characterization, however, long-term averages of data are used on for example climate, hydrology and crop yields. Therefore lower-level data must be always presented in relation to long-term data, by indicating trend deviation.

Extrapolation and transfer mechanisms

Extrapolation of results implies the process to project, extend or expand known data to another area that is unknown, but expected to be similar, so as to arrive at a usually conjectural knowledge of the unknown area. Transfer of results implies the process to carry over or to generalize information from one area to another, where differences are known to exist.

Both extrapolation and transfer aim at conveyance of data, at equal level of characterization. Both processes imply, however, scaling-up (and aggregation), as well as scaling-down (and desaggregation). If extrapolation or transfer prove inadequate, because the units are too diverse for generalized conclusions at the next-higher level, an iterative process as referred to before, should be initiated whereby characterization at the next-higher level leads to a better description of variability at that level and, subsequently, to a better definition, and selection of units of analyses at the next-lower level.

Conclusions

Characterization of inland valleys carried out so far, shows that variation in (bio)physical and land use factors is considerable, both between levels and within valleys. Not only does the set of descriptors now developed, allow for extrapolation in particular of the relation between biophysical driving factors and actual land use, it also allows the identification of geographic areas where improved management is promising, as well as indications on the types of improvement required to overcome constraints.

The appropriateness of particular new soil, water and crop management technologies for inland valleys can vary significantly across distinct agro-ecosystems, as a function of both bio-physical and socio-economic factors. Therefore, research and development strategies must not only consider climatic, hydrologic and edaphic factors in relation to crops and cultural practices, but also demographic patterns, land tenure systems, labour organization, market infrastructure, health risks, and other socio-economic factors that influence the cropping systems of inland valleys. These interrelated factors determine the success with which new management techniques can be introduced for more intensive and sustainable use of inland valleys. Multi-scale agro-ecological characterization is an indispensable tool for the effective extrapolation and transfer of such management techniques.

We have shown that multi-scale agro-ecological characterization is an iterative process involving repeated aggregation and desaggregation at the various levels of study. Such scaling-up and scaling-down is an inherent feature of the methodology. Although many characterization approaches refer to scale, ours is the first attempt to include aggregation and desaggregation systematically. As a result, the approach is not only relevant to West African inland valley agro-ecosystems, but it may be adapted, with some modifications, to other areas and purposes. Possible modifications are the definition of the exact spatial scales corresponding to the levels (e.g. semi-detailed characterization in Bangladesh may be related to a scale larger than what we have used). Also, the predominant lithology and type of land use may influence some of the data collected and measured. However, generally speaking the levels and variables studied are applicable to other regions.

Detailed studies and research as referred to in this text, in as large an area as West Africa, and as variable, benefit from a structured collaborative approach between national and international research centres. Together with (multi-scale) agro-ecological characterization it enables targetting the research and, upon implementation in joint regional programmes, this prevents duplication of efforts. As for the research on inland valley agro-ecosystems, such a Consortium Programme is presently being established, consisting of seven national and four international research institutes (WARDA, 1993).

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