

**Rice-based Production
in Inland Valleys of West Africa:
Research Review and Recommendations**

R. J. Carsky

**Resource and Crop Management Division
International Institute of Tropical Agriculture**

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Resource and Crop Management Research Monograph No. 8

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Preface

The Resource and Crop Management Research Monograph series is designed for the wide dissemination of results of research about the resource and crop management problems of smallholder farmers in sub-Saharan Africa, including socioeconomic and policy-related issues. The range of subject matter is intended 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.

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Dr. Carsky is an agronomist. This monograph is based on his experience as a postdoctoral fellow with the Inland Valley Research Group of the Resource and Crop Management Division, IITA, from 1989 to 1991.

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I. Introduction

The potential of the inland valleys for agricultural production

IITA is concerned with cropping systems research in inland valleys (IVs) which, it is believed, will have a substantial impact on African food production. This is because 20 to 40 million ha of valleys with relatively favorable moisture availability are evenly distributed throughout the humid and sub-humid zones of West Africa alone (Andriessse 1986).

According to West African Rice Development Association (WARDA) 1978 figures from the mid-70s, rice production was dominated by upland rice (60% of total land devoted to rice) and lowland rice was divided into IVs, floodplains, and mangrove swamps with varying levels of water control (WARDA 1978). Moormann (1973) recommended hydromorphic soil areas for the expansion of rice cultivation, giving first priority to inland hydromorphic soils (IVs and river floodplains), and second priority to coastal swamps.

IVs are small valleys which are not located near the coast and do not have a large floodplain. Coastal valleys are distinguished from IVs by their substantial salinity and possibly by excess sulfur problems. An IV, according to Andriessse (1986), starts at a water source as a stream flow valley which further downstream becomes a river overflow valley. Major hydrological processes and valley dimensions change from upper to lower sections of IVs. Runoff and seepage in the upper section are replaced by river overflow in the lower part as the major source of water. The width of valley bottoms increases from tens of meters across in the stream flow sections to hundreds of meters in the river overflow sections. The major river with its large floodplain (greater than 200m width) signals the lower end of an IV.

Although IVs are small, relative to other wetlands, their total area is considerable. According to Andriessse (1986), the IVs make up 8 to 18% of the land area of West Africa south of the sudan savanna, while the estimate for the floodplains, coastal, and other inland wetlands is 4 to 9%. IITA (1988a) in its strategic planning study estimated that the greatest increases in rice production in the region would come from the IV bottoms and associated hydromorphic uplands.

A substantial amount of research has been conducted on rice in West Africa while there has been less study of rice production in IVs. Before a program to develop technologies for improved rice-based cropping system design for the IVs is initiated, an effort must be made to synthesize past research. This, it is hoped, will help to identify major constraints to rice production in IVs, and to propose possible approaches to alleviate them. Gaps must be identified in our knowledge of the IVs related to sustainable rice-based cropping. The goal of future research will be to fill gaps in our basic knowledge of the IVs, and to quantify critical processes which will determine the feasibility of proposed management systems.

The rice-based cropping system in IVs consists of dry season crops in rotation with rainy season rice. Rice is planted near the middle of the rainy season after the planting and weeding of upland crops. This is because IV farmers also have upland fields which

depend completely on rainfall for their crop water requirement. Rice harvest in IVs occurs well after the rains have stopped, because water seeps from the uplands some time after the end of the rains.

A high seasonal labor requirement occurs when farmers must harvest rice and prepare the land for dry season crops. As a result of this and other factors (insufficient moisture in some valleys, other non-farm activities by some farmers, etc.), many farmers leave their fields fallow during the dry season. Other IV farmers take advantage of shallow water tables and residual soil moisture to grow a dry season crop. Thus the potential of the IVs for intensive food production is clear, as well as the risks inherent in intensive cultivation.

Rice research in West Africa

Until very recently, work with rice dealt mainly with germplasm and chemical input components of rice production systems. As an example, WARDA (1978) reports that out of hundreds of their trials conducted in the five years before the report, all involved rice varieties, fertilizers, herbicides, or insecticides.

The earliest efforts in rice research focused on breeding. In general, yields of rice on research stations have increased in all of the rice growing environments since the introduction of Asian (lowland) and Latin American (upland) germplasm. The availability of germplasm is not a major constraint to increased rice production in West Africa (Winslow and Buddenhagen 1989). Meanwhile, yields in farmers' fields have stagnated at levels which are quoted, for example in the IITA (1988a) Strategic Plan, as 0.5 to 1 t/ha upland; 1.5 to 2 t/ha lowland; and 3 t/ha irrigated. A WARDA (1977) report on the use of high-yielding varieties in West Africa makes it clear that the Asian varieties were mainly being used in large irrigation schemes.

More recent WARDA Technical Bulletins reflect a slight broadening in research in rice production systems. For example, Raymundo (1984) reported on traditional methods of fighting termites, rodents, and birds. Studies were initiated on birds (Abifarin 1984, Bashir 1984) and crabs (Agyen-Sampong 1985) as rice pests.

The IITA (1988a) Strategic Planning Study notes that the greatest constraints to rice production in most of the rice-growing environments are in the area of resource and crop management. The following were judged to be important, serious, or very serious constraints to rice production in IVs and hydromorphic uplands: weeds, soil erosion, soil fertility, and vertebrate pests. Other critical but constrained operations are tillage, stand establishment, weed control, and water management.

A serious constraint to developing technology with an impact on rice production in IVs is their heterogeneity. Decisions must be made about the type or types of IV on which to focus research resources for technology development. Then representative sites must be chosen on which to develop and test improved technologies. This can only be possible after a thorough characterization of the West African IVs. Thus, past research will first be examined to aid in the development of procedures for the characterization and classification of IVs.

II. Characterization and classification of IVs

Characterization of IVs

IVs pose a great problem for technology development because they are ecologically heterogeneous, and because they exist in many different economic environments. IVs are found in all of the agroecological zones of West Africa where climate, soils, and topography differ substantially. Consequently, IVs display extreme differences in soil properties and major hydrologic processes. Even within a given zone, differences in valley shape or catchment size can result in large differences in water movement or retention among valleys. Within the valley itself, tremendous changes in soil properties and water availability occur in length and in cross-section. Klinkenberg (1967) mentions that diversity within hydromorphic soils is too great to allow a detailed classification to be attempted.

A complete description of IVs must be undertaken to allow research to be targeted to a few of the most important classes of IV, and to allow technology development and testing to be conducted in sites representative of those classes. From an agronomic viewpoint, the primary properties to be described relate to water and nutrient availability. Thus, the primary properties of IVs to be characterized are soils and hydrology.

Characterization of inland valley soils

Andriessse (1986) notes that:

The soils of the [inland] valley bottoms vary widely in their characteristics, both within and between valleys, because of morphogenesis, location, hydrologic regimes, lithologic origins, and climatic conditions. Chemically, they can be rich or very poor. Their texture ranges from sandy to clay; in cool climates at high elevations, peaty topsoils may develop... Drainage ranges from moderate to very poor, and floods differ widely in depth, duration, and velocity. In general, however, the textures of the soils as well as their chemical characteristics reflect the soils of the surrounding uplands and the parent material from which they are derived.

Though the task of characterizing IV soils looks daunting, we are given some hope by Andriessse's final statement. Soil characterization at the regional level has already been done. Soil maps of regional or national coverage, however, are so small-scale that only the predominant upland soils are shown. Only when the mapping scale increases to 1:100 000 will some of the larger IVs become visible. Precise mapping of IV soils can only be done for a very small fraction of West Africa at a scale of 1:50 000 or larger.

Since the small-scale soils maps (1:5 000 000 to 1:250 000) are already available, an attempt should be made to take advantage of these data. This would depend on established relationships between IV bottom and fringe soils and predominant upland soils. Thus a systematic survey should be conducted to allow a test of the hypothesis that IV soil properties reflect those of the surrounding uplands. The survey would consist of the sampling and analysis of upland, valley fringe, and valley bottom soils from representative valleys. Soil samples from a limited number of valleys (3 to 5) in each agroecological zone should be sufficient to test the hypothesis. Soil texture would be the main property to be analyzed. Delimitation of agroecological zones based on climate, geomorphology, and soils, is an initial task of great priority.

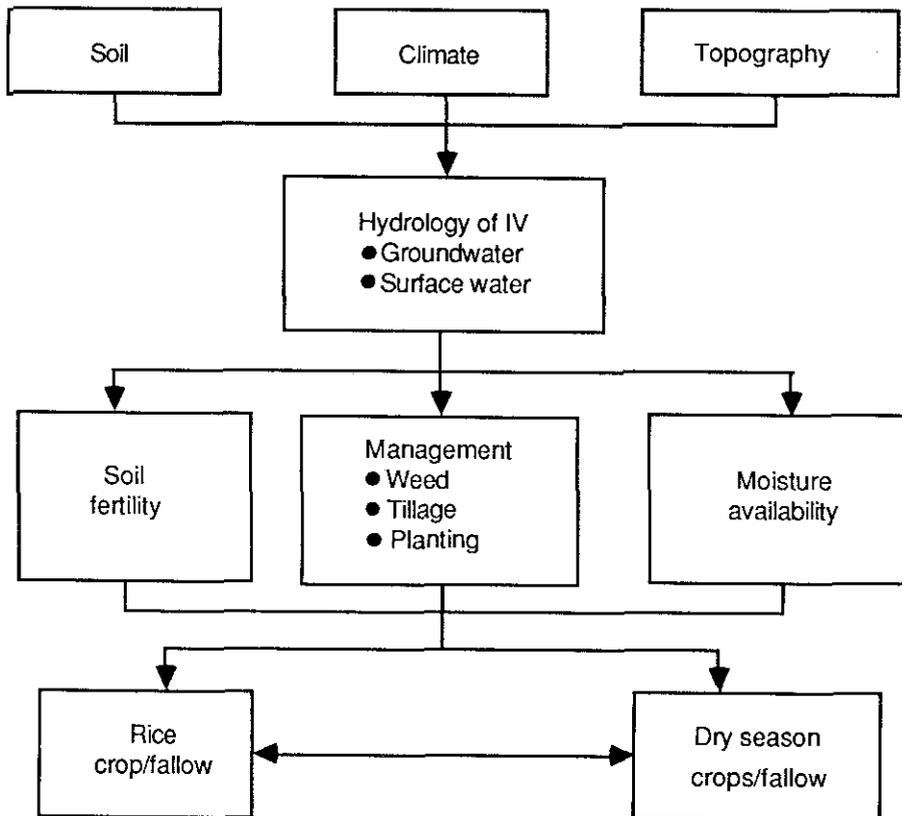


Figure 1. Hydrology as link between physical environment and utilization of inland valleys for cropping excluding equally or more important socioeconomic determinants of utilization.

Characterization of inland valley hydrology

Climate, topography, and soils interact to determine major hydrologic processes which in turn determine the availability of surface or groundwater (Fig. 1). Water from the uplands flows toward the valley bottom along the soil surface (runoff), just below the soil surface (interflow), or well below the soil surface (groundwater flow). The amount of water going to the valley depends on rainfall and catchment size. The path of the water depends on the properties of the soil surface and profile, and on vegetation.

Water is the major physical factor in IV utilization because of its role in plant (crop and weed) growth, and because of its interaction with other important agronomic factors. For example, soil fertility is greatly influenced by the balance of erosion and deposition on IV slopes and bottom. These processes are, in turn, determined by the velocity of runoff water. The efficiency of applied fertilizer is, to a large degree, controlled by water movement. Weed growth is encouraged by water availability, but suppressed by flooding of sufficient depth and duration.

Excess or insufficient water can preclude cultivation in IV fields. Therefore, the major hydrologic processes must be quantified and understood, so that IV fields can be matched with different crops during different times of the year.

A major characteristic to be determined is the depth of flood or depth of groundwater. Direct measurement of surface or groundwater depth is not difficult but may require a long time period (i.e., at least one entire annual cycle). Kilian (1972) attempted to deduce from the presence of reduced soil layers the aptitude in terms of groundwater availability (depth and duration) of a given plot for rice culture. However, Veldkamp (1979) notes that prediction of a groundwater regime from soil characteristics is inaccurate because of variations between years, and because oxidation by incoming groundwater may obscure soil morphological features indicative of long-term saturation. He therefore argues for measurement of actual groundwater depth to determine suitability for crops.

Description of IV surface and groundwater hydrology has been done by Ipinmidun (1973) in northern Nigeria, and by Wakatsuki (1989) in central Nigeria and Sierra Leone. Wakatsuki (1989) devised an ingenious way to depict changing groundwater depth over time for a single transect (Fig. 2). Utilization of parts of the transect for different crops is depicted on the same graph. It is clear from the figure that the farmers know when and where to grow their crops and that groundwater depth is a major determinant. A rainfall histogram could also be plotted on the same figure to show the relationship between groundwater depth and rainfall.

Veldkamp (1979) proposed the classification of IV land according to annual maximum and minimum depth to groundwater or depth of flood. The resulting classes could easily be shown on maps. Technology development would then be targeted to different classes of IV land.

Measurement of surface and groundwater depth is useful since depth is correlated to suitability for crop growth. However, prediction of surface or groundwater depth from climate, topography, and soils data would be much more efficient. The data for all three parameters already exist in map form, but at a low level of resolution. Thus, the first goal of modeling would be to help focus on what experimentation is necessary to gain knowledge of the way these factors interact to determine water movement and retention. Soils in the watershed are variable spatially and in profile, and the presence of layers of varying permeability is known to influence water movement and storage.

Preliminary knowledge required is the degree of precision and spatial resolution of input data which is needed to give useful output in terms of surface and groundwater depth. If intensive soil profile sampling is required to predict surface and groundwater depth with a reasonable degree of confidence, then the effort needed to model hydrology might not be a priority. It is important to first determine the accuracy of the output (prediction of groundwater depth) which would be required to make it useful. This can be learned from trials of crop growth conducted along valley slopes to vary the depth to groundwater table.

Gunneweg et al. (1986) and Huizing (1988) used a model to relate stream discharge to rainfall. With this relationship, changes in groundwater volume can be predicted and used to estimate duration of water availability to rice crops. The model does not seek to present the major hydrologic processes mechanistically, but allows calculation of a

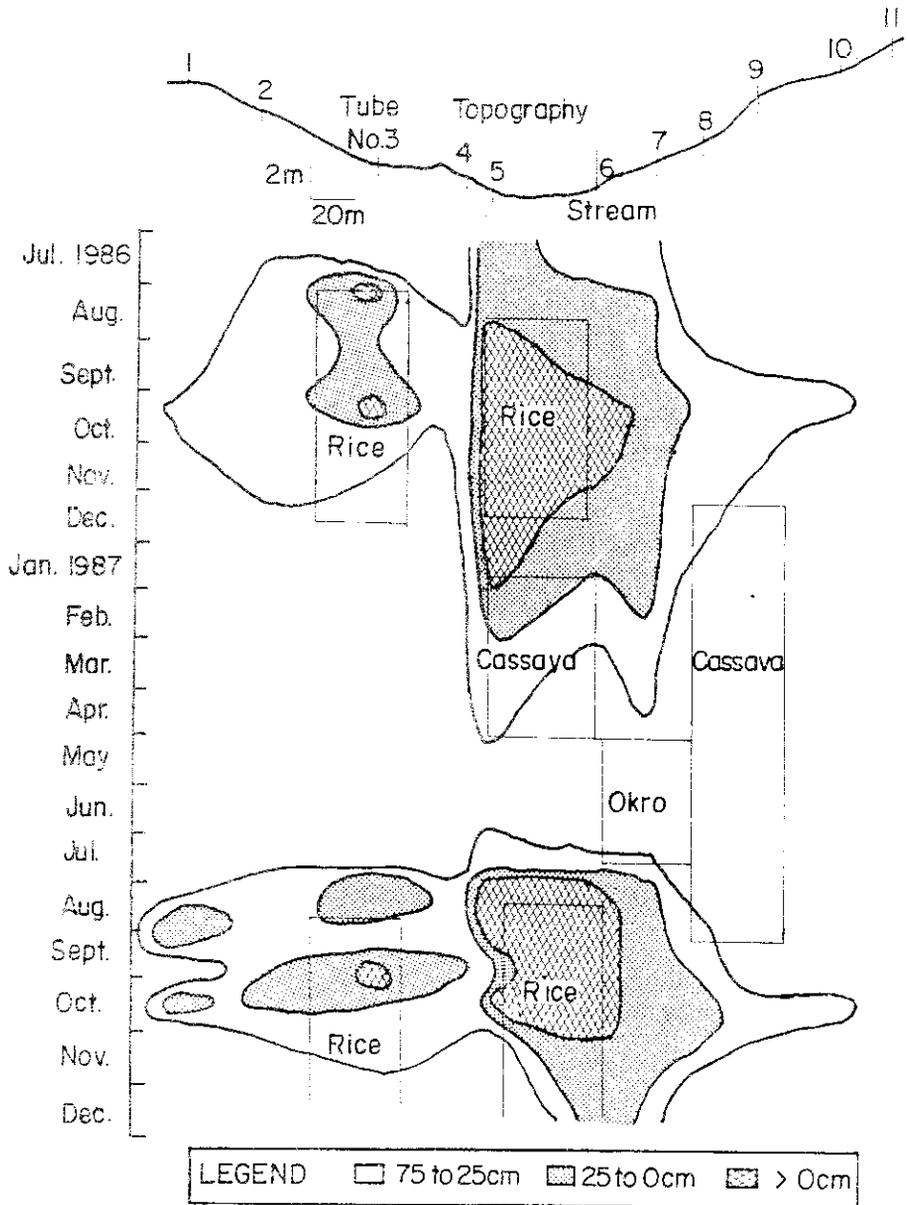


Figure 2. Groundwater depth dynamics (cm below soil surface) and land use along a transect in Gara valley, Bida, Nigeria. Source: Wakatsuki (1986).

coefficient called a 'reaction factor'. This is a characteristic of each catchment (depending on soils, topography, and vegetation) relating stream discharge to rainfall. The procedure may be useful if the 'reaction factor' can be estimated from easily obtained catchment characteristics.

Progress in classification of inland valleys

Kilian and Teissier (1973) classified IVs for rice production using two classification schemes—one for cultivation without water control and another for irrigated cultivation. For rice culture without water control, groundwater table depth and duration were the most important factors, followed by soil texture because of its effect on moisture retention.

For rice culture with water control, a major factor is valley morphology. Kilian and Teissier (1973) specify the size of catchment beyond which the water capture will be too small (minimum 4 km²) or too great (maximum 70 km²). The hydromorphic part of the valley must be at least 2km long and 100m wide with a transverse slope less than 2%. Interestingly, the authors found few valley bottoms with these specifications in Côte d'Ivoire. Furthermore, they concluded that IV development for irrigation must be undertaken only if two rice crops per year are possible, and on an adequate area. This requirement will depend, of course, on local economic circumstances.

In classifying the IVs for cropping, a few useful generalizations are possible. DuPreez and Barber (1965) reasoned that basement complex soils are poor sources of groundwater because the bedrock is generally shallow and because fine textured soils form poor aquifers. This was born out by measurement of borehole water output in Nigeria. On the other hand, soils formed from most sedimentary rocks are associated with good aquifers.

Generally, soils in the valley bottom are finer than on the fringes (Klinkenberg 1967), where seepage water has moved clay sized particles downslope (Raunet 1985). Scientists with the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) have paid considerable attention to the fringe soils—called *sols gris hydromorphes* (Bertrand 1973)—because they have favorable moisture availability, respond well to fertilizers, and occur over a large area of Africa (Bertrand et al. 1978). Most of the IRAT work with *sols gris hydromorphes* was conducted in the Casamance region of Senegal. It was noted that results might be difficult to extrapolate, even locally, due to variability in geomorphology resulting in differences in soil fertility, texture, and especially hydrology (Bertrand 1973).

Bertrand (1973) suggested that the suitability of sites might be estimated by prospecting after the end of the rains when the groundwater is receding slowly at a rate known with some degree of confidence. This would allow extrapolation throughout the dry season to the maximum depth of the groundwater table at the end of the dry season, and possibly the depth at the end of the rainy season. A simple technique of this kind must be developed to help match environments with available technology.

Raunet (1985) described typical valleys found on basement complex soils in semi-arid, sub-humid, and humid zones of West Africa. Valleys are further subdivided in length from source to large river floodplain into upper, middle, and lower sections. The upper section starts at the water source. The middle section starts with a well-defined stream

bed, and the lower section starts at the level where the stream overflows. In this respect, the upper or stream flow portion of Andriessé (1986) has been divided into two distinct parts, with and without a distinct streambed.

In Raunet's system, each section of the valley has distinct soil and hydrologic characteristics which should be fairly similar among different valleys within the same agroecological zone. This is a useful classification scheme which needs to be validated in other areas of basement complex geology and expanded to include IVs in areas of sedimentary geology.

III. Research related to rice-based production in IVs

Overview of rice research in IVs

Most research on rice in West Africa has been conducted on upland and irrigated lowland rice. If the WARDA Technical Bulletins from 1979 to 1984 reflect the situation accurately, less than 10% of rice research effort was placed specifically on IVs, while between 14 and 22% was concentrated on each of the other rice ecosystems: deep-flooded, upland, mangrove, and irrigated. While IV rice production may be irrigated, it is rarely stated clearly whether and to what degree water is controlled in IV trials—a very important characteristic of an IV trial. Wetland nomenclature has also been a source of confusion. For example, the word for seasonally flooded or waterlogged land in the Hausa language, *fadama*, could refer to a large river floodplain or a small valley bottom, two kinds of wetland with very different hydrological properties.

The IVs have rarely been targeted by rice research programs. In Nigeria, the research stations of the National Cereals Research Institute (NCRI) were placed on large river floodplains at Badeggi and at Edozhigi, both with fairly good water control. Improved packages (varieties and fertilizer) were tested on farms (Williams 1979) but the kind of water control used in these trials was not described. Thus, extension of trial results is difficult because conditions under which they were conducted are not made explicit.

IITA in Ibadan constructed large, level, banded paddies in most of its valleys for lowland rice breeding activities. Rice varieties developed there were not adapted to IV conditions. In recent years, the rice research program at IITA has focused attention on selection for the conditions found in valleys without irrigation. Some very good rice varieties have been developed for disease resistance, especially to blast (*Pyricularia oryzae*) and for tolerance to iron toxicity in hydromorphic soils. There has been an awareness that the shortest varieties are not the best because of the weed competition, drought stress, and flooding common to hydromorphic soils (Masajo and Carsky 1989). Some attention has been paid to grain and processing qualities. A wide range of plant height and duration is available. With proper variety, density, moisture, weeding, and fertility, very good yields are possible.

In Sierra Leone, some research is specifically conducted in IVs because of the high density of IV bottoms which constitute about 17% of total rice acreage there (IITA 1980). The All Sierra Leone Coordinated Agronomic Trials project was conducted from 1975 to 1979. Hundreds of trials were conducted, and some of the more useful results will be reported below. In Liberia, the WARDA station at Suakoko was established to work specifically with IV rice production problems especially iron toxicity.

Water management

Water availability is a major factor in increased rice yields in IVs. Palada et al. (1989) reported the results of farmer-managed trials in which rice yields were related to duration of flooding (Table 1). The mean yield on farms where flooding lasted for more than half of the crop growth cycle was twice as high as the mean for farms where flooding lasted for less than half of the cycle. Part of the difference in flood duration between fields was due to position in the toposequence, and part was due to variable water control practices by farmers.

Table 1. Yield increase in farmer-managed rice due to several treatment (variety and fertilizer) and non-treatment factors. From Palada et al. 1989.

Factor	Yield Increase		No. of farmers
	(t/ha)	(%)	
Variety	0.8	32	13
Fertilizer	0.7	33	13
Seedling age	1.3	64	6
Flood duration	1.3	99	5
Weeding frequency	1.7	143	6 vs 10

Differences based on: Variety: ITA 306 vs. Local.

Fertilizer: 15-15-15 vs. 90-60-30 kg N-P₂O₅-K₂O/ha.

Seedling age: seedlings less than 30 days old vs. more than 30 days old.

Flood duration: less than half of the rice crop cycle vs. more than half of the rice crop cycle.

Weeding frequency: 1 handweeding (6 farmers) vs. 2 or 3 handweedings (10 farmers).

Components, levels, and effects of water control

Water control has several agronomic benefits including soil erosion and weed control, and increased water and nutrient availability. For example, the response to flooding reported by Palada et al. (1989) was probably due to weed suppression by flood water as well as by timely water availability.

Each of the agronomic benefits of water control requires different manipulations of the environment. To examine this more closely, it is important to separate water control into its major components: water delivery (including canals, head dikes, and drainage), water retention (including bunding, leveling, and puddling), and drainage.

From an agronomic viewpoint, there are at least five distinct levels of water control.

1. None (no attempt to deliver, retain, or drain water).
2. Minimum level of input needed to control soil erosion (may consist of contour ridges or small square basins).
3. Minimum level of input needed to eliminate or reduce water stress at critical growth periods (needs increased water retention with bunding and puddling and/or water delivery to the field).
4. Minimum level of input needed to suppress non-aquatic weeds and to provide a reduced soil zone for a deep-placed ammonium-N source (requires water delivery to leveled, puddled paddies).
5. Drainage to oxidize the upper soil layer in the case of iron toxicity or to allow cultivation of non-rice crops.

West African farmers practice water control at all of these levels. At IITA on-farm research sites in northern Sierra Leone (rainfall 3200mm), farmers traditionally do little or nothing to control water, or may in some cases drain off excess water. In central Nigeria (rainfall 1100mm), farmers' practices range from small basins for the retention of rain and seepage water to moderately large, leveled paddies fed by diversion canals.

Any level of water control has its own particular costs and benefits. Oosterbaan (1987) described several systems to achieve a moderate to high level of water control (interceptor canal system, head bund system, contour bund system). Each system affords different levels of control and requires different levels of inputs, especially of labor and social organization. The recommended level of water control will be site-specific. A conceptual model (which can be used to develop a decision support system) is needed, matching water control techniques (from simple to complex) to environmental conditions. Some testing of promising systems, requiring substantial resources, will eventually need to be done.

A negligible amount of research has been conducted to compare water control levels or different systems of water control in IVs. It is hoped that the levels proposed above may serve as a basis for this type of experimentation. In trials of this type, the different contributions of water control must be quantified. Methods must be developed to separate the total yield increase due to water control into the individual contributions of reduced water stress, reduced weed competition, increased fertilizer efficiency, etc.

Comparison of different water control levels from an agronomic viewpoint is only part of the information needed. This is because adoption by farmers depends on socioeconomic factors which must be studied concurrently. One worthwhile research activity to pursue is intensified observation of actual farmers' water control practices.

IV farmers control water to various degrees. They synthesize knowledge of their ecological, economic, and social environment, and decide how to produce. They are continually gaining experience in how to best do this. They often try new techniques on their own initiative. It seems valuable, therefore, to survey the zones where farmers are utilizing the IVs to relate their current water control practices to their environment.

Interaction of water control and soil fertility management

It is virtually impossible to separate soil fertility management from water management in IVs. High yields and good response to nitrogen (N) have been reported for rice grown in IVs (Will 1973, Ayotade 1980) but water control is invariably good in these studies. The interaction between water control and fertilizer (especially N) efficiency has been shown repeatedly in irrigated systems (Sanchez 1972, 1976). Thus, response to N in IV rice systems should be conducted under varying degrees of water control.

The rice-based systems group at IITA (1988b) has begun to experiment with water control as a treatment factor. In the IITA experiments, the farmers' current water control practice of irregular water supply to very small paddies with small bunds was compared with regular water supply to large, leveled, and puddled paddies with large bunds. Mean rice yield over all of the varieties was increased from 2.3 to 4.4 t/ha with improved water control. This effect may have been due to improved water or nutrient availability or reduced weed competition. The data in Figure 3 show that the response to an increment of fertilizer (from 15-15-15 to 90-60-60 kg/ha of N-P-K) was only slightly increased when water control was improved. The mean yield increase (all varieties) due to fertilizer was 1.0 t/ha with poor water control and 1.4 t/ha with good water control. Thus, increased fertilizer efficiency appears to contribute little to the total effect of water control.

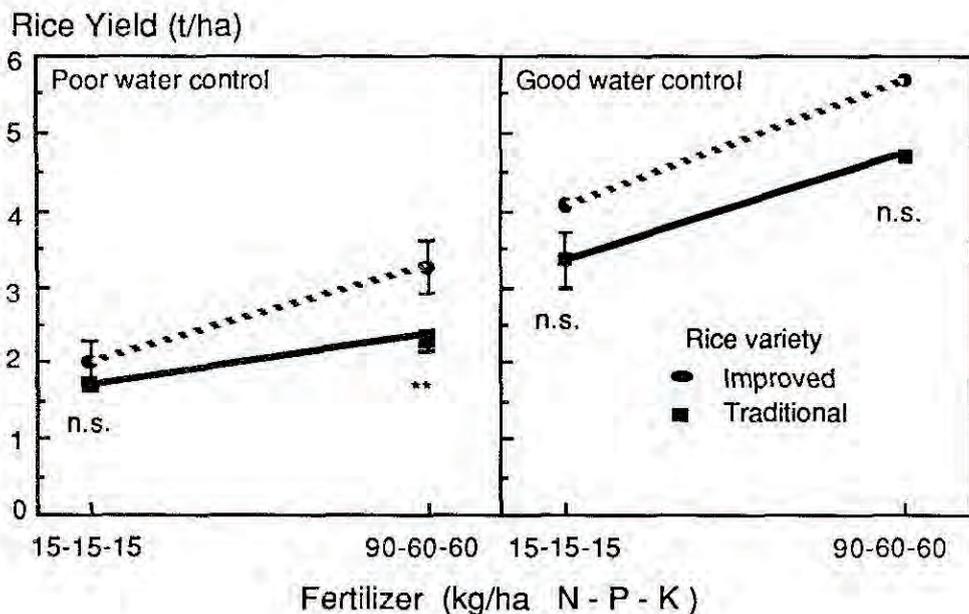


Figure 3. Effect of water control on response to fertilizer of two varieties of recently released and two varieties of currently grown rice. Adapted from IITA/RCMP 1986 Annual Report.

Other trials conducted by the IITA rice-based systems group were analyzed to see if water control had a distinct effect on N use efficiency (i.e., N found in the above-ground crop as a fraction of N applied). Twelve researcher- or farmer-managed trials involving rice and variable fertilizer levels in IVs were conducted between 1985 and 1988. The increased N content in the crop as a fraction of N applied as fertilizer ranged from 15 to 50% (Table 2). The calculation was based on known internal requirement of rice given by Sanchez (1976) and Yoshida (1981). It was not possible from these results to distinguish effects of water control, source of N, or any other factor on N use efficiency by rice. Measurement of the nitrogen content in the rice crop in each case would have allowed more accurate calculation of efficiency without the assumption of uniform internal N requirement of rice.

Nitrogen use efficiency is clearly greater under constantly aerobic (well-drained) and constantly anaerobic (flooded) conditions (Sanchez 1972). Major loss mechanisms are leaching in the former and ammonia volatilization in the latter. Alternating aerobic and anaerobic conditions result in losses from leaching, volatilization, and denitrification combined. In accordance with theory, Moormann et al. (1977) found N deficiency to occur in the middle of an IV toposequence where the soil was saturated but not flooded. Nitrogen deficiency was less apparent in the lower portion of the toposequence where flooding was continuous, and in the upper portion where the water table was deep.

Table 2. Nitrogen use efficiency in IITA rice-based systems group trials.

Year	Site	Management	Water control ^a	NYE ^b (kg/kg)	NRE ^c (%)
1985	Bida	Farmer	Levels 1 to 3	13	26
1986	Bida	Farmer	Level 2	12	24
		Farmer	Level 4	20	22
		Researcher	Level 4	11	40
		Farmer	Levels 1 to 3	10	20
1987	Bida	Farmer-weeded	Level 2	10	20
		Farmer unweeded	Level 2	8	15
		Farmer	Levels 1 to 3	25	51
	Makeni	Farmer	Level 1	16	32
1988	Bida	Researcher	Level 2	21	40
		Researcher	Level 4	8	15
		Farmer	Levels 1 to 3	21	42

^a Water control levels: 1=none; 2=very small paddies; 3=water delivery to contour paddies; 4=water delivery to large leveled puddled paddies.

^b NYE = Fertilizer N yield efficiency calculated as grain yield increase per unit of N applied as fertilizer.

^c NRE = Fertilizer N recovery efficiency (i.e., N found in the above ground plant as a fraction of N applied) calculated assuming 20kg N in the above ground rice crop per ton of rice grain produced (Sanchez 1976, Yoshida 1981).

Deep placement of N is very useful for continuous flooding (Savant and Stangel 1985). Continuously flooded soil has an anaerobic layer just below the soil surface. Ammonium-N placed in this layer will not be mobile enough to be leached but will be absorbed by rice roots. Deep placement of urea or ammonium-N gives a good response in continuously flooded soils, so that the effort has been made to develop appropriate techniques such as a modified lance for the injection of urea solution (Jones and Dixon 1979), and an applicator for the deep placement of solid urea (O'Brien et al. 1985).

For fluctuating moisture conditions, typical of IVs with minimum to moderate levels of water control, deep placement of urea has little effect. The best chemical fertilizer management practice for fluctuating moisture conditions is simply to delay application of N and K until the plant is at the stage when it will absorb nutrients efficiently (active tillering in the case of rice). Frequent broadcast applications of small doses constitute the most efficient use of fertilizer but may be economically prohibitive, depending on the opportunity cost of repeated passes on the field.

Interaction of water control and weed management

Weeds are a major constraint to rice production in IVs with low levels of water control. Growth of non-aquatic weeds is suppressed by continuous flooding, so water control can result in decreased weed competition. This is clearly shown by the results reported by Ahmed (1982) in which flooding made weeding unnecessary (Fig. 4).

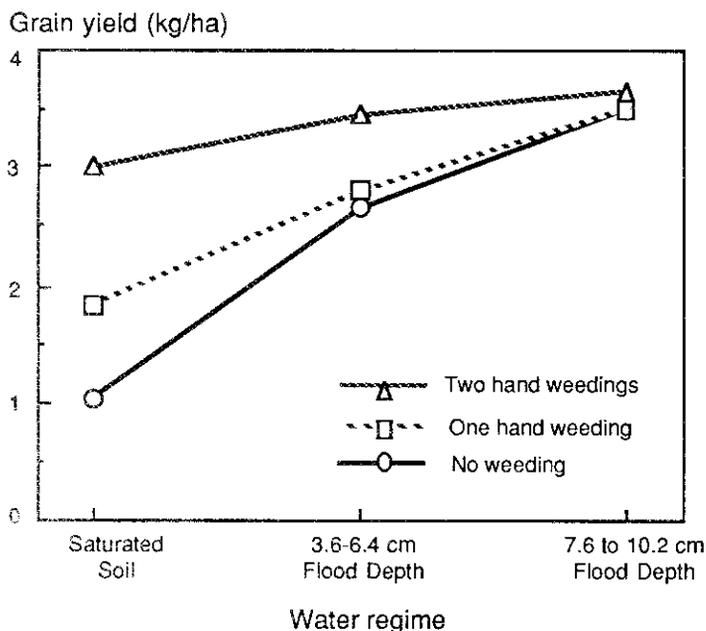


Figure 4. Effect of flood water depth on weed competition in rice. Adapted from Ahmed (1982).

Weed control in rainfed lowland rice has rarely been studied under minimum water control. Certain herbicides which perform well in irrigated lowland rice performed poorly when used in hydromorphic soils (IITA 1974 and 1976 Annual Reports, cited by Akobundu 1981).

Soil fertility management

Major nutrient deficiencies

Intensive crop production requires an adequate supply of nutrients. The main nutrients limiting the yield of rice in West Africa are N and phosphorus (P) and, to a limited extent, potassium (K) and zinc (Zn) depending on soil parent material (Kang 1973). Results from on-farm demonstrations in IVs of Sierra Leone (Das Gupta and Will 1973) give a good idea of the effect of fertilizer in this environment (Table 3). The average yield increase over 88 trials from 45 kg P_2O_5 /ha was almost 500 kg grain/ha and an additional 45 kg N/ha gave another 700 kg grain/ha.

One of the most useful results of the All Sierra Leone Coordinated Agronomic Trials was to generate data for response of rice in the upland, boliland, and IV environments to N, P, and K on farmers' fields (IITA 1980). Examination of the results, summarized in Table 4 reveals that rice responded to N, P, and K in all three environments. In the IVs, application of 50 kg N/ha, 120 kg P_2O_5 /ha, and 60 kg K_2O /ha gave about 90% of maximum yield (which might be expected to be an economic optimum in a competitive economic system). These trials covered enough sites and years to provide national response functions for economic analyses of fertilizer use in IVs.

Table 3. Average paddy yields (t/ha) in inland valley swamp demonstration trials in Sierra Leone. From Das Gupta and Will 1973.

Province	Fertilizer applied/ha (kg N - kg P ₂ O ₅)		
	0 - 0	0 - 45	45 - 45
Northern (n=31)	2.84	3.32	4.58
Southern (n=25)	1.43	1.65	2.02
Eastern (n=32)	2.71	3.35	3.75
Mean	2.39	2.86	3.55

Table 4. Response^a of rice to increments^b of applied N, P, and K on farmers fields in selected inland rice growing environments. From IITA 1980.

Nutrient	Upland (n=84)	Boliland (n=18)	Inland Valley (n=40)
N	312x - 40x ²	412x - 41x ²	257x - 43x ²
P	205x - 47x ²	396x - 54x ²	344x - 48x ²
K	247x - 56x ²	317x - 63x ²	175x - 41x ²

^a Response curves fit through origin.

^b x = 20 kg N/ha, 40 kg P₂O₅/ha, or 40 kg K₂O/ha.

The heterogeneity of IV conditions is evident in the variability in rice yields among districts, whose means ranged from 1.2 t/ha in the northeast to 3.6 t/ha in the south (averaging 2.7 t/ha). In the same subset, upland rice yields were uniformly distributed between 1.7 and 1.9 t/ha.

Little work has been reported on the use of soil improving legumes specifically for hydromorphic soils compared with uplands and irrigated lowlands. *Sesbania rostrata* green manure showed promise as a contributor to the N needs of an irrigated rice crop in Senegal (Rinaudo et al. 1988) and a rainfed lowland rice crop at IITA (Mulongoy 1986). It seems that, in the absence of water control, soil-improving legumes could be used to sustain rice yields in lowlands and should be a topic of agronomic research of moderate priority.

Although P availability increases under waterlogged conditions (Ponnamperuma 1985), this does not appear to contribute enough under native soil conditions in Africa with low levels of water control. As noted above, there was a frequent and substantial response to P in IVs of Sierra Leone. Phosphorus is a much simpler nutrient to study than N because it is more likely to stay in the soil system. Soil erosion is the only important loss mechanism besides crop uptake. Applied phosphorus has a residual effect in years subsequent to its application. The major researchable issues with P are not specific to IVs.

Iron toxicity

The major soil problem in IVs after nitrogen and phosphorus deficiency is iron (Fe) toxicity. The proportion of the IV land area estimated to be affected is 5 to 10% in eastern Nigeria (Kosaki and Juo 1986), 32% in Liberia (94 farms surveyed by Mulbah et al. 1987), and 40 to 50% in Sierra Leone (Abu et al. 1987). In a study of yield reduction due to iron toxicity, Abifarin (1988) reports a range of 0 to 60% reduction for 23 varieties by comparing yields at two sites—one with excessive levels of available Fe and another with low levels.

It is known that ferric ion (Fe^{3+}) is reduced to plant-available ferrous ion (Fe^{2+}) under anaerobic conditions which are favored by the presence of easily decomposable organic matter and available acidity. However, the spatial determinants of high Fe^{2+} are not clearly known.

It is not clear whether the Fe^{2+} is brought in with seepage water or whether Fe^{3+} is reduced *in situ*. Van Breeman and Moormann (1978) could not detect high levels of Fe^{2+} in seepage water. Thus, they hypothesized that seepage water maintains the soil in the seepage zone almost permanently anaerobic, and therefore reduction may occur *in situ*.

Kosaki and Juo (1986) monitored Fe levels in groundwater and found Fe^{2+} levels greater than 20 ppm and almost permanently saturated soil to be typical of an Fe toxic soil zone. Non-toxic areas above and below the seepage zone had lower Fe^{2+} in solution and deeper groundwater during the dry season which could encourage surface soil oxidation. This indicates that the remedy for Fe toxicity should be drainage during either the rainy or dry season.

There have been three different thrusts to combat iron toxicity. In some areas, farmers plant on ridges to aerate the root zone with consequent loss in plantable area but net gain in yields (Winslow et al. 1989). A second thrust has been to combine tolerance to iron toxicity with other desirable characteristics in the rice plant (Winslow et al. 1989, IITA 1980). Germplasm adapted to iron toxicity was developed by IITA staff in an Fe toxic swamp in Liberia (Virmani 1978) and has been used as a source of this trait for further varietal development. Finally, scientists in Sierra Leone and Senegal have been testing certain amendments (burned straw, lime, and basic slag) which reduce soil acidity and available Fe (Beye 1973, IITA 1980). The most dramatic increases in the Sierra Leone experiments have come from drainage, although the different treatments were never compared in one trial. Some combination of variety, drainage, and amendment will probably be used in the future to alleviate the constraint imposed by iron toxicity.

It might be worthwhile to characterize the distribution of Fe toxic soils in West Africa. Van Breeman and Moormann (1978) state that Fe toxicity occurs on poorly drained colluvial and alluvial soils in valleys receiving interflow (subsurface flow) water from adjacent higher land with plinthite or weathering igneous or sedimentary rocks. This broad statement is a worthwhile starting point which must be validated and made more precise. For example, the same authors state that in Sri Lanka, valleys in areas dominated by Plinthudults and Tropudults have toxicity problems.

Weed management

Weed competition is an important source of yield loss in IV rice. In an on-farm trial in which 19 farmers determined their own weeding regime, the yield loss due to weed competition was estimated roughly by grouping farmers by number and quality of weedings (Palada et al. 1989). The mean yield for farms with only one weeding was 1.2 t/ha compared to 2.9 t/ha with two or three weed control operations. Weed control was associated with the highest yield increase, compared with several treatment and non-treatment factors including variety, fertilizer, seedling age, and duration of flood (Table 1).

Planting method has an important effect on weed competition in rice. Compared with direct seeding, transplanting healthy rice seedlings into a weedless seedbed gives rice plants a growth advantage over weeds. Some farmers broadcast pre-germinated seed, which gives rice a few days advantage over the direct seeding of dry rice seed.

Direct seeding of rice saves considerable labor compared with transplanting, but weed pressure is greater. Akobundu (1981) tested herbicides for direct-seeded rice under poor water control (2cm water depth) and found several herbicides to be effective under the conditions of the study. The best herbicides were subsequently examined to determine the appropriate application time and rate (Akobundu 1990). Thus, the technology is ready to be used, if economic conditions become favorable.

Tillage has an important influence on the efficacy of herbicides. Carson (1980) evaluated herbicides and their interaction with tillage in an IV without water control in Ghana. Weed control with the herbicides studied was much less effective with minimum tillage than with conventional tillage.

Realizing the difficulties involved with chemical weed control, Akobundu and Ahissou (1985) conducted work on hand weeding, and its interaction with plant density and varietal height. Compared with a weed-free control, the yield of a tall rice variety, OS 6, was reduced by 40% when weeded only once, while that of a semidwarf variety, ADNY 11, was reduced 60% at the same spacing. Variety / spacing interaction was strong. With one weeding, the semidwarf variety gave the lowest grain yield of the varieties tested when planted at 45cm spacing, and the highest grain yield when planted at 30 and 15cm spacing. A second weeding boosted yield substantially for all varieties at low density and for the shorter varieties at moderate density.

Crop management

Research on crop management has focused on planting density and method, and age of seedlings at transplanting. Traditional planting density is often low, and optimum density has been shown to be much higher in all trials (Williams 1979, IITA 1980, Vodouhe et al. 1981, and Souare 1988). Figure 5, adapted from Souare (1988), shows the interaction of plant density with variety, fertilizer, and water control. With poor water control, yield is hardly affected by plant density, but with good water control, yield is increased substantially by increasing plant density.

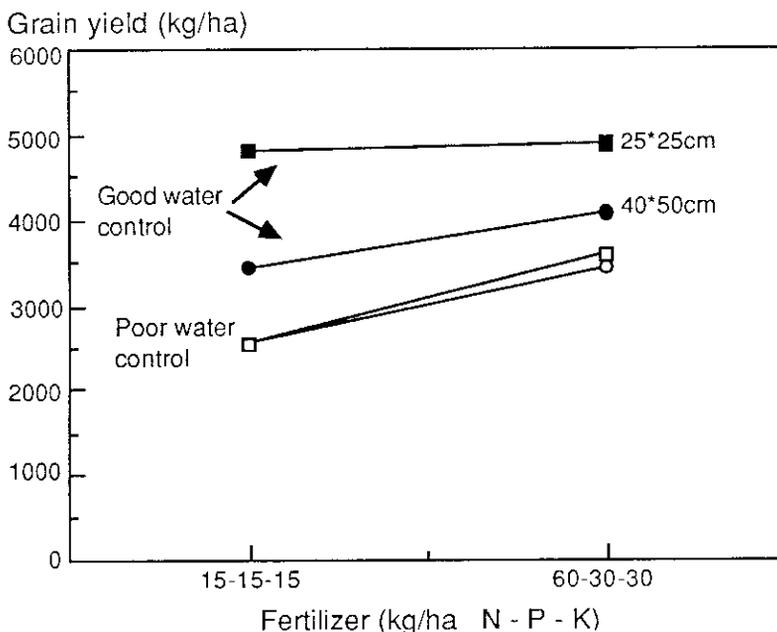


Figure 5. Effect of water control and fertilizer on mean yield of FARO 15 and ITA 312 at low (40 x 50cm) and high (25 x 25cm) planting density. Adapted from Souare (1986)

Planting method influences weed competition in the simple manner discussed in the previous section, but the factors which influence a farmer's planting method are complex. They include, among others, the presence of floodwater, the previous crop, and labor availability for planting and subsequent weeding. Planting in straight rows, advocated by agronomists, increases labor input to an already laborious process but allows faster weeding with small mechanical weeders. The appropriateness of the practice depends on seasonal labor availability and access to the mechanical weeder.

The age of seedlings at the time of transplanting is a factor which has been shown to be important in determining grain yield. A young rice seedling has the capacity to form a variable number of tillers to make maximum use of available resources (soil, water, and light). Old seedlings lose this capacity, and so internal and external inputs to plant growth are wasted if old seedlings are transplanted. Palada et al. (1989) found that farmers who transplanted seedlings more than 30 days old suffered an average yield loss of 40% from 3.5 to 2.2 t/ha (Table 1). Farmers are forced into utilizing old seedlings if the field is not ready for transplanting. Delays on the lowland farms are related to activities on the upland farms, household activities, and social obligations.

Researchers can learn how to address better the problems of farmers by observing their planting practices. It can be hypothesized that planting method and density, rice varietal characteristics (height and tillering), and labor available for weed control are interrelated. An agronomic survey is recommended to gain insight in how management is influenced by weed pressure.

Toposequence studies

While variability of valley soils and hydrology in cross-section appear to be a constraint to research, farmers often utilize spatially variable conditions to their advantage to diversify their crops and to avoid labor-scarce periods by spreading out their activities (Richards 1986). Researchers can also profit from the natural gradients afforded by toposequences to study the response of crop varieties to variable conditions, or to study the processes related to soil properties and water availability.

Rice

The valley toposequence presents a continuum of edaphic (soil) and hydrologic conditions to test the response of rice to stresses. Moormann et al. (1977) recognized this and initiated studies on the toposequence from upland to valley bottom while at IITA, using the toposequence to quantify the soil moisture level beyond which plants suffer moisture stress. Scientists at IRRI (1984) have also studied the physiologic response of the rice plant to differential water stress along a toposequence. Both studies also showed the value of screening for blast disease along a toposequence.

Gradients along a toposequence provide a methodological tool which should have many uses, not only for screening varieties but for understanding relevant processes. Nguu et al. (1988) validated the screening process using 19 rice varieties with a known degree of drought tolerance. Linkage of the screening with measurement of depth to groundwater allowed recommendations to be made for matching rice genotypes with groundwater regimes. The results indicated that lowland genotypes should not be grown where the groundwater is more than 40cm below the soil surface. Veldkamp (1979) screened many crops along the toposequence to develop suitability classes for hydromorphic conditions.

The rice-based systems group at IITA conducted several rice trials along IV toposequences at sites in Sierra Leone and Nigeria (Jalloh and Palada 1989, Palada et al. 1990 a,b). The results of these and other rice trials on IV toposequences are summarized in a separate RCMP monograph (Carsky and Masajo, Effect of toposequence position on performance of rice varieties in inland valleys of West Africa, in preparation). The objective of the work was to identify varieties which perform well at all toposequence positions. All of the varieties performed better in the lower parts of the valley than on the fringes, because of a combination of increased water and nutrient availability. The interaction between variety and toposequence position (T x V) was significant at Makeni, Sierra Leone where water control was not practiced (Fig. 6). Some varieties (for example ITA 312) performed well on the fringe and only slightly better in the valley bottom. Others performed poorly on the fringe and extremely well in the valley bottom. A new variety, TOX 3142-7-2-3-4, performed well at all toposequence positions in Sierra Leone. It is now designated ITA 342.

Upland Crops

The rice-based systems group at IITA also screened upland crops along the toposequence in the dry season. These included a trial of cowpea varieties at Ibadan (Singh and Palada 1989) and sweet potato and cassava varieties in central Sierra Leone (Palada et al. 1990c). IITA varieties of soybean (Dashiell et al. 1990) and sweet potato have been screened in IV bottoms during the dry season in central Nigeria.

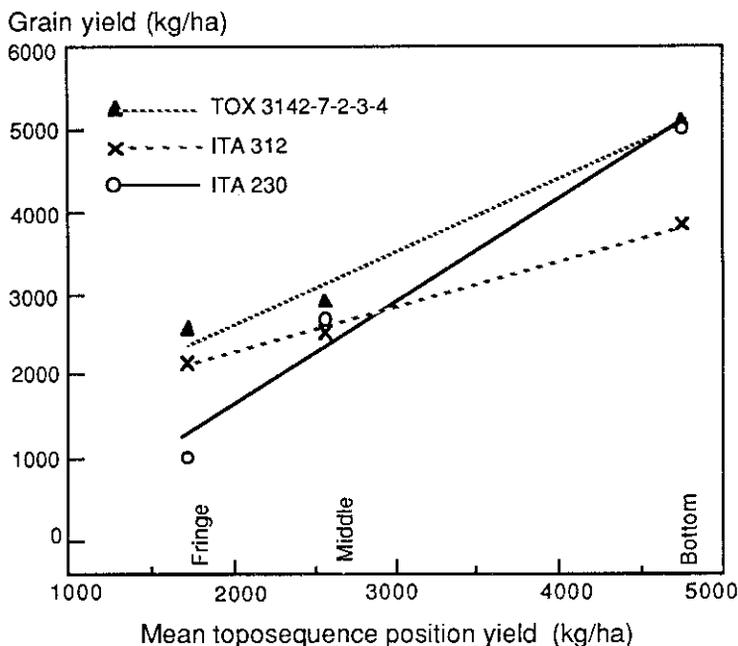


Figure 6. Interaction of rice variety with toposcquence position in a trial of rice varieties along a valley slope near Makeni, Sierra Leone, 1988-89. Source: Palada et al. (1990b).

Cowpea grain yields ranged from 200 to 700 kg/ha in a wet portion of an IV at Ibadan (Table 5). Yield of the same varieties ranged from 900 to 1300 kg/ha in a relatively dry part of the same valley. The wisdom of selecting for different IV slope positions is indicated by the important T x V interactions observed. For example, IT84E-124 had the lowest yield at the upper position and one of the highest at the lower position. IT85F-867-5 had the highest yield at the upper position and one of the lowest at the wet position.

A trial to screen soybean varieties in an IV near Bida revealed tremendous variability in response to wet conditions, grain yield ranging from 70 to 780 kg/ha (Dashieff et al. 1990).

In Sierra Leone, improved varieties of cassava and sweet potato were tested at IV fringe and bottom positions. Cassava tuber yield was reduced in the valley bottom compared with the fringe by 40% for Rocass and by 10% for Nucass (Table 6). Leaf yields were uniform regardless of variety or toposcquence position.

The yields of sweet potato varieties were similar at the two positions whether defoliated or not (Table 7). The yield of tubers and leaves of a local variety were slightly higher in the valley bottom than at the fringe. Yield suppression in the valley bottom for cassava but not for sweet potato is probably related to the length of growing season of the two crops. Cassava stays in the ground an additional two months into the early rainy season when excess water stress becomes severe.

Table 5. Mean grain yield (kg/ha) of promising cowpea varieties in the upper and lower parts of an IV toposequence at Ibadan, Nigeria, 1986-87. From Singh and Palada 1989.

Variety	Upper	Lower
IT86D-612	1120	190
IT86D-766	1110	580
IT86D-734	1150	690
IT84S-2246-4	1040	480
IT84E-124	880	600
IT83D-319	1120	330
IT83S-797	1110	530
IT85F-1380	1120	530
IT85F-867-5	1290	290

Table 6. Tuber and leaf yield of cassava varieties grown during the dry season in an IV near Makeni, Sierra Leone, 1988. From Palada et al. 1990c.

Variety	Tuber yield (t/ha)		Leaf yield (g/mound)	
	Fringe	Bottom	Fringe	Bottom
Rocass	7.7	4.7	370	410
Nucass	8.8	7.8	330	350
Local	3.6	3.0	370	390
SE	0.8	1.2	35	16

Table 7. Tuber and leaf yield (t/ha) of sweet potato varieties grown during the dry season in an IV near Makeni, Sierra Leone, 1988. From Palada et al. 1990c.

Variety	Tuber yield		Leaf yield	
	Fringe	Bottom	Fringe	Bottom
Njala White	10.8	9.3		
defoliated ^a	8.8	7.9	2.6	2.6
Ropot	12.6	11.2		
defoliated	7.8	6.6	2.3	2.3
Kabompoh	6.1	6.3		
defoliated	3.5	3.8	2.0	2.6
SE	0.75	0.59		
defoliated	0.36	0.48	0.11	0.16

^a Leaves harvested 45 days after planting.

Methodological considerations

Trials along the toposequence are most valuable if moisture and nutrient availability are determined. Only in this manner will extrapolation of results to other IVs be possible. Recommendation of varieties must be based on knowledge of groundwater regime which cannot always be known from the toposequence position. For example, the fringe area of one valley may be much drier than that of its neighbor. A valley bottom may be flooded longer and deeper than another nearby. Thus, the trials of upland crops reported above can only be considered as preliminary. Additional trials must be conducted, accompanied by adequate data collection to allow extrapolation of results to other IVs.

Depth of flood or depth to subsurface groundwater table is a very useful indicator of the availability of water to a crop, the degree of potential weed control by water, the risk of soil erosion, and the risk of applied nutrient losses. It is relatively easy to measure, requiring simple equipment. Methodology development must focus on determination of the frequency of measurement and the density of measurement points required for useful results. The most useful soil properties to measure must also be determined.

IV. Crop management systems for minimum water control

From an agronomic perspective, irrigation or full water control is the ideal crop production system. Irrigation technology itself is well known but it is rarely known where irrigation will work in West Africa from a socioeconomic perspective. Therefore, some thought has gone into systems of improved resource and crop management with *minimum water control*. Systems are proposed which, it is hoped, will have relatively small increases in additional labor requirement. One system is green manuring and the other is the system of alternating raised beds known in Indonesia as *sorjan* (Zandstra 1978).

Green manuring

Green manuring has several potential advantages in IVs including nutrient recycling, nitrogen fixation, soil protection, and weed suppression. A way must be found to grow leguminous green manures in a space or time which would not be used for growing crops. A spatial niche presents itself in the gaps between mounds or ridges on which dry season crops are grown. It must be kept in mind that the legume would be growing in the poor soil of the furrow, and therefore a small amount of P fertilizer would usually promote growth and N fixation. Since P is not always available, candidate legumes should be screened by being grown in the furrows without added P. An important characteristic of the legume would be tolerance to waterlogging since the furrows will collect and retain water, starting with the first rains, and remain wet until land preparation for rice.

Labor and propagation methods and costs will be important issues in determining the adoptability of this technology. Since many farmers grow upland crops on mounds or ridges in the dry season, the legumes will be incorporated into the soil with little additional effort as the structures are broken down to plant rice. Seed production may be a problem and the green manure species could itself become a weed if it propagates readily and competes with the food crop. Grain legumes should be considered as well as indigenous and exotic species.

Sorjan system

It would be worthwhile to examine the possibility of extending the *sorjan* system into the IVs of West Africa. This is a flexible soil management system, used in the lowland areas of Indonesia, which consists of raised beds for dryland crops alternating with rice in the furrows (Zandstra 1978). Bed height and breadth can be manipulated to grow a range of diverse crops. If the economic and ecological environment is favorable to rice production, then the distance between the ridges can be increased, resulting in paddies. If upland crop production is favored, then the bed size might be increased and the area of furrows planted to rice reduced (Fig. 7).

The *sorjan* system combines erosion control and some degree of water control, and encourages diversified cropping. A multitude of upland crops might be grown with rice during the rainy season. There is considerable variability in crop response to saturated soil and substantial variability within crop species. Breeding of upland crops should consider the shallow water table conditions of the IVs. The goal of research should be to make available to farmers a broad range of crop varieties with variable response to saturated soil.

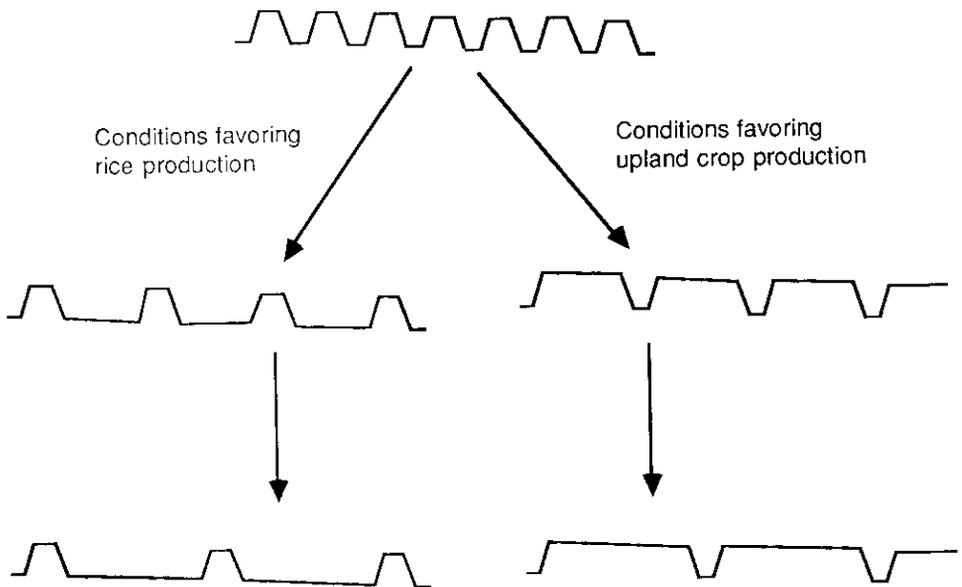


Figure 7. Variation of size of raised beds for upland crops alternating with furrows for rice depending on economic and ecological environment. Height of structures can change as well as distance between structures.

Sorjan is a flexible system which allows upland crops to be grown in any part of the valley in any season, depending on the height of mounds or ridges. To define the height of these structures, the process of capillary rise must be quantified and the response of various crops to shallow groundwater table must be known.

V. Research priorities

Research directions should take into account the major constraints and research needs noted above, and the availability of technology or prototype systems ready to be tested. There are not at present many technologies ready to be tested under farmer-managed conditions. There are some varieties which may increase and stabilize IV rice production. There are also a few upland crop (for example, soybean and sweet potato) varieties which perform well under excess water conditions. Herbicides for IV rice are available, if the economics of their use becomes favorable.

The major agronomic problems are weed competition, soil erosion, and variable water availability. Water management can play a role in alleviating some or all of these constraints. Several levels of water control are possible, each with particular costs and benefits which must be quantified.

New technologies should be developed based on working hypotheses for cropping system improvement. Technology for green manure development should be pursued, at least through the germplasm collection and observation phases, since green manuring can be hypothesized to stabilize the productivity of the rice-based system while reducing fertilizer input without substantial investment in water control.

Diversified cropping can also be hypothesized to stabilize the livelihood of rice-based farmers. Thus, methodology should be developed for screening varieties of crops under IV conditions and for studying crop response, especially to excess moisture. Appropriate practices must be developed which favor crop diversity in combination with varieties. Trials should profit from the gradients in depth to groundwater found along the toposequence.

Weed control requires detailed understanding of the many factors influencing weed seed populations and weed competition. Researchers can learn from farmers how to deal with weeds in efficient ways. Surveys should be designed to explain how farmers' practices are influenced by weed competition.

Research on IV hydrology should continue with a view toward developing the simplest possible models which predict groundwater and surface hydrology adequately, to aid in decisions about water control level requirements and the feasibility of dry season cropping. Models should be developed which utilize existing climate, soils, and topographical data, wherever possible, and do not require too many additional data. This is a very difficult task which needs support.

If surface and groundwater depth cannot be predicted, then it must be measured. Simple methods of measurement are needed for the classification of IVs for rice cropping with various levels of water control and for appropriate dry season cropping.

There is a great amount to be learned about the IVs and farmers' use of them. Characterization of IV soils and hydrology should be conducted in as systematic, yet simple, a manner as possible. The hypothesis that IV soils reflect the surrounding predominant upland soils must be tested. The distribution of IV land with toxic levels of Fe should be mapped.

Characterization of farming systems should focus on farmers' practices related to water management, weed control, and soil fertility management.

To summarize, the priorities are listed in order of feasibility.

1. Development of methodology to screen upland crops under typical IV conditions of shallow groundwater table.
2. Survey of farmers' rice planting and weeding practices in relation to ecological and economic conditions
3. Program to collect and screen candidate leguminous species adapted to waterlogged conditions.
4. Test of hypothesis that IV soils resemble predominant upland soils.
5. Broad survey of farmers' water control practices and relation to ecological and economic conditions.
6. Mapping of occurrence of iron toxicity in West Africa.
7. Validation and expansion of existing IV classification systems with focus on critical factors in IV utilization (such as surface and groundwater depth) and simple ways to measure them.
8. Development of simple models to predict IV surface and groundwater depth.
9. Development of an expert system to match different levels of water control to different ecological and economic conditions and quantification of the various agronomic benefits of water control systems.

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