7 Inland Valley Suitability for Rice Cultivation

7.1 General

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

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

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

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

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

At valley scale, the main constraints to rice production result from the soils, hydrology, and valley shape. If these constraints are not too severe, they can be improved by relatively simple technical interventions. For such improvements to have a distinct and sustainable impact, they have to aim at a substantial increase in the farmers’ net return to rice.

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

7.2 Main Constraints to Rice Cultivation

7.2.1 Soil Constraints

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

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

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

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

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

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

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

Soil reaction (pH) in the valley bottoms of West Africa ranges from extremely acid (pH 4.0 to 4.5) to slightly acid (pH 6.1 to 6.5). For rice production, this is a suitable range, considering that, upon reduction of the (top)soil following submergence, the pH tends to change towards neutral (pH 6.5 to 7.0). Most plant nutrients are most readily available for uptake by roots in a slightly-acid to near-neutral environment (IRRI 1978).
In wetland rice cultivation, puddling (i.e. the destruction of the soil structure through intensive ploughing of the wet soil) is often practised. The advantages of puddling are that a soft bed is created for seeding and/or transplanting, percolation losses are reduced, weeds can be better controlled, and the fields are slightly levelled. Puddling is more difficult in fine-textured soils, which generally have a stronger structure than soils with a less fine texture, but it is more effective in decreasing losses.

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

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

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

Ferrous iron (Fe²⁺) is either formed in the soil by the reduction under acid conditions of ferric iron (Fe³⁺), already present in situ, or it is brought into the rootzone by subsurface flow from the uplands. Under reduced conditions, ferrous iron affects the development of the rice crop in two ways:

- By coating the plant roots with iron oxide and thus reducing the absorption capacity of the plant for other nutrients, such as P, K, Ca, and Mg (Fe²⁺-induced deficiency),
- By direct iron toxicity through excessive Fe²⁺ absorption by the plant.

Iron toxicity in rice plants shows as a characteristic orange discoloration (bronzing) of the leaves (Howeler 1973). Possible remedies, apart from the use of tolerant rice varieties, include seasonal drying of affected fields (oxidation of Fe²⁺ to insoluble Fe³⁺) or interception of the subsurface water flow containing ferrous iron (IITA 1982).

### 7.2.2 Hydrological Constraints

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

The crop water requirement should be covered during the entire growth period. On the uplands, the crops depend entirely on the precipitation. On the footslopes and in the valley bottoms, a shortage of precipitation may be compensated by groundwater, by lateral water inflow, or both. The lateral inflow is basically maintained by upland surface runoff and groundwater flow. The latter forms the core of the base flow in the valley stream. The minimum size of this flow is strongly related to the amount and distribution of the precipitation and the size of the catchment area. In
the Guinea Savanna Zone, about 1 km² of catchment is needed to provide a minimum flow sufficient to cover crop water requirements for rice on a cultivated area of 0.8 to 3.0 ha in the valley. For the Equatorial Forest zone, this ratio is 1 km² for 2.0 to 5.0 ha.

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

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

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

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

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

7.2.3 Engineering Constraints

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

The size of the catchment co-determines the size of the base flow and the peak discharge. To secure a reasonable amount of water in the distribution system on the basis of the factors discussed in Section 7.2.2, the catchment area should be larger than 10 to 30 km² in the Guinea Savanna Zone and larger than 5 to 15 km² in the Equatorial Forest Zone, corresponding roughly with 15 to 50 ha of valley bottom cultivation; if catchments are smaller, contour bunding should be applied to conserve water on the field. These figures should be treated with caution, however, because hardly any information on this subject was found in the reviewed literature.

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

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

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

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

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

7.3 Suitability Classification of Inland Valleys for Rice Cultivation

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

Kilian and Teissier (1973), in their study in northern Benin, give two suitability classifications. The first is for rice cultivation without water control, the second for rice cultivation with water control.
Rice Cultivation without Water Control
The depth of the groundwater level and its fluctuation are of great influence on the crop performance. Several researchers have endeavoured to make a suitability classification for rice incorporating these parameters, with or without soil characteristics.

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

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

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

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

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

This system was tested for the soils of valleys in northern Benin. Though the system is provisional, it is considered applicable for the Sudan Savanna and the Guinea Savanna Zones, which have ecological conditions comparable to those of northern Benin. It is recognized, however, that the scope of its applicability might be restricted. Apparently, this suitability classification does not provide for soils not suitable for rice cultivation and does not comprehend all soils of the toposequence.

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

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

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

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

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

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

Rice Cultivation with Water Control
For the development of valleys in north Benin, Kilian and Teissier (1973) developed
an inland valley suitability classification for rice cultivation with water control, consisting of six classes:

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

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

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

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

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

7.4 Fertilizer and Water Management

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

7.4.1 Fertilizer Management

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

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

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

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

In lowland rice cultivation, the major loss of nitrogen is due initially to NH₃-volatilization, followed by denitrification. Any management techniques aiming at a more efficient use of nitrogen fertilizer and a reduction of N-loss must necessarily look for ways to delay nitrification (Goswami et al. 1986).

On the uplands, urea and NO₃-fertilizer applications are effective, while, on the footslopes, urea gives a higher response than NO₃-fertilizers. Also, topdressing is more efficient than a basal application of fertilizers at planting time.

In the valley bottoms, under waterlogged conditions, the application of urea is recommended whereas NO₃-fertilizer gives a higher response when the groundwater table is below the soil surface. High nitrogen response was found when urea (as urea supergranules) was applied in one deep placement during land preparation or at planting. In other cases, higher nitrogen efficiency was found when half of the urea was applied as basal dressing and incorporated into the soil and the other half was topdressed five days before panicle initiation. The recovery of nitrogen under this system was better than when urea was all basal and surface broadcast (Goswami et al. 1986).

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

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

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

The availability of phosphorus in the soils of the valley bottoms is strongly related to the actual hydrology. During flooding, the availability of phosphorus increases as the subsequent rise in pH results in the higher solubility of various phosphates like variscite (AlPO₄) and strengite (FePO₄). The increased availability of phosphorus ceases once the soil becomes dry. The application of farmyard manure might help
in keeping phosphorus more readily available under alternate wetting and drying. Another possibility is the split application of phosphorus, half at transplanting and half topdressed along with N at tillering and mixed with the soil (Goswami et al. 1986).

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

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

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

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

7.4.2 Water Management

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

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

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

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

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

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

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

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

In periods of high rainfall, the fields are better protected from any rapid overflow...
upland

rivulet

valley fringe

interception canal

basin

valley bottom

contour canal

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

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

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

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

In this system, the stream is obliterated. In order to drain, each individual field is provided with an outlet or spillway to the next field. If, especially in the lower parts, the flow from field to field becomes too great or the drainage of the fields by these outlets is not sufficient, interceptor canals can be dug along the valley slopes to transport the surplus water directly to a stream or river more downstream.
Figure 7.3 A head-bund system in inland valleys (source: Oosterbaan et al. 1987)

Figure 7.4 A contour-bund system in inland valleys (source: Oosterbaan et al. 1987)
The main advantages of the improved water-management systems are that the water levels in the rice fields can be controlled more accurately and that more homogeneous conditions are created over larger areas.

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

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

7.5 Rice-Growing Environments

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

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

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

These descriptions of the various rice-growing environments are small-scale characterizations. More detailed information about soils, climate, hydrology, cropping systems, etc., is needed to develop a comprehensive and quantitative classification framework.

One conclusion that can be drawn is that, for the characterization of the rice-growing environments in West Africa, the existing broad agro-ecological classifications, which are mainly based on the length of the rainy season, are inadequate because the length of the growth period for wetland rice is a function of physiography (toposequence) as much as of the rainfall pattern (Andriesse and Fresco 1991).
Table 7.1 Characteristics, limitations, and potential of rice-growing environments in the Equatorial Forest Zone of West Africa (source: Andriesse and Fresco 1991; adapted)

<table>
<thead>
<tr>
<th></th>
<th>Crests, upper slopes</th>
<th>Middle slopes</th>
<th>Lower slopes</th>
<th>Valley bottoms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydrological regime</strong></td>
<td>Pluvial</td>
<td>Pluvial</td>
<td>Phreatic (groundwater flow), pluvial</td>
<td>Fluxial (seasonal)</td>
</tr>
<tr>
<td><strong>Main soils (descriptive)</strong></td>
<td>Well drained, deep to very deep, coarse- to medium-textured soils of very low fertility; in places gravelly and/or moderately deep over (petro-) plinthite; in places with acid humic top-soil</td>
<td>Moderately well to well drained, deep, coarse- to medium-textured soils of very low fertility; in places gravelly</td>
<td>Imperfectly to poorly drained, deep, coarse-textured soils of very low fertility; in places over soft plinthite</td>
<td>Poorly drained, deep, coarse-textured soils of low fertility; in places with acid humic or peaty topsoil</td>
</tr>
<tr>
<td><strong>Main rice yield limitation</strong></td>
<td>Solar radiation and air humidity (blast) Soil fertility (very low pH, BS, CEC; Al toxicity, P fixation, K deficiency)</td>
<td>Solar radiation and air humidity (blast) Soil fertility (like in crests and upper slopes)</td>
<td>Solar radiation and air humidity (blast) Soil fertility (like in crests and upper slopes but also Fe toxicity) 'Sandiness' for tillage</td>
<td>Solar radiation and air humidity (blast) Flooding Soil fertility (like in lower slopes but also N flushing) 'Sandiness' for tillage</td>
</tr>
<tr>
<td><strong>Required (water) management</strong></td>
<td>Erosion control; contour cropping, terracing</td>
<td>Erosion control, bunding, levelling, drainage</td>
<td>Flood control, contour bunding, levelling, drainage</td>
<td></td>
</tr>
<tr>
<td><strong>Actual rice cropping system</strong></td>
<td>Shifting cultivation and fallow systems (maize) (rice) (yam)-cassava</td>
<td>Single-cropped wet rice, sometimes rice-(taro) (vegetables) on bunds; cassava</td>
<td>Single-cropped wet rice, sometimes rice-(taro) (vegetables)</td>
<td></td>
</tr>
<tr>
<td><strong>Potential rice cropping system</strong></td>
<td>Perennial cropping with rice and other food crops under young trees</td>
<td>Perennial and alley cropping with rice as possible food crop</td>
<td>Single-cropped rice with improved water management, followed by other food crops</td>
<td>Single-or double-cropped rice with improved water management, followed by other food crops</td>
</tr>
<tr>
<td><strong>Representative areas</strong></td>
<td>Interior plains and plateaux in Sierra Leone, Liberia, Ivory Coast and Ghana; southern Nigeria and Cameroon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BS = Base Saturation  
CEC = Cation Exchange Capacity
Table 7.2 Characteristics, limitations, and potential of rice-growing environments in the Guinea Savanna Zone of West Africa (source: Andriesse and Fresco 1991; adapted)

<table>
<thead>
<tr>
<th></th>
<th>Crests, upper slopes</th>
<th>Middle slopes</th>
<th>Lower slopes</th>
<th>Valley bottoms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydrological regime</strong></td>
<td>Pluvial</td>
<td>Pluvial</td>
<td>Phreatic (groundwater flow), pluvial</td>
<td>Fluxial (seasonal)</td>
</tr>
<tr>
<td><strong>Main soils</strong>&lt;br&gt;(descriptive)</td>
<td>Well drained, moderately deep to deep, gravelly, coarse- to medium-textured soils of low fertility; in places shallow, overlying petroplinthite or rock</td>
<td>Moderately well to well drained, moderately deep to deep, gravelly, coarse- to medium-textured soils of low fertility</td>
<td>Imperfectly to poorly drained, moderately deep to deep, coarse- to medium-textured soils of low fertility; in many places over soft plinthite</td>
<td>Poorly drained, deep, coarse- to medium-textured soils of low to moderate fertility</td>
</tr>
<tr>
<td><strong>Main rice yield limitation</strong>&lt;br&gt;Water retention on coarse-textured and/or shallow soils</td>
<td>Water retention on coarse-textured soils</td>
<td>Soil fertility</td>
<td>Soil fertility</td>
<td>Flooding&lt;br&gt;Soil fertility (N flushing)</td>
</tr>
<tr>
<td><strong>Required (water) management</strong></td>
<td>Erosion control, (single-tree) terracing, contour cropping</td>
<td>Bunding, levelling, drainage</td>
<td>Flood control, contour bunding, levelling, drainage</td>
<td></td>
</tr>
<tr>
<td><strong>Actual rice cropping system</strong></td>
<td>Fallow systems; rice marginal with fallow rotation; maize/cowpea; (rice)/cassava; (rice)/maize or sorghum intercropping</td>
<td>Single-cropped wet rice, followed by vegetables (cowpea) (cassava)</td>
<td>Single- or double-cropped transplanted wet rice</td>
<td></td>
</tr>
<tr>
<td><strong>Potential rice cropping system</strong></td>
<td>Perennial tree cropping with food crops (rice) under young trees</td>
<td>Single cropped wet rice under improved management</td>
<td>Double cropped wet rice under pump irrigation and improved management</td>
<td></td>
</tr>
<tr>
<td><strong>Representative areas</strong></td>
<td>Interior plains and plateaux in Guinea Bissau, Guinea, southern Mali and Burkina Faso, north-central Ivory Coast and Ghana, Togo, central Benin and Nigeria</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7.3 Characteristics, limitations, and potential of rice-growing environments in the Sudan Savanna Zone of West Africa (source: Andriesse and Fresco 1991; adapted)

<table>
<thead>
<tr>
<th>Hydrological regime</th>
<th>Crests, upper slopes</th>
<th>Middle slopes</th>
<th>Lower slopes</th>
<th>Valley bottoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrological regime</td>
<td>Pluvial</td>
<td>Pluvial</td>
<td>Phreatic (groundwater flow), pluvial</td>
<td>Fluxial (seasonal)</td>
</tr>
<tr>
<td>Main soils (descriptive)</td>
<td>Well drained, moderately deep, coarse- to medium- textured soils of low to moderate fertility; in many places shallow and/or gravelly over petro-plinthite</td>
<td>Moderately well to well drained, moderately deep to deep, medium- textured soils of low to moderate fertility; in places gravelly</td>
<td>Imperfectly drained, moderately deep, coarse- to medium-textured soils of low to moderate fertility; in places over soft plinthite</td>
<td>Imperfectly to poorly drained, deep, medium- textured soils of moderate fertility; in places coarse textured; in places saline</td>
</tr>
<tr>
<td>Main rice yield limitation</td>
<td>Rainfall</td>
<td>Water retention on moderately deep soils</td>
<td>Surface sealing</td>
<td>Flooding</td>
</tr>
<tr>
<td>Required (water) management</td>
<td>Erosion control, water harvesting</td>
<td>Erosion control, water harvesting</td>
<td>Bunding, levelling, supplementary irrigation</td>
<td>(Pump) irrigation for 2nd crop</td>
</tr>
<tr>
<td>Actual rice cropping system</td>
<td>Rice exceptional; only in highest rainfall areas (&gt; 900 mm) and on soils with high water retention capacity; rice-food crop rotation</td>
<td>Single-cropped wet rice, sometimes rice-(vegetables)</td>
<td>Single-cropped wet rice, broadcast or transplanted</td>
<td></td>
</tr>
<tr>
<td>Potential rice cropping system</td>
<td>Little potential outside favourable areas</td>
<td>Rice followed by vegetables or beans under improved management</td>
<td>(Double-cropped) rice under pump irrigation and improved management</td>
<td></td>
</tr>
<tr>
<td>Representative areas</td>
<td>Aggradational plains, interior plains and plateaux in Senegal, Gambia, southern Mali, Burkina Faso, Niger, northern Benin and Nigeria</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>