LAND AND RICE IN AFRICA: CONSTRAINTS AND POTENTIALS

F.R. MOORMANN and W.J. VELDKAMP

International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

Introduction

While this treatise will deal mainly with soils, we prefer to use the wider concept of land, which includes all reasonable stable and predictable cyclic attributes of a specific area. In the relationship environment-crop production, soil is only one of the attributes determining the actual suitability and potential agronomic capability of land. It should not be seen apart from other attributes such as climatic, hydrologic, topographic, biological and human ones. Hence, our insistence on emphasizing this concept of land.

Cultivation of *Oryza sativa* in West Africa is relatively recent if compared with China (Chang, 1976) and, certainly in its initial stages, rice has been grown by the West Africa farmer using the same methods and technology with which he was familiar for his other more important dryland food crops.

Rice is the only major annual food crop (with the partial exception of aroids) which thrives on land which is water saturated, or even inundated during part or all of its growth cycle. This means that major constraints and potentials of rice land cannot be seen as separate from use and manipulation of water derived from any source. Thus, the African farmer, basically a dryland farmer, has been and still is handicapped with regard to the development of rice production as an important crop for his livelihood.

In the context of this article, not all constraints and potentials for rice in Africa can be examined. Many of these are locale-specific and require further *in situ* studies in actual or projected rice growing areas. Thus we do not present this paper as a complete treatise but rather as a way-station in the study of the African agro-ecological conditions where rice is, or can be, grown.

Water

General

Rice (*Oryza sativa* L.) is a semi-aquatic plant, in all probability originating from, and domesticated in, the well-watered valleys of eastern Asia (Chang, 1976; Huke, 1976). Its range of environmental tolerance extends to the wet parts of the landscape, where other cereals fail. On the other hand, towards the dry side of such environmental conditions, rice is much less tolerant of low soil moisture than other cereals, thus strictly limiting the production of rice to land where water is not in short supply during part or all of the growth cycle. Various studies (e.g. IRRI, 1975; IITA, 1975, 1976; Le Buanec, 1975) show that the main factor involved is the relatively shallow effective rooting depth of the rice plant. In terms of soil and water parameters, this means that the rice plant has to rely for its water supply, needed for productive vegetative and generative growth, on water available in the upper 20 or 25 cm of the soil profile. Since it is this part of the profile which will be most rapidly depleted, during periods of defective water supply, the rice plant will suffer from drought sooner than almost any other cereal crop, even though its consumptive water requirements are quite comparable to those of other cereals (Slayter, 1967).

Available water in the upper 20-25 cm of the soil profile varies not only with water supply, but also with the water retention properties of that layer as determined by texture, kind, and amount of organic matter and its clay mineralogy. These parameters will be discussed below.

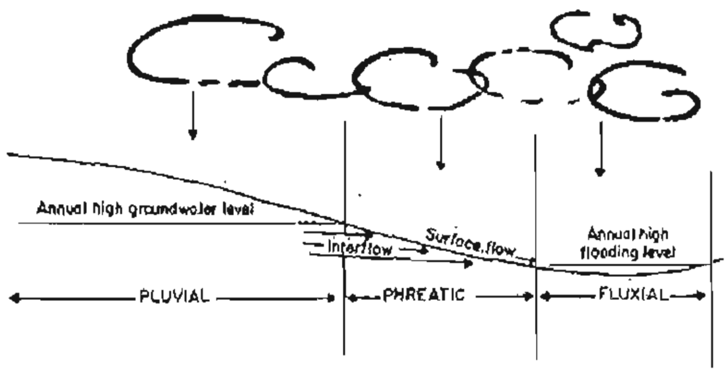

Fig. 1. Model of classes of riceland according to topography and water supply.

Types of rice land as a function of water regime

In West Africa, artificial water management of rice lands by bunding and levelling is as yet only sporadically applied and controlled irrigation is found even less. African rice lands without such water management can be classified as in Figure 1, according to their position in the landscape and to the water supply. Table 1 summarizes the type of water supply of the three main natural categories of rice land.

TABLE 1

Sources of natural direct water supply in rice lands

	Categories of rice land		
Source of water	Pluvial	Phreatic	Fluxial
Rain	Always	Partial[a]	Partial[a]
Subterranean	Not	Always	Partial[a]
Surface	Not	Not	Always

a) Except in the most arid, desert climates where rainwater or more seldom, no subterranean water, is received by rice fields.

The term 'upland' used by WARDA (1975) and most authors would include both 'pluvial' and 'phreatic'. 'Fluxial' rice land would include 'swamp', 'deep water' and most of the 'mangrove'. At IITA (Moormann *et al.*, 1976) the terms 'dryland' and 'hydromorphic' have been introduced and are equivalent for pluvial and phreatic, respectively.

Hydrologic restraints in pluvial rice lands

In pluvial rice lands, water availability in the root zone during the growing cycle of the rice crop is determined by:

a) climatic factors, mainly those related to rainfall
b) inherent soil characteristics
c) soil management factors
d) varietal characteristics of the rice as regards the use of soil water.

Here we will deal mainly with the first two sets of factors. On pluvial rice land, the main production-determining factor is the nature of the rainfall. Though total effective rainfall is important, rainfall distribution is even more so. Rice requires at least 600 mm of rain to complete its growth cycle (Cocheme, 1971), but a 1000 mm annual precipitation with a monthly rainfall of 200 mm during the growth cycle is reported to be a minimum requirement (Brown, 1969; De Datta, 1975).

Less annual rainfall is required for a monomodal than for a bimodal rainfall pattern. In general, for most soil conditions, pluvial rice cultivation appears to be submarginal with a rainfall of less than 1000 mm, marginal between 1000 and 1300 mm, and fair between 1300 and 1600 mm, while the *amount* of precipitation ceases to be a major restraint for pluvial rice cultivation at a higher average annual rainfall. These figures have to be modified by rainfall pattern and distribution, the rate of evapotranspiration, and by soil properties.

The daily rainfall distribution or, alternately, the expectancy of drought during the growth cycle of pluvial rice becomes critical in zones with a relatively low annual rainfall. But even in high rainfall zones, such rainless periods often are damaging to the rice crop. Such drought periods occur regularly in areas of extensive pluvial rice cultivation in West Africa (Moormann, 1973), even in areas with an annual rainfall of 2000 mm or over.

The interplay between drought stress and soil characteristics in pluvial rice cultivation is not well understood. Clayey soils, derived from basic rocks (e.g. basalts, amphibolites) are superior to those from more acidic parent rocks which are usually sandy or coarse loamy. Moreover, clay mineralogy plays an important role as regards available water, and in this respect, the fact that most West African soils are kaolinitic is a restraint for rice cultivation.

Hydrologic quality of phreatic rice lands

Compared to pluvial rice lands, shortage of water is a less severe restraint for phreatic rice cultivation. The presence of groundwater in the root zone during at least part of the growing season diminishes the severity of stress during drought periods.

The superior quality for rice growing of phreatic rice land in Africa is recognized by the farmers, who have extended rice cultivation into hydromorphic areas of the drier climatic zones, where conditions are submarginal for pluvial rice cultivation unless the effective waterholding capacity of the soil is high. The preferred use of phreatic rice land (*riziculture a nappe*) have been studied in Senegal by Bertrand (1973), while Killian (1972), Moormann (1973) and Moormann *et al.* (1976) have emphasized the usefulness of such groundwater-influenced terrains.

Hydrologic restraints on the use of such land for rice cultivation are partly of the same nature as those for pluvial rice land. The degree of hydromorphism plays an important role, and on the drier part of the phreatic range, rice may, and often does, suffer from drought if long dry spells occur during the growing season whereby the groundwater is lowered below the zone where it can feed the rice roots. Rice on such marginal phreatic rice lands then may suffer in the same way as on pluvial rice lands.

Alternate drying and wetting of the root zone in many phreatic rice lands may have a negative effect on the nitrogen status of such soils, especially as regards nitrogen applied as fertilizer. When the rootzone is oxygenated, NH_4-nitrogen is oxidized to NO_3-nitrogen but in subsequent reducing conditions, denitrification takes place below the surface, and nitrogen is lost as N_2 and N_2O. This phenomenon, described for paddy soils (see e.g., Shiori and Tanada, 1954), seems particularly strong in phreatic rice lands (Moormann *et al.*, 1977) where groundwater levels fluctuate during the growth cycle.

Hydrologic quality of fluxial rice land

Fluxial rice lands, as found in river plains, deltas, coastal fringes with mangroves, and also in minor valleys, generally have qualities such as those described for phreatic rice lands. The soil is water-saturated or even inundated during part of the growing season, assuring a sufficient water supply. Nevertheless, where flooding is often uncontrolled in Africa, various negative factors may influence the productivity of the rice crop.

Part or all the rice land may revert to dryland conditions in years when the flood waters are reduced during the growing cycle of the rice crop.

With drying out of such fluxial rice land during the season, drought stress occurs as it does regularly in the semi-arid climates, e.g. in the Senegal river and upper Niger river valleys.

On the other hand, in the wetter zones of Africa, floods may be damaging. Gentle rise of the flood water (mainly less than 15 cm/day) is not particularly damaging in view of the possibility to grow adapted deep water (floating) varieties. But flash floods of a few hours to a few days, often occurring in the narrow valleys in high rainfall zones such as Guinea, Sierra Leone and Liberia, may physically damage the rice crop. Moreover, flash floods, even of a short duration are a severe restraint on the introduction of high yielding, short strawed varieties.

Another limiting factor in fluxial rice lands can be the quality of the flood water in coastal areas, being subject to salt water intrusion. In some West African river estuaries, rice is grown on cleared mangrove land without protection from sea water intrusion (Moormann and Pons, 1975). In normal or wet years, the flux of good quality river water is sufficient to suppress salinity in the rootzone. In dry years, when river flooding is reduced, rice crops fail in the seaward part of these unprotected rice growing areas.

Soils

General

Rice is grown on all soil orders, though some are especially important, while on others, like Aridisols, Histosols and Spodosols, rice is seldom grown. In general, the wet (Aquic) suborders and subgroups are most extensively used, and, globally, it is estimated that only 14-18% of the rice acreage is planted to 'upland rice' (De Datta, 1975; Le Buanec, 1975). Since part of land used for 'upland rice' is in fact phreatic (hydromorphic) rice land, the surface of the freely drained soils planted to rice is even more restricted. In West Africa, rice grown on freely drained soils is relatively more important than in the old rice growing centres of tropical Asia. Pluvial rice lands in West Africa are mainly on Alfisols and Ultisols; the latter order being the most widely used. Phreatic rice lands are mainly found on the Aquic (wet) suborders of Entisols, Inceptisols and the Aquic subgroups of the already mentioned orders. Fluxial rice lands are mainly on wet suborders of Entisols and Inceptisols (Aquents, Aquepts). In the drier Sahel zone, irrigated rice is found on Inceptisols mainly, and on Vertisols and Aridisols in the second place.

The morpho-genetic classification of Soil Taxonomy, and the data from the FAO/UNESCO soil map of the world are useful in making a general evaluation of land quality for rice in West Africa. It is clear from these data that Central and West Africa have a lesser overall potential for rice growing than, for instance, South and East Asia. The major river plains and deltaic areas of that part of the world, which are the "backbone of rice cultivation", are largely absent in Africa.

As regards pluvial (dryland) rice lands, the total available surface in the climatically suitable area of West Africa is, of course, enormous. But the quality of that land for sustained, high-yielding production of rice is low. Soils are generally leached (dominance of Ultisols), have a kaolinitic clay mineralogy with unfavourable cation retention characteristics, mostly have a sandy to coarse loamy surface soil texture and are, for a major part, highly erodable. These, and other related soil factors are responsible for the fact that pluvial rice in Africa is generally low yielding, and that it is mainly if not exclusively grown in a shifting-cultivation pattern.

The situation for the lowlands of Africa is much better. While their total surface in West Africa is rather small in relation to the total land surface, sizeable areas of land with a better actual or potential water regime are still available. Soils of the lowlands in the Sudan and Sahel climatic zones have generally good qualities for (irrigated) rice cultivation. They are not strongly leached, have a better clay mineralogy and a higher cation retention and are, on average, finer textured. In the increasingly wetter areas of the various forest belts, the quality of the soils in the lowlands, whether in broad valleys and coastal plains or in the narrower valleys, is less favourable than in the drier areas. Soils are more acid, and stronger leached and, in the narrow inland-valleys or lower terraces, frequently sandy. Nevertheless, because of their better water regime, they are increasingly becoming the favoured environment for sustained rice cultivation. This preference for the low lying hydromorphic soils is, for example, particularly clear in southern Senegal, where rice is now mainly cultivated in such low areas, even though their general soil quality is less than that of the adjacent plateau areas (Birie-Habas *et al.*, 1970; Bertrand, 1973). The rapid expansion over the last 20 years of rice cultivation in the lowlands of the Abakaliki area, Anambra State, Nigeria, is almost exclusively in such lowland soil areas.

In these lowland soil areas, the superior hydrologic conditions often override soil-imposed restraints. Thus, for instance, while sandy soils are almost always unsuited for pluvial rice cultivation, this is no longer so when such soils are found in hydromorphic areas. They still have a distinctly lower production potential than more finely textured hydromorphic soils, but rice cultivation with reasonable assured returns is possible. Soils of the inland swamps of Sierra Leone, for instance, are dominantly sandy, but are extensively used for rice cultivation on a permanent basis, while pluvial rice lands in the surrounding areas, most of which have finer textured soils, are only used in a shifting cultivation pattern (Odell *et al.*, 1974).

Problems in African rice growing which are related to soil conditions

In this section, some specific problems related to soils in their African environment will be discussed. Soil properties mentioned here are reasonably stable ones, thus mainly excluding those which can be easily influenced by management such as the nutrient status of surface soils. Many more locale-specific problems which may be expected are excluded, both relating to physical and chemical soil properties.

Texture. The often sandy texture of African soils may be considered as a restraint to productivity. For pluvial rice lands, this was already mentioned earlier; effective water retention in such soils is low, and plants will readily suffer from drought. In the lowlands, soils with sandy profiles will lose water rapidly by percolation and nutrients will leach below the reach of rice roots.

Fertilizer management on the sandy soils is, therefore, unfavourable, especially with regard to nitrogen. Even under improved management levels, sandy soils remain relatively low in their productivity (Moormann and Dudal, 1968; Higgins, 1964).

Very high clay contents, as in Vertisols and in some of the marine alluvial soils (e.g. in the Senegal river delta) also have several disadvantages. While with a sufficient water supply such soils can and do produce good rice yields, land preparation is often difficult, requiring an advanced level of mechanization. Shortage of water supply on very fine clay soils can be damaging because of a restricted hydraulic conductivity. Exceptions to this are very fine clay soils, developed on volcanic materials which have a high content of active sesquioxides and consequently a very good structure. Such soils, some of which occur in the volcanic areas of western Cameroon, and on basic rocks such as amphibolites elsewhere in the basement-complex areas of West Africa, have excellent available water holding characteristics for pluvial rice.

Soil mineralogy and parent material. Studies of clay mineralogy of rice growing soils in the last decade have underlined the importance of clay mineralogical composition on inherent fertility and management characteristics of such soils (see e.g. Kawaguchi and Kyuma, 1978). The quantitative influence on productivity of rice growing soils is difficult to evaluate, since clay mineralogy is not an independent growth determining factor, but acts together with others, e.g., texture and organic matter content. Nevertheless, soils that are predominantly or entirely kaolinitic, are known to be less productive than soils containing 2:1 lattice clay minerals in the form of smectites, illites, and vermiclites. Soils with a high content of amorphous materials, such as found in parent materials from volcanic origin, usually have better characteristics for growing rice, though phosphorus may be strongly fixed.

The influence of clay mineralogy is mainly related to differences in effective water-holding characteristics and in cation retention characteristics of the surface soils. Both these values are low to very low for soils with a predominantly kaolinitic clay mineralogy. The great majority of upland soils in West Africa are kaolinitic. Only in the lowlands, except in the perhumid and humid zones, do soils frequently have a more favourable clay mineralogy. Valleys in which the soil materials are derived from adjacent volcanic formations are particularly valuable for rice growing; examples are the plain of Mbo and the plain of Ndop in Cameroon.

From the above statements on clay mineralogy, the role of the nature of the parent material is already partly apparent. Parent materials leading to formation of the better rice growing soils are mainly basic rocks, and especially where young alluvial sediments of mixed origin and without an exclusive kaolinitic clay mineralogy have been deposited. The latter are found in major river plains, lacustrine plains (as Lake Chad) and in coastal plains and deltas. The eolian deposits which cover parts of the Suden and Sahel zones, are moderately rich to poor parent materials for soils in these zones. The best are the loamy to silty textured eolian sediments (loess) and their alluvial/colluvial derivates. The sandy portions of these areas dominated by eolian sediments are much less rich, though their alluvial/colluvial derivates in valleys are frequently finer textured and of better quality for rice growing, if water is available.

The majority of the soils in the wetter zone of West and Central Africa are derived either from intermediate to acid crystalline rocks (basement complex), or from various sedimentary rocks, which are mostly arenaceous. These parent rocks predominantly give rise to soils with a poor inherent potential for rice.

Organic matter. The role of organic matter in regard to the inherent quality of soils on which rice is grown is almost as diverse as the environmental conditions of the crop. Its most important functions are to increase the available water holding capacity, to increase cation exchange capacity, to improve soil structure and, through the process of mineralization, to provide nutrients, mainly nitrogen, to the rice crop. For pluvial rice lands, all these functions are of prime importance. For phreatic and fluxial rice lands, the role of improving water-holding capacity and structure becomes relatively less important with increasing wetness of the soils during the growth cycle of rice. An excess of organic matter, as in peat and peaty soils (Histosols), causes negative effects on the performance of the rice crop. Since such soils are rare in West Africa, no further details are given.

The important role of organic matter in pluvial rice lands is reflected in the cropping system used by the local farmers in West and Central Africa for growing rice. On these dryland soils, the initially moderate content of total organic matter is favourable immediately after clearing from fallow bush or savanna. However, after 1-2 years of cultivation, this content diminishes to the order of 0.5-0.8 percent organic carbon in the topsoil. While the role of organic matter as a nutrient source can be replaced by fertilization, the available water-holding capacity and the CEC of the surface soil will inevitably decrease. This is not so serious on soils with a clayey texture and favourable clay mineralogy. On the predominantly sandy kaolinitic soils on which dryland rice is grown, however, the land may be expected to become progressively more droughty and less fertile in the years after the initial clearing, and this is one of the important reasons that pluvial rice in most of Africa is best grown immediately after clearing in the shifting cultivation cycle. There are also many other reasons for this, and it should be noted that the low organic matter content of continuously cultivated drylands in much of the area under discussion paired with the average sandy surface soil texture and the unfavourable clay mineralogy is, in most cases, a definite restraint for sustained production of pluvial rice.

Calcareous soils. Few rice growing soils in Africa are reported to be calcareous; such soils occur almost exclusively in the drier zone of the African continent. While rice under irrigation can support the somewhat alkaline pH values found on such soils, some deficiencies, especially of zinc (Tanaka and Yoshida, 1975), may become acute under such conditions. Zinc deficiency has been reported on rice in Africa, e.g., on the neutral to calcareous Vertisols near Lake Chad (Kang and Okoro, 1974). Iron deficiency occurs also, but tends to diminish or even disappear when rice is grown on submerged (paddy) lands.

Salinity in rice lands. Moormann and van Breemen (1978) distinguished four basic types of salinity and alkalinity in rice growing areas, according to the sources and to the occurrence in the landscape.

- Marine salinity, derived directly from sea water intrusion.
- Interflow salinity of alkalinity, derived from lateral influx of drainage water, mineralized by weathering of salt bearing rocks above the level of the rice growing lands.
- Groundwater salinity or alkalinity.
- Surface water salinity or alkalinity, due to evaporation of moisture, brought in by river floods or irrigation, on soils of low permeability.

In Africa, all four types of salinity and alkalinity occur, but only the marine and groundwater salinity are of some importance in rice growing; the latter occurs exclusively in the dry zone (Sahel) where rice is grown under irrigation.

Marine salinity of lowland coastal West Africa is at present often a limiting factor. This is mainly related to the fact that, with few exceptions, no satisfactory marine land reclamation has been developed. A typical example of this type of salinity can be found in some river estuaries in southern Senegal (Moormann and Pons, 1975). Here, mangrove swamps with saline Hydraquents are reclaimed without any further protection or water regulation. When the rivers are in flood, and after sufficient leaching of the surface horizon, rice is planted in the land freshly cleared from mangrove. In years with a normal river discharge, salinity during the growing season is low enough to produce a yield of rice. In years with a low rainfall in the catchment and cultivated areas, however, yields can be strongly depressed or fail altogether. The West African low coastal lands, influenced by saline water intrusion, are at the same time potentially acid (acid sulphate soils), which makes their more definite reclamation by empoldering frequently a hazardous and uneconomic enterprise. Small areas of marine saline land without potential acidity will offer excellent possibilities for establishing rice land. Surveys and research is required to locate and delineate such areas.

Iron and manganese excess in the root zone. Nutritional disorders, related to high Fe^{2+} content in the rootzone of rice during flooding, have been extensively studied by IRRI scientists (Ponnamperuma, 1972; Tanaka and Yoshida, 1975). *In situ* development of toxic levels of Fe^{2+} in the rootzone will take place at a low soil pH, strongly reduced conditions, and a low content of 'active' iron. When the active iron content is high, Fe^{2+} levels in the soil solution will, after an initial increase, diminish below toxic levels so that *in situ* iron toxicity in flooded soils though repeatedly demonstrated in pot experiments has only infrequently been observed in the field, e.g. in acid sulphate soils.

In West Africa, however, of much greater importance, is the influence of Fe^{2+} containing interflow water, upwelling phreatic and fluxial rice lands in and adjacent to valley bottoms. While Fe^{2+} level in the rootzone is not necessarily at a toxic level, the continuous inflow of such water appears to cause nutritional disorders, which largely remain to be studied. Yellow and orange discoloration of leaves, increasingly stunted growth, and lower yields are common in such zones of upwelling. In the more serious cases, high levels of Fe^{2+} can be found both in the soil solution and in the plant, leading to characteristic bronzing of the leaves and strong depression of growth and productivity of the plants. This interflow iron toxicity is most severe in areas where the adjacent uplands are strongly leached Ultisols. The source of dissolved iron in the interflow water is usually the weathering zone of rock formation; but ferrous iron may also be derived from plinthite formations in the uplands adjacent to the affected valleys.

In West Africa, the various stages of the effects of Fe^{2+} containing interflow water are widespread. Nutritional disorders, without clear iron toxicity, occur in many valleys even in areas dominated by Alfisols with high base saturation. Typical iron toxicity occurs frequently in Ultisol-dominated landscapes of the high rainfall zone, e.g. in Sierra Leone and Liberia.

Chemical improvement by liming of soils affected by Fe^{2+}

containing interflow water is short lasting, and often ineffective. The development of tolerant rice varieties is promising. When the landscape and hydrologic conditions permit it, land improvement and adapted management techniques can solve the problem, i.e.,

- seasonal drying of affected lands, to cause the oxidation of Fe^{2+} into insoluble Fe^{3+} compounds.
- general drainage of the rice land; affected land in Japan and Taiwan is often tile-drained, but such measures are clearly not yet economic under African conditions.
- interception of the interflow water by deep drainage ditches across the line of flow. This method can be recommended in affected areas of West Africa, where local topographic conditions are favourable.

Not many pertinent data are known on excess manganese and its toxicity in rice fields. Variable Mn^{2+} concentrations may occur in interflow water derived from crystalline and other rocks, high in manganiferous minerals. In Asia, it appears that the Mn^{2+} content in the root zone of rice, though sometimes relatively high, remains below the critical level for rice (Tanaka and Yoshida, 1975).

Acid sulphate soils. Acid sulphate soil conditions are found in coastal areas under past or present mangrove vegetation. In their original swampy conditions, these soils contain variable amounts of pyrite (FeS_2) which, upon aeration of the soil will oxidize, leading to acidification of the soil material (van Breemen, 1977). Collateral effects are the periodic high content of Al^{3+} and Fe^{2+} which when present in the rooting zone will affect the growth and production of rice to a variable degree (see e.g., Bloomfield and Coulter, 1973; and Moormann and Pons, 1975, for the management aspects of such soils).

The majority of the mangrove swamp soils along the west coast of Africa are potential or actual acid sulphate soils. Considerable research on their development for rice has been carried out, especially at the Rokupr Station in Sierra Leone, and several pilot projects have been initiated in the West African mangrove belt. The general conclusion is that development is expensive and, in terms of economic returns, often marginal or submarginal. Plans for rice land development in mangrove swamps recur regularly. Only on mangrove soils with low or zero potential acidity are such plans warranted. Pre-project research and survey in prospective areas are required to avoid costly failures. In West Africa, most mangrove reclamation projects are not justified because of adverse soil conditions (Moormann, 1973).

Conclusion

Considerable land areas in West Africa are suitable for

rice cultivation to a varying degree from the point of view of soil and hydrological conditions. The development of rice-based cropping systems, with continuous land use is difficult for pluvial rice lands. Few soils in the climatically suited areas of West Africa lend themselves to such a system of permanent cropping. Indeed, in the prevailing environmental and socio-economic context of the area, pluvial rice is and will be grown mainly in a shifting cultivation pattern in the foreseeable future. Under phreatic and fluxial conditions, the prospects for the development of permanent rice-base cropping systems are considerably better. On such land, yield potential is higher. The key for increasing production here is improved land and water management. The logical sequence of events would be a development from the simple, non-improved utilization of lands with sufficient additional water over and above the water provided by rain, towards the improvement of such lands by levelling and bunding (paddy construction), and, in a later stage, controlled irrigation. This development sequence can even at the present time already be seen in various parts of West Africa. While most ricelands in the valley bottoms and other hydromorphic areas are still undeveloped with regard to land and water management, there is a definite trend towards better utilization of such lands. Moreover, many of these lands are now in continuous use for rice, without fallowing. The total surface of land suited for improved systems is not large in relation to the total surface of arable land in the zone under discussion. Nevertheless, much of this type of land is as yet not utilized or is definitely underutilized in West Africa, and the potential for improved lowland rice cultivation is considerable.

References

Bertrand, R. (1973). Contribution a l'etude hydrologique, pedologique agronomique des sols gris sableux hydromorphes du Casamance (Senegal). *L'Agronomie Tropicale* 12, 1145-1192.

Biri-Habas, J., Aubin, J.P., Sene, D. and Poisson, C. (1970). Les recherches rizicoles au Senegal. Mimeogr. Doc. FF/IRAT/IITA seminar on rice, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Bloomfield, C. and Coulter, J.K. (1973). Genesis and management of acid sulphate soils. *Advances in Agronomy* 25, 266-319.

Brown, F.B. (1969). Upland rice in Latin America. *International Rice Commission Newsletter* 18/1, 1-5.

Chang, T.T. (1976). The origin, evolution, cultivation, dissemination and diversification of Asian and African rices. *Euphytica* 25, 425-441.

Cocheme, J. (1971). Notes on the ecology of rice in West Africa. *In* "Notes on the ecology of rice and soil suitability for rice cultivation in West Africa", FAO, AGS/WARDA/71/5: 1-5. FAO, Rome.

De Datta, S.K. (1975). Upland rice around the world. *In* "Major

Research in Upland Rice", International Rice Research Institute, Los Banos, Philippines, 110p.
Higgins, G.M. (1964). Soils of some rice growing areas in northern Nigeria. *African Soils* 9, 247-265.
Huke, R.E. (1976). Geography and climate of rice. *In* "Climate and Rice", pp 31-50. International Rice Research Institute, Los Banos, Philippines.
IITA, (1975). International Institute of Tropical Agriculture, Ibadan, Nigeria. Annual Report for 1974.
IITA, (1976). International Institute of Tropical Agriculture, Ibadan, Nigeria. Annual Report for 1975.
IRRI, (1975). International Rice Research Institute, Los Banos, Philippines. Annual Report for 1974.
Kang, B.T. and Okoro, E.G. (1976). Response of flooded rice grown on a vertisol from Northern Nigeria to zinc sources and methods of application. *Plant and Soil* 44, 15-25.
Kawaguchi, K. and Kyuma, K. (1978). "Paddy Soils of Tropical Asia". Kyoto, Japan (in press).
Killian, J. (1972). Contribution a l'etude des aptitudes des sols a la riziculture des bas-fonds sans amenagements dans le Nord-Dahomey. *L'Agronomie Tropicale* 27-3, 322-375.
Le Buanec, B. (1975). La riziculture pluviale en terrain draine, situation, problemes et perspectives. *L'Agronomie Tropicale* 30, 358-381.
Moormann, F.R. (1973). General assessment of lands in which rice is grown in West Africa. WARDA doc. S/73/10, West African Rice Research Development Association, Monrovia, Liberia, 93p.
Moormann, F.R. and Dudal, R. (1968). Characteristics of soils on which paddy is grown in relation to their capability classification. International Rice Commission doc. S/68/76, Kandy, Sri Lanka.
Moormann, F.R. and Pons, L.J. (1975). Characteristics of mangrove soils in relation to their agricultural land use and potential. *In* "Proceedings of International Symposium on Biology and Management of Mangroves", pp 529-547, University of Florida Press.
Moormann, F.R. and van Breeman, W. (1978). "Rice: Soils, Water, Land". IRRI/IITA publication. International Rice Research Institute, Los Banos, Philippines (in press).
Moormann, F.R., Perez, A.T. and Veldkamp, W.J. (1976). Potential of hydromorphic rice cultivation in Nigeria. National Accelerated Food Production Programme (NAFPP) Workshop Paper, 8p. (mimeo.). International Institute of Tropical Agriculture, Ibadan, Nigeria.
Moormann, F.R., Veldkamp, W.J. and Ballaux, J.C. (1978). The growth of rice on toposequence - a methodology. *Plant and Soil* 48 (in press).
Odell, R.T., Dijkerman, J.C., van Vuure, W., Melsted, S.W., Beavers, A.H., Sutton, P.M., Kurtz, L.T. and Miedema, R. (1974). Characterisations, classification and adaptation of soils in selected areas in Sierra Leone, West Africa. Bulletin 4, Njala University College, Sierra Leone, 194p.
Ponnamperuma, F.H. (1972). The chemistry of submerged soils. *Advances in Agronomy* 24, 29-88.
Shioiri, M. and Tanada, T. (1954). The chemistry of paddy soils in Japan. Japanese Government Ministry of Agriculture and Forestry,

45p.
Slayter, R.O. (1967). "Plant-Water Relationships". Academic Press, New York and London, 366p.
Tanaka, A. and Yoshida, S. (1975). Nutritional disorders of the rice plant in Asia. *Technical Bulletin* 10. International Rice Research Institute, Los Banos, Philippines, 51p.
WARDA, (1975). Rice Vocabulary. West African Rice Development Association, Monrovia, Liberia, 207p.
van Breeman, W. (1977). Genesis and solution chemistry of acid sulphate soils in Thailand. Centre for Agricultural Publishing and Documentation (PUDOC), Wageningen, 264p.