RCMP Research Monograph No. 5

A Strategy for Inland Valley Agroecosystems Research in West and Central Africa

A-M. N. Izac, M. J. Swift and W. Andriesse

Resource and Crop Management Program
International Institute of Tropical Agriculture

1990

The International Institute of Tropical Agriculture (IITA) is an autonomous nonprofit institution, with headquarters on a 1,000-hectare experimental farm at Ibadan, Nigeria. It was established in 1967 as the first major African link in an integrated network of international agricultural research and training centers located in the major developing regions of the world.

Funding for IITA came initially from the Ford and Rockefeller foundations. Land for the experimental farm was allocated by the Government of the Federal Republic of Nigeria. Principal financing has been arranged since 1971 through the Consultative Group on International Agricultural Research (CGIAR).

The Resource and Crop Management Program (RCMP) is concerned with two of the three main thrusts of IITA research, namely: resource management research, which is the study of the natural resource base with a view to refining existing resource management technologies and devising new ones, and crop management research which aims at the synthesis of the products of resource management research and plant breeding into sustainable and productive cropping systems.

The goal of RCMP is to develop economically and ecologically viable farming systems for increased and sustainable production by the smallholder or family farmer of Africa, while conserving the natural resource base.

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Preface

The RCMP Research Monograph series is designed to widely disseminate results of research on the resource and crop management problems of smallholder farmers in sub-Saharan Africa, including socioeconomic and policy-related issues, and to contribute to existing knowledge on improved agricultural principles and policies and the effect they have on the sustainability of small-scale food production systems. These monographs summarize results of studies by IITA researchers and their collaborators; they are generally more substantial in content than journal articles.

The monographs are 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:

The Director
Resource and Crop Management Program
International Institute of Tropical Agriculture
PMB 5320, Ibadan, Nigeria

Contents

I. Introduction

Inland valleys (IVs) are distributed throughout all the agroecological zones of West Africa. They have been estimated to cover between 10 to 20 million ha in the West African equatorial and guinea savanna zones (Hekstra and Andriesse 1983), and 130 million ha in intertropical Africa (Raunet 1985).

IVs, which are also called bas-fonds, marigots, dambo, dwala, fadama, or vlei, are one of the various categories of wetlands, and are perhaps best defined in relation to the entire West African landscape. They are the relatively shallow and narrow valleys which occur in the upper reaches of major and minor watersheds throughout the West African landscape. Their length can extend over distances of about 25km and their width varies from around 10m in their upper levels to about 800m in their lower stretches. IVs comprise the watersheds of drainage axes in which seepage and surface runoff from adjacent uplands converge. In addition, the water table in the lower parts of the valleys and valley bottoms is near or even above the soil surface, at least during the wet season. IVs are thus characterized by three hydrological processes: seepage, runoff, and vertical fluctuations in the water table. These are represented in Figure 1 for three different IV profiles.

Problem statement

Because of their particular hydrological characteristics, IVs are likely to be favorable ecosystems for rice production during the rainy season, and for the cultivation of various "upland crops" in the bottom of the valleys, during the dry season. IVs are significant ecosystems for two principal reasons. First, these valleys have the potential to be used for agricultural production in a sustainable way. Wetland rice cultivation has a potential for sustainable production, as demonstrated by the sawah systems of Southeast Asia where rice has been grown for centuries. Such a potential is particularly relevant in view of the degradation of the resource base of agriculture which is occurring on the uplands of West and Central Africa, e.g., desertification, shortened fallow period, declining soil fertility and degradation of soil structure (surface crusting, "capping"). The sustainable utilization of IVs for agricultural production is, conceivably, one way of relieving some of the current pressures on the natural resource base of upland agroecosystems.

The second (and complementary) reason why IVs are important ecosystems is that they have a high physical potential for increasing food production. Physical conditions for cropping in IVs are more favorable than on the uplands particularly since more water is available. Potential yields of rice have been estimated at 2.3 t/ha in IVs, but at a maximum of 1.5 t/ha on upland fields (IITA 1988). Irrigated rice production, the other substantial type of rice production, requires significant capital investments and has very high monetary and non-monetary operating costs, so that it is not a feasible alternative in the socioeconomic context of West and Central African agriculture (Raunet 1985). Rice production in IVs is thus, potentially at least, an important type of rice cultivation in the region. In addition, during the dry season, IV bottom and fringes are almost the only location in the guinea savanna zone where crops can be grown, outside irrigated areas.

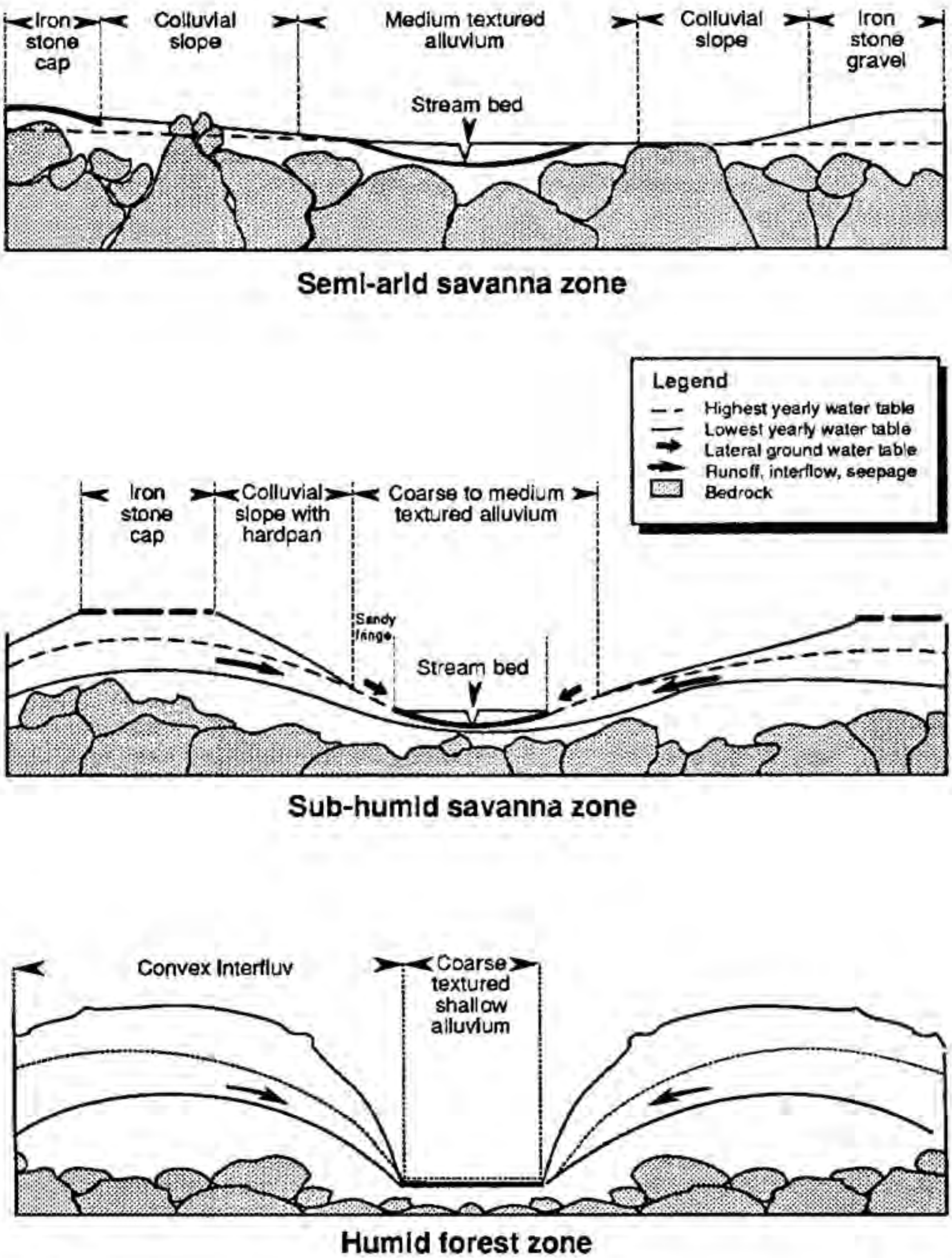

Figure 1. **Crossection of IVs in three agroecological zones of West Africa (adapted from Raunet 1985).**

These factors regarding the yield potential of IVs are all the more significant in view of the facts that:

- per capita food production has been declining in West and Central Africa,
- the demand for rice, which is the principal crop grown in IVs, has been increasing at about 8.4% per annum (from 1960 until the mid 1980s),
- imports of rice by West African countries have increased by about 28% during the same period (West Africa Rice Development Association (WARDA) 1988), thereby further worsening the already substantial balance of payment deficits in these countries.

The principal problem posed by these agroecosystems is that, for reasons which are unclear, the potentials of IVs have remained relatively untapped. Only between 10 and 25% of IVs are used for agricultural production, although a trend toward a greater use of IVs is apparent in many areas of West Africa (Berton 1988). Furthermore, the yields currently obtained by most farmers in IV fields are significantly below potential yields. For example, average rice yields in some IVs which have been monitored by IITA in the Bida area, Central Nigeria, are only 1.2 t/ha.

This problem is further complicated by three factors. First, symptoms of non-sustainable use, such as erosion and decreased soil fertility, have been observed in some IV agroecosystems by IITA researchers (Wakatsuki et al. 1989).

Second, the various attempts which have been made in the past to introduce improved technologies in IVs in West and Central Africa have been unsuccessful. These technologies consisted of high levels of water control and extensive use of chemical fertilizers and pesticides, following the Asian rice paddy model (see Brautigam 1987 for details). Alternative technologies, with input requirements which might be more acceptable to farmers, are presently not available.

Third, IV agroecosystems are highly complex and heterogeneous, so that simple causes cannot be ascribed to the problem of their under-utilization, nor do simple solutions exist. The only two characteristics common to all IVs are their hydromorphic soils and the fact that they are favorable habitats for the vectors of many debilitating or fatal human and animal diseases, namely schistosomiasis (bilharzia), onchocerciasis (river blindness), dracunculiasis (guinea worm), trypanosomiasis (sleeping sickness), and malaria.

Background: complexity and heterogeneity of inland valley agroecosystems

IV agroecosystems are particularly complex for a variety of reasons. First, IV fields are generally cultivated by small-scale farmers who also cultivate upland fields. These farmers are still largely subsistence oriented, but they are rapidly becoming more integrated in regional and national market systems. Their objectives and motivations reflect this change and are thereby diverse. It is not possible, therefore, to subsume these objectives by a single and simple goal such as "increasing rice yields in IV fields", or "increasing profits from farming activities".

Second, since the cultivation of IV fields is integrated in upland farming activities, the interrelationships which link upland and lowland activities are a particularly important dimension of IV agroecosystems. These interactions are both complementary and competitive. For example, rice may be grown as a cash crop in IV fields, whereas crops grown on upland fields often are the food crops consumed by the household. At the same time, farmers must throughout the year establish trade-offs between the competing demands of their upland and IV fields in terms of scarce inputs (e.g., labor).

Third, two different categories of crops are grown in IV fields, rice and "dry season" crops, such as cassava, yams, sweet potatoes, and cowpeas. Interrelationships exist among these categories of crops, although different management skills are required. For example, big mounds are used by farmers who grow cassava in their IV fields after rice is harvested. These mounds are spread when cassava is harvested, before rice is grown again. IITA researchers have hypothesized that such a system of mound building significantly contributes to the control of weeds during rice growth as well as to the build-up of organic fertility.

Finally, the hydrological characteristics of IVs and the interactions between the hydrological cycle and the other components of these systems further contribute to the complexity of IV agroecosystems, especially when these are compared with upland systems.

Since IVs exist in all the agroecological zones of West and Central Africa, there is a high level of heterogeneity in the ecological and economic parameters which characterize these valleys. Furthermore, this heterogeneity is also manifest within agroecological zones and within valleys. Because of their morphologic heterogeneity, catchment areas range from 100 to 2000ha (Andriesse 1986), while IVs differ in length and cross-section. Their longitudinal slope (from 1 to 5%) can be continuous or stepped, depending on the underlying rock formations. These formations will also determine the profile (cross-section) of IVs, which ranges from narrow bottoms with steep, convex slopes, to wide bottoms with gentle, concave slopes (see Fig. 1).

In general, IV soil characteristics reflect those of the surrounding uplands, and are highly variable throughout West Africa. Furthermore, since IVs can have a wide range of shapes with differences in hydrological regimes and parent rocks, valley bottoms differ in soil texture and fertility levels (Hekstra and Andriesse 1983). The hydrologic characteristics of IVs are determined by rainfall, soil texture, soil depth, catchment area, and valley morphology. As a result, there is great variability across valleys.

In addition to variability among valleys over space and time, there is significant variability in moisture content and soil characteristics within the length and cross section of any valley.

Finally, socioeconomic parameters, such as land tenure systems, soil management practices, water control systems, population density, national and regional agricultural policies, vary substantially across regions and IVs as well. In some regions, IV fields are owned by absentee landlords, in others, they are owned collectively, by an entire village.

These different land tenure systems will have different implications in terms of soil and water management practices and of the viability of improved practices.

This large variability in physical characteristics (between, within, and across IVs) results in highly complex and heterogeneous physical systems. When the diverse human dimensions of IV agroecosystems are combined with this physical heterogeneity, the complexity of the resulting structure is compounded.

Past approaches

Research on African IV agroecosystems has been carried out, for the past three or four decades, by a variety of institutes and scientists. These diverse research efforts have four common features. First, the bulk of the work has concentrated on rice cropping in IVs, rather than on IV agroecosystems. Second, this research has been largely unidisciplinary in nature and has focused on one component or one sub-component of rice cropping in IVs. Third, the results yielded by this research are site-specific, because no classification of IVs has been undertaken. Fourth, most of this research was greatly inspired by the Asian experience with rice systems in IVs, and with the experience and findings of the International Rice Research Institute (IRRI) in Southeast Asia. The sustainability of Southeast Asian intensive rice cultivation in IVs and its high yields led many researchers to believe that the introduction of such a system into West African IVs would meet with equal success. Such research has not had the hoped-for impact on IV rice production (Winslow and Buddenhagen 1989) and has had no impact on the other crops grown in IVs. This clearly suggests that the physical and socioeconomic differences between IV systems in Southeast Asia and West and Central Africa were not fully appreciated. (Evidence is provided in various studies, such as Spencer 1981).

Past research contributes partial insights into some ecological and economic aspects of IVs. For example, at the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and Institut de Recherches Agronomiques Tropicales (IRAT), French scientists have had a research program on IVs for some years. They have focused on some areas in Madagascar, Benin, Burkina Faso, and Senegal, and have produced detailed biophysical inventories of IVs and descriptions of the soils and hydrological conditions of IV agroecosystems in these areas (Raunet 1985, 1989). The findings of CIRAD will provide interesting points of comparison for the IV classification component of the present strategy.

Another example of the contribution of past research is provided by the work of Dutch and IITA scientists in the context of the Wetlands Utilization Research Project (WURP) which was undertaken in Nigeria and Sierra Leone in the 1980s. Secondary information on key physical aspects of wetlands in the humid tropics was compiled during the first phase of the WURP. Later on, the project focused on water management in some IVs near Makeni (Sierra Leone) and Bida (Nigeria). The WURP contributes to this present project useful baseline data and qualitative information, and a description of some aspects of IV farming systems in Makeni and Bida (e.g., cropping calendar, description of constraints to higher yields of rice in these IVs, hydrological model for one valley).

Although the current project thus builds upon the information obtained during the WURP, its objectives and methodology are different. In this sense, this project is not a continuation of the WURP, but rather the result of a re-orientation of IV research at IITA.

Notwithstanding these contributions, current knowledge concerning IV agroecosystems has substantial gaps. Past research does not provide the information needed to develop an understanding of IV agroecosystems, because no attempts were made by researchers to adopt a systems approach to IV issues. Consequently, it is not possible to ascertain how the results obtained fit into the relevant agroecosystems, nor to assess the implications of these results for these systems. Furthermore, as already mentioned, these results are site-specific and therefore cannot be extrapolated. (This is a very severe shortcoming, given the high heterogeneity of IVs). Past research thus yields fragmented and sporadic insights into IV agroecosystems.

Brief methodological justification

A first challenge is to understand the role of IVs in the agricultural systems of West and Central Africa and the dynamics of land use patterns in IV agroecosystems. This will highlight the reasons for the underutilization of IVs and serve to identify the factors which have led to the agricultural development of IVs over time. An analysis of historical trends in land-use patterns in IVs, and an assessment of the agricultural potential of IVs in West and Central Africa in the light of projected increases in population over the next 20 years or so, will further contribute to such an understanding of the role of IVs. This will also permit an assessment of the long-term theoretical target of production from IV agroecosystems which scientists can use for designing improved technologies for IVs.

The second major challenge is to quantify, analyze, and understand the great heterogeneity and complexities of IV agroecosystems. By building upon the existing body of knowledge of rice cropping systems in IVs and investigating the objectives of small-scale farmers who cultivate upland and IV fields, we will identify the structure and functions of IV agroecosystems. A systems approach is the most promising methodology to use to reach this goal, given the complex interactions which exist within IV agroecosystems and the heterogeneity and variability of these systems.

The third major challenge is to develop, in collaboration with small-scale farmers, improved (and adoptable) technologies for different categories of IV agroecosystems. These improved technologies will enable farmers to better achieve their objectives in the short term. Different technologies may be identified for reaching the long-term production target which we will have established.

Indeed, it is likely that optimal uses will differ for IV systems having different characteristics (e.g., some valleys may be best suited to the preservation of their genetic potential, and for hunting and gathering; others may be best suited to rice production with high water control, and others yet to rice and other food crop production with low water control). By building models of the biophysical and socioeconomic interactions which characterize IV agroecosystems (including interactions, both ecological and economic, between upland and IV fields), and using simulation, we will investigate quantitatively the short-term and long-term effects of different improved technologies (e.g., water management, fertility management). This will enable us to ensure that these technologies are ecologically sustainable and increase the welfare of small-scale farmers while meeting their production objectives. The improved technologies thus designed should help alleviate:

- poverty and inequalities, by improving the welfare of small-scale farmers in the area (including female farmers and female members of farming households);

- resource degradation on the uplands of West and Central Africa, by resulting in sustainable IV production;

- food problems in West and Central Africa, by leading to increased rice and food production in IVs.

One dimension of any attempt at addressing issues of hunger, poverty, and sustainability is that of public policies, in this case, those bearing on IV agroecosystems. Most analysts (e.g., Eicher 1984) concur that agricultural price policies, in particular, are of vital importance to agricultural production systems in Africa. Such issues are so complex that they would constitute a project in themselves; they thus lie outside the scope of the present project.

II. Research Objectives and Hypotheses

General objective

The general objective of the present research project is to evaluate existing natural resource management and crop management systems in IVs of West and Central Africa in terms of economic and ecological sustainability, and farmers' welfare, and to design feasible improvements in these systems on the basis of this evaluation.

The geographical areas concerned are those parts of West and Central Africa where IVs receive at least 600mm of annual rainfall.

Specific objectives and hypotheses

This general objective can be broken down into eight specific research objectives.

1. *To measure the land area occupied by IVs in West and Central Africa, the percentage and physical location of those IVs which are used for agricultural production.* As mentioned in the introduction, this is between 10 and 20 million ha.

The following hypothesis underlies this objective:

(H.1) The lower the rainfall in a given area, the more likely it is that IVs are used for agricultural production; the higher the rainfall, the less likely it is that IVs will be used for agricultural production.

2. *To identify the factors which lead to a low rate of utilization of IVs for agricultural production, and the changes which have occurred over time in land uses in IVs, and the factors which lead to changes in land use patterns in IVs.*

The following hypothesis underlies this objective:

(H.2) Changes in land uses in IVs are principally determined by increases in population pressure, and increases and improvements in transport infrastructure. As mentioned in section I, governmental policies lie outside the scope of this project.

3. *To classify IVs of West and Central Africa and select representative experimental sites within the principal categories of IVs.*

This objective is based on the hypothesis:

(H.3) Variations in land use patterns in IVs are determined by both ecological and socioeconomic factors.

4. *To identify and quantify constraints to different land uses in terms of ecological and economic sustainability, and farmers' welfare for the principal categories of IVs*

Various hypotheses underlie this objective:

(H.4) Ecologically sustainable agricultural production in IVs is primarily dependent upon water control.

(H.5) When water control is adequate in IVs, then agricultural productivity is constrained by soil fertility, weed pressure, and vertebrate pests.

(H.6) When water control is not adequate, significant increases in agricultural production can still be gained in IVs through weed, soil, and pest management.

(H.7) IVs have a high potential for rice production and dry season cropping.

(H.8) Cultivation of IV fields in all categories of IVs is significantly more labor-intensive than of upland fields, per unit of land cultivated.

(H.9) In some categories of IVs, the productivity of labor is higher than in upland fields.

(H.10) In some categories of IVs, farmers give priority to their upland farming activities and to social ceremonies when timing their IV farming activities and allocating labor to their IV fields.

5. *To develop integrated models of biophysical and socioeconomic processes in the principal categories of IV agroecosystems.*

This objective is based on the following three hypotheses:

(H.11) If land tenure systems and social systems prevent the management of IV watersheds as single units, soil degradation and changes in water quality and regime will result in IV agroecosystems which are not ecologically sustainable.

(H.12) Small-scale farmers in IVs have three principal production objectives: generating a satisfactory income, meeting the food security requirements of the family, and fulfilling their social obligations.

(H.13) The management practices which (in terms of sustainability and farmers' objectives) can lead to the greatest improvements in most IV agroecosystems are water management, soil fertility management, and weed management.

6. *To design feasible improvements in land use and/or management practices for different categories of IV agroecosystems and to test these modifications at representative sites.*

Two hypotheses underline this objective:

(H.14) Different kinds of land use and technologies will be optimal for different categories of IVs classified in terms of socioeconomic and ecological parameters.

(H.15) Significant and sustainable increases in the productivity of IV agroecosystems cannot be achieved without the use of integrated water, crop, soil, and pest management practices, including organic and inorganic soil management, and manual and chemical weed management.

7. *To validate the models developed, on the basis of the results obtained.*

8. *To extrapolate these results to other categories of IVs.*

III. Methodology

To fulfil the research objectives described in section II, three major sets of activities will be undertaken. These are represented in Figure 2. Transfers of methodology and technology to NARS are discussed below, in section IV.

Inventory and classification of IV agroecosystems

This set of activities extends and builds upon the previous WURP physical characterization work. It will be conducted at three sequential levels and will proceed from a large-scale definition of agroecological and economic zones to a small-scale characterization of different kinds of IVs within these zones. These 3 levels are presented in Figure 3.

The objectives of this characterization are to:

- classify IVs and select representative sites for the two other major sets of activities;
- quantify IV land area and water catchment area for all agroecological zones relevant to this project, as well as on a country-by-country basis;
- identify land use patterns in IVs; and
- identify causal relationships between the low rate of use of IVs and ecological and/or economic factors.

Level 1 characterization

At this first level, basic parameters are used to map broad agroecological and economic zones for West and Central Africa. These parameters are:

- climate,
- soil,
- population density,
- income per capita.

Secondary data are utilized in a GIS framework to quantify the parameters and produce maps at a scale of 1:5,000,000. Secondary sources include the FAO/UNESCO Soil Maps of the World (FAO 1977), the WURP reports (Hekstra and Andriesse 1983), the FAO Agroecological Zones Project reports (FAO 1978) National Census data on population density and per capita income, and others. At a sub-level of characterization, WARDA is concurrently mapping rice production and rice-growing environments for Côte d'Ivoir, at a scale of 1:1,000,000

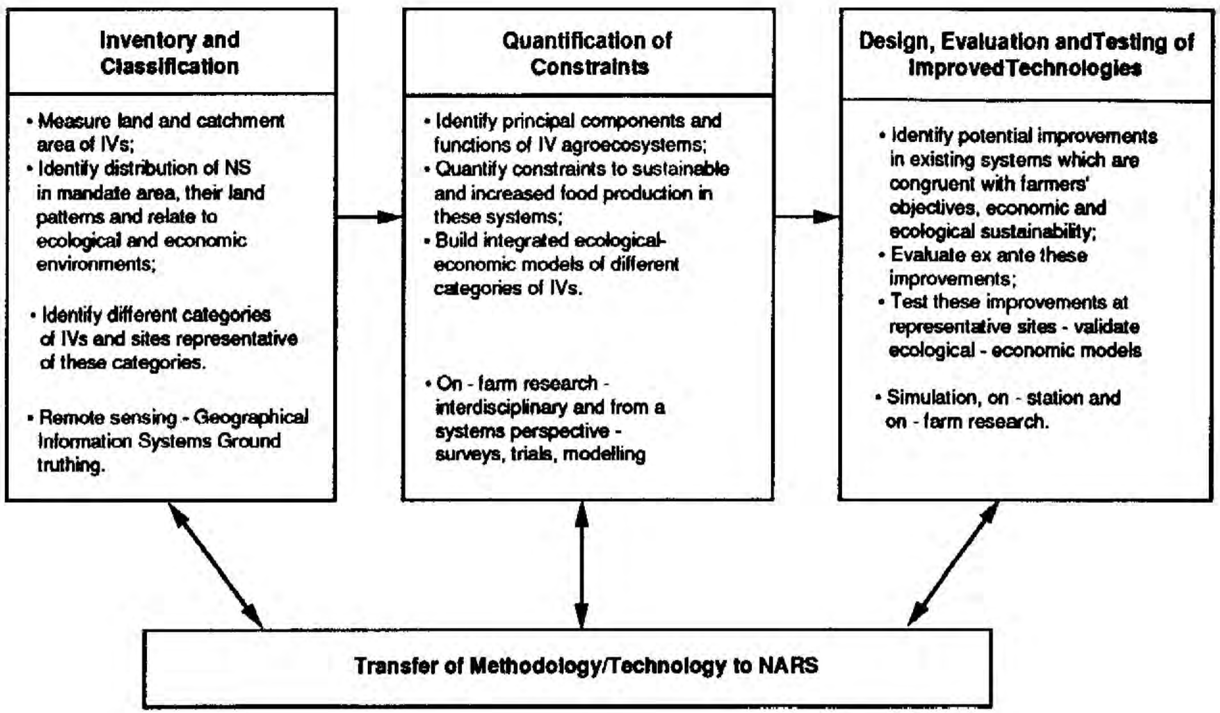

Figure 2. Principal sets of activities for Inland Valley agroecological research.

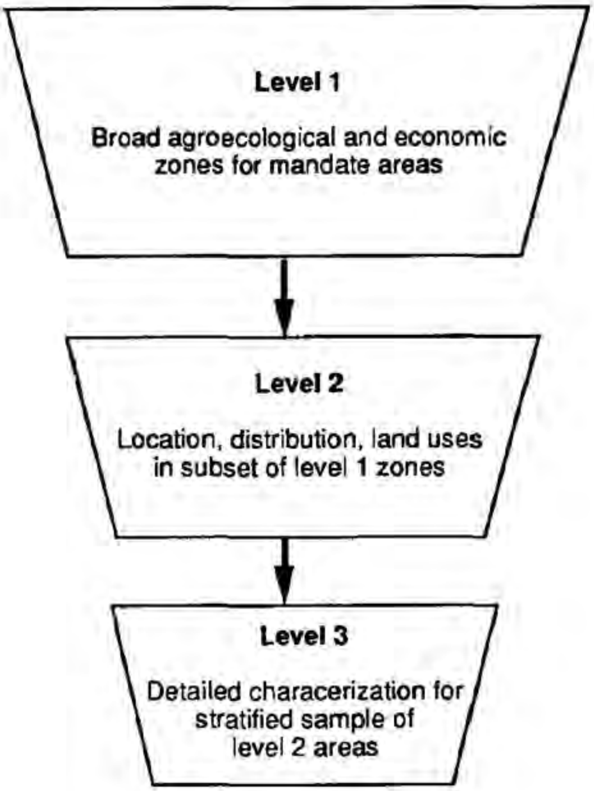

Figure 3. Inventory and classification of IV agroecosystems.

Level 2 characterization

A stratified sample of areas within the broad agroecological and economic zones distinguished in the level of the characterization will be built (on the basis of the parameters used in Level 1 characterization) and SPOT satellite pictures will be obtained for these sample areas. This remote sensing component of the project will be undertaken in collaboration with the Regional Centre for Training in Aerospace Surveys (RECTAS) located at the University of Ife, Nigeria. Since RECTAS is under the umbrella of the International Institute for Aerospace Survey and Earth Sciences (ITC) in the Netherlands and Le Groupement pour le Développement de la Télédétection Aérospatiale (GDTA) in France, collaboration with RECTAS is in effect collaboration with ITC and GDTA.

The satellite images will be used to identify and/or measure:

- location and distribution patterns of IVs in relation to uplands, watersheds of IVs;
- land uses in IVs;

- occurrence of surface water bodies and location of IVs within river basin systems;
- transport infrastructure;
- population distribution (towns, markets).

Upon the basis of this information, different categories of IVs will be identified within Level 1 zones.

Level 1 and part of Level 2 characterization are undertaken in the context of the collaborative Pre-Project between WARDA, IITA, Winand Staring Center (WSC), and Wageningen Agricultural University (WAU) which was recently submitted to the Dutch Government for funding.

Level 3 characterization

Level 3 characterization will be carried out on a subset of the IV types identified at Level 2. This subset will be selected using stratified sampling methods; criteria for stratification will be derived from the results of Level 2 characterization. The purpose of Level 3 characterization is twofold:

1. to verify Level 2 characterization by ground-truth observation;
2. to extend the characterization to a higher level of detail using biophysical, agronomic, and socioeconomic parameters critical to IV utilization.

The following factors will be evaluated for all IVs in the chosen subset, through ground truthing, direct observations and measurements, surveys, and secondary sources where relevant.

Hydrological parameters

topographical survey of catchments, rainfall input to catchments,
stream water discharge from valleys,
water table fluctuations in zones of catchments and valleys with hydromorphic soils,
surface waterflow between the top of the toposequence and valley bottoms.

Vegetational and landuse parameters

identification and confirmation of distribution of land use categories in watersheds,
classification of vegetation type,
erosion patterns within watersheds,
sedimentation and water toxicities.

Soil parameters

Soil classification stratified by topographic position in and in relation to hydrologic regime,
fertility classification including organic matter and toxicities,
soil structure and water regime determinants.

Resource and crop management parameters

level of water control and water rights,
land tenure and land rights,
soil fertility management practices,
weed and pest management practices,
cropping patterns and calendar,
contribution of IV fields to farmer's welfare (i.e., percentage of income and of food consumed),
uses of IVs which are not cultivated (e.g., firewood collection, fish farming, raffia, bamboo, thatch for roofing).

Past changes in these factors should also be documented to ensure that the dynamics of land use patterns in IVs are apprehended. In this respect, existing aerial photographs will be used wherever possible.

Farming systems parameters

income sources and recent changes in these sources,
division of labor between the sexes, and recent changes,
farm size and recent changes,
size and age of households, and recent changes,
ownership of the means of production,
availability of inputs (labor, capital, chemicals), and recent changes,
poverty level, and recent changes,
health status,
percentage of food produced which is sold,
percentage of income spent on non-food items,
in and out migrations, and recent changes,
cropping patterns,
percentage of time spent engaging in social and religious activities in relation to cropping calendar,
farmers' norms and beliefs regarding IVs,
governmental investment in IV water control,
verification of marketing opportunities (roads, markets),
verification of population density,
environmental hazards associated with different land uses.

Based on the above ecological and economic parameters, a final classification of IVs will be developed to lead to the fulfilment of objectives 1 and 2. In addition, it will have the following output:

- Maps of parts of West and Central Africa (1:100,000) showing the distribution of different categories of IVs, and land use patterns in these valleys,

- Digitized data base covering sampled areas which will be used as a point of departure for the ecological-economic modelling of IV agroecosystems. (See objective 4),

- Estimation of the present food production levels and future potential of the different categories of IV agroecosystems.

- Tentative identification of major constraints to different land uses in different categories of IVs. (See objective 3).

Quantification of constraints to sustainable and increased food production

As shown in Figure 2, the objectives of the second set of research activities are to:

1. identify and quantify the principal components, processes and functions of IV agroecosystems (e.g., sustainability of current farming practices, objectives of farmers, water and nutrient cycles)

2. identify and quantify constraints to different land uses in different categories of IV agroecosystems in terms of ecological and economic sustainability and farmers' welfare,

3. build integrated models of the principal ecological and economic processes in different categories of IVs.

A combination of diagnostic surveys, experiments, and process studies, conducted at representative sites, will be used to identify and quantify the relevant parameters, and to quantify their interactions.

The diagnostic surveys will be structured on the basis of the existing information regarding IV farming systems which is available from secondary sources such as the WURP. These surveys will deal principally with the constraints to different land uses and to agricultural production in IVs, farmers' production objectives, and decision-making processes regarding their resource and crop management practices and intrahousehold distribution of rights and responsibilities. Individual interviews of male and female household members will be conducted under the supervision of a consultant agricultural anthropologist to obtain this information. This anthropologist will also help devise and frame the survey questions to ensure that these questions are meaningful and relevant for the different ethnic groups represented at the various sites.

One possible major experimental trial could be established at one or more of the experimental sites to test hypotheses 4, 5, and 6 and to obtain data dealing with processes related to soil fertility and weed pressure, according to particular valley types. A possible design would be where the major treatment is varying levels of water management, defined in terms of length of submergence period and depth of standing water. A subtreatment of imposed variations in soil fertility management would be used. Rice and dry season crops would be in transections across the toposequence (following the method of Moorman, Veldkamp and Ballaux 1977), representing a spectrum of differing soil, water and nutrient conditions. Figure 1 illustrates differences in toposequences for different valley types. Process level studies on nutrient cycling and plant interactions would be conducted within the framework of the trial.

In order to ensure that a systems perspective is maintained throughout these experiments and diagnostic surveys, the planning of these studies and the analysis of their results will be undertaken by the relevant members of the IITA Inland Valley Systems Research Group from an interdisciplinary perspective. The main model building phase of the project will be initiated shortly after the commencement of these surveys and trials. Models of the different categories of IV agroecosystems will be built at the watershed level. These models will depict the most significant ecological, hydrological, agronomic, and socioeconomic components, processes, and functions of IV agroecosystems. The models will be used to analyze quantitatively the data obtained during the inventory, the diagnostic surveys, and experiments.

The models will be structured around the decision-making mechanisms used by farmers. This is because the driving forces behind adoption or rejection of a new technology are farmers' objectives and decision-making processes. This implies that these models will be stochastic, in order to account for the risks particular to agricultural production in IV agroecosystems (drought, flooding, human diseases). In addition, they will have a sustainability component, consisting of the ecological "feedback" mechanisms which characterize these ecosystems, and a farmers' welfare component. Such models are not reductionist, in that not all variables are measured in a single unit used as a common denominator (e.g., dollars). Rather, they are based on the principles of multiple criteria analysis, in which trade-offs are established between variables measured in different units (e.g., levels of soil fertility, water quality, farmers' welfare).

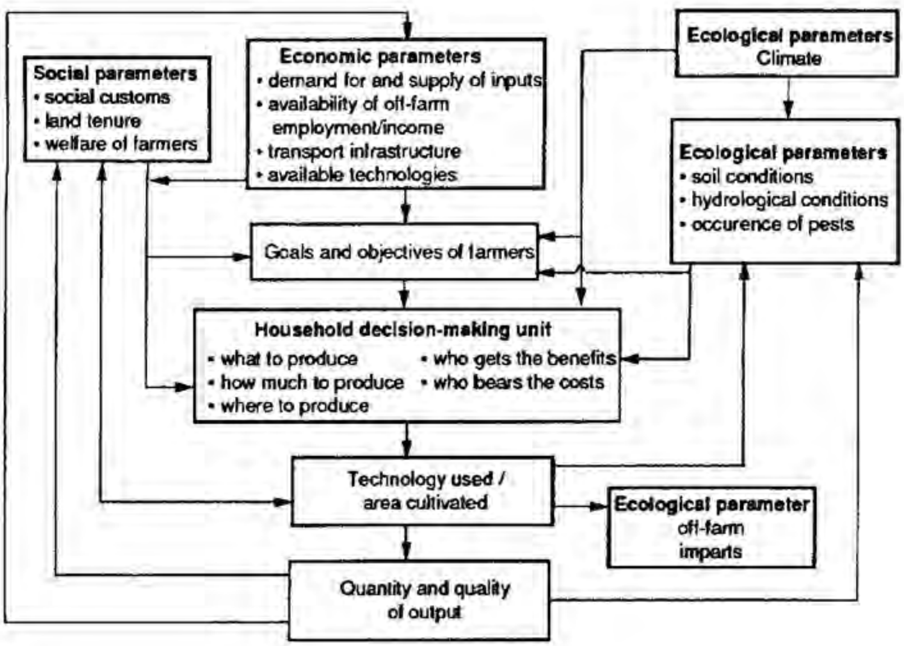

Figure 4. Simplified ecological-economic model of IV agroecosystems.

Figure 4 is a diagram of a simplified ecological-economic model, which is used as a point of departure in this project. The surveys and experiments will help focus and sharpen our understanding of the parameters (i.e., the contents of each box) in this figure. Modeling will result in the specification of the functional form of the interdependences represented by arrows in Figure 4, as well as of the interactions among parameters within each box (not represented). In addition to the fulfilment of objective 3, the expected outputs of this second stage of our methodology are:

- Definitions, and methods of measurement of the following concepts in the context of IV agroecosystems: ecological and economic sustainability, farmers' objectives, farmers' welfare;
- Ecological-economic models of different IV agroecosystems, and farmers' decision-making algorithms.

Design, evaluation and testing of improved technologies

During this last set of activities, with the participation of farmers, we will first identify potential improvements in existing natural resource and crop management systems for the major types of IVs (e.g., modified water control use of rice straw as a mulch, use of green manures). We will focus on the farmers' principal management practices which have a bearing on ecological and economic sustainability. At this stage, we hypothesize that these practices are water management, soil management, and weed management. Second, we will then evaluate these improvements at the farming system and watershed levels, in terms of the ecological and economic sustainability of the system and farmers' welfare. Third, we will test the most promising of these technologies at representative sites. Fourth, we will extrapolate the results to each relevant type of IVs and validate our economic-ecological models. Lastly, we will transfer the technologies thus developed to NARS.

On-station and on-farm experiments will lead to the design of potential improved technologies. The evaluation of these technologies will entail the simulation of their ecological and economic effects in different categories of IV agroecosystems, on the basis of the ecological-economic models previously developed. That is, the short-term and long-term ecological and economic consequences of alternative technologies will be predicted, at the levels both of the individual farmer and the watershed. This is because a given technology may have positive consequences from the perspective of an individual farmer, and negative effects at the watershed level, for example, if negative externalities are generated by individual farmers.

An impact matrix will then be used for assessing these ecological and economic effects in terms of the general criteria used in this project for assessing improved technologies, namely, ecological and economic sustainability and farmers' welfare - however specifically defined.

Since it is highly likely that most technologies will perform differently with respect to different criteria (e.g., a technology may be ecologically sustainable but economically unsustainable) techniques for multi-criteria analysis will be used to assess the trade-offs between criteria. The technologies with the highest performance score will be tested at our experimental site under farmers' conditions to determine their adoptability.

IV. Collaboration with NARS

The scope, methodology, and philosophy of the present project are such that collaboration with NARS is an essential component of successful completion. The main objectives of this collaboration are:

1. to integrate the expertise of NARS about IV agroecosystems into all phases of the project, but particularly in the levels 2 and 3 in order to increase the relevance and the depth and broaden the scope of the results obtained;

2. to further develop the capacity of NARS to undertake agricultural research through the involvement of NARS personnel with the project from its inception. This is being achieved by exposing them to project methodologies by the formal training at IITA, and by making available research resources and facilities to which the staff may not otherwise have had access.

Since NARS in different countries have different objectives and different means, it would be inappropriate to use the same approach to collaboration for all the countries involved in the project. Rather, a different framework, adapted to the needs of each NARS, will be developed for each collaborating country. The approach taken with NARS in Sierra Leone and Ghana for collaboration on IV agroecosystems serves to illustrate this point.

In Sierra Leone, we collaborate with two NARS: the Land and Water Development Division (LWDD) of the Ministry of Agriculture, Natural Resources and Forests, and the Institute for Agricultural Research (IAR). LWDD is interested in the inventory and classification phases of the present project. It is currently developing a specific collaborative research proposal with the Inland Valley Group, on the basis of the present project. LWDD has been interested in such inventory work for a while but has lacked the means to undertake it. Moreover, LWDD has been involved in earlier related collaborative activities through the WURP. Collaboration with IITA will enable them to develop the maps of IV systems throughout Sierra Leone which they need. LWDD has nationwide aerial photography of Sierra Leone which will be used in conjunction with SPOT imagery to develop new detailed maps of IV systems. Both the interpretation work and the ground truthing will be undertaken collaboratively. In addition, LWDD will develop its own inventory agenda, to fulfil some of its classification objectives which have greater data requirements than those of the present project. Our collaboration will continue until the end of LWDD's inventory activities.

Members of staff from IAR and Njala University are collaborating with us for the quantification of constraints and, later on, the design, evaluation, and testing of new technologies. This collaboration enables us to conduct trials and surveys in three different IV agroecosystems in Sierra Leone and to benefit from the experience of IAR and university staff with farming systems in Sierra Leone. Trials and surveys are planned collaboratively, administered by IAR and university staff with regular supervision from IITA scientists, and analyzed collaboratively.

Finally, we have agreed with the Rice Research Institute in Rokupr that collaboration with the Institute will be initiated when its Farming Systems Division becomes operational. This should occur in the near future.

In Ghana, we will collaborate with the Crop Services Department of the Ministry of Agriculture. The objective of the Crop Services Department is to develop improved technologies for rice production in the IVs of the Western Region of Ghana, in keeping with the Ghanaian government's policy to make Ghana self-sufficient in rice. This Department has requested IITA and WARDA to provide the conceptual framework and technical back-up for their project.

V. Expected Output and Target Groups

This project will generate three kinds of output, viz., data banks and geographic information systems, technologies and training for NARS staff, and concepts and methods which are of interest to the international scientific community.

Data banks and geographic information systems

The inventory work will result in the development of the following:

- digitized databases interlinked with GIS of West and Central Africa at 1:5,000,000 showing physical parameters (climate, land regions) and socioeconomic parameters (population density, income), as well as regional maps at 1:200,000, and satellite imagery of relevant areas;

- identification on these maps of the location and land area occupied by IVs and their watersheds;

- for each country, evaluation of the agricultural potential of IVs in the light of projected food needs;

- digitalized data banks concerning the natural resource base and farming systems in IV agroecosystems.

Such information and data have been requested by a number of NARS. They will enable policy-makers and agricultural planners to base their land-use and/or natural resource management decisions on quantitative information. This will lead to more effective policy formulation, program development, and priority determination in public spending.

Technologies and training

During all phases of the project, NARS staff collaborating with IITA will be trained through formal courses and workshops in the methods being developed and used. Among these are classification techniques (in collaboration with the Regional Centre for Training in Aerospace Surveys, at the University of Ife, Nigeria), systems approach for the assessment and analysis of the sustainability of agroecosystems, and on-farm research methods. In addition, NARS scientists in some countries will work on a higher research degree, under the supervision of IITA staff, while engaged in collaborative work for the project. Other training possibilities will also be considered, wherever feasible, such as the participation of IITA scientists in some courses offered by African universities.

The technologies performing the best, in terms of the criteria used in the project, and which will have been successfully tested will be directly "usable" by NARS and extension services in countries of West and Central Africa. They will be directly applicable in the sense that (i) they will not be site-specific, but relevant to all IV agroecosystems within a specific category of IVs, and (ii) they will incorporate farmers' objectives and will thus have a high potential for adoption. In addition, the methodologies developed in this project to design improved technologies will be available for NARS to use in the development of other improved technologies for all other categories of IVs.

Finally, we will create a collaborative network among all NARS working on IV agroecosystems, to facilitate the exchange of information between network members and create a formal channel for collaboration on various research issues among members. This network will also be instrumental during the on-farm validation portion of phase IV, since this validation will be undertaken in collaboration with NARS members of the network.

Concepts and methods

The last category of output from this project has a direct scientific and academic relevance. Findings will be published in appropriate and widely circulated journals, on the following aspects of our work:

- definition and measurement of sustainability for an IV agroecosystem, farmers' objectives, farmers' welfare;
- ecological-economic models of IV agroecosystems;
- hydrological models of IVs watersheds.

In addition, we will produce monographs, manuals, guidelines, and handbooks at each stage of the project, for dissemination to NARS in our mandate area.

Target groups

The immediate target group of this project consists of the NARS and their scientific staff in IITA's mandate area. As mentioned above, they will benefit directly from the training offered, the technologies which will be developed, and the methodologies which will be made available to them.

In addition, policy-makers and planners in national and regional governmental institutions will also gain valuable inputs from this project.

The ultimate target group of this project is made up of the resource-poor farmers, including the women farmers who participate in agricultural production in IVs of West and Central Africa. These farmers will benefit from this project since it will result in the planning of more productive and more sustainable land uses in IVs and in a reduction in poverty and inequalities.

VI. Calendar of Activities

As shown in Figure 5, the inventory and the quantification phases were initiated in June 1990. The inventory and classification work are undertaken as part of the collaborative pre-project between WARDA, IITA, WSC, and WAU. The quantification of constraints to increased and sustainable production was started at two sites, Makeni (Sierra Leone) and Bida (Nigeria). Trials and surveys are being used to identify and quantify the interactions between farmers' weed management practices, their soil fertility and water management practices, their land tenure status, and the priorities they establish between their upland and lowland fields.

Once a sufficiently good understanding of farmers' practices and IV agroecosystems has been developed, around June 1992, the actual design and testing of improved technologies will be initiated.

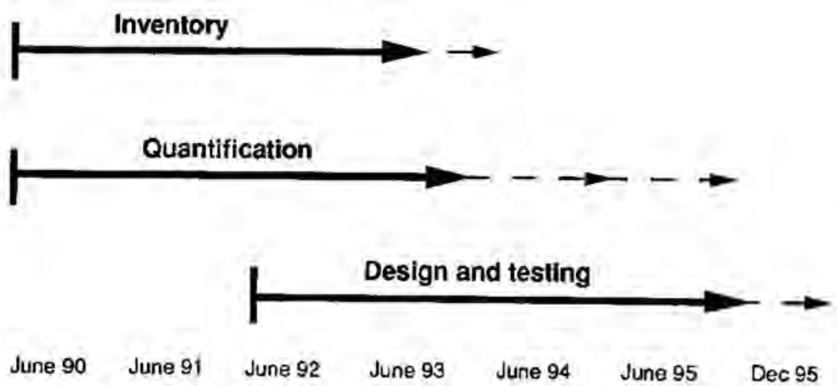

Figure 5. Calendar of activities.

Acknowledgements

The research strategy presented in this monograph is the outcome of a year-long planning effort by the Inland Valley Systems Research Group of the Resource and Crop Management Program and its collaborators in inland valley work, WARDA, the Winand Staring Center and Wageningen Agricultural University. Numerous discussions and meetings with various individuals and groups were held during this time. We should particularly like to acknowledge the contribution of Dr. S. Jagtap, Climatologist at IITA.

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Contributors to the discussions included:

- from IITA: Drs. R. J. Carsky, K. Fischer, S. Hauser, Y. Mohamoud, D. S. C. Spencer, E. Tucker, M. Winslow.
- from WARDA: Drs. A. Adesina, L. Becker, S. Diatta, E. Heinrichs, P. Matlon, T. Remington.
- from the International Institute for Land Reclamation and Improvement: Ir. R. J. Oosterban.
- from the Wageningen Agricultural University: Professors C. T. A. de Wit, and Dr. L. O. Fresco, and Ir. H. ten Berge.
- from the Free University of Amsterdam: Professor P. Nijkamp.
- from Utrecht University: Dr. F. Moorman, (Emeritus Professor).
- from the University of Amsterdam: Dr. Th. Wormer, (Emeritus Professor of Tropical Botany) formerly at the Royal Tropical Institute, Amsterdam.

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A-M. N. Izac is a natural resource economist and the Coordinator of the Inland Valley Systems Research Group, RCMP, IITA.

M.J. Swift is an ecologist and the leader of Resource Management Research, RCMP, IITA.

W. Andriesse is a soil scientist and the Head of the Department of International Cooperation, Winand Staring Center, Wageningen, The Netherlands.