Land evaluation of valleys in a tropical rain forest area - a case study

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LAND EVALUATION OF VALLEYS IN A TROPICAL RAIN AREA - a case study

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
Dr. H.C. van der Plas,
hoogleraar in de organische scheikunde,
in het openbaar te verdedigen
op donderdag 13 september 1979
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen.

STELLINGEN

1. Het grondwater regime geldt als de belangrijkste factor voor de bepaling van de actuele landbouwkundige waarde van de bestudeerde hydromorfe gronden.

Dit proefschrift.

2. Land evaluatie van hydromorfe land types moet, naast de bestudering van bodem kenmerken, gebaseerd worden op observaties van de dynamiek van het grondwater en het bodemvochtgehalte in functie van de weersomstandigheden in het stroomgebied gedurende tenminste een jaar.

3. Gezien de vaak marginale omstandigheden waaronder tropische landbouwgewassen worden verbouwd en de vergroting van het landbouwareaal door middel van een verhoogd gebruik van marginale gronden, is het aangeven van het onder die omstandigheden te behalen produktieniveau moeilijk op een redelijke wijze voorspelbaar, omdat te weinig kennis bestaat omtrent de ecologische eisen van de gewassen.

4. De methode waarbij gewasssen op toposequenties (of catena's) worden bestudeerd is zeer wel bruikbaar om de geschiktheid van de bodem voor de betreffende gewassen te onderzoeken, echter niet om de invloed van afzonderlijke bodemeigenschappen op de groei en opbrengst van de gewassen te bepalen.

5. Uitgaande van een bestaand evenwicht tussen land en landgebruik, dient bij landbouwkundige ontwikkeling in "shifting cultivation" gebieden het bereiken van een nieuw evenwicht een eerste vereiste te zijn.

6. De samenstelling van het grondwater is ook buiten verzoute gebieden van belang ten aanzien van accumulatie van bepaalde verbindingen en de daaruit voortvloeiende vergiftigingen van gewassen.

7. Om als een goede basis voor land evaluatie te dienen, zou in een bodemklassificatie systeem als de Soil Taxonomy gestimuleerd moeten worden om fasen op subgroup of family niveau te onderscheiden.

8. De gradering van land kwaliteiten en de benoeming van landgebruiks typen zou globaal gestandariseerd moeten worden.

9. Bij ontwikkelingsstrategie voor vele delen van Afrika wordt te weinig rekening gehouden met de aanwezige behoefte van de boer aan vrije tijd.

10. Hoewel sommige traditionele gebruiken gebaseerd kunnen zijn op bijgeloof en onwetendheid, dient aandacht besteed te worden aan: "one's view on a particular culture in comparison with socalled modern cultures whose associated scientific and materialistic achievements tend to unwillingly set the standards for other cultures, that are caught in a tide against which they are more or less powerless".

B.N. Okigbo, The role of agriculture in rural development and employment, 1972.

11. Het wegvallen van ruimte en tijd, als aangetoond in de parapsychologie, is te verwonderlijk om niet bij stil te staan.

12. De verkeersveiligheid op T-kruisingen is gediend met een regeling waarbij het doorgaande verkeer voorrang heeft.

13. Ter voorkoming van de toepassing van de buitenspelval, als zijnde een vorm van spelbederf, zou in de spelregels van het voetbal opgenomen kunnen worden dat een aanvaller niet opzettelijk buitenspel gezet kan worden.

CONTENTS

ACKNOWLEDGEMENTS

This thesis was initiated by the two promotors, Prof.Dr. F.R. Moormann, my supervisor at IITA, Ibadan, Nigeria, and Prof.Dr. J. Bennema, my major professor in tropical soil science at the State Agricultural University in Wageningen. I am very grateful to them for their advice and encouragement that helped me to handle the broad subject. I would also like to thank the State Agricultural University for employing me as "promotie-assistent".

The following people I would like to mention as they read parts of the manuscript and gave useful comments: Prof.Dr. W.H. van der Molen, Prof.Dr. A. van Diest, Prof.Dr. J.D. Ferwerda, Dr. M. Wessel and Dr. H.A. Luning.

Much support was given by many people of IITA: Dr. W. Gamble, Dr. J. Flinn, Dr. A.S.R. Juo, Dr. B.T. Kang, Dr. A. Ayanaba, Dr. K. Treharne, Dr. K. Alluri, Dr.Ir. H.P.F. Curfs, Dr. A. Sangjapongje, Dr. W.H. Reeves, Dr. D. Nangju, Mr. D. de Vleeschauwer, Mr. P. Devos, and Mr. M. Adamou.

The ladies of the department "Tekstverwerking" are greatly acknowledged, in particular Mrs. G.B. Vermeer. The department of Mathematics, especially Ir. J.M.P. Geerts, helped me to a great extent with the correlation studies. Miss R. Borgan and Mr. P.G.M. Versteeg made the figures. Mrs. T.A. Chadwick and Mrs. M.F.L. Wiersma edited the english text.

ABSTRACT

In the forest zone of south-western Nigeria, hydromorphic and adjacent land types are hardly used for agriculture. To determine their potential, the soils, groundwater regimes and soil moisture regimes were studied, together with the social environment, geology, hydrology, climatology and natural vegetation. Crop performance, especially in relation to the groundwater regime, was studied in toposequence experiments. In an ecological suitability classification, land qualities, management levels, and crop performance were considered, resulting in ecological crop suitabilities for specific management units. For some management units the suitabilities, including some socio-economic aspects, have been evaluated.

SUMMARY

The forest zone of south-western Nigeria (the states of Oyo, Ogun, and Ondo) was investigated for the agricultural land use potential of its hydromorphic and adjacent land types. These land types are found in valley bottoms and on lower slopes. To make the study more complete, the more common well-drained soils were partly included for comparison. The study area is geologically divided into a northern part (Basement Complex) and a southern part (sedimentary formations). Poorly and very poorly drained land occupies 15 to 19 per cent of the land surface (in the northern and southern parts, respectively); for the imperfectly drained adjacent slopes, these figures are 22 and 6 per cent, respectively.

With a few exceptions, the hydromorphic land is not used for agriculture but only for the provision of forest products which are gathered rather than cultivated. This study concentrates on feasible ways of farming these land types in the context of the current conditions.

Two methodologies were used for the investigation:

- the performance of crops as a function of the location on toposequences, in particular the drainage conditions.
- the ecological land suitability classification, in which land qualities are related with the ecological and agricultural requirements of crops.

After an introductory chapter, a description of the social environment, geology, hydrology, climatology, and the natural vegetation is given. The soils and soil formation are described in more detail in Chapter 3. Nine soil units (or mapping units) were distinguished for the northern part and four for the southern part.

As the emphasis was on hydromorphic soils, the groundwater regimes and the soil moisture conditions are discussed separately in Chapter 4. Groundwater regimes are described as groundwater classes, each defined by the average highest and lowest groundwater level during a specific period or season. The soil moisture condition of the surface soil and the groundwater class resulted in a moisture situation of the root zone per groundwater class per season.

The land qualities are considered in Chapter 5. Three land qualities are of general importance: the availability of water, the availability of oxygen, and the availability of nutrients (or natural fertility). For the availability of water, a distinction of phases within the soil units was found to be necessary. The response to applied N was treated as a separate land quality because of the important effect of denitrification on nitrogen applications to hydromorphic soils. Additional land qualities, of local importance only, include the probability of occurrence of iron toxicity (in rice only), the probability of occurrence of soil erosion, the difficulty of land preparation and harvesting of root crops, and the (mechanical) impediment of root development. Apart from the availability of

water, the land qualities are described in a qualitative way. Together with soil characteristics, the groundwater class was an important factor in the determination of the land qualities on several occasions.

Two management levels are defined in Chapter 6: traditional and improved management. The improved management level only differs from the traditional one by some simple and relevant improvements, especially in fertilization and drainage, while the establishment of bunded and levelled fields (or paddies) is considered for rice cultivation. The effect of management is incorporated in the grading of the relevant land qualities.

In Chapter 7 the crop performance of rice, maize, yam, cassava, sweet potato, cocoyam, cowpea, soybean, pigeon pea, tomato, okra, celosia, sweet pepper, banana and plantain is dealt with in two ways:

- by considering the expected yield per groundwater class. Yields of crops grown on toposequences could be related to the groundwater class; four expected yield classes were used. The toposequence experiments could not be used for considering the effect of non-groundwater factors on crop performance.
- by considering the requirements of the crops with respect to the land qualities. In general, only a few facts are known about these requirements, but on the basis of literature data, toposequence experiments and observations, four ecological suitability classes for the various crops could be established.

Both the expected yield per groundwater class and the ecological suitability class, resulting from the requirements of the crops with respect to the land qualities, were matched with each other (Chapter 8). The result is the ecological crop suitability for each management unit i.e. the combination of soil unit, phase if any, groundwater class per growth or climatological season and management level.

In Chapter 9, which is a specific application of the foregoing for the study area, the ecological crop suitabilities of a number of management units are discussed. A total of twenty-seven management units, divided into eleven groups, dominating in three study areas, were evaluated according to the ecological crop suitabilities. Only the highly and moderately suited crops expected to give satisfactory yields were considered. For the comparison of management units, an ecological crop suitability index was compiled, including kind of crop, ecological suitability, length of the growth cycle, and the number in the list of suited crops per season. Some socio-economic data are given about the clearing of the natural vegetation, the preference for certain crops, and the net labour productivity. These data were used in the evaluation of the management units. The best management level, resulting in the highest ecological suitability, was chosen. If the ecological suitability for both management levels happened to be equal, the best management level was considered on the basis of supplementary factors such as the crop, the length of time between the clearing of the vegetation and cultivation, the frequency of cultivation, the intensity of weed growth, and the degree of hydromorphism in case of rice cultivation.

For rice cultivation on hydromorphic land, a higher ecological suitability is usually obtained with improved management. However, the main limitation for improved management of rice on hydromorphic land is the relatively low net labour productivity compared to that of the traditional management level. Due to a limited availability of labour in the study area, more economic considerations are necessary to determine the best management level for rice.

Furthermore the study revealed that the result of the evaluation of the well-drained upper slopes resembles the current land use of these soils. On the other hand, the results for the hydromorphic land types can be regarded as a real evaluation of the potential land use. Of the hydromorphic and adjacent land types, the heavier textured soils have a greater potential for cultivation. The main crops suited to hydromorphic valley-bottom land are rice and (Colocasia) cocoyam; additional dry season crops are tomato, okra, and soybean. The adjacent somewhat better drained land types, occurring on a strip with a varying width along the lower slope, have a high potential; many crops are suited to cultivation. Although differing over short distances, the ecological crop suitabilities on lower slope positions are strongly dependent on groundwater regimes and soil texture.

SAMENVATTING

Het bosgebied van zuid west Nigeria (Oyo, Ogun en Ondo provincies) is bestudeerd naar het potentiële landgebruik van de hydromorfe en aanliggende land types. Deze land types komen voor in de lagere gedeelten van valleien. Daarnaast zijn de meer voorkomende, goed gedraineerde gronden toegevoegd om een completer beeld te krijgen en tevens om ze met de slechter gedraineerde gronden te kunnen vergelijken. Het studie gebied is geologisch te verdelen in een noordelijk gedeelte (Basement Complex) en een zuidelijk gedeelte (sediment formaties). Slecht en zeer slecht gedraineerd land beslaat 15 tot 19 procent van het land oppervlak (respectievelijk in het noordelijk en het zuidelijk gedeelte); voor de aanliggende, matig gedraineerde hellingen bedragen de percentages respectievelijk 22 en 6 procent.

Op enkele uitzonderingen na wordt slecht gedraineerd land niet gebruikt voor de landbouw. Wel wordt dit land type gebruikt om bosprodukten te verzamelen. Deze studie richt zich speciaal op de wijzen waarop landbouw bedreven kan worden op deze land types onder de huidige omstandigheden.

In de studie zijn twee methodes gebruikt:

- de groei van gewassen in functie van de locatie op toposequenties, in het bijzonder in functie van de drainage.
- de ecologische land geschiktheids classificatie, waarin land kwaliteiten gerelateerd worden aan de ecologische en landbouwkundige eisen van gewassen.

Na een inleidend hoofdstuk worden achtereenvolgens de sociale omgeving, de geologie, de hydrologie, de klimatologie en de natuurlijke vegetatie beschreven. Een apart hoofdstuk (3) is gewijd aan de beschrijving van de bodems en de bodemvorming. In het noordelijk gedeelte zijn negen bodemeenheden onderscheiden, in het zuidelijk gedeelte slechts vier.

Omdat de hydromorfe gronden centraal staan in deze studie, zijn de grondwater regimes en de fluctuaties van het bodemvochtgehalte van de bovengrond in een apart hoofdstuk (4) behandeld. Grondwater regimes zijn beschreven door middel van grondwaterklassen, die elk gedefineerd worden door de gemiddeld hoogste of laagste grondwaterstand gedurende een bepaald seizoen. Het vochtgehalte van de bovengrond en de grondwaterklasse leiden tot het karakteriseren van de vochtsituatie in de bewortelingszone per grondwaterklasse per seizoen.

De land kwaliteiten krijgen aandacht in hoofdstuk 5. Drie land kwaliteiten zijn van primair belang: de beschikbaarheid van water, de beschikbaarheid van zuurstof en de beschikbaarheid van voedingselementen (of natuurlijke vruchtbaarheid). Voor de beschrijving van de beschikbaarheid van water bleek een onderscheid in fasen binnen de bodemeenheden noodzakelijk. De "response" van stikstofkunstmest wordt behandeld als een aparte land kwaliteit, vanwege de belangrijke stikstof verliezen via denitrificatie, die op kunnen treden in hydromorfe gronden.

Additionele land kwaliteiten, die slechts van lokaal belang zijn, zijn de waarschijnlijkheid dat ijzer toxiciteit voorkomt (alleen voor rijst), de waarschijnlijkheid dat bodemerosie optreedt, de moeilijkheid van land bewerking en oogsten van knolgewassen en de (mechanische) belemmering van wortelontwikkeling. Behalve de beschikbaarheid van water, zijn alle land kwaliteiten beschreven op kwalitatieve wijze. De grondwaterklasse, tezamen met bodemkenmerken die deze beïnvloeden was in de meeste gevallen een belangrijke factor in de bepaling van land kwaliteiten.

In hoofdstuk 6 worden twee management niveaus gedefinieerd: traditioneel en verbeterd management. Het verbeterde management niveau verschilt slechts van het traditionele door enkele eenvoudige en relevante verbeteringen, vooral wat betreft bemesting en drainage en ook het aanleggen van afzonderlijke door dijkjes omringde en gedeeltelijk geëgaliseerde veldjes (of paddies) voor de verbouw van rijst. Het effect van management op de gradering van de land kwaliteiten is daarna beschreven.

In hoofdstuk 7 worden de gewassen (rijst, maïs, yam, cassava, bataat, cocoyam, cowpea, sojaboon, pigeon pea, tomaat, okra, celosia, paprika, banaan en plantaan) besproken in functie van groei en opbrengst op de volgende twee manieren:

- door middel van de verwachte opbrengst per grondwaterklasse. Opbrengsten van gewassen, die op toposequenties werden verbouwd, konden in verband gebracht worden met de grondwaterklassen; vier verwachte opbrengstklassen werden gebruikt. De toposequentie experimenten konden niet gebruikt worden om het effect van andere dan grondwater factoren op de groei van gewassen te isoleren.
- door middel van de eisen van gewassen met betrekking tot de land kwaliteiten. In het algemeen zijn slechts een gering aantal gegevens bekend over deze eisen, echter konden met behulp van de toposequentie experimenten en andere observaties vier ecologische geschiktheids klassen beschreven worden voor de diverse gewassen.

De verwachte opbrengst per grondwaterklasse en de ecologische geschiktheidsklasse, resulterend uit de eisen van de gewassen met betrekking tot de land kwaliteiten, worden met elkaar gecombineerd ("matching") (hoofdstuk 8). Het resultaat is de ecologische gewas geschiktheid voor een management eenheid, die berust op de combinatie van bodemeenheid, ev. fase, grondwaterklasse per (groei of klimatologisch) seizoen en management niveau.

In hoofdstuk 9, dat een specifieke toepassing van het voorgaande is voor het onderzochte gebied, worden de ecologische gewas geschiktheden van een aantal management eenheden besproken. Zevenentwintig management eenheden, verdeeld in elf groepen zijn geëvalueerd met betrekking tot de ecologische gewas geschiktheden. Alleen zeer geschikte en geschikte gewassen, waarvan een bevredigende opbrengst verwacht kan worden, zijn beschouwd. Ter vergelijking van de management eenheden is een ecologische gewas geschiktheids index samengesteld, waarin soort gewas, ecologische geschiktheid, lengte van groeiseizoen en het aantal geschikte gewassen per seizoen worden beschouwd. Enkele socio-economische gegevens met betrekking tot de ontginning van het natuurlijke of secundaire vegetatie bestand, de voorkeur voor bepaalde gewassen en de netto arbeidsproductiviteit worden besproken. Deze gegevens werden gebruikt in de evaluatie van de management eenheden. Het beste management niveau, namelijk datgene, dat resulteert in de hoogste ecologische geschiktheid, werd gekozen. Als de ecologische geschiktheid gelijk was voor beide management niveaus, dan werd het beste management niveau gekozen op basis van nevenfactoren zoals het soort gewas, de lengte van de periode tussen ontginning en verbouw, de frequentie van verbouw en de intensiteit van de onkruidgroei en de graad van hydromorfie in verband met de verbouw van rijst.

Wat betreft de verbouw van rijst op hydromorf land wordt meestal een hogere ecologische geschiktheid bereikt met het verbeterde management niveau. Het belangrijkste nadeel voor dit verbeterde management niveau echter is de relatief lage netto arbeidsproduktiviteit, vergeleken met die van het traditionele management niveau.

Uit het onderzoek blijkt verder dat het resultaat van de evaluatie van de goed gedraineerde hogere gedeelten van de hellingen overeenkomt met het huidige gebruik van deze gronden. Daarentegen dienen de resultaten voor de hydromorfe land types beschouwd te worden als een reeële evaluatie van het potentieel land gebruik. Van de hydromorfe en aanliggende land types hebben de zwaardere gronden een hoger potentieel voor landbouwkundig gebruik. De belangrijkste gewassen, die geschikt zijn op de laagste gedeelten van de valleien zijn rijst en (Colocasia) cocoyam; verdere geschikte droog-seizoen gewassen zijn tomaat, okra en sojaboon. De aanliggende iets minder hydromorfe land types, meestal voorkomend als een strook met een variërende breedte langs de lagere helling, hebben een hoog potentieel; vele gewassen zijn geschikt. Hoewel variabel over korte afstanden zijn de ecologische gewas geschiktheden op de lagere hellingen sterk afhankelijk van de grondwater regimes en de bodemtextuur.

1. INTRODUCTION

1.1 SCOPE AND PURPOSE OF THE STUDY

1.1.1 Background

The hydromorphic valley soils in south-western Nigeria, and in Africa in general, are underutilized, unlike similar soils in other parts of the world.

Obvious ways of increasing food crop production in West Africa are intensified land use and the introduction of cropping systems adapted to local conditions.

Traditional farming in the forest zone of south-western Nigeria takes place almost exclusively on freely drained soils. Poorly drained soils, however, occupy considerable areas. The only purpose they serve at present is to provide forest products, which are gathered rather than cultivated. Some cocoa is planted where drainage problems are less severe. Any farming system on poorly drained soils differs from that on well drained soils, so that the traditional farming system cannot be applied in intensifying the use of hydromorphic soils.

The climate of south-western Nigeria is characterized by a severe dry season of four to five months and a bimodal rainfall pattern, conditions that are not ideal for most annual crops. Irregular drought periods in the rainy season, besides the short dry season in the middle of the rainy season, severely affect drought-susceptible crops. Irrigation is unknown in the region and would probably be uneconomic in the existing farming systems on freely drained soils. In this respect, hydromorphic land has certain advantages over well-drained land. With proper management and suitable crops, its productivity can be relatively high and can be sustained without the need to revert to bush fallow.

Rice would be an obvious crop on hydromorphic land. Indigenous African rice (*Oryza glaberrima* Steud.) has been grown in West Africa for about 3000 years, and the central Niger floodplain is one of the early rice-growing areas in West Africa (Porteres 1976). *Oryza sativa* L. has only been cultivated since 1900, with expansion occurring locally from 1950 onwards (Buddenhagen 1977). Rice (*O. sativa* L.) is grown in one part of the study area, but mainly as a rain-fed crop. The importance of rice as a staple food crop is increasing in West Africa (Table 1.1). Production increased by 1.6 per cent annually from 1960 to 1970, with a consequent rise in consumption (De Boer 1974b). Other relevant crops for cultivation on hydromorphic soils are maize, yam, cassava, cocoyam, sweet potato, grain legumes, vegetables, and plantain/banana.

The major constraints to using hydromorphic valleys in south-western Nigeria are:

- the difficulty of clearing the vegetation
- the lack of knowledge concerning water management and water conservation
- the local farmers' lack of knowledge about the requirements of rice in new rice-growing areas.

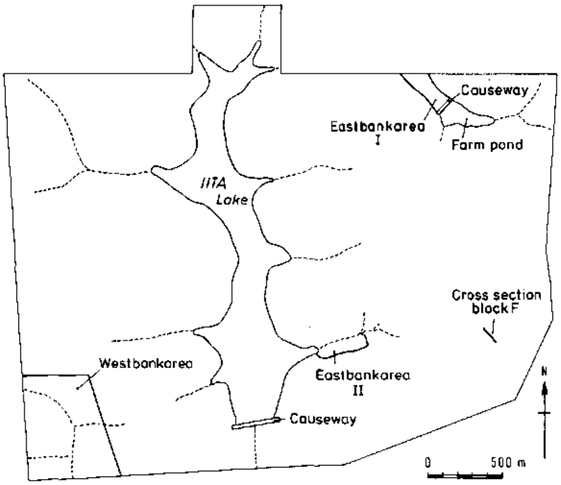


Fig. 1.2. Location of the Westbank area and the Eastbank areas I and II at IITA, Ibadan.

- the northern part, dominated by intermediate crystalline rocks of the Basement Complex, for which the terrain of IITA (International Institute of Tropical Agriculture) (7°29 N, 3°53 E) near Ibadan is representative, lying in the ecological zone of the drier forest (Murdoch and Moormann 1974). Three areas were studied in detail (Fig. 1.2): the area in the south-western corner of IITA known as the Westbank area, on the northern side Eastbank area I, and the area in the centre, Eastbank area II.
- the southern part dominated by sedimentary formations. An area near Ikenne (6°51 N, 3°41 E) (Fig. 1.1), also lying in the ecological zone of the drier forest, was chosen as being representative.

The south-eastern part of the study area, lying in the ecological zone of the wetter forest, has a somewhat higher rainfall (up to 2200 mm annually), but no experiments were done in that region.

1.1.4 Extent and use of hydromorphic land in the study area

Smyth and Montgomery (1962) surveyed a major part of the study area north of the boundary of the Basement Complex and sedimentary formations (Fig. 1.1). They estimated that poorly and very poorly drained valley-bottom land occupies about 15 per cent of the surveyed area and the adjacent, well-to-imperfectly-drained lower slopes, about 22 per cent. In the southern part of the study area, Moss (1957), found 19 per cent of very poorly and poorly drained land, and 6 per cent of imperfectly drained land.

Although rice had been a familiar crop along the coast since the 17th century, missionaries in the middle of the 19th century started to spread it into south-western Nigeria (Mabogunje 1959). Experiments in 1933, in tidal mangrove swamps, failed because of the laborious and costly clearing of the mangrove vegetation and the foreign nature of rice cultivation under these conditions. Since the introduction of rice mills in 1946, cultivation has increased, but mainly on well-drained soils. Swamp rice is found around Ofada, south of Abeokuta (Fig. 1.1). Moormann et al. (1975b) estimated that about 40 to 50 per cent of the rice in this area is dryland rice.

Apart from rice, the present use of hydromorphic land varies with the degree of wetness. Outside the urban areas, poorly drained soils are only used to a small extent for the gathering rather than the cultivation of products of oil palm (*Elaeis guineensis* Jacq.), raffia palm (*Raphia hookeri* Mann and Wendl.), cocoyam (*Colocasia esculenta* (L.) Schott and *Xanthosoma sagittifolium* (L.) Schott), plantain and banana (*Musa spp.*), bamboo (*Bambusa vulgaris* Schrad. ex Wendland), and for cocoa (*Theobroma cacao* L.). Cocoa is cultivated on hydromorphic land more in the northern part of the study area because of the longer dry season (Adejuwon 1970). Raffia palm (used for making palm wine and building materials) and bamboo (for building materials) occur specifically on hydromorphic soils. On the better drained lower slope soils, early maize occasionally is grown either as sole crop or interplanted with yam. The cultivation of early maize on these soils is increasing, mainly because of the high prices of green maize in May, when the bulk of the maize has still not been harvested. In urban areas, poorly drained soils, if utilized for agriculture, are used for sugarcane and vegetables, while maize, planted early in the growing season, is found on adjacent lower slopes.

1.2 PRESENT AGRICULTURAL USE OF HYDROMORPHIC LAND IN WEST AFRICA, COMPARED WITH OTHER REGIONS

1.2.1 West Africa

Agricultural use of hydromorphic land in West Africa mainly is confined to rice, sometimes with vegetables during the early dry season. Water management is hardly practised at all. Most rice is grown by subsistence farmers who produce yields of 600 to 1500 kg/ha; only 5 per cent is grown under improved production methods with yield levels of 3000 to 4000 kg/ha. According to de Boer (1974c) about 60 per cent of the rice cultivated in West Africa is rain-fed rice, 30 per cent is cultivated on flood plains (deep flooded and floating rice), 6 per cent in tidal freshwater swamps, and the remaining 4 per cent under irrigation.

Another important crop found locally on hydromorphic soils is yam, planted on mounds 25 to 100 cm high. Sweet potatoes or maize are sometimes grown on the sides of the mounds. Yam cultivated in this way is common in eastern Nigeria (Abakaliki-area), in the Makeni-area in Sierra Leone (van Vuure and Miedema 1973), and in the Lama Kara area in northern Togo (Moormann, personal communication). In the Cameroons, cocoyams are often grown on hydromorphic land.

1.2.2 Temperate zone

When hydromorphic land is to be used in the temperate zone, the land is adapted to particular crops, used as range land or pasture, or left under forest. Actually, no adapted crop - like rice in tropical regions - is available. In determining the agricultural use of hydromorphic land in temperate zones, the rate of decrease of groundwater in spring-time, due to the increasing evapotranspiration, is crucial. With appropriate management (especially drainage), hydromorphic land can become very productive for several cereals, legumes, and root crops. Even land formerly under the sea, such as the newly reclaimed polders in The Netherlands, can be made useful for agriculture. In general, while adapted cropping systems are available in the tropics, in temperate regions hydromorphic land, unless left as pasture, has to be adapted before cultivation.

1.2.3 Asia

In south and east Asia the main food crop is rice, where it is mainly grown on the wet soils of the lowlands or on other lowland soils which are less wet in their natural status, but on which an aquatic regime has been imposed by artificial water retention and irrigation. While rice can be grown under dry-land conditions in more humid areas, it is originally, and by Asian farmers' preference, mainly a "wet-land" crop (Moormann and van Breemen 1978).

Oryza sativa L. originated in the middle of central south-east Asia, from where it extended into the major river valleys, deltas, and coastal plains. These Asian lowlands are unique. The deltas and adjacent river plains of the Nile and the Niger are much smaller. Even the equatorial rivers, the Zaire and the Amazone, have smaller deltas, although the Zaire has large zones of wet lowlands in its middle course. Rice cultivation not only extended to natural hydromorphic land, but was continued to better drained soils where, by bunding and levelling of fields, paddies were made. Water, from either groundwater or rain, is conserved in this system. The following step in development was irrigation (Moormann and van Breemen 1978).

In general, the Asian rice farmer considers land- and water management important practices. This is the big difference between Asia and Africa as far as the use of hydromorphic land is concerned. In Asia, the dominance of rice as a food crop has strongly influenced the preference for farming on hydromorphic land, while in Africa rice has never been an important crop. With the exception of cocoyam, no adapted crops have been cultivated in Africa. Therefore, only reasonably well-drained soils have been cultivated. The result is that, with the extension of land use, the African farmer occupies land downslope, while the Asian farmer moves upslope.

1.3. ATTITUDE OF THE LOCAL FARMERS

1.3.1 General attitude to agriculture and to changes in farming practices

Webster and Wilson (1966) see the development of sounder and more productive land use as being merely dependent on technical improvements, which require people to abandon their traditional customs; instead, a commercial attitude towards the raising of crops for sale and profit must be developed. Apart from a change in agricultural techniques, a process of general education and guided social change is necessary.

Faulkner and Mackie (1933) stated that in traditional farming, as in the study area, labour is often the major limiting factor to any change. Also, capital to buy fertilizers, machinery, etc., is often lacking and even land may be scarce. Any new technological item, if cheap, simple, and available, can be included, but has a greater effect if it reduces the labour input. The traditional farming methods are mainly suited to the local land conditions, but also to the farmer's economic position, his social circumstances, his personality, and his taste. He gets a maximum return for a minimum of labour and he prefers a slower method to a quick one that involves harder work for a shorter period.

Besides farming, much time is spent on other matters. Galletti et al. (1956) during a survey in 1951/52 found that among cocoa farmers in the study area (of the main tribe, the Yoruba) festivals and ceremonial obligations took 6.4 per cent of their time, social obligations and business 15.6 per cent, work on other farms or in trade and crafts 31.6 per cent, and illness 11.4 per cent. So only 35 per cent is actually spent on their own farms. Besides one normal free day a week, another day was spent on "extra" leisure (bad weather or no work available at the time are included as leisure). They also described what the Yorubas think about social obligations and leisure:

> "Among the incentives to effort is the desire to earn money with which ceremonial functions such as marriages, funerals, and festivals can be conducted in a socially acceptable way or even with a lavish display augmenting the family's prestige. When money cannot be earned or is insufficient for these purposes the Yorubas will borrow rather than incur a reputation for meanness or nonconformity. Gifts to friends and strangers also form a part of the acceptable social pattern and must find a place in the family budget, but these are in due course reciprocated and have less economic importance.
> The desire for leisure may have different roots. The desire to celebrate ceremonials and entertain friends is obviously one of them. The climate, which makes long hours of arduous labour unenjoyable, is another. There is not yet evidence from psychological and social studies to show whether the Yorubas have any temperamental aversion from labour, or evidence from economic studies to show whether they will prefer increased leisure to increased income when prices become more favourable and a certain amount of real or money income is more easily earned. What does appear to be sufficiently established is that Yoruba farmers and their families like a working day of moderate length and many days or even weeks of idleness and festivity during the year..... It is possible and consistent with observations made during the survey that Yoruba farmers prefer leisure to any increase of income they might achieve by working much more than their accustomed hours in the day and days in the year".

Another effect of change could be that, as education is improved, children are taken off the farms and that this is negatively felt by the farmers. Children are very useful and cheap to use as bird scarers in rice cultivation. As in Europe in the past, school holidays take place during busy times on the farm.

1.3.2 Specific attitude to hydromorphic land use

The use of hydromorphic land will involve a basic change in agriculture. Hydromorphic land is hardly included at all in the existing farming system. Two main factors determine the attitude of the traditional farmer towards hydromorphic land use:

- the different farming practices involved because of the hydromorphic character of the soils.
- the clearing of the existing vegetation and at the same time the abolishment of the gathering forest products (cf. Section 1.1.4).

The traditional land use system, involving yam, cassava, and maize as main crops, is completely adapted to the ecological conditions. Crops, such as swamp rice and vegetables, mean for the farmer a knowledge of farming different from his traditional knowledge. In rice-farming, special problems arise in the necessary cropping practices of water management, transplanting, weed control, and fertilizer application, as well as in post-harvest practices like threshing, drying, and milling. In addition, attacks by birds and rodents may seriously damage crops, especially in the early stages of hydromorphic land development. Vegetables, when grown as cash crops, need special care, and harvesting and marketing problems can arise. In general, a strict discipline is needed in hydromorphic land use if all the necessary practices are to be performed. Development in stages, by which the farmer can learn gradually, is important.

Because hydromorphic land is scarcely cultivated at the present time, any farming on such land must start with the clearing of the natural vegetation. This vegetation can be very old and can consist of high trees. Heavy machinery cannot be used when the soils are wet, because of their generally low bearing capacity. Therefore, it is only at the end of the dry season, if the groundwater is sufficiently deep, that the use of heavy machinery is possible. Usually, however, clearing is done by hand using simple tools such as matchets and axes. Chain-saws and winches are sometimes used. Not only the felling of trees is laborious, if done by hand, but also their removal. Bigger trees are sawn up and burnt. Very high trees are left standing, because their felling and removal cause too many problems. The light interception of very high trees does not severely affect the crops below. On the other hand, they obstruct machines and use nutrients that would otherwise benefit the crops. As observed in other areas like Sierra Leone and Abakaliki in eastern Nigeria, however, clearing does not necessarily form a seriously limiting factor, and there is a progressive tendency to enlarge clearings once the process has started.

The abolishment of gathering forest products is not severely felt by the farmer. Raffia palms and bamboo are often found in the valley-bottom land and the cultivation of some of this land does not mean a serious decrease in these products. Moreover, the farmer can include these plants or trees in his cropping system.

There are side factors involved in farming on hydromorphic land. Working on wet or flooded soils is difficult. Relatively more insects live near wet places, causing diseases which originate in swampy areas. In the study area, malaria is very common. Billharzia seems to be present in some areas but was not observed by the author. River-blindness does not occur in the study area, but it is known in the area west of Iseyin (Moormann, personal communication).

Mabogunje (1959) reported that in inland swamps such as the Ofada area, rice cultivation is strongly associated with young farmers, who make the change from their traditional farming environment more easily than the older farmers. Because those swampy areas are very localized, these young men often have to move into areas not necessarily belonging to their village. This gives rise to an "alien farmers problem", which finds expression in the opposition of autochtonous people against them and local rules against the planting of rice.

In Senegal, the cultivation of rice meant a change in the distribution of labour in a way that women became more involved in actual farming (Moormann, personal communication).

In general, as found by Zuckermann (1973), investment in agriculture has a low priority in the study area; farmers attach a much higher priority to non-farm investments, especially housing, education, and trading. It must be expected that the high initial costs of the development of hydromorphic land cannot be paid by the farmer or that he is not willing to invest his money in this kind of development. Spreading the development over a number of years or by subsidizing would facilitate any development.

Apart from food crops, Flinn et al. (1974) pointed out that the average return per man-day devoted to tree crops such as cocoa, kola, etc., (normally grown on well-drained land) is as much as twice that obtained from traditional food crops. When asked to array crops on the basis of profitability, farmers in areas where cocoa can be grown invariably rank it at the top.

2. GENERAL SETTING OF THE STUDY AREA

2.1 SOCIAL ENVIRONMENT

2.1.1 History

The Yorubas form by far the most representative tribe of south-western Nigeria. According to tradition their history began at Ife (Fig. 2.1) after their immigration from somewhere in the eastern Sudan zone (Ajayi and Smith 1964). Ife was founded in about

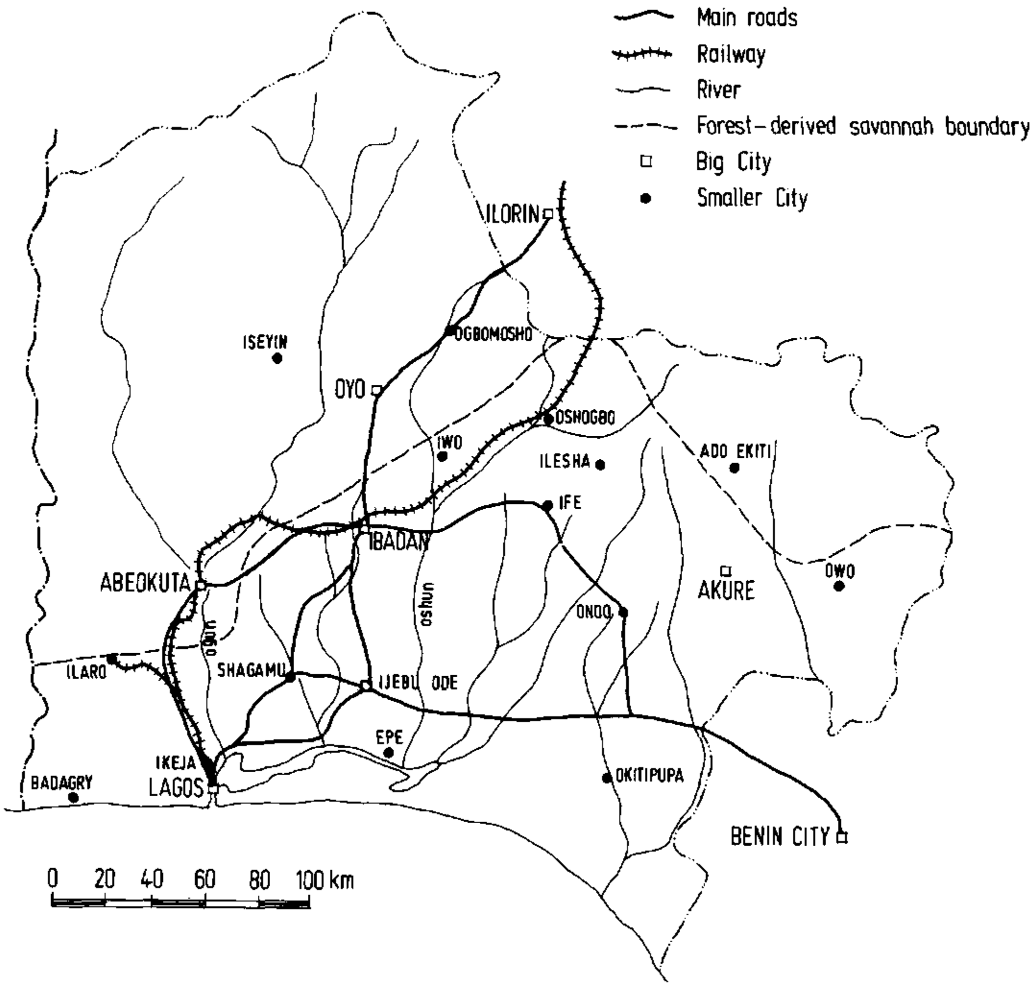


Fig. 2.1. Towns, main roads, main rivers, and the railway in the study area.

1000 A.D. Most of the Yorubas lived in the derived savanna zone, north of the forest zone. Important kingdoms such as those of Oyo (Old Oyo or Katunga) in the derived savanna and Benin in the forest zone have existed for a long time. Old towns such as Ife and Ilesha are just within the forest zone (Morgan 1972).

In the 17th century, Portugese traders introduced maize, cassava, groundnut, sweet potatoes, tobacco, and various fruits to the area (Udo 1970). Of these crops maize and tobacco spread rapidly. Maize became one of the main crops in the derived savanna and an important second crop in the forest zone. Cassava did not spread so rapidly since yam was the preferred indigenous root-crop. In the 17th and 18th centuries a trade in palm oil and palm kernels began.

The kingdoms disintegrated at the end of the 18th century and Oyo was invaded by the Fulani tribe at the beginning of the 19th century. The Yorubas moved southwards into the forest zone, where a number of towns sprang up in a short time (Adejuwon 1970). On the northern edge of the rain forest a new capital of Oyo was founded, but its importance declined rapidly and political power shifted to new cities in the forest zone, such as Ibadan, established around 1820.

Most of the larger Yoruba towns are grouped in an area of about 35 km wide in the forest zone, which follows the derived savanna rain forest boundary quite closely. These towns are therefore also concerned with the interchange of savanna and forest produce together with other forms of exchange (Morgan and Moss 1972).

The southward shift into the forest was accompanied by a number of civil wars, which kept people in or close to the towns during the 19th century. The wars ended at the beginning of the colonial period towards the end of the 19th century. Roads and a railway were built and inter-regional trade developed. Agricultural export production increased rapidly; firstly wild rubber (*Funtumia elastica* and the vines *Landolphia* and *Clitandra*), together with the already existing oil palm trade, followed by cocoa, coffee, kola (*Cola nitida*), and Hevea rubber (*Hevea brasiliensis*). Oil palm as a plantation crop is nowadays found east of the study area, where the annual rainfall is higher. Cocoa is now the most important export product from south-west Nigeria. The forest reserves are important for timber extraction. The different cash-crop belts and the forest reserves are shown in Fig. 2.2. Nowadays the acreage under kola shows an increasing trend at the expense of cocoa. Kola is more tolerant to poor soil conditions and is mainly grown on soils derived from sedimentary rocks. In most of the cocoa-growing areas, kola was initially planted along with cocoa, but its greater vigour and stature gradually helped it to oust the latter (Mabogunje and Gleave 1964).

2.1.2 Demography

Adegeye et al (1975) gave population density figures of the five provinces of the Western State in 1970 (Table 2.1). The Oyo province, mainly in the savanna zone, shows a lower density than the other provinces, which are situated more or less in the forest zone. The density of the Ibadan province is relatively high, due to the presence of the big city of Ibadan, with an estimated population of about 2 to 2.5 million. Most people in the study area are Muslims or Christians.

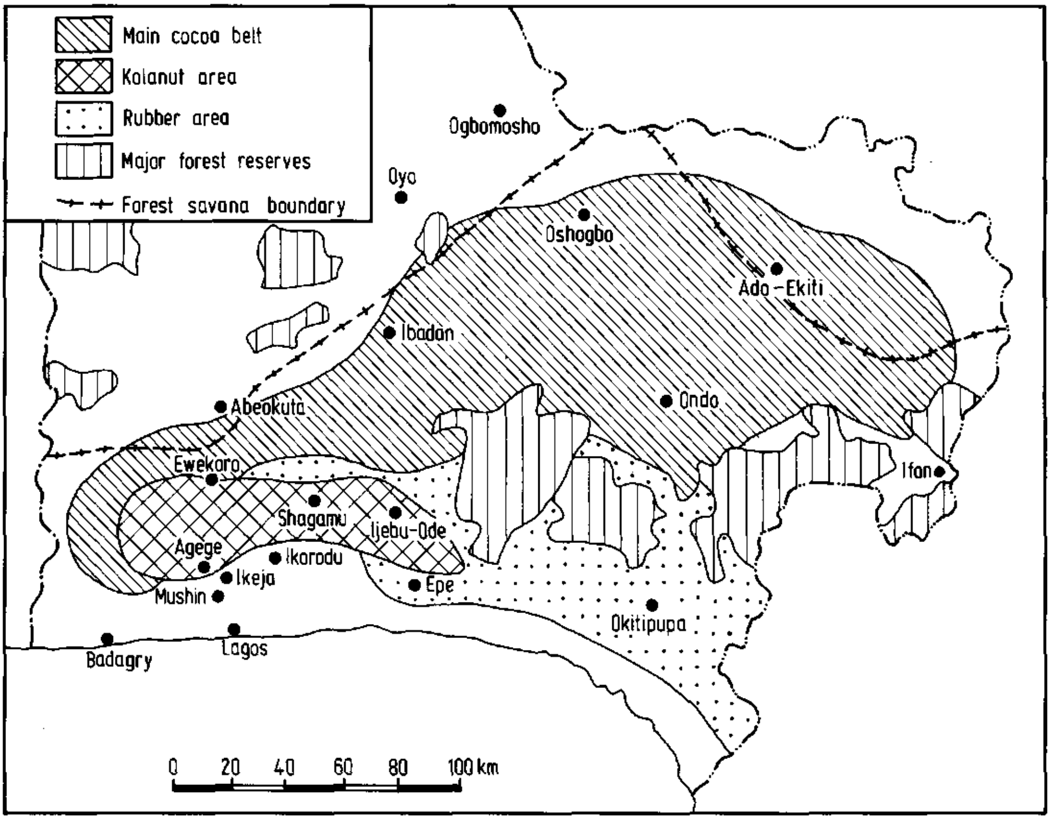


Fig. 2.2. Cash crop belts and forest reserves in the study area. Source: Udo (1970).

Table 2.1. Population density of the Western State in 1970 (after Adegeye et al. 1975).

Province	Inhabitants/km^2
Abeokuta	118
Ibadan	353
Ijebu	123
Ondo	176
Oyo	99
average	165

Bath and Adeogun (1966) estimated that 80 per cent of the total population of the study area i. ..ade up of farm families. The Yorubas, however, are much more urban than most other A.'rican peoples. In 1952, 48 per cent of the population lived in settlements with over 5000 inhabitants and 23 per cent in towns with over 50,000 (Udo 1970). These percentages have probably increased since then, as a rapid population increase in cities such as Lagos, Ibadan, and Abeokuta can be observed.

Because of the custom of most Yoruba farmers of living in small or large communities, two types of farm lands exist, one in the vicinity of the settlement (within 6 to 10 km) and the other in the forest or bush at greater distances from the living quarters. Some farmers live on the land during the farming season, returning to the town only during the weekends.

The Yorubas have a strong sense of community and kinship. The strongest ties between individuals are those within the family, a unit which normally consists of a man with one or more wives and their children. For different social and economic reasons, a group of elementary families form an extended family of a much larger size, which retains its unity in the holding of land. The heads of these extended families descend in the male line (Galletti et al. 1956).

There is a clear division of labour between the men and the women. The head of an elementary family is the farm operator. If he is a cocoa farmer, he, together with his unmarried sons, is engaged in cocoa farming and trade, and to a variable extent with food production, both for sale and for family consumption. The women are mainly occupied with housework, including home industry, but also with the processing and selling of palm products, gari (a cassava product), maize, and beans. They are not really involved in the cultivation and harvesting of crops. On large holdings hired labour is common.

According to Adegeye et al. (1975) in a study on the Ondo area, there is an increasing investment trend in agriculture by part-time farmers, who live in town and have labourers to do the actual farming. Since these part-time farmers have better access to information, they often bring useful innovations to farming in the area.

During the past century, much of south-western Nigeria has changed from appropriated forest land to settled and cultivated land over which families and individuals claim exclusive rights. Due to the increasing population, the extent of land available for each family and each farmer has been declining. Increasing demand for land occurred after the opening of export markets and the exploitation of large areas for cocoa. Through inheritance in the large families, a constant subdivision and fragmentation of family holdings takes place. Purchase and rent of land is not a custom in Yoruba land, although in recent years the common way of obtaining land has been by way of an outright gift from another family, which has forest land in excess of its own needs; on the other hand there may be possibilities for borrowing a farm for temporary or permanent occupation or, where allowed, purchase of land. However, when a man borrows land, he is in the position of a tenant, even if he does not pay any rent. In the other two ways of obtaining land, the rights of the occupant are the same as those of the former owner.

Land tenure is not specific for hydromorphic land and follows the general trend of fragmentation in the area, which may be one of the socio-economic constraints to development and water management in the valleys.

In general, farm sizes are small. Zuckermann (1973) gives the distribution pattern for a village in the cocoa belt near Ife, and Adegeye et al. (1975) give figures for the Ondo-division, both in areas on the Basement Complex (cf. Fig. 1.1) (Table 2.2).

2.1.3 Transport and internal accessibility

The transport system of south-western Nigeria (Fig. 2.1) consists of roads, a railway, some rivers, a seaport (Lagos), an international and a local airport (Lagos and Ibadan, resp.). Transport of goods is mainly by lorries and by head loading. Major roads between such cities as Lagos, Abeokuta, Ibadan, and Ijebu-Ode are in good condition and

Table 2.2. Distribution of farm sizes for two locations on the Basement Complex.

village near Ife[1]		Ondo-division[2]	
size (ha)	per cent	size (ha)	per cent
less than .75	6	0 - 2	41
.75 - 1.50	43	2 - 4	20
1.50 - 2.25	24	4 - 6	14
2.25 - 3.00	15	6 - 8	8
more than 3.00	12	more than 8	17
	100		100

1. After Zuckermann 1973.
2. After Adegeye et al. 1975.

suitable for heavy transport from the north or from the seaport. Most minor towns are linked by asphalt roads. Most villages can be reached by lorries ("mammy-wagons") in spite of the often bad condition of the unhardened roads. There are no draught animals in the area, owing to the presence of the tse-tse fly. The major rivers, the Oshun and the Ogun, are only used for canoe transport. The single railway is rather inefficiently used, but could relieve a great part of the north-south transport, which at present mainly takes place by road.

Hydromorphic land is generally very poorly accessible. The road system, especially the secondary and tertiary roads, is in no way adapted to the use of hydromorphic land. Near the villages, narrow unhardened roads may lead to waterholes in the valleys. Footpaths sometimes cross valleys, but often avoid the wet places; this is also caused by the farming system, which is exclusively based on well-drained land. In Sri Lanka, where there is a comparable physiographical situation, accessibility is considerably better. Before any development of hydromorphic land, roads towards and along the valleys must be established. This means another direct constraint to development.

2.2 GEOLOGY

2.2.1 Introduction

Geologically the study area is divided into a northern and a southern part. The formation in the northern part is of Pre-Cambrian age and belongs to the Basement Complex, which forms large shields on both sides of the Niger river, belonging to the African crystalline shields (Jones and Hockey 1964). To the south it is covered by marine and continental sediments of Cretaceous and Tertiary age (Fig. 2.3). The study area is gently to strongly undulating and descends gradually to the south, with the exception of two cuestas. The northern part is in general more hummocky and has a closer drainage pattern, whereas the southern part is flatter and more swampy.

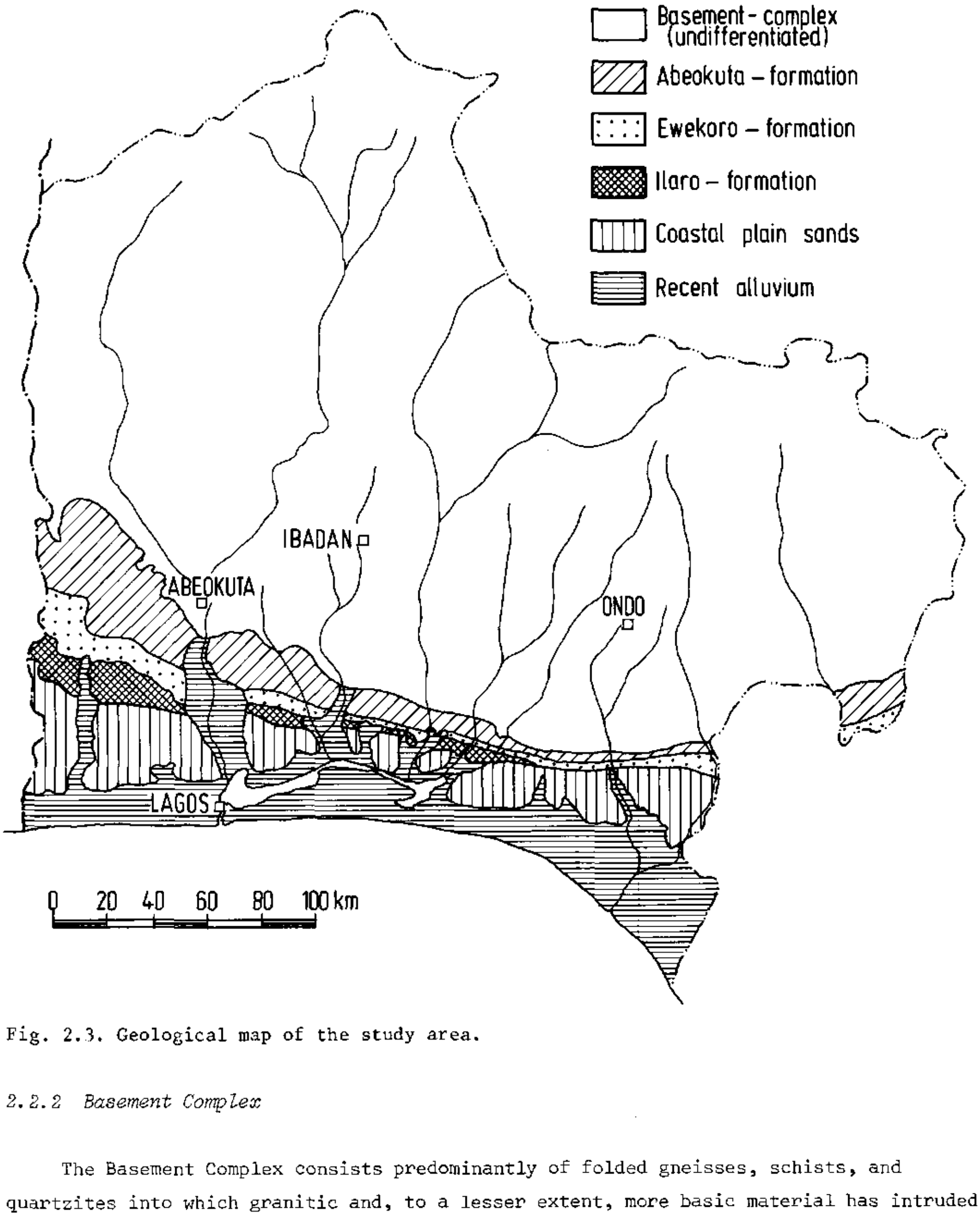


Fig. 2.3. Geological map of the study area.

2.2.2 *Basement Complex*

The Basement Complex consists predominantly of folded gneisses, schists, and quartzites into which granitic and, to a lesser extent, more basic material has intruded. The gneisses are considered to be of sedimentary origin and are metamorphosized to a varied extent. Biotite gneiss and biotite hornblende gneiss (together known as banded gneiss), mica schists, and amphibolite schists are the most common gneisses and schists. Quartzites appear as long ridges, which form distinctive topographic features. Of the granitic rocks coarse porphyritic gneiss and granitic gneiss are the most common. Amphibole-rich rocks are common in the area, but their extent is relatively small. Quartz veins occur in all rocks throughout the area and may be locally abundant (Jones and

Hockey 1964).

Freeth (1971) indicated three major rock types in the IITA area, notably banded gneiss with associated schists, granite gneiss and quartzites and quartz schists. On average, banded gneiss and associated schists form the bedrock in 80 per cent of the IITA area, followed by quartzite (15 per cent) and granite gneiss (5 per cent).

The banded gneiss is a grey quartz-biotite-plagioclase-hornblende paragneiss which weathers readily so that outcrops are few. It is a metamorphosized sedimentary rock, probably graywacke, of Pre-Cambrian age. The main minerals in banded gneiss are quartz, plagioclase, alkali feldspars, biotite, and hornblende. The average chemical composition of banded gneiss in the Ibadan area is given in Table 2.3. Considerable variation in composition is found between the alternating lighter and darker components.

The granitic gneiss is a hornblende-biotite granite orthogneiss, intruded in the Pre-Cambrian bedrock at a considerably younger period. Because of its resistance to erosion, it frequently forms inselberge and well demarcated ridges. Small bodies, often visible in the terrain as rock outcrops and rock ledges, accompany the main intrusions. The main minerals in the granite gneiss are quartz, orthoclase, albite and ferro silicates. Table 2.3 gives the average chemical composition.

The quartzites and quartz schists, being more resistant to erosion, often form prominent ridges. The age of these rocks is similar to that of the banded gneiss. Freeth (1971), on the basis of many analyses, distinguished two groups, the average mineralogical compo-

Table 2.3. The chemical composition of banded gneiss and granitic gneiss in the Ibadan area (Freeth 1971).

	banded gneiss		granitic gneiss	
	range (per cent)	average	range (per cent)	average
SiO_2	61 - 69	64	72 - 75	73
Al_2O_3	15 - 18	16	12 - 13	12
Fe_2O_3	1.7 - 3.2	2.0	0.6 - 1.8	0.9
FeO	2.1 - 3.5	2.8	1.5 - 3.2	2.3
MnO	0.05 - 0.10	0.07	0.03 - 0.05	0.04
TiO_2	0.3 - 0.9	0.6	0.1 - 0.3	0.2
CaO	2.7 - 5.2	4.0	1.1 - 1.4	1.2
MgO	1.2 - 2.3	2.0	0.10 - 0.12	0.11
K_2O	1.6 - 2.8	2.5	5.6 - 6.4	6.2
Na_2O	4.0 - 6.3	4.8	2.2 - 2.6	2.4
P_2O_5	0.1 - 0.5	0.2	0.01 - 0.05	0.02

Table 2.4. The average mineralogical composition of two groups of quartzite rocks in the Ibadan area (Freeth 1971).

	per cent	
quartz	99	88
alkali feldspar	0	2.3
muscovite	0.93	2.5
biotite	0.02	6.1
others	0.05	1.1

sition of which is given in Table 2.4.

The dominant land forms of the northern part of the study area are gently inclined pediments and steep residual hills (Burke and Duratoye 1971). The hills show a north-south trend according to Smyth and Montgomery (1962), reflecting the general strike of the underlying rocks. In the pediment plain a drainage pattern was incised, forming a trellis pattern. During the Pleistocene, rejuvenation of the drainage system eroded the pediment plain near the rivers. At present, small streams are actively cutting back, leaving small remnants of the pediment plain. Within a few hundred metres of a river, gentle pediment slopes (less than 1 per cent) change to much steeper slopes (up to 8 per cent, but an average of 4 per cent) and the river occupies a narrow valley. As a result, the major rivers have narrow flood-plains. In areas with basic rocks the valley slopes are steeper than on the Basement Complex.

The general topography of the IITA area is rolling, with dominant slopes of between 3 and 10 per cent. Flatter parts with slopes of 1 per cent or less are confined to some of the wider valley bottoms and to the upper parts of the ridges and plateaus. Rarely do these flat-to-gently-sloping uplands occupy consolidated areas of more than 5 ha. Steeper slopes of up to 25 per cent are quite common.

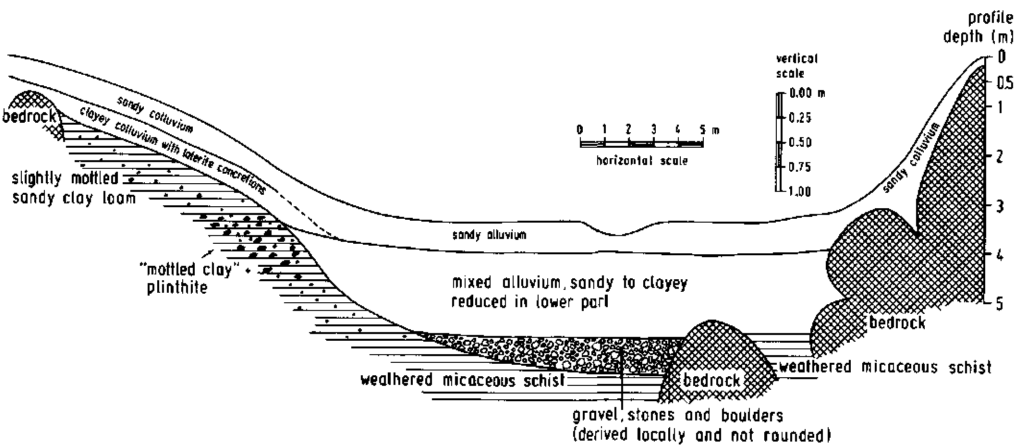


Fig. 2.4. Cross-section through a valley at IITA (cross-section block F).

Although the overall drainage system of rivers and streams is mature, the valleys themselves are young, as witnessed by the rocky stream floors in many rivers, and by the generally thin layer of sediments in most valleys. The major river valley at IITA (Fig. 1.2) showed a maximum deposit of slightly more than 3 m of alluvial sediments over weathered bedrock. A similar depth was found in a side valley (Fig. 2.4). The basis of the alluvial sediments is formed by a gravel layer; the other alluvial fill of the valleys varies widely in texture.

2.2.3 Coastal sedimentary formations

During the end of the Cretaceous period, the sea gradually invaded the coast of West Africa (Slansky 1962). At the same time weathered detritus, containing mainly quartz sand and kaolinitic clay, was transported to the coasts from inland. During this period, different modes of deposition are recognized: fluvial, estuarine or coastal, and lagoonal or deltaic deposition. The Cretaceous and Tertiary sediments overlying the Basement Complex in the southern part of the study area consist of the following formations, as distinguished by Jones and Hockey (1964):

- Abeokuta formation (Upper Senoon)
- Ewekoro formation (Paleocene)
- Ilaro formation (Eocene)
- Coastal Plain "Sands" (Oligocene-Pleistocene)

Fig. 2.5 shows the stratification of these formations from Ikenne southwards. The Abeokuta formation consists mainly of sandstones with more clayey rocks in the middle of the formation, in which a transition from continental to marine deposition is shown. The Ewekoro formation is a marine deposition, consisting of limestone overlain by shales. The Eocene and Post-eocene succession as a whole was deposited in a basin whose northern shore retreated southwards during the Tertiary; they consist of shales and sandstones. The Coastal Plain "Sands" are mainly clayey sands and sandy clays, which are locally pebbly and poorly sorted. Deposits from Ikenne southwards include a recent cover of Plio-Pleistocene Coastal Plain "Sands" materials. The transition between the Plio-Pleistocene cover and the older formations is frequently characterized by an ironstone (laterite) formation varying from a thin ironstone pebble layer to a thick laterite pan (Fig. 2.6). The latter,

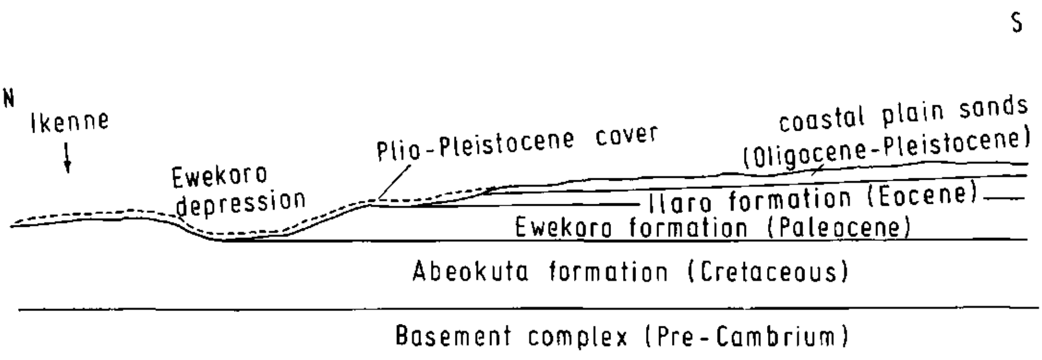


Fig. 2.5. Idealized geological cross-section from Ikenne south towards Lagos lagoon.

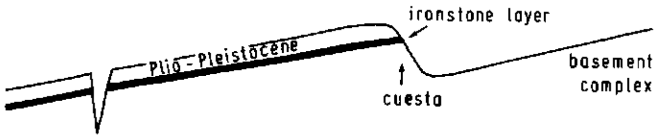


Fig. 2.6. Occurrence of ironstone layer at transition of Plio-Pleistocene and underlying older formations.

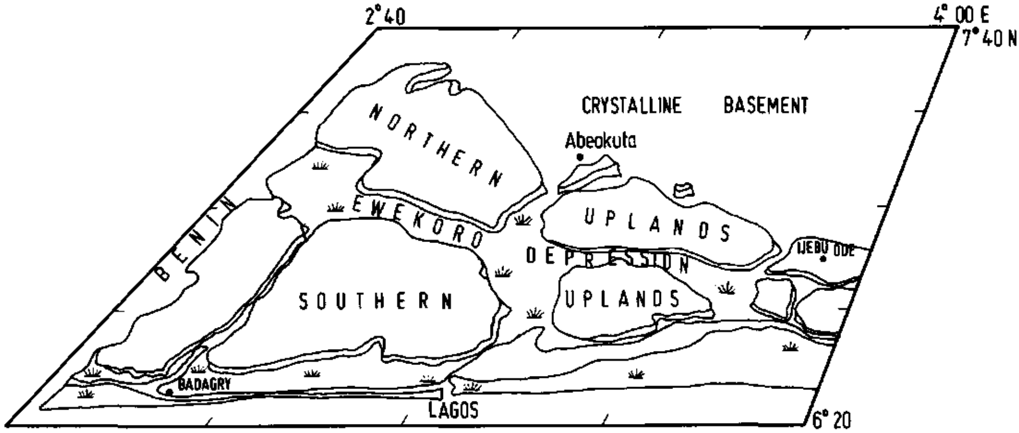


Fig. 2.7. Relief of southern part of the study area. Source: Jones and Hockey (1964).

which can easily be seen on the steep sides of the cuesta, was reported by Fauck (1972).

The northern part of the coastal sedimentary area consists of flat to gently undulating plateaus rising to a maximum height of 230 m, dissected by deep V-shaped valleys. Southwards it falls away to a low-lying marshy belt situated about 30 m above sea-level (Fig. 2.7). This is the Ewekoro depression which is bounded to the south by a low, gently sloping, dissected escarpment of the southern uplands. These southern uplands reach a maximum height of 130 m and drop gently southwards to the coastal plain. The drainage system is usually deeply incised. The southern limit is often sharply defined by a step about 15 m high, rising above the coastal strip which stands only a few metres above sea level. The low-lying coastal strip and the extensive alluvial plain of the major rivers are topographically similar to the Ewekoro depression (Jones and Hockey 1964).

The upland soils in the Ikenne study area are formed in the Plio-Pleistocene cover on top of the older formations. Slansky (1962) gave the chemical composition of the Coastal Plain "Sands" (brown, fine clayey sand, sampled at 15 m depth at Bopa, Rep. of Benin) (Table 2.5).

Table 2.5. The chemical composition of Coastal Plain Sands (after Slansky 1962) (percentages).

SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+CO_2	P_2O_5	MnO
56.9	13.4	11.9	-	1.4	0.4	0.2	2.1	14.4	0.3	trace

2.3 HYDROLOGY AND LAND FORMS OF VALLEYS

2.3.1 Hydrology

A major watershed exists north of the study area (Fig. 2.8). South of this watershed all major rivers flow southwards to join the coastal lagoons.

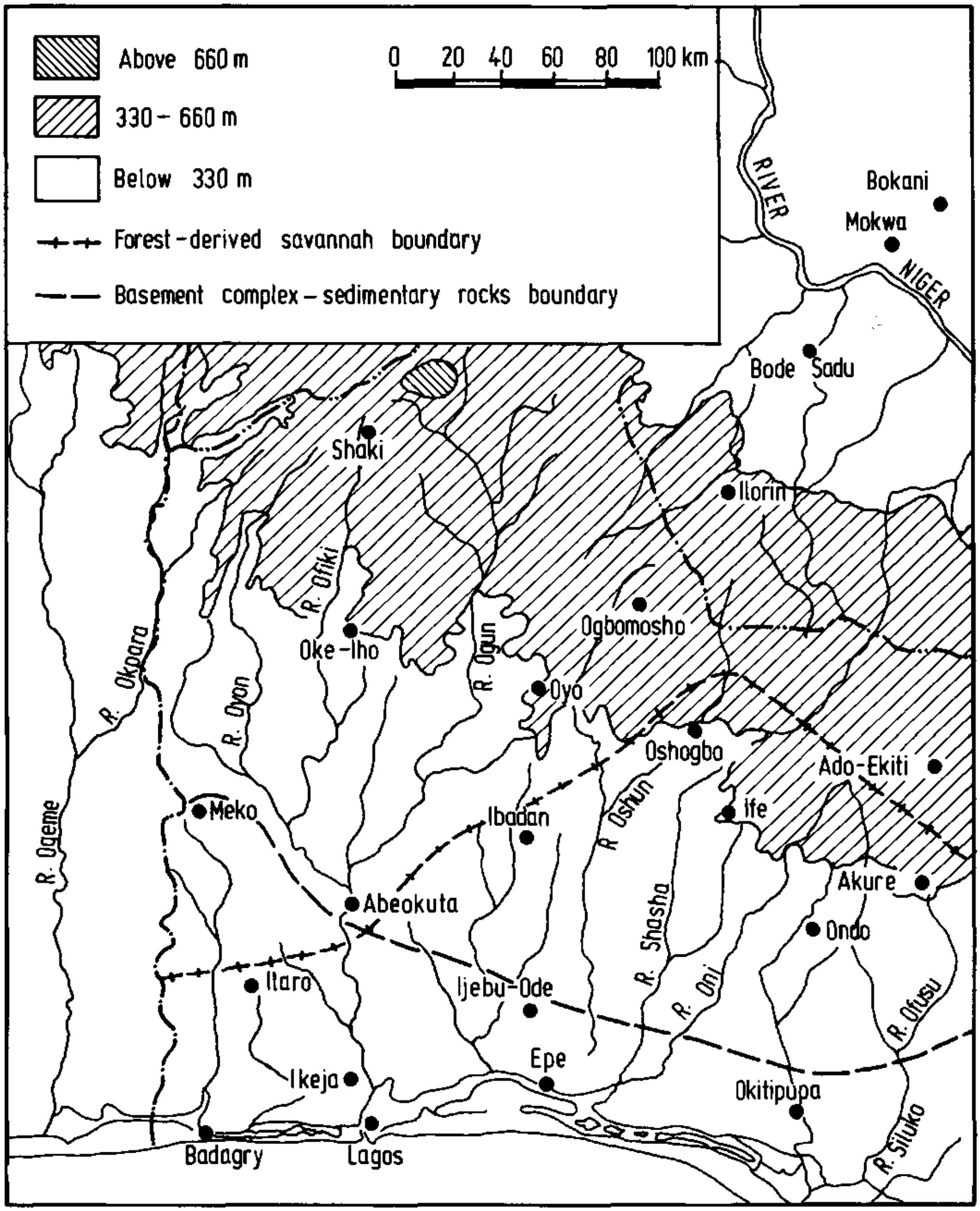


Fig. 2.8. Main rivers in south-western Nigeria and location of the main watershed, north of the study area. Source: Udo (1970).

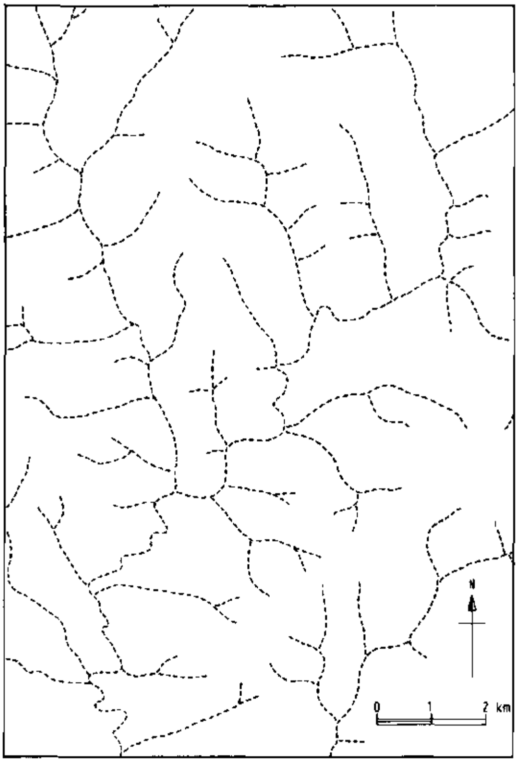


Fig. 2.9. Drainage system on Basement Complex formations; Ibadan-IITA area.

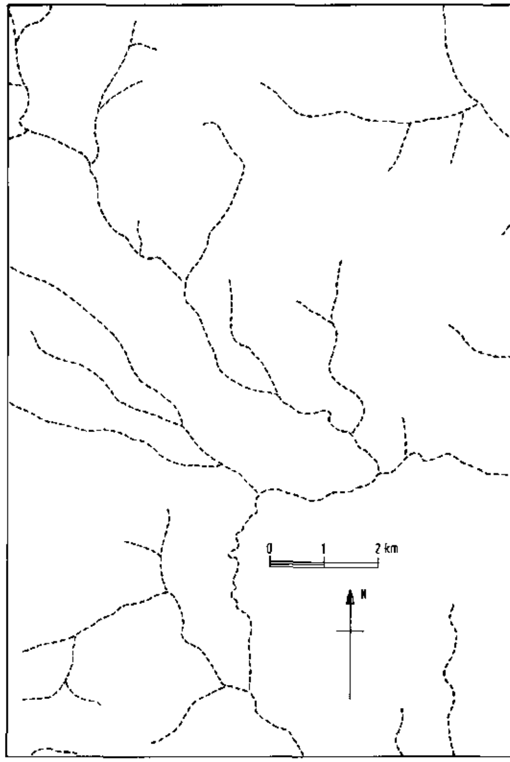


Fig. 2.10. Drainage system on sedimentary rock formations; Ikenne area.

In the Basement Complex area, the stream direction is largely controlled by the trend of the foliated rocks and by jointing, particularly on the more resistant rocks. These two factors impose a trellis pattern upon the minor drainage. Where the underlying rocks are deeply weathered, a dendritic pattern unrelated to the structure results. Smaller streams, although controlled by geological structure, have seldom cut down to fresh rock, but the bigger ones have stripped off the weathered zone over considerable distances (Jones and Hockey 1964). Fig. 2.9 shows the drainage pattern in the Basement Complex area, in particular the area between the city of Ibadan and the IITA site. Burke and Duratoye (1971) stated that some rivers and parts of others, such as the Ogun, flow from north-east to south-west. This direction is not structurally controlled by the Basement Complex; the explanation for this direction might be a possible cover of Cretaceous and Tertiary in which this trend was developed.

Low drainage densities within the range of 0.5 to 1.5 km/km^2 have been found on the Basement Complex (Wigwe 1966 and Jeje 1970, as stated by Thomas 1974). Nye (1954) stated that such low densities probably reflect the widespread occurrence of deep regoliths with infiltration capacities high enough to absorb a large proportion of the precipitation. According to Moormann et al. (1975a), however, sizeable aquifers in the Basement Complex are rare. Infiltration water seeps down and subsequently moves to the valleys without forming a general watertable in the higher parts of the landscape. Shallow groundwater may only be found in localized fractured strata of faults and in places where the impervious subsoil or bedrock forms a trough.

The main rivers normally run the whole year with a variable flow, but the smaller ones are intermittent. Small streams are dry for a certain period each year and the smallest ones may flow only for a few weeks during the latter part of the rainy season (Smyth and Montgomery 1962).

The Cretaceous escarpment on the boundary with the Basement Complex forms a divide of some importance, although it has been crossed by a number of streams in addition to the main rivers. The drainage pattern on the sedimentary rocks is markedly different from that on the Basement Complex. On the northern uplands of the sedimentary rock formation area, rivers are relatively widely spaced and deeply incised in a southern direction. Fig. 2.10 shows the drainage pattern in the sedimentary rock formations, in particular the Ikenne area. In the Ewekoro depression, much of the ground is waterlogged for part of the year and streams draining the higher grounds lose their identity in swamps and networks of creeks. The drainage pattern on the southern uplands is closer than on the high grounds to the north as there is more surface run-off owing to the higher proportion of impermeable strata in the underlying sediment (Jones and Hockey 1964). Moss (1961) reported densities of streams in the southern part of the study area ranging from 0.37 to 1.05 km/km^2 with an average of 0.62 km/km^2.

2.3.2 Land forms of valleys

The land forms of valleys can be described by five main characteristics:

- topography of surrounding landscape and the valley system
- length-profile characteristics
- cross-profile characteristics
- hydrology characteristics such as drainage, duration of high groundwater levels, amount of water passing a valley, and the eventual excess of water
- soil characteristics such as textural profile, soil drainage, and other specific soil characteristics such as high Fe-contents, salinity, or nutrient deficiencies.

The length and cross-profile characteristics of valleys in the study area will be discussed in this section. The characteristics of topography have been dealt with in Section 2.2. Those of soils and hydrology will be treated in Chapters 3 and 4, respectively.

The length-profile characteristics of a valley are its form and its overall slope. The form of the valley may be smooth or stepped. Stepped valleys are common on the Basement Complex; they occur when harder and softer rock formations alternate on the surface when the valley is situated across the strike of the rocks. On sedimentary rocks only smooth valleys are found. The overall length-slope of the valleys is very gentle owing to the gradually descending level of the land towards the ocean.

The cross-profile of a valley consists of two characteristics: the form and the width. Several forms can be distinguished. Relatively young valleys, mainly the lower order streams on the Basement Complex and the valleys dissecting the plateaus of the sedimentary rock formations, have narrow valley bottoms and relatively steep slopes, resulting in V-shaped valley forms. The older and higher order streams have a more concave valley bottom and less steep slopes, due to colluviation of gravel-free material from the slopes after rejuvenation during the most recent erosion cycle. The width of a valley can be variable; at the junction of two valleys wider valley bottoms occur. The true boundaries of concave valley bottoms are difficult to determine. The width of the valley bottom of second and higher order streams generally ranges from 10 to 100 m. Some characteristic cross-profiles of valleys at IITA are shown in Fig. 2.11.

On the basis of the width of the valley and the depth of the soils of the substratum, Kilian and Teissier (1972) distinguished five types of valleys in the Basement Complex area:

- narrow and shallow valleys: slightly embanked; straight sides, modest length, 2 to 4 per cent slopes; small valley bottom; particularly in granite areas.
- narrow and well-marked valleys: embankment may reach 20 m; short sides, convex or concave, up to 10 per cent slopes; valley bottom is clearly defined and narrow and its width is almost constant along the whole length of the valley; granite-gneiss (and schist).
- wide and shallow valleys: extensive catchment area, including those of smaller

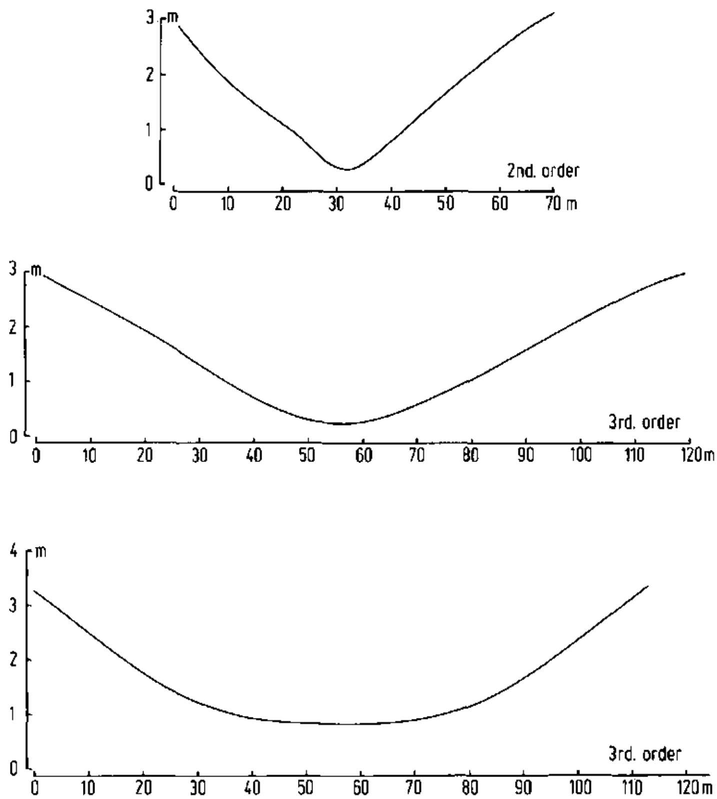


Fig. 2.11. Characteristic cross-profiles of valleys at IITA, Ibadan.

valleys; reduced embankment; straight sides, very long slopes, 2 to 4 per cent; valley bottom is regular in shape; granitic areas.

- wide and deep valleys: unlike the wide and shallow valleys, embankment is very marked and often higher than 20 m; the sides are straight, long, with slopes of about 10 per cent; schist areas.
- connecting valleys: they are found downstream of the confluence of the wide and shallow valleys; while they present the same morphological features as wide and shallow valleys, they differ from them by a widening of the valley bottom where vegetation is marshy.

2.4 CLIMATOLOGY

2.4.1 General

The climate of Nigeria is dominated by the influence of two major wind currents. The one from the north-east is hot and very dry; the other from the south-west is warm and very moist. The hotter north-easterly current rises over the south-westerly one, so that at the surface there is a demarcation zone, the Inter-Tropical Convergence Zone (ITCZ). This ITCZ runs approximately east-west and separates the regions influenced primarily by one current or the other. The position of this zone moves seasonally and is also subject to considerable short-period fluctuations. In general, it is situated well to the north of Nigeria in July and August and is over southern Nigeria in January. As a result, the country is subject to marked wet and dry seasons, associated with the moist and dry wind currents (Smyth and Montgomery 1962).

The study area has a humid to subhumid tropical climate with a bimodal rainfall

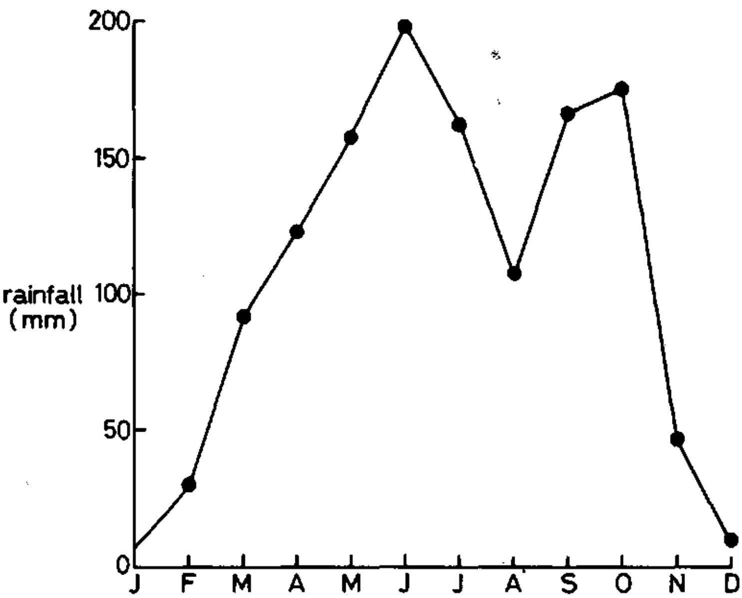


Fig. 2.12. Average annual rainfall pattern over a 20-year period at Ibadan.

Table 2.6. Climatic data, University of Ibadan.

	J	F	M	A	M	J	J	A	S	O	N	D
mean rainfall (mm)	3	30	103	129	151	185	146	112	195	183	37	8
mean potential evapotranspiration[1] (mm)	112	114	132	126	123	109	97	95	105	115	118	119
average mean temperature (°C)	26.5	28.2	28.1	27.3	26.7	25.6	24.7	24.2	25.0	25.7	26.8	26.3
average relative humidity (per cent)	63	61	67	74	76	80	82	83	82	78	70	64
mean bright sunshine hours	229	215	213	194	214	163	116	88	112	160	231	207

1 Potential evapotranspiration calculated according to Turc (1961).
Source: Moormann et al. (1975a).

pattern with peaks in June and again in September-October, and a period of lower precipitation in August. The major dry season lasts from December to February (Fig. 2.12). Table 2.6 lists some climatic data for the Ibadan area. The potential evapotranspiration is marked by a single peak in March but falls to its lowest value in August when insolation is also at a minimum. The soil temperature regime according to Soil Taxonomy (1975) is isohyperthermic.

Two soil moisture regimes prevail: the ustic regime for the well-drained soils and the aquic regime for the hydromorphic soils. From the eastern border of the study area, the soil moisture regime of the well-drained soils changes from ustic to udic; in south-eastern Nigeria a clear udic regime exists.

2.4.2 *Rainfall reliability and cropping periods on well-drained soils*

The rainfall in the study area is variable, ranging from 788 to 1884 mm within a 20-year period at Ibadan (Moormann et al. 1975a). It has a bimodal pattern as shown in Fig. 2.12. In the dry season, a severe water deficit occurs and, even during the rainy season, drought periods occur, and not only in August. The growing season is divided into two periods, roughly from March/April to June/July (first season) and September to November (second season).

The predictability of rainfall is small. Table 2.7 shows the probability of rainfall in Ibadan, calculated over the period 1905 to 1968. It shows that for dry land conditions March is the first month for early planting, but the chance of enough rainfall is slight. In practice, this means that early planting usually takes place only after the second or third good rain (a good rain meaning more than about 20 mm). The second season planting is done in late August or September. This second season may be rather short, because not much rainfall can be expected in November.

In Fig. 2.13 the rainfall distribution of four stations within the study area in the four crucial months can be compared. These months are February and March (beginning of first rainy season), August (end of first rainy season, beginning of second rainy season)

Table 2.7. Probability of monthly rainfall exceeding specified amounts (mm); data of meteorological station Ibadan 1905-1968 (1912 missing).

probability	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
January	45	27	12	5	2	1	0	0	0	0	0
February	108	72	40	23	14	8	4	2	1	0	0
March	240	191	141	111	89	71	56	42	30	17	10
April	233	206	176	157	141	128	115	103	89	72	60
May	245	220	193	174	159	146	134	121	108	91	78
June	292	265	235	215	198	184	170	156	140	121	106
July	372	306	237	194	161	134	111	89	67	44	30
August	274	211	148	112	85	65	48	34	21	10	5
September	323	283	239	211	188	168	150	132	113	90	73
October	279	249	215	192	174	158	143	129	113	93	78
November	138	106	73	54	41	30	22	15	9	4	2
December	45	26	11	5	2	1	0	0	0	0	0
Annual	1650	1552	1439	1361	1297	1239	1182	1123	1057	970	902

Source: T. Lawson, IITA agroclimatologist.

and November (end of second rainy season). In Tables 2.8 and 2.9 numerical data of all months of the four stations are given.

February is not a successful month for planting, except for a rootcrop such as yam (in this case part of a tuber is planted and germination takes place after the first good rain; the tuber can overcome drought periods until the rainy season starts). In this month not much rain can be expected and, even with one good rain, another good rain is unlikely, especially in the Ibadan area.

March does not show much difference among the four stations. Planting in this month mainly depends on whether the quantity of precipitation per rain is sufficient to moisten deeper soil layers; owing to the high evaporation small rains hardly contribute to higher moisture contents in these layers.

In August the first-season crops mature or are already harvested. It is important that planting for the second season takes place as early as possible because of the shortness of this season. Chances of enough rainfall for planting are highest in the Ondo area.

In general, November does not have enough rainfall to allow crops to grow actively, even in the Ondo area. So second season crops on well-drained soils should have a short growth period (2 to 3 months) or be drought-resistant crops like pigeon pea or cassava.

Summarizing, two general cropping seasons can be distinguished:

- a first season from April to July/August
- a second season from September to November.

In some years early planting can take place in March.

On hydromorphic soils, the distinction in cropping seasons is less dependent on rainfall, because of the relatively high groundwater levels in these soils. The fluctuation of the groundwater is often the factor that determines the beginning of the cropping period. If groundwater levels are deep and the surface soil is dry, rainfall that moistens the soil may then of course be important in determining planting dates.

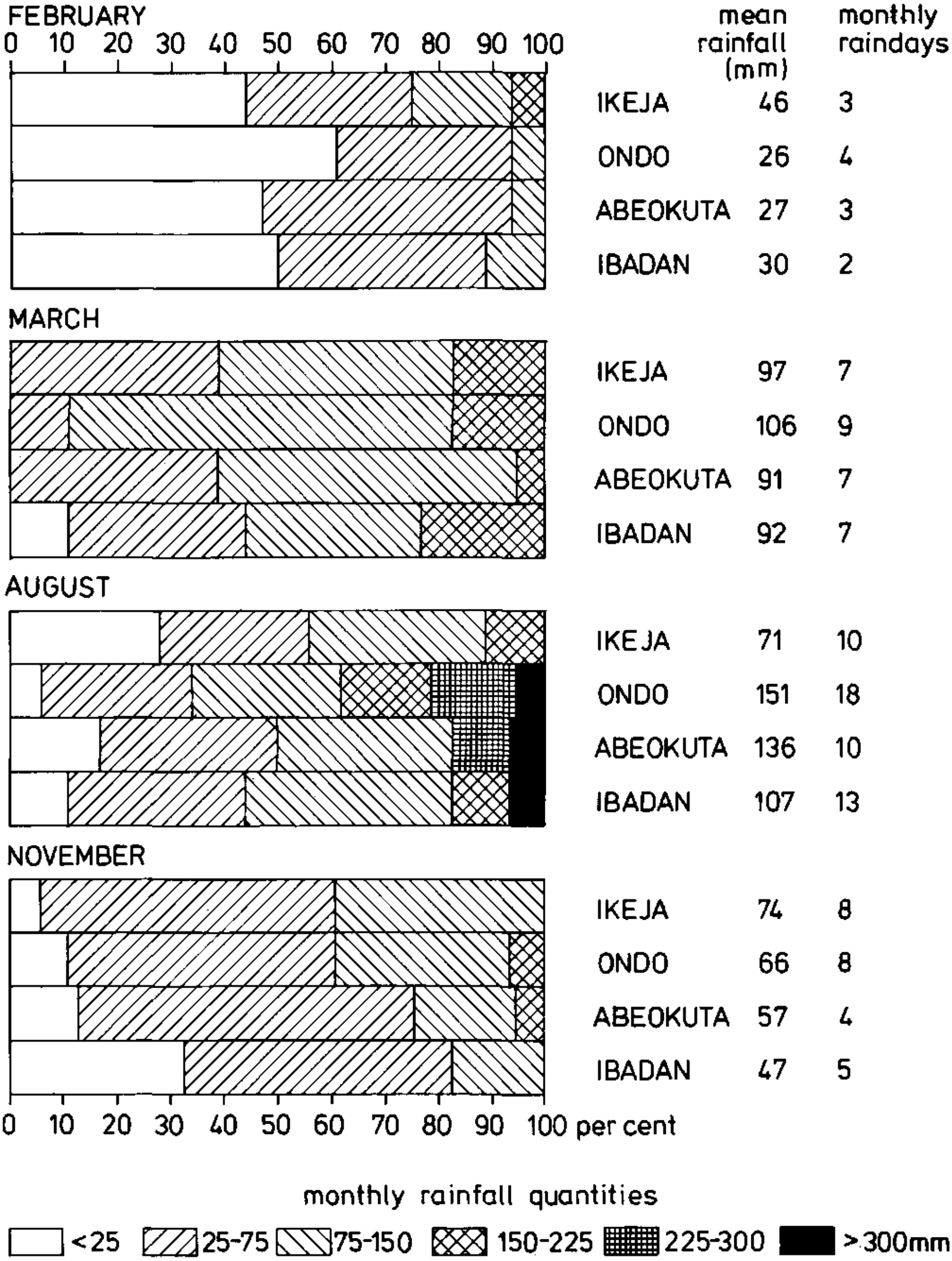


Fig. 2.13. Monthly rainfall distribution of four stations within the study area in the four crucial months (February, March, August, and November).

2.4.3 *Paleoclimates*

Many authors have considered the climatic changes during the Quaternary and earlier ages. Thomas (1974) summarizes the climatic controls in tropical land form development.

Table 2.8. Rainfall data and number of rain-days for four stations (data from 1949-1966); rainfall in mm.

Station (height above sea level in metres)		annual	J	F	M	A	M	J	J	A	S	O	N	D
Ikeja (40)	rainfall	1650	27	46	97	134	232	356	212	71	177	195	74	30
	rain-days	123	2	3	7	9	14	20	16	10	16	15	8	3
Ondo (310)	rainfall	1636	12	26	106	139	169	221	260	151	246	217	66	22
	rain-days	150	1	4	9	12	14	19	22	18	22	19	8	2
Abeokuta (115)	rainfall	1343	10	27	91	136	174	205	189	136	146	164	57	8
	rain-days	98	1	3	7	10	11	14	13	10	12	12	4	1
Ibadan (245)	rainfall	1275	7	30	92	123	158	198	162	107	167	175	47	9
	rain-days	118	1	2	7	10	13	16	16	13	16	17	5	1

Note: a rain-day is a day with more than 0.25 mm of rainfall.

Table 2.9. Percentage occurrence of specified amount of monthly rainfall for four stations (data from 1949 to 1966).

Station	Ikeja						Ondo					
rainfall (mm)	<25	25-75	75-150	150-225	225-300	>300	<25	25-75	75-150	150-225	225-300	>300
January	67	22	6	6	-	-	89	11	-	-	-	-
February	44	31	19	6	-	-	61	33	6	-	-	-
March	-	39	44	17	-	-	-	11	72	17	-	-
April	-	17	56	17	11	-	-	6	61	28	6	-
May	-	-	17	39	22	22	-	-	28	61	11	-
June	-	-	-	11	17	72	-	-	17	44	22	17
July	6	11	28	17	11	28	-	6	11	11	44	28
August	28	28	33	11	-	-	6	28	28	17	17	6
September	-	6	41	29	18	6	-	-	22	28	22	28
October	-	6	33	22	33	6	-	-	22	44	17	17
November	6	56	39	-	-	-	11	50	33	6	-	-
December	50	39	11	-	-	-	67	28	6	-	-	-
Station	**Abeokuta**						**Ibadan**					
rainfall (mm)	**<25**	**25-75**	**75-150**	**150-225**	**225-300**	**>300**	**<25**	**25-75**	**75-150**	**150-225**	**225-300**	**>300**
January	89	11	-	-	-	-	94	6	-	-	-	-
February	47	47	6	-	-	-	50	39	11	-	-	-
March	-	39	56	6	-	-	11	33	33	22	-	-
April	-	29	35	18	12	6	-	17	56	28	-	-
May	-	6	24	47	24	-	-	6	33	61	-	-
June	-	12	12	24	41	12	-	-	11	61	28	-
July	6	17	22	28	22	6	6	11	22	39	11	11
August	17	33	33	-	11	6	11	33	39	11	-	6
September	-	19	38	31	13	-	-	-	44	33	17	6
October	-	6	44	22	28	-	-	6	28	50	17	-
November	13	63	19	6	-	-	33	50	17	-	-	-
December	94	6	-	-	-	-	83	17	-	-	-	-

According to Douglas (1969), the inner core of the humid tropics can be interpreted as one of the few really stable ecosystems, as far as these areas have been outside the influence of changes in Quaternary sea levels and in areas without tectonic disturbance. Towards the margins of the rain forest zone, seasonality increases and during the Quaternary Era repeated desiccation occurred (Brückner 1955, Fölster 1969). Several studies have shown that during glacials in the temperate zone a dry climate (interpluvial) must have existed in the present rain forest area, due to a shift of the intertropical convergence zone (Bernard 1962, Bishop 1962, Elouard et al. 1969, Michel 1970). From pollen analytical data, Coetzee and van Zinderen Bakker (1970) concluded a synchronous cooling of both the northern and the southern hemispheres, which shifted the pressure systems and climatic belts towards the equator and had the opposite effect in warmer periods. Various authors have tried to establish a chronological climatic framework for Nigeria: for example, Fölster (1969) and Burke and Duratoye (1971) with respect to the study area in particular, and Sombroek and Zonneveld (1971) for northern Nigeria. Fölster based his chronology on analogy with events in the Chad basin. Burke and Duratoye (1971) presented a similar but less detailed sequence of events; they recognized a common sequence from weathered rock through a ferruginised or older pediment gravel, above which a younger pediment gravel was found. The younger pediment gravel deposition has been assigned to the glacial maximum around 20,000 years ago. Because it is a pediment gravel its deposition must have taken place during a dry phase and a major dry phase would be required to bring pediment-forming conditions as far as south-western Nigeria. The artefacts contained in the gravel are less than 40,000 years old and there is only one glacial maximum, or major dry phase, which is younger than that. The older pediment gravel, again requiring dry conditions, was ascribed to a glacial maximum at about 60,000 years ago. The deposition of the gravel-free layer was assigned to the whole interval after the last glacial maximum.

In the southern part of the study area, the influence of the fluctuating climates is less complex. Before the Plio-Pleistocene period erosion had formed the Ewekoro depression and had exposed Cretaceous and Tertiary sediments; the major north-south drainage system was also formed at that time (Slansky 1962). After deposition of the Plio-Pleistocene sediments, dissection of the plateaus occurred, together with some local transportation of material, but the plateaus are relatively stable. The climate fluctuations during the late Quarternary are superimposed on the landscape and did not cause any separate depositions.

2.5 NATURAL VEGETATION

2.5.1 Natural vegetation of the study area

On the basis of bioclimatic parameters, Keay (1953) established a broad zonation of vegetation in Nigeria. Important for our purposes are the lowland rain forest and the derived savanna, the boundary between which forms the northern boundary of the study area (cf. Fig. 1.1). The lowland rain forest of the study area has been described by Richards (1939, 1952), Keay (1953), and Jones (1955).

The northern part of the forest zone in the study area differs from the southern, wetter, forest in the higher proportion of deciduous trees and in the lower frequency of species such as *Triplochiton scleroxylon* (K. Schum.) and *Celtis* spp. (Clayton 1958). Besides the forest reserves, the greater part of the vegetation consists of secondary forest, which shows a great variation due to the commonly practised shifting cultivation system. The relatively high occurrence of oil palm, which can withstand the burning prac-

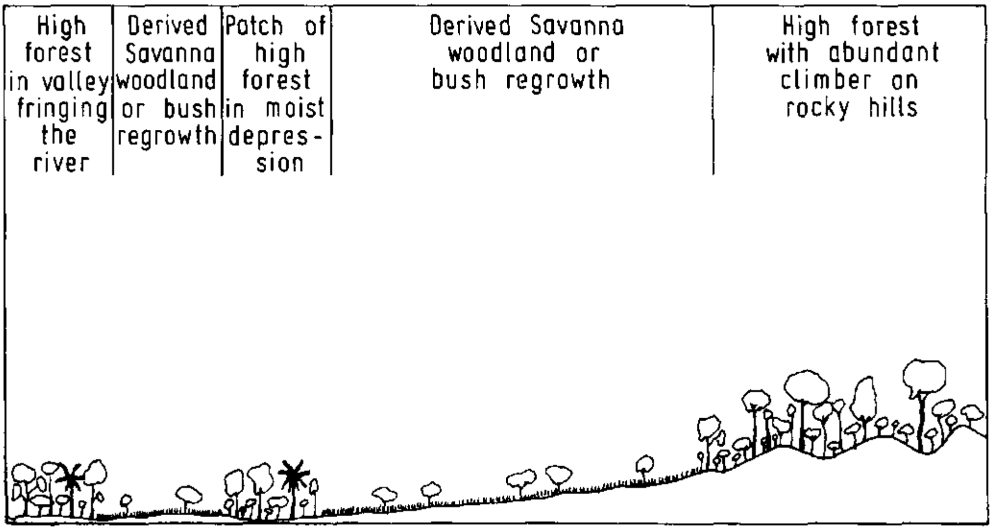


Fig. 2.14. Characteristic vegetation pattern of the drier parts of the study area. Source: Smyth and Montgomery (1962).

tices during clearing, is characteristic; moreover, these oil palms are kept as a "gathering" crop. Within the forest zone patches of derived savanna are found, the result of repeated cultivation, which causes a degeneration of the fallow re-growth. Fig. 2.14 shows this characteristic vegetation pattern. The well-drained and relatively non-steep land is used for cultivation, but valleys and steep areas are not cultivated. The degenerated fallow vegetation consists mainly of grasses such as *Andropogon* and *Hyparrhenia* and, recently, also *Eupatorium odoratum* (L.).

2.5.2 The woody element in the vegetation of the Westbank area, IITA

The Westbank area is one of the study areas on the Basement Complex and is situated at the IITA side, Ibadan. In this area, a vegetation study, involving only the woody elements, was done by Hall (1973). From two 20 m wide strips across the area, trees with a girth of more than 25 cm at chest height were recorded.

The vegetation of the Westbank area has replaced a more complex forest type following disturbances of varying intensity and at various times; the present forest is completely secondary. The re-growth vegetation includes abandoned cocoa plantations. The area was fenced and cultivation was stopped three years before the study. The following trees, in descending order of frequency, were found to be most widespread:

- *Elaeis guineensis* (Jacq.)
- *Albizia glaberrima* (Schum. and Thonn.) Benth/*A. zygia* (DC.)J.F. Macbr.
- *Stercularia tragacantha* (Lindl.)
- *Cola nitida* (Vent.) Scholl and Engl.
- *Newbouldia laevis* (P. Beauv.) Seemann ex Bureau
- *Spondias mombin* (L.)
- *Theobroma cacao* (L.)

- *Holarrhena floribunda* (G.Don) Dur. and Schinz
- *Funtumia africana* (Benth.) Stapf.
- *Antiaris africana* (Engl.)
- *Lonchocarpus sericeus* (Poir.) H.B. and K.
- *Millettia thonningii* (Schum. and Thonn.) Bak.
- *Cola millenii* (K. schum)
- *Rauvolfia vomitoria* (Afzel.)
- *Lecaniodiscus cupanioides* (Planch. ex Benth)

Floristic differences separate the vegetation of valleys and other poorly drained sites from that of better drained sites. The principal communities distinguished by their constituent parts are:

wetter places: *Elaeis guineensis* (Jacq.)
Stercularia tragacantha (Lindl.)
Cleistofolia patens (Benth.) Engl. and Diels
Raphia hookeri (Mann and Wendl.)
Canthium vulgare (K. Schum.) Bullock
Anthocleista djalonensis (Afzel. ex R. Br.)
Napoleona vogelii (Hook.f. and Planch.

intermediate conditions: *Lonchocarpus sericeus* (Poir.) H.B. and K.
Millettia thonningii (Schum. and Thonn.) Bak.
Spondias mombin (L.)

drier places: *Newbouldia laevis* (P. Beauv.) Seemann ex Bureau
Anthiaris africana (Engl.)
Lecaniodiscus cupanioides (Planch. ex Benth)
Harungana madagascariensis (Lam. ex Poir.)
Allophylus africanus (P. Beauv.)

Elaeis and *Stercularia* are abundant on the poorly drained areas and *Cleistofolia* may be considered characteristic of such edaphic conditions. *Theobroma*, *Cola*, *Newbouldia*, *Lecaniodiscus*, and *Antiaris* are typical of the drier places. Under intermediate edaphic conditions, the vegetation is not simply a mixture of the above but is also richer in *Spondias*, *Lonchocarpus*, and *Millettia* and is therefore considered an intermediate but

Table 2.10. The relation between the occurrence of common tree species as number/ha and the drainage class of the soil in a strip survey in the Westbank area, IITA.

	drainage class			
tree species	very poorly drained	poorly drained	imperfectly drained	well and moderately well-drained
Elaeis	37	20	17	6
Theobroma	3	1	-	2
Cola	4	3	6	1
Lecaniodiscus	-	-	1	1
Newbouldia	1	1	3	1
Antiaris	-	-	1	1
Millettia	1	1	2	1
Spondias	4	3	3	2
Lonchocarpus	2	3	1	1
Cleistofolia	24	4	2	-
Albizia	3	1	-	3
Stercularia	3	8	6	6
total	82	45	42	25

distinctive vegetation type.

Table 2.10 gives the number and kind of trees per ha according to the drainage class of the soils. In general, more trees are found in the wettest places, which have never been cultivated and have therefore had fewer trees felled and removed than the better drained sites. *Elaeis* and *Cleistofolia* appear abundantly on the very poorly drained soils. *Theobroma* was found on both poorly and well-drained sites.

3. SOILS OF THE STUDY AREA

3.1 GENERAL DESCRIPTION

3.1.1 Review of soil conditions in the study area

Geographically, the soils in the study area can be grouped into soils on Basement Complex formations (with minor inclusions) and soils on the coastal sedimentary formations.

On the Basement Complex, Smyth and Montgomery (1962) distinguished soil associations according to the drainage (well-drained soils, soils with impeded drainage, and soils with a seasonally high watertable) and, for the well-drained soils, a further division according to parent rock (granite and gneisses, amphibolite, quartz schists, and sericite schists).

The well-drained soils on gneisses and granites are the most extensive, occupying about 80 per cent of the surveyed area. These soils are characterized by a brownish loamy sand to sandy loam surface soil, the upper 5 to 10 cm of which is rich in organic matter,

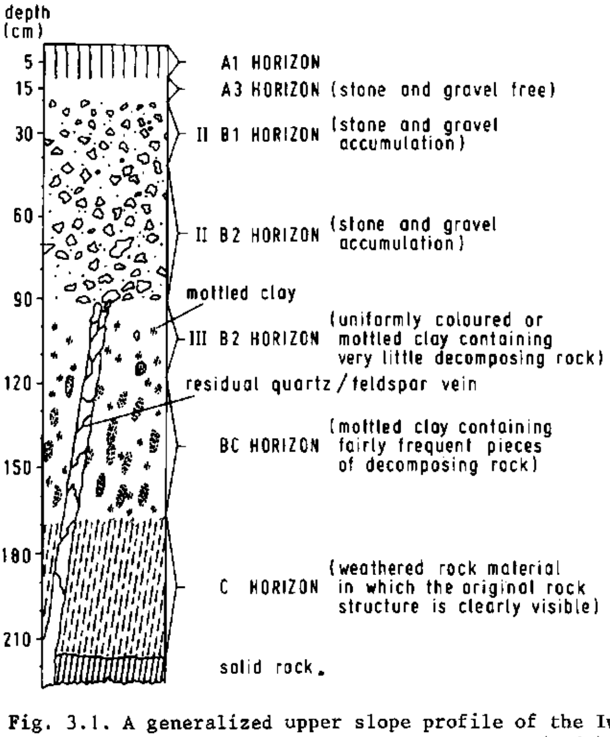


Fig. 3.1. A generalized upper slope profile of the Iwo-series, illustrating horizon differentiation. Source: Smyth and Montgomery (1962).

separated by a greyish-brown to reddish-brown gravelly layer from the reddish sandy clay loam to sandy clay, sometimes mottled, subsoil. The dominant clay mineral is kaolinite. Weathered rock is found at a depth of about 1.5 m. These soils are mainly oxic Paleustalfs. A characteristic profile is shown in Fig. 3.1. Besides the A, B, and C horizons, a distinction in three separations (I, II and III) has been made. A profile description of a similar soil, the Iwo series, is given in Appendix B, profile no. 1.

Well-drained soils on the other parent rock associations are briefly summarized, but are not further included in this study. Soils on amphibolites are more clayey than the previous ones and contain hardly any gravels. Their colour is often a uniform dark red. In the small regions where amphibolites occur, valleys have steep slopes and the valley bottoms are narrow.

On upper and middle slope positions, soils derived from quartz schists have more gravels and stones than those on gneisses and granites and are often shallower. Lower slope soils are mainly sandy with gravel at a shallow depth.

Soils from sericite schists are characterized by a pinkish colour and, apart from a higher content of quartz and mica in the coarse fraction, are similar to soils derived from fine biotite-gneiss of the associations on granites and gneisses.

The soil associations mentioned above include the moderately well and well-drained "hillwash" soils on lower slope sites. These soils do not contain gravels within their upper 50 cm. They are separated according to the texture between 25 and 50 cm depth into Oba (sandy clay), Iregun (sandy clay loam), and Apomu (sandy loam or lighter) series.

A separate unit of well-drained soils comprises the Gambari series; these are the very concretionary soils, occasionally containing an iron pan. They are usually situated at the break of the slope at lower slope sites. They are not very extensive, but appear on almost every slope.

Soils with impeded drainage in flat-to-very-gently sloping terrains (Origo association) occur only in about one per cent of the surveyed area. They are characterized by a sandy loam surface soil overlying greyish, plastic, montmorillonitic clay, occasionally containing gravels and concretions. The perched groundwater table may rise up to 20 cm depth during the rainy seasons. The depth of the sandy loam surface soil ranges from 10 to 75 cm with an average depth of 15 to 20 cm. Though hydromorphic in nature, this association was not studied in detail.

Most hydromorphic soils are in the Jago association, defined by Smyth and Montgomery as comprising those soils, subject to waterlogging within 1.2 m of the surface during at least a part of the year. Separation is made between soils with a watertable not rising above 25 cm from the surface ("poorly drained") and those in which the watertable rises above 25 cm ("swampy"). A further distinction is made by the texture between 25 and 50 cm depth; for poorly drained soils: Adio (sandy clay loam or heavier), Jago (sandy loam), and Matako (loamy sand or lighter) series; for swampy soils: Oshun (sandy clay loam or heavier) and Ikire (sandy loam or lighter) series. The Jago association described by Smyth and Montgomery is in fact a complex in which the series cannot be mapped accurately on a detailed scale. The five series are assumed to be characteristic for the whole complex.

The soils of the coastal sedimentary formations have been described by Moss (1957, 1961). As on the Basement Complex, soils are distinguished in the first place by drainage, ranging from well-drained soils (groundwater never higher than 4.5 m depth) to poorly drained soils (groundwater during rainy season between 40 and 80 cm depth) and seasonally swampy or flooded soils (with, respectively, a watertable very near the surface or flooded during the rainy season). The well-drained soils occupy 65 per cent of the area surveyed by Moss. A second parameter for distinction is the parent rock: sandstones (68 per cent of the surveyed area), terrace sands (7 per cent), shales (9 per cent), river alluvium (10 per cent), and miscellaneous types of rock (6 per cent). However, later work (Slansky 1962, Forbes 1975) indicates that much of the sandstone described by Moss is in fact an unconsolidated Plio-Pleistocene coastal formation.

A major difference with soils on the Basement Complex is the absence of gravels. A characteristic well-drained soil is the Alagba series (Appendix B, profile no. 8), which is a uniform dark red sandy clay loam soil, classified as oxic Paleustalf.

3.1.2 Soil characterization and classification

A total of eleven profiles were selected. Seven profiles were taken from the Westbank area at the IITA site (cf. Fig. 1.2) and four from the Ikenne area (cf. Fig. 1.1). The profiles are described according to the "guidelines for soil description of FAO". Analytical methods used to determine the chemical, physical, and mineralogical characteristics can be found in Appendix C. Each profile has been classified according to Soil Taxonomy (1975), FAO/UNESCO (1974), and CPCS (1967) (Table 3.1). The French soil classification

Table 3.1. Classification of the 11 profiles, 1 to 7 from the Westbank area and 8 to 11 from the Ikenne area.

profile number	series name[1]	lab.nr.	SOIL TAXONOMY	FAO/UNESCO	CPCS
1	Iwo	55	oxic Paleustalf	Ferric Luvisol	Sol ferrallitique faiblement désaturé, remanié, faiblement rajeuni ou pénévolué
2	Ibadan	65	oxic Plinthustalf	Ferric Luvisol	Sol ferralitique faiblement désaturé remanié
3	Apomu	140	(aquic) Ustorthent	Eutric Gleysol	Sol peu evolué non climatique d'apport colluvial hydromorphe
4	Gambari	144	oxic Haplustalf	Ferric Luvisol	Sol ferrallitique faiblement désaturé typique induré
5	Ikire	124	(typic) Tropaquent	Eutric Gleysol	Sol hydromorphe peu humifère à pseudogley à nappe perché
6	Ikire	130	(typic) Tropaquent	Eutric Gleysol	Sol hydromorphe peu humifère à pseudogley à nappe perché
7	Adio	57	aeric Tropaqualf	Eutric Gleysol	Sol hydromorphe peu humifère à pseudogley à nappe perché
8	Alagba	80	oxic Paleustalf	Eutric Nitosol	Sol ferrallitique peu désaturé appauvri modal
9	Owode	69	oxic Haplustalf	Ferric Luvisol	Sol ferrallitique faiblement désaturé appauvri hydromorphe
10	Atan	79	(aquic oxic) Plinthustult	Plinthic Acrisol	Sol hydromorphe peu humifère à pseudogley à nappe perché
11	Oji	161	(typic) Tropaquent	Dystric Gleysol	Sol hydromorphe peu humifère à gley peu profond

1 According to Smyth and Montgomery (1962) and Moss (1957).

system (CPCS 1967) is different from the other two in that diagnostic horizons are not mentioned in the French system. Instead, the conventional ABC horizon nomenclature is used at the highest categorical level ("classe").

3.2 SPECIFIC DESCRIPTIONS

3.2.1 Detailed soil survey in the Iwo and Jago associations

A detailed soil survey was done in the south-west corner of the Westbank area at IITA (cf. Fig. 1.2). The area is underlain by banded gneisses, granitic gneisses and mica schists of the Basement Complex. The area covers 39.1 ha with, in the middle, a stream entering at the north-eastern corner and leaving on the southern side. This stream flows during some parts of the rainy season and some deposition of clayey material takes place by flooding. Near the exit, flooding occurs more frequently, partly because of the construction of a road at this point, and partly because of the presence of a threshold towards the next step on the slope (see Section 3.3.1.1). The area has a rolling topography. Its vegetation has been discussed in Section 2.5.2.

Borings of up to 1.2 m were made in a grid-system of 25 by 50 m, using a Dutch "Edelman" auger. Use of aerial photographs was not possible, because of the poor quality and small scale of the available photographs. The detailed soil map is given in Fig. 3.2, the legend in Table 3.2.

The legend of the detailed survey was based mainly on textural profile, appearance of gravels and/or concretions, and on colour. A total of nine map units were distinguished, and five drainage phases were superimposed. On the soil map, no distinction is made between moderately well- and well-drained soils. For convenience the phases are named as follows:

gley mottling in surface layer - very poorly drained
gley mottling just below surface layer - poorly drained
gley mottling at about 40 to 80 cm depth - imperfectly drained
gley mottling around 1 m depth - moderately well-drained
no gley mottling within 1.2 m depth - well-drained

Map units 1, 2, and 3 are common in the valley bottom. All three units have a loamy particle size class according to Soil Taxonomy, but in the survey their main distinction was based on texture. Unit 1 has sandy clay or clay at less than 50 cm depth; unit 2 has sandy clay or clay between 50 and 100 cm depth; unit 3 has no sandy clay or clay at less than 1 m depth, but has a loamy texture over more than 20 cm within 1 m depth.

Map unit 4 occurs on lower and middle slopes, but was found in the valley bottom as well: these are sandy soils. Unit 5 resembles unit 4, but is found on well-drained places on the slope, has redder colours (7.5 YR versus 10 YR), and a somewhat heavier texture than unit 4. Unit 6 appears in crescent-shaped areas around the valley bottoms. A transition between units 6 and 9 is formed by unit 7, which has a redder colour and less concretions than unit 6 but is not as clayey as unit 9. Unit 8 contains less gravel than unit 7. A more extensive description of the range in characteristics of the nine map units is given in Appendix A. With the exception of units 5 and 8, profile descriptions can be

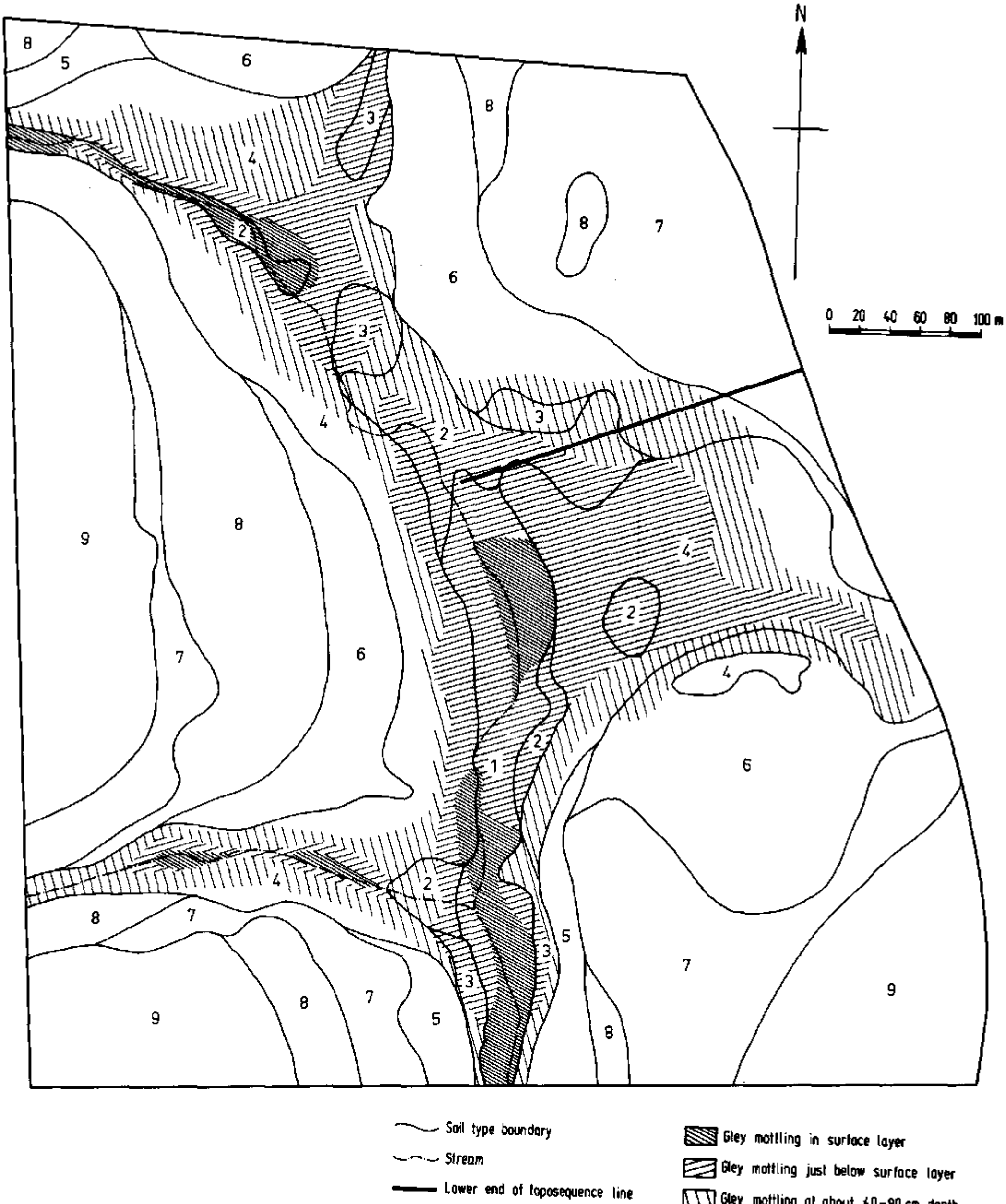


Fig. 3.2. Detailed soil map of the Westbank area at IITA.

found in Appendix B.

A correlation between the morphometric map units used in this survey and the series as defined by Smyth and Montgomery (1962) is only partially possible, because distinguishing criteria were sometimes different. In Table 3.3 an approximate correlation is given. Most series are subdivided into several morphometric units while, on the other hand, due to slightly different diagnostic characteristics, some morphometric units occur under two series. It should be pointed out, that the definition of the existing series, according

Table 3.2. Legend of the soil map. (S.W. corner, Westbank area, IITA).

map unit	textural profile and colour at less than 100 m depth	topographic location[1]	slope (per cent)	drainage phases[2] well	mod. well	imp.	poorly	very poorly	surface (ha)
1	bluish-green to greyish-brown, often concretionary, sandy clay loam to clay, dominant at less than 50 cm depth, with sandy and/or loamy layers	valley bottom	0– 2			+	+	+	1.4
2	dark grey to brown sand to sandy loam over bluish-green to brownish-grey, concretionary and often slightly gravelly, sandy clay loam to sandy clay at more than 50 cm depth	valley bottom and lower slope	0– 5		+	+	+		1.6
3	grey to yellowish-brown sand to sandy clay loam with a layer of sandy loam or sandy clay loam over at least 20 cm	valley bottom and lower slope	2– 5		+	+			0.9
4	grey to yellowish-brown sand to loamy sand sometimes with a finer textured layer of less than 20 cm	valley bottom, lower and middle slope	1– 8	+	+	+	+	+	9.2
5	brownish-yellow to yellowish-red loamy sand to sandy loam, usually finer textured in the subsoil	lower and middle slope	5– 8	+					1.4
6	brown to yellowish-red sand to sandy loam covering at 30/80 cm depth brown to yellowish-red gravelly and very concretionary sandy loam	lower and middle slope	3–10	+	+	+			6.6
7	yellowish to reddish-brown sand to sandy clay loam over strong brown to yellowish-red (very) gravelly sandy clay loam to clay	lower and middle slope	3–14	+					7.1
8	yellowish to reddish-brown loamy sand to sandy clay loam over strong brown to yellowish-red, often slightly gravelly, clay	middle slope	3–12	+					4.3
9	reddish-brown to yellowish-red sand to sandy clay loam over reddish-brown to yellowish-red gravelly clay with a marked stoneline between 10 and 30 cm depth	upper slope	4–20	+					6.6
							Total		39.1

Notes:

1 The valley bottom is defined as the flat to almost flat lowest part of the land in which one or more streams flow during the rainy season. The slope, from the valley bottom to the summit of the hill, is divided into three parts with a more or less equal length along the slope.

2 See text.

Table 3.3. The correlation between the morphometric units used in this study and the series as defined by Smyth and Montgomery (1962).

Series (Smyth and Montgomery 1962)	Map units and drainage phases (morphometric units)
Oshun	$1^{vp,p}$
Ikire	$2^{p}, 4^{vp,p}$
Adio	$1^{p,i}$
Jago	$2^{i}, 3^{i}$
Matako	$2^{p;i}, 3^{i}, 4^{p,i}, 6^{i}$
Apomu	$2^{mw}, 3^{mw}, 4^{mw,w}, 5^{w}, 6^{mw,w}$
Iregun	5^{w}
Gambari[1]	$6^{mw,w}$
Ibadan	$7^{w}, 8^{w}$
Iwo	$7^{w}, 8^{w}, 9^{w}$

Note:
1 subdivided into several series in later unpublished work

Explanation:
w = well-drained
w = moderately well-drained
i = imperfectly drained
p = poorly drained
vp = very poorly drained

to Smyth and Montgomery, lacks in clarity and precision and that sometimes criteria other than the currently accepted ones have been used.

3.2.2 Description of the Westbank toposequence

In their study on the identification of soil toposequences in the humid tropics of West Africa, Murdoch and Moormann (1974) selected the Westbank (IITA) toposequence as being representive for soils on intermediate crystalline rocks in the ecological zone of the "drier" forest. A toposequence means a succession of soils from a crest or plateau to a valley bottom. This is the same as the concept of catena according to Milne (1936).

Fig. 3.3 shows the cross-section of the toposequence with the location of the benchmark profiles. Profiles included in the extended studies of this toposequence are summarized in Table 3.4. Together with profiles 1, 2, 4, 5, 6, and 7, three more profiles (X, Y, and Z) have been included to describe this toposequence. The complete data on these additional profiles are not reported in detail here, but a summary of their characteristics follows:

- X: a shallow relatively young soil, found locally on upper slope positions and occupying only 0.2 per cent of the total surface (lithic ustic Dystropept)
- Y: a sandy soil overlying, at 85 cm depth, a thin concretionary B-horizon and the *in situ* weathered clayey C-material (this soil is a variant of map unit 4) (oxic Ustropept)
- Z: an intergrade of map unit 3 and 6 (typic Haplustalf).

In general, the thickness of the soil above bedrock is considerable on the crests and plateaus; it decreases on the middle convex slopes, but increases again on the lower concave slopes and in the valley bottom. Rock ledges with shallow soils occur on various slope positions (e.g. profile X).

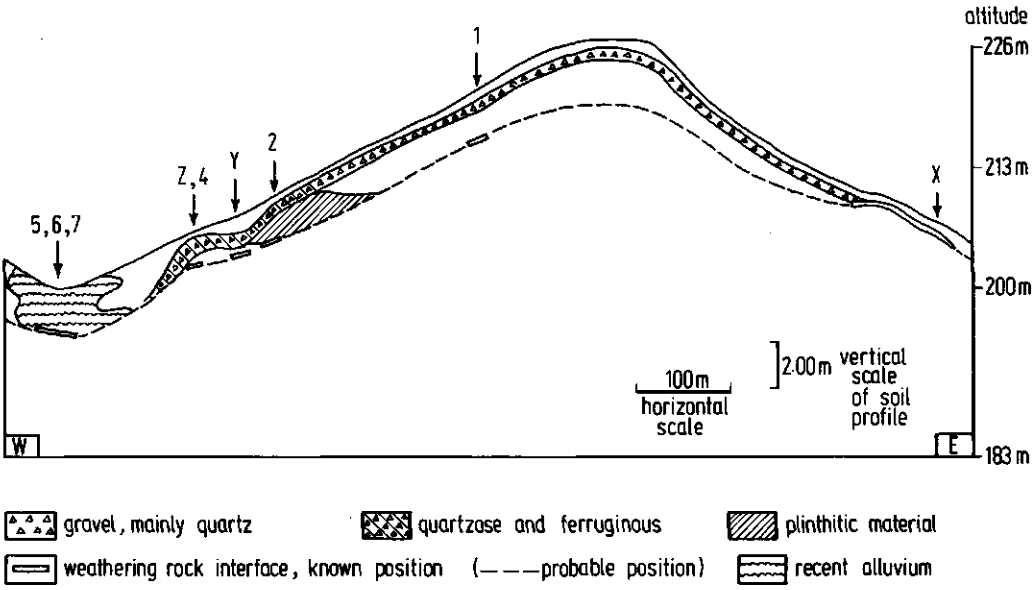


Fig. 3.3. Cross-section of the Westbank toposequence; numbers refer to profile numbers in Appendix B; the figures X, Y, and Z are explained in the text.

Table 3.4. Profiles of the Westbank toposequence.

Profile no.	USDA classification	Topographic position	Map unit	Drainage
1	oxic Paleustalf	convex upper slope	9	well
2	oxic Plinthustalf	middle straight slope	7	well to mod. well
4	oxic Haplustalf	convex to straight middle slope	6	mod. well
5	(typic) Tropaquent	valley bottom	3	poorly
6	(typic) Tropaquent	valley bottom	2	poorly
7	aeric Tropaqualf	valley bottom	1	poorly
X	lithic ustic Dystropept	convex upper slope	-	well
Y	oxic Ustropept	middle and lower slope	4	mod. well
Z	typic Haplustalf	middle and lower slope	3/6	mod. well

The upper slope profiles show a yellowish-red colour with some faint mottling. This mottling is not caused by actual hydromorphic conditions, but is probably due to the variance in the bedrock and the rate of weathering of each component. Towards the valley bottom hydromorphic characteristics, such as greyish colours and more distinct mottling, increase. Greyish-brown subsoil colours, accompanied by concretions, are characteristic. In the valley bottom, soils are greyish; in coarse-textured soils severe leaching has caused almost an absence of mottling, whereas in finer textured soils mottling occurs throughout the profile, increasing with depth to the permanent reduced horizon. The latter horizons are uniformly grey.

The upper slope soils are characterized by a thin sandy loam surface soil with increasingly heavier textures with depth. Towards the middle slope the sandy loam surface soil is thicker, separated from the *in situ* weathered clayey material by sandy clay loam colluvial material. On the lower slope various textural profiles occur, ranging from sand to sandy clay, directly overlying *in situ* weathered clay or interlayered with a concretionary B-horizon. The non-gravelly colluvial layer, derived from the sandy loam surface soil (biogenetic layer) on the upper slopes, on top of the gravelly layer varies in thickness owing to minor undulations of the bedrock and the uneven erosion and deposition of the colluvial material. Profile Y is an example of a depression where the non-gravelly colluvial material is more than 80 cm thick; this layer may amount to more than 150 cm, as was seen in other locations in the study area. In the valley bottom, textural profiles are highly variable owing to a changing sedimentation, either alluvial or colluvial.

The structure of the upper surface soil all over the toposequence is crumb or subangular blocky. In the subsoil of the profiles subangular blocky structures dominate; only sandy clay loam or heavier material above the saprolitic material has angular blocky structures.

The gravel in profile 1 consists mainly of quartz with a small proportion of Fe/Mn-concretions. Downslope the content of gravels and concretions increases, mainly because of an increase in Fe/Mn-concretions. On the lower slope, gravelly and concretionary layers appear at various depths or are absent. In profile 4, accumulation of Fe/Mn-concretions is accompanied by a rather cemented laterite bank. Plinthite, which has not yet hardened to laterite, was found in the subsoil of profile 2, probably caused by the accumulation of iron by interflow. This process has taken place here on the slope above the zone where the Fe/Mn-concretions accumulate.

The pH(H_2O) values of the well-drained soils vary from 5.5 to 6.2 and there is no systematic change in pH with depth. In the hydromorphic soils, however, the pH(H_2O) increases with depth. Delta pH (pH(KCl)-pH(H_2O)) for all soils is negative and varies from 0.3 to 1.9.

All soils of the toposequence contain a moderate amount of exchangeable Ca and Mg. The exchangeable K-content is fairly high in the A_1-horizons (0.09 to 0.44 me/100 g), but is below 0.1 me/100 g in the lower horizons; in profile 1 a higher content was found, related to the presence of strongly micaceous material (cf. Appendix B, profile no. 1). All soils contain a little KCl-exchange acidity, thus making base saturation, calculated on the basis of effective CEC (Kamprath 1970), more than 85 per cent. Effective CEC values of the well-drained profiles range from 1.3 to 10.8 me/100 g, the higher values occurring in the A_1-horizons because of the presence of organic matter. The values for effective CEC of the hydromorphic profiles range from 1.0 to 18.8 me/100 g. The higher values occur in the lower horizons due to an increasing amount of smectite with depth, especially in profile 7. The clay fraction of the upper slope profiles have values for effective CEC (in me/100 g clay) that fall within the range of kaolinites. On the same toposequence and especially in the better drained soils, Gallez et al. (1976) found evidence of the occurrence of constant-potential colloïds i.e. iron and aluminium oxides and hydrous oxides, while profile X showed evidence of amorphous Al silicates.

Clay mineralogical studies at the University of Louvain (Gallez et al. 1975) and Rothemsted Agricultural Station (Hughes, unpublished thesis, Univ. of London), confirmed that kaolinite is the most abundant clay mineral in the well-drained profiles, while in the hydromorphic profiles kaolinite and smectite become equally abundant. The presence of tubular halloysite (metahalloysite), mica, and feldspar in the clay fraction in profile X indicated the recency of this profile. With the exception of profile X, smectite exists in all profiles with the amount increasing strongly downslope. Goethite and hematite were found in all well-drained profiles. In profile 7 only trace amounts of goethite occur in the B-horizon. A trace amount of gibbsite was found in profile X but none in the rest of the profiles. Mica-vermiculite and mica-smectite mixed layer material were also found in the lower slope profiles. The clay mineralogical data indicate that the well-drained profiles of the plateau and convex upper slopes are the most highly weathered ones in the toposequence (with the exception of shallow profiles such as profile X). The presence of smectite in lower slope and valley bottom indicates that these profiles are enriched with Mg and Ca. The process of ferrolysis (Brinkman 1970) could be important in the hydromorphic soils because a clear oxidative (dry season) and reductive (rainy season) period exist; however, the occurrence of this process has not been studied.

In the studied toposequence the profiles on the slope can be grouped as follows:

- the soil of profile X with its own history, based on the shallow occurrence of banded gneiss. Weathering of this material caused a thin soil with evidence of its recency in, for example, its mineral composition, although the upper surface soil might have some colluvial influence.
- the soil of profile 1 and the subsoil of profile 2, which show a high degree of weathering. The clay fraction consists of kaolinite and iron and aluminium oxides and hydrous oxides. They are overlain by younger material consisting of the gravelly layer, mainly quartz gravels with some Fe/Mn-concretions, and the non-gravelly layer increasing in depth along the slope.
- the soils of profiles Y, Z, and 4 with colluvial material consisting of a concretionary layer overlain by the gravel-free layer. This gravel-free layer varies in thickness. The soils of profiles Z and 4 are dominated by large amounts of Fe/Mn-concretions, rather cemented. A spring-level probably existed there in a wetter period. Whether the concretions are of primary or secondary origin is not certain. Cementation has certainly taken place, but is not active at the moment.
- the soils of profiles 5, 6, and 7 are valley bottom soils, consisting of several layers of different textures. The clay fraction of profile 7 contains a fair amount of smectite, compared with profiles 5 and 6.

3.2.3 Description of Eastbank areas I and II

On the Eastbank of the IITA site two experimental areas, Eastbank area I and II, have been studied.

Eastbank area I (cf. Fig. 1.2) covers about 1.4 ha, consisting of a valley bottom (0.4 ha) with slopes on both sides (1.0 ha). The valley bottom is flat and is drained on either side by a small stream. The adjacent slopes, each 80 m long, belong to the lower slope of a 300 to 500 m long slope and can be divided into three parts: a lower part with slopes of 0 to 2 per cent, a middle part of 2 to 5 per cent, and an upper part of 5 to 8

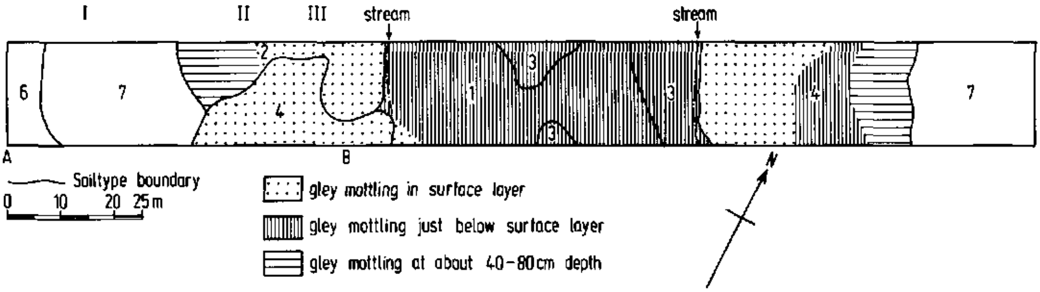


Fig. 3.4. Detailed soil map of a 18 m wide strip across Eastbank area I.

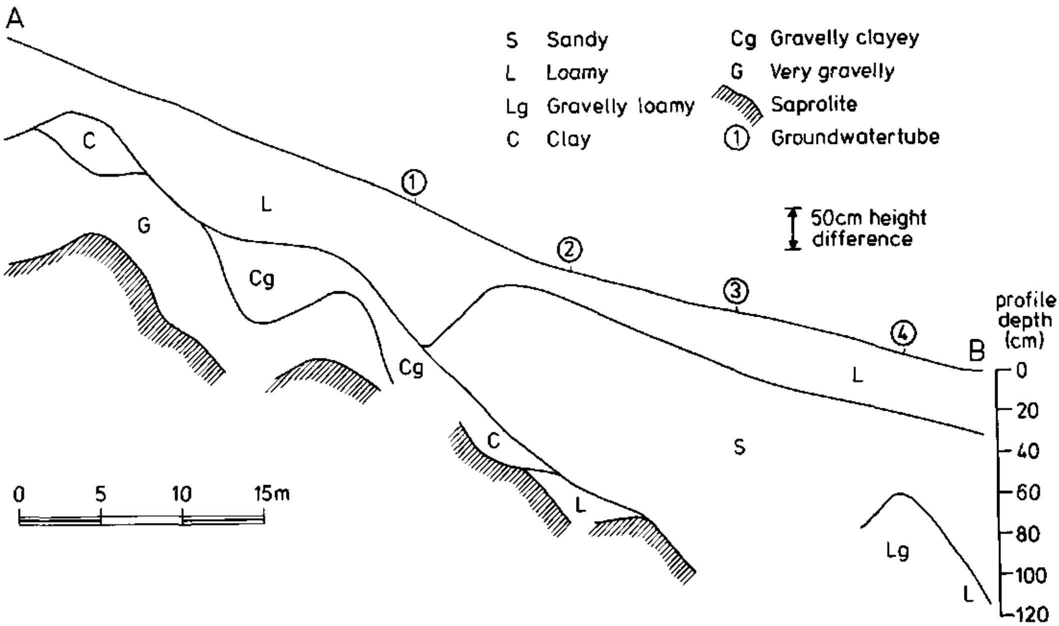


Fig. 3.5. Cross-section AB in Eastbank area I.

per cent, locally up to 12 per cent. The vegetation was cleared in 1970. Whereas in the Westbank area no experiments were performed, both this area and Eastbank area II were used for several experiments.

Using the same legend as on the Westbank area, an 18 m wide strip was surveyed in detail. The resulting map is shown in Fig. 3.4. The cross-section A-B of one of the slopes (see for location Fig. 3.4) is given in Fig. 3.5. Saprolitic material is found on the slopes (middle and upper part) at a depth of 80 to 150 cm. The microvariability on the slopes is high owing to variations in the depth of the loamy surface soil to clayey or gravelly subsoil layers, in the amount of gravels and/or concretions, and in the depth of saprolite. It is further increased by termite hills and former oil palm sites. In Eastbank area I, termite hills have influenced 3 to 4 per cent of the valley bottom and 2 per cent of the slopes. In general, a higher percentage of termite hills is found on upper slopes

(Kang, personal communication). The termite hills on hydromorphic soils are larger than those on well-drained soils. Influence on the soil by former oil palm sites was observed on 3 per cent of the valley bottom and on 5 per cent of the sloping area.

The complexity of the texture pattern of the surface soil in the valley bottom together with the depth at which the bluish-green reduced horizon appears is shown in Fig. 3.6.

Most of Eastbank area I is influenced by high groundwater levels. The valley bottom

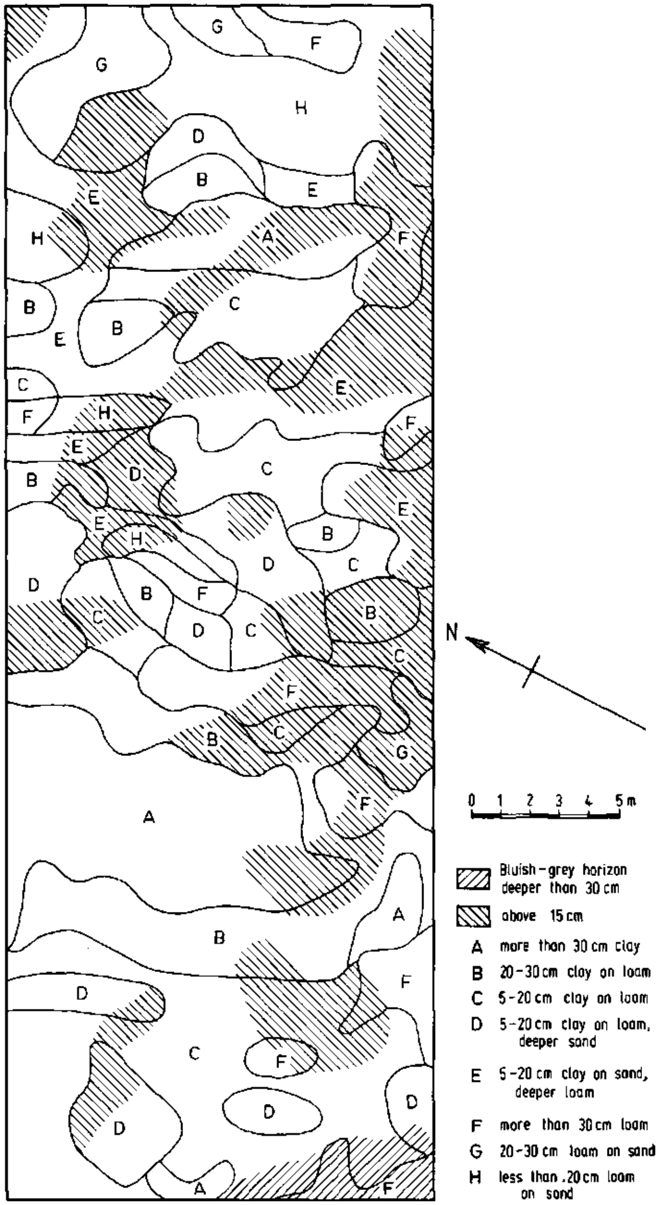


Fig. 3.6. Detailed soil map based on the texture of the surface soil and the depth of bluish-green reduced soil conditions, valley bottom Eastbank area I.

Table 3.5. Some analytical data of well-drained upper slope soils and very poorly drained lower slope soils, Eastbank area I (mean and standard error of 100 samples, sampling depth 0-15 cm).

Location	Drainage	sand	clay	org. C	total N	$pH(H_2O)$	Ca	Mg	K	Na	Mn
		per cent		per cent			exchangeable cations me/100 g soil				
upper slope	well-drained	77.4 (0.4)	12.6 (0.2)	1.19 (0.02)	0.124 (0.003)	5.3 (0.03)	4.98 (0.26)	1.05 (0.05)	0.21 (0.01)	0.09 (0.01)	0.11 (0.01)
lower slope	very poorly drained	79.9 (0.5)	10.2 (0.2)	1.36 (0.04)	0.126 (0.003)	5.6 (0.05)	4.48 (0.20)	1.28 (0.05)	0.10 (0.01)	0.17 (0.01)	0.08 (0.00)

is somewhat better drained than the lowest part of the slopes because of the occurrence of spring-levels on the boundary of the middle and upper parts of the slope and the two streams. The *in situ* weathered clayey saprolitic material causes groundwater to stagnate on the spring-level locations and makes the lower slope waterlogged for almost the whole year. In contrast the valley bottom is waterlogged only during parts of the rainy season.

The means of 100 samples taken at 0 to 15 depth from the well-drained upper slope soils and the very poorly drained lower slope soils are given in Table 3.5. (sampling was done in February 1976 after four years of cultivation.) In general, the lower slope surface soils are somewhat sandier and have a higher organic C-content. All the data from the upper slope soils are significantly different from the lower slope soils, except for total N-percentage and exchangeable Ca-content. In particular, it is the K and Na contents that differ.

Eastbank area II covers 4.5 ha, consisting of a valley bottom (1.0 ha) and the adjacent slope to the south-east (3.5 ha). The valley bottom is almost flat (1.5 per cent slope) with one main stream and several small short tributaries. The adjacent slope 70 to 90 m long is the lower part of a 200 m long slope and has a regular 6 to 9 per cent gradient, very locally up to 15 per cent. The vegetation was cleared early in 1976.

This area was surveyed using a grid system of 10 m (upslope) by 20 m (along the slope). The legend of the Westbank area was used. The soil map is shown in Fig. 3.7. A large part of the slope is occupied by loamy gravelly soils with a loamy sand to sandy loam surface soil overlying a more clayey gravelly subsoil (map unit 7). Here it forms a complex of soils differing in depth of the surface soil to the gravelly/concretionary layer, the sharpness of the boundary between the surface soil and the gravelly/concretionary layer, and the occurrence of plinthite. Only the first characteristic was observable by auger; in general, deeper surface soils appear in the north-eastern part of the area, but are not indicated on the map as a separate unit. Saprolitic material on the slope is found within 1.5 to 2 m depth. Compared with Eastbank area I, the proportion of well-drained soils is much higher. The valley bottom is much wetter; high groundwater levels were observed throughout the year.

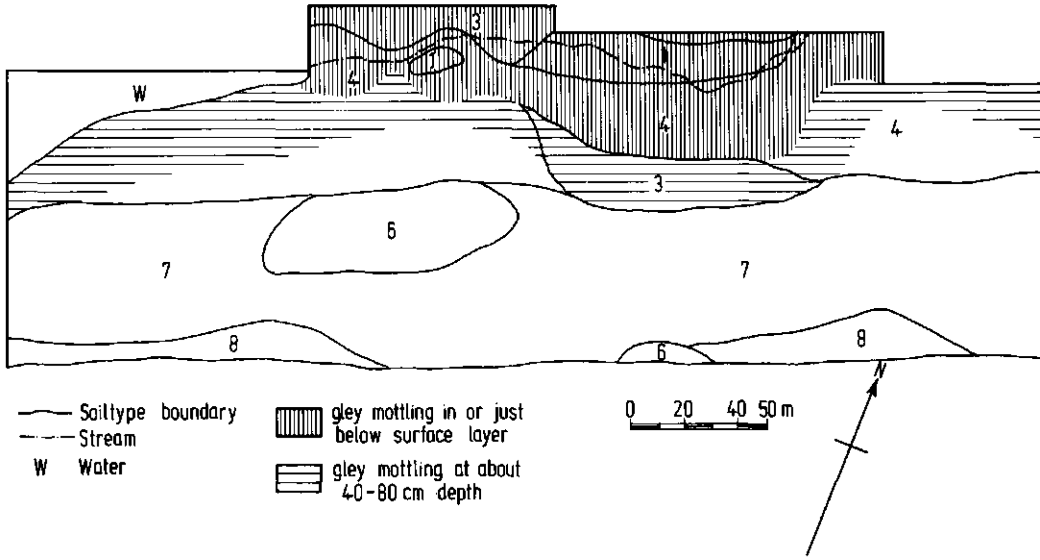


Fig. 3.7. Detailed soil map of Eastbank area II.

Table 3.6. Profiles of the Ikenne toposequence.

Profile no.	USDA classification	Topographic position	Unit	Drainage
8	oxic Paleustalf	long straight slope	A	well-drained
9	oxic Haplustalf	long straight slope	B	well-drained
10	(aquic oxic) Plinthustult	long straight slope	C	imperfectly drained
11	(typic) Tropaquent	transition of lower slope and valley bottom	D	poorly drained

3.2.4 Description of the Ikenne toposequence

In the study by Murdoch and Moormann (1974), a toposequence near Ikenne (cf. Fig. 1.1) was chosen as being representative for the soils on arenaceous sedimentary formations in the ecological zone of the "drier" forest. No systematic soil survey was done in this area. Four profiles were found to be characteristic (Table 3.6); the profile descriptions can be found in Appendix B. Fig. 3.8 shows the topographic position of these profiles. Profiles 8, 9, and 10 (units A, B, and C) are soils on the very gently sloping plateau, formed in the Plio-Pleistocene parent material, covering the older underlying formations. Profile 8 (unit A) is by far the most common well-drained soil in the area; it is a uniform dark red clayey soil in which an argillic horizon has developed. Profiles 9 (unit B) and 10 (unit C) are important, but to a lesser extent; they have developed in colluvial material. In the subsoil of profile 10, the influence of pyrite clay or shale, probably a Tertiary formation, is observed in lower pH values and an increasing sulphur content with depth. This subsoil material has the characteristics of an acid sulphate soil (Moormann, personal communication).

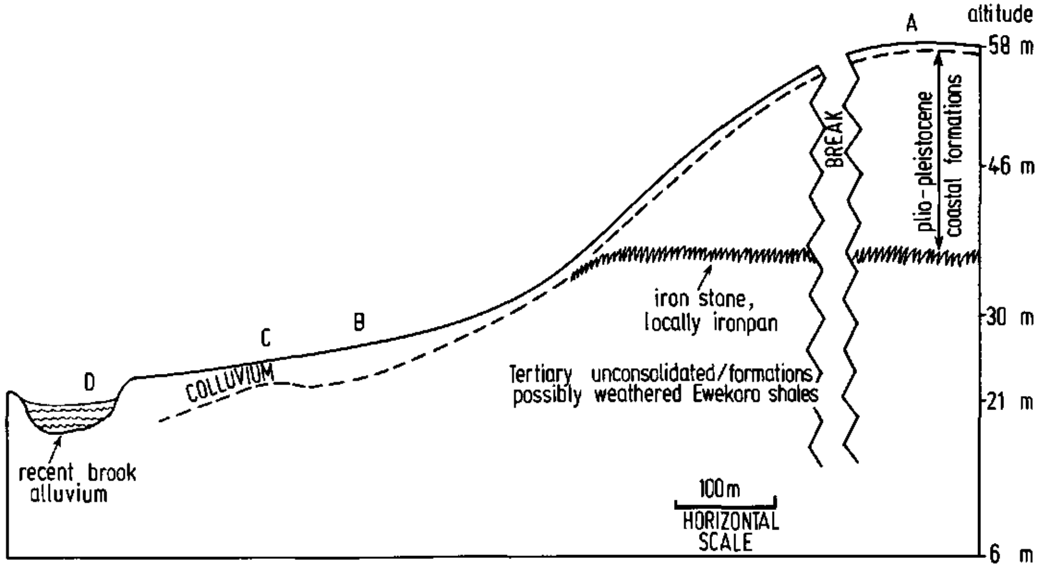


Fig. 3.8. Cross-section of the Ikenne toposequence.

Profile 11 (unit D) is a characteristic profile of the narrow hydromorphic flood plains, formed in alluvial and colluvial parent material. A colluvial layer about 10 cm thick, the result of recent clearing and consequent erosion, covers this profile. These soils are lighter in texture than the well-drained profiles; the texture is increasingly heavier with depth. Its colour is greyish-brown with grey colours in the subsoil.

The streams in the deep valleys are fed by lateral seepage from groundwater, which may be as deep as 30 to 40 m (Vine 1956). There is no lateral seepage through the soil at shallow depth, as on the Basement Complex, because of the absence of slowly permeable layers.

Physically, the soils of the Ikenne area are superior to the soils of the IITA area; chemically, the soils of the Ikenne area are poorer.

3.3 REVIEW OF SOIL FORMATION

3.3.1 Soil formation in the Basement Complex study areas

3.3.1.1 Formation of the soils on the toposequence

The main problem concerning the soil formation in the Basement Complex is the allochtonous or the autochtonous origin of different soil layers. Three main topographic situations have to be distinguished:

- the upland situation with three-layered profiles consisting of a gravel-free layer, a gravelly layer, and the *in situ* weathered soil material
- the intermediate situation with biogenetic and colluvial materials, sometimes

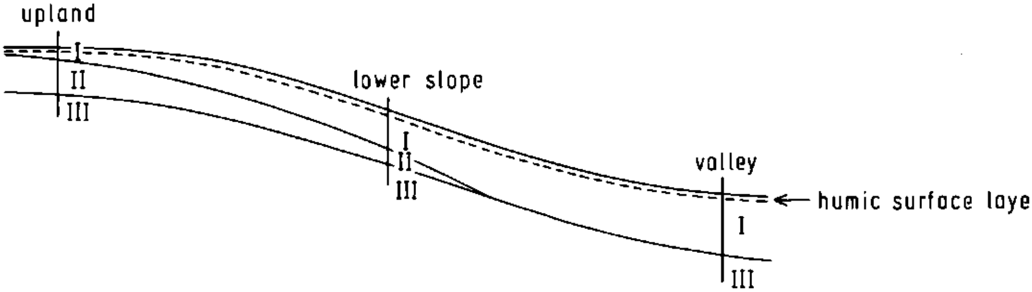


Fig. 3.9. Schematic cross-section of a slope in the Basement Complex area, illustrating the differentiation of soil layers with respect to the soil formation.

mixed with a varying quantity of laterite concretions, overlying the *in situ* weathered soil material

- the lowland situation with hydromorphic soils formed in materials of alluvial and colluvial origin.

In Fig. 3.9 the topographic situations are illustrated; roman figures indicate the different parts of the soils. Two opinions exist about the way soils have been formed, especially the II-layer. This layer is gravelly and has several names: stoneline, gravel layer, and gravelly layer. A stone-line is a gravel layer in creeping upper soil materials, derived from veins in the bedrock, which are apparently more resistant to weathering than the surrounding rock components. As this layer has a varying thickness on the slope and has a varying frequency of gravels, the term gravelly layer was considered the most appropriate for the study areas.

The two opinions about the formation of the gravelly layer are as follows:

- the opinion considering a stratification of soil layers, each layer above the *in situ* weathered material representing a different deposition cycle connected with climates prevailing during the Quaternary (Brückner 1955, Fölster 1969, Rohdenburg 1970, Burke and Duratoye 1970). Erosion periods alternated with deposition periods. An original large pediment plain was dissected by erosion, resulting in an undulating to rolling topography in which the pediment gravel can be found mainly on the upper slopes and partly on middle slopes. Valleys were either filled with alluvial-colluvial materials or were rejuvenated until the underlying bedrock was reached. The present fill of the valleys was, therefore, recently formed.
- the opinion considering all the soil layers to be mainly autochtonous, except for the transportation of soil material locally by creep and mild erosion processes such as sheet wash (Charter 1949, Nye 1954, 1955, Smyth and Montgomery 1962, Watson 1974). Apart from climatic changes, these authors consider the biogenetic way of soil formation the most important factor. Soil fauna, and especially the activity of termites, are responsible for the separation of gravel-free material from underlying soil material, thus forming the gravelly layer. The increasing thickness of the gravel-free layer results mainly from local wash down the slope.

According to the present author, both opinions could be valid in explaining the soil formation. Evidence in support of each was found in the study areas. Neither is completely satisfactory, so both theories will be taken into consideration.

The *in situ* weathered material varies in physico-chemical composition owing to the nature of the parent rock. Considerable variations have been observed in cuttings and trenches in the weathered banded gneiss and related mica schists. Where the rock contains fine-grained, dark minerals, the weathered zone is clayey and typically mottled. Other parts are more sandy, showing an excess of both quartz and decomposing feldspars. Consequently, the banded gneiss gives a parent material of variable composition, the variations mainly occurring over a distance of a few metres. Total depth of weathering of banded gneiss can be considerable; more than 6 metres of weathered rock have been observed. On steep slopes and on eroded hill crests, however, the hard banded gneiss is often found at shallow depth or occasionally as an outcrop.

The other main rock types, granite gneiss and quartzite, are less deeply weathered. Granite gneiss is often exposed in an unweathered form at the surface. Quartzite layers may be weathered to a depth of a few metres, but abundant quartz in these layers remains largely unweathered. Schistose quartzites are usually deeply weathered, the quartz remaining as unweathered veins.

A factor influencing the type of weathering is the topographical and hydrological position. The rocks, weathering on the lower slopes, are clearly influenced by seepage water from the higher slopes and a typical mottled clay is developed, regardless of the original composition of the rocks; on better drained places a saprolite is found (Moormann et al. 1975a). As stated by Smyth and Montgomery (1962), the upper slope soils are closely related to the texture of the parent rock, while the lower slope soils have a morphology less influenced by the underlying rock formations.

The main coarse component of the gravelly layer is subangular gravel. Rounded quartzite gravels, indications of the presence of an alluvial terrace, have been found locally on the lower slope of the central river valley at the IITA site. Fresh or slightly weathered rock fragments, mainly banded gneiss and granitic gneiss, are relatively rare, but occur on the downslope from rock outcrops and on some of the crests.

The gravelly layer varies both in the texture of its fine material and in its content of coarser gravels. The content of subangular gravels in the gravelly layer of 0.5 to 7.5 cm diameter may be well over 50 per cent in some places, but decreases to less than 20 per cent in others. At the IITA site there are small areas with poorly developed gravelly layers, where the content of coarser gravels is only a few per cent. In most places, however, the gravelly layer is well developed and is gravelly to very gravelly.

The thickness of the gravelly layer varies, both in the micro and in the meso sense. No specific pattern of microvariation could be established, but an overall increase in thickness of the layer from 20 cm on upper slope and crests to well over 100 cm on certain concave lower slopes has been observed in various places at IITA.

Based on the consideration of Burke and Duratoye (1971) that landforms and superficial deposits on the Basement Complex are products of erosion and deposition under fluctuating conditions during the Quaternary, the following can be concluded. The erosion of pediments and the development of a mature drainage system by numerous captures and adjustment to the structure of the underlying rock must have taken a long time. If a Cretaceous and Tertiairy cover has been stripped from much of south-western Nigeria, as the direction of flow of some rivers indicates, then these two processes probably started in the late Neogene and have continued throughout the Quaternary.

The sediments on any pediment surface are in transit from the foot of a residual towards the distal end of the pediment where they are either deposited in depressions or, if the pediment is linked to a river system, carried away. For this reason although the south-western Nigerian pediments may have developed through several alternations of wet and dry conditions, the deposits on them can be expected to represent only the more recent of these phases.

The oldest, readily distinguisable, deposit on the pediments is the cemented gravel. It was formed in a dry phase and cemented in a phase of wet and dry seasons. This deposit was not found in the Westbank and other study areas. More recent, and representing a second dry phase, is the widely distributed, uncemented pediment gravel. The more recent deposit has two facies, an upslope facies predominantly consisting of quartz and quartzite fragments and a downslope facies with a predominance of laterite crust fragments. No later general cementation has taken place.

The movements of the pediment gravel, caused by the rejuvenation of the drainage system, become clear when the composition of the gravel on hilltops and steep slopes is studied. Whereas on the undisturbed pediment plain, quartz and quartzite fragments are the main components of the gravelly layer, this is not the case on such steep places, especially on the slopes immediately below outcrops of the bedrock. Here, moderately weathered granite gneiss or banded gneiss fragments, up to boulder size, are mixed with the pediment gravel. This indicates a fairly recent movement of the gravel-containing material, since in the older formations all or nearly all the rock fragments have weathered completely, leaving only the resistant quartz and quartzite.

During the current humid period, rejuvenation of the river system has caused downcutting which intersects the younger pediment gravel and much of the gravel-free layer. The cause of the rejuvenation is not certain; it may be related to the retreat of a nick point from the edge of the continental shelf during one or other of the Würm low sea stands.

On the Basement Complex, concentrations of laterite occur both in patches on summits and crests and in strips along the lower slopes. Summit laterites are remnants of older land surfaces. These laterites were originally formed in basins as groundwater laterites or more localized lacustrine laterites. *In situ* laterite on hill summits, described by Smyth and Montgomery (1962) and Kreit (1975), occurs mainly on basic rocks, although patches also occur on intermediate rocks, as found north of Ilaro. More extensive caps are found in the "middle belt" of Nigeria, west of the Niger river (Wigwe 1974).

The occurrence of laterite concretions on lower slope positions, in some cases forming a consolidated pan, can be explained by iron-containing interflow water. The iron becomes oxidized and accumulates on spring-level locations on the lower slope (Smyth and Montgomery 1962). Irreversible hardening to hard laterite zones along the slope is mainly due to a lowering of the valleys by cyclic erosion. Younger spring-level locations on middle or lower slope positions show signs of active plinthite formation, e.g. profile

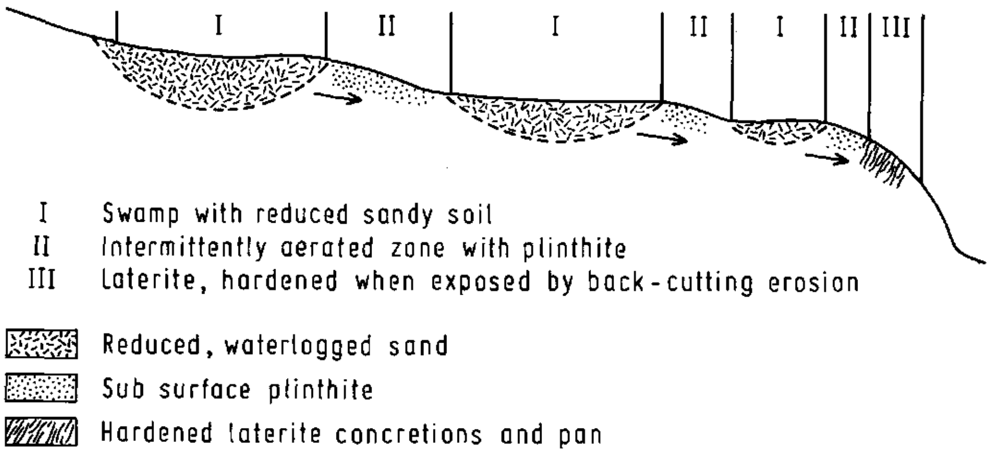


Fig. 3.10. Schematic cross-section of a "stepped" suspended valley at IITA.

no. 2 in the Westbank toposequence (cf. Fig. 3.3). Fölster (1969) described several laterite bands in zones along slopes, indicating several fossil spring-levels. The downward side of the laterite banks is often eroded, causing a break of slope. Maignien (1958) reported a stepwise formation of subhorizontal plateaus around valleys in Guinea, formed by mobile iron, which concentrates in small depressions on the slope. An example of such active plinthite formation was also found in a "stepped" valley at IITA. The schematic length-section of this valley is given in Fig. 3.10. The "step" formation is common in valleys across the strike of the rocks, where slightly harder formations weather and denude to a lesser extent than the softer ones. In the flat or slightly depressed parts of the valleys, hollows, mainly filled with sandy material, exist. In these, interflow water, rich in bivalent Fe and Mn accumulates. Soil dug from these swamps shows a quick brown discolouration when the Fe oxidizes. In the swamps, the soil remains reduced and no Fe/Mn deposits (plinthite) are found. At the lower end of the swamps, however, slow seepage takes place through aerated soil and both Fe and Mn of the soil solution are oxidized and irreversibly deposited, forming soft irregularly shaped concretions, rich in Fe and Mn. Upon exposure, this material will harden irreversibly to hard concretions or to "carapace", depending on how much enrichment has taken place.

The texture of the gravel-free biogenetic-colluviated layer varies from loamy sand to sandy clay loam; in the Westbank toposequence only loamy sand and sandy loam textures were found. The texture of the biogenetic surface material of upper slope profiles does not vary on a micro scale; moreover, it seems to be related to the texture of the lower layers and horizons, unless it has moved downslope. The thickness of this layer is a function of the slope; through gradual run-off, colluviated biogenetic material may form layers of well over 1 m thick. In most of the upland soils, the biogenetic layer is 12 to 20 cm thick, but on old habitation sites it has completely disappeared and the gravelly layer is exposed.

Fölster (1969) stated that multiple stratification, the rather sharp boundary, and the prehistoric implements found in the underlying gravelly layer can explain the depositional character of the gravel-free layer (I), it being the product of unconcentrated wash of material mobilized on the soil surface by direct impact of rain and rill action.

The biogenetic surface material, found in upper slope profiles, and the gravel-free layer found on lower slopes are directly related, according to Burke and Duratoye (1970). Transportation by run-off is the main cause of the formation of the gravel-free colluvial layer derived from the biogenetic surface material of the upper slope profiles. This is illustrated in Fig. 3.11, where rejuvenation of the valley has caused the removal of the pediment deposits from the valley bottom and where the resulting slope is covered by river-terrace material and a material attributable to colluviation (mainly of biogenetic surface material) from upper slope profiles. This figure shows one of the sides of the river Ogun, just north of the study area.

The biogenetic surface layer on upper slope profiles, indicated by the Roman I (Fig. 3.9) is explained by the second group of authors as being the activity of termites and to a minor extent of earthworms. Fine material is transported upwards to build mounds (or wormcasts) at the surface, which are later flattened by erosion. In this way, the fine material give rise to a gravel-free mantle, while stones move downwards under the force of gravity when material is removed from beneath them (Watson 1974). Particles larger than 2 mm are not carried by the termites (e.g. Nye 1955 and Miedema and van Vuure 1973). The material used to build the mound is brought up by the termites from the subsoil, between depths of 20 and 100 cm. The gravels which are not carried by the termites, accumulate as a gravelly layer at the base of the zone of intense termite activity. Several authors (Grassé and Noirot 1959, Watson 1960, De Ploey 1964, Boyer 1971) have pointed out that termite mounds have been constructed, at least in part, of material taken from below the gravelly layer. Termite galleries extending below that layer have also been found (Lévèque 1969, Nye 1955). De Heinzelin (1955) stated that run-off and colluviation would be insufficient to cause the thick layers of gravel-free material found on lower slope sites; the rate of transfer of material by termites from the weathered rock zone to the gravel-free layer has been estimated at 2.5 to 20 cm per 1000 years (Nye 1955, De Heinzelin 1955, De Ploey 1964).

Nye (1954, 1955) focussed attention on the importance of soil creep, dividing the soil profile, especially upper slope profiles, into two major parts: an upper part influenced by soil creep and a lower sedentary part. Nye considers that the surface soils

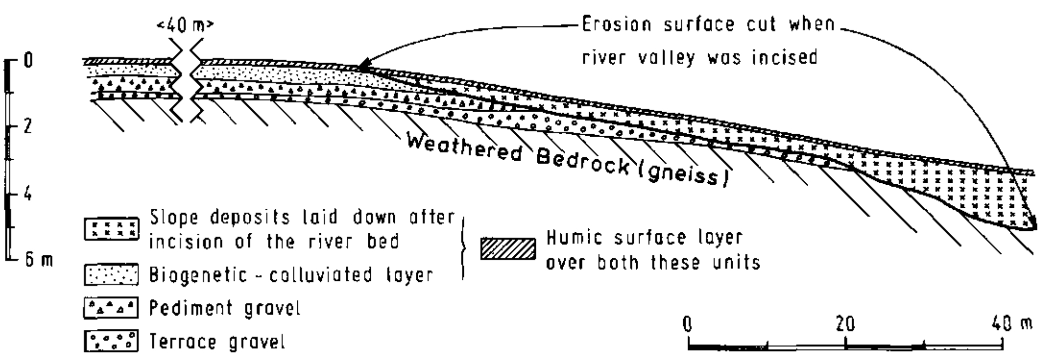


Fig. 3.11. Cross-section through slope deposits after rejuvenation of a valley. Source: Burke and Duratoye (1971).

are not derived from material directly below, but from soil higher up the slope. The explanation by way of erosion is doubtful in a vegetated area; water penetrates the surface soil rather than moves over the surface, depending on the structure of the vegetation and the stability of the structure of the surface soil.

With the exception of Doyne et al. (1938) (quoted by Nye and Greenland 1960), no studies have yet been made to determine the influence of the annual "harmattan" winds in the dry season. Deposition of dust, transported from northern regions by these northerly winds, may certainly add fine material to the surface soils. This is confirmed by the generally high silt (2-20 u) contents of the surface soils and the gradual decrease in silt down the profiles. Moreover, the relatively high content of organic matter (probably due to burning practices) and calcium add some fertility to the soils each year (Lawson, personal communication). It is difficult to estimate how much soil material may be added in this way each year, but it may well be 0.1 to 0.5 mm. This would mean a remarkable addition to the soil. Doyne et al. (1938) reported the composition of "harmattan" dust collected in northern Nigeria as containing no P_2O_5, 1.62 per cent K_2O, 5.28 per cent CaO, 2.07 per cent MgO, and 0.80 per cent Na_2O.

The soils in the valley bottom are probably depositions of a braided river system. The variation of soils, especially the variation of soil layers of different textures, occurs irregularly within short distances (cf. Fig. 3.6). Loamy and sandy profiles dominate; heavy clay soils are rare. At present, in the Westbank valley at IITA, flooding hardly occurs and the main stream and its tributaries are meandering streams.

3.3.1.2 Genetic horizons in different positions along the Westbank toposequence

The morphometric horizon sequence in the upper slope profiles, and also in the gravelly layer and *in situ* weathered material of lower slope profiles, is determined by two processes:

- the formation of an argillic horizon
- the formation of low activity clays (ferrallitic weathering)

Juo et al. (1974) found on the Westbank toposequence that the upper profile no. 1 (cf. Fig. 3.3) had more total free iron oxides than profiles Y and 7, and that the amount increased with depth. The clay/Fe-oxide ratio in that profile indicated a downwards or lateral migration of clay and Fe-oxide in the same proportion.

As stated in Section 3.3.1.1, the upper slope profiles have variations in the three soil layers I, II, and III, forming the solum of these soils. In Fig. 3.12 this is indicated by the same Roman figures. Together with the genetic horizon nomenclature, a number of horizons, determined both by genesis and stratification, can be found.

The lower slope soils show a variation in thickness of the gravel-free colluviated layer and the occurrence of the rather concretionary gravelly layer. Three characteristic lower slope profiles are shown in Fig. 3.13; for the valley bottom position two characteristic profiles, a light-textured soil over *in situ* weathered material and a heavier textured soil, are also shown. The loamy sand to sandy loam gravel-free colluviated layer on lower slope sites on the Westbank toposequence has shown little or no alteration since its deposition. In other places, in the case of heavier textured material (e.g. the Iregun

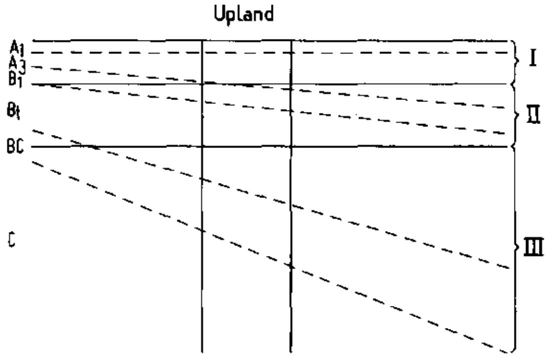


Fig. 3.12. Variability in horizon differentiation and stratification of soil layers in upper slope profiles on the Basement Complex.

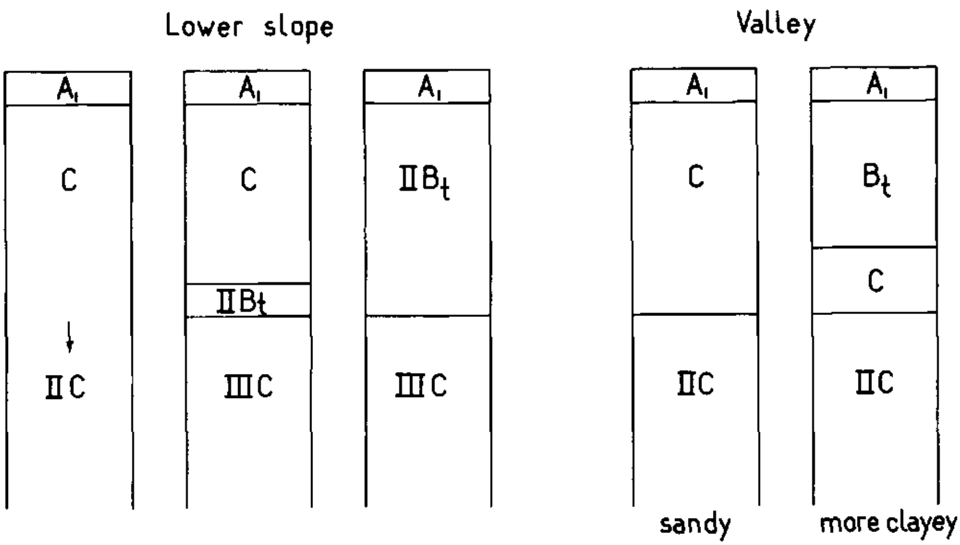


Fig. 3.13. Characteristic schematic profiles on lower slope and valley bottom (Basement Complex).

series in Moormann et al. 1975a), a moderate amount of smectite was present, particularly in deeper layers. This formation is thought to have taken place under conditions of impeded drainage in the presence of an adequate supply of bivalent cations, mainly Mg. This process is also common in the heavier textured soils in the valley bottom. Profile no. 7 is an example of such a soil and shows slickensides and stress cutans, especially under dry conditions. Also, clay illuviation has been observed in thin sections (Anon. 1975). In lighter textured valley bottom soils no alteration has yet taken place, but the clayey subsoil, developed in *in situ* weathered material, shows stronger structures and may contain a certain amount of smectites.

3.3.2 Soil formation in the sedimentary formation area

The similarity of all the soils formed on the undulating plateaus is probably due to the highly weathered nature of the sediments prior to their deposition during the Plio-Pleistocene and to the effects of mixing on these surfaces during periods of erosion following the Pleistocene (Forbes 1975). Variability among these soils is mainly limited to the texture and to the depth of the more sandy surface horizons.

Compared with the soils on the Basement Complex, the deep uniformly textured soils on the Plio-Pleistocene formations are considerably more resistant to surface erosion. The low degree of denudation of the Plio-Pleistocene cover explains that, on average, soils in the southern part of the study area are older and much deeper than those on the Basement Complex, where cyclic stripping of the pedons occurred throughout the Pleistocene. It also explains the virtually complete disappearance of weatherable minerals from the sand fraction. Also, and even more important, is that soil formation in sedimentary materials can take place much more rapidly than in soils on the Basement Complex, where soil formation could occur only after the rock had weathered.

The sand fraction of the soils in this area is mainly composed of quartz, while the clay fraction is a mixture of kaolinite and sesquioxides (mainly iron-oxides). The formation of an argillic horizon is the main soil-forming process involved in the well-drained soils in the area.

Soils in the valley bottom consist mainly of alluvial deposits and, to a very minor extent, of colluvial deposits. The often steep slopes along valleys remain stable if uncultivated and cause hardly any colluviation. Valley bottom soils are generally sandier than the soils of the plateaus. In profile no. 11, no soil formation could be detected. Owing to the high groundwater levels, very weak structures were observed. Several layers can be found in these soils, indicating their alluvial character.

4. GROUNDWATER REGIMES AND SURFACE SOIL MOISTURE CONDITIONS ON SOME OF THE STUDIED TOPOSEQUENCES

4.1 GROUNDWATER REGIMES

4.1.1 Types of hydromorphic soils

The term hydromorphic soil is used for a soil with morphological characteristics associated with wetness and, unless artificially drained, the resulting reduction during at least some period of the year. In terms of Soil Taxonomy (1975) such soils have an aquic moisture regime.

A common characteristic of hydromorphic soils is the mobilization of iron and its redistribution through the soil mass. Specific characteristics are:

- neutral grey colours due to continuously water-saturated and reduced conditions
- mottles and possibly Fe-rich concretions due to alternately reduced and oxidized conditions
- uncoated sand grains in very sandy soils
- a generally higher organic matter content in the surface horizon occurring under conditions of complete saturation for part or most of the year.

Pedologically, soils are called hydromorphic when they show one or more of these characteristics within an arbitrary depth. As the main point in this study is the actual effect of hydromorphism on plant growth, the degree of hydromorphism in soils is stated in terms of the influence of high groundwater on crop performance. These groundwater dynamics can only be determined by actual measurements of groundwater levels over time.

In Soil Taxonomy (1975), the concept "aquic moisture regime" is used as follows:

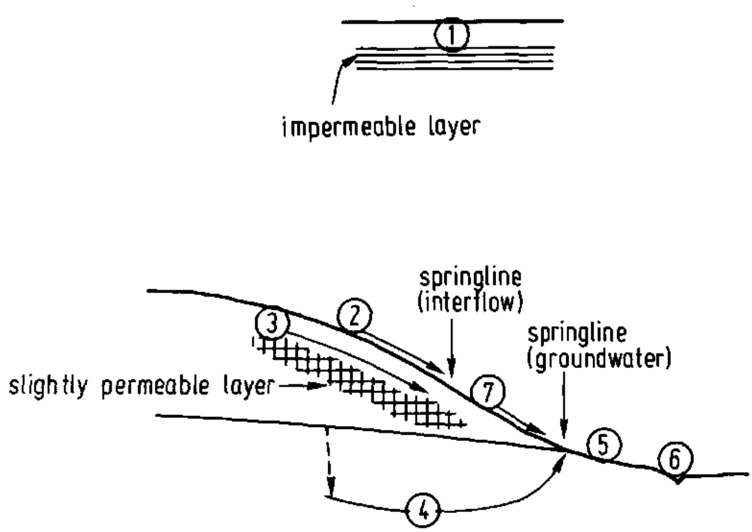
- for differentiation on sub-order level, the whole soil must be saturated (by groundwater and capillary fringe) for at least a few days when the temperature is above 5°C. The regime should be a reducing one, in which unless the soils are artificially drained, little or no dissolved oxygen is present in the soil solution.
- for differentiation on sub-group level only the lower horizons have to be saturated. Saturation should take place or low chroma colours should be present at depths, varying according to the great group, of 50 to 150 cm, but generally at depths of less than 75 cm.

In the FAO-Unesco classification (1974), a distinction is made between hydromorphic soils that are strongly influenced by groundwater, the Gleysols, and the soils of which only the lower horizons are influenced by groundwater or which have a seasonally perched watertable within the profile, the "gleyic" groups. The Gleysols have a reducing moisture regime virtually free of dissolved oxygen due to saturation by groundwater or its capillary fringe. Since hydromorphic processes are dominant, the occurrence of argillic and other diagnostic B-horizons is not considered in defining Gleysols. Hydromorphic properties in this classification refer to:

- saturation by groundwater
- occurrence of a histic horizon
- dominant hues that are neutral N or bluer than 10 Y
- saturation with water at some period of the year or artificially drained, with evidence of reduction processes or of reduction and segregation of iron reflected by features such as mottling, low chroma, or concretions.

The French classification (CPCS 1967) does not give a clear definition of a hydromorphic soil. Important implied characteristics are accumulation of organic matter in the topsoil and/or high groundwater levels. A differentiation is made according to the dynamics of the groundwater level between pseudogley, stagnogley, and gley. Pseudogleys have a temporary high perched groundwater table. Stagnogleys occur in very humid climates and have an almost permanently stagnant high groundwater level. Gleys have permanent high true groundwater levels, fluctuating within 1 m depth (Duchafour 1970).

In the study area, several factors cause hydromorphism. Climatically, there is enough water available to cause the saturation of soils in parts of the landscape. The undulating to rolling topography includes numerous valleys where water accumulates. Slightly permeable to impermeable layers at certain positions in the landscape cause hydromorphism. The relation between landscape position and the occurrence of hydromorphism is schematically indicated in Fig. 4.1. The situation in the Origo-association (cf. Section 3.1.1) is



1. stagnation of rainwater on impermeable layer
2. run-off during heavy rains
3. interflow over slightly permeable layer
4. groundwater flow towards valley
5. wet valley
6. semi-perennial stream
7. run-off from springs

Fig. 4.1. Location of hydromorphic soils in the landscape and their causes.

illustrated in this figure as (1): an impermeable clayey subsoil causes a pseudogley condition in the rainy season. (This Origo-association is uncommon in the study area and is not included in this study.) A lateral flow of groundwater over slowly permeable *in situ* weathered clayey material causes "pseudogleyic" conditions on lower slope positions (after Kilian 1971). Spring-levels, in places where the lateral flow reaches the surface, are widespread at the lower end of the slopes, where gleyic conditions prevail. In the valley bottom high groundwater levels are the result of accumulation of water caused by:

- groundwater originating from the uplands
- interflow through the soils on the slope
- run-off on the slope
- directly by rainfall
- discharge of springs in the lower parts of the slopes
- stagnating drainage of the valley itself by obstructions in the stream(s), as is the case in stepped valleys (cf. Section 3.3.1.1).

4.1.2 Groundwater regimes on some of the studied toposequences

In two areas, the Westbank area and Eastbank area I, groundwater depth was measured in 5 cm diameter groundwater tubes, reaching to 100 cm below the surface and perforated every 10 cm by four small holes. From the data thus obtained, characteristic groundwater fluctuations are shown in Fig. 4.2, 4.3, 4.4 and 4.5.

Fig. 4.2 shows the groundwater fluctuation at valley bottom sites and on the adjacent slope in the non-cleared Westbank area during 1976. In this area, groundwater rose to within 1 m depth at the lower places of the landscape during the rainy season. In the dry

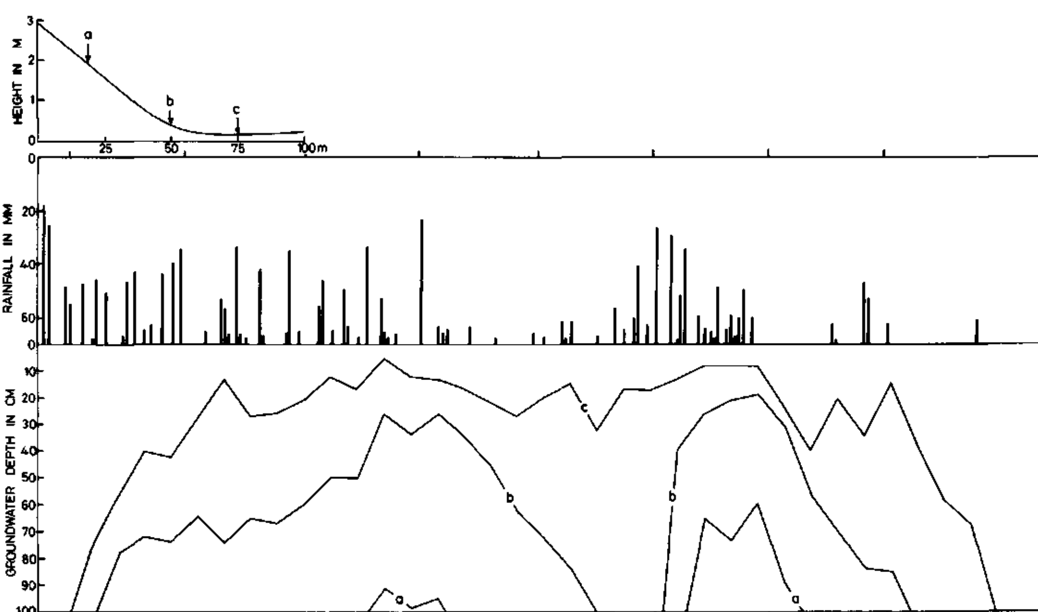


Fig. 4.2. Three characteristic groundwater fluctuations and rainfall pattern in the non-cleared Westbank area during 1976.

season, the groundwater remained at a greater depth, varying between 1.5 and 4 m. On the higher slopes, no groundwater was observed within 1 m depth. However, it may have been very temporarily at less than 1 m depth just after heavy rains owing to stagnation on the slightly permeable clayey subsoil on middle and lower slope sites. The Westbank area is covered with a secondary forest vegetation, which is able to lower the groundwater levels in the dry season to below 1 m; it is believed that the clearing of that vegetation will cause a general rise in the groundwater, particularly in the dry season levels. (In Section 4.1.5, more details about the influence of a forest cover on the groundwater level are discussed.)

The groundwater fluctuation shown in Fig. 4.2 is characteristic of many valleys in the study area which are covered by forest. Three characteristic sites were chosen for the groundwater measurements: Tube *c*, in the flat valley bottom, showed a fast rise at the onset of the regular rains in April-May. The level in this tube remained high until the rains diminished in November-December when the groundwater level fell accordingly. Tube *b*, at the transition of the flat valley bottom and the lower slope, showed a groundwater level that rose more gradually at the beginning of the first rainy season. The influence of the short dry season in August-September was remarkable: the groundwater fell below 1 m depth during this period. (In the year when the tests were done, the short dry season was longer than usual.) With the first heavy rains of the second rainy season (end of September) the groundwater level rose rapidly and was followed by a fall at the end of the rainy period. This fall cannot be related to transpiration alone; some discharge through the subsoil must also have been responsible. Tube *a* was placed in the lower slope, where groundwater was still observable within 1 m depth at the end of the first and second rainy seasons. During these seasons rainfall exceeds potential evapotranspiration, so at the location of the tube *a* discharge must have taken place vertically through the subsoil or laterally along the slope, the vertical discharge probably being the most important one.

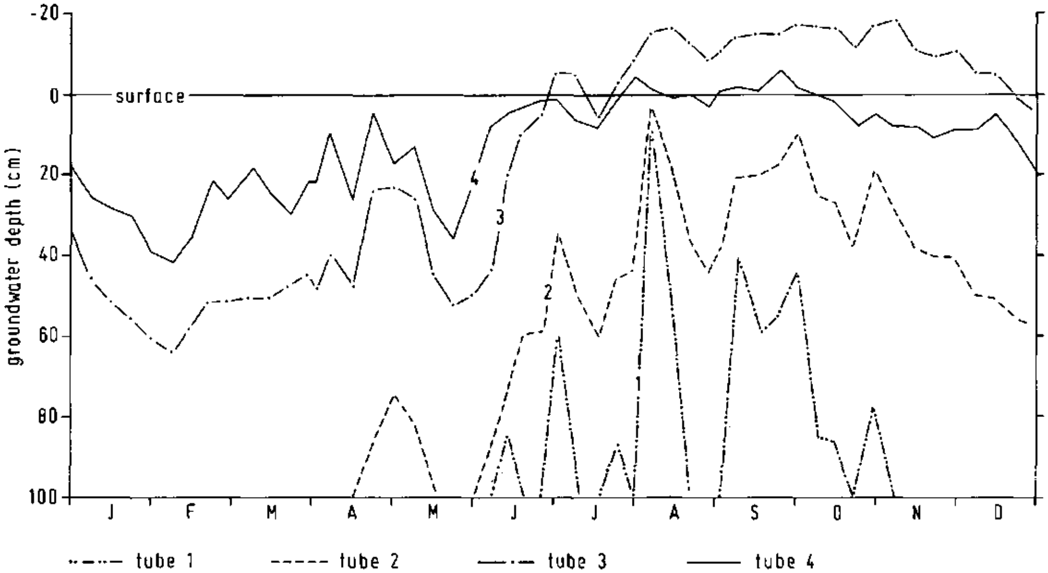


Fig. 4.3. Groundwater fluctuations in four groundwater tubes, 10 m apart, on a slope in Eastbank area I, 1973.

Fig. 4.3 shows the groundwater fluctuations on a slope in Eastbank area I during 1973. The vegetation of Eastbank area I was cleared in 1970. The figure shows fluctuations in four tubes, 10 m apart. Their location can be found in Fig. 3.5. Tube *1* is the highest and is comparable with tube *a* of Fig. 4.2, although the fluctuations in the former were greater. The high peak in August was due to two extremely heavy showers (total of about 200 mm) within a period of 24 hours. Tube *2* showed a groundwater fluctuation characterized by low levels, below 1 m, in the dry season. With the first heavy rains in April-May there was a rise to within 1 m. Drought periods during the rainy season caused a temporary lowering of the groundwater level. After the second rainy season, there was a gradual fall. Tubes *3* and *4* were in a much wetter zone, where the groundwater remains within 1 m depth throughout the year. In the dry season, tube *3*, higher up the slope than tube *4*, had somewhat lower levels, but in the rainy seasons higher levels were observed in tube *3*, due to the presence of a spring-level at the location of tube *3* during the rainy season.

The spring-level location of tube *3* is shown in Fig. 4.4, illustrating the same slope of Fig. 4.3 in 1972. The four extreme groundwater situations of that year are also shown. In the major first rainy season, the spring-level was clearly located on the slope, indicated by the occurrence of stagnant surface water. In the short dry season, the spring-level almost disappeared, but returned very markedly in the second rainy season. In the major dry season, the spring-level no longer existed. Fig. 4.5 shows a similar pattern to Fig. 4.4, but in a different year (1976) and located on the opposite slope in Eastbank area I. Again there was a clear spring-level location on the lower slope, disappearing both in the short dry season and in the major dry season. Both Figs. 4.4 and 4.5 show the generally higher groundwater levels in the second rainy season than in the major first

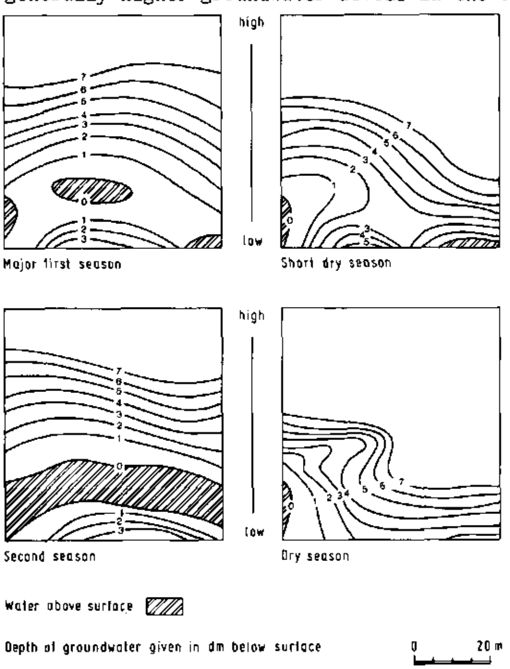


Fig. 4.4. Four groundwater situations in Eastbank area I, western slope, 1972.

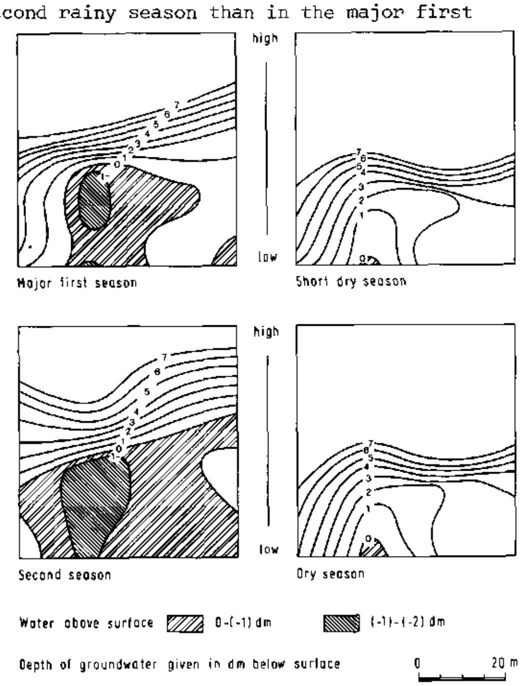


Fig. 4.5. Four groundwater situations in Eastbank area I, eastern slope, 1976.

rainy season. With the first rains in the major first rainy season, groundwater rose from a greater depth, as was reached in the major dry season. In the short dry season around August, the fall of groundwater was less than in the major dry season, causing the comparably higher levels of the second rainy season. Besides the difference in the height of the groundwater in the two rainy seasons, there was also a difference in the rate of rise, it being more gradual in the major first rainy season than in the second rainy season.

4.1.3 Division in classes

To relate the groundwater regime to crop performance, both the growth period of a crop and the fluctuation of the groundwater within this period are relevant. Most studied crops were annuals, with a growth period ranging from 2.5 to 5 months. Some of the studied crops (plantain, banana, cassava, and pigeon pea) have growth periods longer than one year; in those cases the annual groundwater fluctuations are useful. The performance of crops with respect to high groundwater levels is discussed in more detail in Section 7.2.

Figure 4.6 gives an example of the groundwater fluctuations in one of the tubes to indicate the different seasons distinguishable in the groundwater fluctuations. Five seasons can be distinguished; one of them, the short dry season, is taken as belonging to

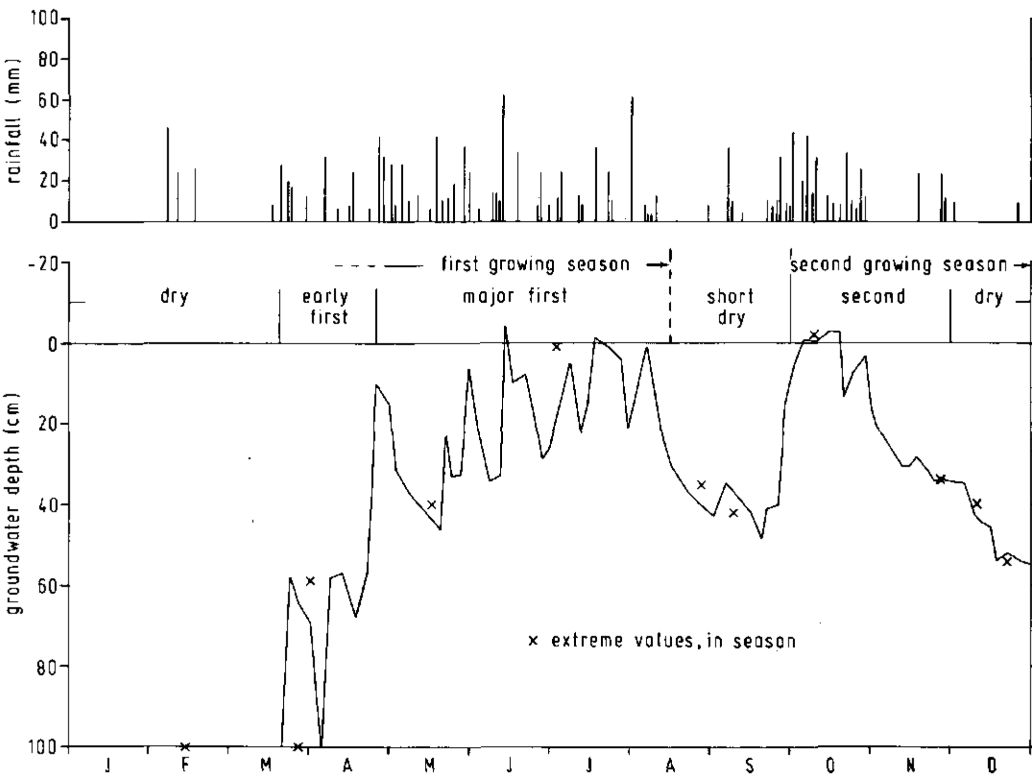


Fig. 4.6. Groundwater fluctuations in relation to the rainfall pattern in one of the tubes on the slope of Eastbank area I during 1975, illustrating the seasonal extreme values for the determination of the groundwater classes (biweekly measurements).

the major first season. Within each season extreme values can be determined: an extreme value is defined as having a minimum duration of 1 to $1\frac{1}{2}$ weeks. These extreme values for any location may differ from year to year; when taken over a number of years an average highest and lowest groundwater level per season could be determined. These figures were used to divide the groundwater regimes into classes, which was done for each separate season, namely dry, early first, major first, and second.

For the dry season, three extreme values are indicated in Fig. 4.6. To determine the two extreme values, the second secondary minimum, reached at the end of the observation period, was omitted because a lower minimum was reached in February. In the major first season, the lower extreme value can be reached either at the beginning of this season (during a drought period in May) or during the short dry season (August-September); in this case, the lower extreme value at the beginning was preferred because of its higher relevance to crop growth. The early first season is characterized by the rising groundwater levels after the beginning of the first rains; this season ends when rains falls more regularly resulting in higher groundwater levels. The early first season may hardly be distinguishable as groundwater levels start to rise quickly from the low dry-season level to the high levels of the major first season. The second season is often easy to distinguish; a sharp rise after the short dry season indicates its start; the first day of December was chosen as its end.

The principle of using average *annual* high and low groundwater levels to characterize the groundwater regime of soils was worked out by Haans (1961) and van Heesen (1970) for conditions in The Netherlands and was used by Laperre (1971) for Mozambique. The groundwater classes or "steps" determined in those studies are valid for annual variations. In this study, similar groundwater classes were established, but instead of annual variations, the model (Fig. 4.7) is based on in-season variations so as to be able to relate crop performance to a given groundwater class for any season during the year.

Class 1 of Fig. 4.7 represents a groundwater regime, common for all well to moderately well-drained "upland" soils, which have no groundwater at less than 75 cm depth in any season. It was assumed that, for the crops included in this study, the highest groundwater level of 75 cm or deeper would scarcely influence crop performance. Class 4 represents a pseudogleyic groundwater regime in which groundwater levels at less than 25 cm and below 1 m occur within a season. Class 2 is intermediate between classes 1 and 4. Class 11 is situated on the other side of the diagram, and represents a seasonal lacustrine, marshy situation with groundwater levels above the soil surface throughout the season. Further distinctions were made according to the average highest groundwater level during a period longer than 1 to $1\frac{1}{2}$ weeks above or below the soil surface, subdivided again into six classes (classes 5, 6, 7, 8, 9, and 10) according to the average lowest groundwater level. Class 3 is a rest group, representing groundwater regimes that fluctuate within a season between depths of 25 and 75 cm below the soil surface.

If groundwater regimes in the study area were to be determined on an annual basis, this would result in a dominance of classes 1, 2, and 4 on the slopes and classes 6, 9, and 10 in the valley bottom. However, on a seasonal basis most classes are present. Classes 3, 4, 7, and 8 appear less frequently than the other classes, because of a relatively large fluctuation in classes 4 and 8 and a relatively small fluctuation in classes 3 and 7.

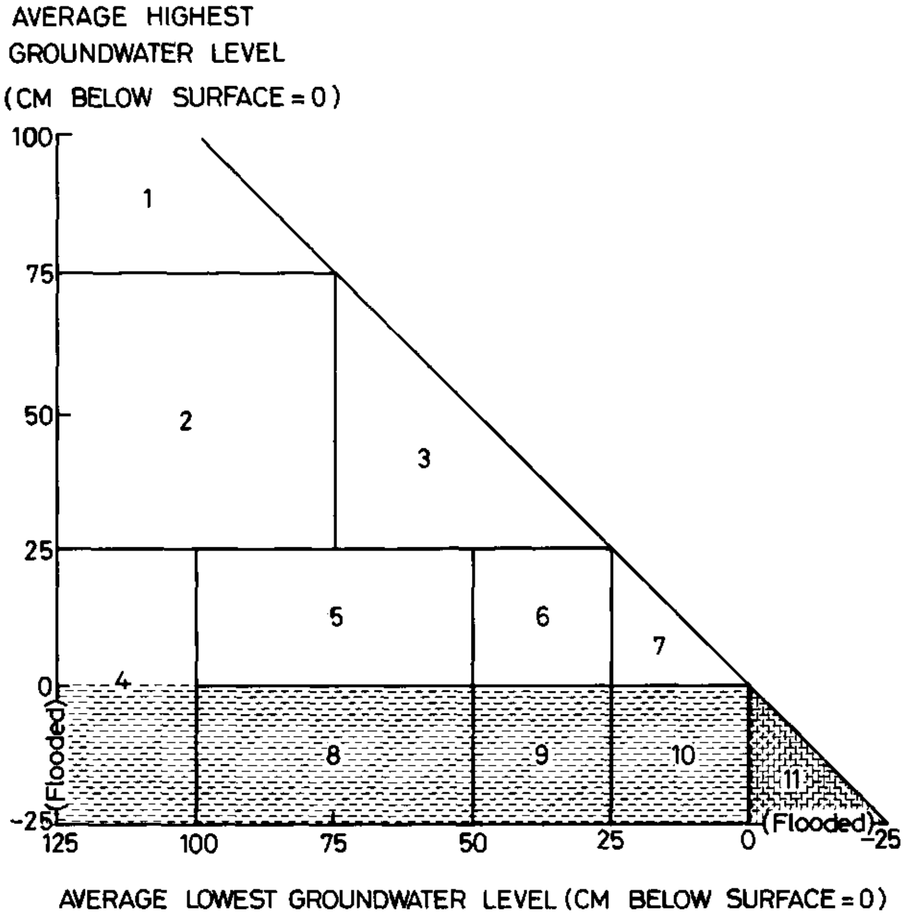


Fig. 4.7. Groundwater classes as a function of the average highest and average lowest groundwater levels (in cm below surface), each determined within a season (positive values = below surface, 0 = surface, and negative values = above surface).

Within the soil units, which were discussed in Chapter 3, certain groundwater classes occur:

- all eleven groundwater classes occur in soil units 1, 2, 3, 4, and D
- groundwater classes 1 and 2 occur in soil units 6 and C
- groundwater class 1 occurs in soil units 5, 7, 8, 9, A, and B.

The groundwater classes form an important basis in determining the land quality "availability of water", which will be discussed in Section 5.2.1.

4.1.4 Relation of the degree of wetness to soil morphological features

The degree of wetness of a soil is in some way expressed by soil morphological features. Saturation of the soil may cause reduction, depending on the presence of organic matter whereby the colour of the Fe-compounds becomes greyish; on the other hand, reduction-oxidation processes cause mottled soil material in which more bright colours of oxidized Fe-compounds and greyish colours of the reduced Fe-compounds alternate (Vizier 1971, Bloomfield 1973, and Ottow 1973).

As stated in the Soil Survey Manual (1951) "the internal soil drainage is that quality of a soil that permits the downward flow of excess water through it. Internal drainage is reflected in the frequency and duration of periods of saturation with water. It is determined by the texture, structure and other characteristics of the soil profile and of underlying layers and by the height of the watertable, either permanent or perched, in relation to the water added to the soil". Six classes are distinguished, each described by the height and duration of the watertable and by soil characteristics. For these soils that have high groundwater levels for longer than one month, two broad groups are distinguished: a group in which there is no internal drainage (the watertable is at or near the surface for most of the year), and a group in which the internal drainage is very slow (the soil may be saturated with water in the root zone for a month or two).

In the Soil Taxonomy (1975) an aquic moisture regime, to differentiate between the higher categories of soils, involves complete saturation of the soil. For differentiation on subgroup level (aquic subgroups) only the lower horizons need to be saturated. The duration of the saturation period is not known; it must be at least a few days, because of the implication in the concept that dissolved oxygen is virtually absent. A soil moisture regime in which the groundwater is always at or very close to the surface is called "peraquic" in the Soil Taxonomy.

Several authors have been working on the relation of soil morphological features and groundwater measurements. Vepraskas et al. (1974) found soils in Wisconsin with a low chroma colour, which were saturated only for insignificant periods. Bouma (1973), studying the same region, described unmottled soils that had perched watertables for several months. Veneman et al. (1976) were able to characterize the degree of wetness in a number of soils in Wisconsin by studying the colour and micromorphological features of the soil.

In The Netherlands, van Wallenburg (1973) found a fair relation between the upper boundary of the permanently reduced G-horizon and the average lowest groundwater level.

For soils in Sierra Leone, Dijkerman (1975) showed a relation between the duration of waterlogging at the surface and commonly occurring soil characteristics. Hues redder than 10 YR and chromas more than 4 in the subsoil were good indications of the absence of waterlogging. Hues yellower than 10 YR and neutral colours were signs of waterlogging. Poor drainage conditions were further indicated by low chroma colours in the subsoil and the presence of mottles in the surface soil and upper subsoil. These relations are broad and no detailed information on exact fluctuations of a groundwater table can be derived from soil morphological observations.

For the study area, three broad groups of soils could be distinguished by measuring the presence of groundwater within 1 m depth in the dry season:

- soils with groundwater levels within 1 m throughout the year
- soils with groundwater levels only during parts of the year
- soils without groundwater levels within 1 m.

At IITA, no clear relation was found, however, between actual groundwater levels and mottling and matrix colour characteristics, taking into account the organic matter content. Upper subsoil horizons, saturated for an average of six months each year, showed only very faint mottling in a 10 YR 4/4 matrix. A distinct mottled zone in the subsoil with a 10 YR 5/4 matrix colour was saturated from 10 months each year, whereas a prominent mottled zone with a 5 B 5/1 matrix colour was saturated for 11 months each year. When horizons were completely reduced, they were saturated for the whole or almost the whole year. However, horizons above the completely reduced horizon did not show any clear morphological features indicating the exact time of saturation.

The reconstruction or prediction of a groundwater regime by careful description of several soil characteristics is difficult, if not impossible, both in accuracy and because of variations between years. The oxygen content of laterally moving groundwater, especially on the slope, but also to some extent in the valley bottom, may obscure any clear soil morphological features, indicative of long periods of saturation. Therefore, actual measurements of groundwater levels are needed to provide data concerning the degree of wetness of a soil.

4.1.5 Effect of clearing of natural vegetation on the groundwater regime

In general, clearing of the forest vegetation has an impact on the groundwater regime. Under a forest vegetation, part of the rainfall is intercepted by leaves and roots, and subsequently returned to the atmosphere by evaporation and transpiration. The deep rooting system of trees also causes deeper groundwater levels during the dry season. In this way, trees are sometimes planted to lower the groundwater table. The processes of evaporation and transpiration diminish when the forest vegetation is cleared and replaced by crops with a lower degree of interception (Wilde et al. 1953) or a short growing season. It was assumed for the IITA area that without a forest cover more water will reach the subsoil, even though loss of water by run-off may increase (Lal 1976).

More water will reach the low-lying areas, as was shown in the Casamance (Senegal), where the groundwater level rose 8 m, 20 years after clearing (Charreau and Fauck 1970). Moreover, springs in adjacent valleys, which were seasonal before clearing, became perennial after clearing. The main reason given for this phenomenon was the reduction of evapotranspiration during the dry season. It was calculated that the 8 m increase in 20 years was more or less equal to the cumulative transpiration of the forest during the dry season, which lasts four to five months.

Kilian (1972) reported an important increase of interflow water along the slopes after clearing. Similar observations were made at IITA, where valleys in the cleared part became increasingly hydromorphic and where the flow of springs extended to well within the dry season, in contrast to spring flow in the non-cleared part. No quantitative measurements however, were made of these phenomena.

For the Basement Complex part of the study area, it may be expected that groundwater levels in the valleys will become higher due to an increase of interflow water after clearing.

4.2 MOISTURE CONDITIONS IN THE SURFACE SOIL ALONG THE TOPOSEQUENCE IN FUNCTION OF TIME AND LOCATION

4.2.1 Texture and organic matter content in relation to pF-values

To characterize surface soils with respect to fluctuations in moisture content and moreover the availability of water, pF-values were determined. Fig. 4.8 shows some pF-curves of surface soils, sampled in Eastbank area I; most surface soils in the IITA study areas have pF-curves between nos. 1 and 4.

The moisture retention characteristics of the soil, determined by pF-values, are strongly related to texture, clay mineralogy, and organic matter content (Salter and Williams 1966, 1969; Abrol et al. 1968; Dijkerman 1975; Lal 1978). According to Shaykewich (1970), air-drying and sieving the samples influences the retention characteristics. For field capacity of a soil, pF 2.0 or pF 2.5 can be taken, but the former value is more realistic in the study area (Vine 1970, Dijkerman 1975, Lal, personal communication).

In order to calculate the available moisture of soil profiles, in the case of missing pF-determinations, a regression analysis for texture components and percentage of organic C on the one hand and the difference between the moisture content (on weight basis) at pF 2.0 and 4.2 on the other was done for 36 surface soil samples of Eastbank area I. Their textures ranged from sand to sandy loam (particle sizes taken: more than 20 μ - sand, 2 to 20 μ - silt, less than 2 μ - clay) and their organic C contents ranged from 0.3 to 1.7 per cent. The highest correlation coefficient was reached by applying formula (1):

$$\text{pF } 2.0 - \text{pF } 4.2 = 34.54 - 0.34 \text{ (per cent sand)} + 1.93 \text{ (per cent organic C)} \quad (1)$$

$r = 0.85^{+++}$

With percentage sand = 100 - percentage (silt + clay), formula (2) results:

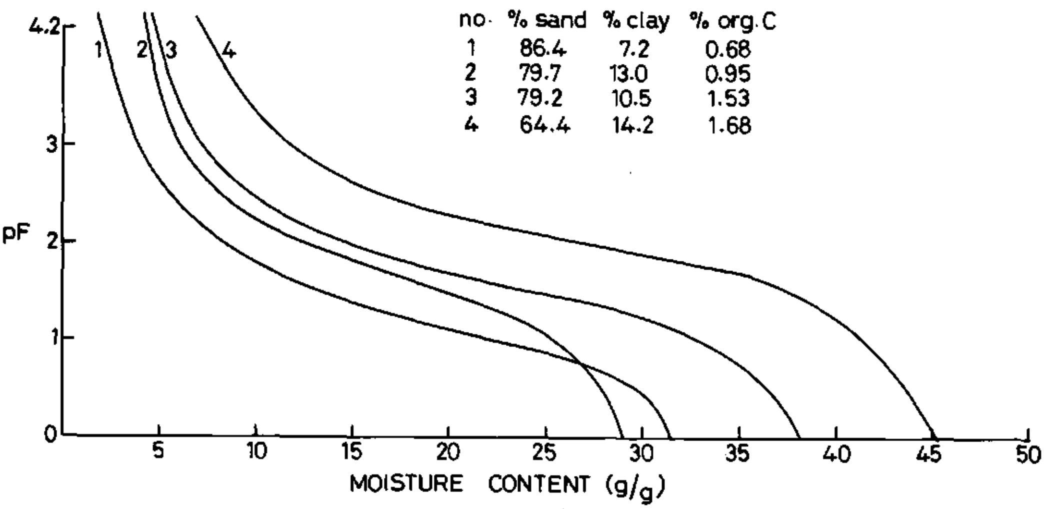


Fig. 4.8. pF-curves of four different surface soils.

$$pF\ 2.0 - 4.2 = 0.54 + 0.34\ (\text{per cent silt + clay}) + 1.93\ (\text{per cent organic C}) \quad (2)$$

The correlation of the available moisture with the percentages of silt, clay and organic C was also found to be highly significant (formula 3)

$$pF\ 2.0 - pF\ 4.2 = 0.56 + 0.39\ (\text{per cent silt}) + 0.27\ (\text{per cent clay}) + 1.78\ (\text{per cent organic C}) \quad (3)$$

$r = 0.85^{+++}$

No significant correlation was found between texture components and organic C and the difference between the moisture content (on weight basis) at pF 0 and pF 2.0.

4.2.2 Annual variations in moisture conditions of the surface soil along the toposequence

Moisture conditions in the surface soil can be related directly to rainfall or to the introduction of water from elsewhere, e.g. by groundwater flow, by interflow, by surface flow or by their combinations. To evaluate the resulting variations, gravimetric moisture determinations in the surface layers were made along the toposequence. These determinations were done in Eastbank area I. Three locations on the slope were taken as characteristic sites; they are indicated in Fig. 3.4 by I, II, and III. Location I is the "dry-land" location, which is not influenced by groundwater; location III is the "wet-land" location, strongly influenced by groundwater; location II is intermediate between locations I and III. In Table 4.1, the particle size distribution and the organic C content of the three locations are given, together with the moisture contents at three pF-values. Fig. 4.9 gives the fluctuation of the moisture content of the 10 to 20 cm layer with time during 1973 to 1975, including two rainy seasons and two dry seasons. From this figure a distinct progression from "dry-land" to "wet-land" can be inferred. The 10 to 20 cm layer was chosen because it is less influenced by rapid superficial drying than the 0 to 10 cm layer.

In the dry-land position, the moisture content closely followed the rainfall pattern, with a severe drying-out of the soil in the dry season and with short duration drying-out during periods of the rainy season in which the rain failed. The surface soil of location

Table 4.1. The particle size distribution, the organic C content and the moisture contents at three pF-values of three locations on the toposequence, Eastbank area I (sampling depth 10-20 cm).

location	particle size distribution			org. C	moisture content at		
	sand	silt	clay		pF 0	pF 2.0	pF 4.2
		per cent		per cent		weight per cent	
I	71.4	11.4	17.2	0.92	40.4	16.0	6.2
II	79.4	8.4	12.2	0.92	33.6	11.7	5.0
III	78.4	10.4	11.2	0.68	32.3	13.2	3.9

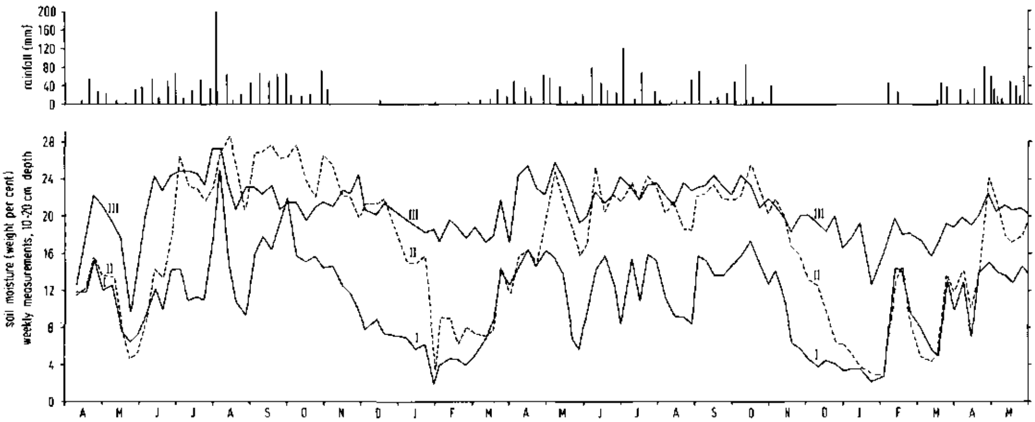


Fig. 4.9. Weekly soil moisture determinations at 10-20 cm depth on three locations on a toposequence, Eastbank area I, and the weekly rainfall, April 1973 to May 1975.

I had a moisture content above field capacity (pF 2.0) only after heavy rains or during periods with regular rains, which is normal for well-drained conditions.

The evolution of the moisture content in the lowest location (III) was mainly determined by inflowing groundwater. Some influence of the dry season could be observed, but this was mainly due to a diminished water supply from elsewhere. Hence, variation in moisture content in the rainy season did not necessarily coincide with rainfall variation. Complete saturation (at pF 0) did take place in the field, but the low accuracy of sampling very wet soil material caused moisture contents that were somewhat less.

The intermediate position (II) was specifically chosen to represent the transitional moisture pattern of a soil which was wet and strongly influenced by groundwater in the rainy season and where the moisture content in the surface soil was independent of the groundwater in the dry season. Location II had moisture contents below field capacity during the latter half of the dry season and during severe drought periods in the rainy season. The decrease in moisture content at the onset of the dry season was a consequence of the gradual decrease of inflowing groundwater. At the beginning of the rainy season the first rains moistened the surface soil, but it was some weeks before a rise in the groundwater directly influenced the moisture content of the surface soil.

While these examples are local-specific, the pattern demonstrated may be generalized, taking into account the rainfall pattern, the topographic position, and the nature of inflow.

According to the rainfall pattern and the fluctuation of the moisture content in the surface soil, four cropping seasons have been defined:

- the early first season: from the first rains to mid-April when groundwater levels start to rise to the first peak height because of the regularity of rainfall.
- the major first season: from mid-April to the end of the short dry season in August.
- the second season: from the first rains after the short dry season in August to

about 2 to 3 weeks after the last regular rains, usually about 1st December.

- the dry season: from about 1st December to the first rains, usually in March.

The early first season is especially used for maize, which is harvested green in May. The unripe cobs can be sold for relatively high prices.

To evaluate the availability of water per growing season, the moisture situation of the root zone is taken as one of the elements to be used in determining the land quality "availability of water", which will be discussed in Section 5.2.1. The moisture situation of the root zone is determined qualitatively per groundwater class per season by extrapolation of the moisture content data of the 10 to 20 cm layer. The moisture situation of the root zone is defined in terms of pF-values, using the following pF-ranges:

less than 0 - saturated
0 to 2.0 - wet
2.0 to 4.2 - moist
more than 4.2 - dry

To characterize a situation in which a soil is "moist" for most of the time during a season but may become dry in severe drought periods, the characterization "moist$^+$" is used.

The locations I and III of Fig. 4.9 show two situations which can serve as examples of the determination of the moisture situation of the root zone during the seasons. Location I represented a situation with groundwater class 1 during the dry season and classes 1 or 2 in the other seasons; the degree of wetness increased from the early first to the second season. The moisture situation of the root zone can be characterized as dry, moist$^+$, moist$^+$-moist and moist for the dry, early first, major first and second season respectively. Location III, on the other hand, represented the following groundwater classes: dry season - class 6; early first season - class 9; major first season - class 10; second season - class 11 and the moisture situation of the root zone can be characterized as wet, wet, wet to saturated and saturated respectively. The interpretation of the other combinations of season and groundwater class could be determined with the use of the available data on moisture contents of the 10 to 20 cm layer in Eastbank area I. In Table 4.2 the moisture situation of the root zone per groundwater class is given for each of the four seasons. The moisture situation of the root zone, determined with the pF-ranges mentioned above, is meant as indicative for the study area, independent of the soil characteristics. Differences in soil characteristics concerning the moisture situation are not included in the determination as this aspect will be applied in another determinant of the land quality "availability of water".

Table 4.2. Moisture situation of the root zone per groundwater class per season.

groundwater class	season			
	dry	early first	major first	second
1	dry	dry-moist$^+$	moist$^+$-moist	moist
2	dry-moist$^+$	moist$^+$	moist$^+$-wet	moist-wet
3	moist-wet	moist-wet	moist-wet	moist-wet
4	dry-moist$^+$	moist$^+$-moist	moist(-wet)	moist-wet
5	moist-wet	moist-wet	moist-wet	wet
6	wet	wet	wet	wet
7	wet	wet	wet	wet
8	(moist)-wet	wet	wet	wet
9	wet	wet	wet	wet-saturated
10	wet	wet	wet-saturated	wet-saturated
11	saturated	saturated	saturated	saturated

moist$^+$: moist most of the time, but dry during dry spells.

5. LAND QUALITIES

5.1 INTRODUCTION

A land quality is defined as a complex attribute of land which acts in a manner distinct from the action of other land qualities in its influence on the suitability of land for a specific kind of use (Beek and Bennema 1972, also FAO 1976). Land qualities form the basis of land evaluation. The final process of matching land qualities and crop requirements leads to conclusions about the suitability of a piece of land for certain agricultural uses. (More details about the procedure can be found in Section 7.1.)

Beek and Bennema give a list of possible land qualities, some of which, as far as crop productivity, management, and inputs are concerned, are given in Table 5.1. The present study was concentrated on food crops, so land qualities concerning domestic animal productivity and forest productivity have been omitted.

Only some of the land qualities mentioned in Table 5.1 were studied. The land was considered in the context of the existing climate and only those food crops were included that are common in the study area or suited to it. The qualities h, i, j, k, and l were therefore not relevant. Nor was salinity or alkalinity (o) because they do not occur in

Table 5.1. List of land qualities, concerning crop productivity, management, and inputs (Beek and Bennema 1972).

Land qualities related to crop productivity or other plant growth:
a. moisture availability
b. oxygen availability in the root zone
c. nutrient availability
d. adequacy of foothold for roots
e. conditions for germination
f. pests and diseases related to the land
g. flooding hazard
h. temperature regime
i. radiation energy and photo-period
j. climatic hazards affecting plant growth
k. air humidity as affecting plant growth
l. drying periods for ripening of crops
m. workability of the land
n. soil toxicity
o. salinity or alkalinity
p. resistance to soil erosion
q. crop yields (a resultant of many qualities listed above)

Land qualities related to management and inputs:
r. terrain factors affecting mechanization (trafficability)
s. terrain factors affecting construction and maintenance of access roads (accessibility)
t. size of potential management units
u. location in relation to markets and to supplies of inputs

the study area.

Pests and diseases related to the land (f) are mentioned to some extent in the discussion on crops (cf. Section 7.2), but this was not considered a separate land quality, owing to the crop-specificity and its interrelation with other land qualities. Flooding as a hazard (g) was not considered in the general sense of influencing crop suitability because, wherever flooding occurs within the study area, its influence on crop suitability is only minor. Nevertheless, it is known that short straw rice cultivars are susceptible to flash-floods at the beginning of the rainy season. In Sri Lanka flash-floods can be a severe constraint to the cultivation of these rice cultivars (Moormann, personal communication). Crop yields were not considered a land quality. Crop yields, resulting from toposequence experiments, were used, however, in later stages of the evaluation (see chapter 7).

Land qualities related to management and inputs have been included, but in a general context. Mechanization (r), as pointed out in Section 5.3.3, is not included in the study; only traditional management with and without simple improvements has been taken as management and technology levels (cf. Section 6.2). The size of potential management units (t) is considered in the same way; fields managed by the common smallholder in the study area, are generally small.

Table 5.2 lists the land qualities of this study; they have been separated into two categories, namely general and additional land qualities. General land qualities are relevant for every piece of land, whereas the additional land qualities are only relevant at particular locations. The occurrence of an additional land quality is therefore exceptional; when it exists within a soil unit, it is expressed by a special phase of that soil unit.

Among the land qualities, the *availability of water* and the *availability of oxygen* are the most important. These two qualities are interrelated in so far as *availability of oxygen* is important with high moisture contents. This integration is expressed by the use of groundwater classes. Because in a later stage of the study the requirements of crops were considered, land qualities, and in particular the availability of water and oxygen, were considered *per season*. This was done to express their dynamic character as a relevant quality related to crop suitability per season. An example of this seasonal character is shown in Fig. 4.2.

Table 5.2. General and additional land qualities considered in this study.

General land qualities:
- availability of water
- availability of oxygen
- availability of nutrients (fertility)
Additional land qualities:
- probability of occurrence of iron-toxicity (in rice)
- probability of occurrence of soil erosion
- difficulty of land preparation and harvesting of root crops
- (mechanical) impediment of root development

5.2 GENERAL LAND QUALITIES

5.2.1 Availability of water

In considering this land quality four aspects were taken into account:

- moisture situation of the root zone throughout a specific season
- groundwater class in that season
- available water-holding capacity of the soil in the root zone
- availability of water in the root zone by capillary rise from the groundwater.

Each of the four aspects has its own importance in determining the land quality *availability of water*, when this land quality is used to determine the suitability of a crop in a certain period.

Reference is made to Sections 4.1.3 and 4.2.2, where the division into groundwater classes and the moisture situation of the root zone were discussed. Figure 4.7 and Table 4.2, representing these two aspects, were used in determining the overall availability of water.

The available water-holding capacity of the soil was defined as the difference in moisture content at pF 2.0 and pF 4.2. To determine this difference, the regression equation (1) (Section 4.2.1) was used for the soil units 1-9 at IITA; the actually measured values were used for the soil units A-D of the Ikenne area. For each horizon, the available water-holding capacity (AW) was calculated according to the formula

$$AW = (F.C. - W.P.)\ d_s .\ (100/(100 + G))$$

in which:

AW = available water-holding capacity per horizon (Vol. per cent)

FC = moisture content at 0.1 bar suction (pF 2.0)

WP = moisture content at 15 bar suction (pF 4.2)

d_s = bulk density

G = percentage gravels (more than 2 mm diameter); gravels excluded from soil sample.

The bulk density of the surface soil under forest conditions is generally low; after clearing and under cultivation, the bulk density of the surface soil increases. In the calculation, a value of 1.4 g/cm^3 was taken as a theoretical value; it is the average bulk density of the surface soils in Eastbank area I. For well-drained soils on upper slopes, however, Curfs (1976) found even higher bulk density values for surface soils after several years of mechanical cultivation.

Organic matter losses during cultivation range from 7.5 to 2.6 per cent a year (IITA 1975a, Nye and Greenland 1960). For the calculation of the difference in moisture content at pF 2.0 and pF 4.2, the organic C content of the 0-15 cm depth of the surface soils at IITA was diminished by 5 per cent of the total organic C content, being the average rate of decline of organic C content in surface soils under the existing cultivation system.

A correction was made for the gravel content, since gravels are assumed to have no water-holding capacity.

Given in Appendices D and E respectively, are the determination of the difference in moisture content at pF 2.0 and pF 4.2 and the determination of the available water-holding capacity per horizon for soil units 1-9 (IITA) and A-D (Ikenne).

Rooting systems differ among crops; moreover, roots in the early stage of growth are shallower than in the later stages. This means that the available soil depth for moisture extraction by roots differs among crops and among their different stage of development. To take these differences into account in calculating the relevant availability of soil moisture, two sets of coefficients were introduced, i.e. one for shallow-rooting crops and crops in their early development stage, and one for deeper rooting crops in their later stages. Both groups have the same coefficient for the 0-30 cm depth, but differ in the 30-80 cm depth. Gradually diminishing coefficients were used for depths below 30 cm: for the shallow-rooting group up to 60 cm, for the deeper-rooting group up to 80 cm (Table 5.3). The equations used for the two cases are:

$$AW_s = a_1b_1 + a_2b_2 + \ldots\ldots\ldots\ldots + a_6b_6 \quad (4)$$

$$AW_d = a_1b_1 + a_2b_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_8b_8 \quad (5)$$

In these equations, AW_s and AW_d are the total available water-holding capacities in mm for the shallow (s) and deeper (d) rooting conditions, respectively; a is the coefficient applied for each increment with depth of 10 cm; b is the available water-holding capacity per horizon (in volume percentage).

Table 5.4 gives the determined AW_s and AW_d values for the soil units, as calculated with equations (4) and (5), respectively, and based on the available water-holding capacity (AW) per genetic horizon (Appendix E); Table 5.4 also gives the grading system of both values. Due to the generally small differences in the available water-holding capacity of the horizons, especially those at depths of 30-80 cm, the difference between AW_s and AW_d was too small to separate them into different grades for each of the two rooting conditions. However, when the deeper subsoil (60-80 cm) has an available water-holding capacity remarkably different from the upper part of the soil, different grades for AW_s and AW_d may occur. In that case, a separation of land quality *availability of water* is necessary to determine the suitability of shallow and deeper rooting crops separately.

Table 5.3. Coefficients applied to 10 cm soil layers with respect to rooting systems or stage of growth.

depth (cm)	coefficient	
	shallow rooting system or early stage of growth	deeper rooting system or later stage of growth
0-10	1.0	1.0
10-20	1.0	1.0
20-30	1.0	1.0
30-40	0.6	0.8
40-50	0.3	0.6
50-60	0.1	0.4
60-70	0.0	0.2
70-80	0.0	0.1

Table 5.4. AW_s and AW_d (in mm) as determined for the soil units and their grade.

soil unit	AW_s	AW_d	grade[1]	remarks
1	73.4	93.5	high	very high, when more clayey (phase 1^{cl})
2	53.1	66.0	medium	
3	55.0	70.7	medium	
4	33.9	42.7	low	very low, when coarse sandy (phase 4^{cs})
6	39.6	47.1	low	
7	52.9	64.8	medium	
9	73.8	96.5	high	very high, when eroded (phase 9^{er})
A	50.7	66.5	medium	
B	56.4	75.7	medium	
C	71.3	93.7	high	
D	57.8	69.7	medium	

No determinations were done for units 5 and 8; by interpolation, grades for these soil units are both estimated as medium

[1] Grading system:

grade	abb.	AW_s	AW_d
very high	(vh)	more than 75	more than 100
high	(h)	60-75	80-100
medium	(m)	45-60	60-80
low	(l)	30-45	40-60
very low	(vl)	less than 30	less than 40

For three soil units (1, 4, and 9) in which the AW_s and AW_d values are close to a lower or higher grade, phases were established on the basis of specific characteristics that influence the availability of water. These phases are important only for this land quality.

For a number of samples, both from IITA and the Ikenne areas, the capillary rise was determined by the method of Emerson and Bond (1963), who defined the height of capillary rise as the maximum height below which the moisture content is uniform. Water may rise above this height, but it will be restricted to progressively smaller pores. The height of capillary rise is used as an indicator of the effect of capillary rise on the availability of water in the root zone. Table 5.5 shows the height of capillary rise in a number of soil samples.

Fig. 5.1 shows the relation between the height of capillary rise and the clay content; for the IITA-samples a clear relation was found. On the basis of this relation, the capillary rise of the studied soil units was interpreted.

Determining the influence of capillary rise from the groundwater into the root zone was only relevant for seven groundwater classes, namely classes 2, 3, 4, 5, 6, 8, and 9. Of the other classes, class 1 is assumed to have no capillary rise into the root zone, as the groundwater in this class remains below 75 cm throughout the year; classes 7, 10, and 11, with groundwater levels at less than 25 cm depth, have a very high availability of water at any time, so for these classes any eventual capillary rise has no increasing effect on the land quality *availability of water*.

The expected average lowest groundwater level per groundwater class was taken as the basis for determining the influence of capillary rise from groundwater on the availability

Table 5.5. The height of capillary rise in soil samples from IITA and Ikenne, determined according to the method described by Emerson and Bond (1963).

IITA-samples: sample number	clay	silt	sand	org. C	height of cap. rise, cm
	per cent				
1	6	6	88	0.60	21.0
2	8	10	82	0.37	36.5
3	16	8	76	0.10	45.1
4	25	16	59	0.88	62.0
5	41	8	51	0.22	65.2
6	57	11	32	0.48	51.0
Ikenne-samples:					
1	7	17	76	0.20	43.7
2	14	12	74	0.57	57.0
3	25	4	71	0.29	32.2
4	29	13	58	0.18	47.1
5	33	9	58	0.23	50.2
6	45	2	53	0.30	40.0

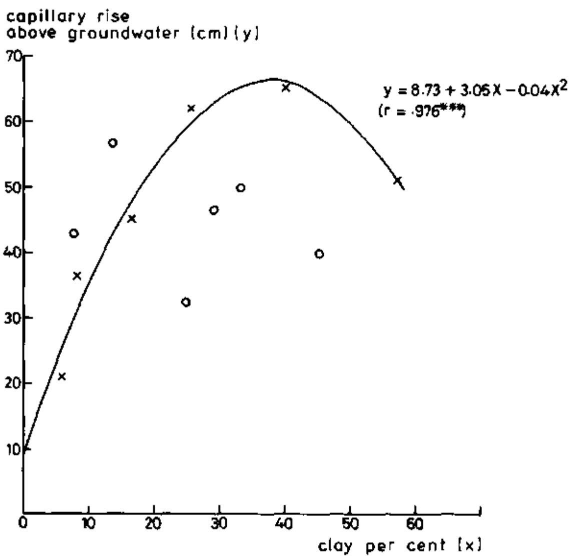


Fig. 5.1. The relation between the capillary rise in soil samples from IITA and Ikenne and their clay content, x IITA samples, o Ikenne samples.

of water in the root zone. The expected average lowest groundwater levels for the relevan groundwater classes are given in Table 5.6(A). A separation between the dry and early first season on the one hand and the major first and second season on the other hand was made to indicate the generally lower extreme groundwater levels of the dry and early firs seasons compared with those of the major first and second seasons.

For the relevant IITA soil units, the capillary rise was estimated from the relation between clay content and capillary rise (Fig. 5.1). As no such relation was available for the Ikenne soil units, the capillary rise for units C and D was estimated by comparison with the IITA units.

Table 5.6. A. Expected average lowest groundwater levels (in cm below surface)

season	groundwater class				
	2	3	4	5,8	6,9
dry or early first season	> 125	75	> 150	100	50
major first or second season	100	50	125	75	40

B. The depth of water saturation by capillary rise from the groundwater during average lowest groundwater level periods.

average lowest groundwater level (cm below surface)	soil units				
	1	2	3	4	6
150	97	90	118	105	100
125	59	65	93	95	75
100	45	65	50	70	58
75	30	44	32	45	36
50	10	23	10	25	15

C. Grading system for the estimated depth of water saturation by capillary rise from the groundwater on the basis of expected average lowest groundwater levels.

average lowest groundwater level (cm below surface)	grading
deeper than 50/55 cm	low (l)
25/30 - 50/55 cm	medium (m)
less than 25/30 cm	high (h)

D. Availability of water by capillary rise into the root zone for seven groundwater classes for the relevant soil units per season; A: dry or early first season; B: major first or second season.

soil unit	groundwater class									
	2		3		4		5,8		6,9	
	A	B	A	B	A	B	A	B	A	B
1	l	m	h	h	l	l	m	h	h	h
2	l	l	m	h	l	l	l	m	h	h
3	l	l	m	h	l	l	l	m	h	h
4	l	l	m	h	l	l	l	m	h	h
6	l	l	-	-	-	-	-	-	-	-
C	l	l	-	-	-	-	-	-	-	-
D	l	l	m	h	l	l	l	m	h	h

Addition of the maximum capillary rise per soil unit and the expected average lowest groundwater level per groundwater class results in the depth of water saturation by capillary rise during the period that the groundwater level is at the average lowest point within a groundwater class (Table 5.6(B)).

Grades were compiled to indicate the influence of capillary rise on the availability of water in the root zone. This depended on the depth of water saturation by capillary rise during the period when the average lowest groundwater level occurs (Table 5.6(C)).

On the basis of Table 5.6(A-C), the availability of water by capillary rise into the root zone could be determined for the relevant groundwater classes and soil units, separated into two groups of seasons (Table 5.6(D)).

Finally, the land quality *availability of water* was determined for the soil units and the groundwater classes. This was done according to the grading system given in Table 5.7. This system is based on the moisture situation of the root zone (Table 4.2) and the available water-holding capacity (Table 5.4). For each combination of these two factors, the grade of availability of water was qualitatively determined for the relevant groundwater classes and, if necessary, the influence of the capillary rise (Table 5.6(D)). Table 5.8 presents the availability of water of all soil units and groundwater classes, in the dry, early first, major first, and second season. For soil units 1, 4, and 9 special phases are mentioned, because of their different available water-holding capacities, as shown in Table 5.4: 1^{cl} being the more clayey phase of unit 1, 4^{cs} the coarse sandy phase of unit 4, and 9^{er} the eroded phase of unit 9.

5.2.2 *Availability of oxygen*

Oxygen in the soil plays an important role as final electron acceptor in the respiration of roots of intact plants and in their individual cells or tissues (Grable 1966). Harris and van Bavel (1957) stated that root respiration is the most sensitive aspect of plant activity in regard to soil aeration and that it may be assumed that reduction in respiratory activity is the first step in the growth-limiting effects of insufficient aeration. On a long-term basis, according to Grable (1966), the detrimental effect of oxygen deficiency can be explained by the fact that fermentation produces only a fraction of the usable energy produced by respiration and that subsequently energy-requiring processes suffer. This shortage of energy might explain the injury to roots by flooding, but, as indicated by Kramer (1951), lack of energy cannot explain why shoots are injured so quickly. After the flooding of a soil in which plants are growing, a rapid reduction in transpiration and water-absorbing capacity of the roots takes place and is usually followed by wilting of the shoots. While lack of water might explain the death of the leaves, it cannot explain the characteristic effects of flooding. Flooding probably stops the downward translocation of carbo hydrates and auxin; their accumulation at the waterline is possibly responsible for hypertrophy and for the development of adventitious roots. Accumulation of auxin in the lower half of the stem might also be responsible for the epinastic curvature of the leaves and petioles. The injury and death of the leaves may be caused, at least partly, by toxic substances moving up from the dead roots or even from the surrounding soil (Kramer 1951).

Among plants, there are differences in tolerance of low oxygen contents of the soil air; some have a highly functional fermentation system. Toxic products such as ethanol might be formed, but rice for instance is fairly tolerant to high ethanol contents (Grable 1966). Vlamis and Davis (1944) found no influence of aeration on the growth of young barley seedlings; on the other hand, tomato seedlings reacted strongly to aeration. Finn et

Table 5.7. Grading system for the overall availability of water.

available water holding capacity	moisture situation: wet — groundwater class	wet — cap. rise	wet — grade	moist — groundwater class	moist — cap. rise	moist — grade	moist$^+$ — groundwater class	moist$^+$ — cap. rise	moist$^+$ — grade	dry — groundwater class	dry — cap. rise	dry — grade
vh	2	-	vh	1	-	vh	1	-	h	1	-	l
	3	-	vh	2	-	vh	2	-	h	2	-	l
	4	-	vh	3	-	vh	4	-	h	4	-	l
	5	-	vh	4	-	vh						
	6	-	vh	5	-	vh						
	8	-	vh	8	-	vh						
	9	-	vh									
h	2	-	vh	1	-	h	1	-	m	1	-	l
	3	-	vh	2	h	vh	2	m - h	h	2	-	l
	4	-	vh		l - m	h		l	m	4	-	l
	5	-	vh	3	m - h	vh	4	m - h	h			
	6	-	vh		l	h		l	m			
	8	-	vh	4	h	vh						
	9	-	vh		l - m	h						
				5	m - h	vh						
					l	h						
				8	-	vh						
m	2	-	h	1	-	m	1	-	l	1	-	vl
	3	m - h	vh	2	h	h	2	m - h	m	2	-	vl
		l	h		l - m	m		l	l	4	-	vl
	4	-	h	3	m - h	h	4	m - h	m			
	5	-	h		l	m		l	l			
	6	-	vh	4	h	h						
	8	-	h		l - m	m						
	9	-	vh	5	m - h	h						
					l	m						
				8	m - h	vh						
					l	h						
l	2	-	m	1	-	l	1	-	vl	1	-	vl
	3	m - h	h	2	h	m	2	m - h	l	2	-	vl
		l	m		l - m	l		l	vl	4	-	vl
	4	-	m	3	m - h	m	4	m - h	l			
	5	-	m		l	l		l	vl			
	6	-	h	4	h	m						
	8	-	h		l - m	l						
	9	-	vh	5	m - h	m						
					l	l						
				8	m - h	h						
					l	m						
vl	2	-	l	1	-	vl	1	-	vl	1	-	vl
	3	m - h	m	2	h	l	2	-	vl	2	-	vl
		l	l		l - m	vl	4	-	vl	4	-	vl
	4	-	l	3	m - h	l						
	5	-	l		l	vl						
	6	-	h	4	h	l						
	8	-	m		l - m	vl						
	9	-	h	5	m - h	l						
					l	vl						
				8	m - h	m						
					l	l						

Explanation: moisture situation cf. Table 4.2
available water-holding capacity cf. Table 5.4
groundwater class cf. Fig. 4.7
cap. rise = capillary rise cf. Table 5.6(D)
grade = grade of overall availability of water, divided into:
vh: very high; h: high; m: medium; l: low and vl: very low.

Table 5.8 A. Overall availability of water for soil units 1, 2, 3, 4, and D, two phases (1^{cl} and 4^{cs}) and eleven groundwater classes for four seasons.

season	dry					early first					major first					second				
soil unit (ev. phase) groundwater class	1	1^{cl}	2,3,D	4	4^{cs}	1	1^{cl}	2,3,D	4	4^{cs}	1	1^{cl}	2,3,D	4	4^{cs}	1	1^{cl}	2,3,D	4	4^{cs}
1	l	l	vl	vl	vl	l-m	m	vl-l	vl	vl	m-h	h-vh	l-m	vl-l	vl	h	vh	m	l	vl
2	l-m	m	vl-l	vl	vl	m	h	l	vl	vl	h-vh	h-vh	m	vl-l	vl-l	h-vh	vh	m-h	l-m	vl-l
3	vh	vh	h-vh	m-h	l-m	vh	vh	h-vh	m-h	l-m	vh	vh	h-vh	m-h	l-m	vh	vh	h-vh	m-h	l-m
4	l-m	m	vl-h	vl	vl	m-h	h-vh	l-m	vl-l	vl	h-vh	vh	m-h	l-m	vl-l	h-vh	vh	m-h	l-m	vl-l
5	vh	vh	m-h	l-m	vl-l	vh	vh	m-h	l-m	vl-l	vh	vh	h	m	l	vh	vh	h	m	l
6	vh	vh	vh	h	h	vh	vh	vh	h	h	vh	vh	vh	h	h	vh	vh	vh	h	h
7	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh
8	vh	vh	h	m-h	l-m	vh	vh	h	h	m	vh	vh	h	h	m	vh	vh	h	h	m
9	vh	vh	vh	vh	h	vh	vh	vh	vh	h	vh	vh	vh	vh	h	vh	vh	vh	vh	h
10	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh
11	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh	vh

B. Overall availability of water for the soil units 5, 6, 7, 8, 9, A, B, and C, one phase (9^{er}) and two groundwater classes for four seasons.

season	dry							early first							major first							second						
soil unit (ev. phase) groundwater class	5	6	7,8	9	9^{er}	A,B	C	5	6	7,8	9	9^{er}	A,B	C	5	6	7,8	9	9^{er}	A,B	C	5	6	7,8	9	9^{er}	A,B	C
1	vl	vl	vl	l	l	vl	l	vl-l	vl	vl-l	l-m	m	vl-l	l-m	l-m	vl-l	l-m	m-h	h-vh	l-m	m-h	m	l	m	h	vh	m	h
2	-	vl	-	-	-	-	l-m	-	vl	-	-	-	-	m	-	l	-	-	-	-	h	-	l-m	-	-	-	-	h-vh

al. (1961) found a higher tolerance to high soil moisture contents for some grasses than for some legumes. In general, herbage yields of legumes increased with increasing availability of oxygen, whereas yields of grasses showed a tendency to decrease.

Geisler (1973) found a better growth of roots and dry matter production of maize under intermediate oxygen concentrations under moisture conditions between field capacity and wilting point. Whereas the increase of root length was determined by oxygen concentration, the dry-matter production was determined by the moisture content. With oxygen concentrations of less than 10 volume per cent, the number of first- and second-order roots of peas decreased, but more third-order roots were formed, resulting in a denser root system.

Carbon dioxide is produced mainly as a result of microbial dissimilation processes. CO_2 concentrations in the soil are seldom toxic; hence, stimulation of plant growth by CO_2 is more common than CO_2 toxicity (Grable 1966). According to Geisler (1973) a concentration of 1 to 2 volume per cent of CO_2 is optimal for root growth and dry-matter production. Even CO_2 concentrations of 8 and 16 volume per cent were tolerated by maize. In this respect, the difference in CO_2 concentration between roots and surrounding soil is important to enable roots to release CO_2.

Among major food crops, rice occupies a special position concerning the land quality *availability of oxygen*, as it is often grown in flooded yields (paddies). Within one or two days after a soil is flooded, the availability of oxygen decreases to zero. Aerobic micro-organisms rapidly consume the remaining oxygen and the rate of diffusion of atmospheric oxygen through the water layer is much slower than the rate at which oxygen is reduced in the soil. The upper few centimetres of a paddy soil, however, are in an oxidized form (Takai et al. 1956).

The rice plant is clearly adapted to flooded soil conditions. As stated by Vlamis and Davis (1944), rice can grow without aeration from the soil. Van Raalte (1940) showed that oxygen can be transported from the air downwards through the plant to the roots. Alberda (1953) found that a superficial root mat is formed at the end of the tillering period by horizontally growing roots; at this stage of growth the oxygen transport from the air through the plant is hampered and the development of a root mat at the soil surface makes oxygen transport through these roots to the rest of the root system possible.

After the oxygen concentration has diminished in a flooded soil, facultative and true anaerobic micro-organisms multiply rapidly and take over the decomposition of organic matter from the aerobic micro-organisms using, instead of oxygen, oxidized soil components as electron acceptors. Different soil components reduce in the following sequence: nitrates, manganese oxides, ferric oxides and hydro-oxides and, at a further stage, also sulphates (Ponnamperuma 1964).

Nitrate is usually present in small amounts and soon after flooding is completely reduced. Hydrated ferric oxides and manganese oxides are usually present in much larger quantities, and serve as buffers against the development of strong reducing conditions in the soil (Takahashi 1960). This buffering takes place at intermediate redox potentials of +100 to +300 mV, and both iron and manganese components must be completely reduced before intense reduction can set in. Prolonged waterlogging is usually necessary before all the hydrated ferric oxyde is reduced (Patrick and Mahapatra 1968). The reduction process is intensified by the presence of easily decomposable organic matter (Ponnamperuma 1964).

The most important processes taking place upon flooding are summarized by Ponnamperuma (1964). They include:

- accumulation of gases such as CO_2, H_2 and CH_4.
- reduction of nitrate to e.g. N_2.
- reduction of manganese and iron oxides to Mn^{2+} and Fe^{2+}.
- reduction of sulphates to sulphides.
- considerable increase in the concentrations of Ca^{2+}, Mg^{2+}, K^+, Na^+, $H_2PO_3^-$ and HCO_3^- in the interstitial water.
- production of ammonia and soluble organic compounds as a result of the anaerobic decomposition of fresh organic matter.
- stabilization of the pH between 6.5 and 7.0 and decrease of the redox-potential.

Studies on the partial pressure of CO_2 in paddy fields were done at the International Rice Research Institute (IRRI 1964). It was reported that shortly after flooding, the partial CO_2 pressure increases to 0.2 to 0.8 atm., but decreases to values between 0.05 and 0.2 atm. after 2 to 6 weeks. Especially high partial CO_2 pressures directly after flooding were measured in soils with a low pH, a high organic matter content, and a low manganese content.

Discussed in sections 5.2.3 and 5.3.1 are the processes in flooded soils with respect to the availability of nutrients and the occurrence of iron toxicity.

Attempts to determine the composition of the soil atmosphere with time at shallow depth on four locations on a toposequence in Eastbank area I failed because of the lack of standard samples and irregularities with the gaschromatography equipment. Qualitatively, the CO_2 content was higher in the two lower wet locations than in the two higher and well-drained locations; the variation in O_2 content, unfortunately, is unknown. Therefore, from the scarce data of Burford (1975) (Table 5.9), some conclusions were drawn. Burford analysed the composition of the soil atmosphere in some surface soils of IITA at the end of the rainy season in 1975, just after the last rains. Results from this study indicate that severe oxygen deficiency did not develop in the surface soils on well-drained sites during periods of high soil moisture content. The oxygen concentrations were in the range of 17.8

Table 5.9. Soil atmosphere composition at 15 cm depth on the toposequence of Eastbank area I (after Burford 1975).

position	27 October			29 October		
	O_2 per cent	CO_2 per cent	other gases	O_2 per cent	CO_2 per cent	other gases
upslope	15.6	0.40	nd	20.5	0.50	nd
midslope	nd	6.25	nd	nd	6.97	13 ppm N_2O
downslope	nd	nd	0.3 ppm C_2H_4	15.7	2.39	3.9 % CH_4

Note: nd = not determined.

Remarks: during the two weeks previous to measuring it rained every day, with high rainfall on October 18 (34 mm), October 24 (27 mm) and October 26 (12 mm). The rain on October 26 was the last of the rainy season.

to 20.6 per cent with CO_2 concentrations of 0.30 to 0.51 per cent. Sampling on the midslope position on the toposequence in Eastbank area I yielded only water samples; in wet soils extraction of soil-air by syringes easily leads to extraction of water as well, which causes problems when determining the soil atmosphere in a gaschromatograph. The CO_2 concentration in the water samples indicated oxygen depletion. The detection of methane in the downslope site, together with the iron exudations on the midslope site, demonstrated that the intensity of reduction in the soil was much greater than required for nitrate reduction.

On a toposequence in Eastbank area I, the soil solution was sampled at the same sites as used by Burford: a midslope and a downslope site (cf. Appendix C). The difference between the two is that the midslope site is saturated with water only during the height of the rainy season, while the downslope site is flooded almost throughout the year. The HCO_3^- concentration was determined in the soil solution samples (cf. Appendix C). From these values, the partial CO_2 pressures were calculated using the following equation:

$$P_{CO_2} = a_{H^+} \cdot a_{HCO_3^-} / k \cdot K_1 \text{ (after Ponnamperuma et al. 1966)}$$

in which:

P_{CO_2} = the partial pressure of CO_2 in atmospheres

a_{H^+} = the activity of hydrogen ions (derived from pH according to $a_{H^+} = 10^{-pH}$)

$a_{HCO_3^-}$ = the activity of bicarbonate ions (the activity coefficient of HCO_3^-, being taken as 0.916)

k = the solubility coefficient of CO_2 in water ($= 10^{-1.47}$)

K_1 = the first dissociation constant of H_2CO_3 ($= 10^{-6.38}$)

The calculated P_{CO_2} values are given in Table 5.10. The observed pH-log P_{CO_2} relation on the midslope and downslope sites is given in Fig. 5.2. In one year, the P_{CO_2} ranged from 0.005 to 0.085 atm. at the midslope site and from 0.076 to 0.160 atm. at the downslope site. Although the pH-log P_{CO_2} relation for the downslope site is not very clear,

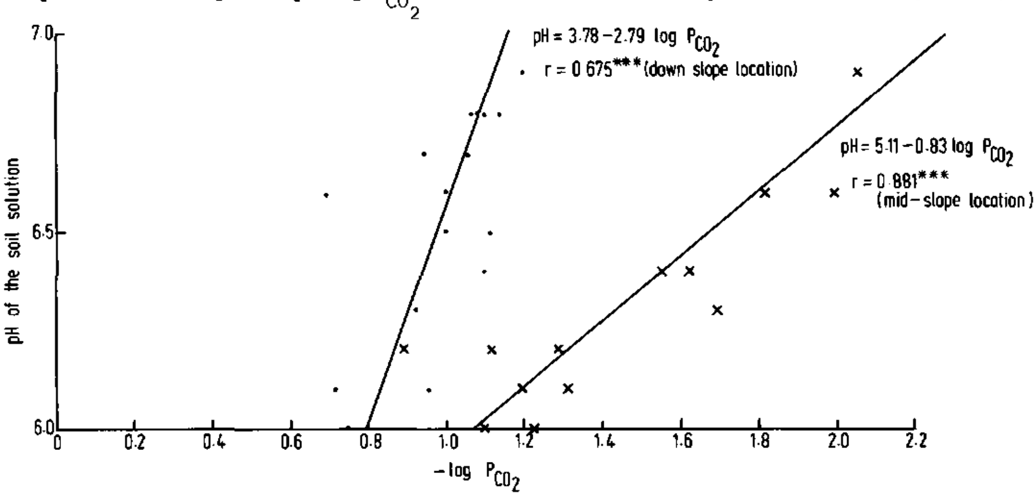


Fig. 5.2. The relation between P_{CO_2} and pH on two sites on the toposequence in Eastbank area I.

Table 5.10. The calculation of P_{CO_2} values from pH and HCO_3^- determinations for two sites on a toposequence in Eastbank area I according to the formula $P_{CO_2} = 10^{-pH}.\left[HCO_3^-\right].0.916 / 10^{-1.47}. 10^{-6.38}$.

pH	HCO_3^- (ppm)	P_{CO_2} (atm)	$-\log P_{CO_2}$
<u>midslope position</u>			
6.9	70	0.009	2.05
6.6	60	0.015	1.82
6.6	40	0.010	2.00
6.4	70	0.028	1.55
6.4	60	0.024	1.62
6.3	40	0.020	1.70
6.2	80	0.051	1.29
6.2	120	0.076	1.12
6.2	200	0.127	0.90
6.1	60	0.048	1.32
6.1	80	0.064	1.19
6.0	80	0.081	1.09
<u>downslope position</u>			
6.9	500	0.063	1.20
6.8	460	0.073	1.14
6.8	500	0.079	1.10
6.8	520	0.083	1.08
6.8	540	0.086	1.07
6.7	440	0.089	1.05
6.7	560	0.113	0.95
6.6	400	0.101	1.00
6.6	800	0.202	0.69
6.5	240	0.076	1.12
6.5	320	0.102	0.99
6.4	200	0.080	1.10
6.3	240	0.121	0.92
6.1	240	0.192	0.72
6.1	140	0.112	0.95
6.0	180	0.181	0.74

the pH-log P_{CO_2} relations are different from those of Ponnamperuma et al. (1966) for lowland rice soils from the Philippines, Taiwan, and Viet Nam; the intercept is higher and the gradient is lower than their values.

It may be concluded that although no low oxygen values were measured in the surface soils on the slope of the toposequence in Eastbank area I, oxygen depletion occurs in the flooded soils at the lower end of the toposequence, together with an increased amount of CO_2 and occasionally other gases such as N_2O, C_2H_4, and CH_4. The laterally moving groundwater probably contains a certain amount of oxygen. The CO_2 concentrations are generally no higher than normal values of paddy soils and are not considered toxic, except perhaps the values of 6 to 7 per cent as measured by Burford.

Due to the lack of enough exact data about the aeration status of the soils and the oxygen regime in the groundwater classes, a qualitative way of division of the land quality *availability of oxygen* was followed. Three situations were distinguished:

- permanently saturated soils (groundwater class 11)
- periodically saturated soils (groundwater classes 2-10)

- permanently unsaturated soils (groundwater class 1)

On the basis of this division, groundwater classes 1 and 11 were given the extreme grades in the land quality *availability of oxygen*: class 1 very high and class 11 very low. The intermediate groundwater classes were given grades by interpolation as shown in Table 5.11(A). According to the average highest and lowest groundwater levels, a grade of the availability of oxygen in the root zone (taken as less than 75 cm) was given. On the basis of these grades, the dominant grade(s) and, where applicable, secondary grade(s) were determined: two dominant grades mean that both grades occur within the groundwater class; a secondary grade means a grade that is relevant but is assumed to be less important than the dominant grade. No separation between seasons was made because the groundwater class, as main determining factor, is always determined for a specific season.

To give some relief to the differences in soil characteristics affecting the availability of oxygen in the root zone, the permeability and particle size class were taken as parameters for a qualitative distinction among soil units. This concerned only the "drier" groundwater classes 1, 2, 3, and 4. The availability of oxygen in the remaining "wetter" groundwater classes was assumed to be only slightly affected by soil characteristics, and was omitted in the final grading. The soil units 1, 7, 8, 9, and C had a slow permeability, while in unit 9 this was combined with a clayey particle class. As shown in Table 5.11(B) a correction in the grades of availability of oxygen was made by diminishing by $\frac{1}{2}$ or 1 grade. The overall availability of oxygen (Table 5.11(C and D)) results from the dominant grades and from the correction, if any.

5.2.3 Availability of nutrients

The land quality *availability of nutrients* has a complex nature, and data on several aspects of it were not available in the study area. The availability of nutrients can be determined for a special crop or, as was done in this study, it can be taken as general fertility status of the soil. In the special crop case, fertility trials have to be conducted to discover the response of a crop to a special nutrient on a particular soil so as to find out the original availability of that nutrient. According to the "Glossary of Soil Science Terms" (SSSA 1971) "fertility" is "the status of a soil with respect to the amount and availability to plants of elements necessary to plant growth". The Soil Survey Manual (1951) defines "soil fertility" as "the quality that enables the soil to provide the proper compounds in the proper amounts and in the proper balance for the growth of specified plants when other factors, such as light, temperature, moisture, and the physical conditions of the soil, are favorable". In this study, the concept of "natural fertility" agrees with both definitions. Some aspects of the specified reaction of soil and plant to applied fertilizers will be discussed.

An important factor in soil fertility is the management of the soil, especially in the clearing of the land. In this respect, the type of vegetation and the method of clearing are the main factors (Nye and Greenland 1960, Sanchez 1973, Seubert 1975, Kang and Moormann 1977). Permanent agricultural systems for annual crops are unknown in the study area. Bush fallow is practised with about 2 to 3 years of cultivation alternating with a fallow period lasting from 4 to 20 years. The availability of nutrients in particular and

Table 5.11 A. Grades of availability of oxygen for the groundwater classes.

groundwater class	grade according to average highest groundwater levels	grade according to average lowest groundwater levels	dominant grade(s)	secondary grade(s)
1	vh	vh	vh	-
2	m-h	vh	h-vh	m
3	m-h	m-h	m-h	-
4	vl-l	vh	h	l,m,vh
5	l	h	m	l,h
6	l	m	l-m	-
7	l	l	l	-
8	vl	h	l-m	vl,h
9	vl	m	l	vl,m
10	vl	l	vl-l	-
11	vl	vl	vl	-

B. Qualitative correction due to soil factors of the grades of the availability of oxygen for groundwater classes 1, 2, 3, and 4.

soil unit	permeability	particle size class	correction in grade
1	slow	loamy	$-\frac{1}{2}$
2	rapid	loamy	0
3	rapid	loamy	0
4	rapid	sandy	0
5	rapid	loamy	0
6	rapid	loamy-skeletal	0
7	slow	loamy-skeletal	$-\frac{1}{2}$
8	slow	loamy	$-\frac{1}{2}$
9	slow	clayey	- 1
A	rapid	clayey	0
B	rapid	loamy	0
C	slow	loamy	$-\frac{1}{2}$
D	rapid	loamy	0

C. Overall availability of oxygen for soil units 1, 2, 3, 4, and D and eleven groundwater classes.

soil units / groundwater class	1	2,3,D	4
1	h-vh	vh	vh
2	h	h-vh	h-vh
3	m	m-h	m-h
4	m-h	h	h
5	m	m	m
6	l-m	l-m	l-m
7	l	l	l
8	l-m	l-m	l-m
9	l	l	l
10	vl-l	vl-l	vl-l
11	vl	vl	vl

D. Overall availability of oxygen for soil units 5, 6, 7, 8, 9, A, B, and C and two groundwater classes.

soil units groundwater class	5	6	7,8	9	A,B	C
1	vh	vh	h-vh	h	vh	h-vh
2	-	h-vh	-	-	-	h

the natural fertility in more general terms are strongly related to the present stage of the land in the cultivation-fallow cycle and to former cultivation and fallow practices. At the end of the cultivation period, the low fertility status of the soils becomes besides weed control, the main reason for the farmer to abandon the land and to start on a freshly cleared piece of land. The influence on soil fertility of the method of removal of the fallow vegetation and the type of vegetation was not considered in the determination of the land quality. An estimate was made of the natural fertility status, mainly considering qualitatively the expected degeneration of the fertility of the various soil units under cultivation after a relatively long fallow period.

The elements discussed in this section are nitrogen, phosphorus, potassium, and sulphur, with special attention to nitrogen because of its specific behaviour in hydromorphic soils.

Nitrogen

Nitrogen is the most important single element affecting the growth and performance of crops in the study area. In soil, nitrogen is present both in organic and inorganic form, the organic form being the more abundant. In the soil solution, plant-available N is present as NO_3^- and NH_4^+, while NH_4^+ can also be available in exchangeable form. Plants take up nitrogen as nitrate or ammonium.

It is well known that analytical estimates of total soil N are not always reliable as a measure of N-availability, especially when availability over a whole growing season is considered. Factors such as the rate of mineralization of organic N, leaching, denitrification, volatilization, and run-off influence the availability of N especially in paddy soils, but also, to a lesser extent, in better drained soils.

In the area under consideration, the total N contents in surface soils under forest or bush re-growth range from 0.08 to 0.35 per cent. The N level is therefore moderate. In general, the first crop grown after clearing, at least on well-drained land, hardly responds to added nitrogen. During cultivation, the N content of the soil follows the same trend as that of organic C values, which range from 1.4 to 3.7 per cent. The C/N ratios of the surface soils vary between 7 and 14 (Anon. 1975).

The decomposition of organic matter in the soil is generally microbially regulated with a wide range of heterotrophic micro-organisms involved. The anaerobic decomposition of organic matter in waterlogged soils differs from aerobic decomposition by its much slower rate, anaerobic bacteria operating at a much lower energy level than aerobic bacteria (Tenney and Waksman 1930, Tusneem and Patrick 1971). Hence, organic N is released more slowly under anaerobic conditions, but the inorganic N release from decomposing organic matter starts at a wider C/N ratio under waterlogged conditions than under well-drained conditions (Acharya 1935 and Sircar et al. 1940, cited by Patrick and Mahapatra 1968).

The most important aspect to be taken into consideration when estimating the availability of soil nitrogen in hydromorphic soils is the extent to which nitrogen is lost from such soils. Important in this respect are leaching of NO_3^-, denitrification resulting in a loss of N_2 and N_2O to the atmosphere, ammonia-volatilization, and run-off.

Denitrification is one of the major mechanisms by which nitrogen is lost from a waterlogged soil. Oxidized forms of nitrogen are used by certain facultatively anaerobic micro-organisms as electron acceptors, and are reduced to N_2 or N_2O. The rapidity with which nitrate is denitrified in a waterlogged soil depends largely on the availability of an energy source (organic matter), since denitrifiers occur in large amounts in most soils (Alexander 1961). Frequent fluctuations in the moisture content of a soil as a result of flooding and drainage create ideal conditions for denitrification. Nitrogen, converted to the nitrate form in the period when the soil is drained, is lost through denitrification when the soil is flooded (Patrick and Mahapatra 1968). In a laboratory experiment with a soil containing 1000 ppm total N of which 18 ppm was NO_3^- - N, Patrick and Wyatt (1964) observed large losses of nitrogen up to 20 per cent of the total N, or 400 kg/ha, as a result of several drying and submergence cycles. A major portion of the loss occurred during the first submergence period. Continuously submerged soils lose only the nitrate initially present. Cooper and Smith (1963) found that the time period required for complete reduction of 300 ppm NO_3^- in an incubated soil, to which KNO_3 was added, was only 28 to 96 hours at a temperature of 30 $^{\circ}C$. Grable (1966) stated that nitrogen losses from submerged soils by denitrification range from 20 to 500 ppm NO_3^- - N per day. Current research at IRRI, Philippines, seems to indicate that N-losses from rice soils by denitrification are confined mainly to N applied as fertilizer (Moormann, personal communication).

Leaching of nitrate can easily occur during periods of heavy rainfall. In soils with high groundwater levels, however, nitrate, if leached into the reduced soil, can be denitrified, depending on the presence of organic matter. Ammonium is less subject to leaching because of its being adsorbed on exchange sites. Displacement of adsorbed ammonium by ferrous and manganous ions may cause some leaching of ammonium (Patrick and Mahapatra 1968).

Ammonia volatilization is an important form of N-loss in places where a high ammonia concentration occurs in conjunction with a high pH, a high temperature, and a low CEC value (Willis and Sturgis 1944). In experiments in the Philippines, ammonia volatilization occurred especially during the first five to ten days after broadcast application of 100 kg N/ha; in 21 days, 8.1 per cent urea and 3 per cent ammonium sulphate were lost (IRRI 1972). Waterlogged soils, which have a pH-value around 7.0, may be subject to N-losses by NH_3-volatilization. Current research at IRRI, Philippines, indicates an increased growth of algae after broadcast application of any N-fertilizer, normally urea, causing a temporary increase in pH of the surface water, sometimes to values above 9, which in turn induces NH_3-volatilization (Moormann, personal communication).

Run-off can be a possible form of N-loss, but the nitrate content of surface water is generally very low (Patrick and Mahapatra 1968).

On the toposequence in Eastbank area I, locally acute N-deficiency was observed in rice in most cropping seasons. It mainly occurred halfway down the slope in the area where the surface soils are alternately wet (reduced) and moist (oxidized) owing to groundwater fluctuations in the superficial soil layers (Fig. 5.3). It should be pointed out that all plots in the toposequence receive a uniform application of N. Table 5.12 shows the N-contents, as percentage and as total N per plant, of above-ground parts of one-month old

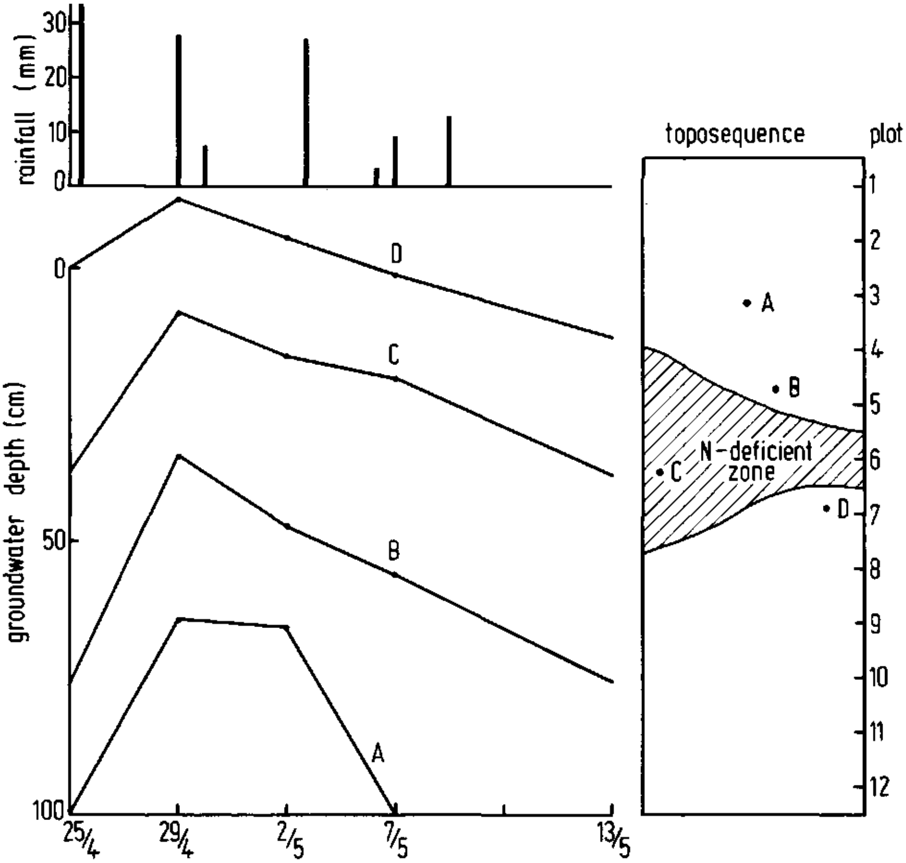


Fig. 5.3. The occurrence of a N-deficient zone on the toposequence in Eastbank area I in relation to groundwater depth and rainfall.

Table 5.12. Colour and N-content of above-ground parts of young rice plants, as affected by location on the toposequence in Eastbank area I (means of twenty plants) (after Moormann, Veldkamp, and Ballaux, 1977).

location on toposequence	colour of leaves	dry matter weight g/plant	N-content of dry matter per cent	total N mg/plant
A	green	0.124	3.70	4.6
B	intermediate green	0.102	2.63	2.7
C	yellow-green	0.066	1.43	0.9
D	intermediate green	0.102	2.57	2.6

soil gives the highest rate of denitrification; groundwater class 7 was therefore given the lowest rating. Class 11, with groundwater above the soil surface throughout the observation period, was rated high, assuming that nitrogen fertilizer is applied in the ammoniu form. The response to applied N was not assumed to be very high in class 11, because of some losses by denitrification, leaching, and volatilization (if pH is about 7.0 or higher). Class 1 with no groundwater within 75 cm depth was given a very high rating, assuming that leaching losses could be neglected. The other groundwater classes were interpolated. Table 5.14 shows the results.

Phosphorus

Phosphate deficiency in the second limiting nutritional factor. The total P-content of surface soils ranges from 217 to 638 ppm for soils on the Basement Complex and from 191 to 243 ppm for soils on the sedimentary formations. The organic P-content was correlated in the study area with soil pH, organic matter content, and total P-content (Uzu et al. 1975). In surface soils of the Basement Complex, about 65 per cent of the total P is in organic form (an average of 260 ppm); on sedimentary formations this is about 30 per cent (an average of 87 ppm). Occluded P, including the reductant soluble Fe-phosphate and the (Al, Fe)-phosphate occluded in Fe-oxides, forms by far the largest component of the inorganic P in well-drained soils, followed in decreasing order of importance by Fe-P, Al-P, and Ca-P. In general, the levels of Fe-P, Al-P, and Ca-P in poorly drained soils differ only slightly from each other, whereas occluded P remains the predominant form of inorganic P (Uzu et al. 1975). The predominance of occluded P and the low levels of Al-P and Fe-P fractions indicate the limited capacity of the soils to supply P from the inorganic pool to crops (Chang and Chu 1959, Juo and Ellis 1968). Organic P remains an important source of P for crops under the traditional farming practices on recently cleared land (Uzu et al. 1975).

The P requirements for maximum yield, which is the quantity of P required to maintair a level of 0.2 ppm P in the soil solution, are given for some soils in Table 5.15. The well-drained upper slope soils of the Basement Complex have a higher P requirement for optimum crop production than the lower slope and valley bottom soils, probably because of

Table 5.14. Ratings of soils according to their responses to applied N for the various groundwater classes.

groundwater class	rating
1	very high
2	very high
3	high
4	medium-high
5	medium
6	low
7	very low
8	low-medium
9	low
10	low-medium
11	high

Table 5.13. Number of denitrifiers and NH_4^+-N and NO_3^--N concentrations on the toposequence in Eastbank area I, at the onset of the second season, 1975.

plot no.	range of groundwater levels in the 3 weeks before sampling (cm below surface)	number of denitrifiers per gram of soil	NH_4^+-N ppm	NO_3^--N ppm	total N ppm
5	90-100+	$5.5 \cdot 10^3$	4.4	11.0	15.4
6	47- 53	$3.8 \cdot 10^4$	3.2	2.6	5.8
7	19- 28	$5.5 \cdot 10^5$	3.2	1.3	4.5
8	1- 9	$2.1 \cdot 10^5$	1.9	2.0	3.9
10	(-7)-(-3)	$2.7 \cdot 10^4$	7.8	0.0	7.8

The counting of the denitrifiers and the determinations of the NH_4^+ and NO_3^--concentrations were done by Dr. Ayanaba, IITA.

rice seedlings at four locations A-D (Fig. 5.3); urea at the rate of 40 kg/ha was applied 20 days before the sampling. N-percentages varied by a factor of 2.5 and so did yields, resulting in quantities of N absorbed by plants varying by a factor of 5.

The N-deficiency zone on the slope is not constant. It moves higher upslope during periods of heavy rain that induce higher groundwater levels. Reasons for the N-deficiency are denitrification and possibly increased local leaching of nitrate. In Table 5.13, the denitrification process is expressed by the number of denitrifying bacteria, which reduce nitrate to dinitrogenoxide or nitrogen gas, and the NH_4^+- and NO_3^--concentrations in a number of plots along the same toposequence as shown in Fig. 5.3. Each location is characterized by the range of groundwater levels in the last three weeks before the date of sampling. The location with groundwater levels ranging from 19 to 28 cm depth showed the highest number of denitrifiers, though the lowest total N quantity in plant material was found in the next wettest plot. Denitrification is thought to be responsible for a gradual decrease in nitrate content downwards along the toposequence.

The leaching of nitrate was studied by weekly determinations of the nitrate contents of the groundwater, sampled directly from groundwater tubes. The results showed variations in NO_3^--content ranging from 0 to 5 ppm NO_3^-, with an occasional peak of 15 ppm. Sometimes these peaks could be associated with urea applications, but in general the NO_3^--content varied to such an extent that no clear reason for the fluctuation could be given.

Qualitative measurements of the occurrence of NH_3 by volatilization were done in the lower part of a toposequence in Eastbank area I (Appendix C). Observable volatilization occurred only in the lowest totally reduced plot with a pH-H_2O value near 7.0 (as measured after drying of the soil sample), but not in the somewhat higher plots with pH values of 5.5 to 6.5.

The losses of applied N from hydromorphic soils cultivated under a relatively low management level were thought to be important enough to warrant separate consideration as a land quality in the land evaluation. The land quality is called *response to applied N*.

Denitrification is considered to be the main cause of losses of applied N. As denitrification is clearly related to groundwater fluctuations close to the surface, the groundwater classes were taken as a basis for a qualitative rating of the response to applied N. As shown in Table 5.13, a groundwater fluctuation in the upper 25 cm of the

Table 5.15. P requirements of some soils for maximum yield (after Juo and Fox 1977).

soil unit	µg P sorbed per g of soil at equilibrium concentration of 0.2 ppm P in the soil solution	
	surface soil	subsurface soil
1	50	38
4	35	38
9	85	155
A	34	105
B	0	110
C	15	95

higher Fe-contents of well-drained soils, resulting in more P-fixation. Soils on sedimentary formations generally show a low requirement in the surface soil, but a higher requirement in the subsoil.

Potassium

The exchangeable K-content depends on the cation-exchange capacity of the soil, on the selectivity of exchange between K-ions and other cations on the exchange complex, on the intensity of weathering of K-bearing minerals present in the soil, and on the quantity of fertilizer used. The surface soils on the Basement Complex in general have exchangeable K-contents above the critical level of 0.10 me/100 g (Boyer 1972); the subsoils, except in soil unit 9, contain less exchangeable K than the critical level. Most soils on the sedimentary formations contain low contents of available K, and K-deficiency might be expected to occur. According to research done by Juo in the soils of the study area, the A-horizon is especially important for the availability of K.

Sulphur

Although sulphur deficiency has been observed in the savanna region of southern Nigeria, little is known about the sulphur status of the soils in the study area (IITA 1974). Some surface soils at IITA required less than 10 kg S/ha to adjust the SO_4-S in the soil solution to a concentration of 5 ppm SO_4-S, which is enough for most crops. Moreover, it appeared that SO_4-S, utilizable by crops, increased with depth.

SO_4-S concentrations in the soil solution on the toposequence of Eastbank area I (Appendix C) ranged from 0 to 33 ppm without a clear trend with respect to location. In very wet periods, generally higher values were observed (Table 5.16).

Rice leaves showed marginal S-contents when grown with application of N as urea on hydromorphic soils, even though superphosphate was applied at transplanting (Table 5.17); use of ammonium sulphate instead of urea would be advantageous for rice on these hydromorphic soils.

Reduction of sulphate takes place under conditions of a low redox-potential. Nevertheless, H_2S-toxicity is not very likely to occur in soils with sufficient Fe^{2+} (Ponnamperuma 1964). It is unknown whether SO_4^{2-}-reduction takes place to any considerable

Table 5.16. The influence of variations in groundwater depth on the SO_4-content in the soil solution at 40 cm depth of soils at midslope sites on the toposequence in Eastbank area I, 1976.

date	groundwater depth, cm below surface	SO_4-content in soil solution, ppm
19-3	56	3.4
9-4	58	1.4
30-4	48	1.0
21-5	45	1.4
11-6	3	12.9
25-6	17	17.9
9-7	22	7.5
30-7	38	4.4

Table 5.17. S-content in rice leaves on several locations in Eastbank area I (after four years of cultivation) and Eastbank area II (in the first year of cultivation).

drainage condition	age of leaves	cultivar	Eastbank area	S-content of leaves, per cent	remarks
well-drained	young and old	IR20/OS6	I	0.22	
poorly drained	young	IR20	I	0.16	possible S-deficiency
poorly drained	old	OS6	II	0.11	S-deficiency likely
well-drained	old	IR20	II	0.21	

extent in the hydromorphic soils of the study area, but field observations in the wettest part of Eastbank area I toposequence sometimes revealed a weak H_2S odour. Even so, the very low redox potentials required for S reduction do not normally occur.

To summarize, it can be stated that the natural fertility of a soil, reflected in the levels of availability of plant nutrients, depends on several factors. The situation under a fallow vegetation or under forest is different from a situation under cultivation. Management of the soil is very important with respect to availability of nutrients. Measurements of phosphate show some differences in P-status of the studied soils. For the availability of K, the surface soil seems to be most important. In the study area the soils on sedimentary formations show a lower availability of K than those in the Basement Complex areas. Sulphur may be deficient in rice on hydromorphic land, but this problem can be solved by using a S-containing N-fertilizer (e.g. ammonium sulphate).

Especially in the first year after clearing, the differences in natural fertility among the soil units are small, except in soils of unit 6, the poorly and very poorly drained variants of unit 4, and the eroded phase of unit 9, all of which have lower natural fertility levels. After several years of continuous cultivation, the differences between soil units become more pronounced, but not extreme. Nevertheless, a qualitative rating system was constructed for the land quality *availability of nutrients* or *natural fertility*, as is shown in Table 5.18.

Table 5.18. Relative rating of "natural fertility" for the soil units employed.

soil unit	rating	remarks
1	high	
2	low-medium	
3	low-medium	
4	low	very low when poorly or very poorly drained (groundwater classes 3, 5-11)
5	medium	
6	very low-low	
7	medium	
8	medium	
9	high	low when eroded (phase 9^{er})
A	medium	
B	medium	
C	low-medium	
D	low-medium	

This rating system can be compared with the relative rating system based on the fertility-capability classification (NCSU 1973) as given in Appendix F. There are only minor differences between the two systems. For Asian paddy soils, Kyuma and Kawaguchi (1973) developed the term "inherent potentiality", representing a refined form of the fertility status, excluding organic matter, nitrogen, and phosphorus status. Their method of calculation, in an adapted form, was used for the soils of the study area (Appendix F). For clayey soils, higher ratings than for sandy soils resulted, which is also reflected in Table 5.18.

5.3 ADDITIONAL LAND QUALITIES

5.3.1 Probability of occurrence of iron toxicity in rice

Although the term iron toxicity is used here, it should be noted that actually a nutritional disorder is meant, related to high Fe^{2+} contents in the root zone. The nutritional disorder is rather complex and largely remains to be studied (Moormann and Veldkamp 1977).

Upon flooding or saturation of the soil, reduction of iron and manganese can take place under low redox potentials. The reduction is the result of metabolic processes of anaerobic bacteria (Mann and Quastel 1946, Kumura et al. 1963) with organic matter as energy source and Mn_2O_3 and Fe_2O_3 as main oxygen sources.

The concentrations of Fe^{2+} show a distinct increase during the first weeks after onset of reduction, and decrease gradually to a fairly constant and non-toxic level afterwards. The kinetics of Fe^{2+} are influenced by soil characteristics such as pH, organic matter content, and the amount of easily reducible "active" iron present (IRRI 1964).

Upon submergence of the soil, the pH increases and stabilizes at values between 6.5 and 7.0 when Fe^{2+} begins to precipitate, when sufficient amounts of CO_2 and HCO_3^- are formed, and when the Fe-precipitates come into equilibrium with Fe in the soil solution (Ponnamperuma et al. 1966). As an increase of 0.5 pH unit lowers the concentration of Fe^{2+} ten times, the stabilization of pH around 7.0 is important with respect to iron-toxicity. However, when the amount of easily reducible iron is low, the total amount of reduced iron will also be low. This causes a limitation in the increase in pH towards neutral values. When the pH remains low, high concentrations of dissolved Fe^{2+} can be maintained, resulting in iron-toxicity (Ponnamperuma 1972, Moormann and van Breemen 1978).

A major cause of iron toxicity is the transportation of dissolved iron by interflow water under the following conditions (Moormann and van Breemen 1978):

- a source of ferrous iron is present at a higher level in the landscape than where seepage occurs (weathering zone of rocks such as granite, gneisses, rich in iron-containing minerals or plinthite).
- the interflow water, while being laterally transported, remains reduced so that the iron is kept in the dissolved bivalent form.
- where interflow water enters the root zone, the soil is either reduced or, if slightly aerobic, is sufficiently acid to prevent rapid oxidation and precipitation of the iron to insoluble ferric oxides.
- the concentration of dissolved iron in the interflow water is sufficiently high.

Howeler (1973) stated that iron-toxicity in rice can be indirect, in that Fe coatings on roots induce deficiencies of other nutrients.

Iron-toxicity symptoms or "bronzing" are often related to symptoms of Mn-toxicity or of Zn-deficiency. Mn-toxicity, however, is more common on acid well-drained soils, whereas Fe-toxicity is associated with waterlogged soils (Ponnamperuma 1974). Tanaka and Yoshida (1975) reported that high Mn-contents have been found in high-yielding rice; rice is more resistant to Mn-toxicity than many other crops and the critical level for rice is much higher. A high level of iron in the growth medium may counteract an excessive uptake of manganese (Tanaka and Navasero 1966). In comparison with nitrate, ammonium, as the major form of nitrogen in flooded soils, also has a retarding effect on the uptake of manganese. To summarize, Mn-toxicity in rice is not very likely to occur, at least not in flooded soils.

Fe-toxicity has been associated with Zn-deficiency (Krishnamoorty et al. 1971). Both phenomena have quite similar characteristics (Yoshida and Tanaka 1969), but Zn-deficiency is, in general, a problem of alkaline soils and Fe-toxicity of acid soils (Katyal 1975). Yoshida (1968) stated that zinc might be immobilized in roots in the presence of a large excess of bicarbonate ions; in submerged soils, abundant CO_2 is produced during the early period of submergence, which at a high pH value is converted to the bicarbonate form.

On the toposequence in Eastbank area I, the soil solution was sampled at two locations (Fig. 5.4) (Appendix C). Shown in Table 5.19 are the total Fe-contents, the total Mn-contents, pH, and specific conductance of the soil solutions at the two locations at various depths. The soil solutions contained Fe-concentrations ranging at the midslope site between 1 and 30 ppm and at the downslope site between 15 to 50 ppm. The Mn-concentrations of the soil solutions of both locations were in the range of 1 to 7 ppm. Actually, there was no clear trend in the concentration of either element. The pH values were higher close to the surface in the midslope sampling-tube. The specific-conductance values were in the range of 0.16 to 0.52 mmho/cm, which are normal values for submerged soils. The Fe- and Mn-concentrations reflect the equilibrium situation for slightly acid soils, as shown by Ponnamperuma (1964), with maximum values of 50-100 ppm Fe and 10 ppm Mn in the soil solution.

In the rice crop cultivated on the same toposequence in Eastbank area I, bronzing

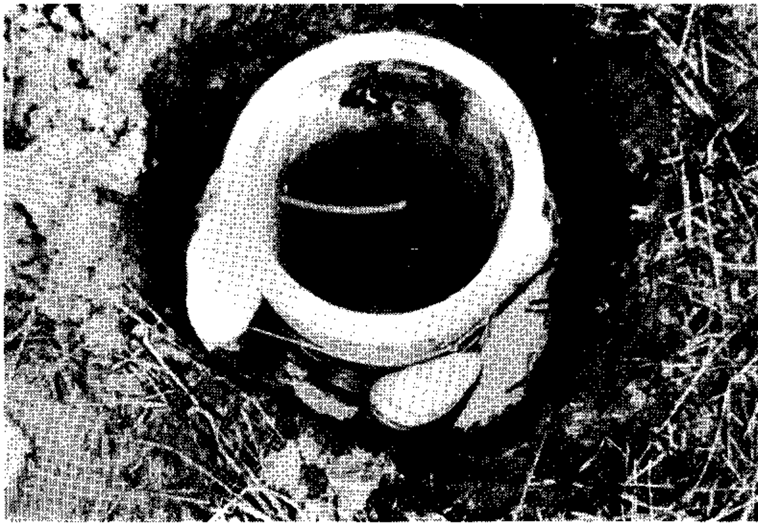


Fig. 5.4. Asbestos sampling tube for the extraction of the soil solution in hydromorphic soils; Eastbank area I. Every 10 cm a perforated plastic bag filled with a small perforated plastic tube and glasswool is fixed and connected to the inside of the asbestos tube by a rubber tube.

was observed only on the downslope site in a cultivar (OS6) that is known to be sensitive to iron-toxicity. In other places in Eastbank areas I and II and in an experimental plot in a valley bottom at Ikenne, bronzing was observed. From analyses of leaf samples, no clear indication could be obtained as to whether Fe, Mn, or Zn was involved and in what way. Bronzing systems were associated with almost continuous waterlogging of the soils, with iron-exudations, and with the occurrence of spring-levels close by. Apart from soil chemical factors, the supply of excess iron by inflowing groundwater seemed to be the most important cause of bronzing.

It should be pointed out, however, that the quantity of Fe^{2+} entering the root zone by inflowing groundwater is not particularly high and is apparently below the critical levels mentioned by several authors. Nevertheless, bronzing phenomena at IITA and Ikenne were clearly related to Fe^{2+} brought into the root zone by inflowing groundwater. The mechanism by which continuous influx of even low levels of Fe^{2+} in the soil solution is harmful is not well understood and requires further study.

To summarize, the problem of bronzing is site-dependent, but may occur throughout the study area at lower slope sites where spring-levels are found. Iron sources are present, in the Basement Complex by weathering of primary minerals under conditions of waterlogging, and in the sedimentary formations by the presence of plinthite formations. From such sites, iron can be transported by the groundwater towards lower slope sites. As bronzing is often spotty and temporary and is related to high levels of dissolved Fe^{2+}, the additional land quality under discussion is expressed as the *probability of occurrence of iron-toxicity*. The locations where iron-toxicity was observed can be associated with the "wetter" groundwater classes 9, 10, and 11. Therefore, these classes were rated according to the probability of occurrence of iron-toxicity in rice (cf. Table 6.5). As the soils in which these groundwater classes occur show no wide differences in values of pH and organic

Table 5.19. Iron and manganese contents, pH and specific conductance of solutions of soils located at midslope and downslope positions on a toposequence in Eastbank area I, 1975/1976).

date		23/9	9/10	28/10	18/11	9/12	5/2	26/2	19/3	8/4	30/4	21/5	11/6	9/7	30/7
<u>midslope</u>															
groundwater level		22	-9	-10	12	22	44	53	54	58	48	16	2	22	39
ppm Fe^{2+}															
depth (cm)	10	30	23	19	28	31	-	-	-	-	-	-	1	21	-
	20	20	16	14	18	22	-	-	-	-	-	-	2	15	25
	30	14	15	13	16	16	13	-	-	-	4	19	12	18	19
	40	13	8	7	5	12	12	11	10	11	17	15	6	12	12
ppm Mn^{2+}															
depth (cm)	10	7	4	3	4	5	-	-	-	-	-	-	1	5	-
	20	4	3	2	3	3	-	-	-	-	-	-	3	2	5
	30	3	2	2	2	3	2	-	-	-	4	3	3	3	2
	40	2	1	1	2	2	2	2	2	2	3	3	2	1	1
pH															
depth (cm)	10	6.7	6.6	6.4	6.2	6.5	-	-	-	-	-	-	7.2	nd	nd
	20	6.6	6.5	6.3	6.2	6.4	-	-	-	-	-	-	6.5	nd	nd
	30	6.3	6.2	6.1	6.1	6.2	6.6	-	-	-	6.0	6.6	6.3	nd	nd
	40	6.3	6.2	6.1	6.0	6.2	6.7	6.4	6.4	6.0	6.1	6.4	6.2	nd	nd
specific conductance (mmho/cm)															
depth (cm)	10	0.43	0.24	0.21	0.37	0.34	-	-	-	-	-	-	0.52	nd	nd
	20	0.30	0.22	0.19	0.29	0.31	-	-	-	-	-	-	0.31	0.38	nd
	30	0.20	0.18	0.17	0.22	0.22	0.22	-	-	-	0.32	0.31	0.25	0.24	nd
	40	0.22	0.18	0.16	0.19	0.20	0.22	0.20	0.22	0.22	0.32	0.28	0.20	0.20	nd
date		23/9	9/10	28/10	18/11	9/12	5.2	26/2	19/3	8/4	30/4	21/5	11/6	9/7	30/7
<u>downslope</u>															
groundwater level		-12	-12	-13	-13	-15	2	6	7	9	-8	-8	-12	-11	-7
ppm Fe^{2+}															
depth (cm)	20	40	36	33	40	39	34	33	35	15	60	38	44	41	50
	30	36	17	30	36	38	32	31	32	34	48	34	29	34	41
ppm Mn^{2+}															
depth (cm)	20	3	3	3	3	3	2	3	4	4	5	4	4	3	3
	30	2	1	1	1	2	3	1	2	1	2	1	2	1	1
pH															
depth (cm)	20	6.7	6.5	6.4	6.1	6.2	6.7	6.8	6.2	6.4	6.2	6.8	6.4	nd	nd
	30	6.5	6.4	6.5	6.2	6.2	6.6	6.7	6.3	6.4	6.3	6.7	6.4	nd	nd
specific conductance (mmho/cm)															
depth (cm)	20	0.44	0.40	0.40	0.43	0.42	0.46	0.50	0.48	0.42	0.42	0.48	0.49	0.42	nd
	30	0.38	0.34	0.36	0.32	0.40	0.34	0.36	0.40	0.40	0.30	0.42	0.36	0.38	nd

Note: groundwater level in cm (positive: below surface; negative: above surface).
- : no sample available
nd: no determination

matter, no further subdivision into soil units was considered.

5.3.2 Probability of occurrence of soil erosion

As surface layers are vital for the agricultural value of a soil, erosion can be highly destructive.

Soil erosion can be caused by a climate that is sufficiently erosive. According to Hudson (1971), the erosivity of the climate is the potential ability of rain to cause erosion; it is a function of such physical characteristics of rainfall as intensity and kinetic energy. High rain intensities are reached in the study area; intensities of more than 100 mm/hour were measured during the first rains in March and April. The erodibility of the soils is the second important factor in soil erosion. The erodibility is the vulnerability or susceptability of the soil to erosion; it is a function of both the physical characteristics of the soil and the management of the soil (Hudson 1971). The total soil loss by erosion can be predicted by the universal loss equation (Wischmeier and Smith 1965) in which, besides the two factors mentioned, others such as slope, length of slope, growth stage of the crop, and management are involved. For the land quality *probability of occurrence of soil erosion*, the erodibility and the slope were considered. (Management aspects will be discussed in Section 6.2.2).

Lal (1976) shows the effect of the slope on run-off and soil loss on a bare fallow upper slope soil, comparable to soil unit 9 (Table 5.20). Under these conditions the slope has no effect on the run-off, but the soil loss increases with slope and varies per season.

Lower slope soils are in general not erodible because of the relatively high infiltration rates of the gravel-free layer and the gentle slope on which they occur. Some upper slope soils in the study area can be subject to soil erosion, especially at the beginning of the first rainy season, when plots are bare or just planted. Such susceptible soils occur in soil unit 9 and to a much lesser extent in units 7, 8, A, and B. Some of the soils of unit 9 are already eroded, to some extent due to former cultivation practices, while in those of units A and B, on the sedimentary formations, gully erosion has been observed on steep slopes bordering the valleys.

Under the circumstances in which the local farmer cultivates his land, plots are relatively small. Land for crops such as yam or cassava is prepared by making mounds and putting debris in the interlying furrows. This system prevents erosion. During each weeding the mounds are restored, translocated soil material being put back in place. Ero-

Table 5.20. Effect of slope on run-off and soil loss on a bare fallow upper slope soil, comparable to soil unit 9, major first and second season of 1972 and 1973 (after Lal, 1976).

Run-off (mm)	season and year			
slope (per cent)	major first 1972	second 1972	major first 1973	second 1973
1	226	23	316	192
5	262	39	347	196
10	259	28	311	193
15	214	26	317	185

Soil loss (tons/ha)	season and year			
slope per cent	major first 1972	second 1972	major first 1973	second 1973
1	4	1	8	4
5	32	11	80	76
10	46	13	153	80
15	101	15	155	74

Table 5.21. Grades of probability of occurrence of soil erosion for the soil units (only for moderately steep or steep slopes) (not for the dry season).

soil unit	grade[1]
7	++
8	++
9	++++
A	+++
B	+++
others	-

Note: [1]the probability of occurrence is expressed by the frequency of the symbol +.

sion on traditionally farmed plots is usually minor. However, if the steeper slopes are cultivated, erosion can be severe.

As land quality, the *probability of occurrence of soil erosion* was considered in a qualitative and relative way, no conservation structures nor other land practices being taken into account. The relevant soil units, if situated on steep slopes, were given a grade of probability of occurrence of soil erosion (Table 5.21). (These grades are not applicable in the dry season because unseasonal rains are rare.)

5.3.3 Difficulty of land preparation and harvesting of root crops

Land preparation and harvesting of root crops were regarded in this study as being done exclusively by manual labour, with use of hoes. Although mechanization is feasible under certain conditions, especially on hydromorphic soils, it was not included in the study.

Mechanized agriculture is dependent on land characteristics such as slope, texture, and structure of the surface soil and its ability to bear heavy weights. At IITA, small and lightweight machinery has been developed for local farming systems (IITA 1975a), but this machinery can only be used on thoroughly cleared land from which all woody remnants of the fallow vegetation have been removed. During such a thorough clearing, the soil is disced and raked by heavy machinery, which can cause translocation of the surface soil material and higher erodibility at the beginning of the rainy season. Such clearing can also be done by hand, but this entails an enormous amount of work. One result of the removal of woody remnants is the growth of a different vegetation in the next fallow period. Trees are less likely to develop if the stumps have been removed, and instead broad-leaved weeds and, after some time, grasses or *Eupatorium odorata* (L.) will grow (Moody 1973), causing a slower restoration of the soil fertility (Nye and Greenland 1960); weed growth during cultivation after such a fallow period can also be more severe. Therefore, for economic reasons, mechanization of agriculture is only feasible in a permanent rotation system which does not need a fallow period to sustain yield levels or extra labour to suppress weed growth. On hydromorphic land, a permanent system may be feasible under certain conditions and, on such land, mechanization can be applied to some extent (Curfs 1976). This, however, was not taken into consideration in the studied management levels.

Workability in the case of manual labour plays only a minor role in the study area.

The plasticity characteristics of the typical surface soils do not show any significant differences (Lal 1978). The moisture content and the structure of the surface soil determine their workability and they are particularly dependent on management (Curfs, personal communication). Therefore no separation of the land quality *difficulty of land preparation and harvesting of root crops* was made.

5.3.4 Impediment of root development

Root development can be mechanically obstructed by hard gravelly or lateritic layers at shallow depths in the soil. Especially in soil unit 6, a hardened lateritic layer can occur between depths of 30 to 80 cm. Occasionally, a layer with frequent (more than 50 volume per cent) gravels occurs in soil units 7 and 9. When such a layer lies deeper than 80 cm, it is assumed not to interfere with root development. If it occurred within 80 cm depth, two grades of the land quality *impediment of root development* were considered:

i_s: 30-50 cm high impediment

i_d: 50-80 cm medium impediment

Impediment at less than 30 cm depth does not occur in the study area, except very locally at eroded places. Table 5.22 gives the grading of the impediment of root development for the soil units.

Table 5.22. Grading of the impediment of root development for the soil units.

soil unit	impediment depth	grade[1]
6	30-50 cm, i_s	+++
	50-80 cm, i_d	++
7	30-50 cm, i_s	+++
	50-80 cm, i_d	++
9	30-50 cm, i_s	+++
	50-80 cm, i_d	++

Note: [1] the impediment is expressed by the frequency of the symbol +.

6. MANAGEMENT-TECHNOLOGY LEVELS AND THE EFFECT OF MANAGEMENT ON THE LAND QUALITIES

6.1 INTRODUCTION

Management-technology levels have been distinguished to define the framework of the land utilization types used in this study. The intelligence and experience of a farmer and his communication with other farmers and institutional agencies involved in agriculture, may bring certain improvements in the way in which agriculture is practised. Many farmers in the study area still farm in a traditional way, but technological improvements such as fertilizers are penetrating into the traditional practices. The technology used on the larger farms differs little if at all from that used on small farms, since there is little or no mechanization (Flinn et al. 1974); the number of working units determines the area of cultivated land. In this study two management-technology levels, abbreviated to management levels, were considered: traditional and improved management. The improved management level differs from the traditional in two ways:

- better care of crops and the use of modern technology
- minor land improvements and, for rice, the bunding and partial levelling of fields.

A minor land improvement is one that has relatively little effect or is non-permanent or both, or that lies within the capacity of individual farmers (FAO 1976). Not included in the study are major land improvements, defined as substantial and reasonably permanent improvements (except for rice), nor are capital intensive farming systems. Such farming systems are applied in state and private schemes, but do not form part of this study. Moreover, due to the restraints of the environment in the forest zone and the lack of adequate technology, this type of farming has proved to be generally unsuccessfull.

In FAO (1976), the suitability classification as used in this study (under both management levels) is called the *current* suitability classification, in contrast to the *potential* suitability classification in which land units are considered at some future date, after specified major improvements have been completed.

Any measures to lower groundwater levels by major drainage channels, or to raise them, may induce a change in the groundwater class at that particular location and the land evaluation takes place on the basis of the "new" groundwater class.

6.2 MANAGEMENT-TECHNOLOGY LEVELS

6.2.1 Traditional management

Traditional management, as the term is used here, means the dominant method of farm management in the study area. Traditional food crop farming there is characterized by:

- low level of technology, with low non-recurrent and expended recurrent inputs; expended farm costs are limited to the purchase of tools such as matchets, hoes, and axes, and occasionally to very modest quantities of fertilizer.
- the work is done by members of the family, with the occasional addition of hired labour; no draught animals are used.
- products are mainly consumed by the family; the traded surplus is small.

Besides food crops, other crops are cultivated to provide the farmer with a cash income; these crops are cocoa, cola, citrus, and to some extent, as a gathering crop, oil palm. Bush fallow plots provide useful products such as firewood and stakes. Apart from their domestic use, these crops will not be considered any further in this study.

A brief outline of the common food cropping practices follows. There are established fields around the village, which are cleared and used for farming in a pattern depending on the quantity of land owned, the needs of the family, and commercial purposes. Some fields are under fallow for only 4 years, while others may bear a 20 year old bush growth. Clearing is done by hand during the dry season, mainly with matchet and axe. A chainsaw or winch may be borrowed to fell the bigger trees. Oil palms and trees remain, either because they are too big or because they are useful for domestic purposes. No complete stumping is done which promotes a quick regeneration of the bush after the cropping period. The underbrush and trees which have been cut and felled are then burnt. Thick stems are not usually burnt completely and are left in the field.

Interplanting of crops is common. If yam is cultivated, it is the first crop in the rotation; mounds are made and the yam is planted on the mounds usually during the latter half of the dry season. Maize and cassava and minor crops are planted after the start of the rains. Cassava is also grown on mounds. Maize is planted in a row in between cassava or yam mounds often with 2-3 plants per hill. Minor crops are cowpea, tomato, pepper, okra, and other vegetables. In the higher rainfall zone in the eastern part of the study area, cocoyam is an important crop (Agboola 1968). First season maize is harvested green or dry around June-July. In the second season (starting early September) another maize crop is sometimes planted and harvested dry in November-December. Yams are harvested around September-November. Cassava is harvested 1-3 years after planting.

Whereas yams and maize are often planted in the first year after clearing, cassava is more a second or third year crop. Cassava is normally the last crop in the rotation. After it has become established it is no longer weeded and is left as a food reserve in the bush re-growth. Plantains and bananas are found scattered around fields and close to the village.

With the exception of the area south of Abeokuta, rice is not common. On well-drained soils it can only be grown in the major first rainy season, and even then the risk of drought stress exists. It is grown more successfully on the less well-drained soils in the valley bottoms and the lower slopes. Traditional management of rice includes a small quantity of N-fertilizer, but little or no water management.

6.2.2 Improved management

The improved management level is based on the traditional management level and involves, besides a better care of crops, a number of simple improvements. These improvements vary per crop and per land type. Sometimes they involve a higher capital input than under traditional management. Fundamentally, the improved management level differs from the traditional one only in the minor improvements, and remains within the reach of each individual farmer in the study area. Relevant improvements are:

- soil fertility improvement (higher applications of suitable fertilizers)
- plant improvement (better cultivars)
- plant protection (spraying of insecticides)
- erosion control
- water management in hydromorphic land types (drainage, bunding, levelling, and irrigation direct from streams without the use of a power source).

Fertility improvement. The fertility status of the soils can easily be improved by fertilizer applications. Under traditional management no fertilizers are applied, except occasionally on maize and more frequently on rice, for which a small quantity of N-fertilizer (e.g. 25 kg/ha) is used. Under the improved management level, greater fertilizer quantities are to be applied. The type of fertilizer, the quantity, and the time of application depend on crops, cultivars, and soils. Traditionally-grown rice cultivars will lodge with high applications of N, but improved, short-straw rice cultivars, respond well to relatively high applications of N. On clayey soils a smaller quantity may be needed than on sandy soils. As explained in Section 5.2.3, groundwater plays an important role with respect to nitrogen losses. In general, the elements needed will be nitrogen and phosphorus.

Plant improvement and *plant protection.* Improvements of this kind do not influence any of the land qualities, but some details are given in order to describe the cultivars to be used and any plant protection measures to be applied. Under both management levels, the best available cultivar should be used; the choice of cultivar depends not only on yield performance, but also on taste, method of cultivation (e.g. dryland versus swamp rice), colour, etc.

Cocoa farmers spray chemicals on both cocoa and food crops, but in the area near IITA, cocoa is not as important as in the area south and east of Ibadan. To spray chemicals, a farmer needs a knapsack sprayer and appropriate chemicals, which are not common items in the study area, especially the chemicals. Such plant protection measures are therefore not included in either of the management levels with the exception (in improved management) of high-yielding cultivars such as newly bred cowpea cultivars, which must be sprayed if high yield levels are to be obtained.

Erosion control. Under traditional management, erosion control is inherent in the method of land preparation and weeding. When making mounds for planting yam and cassava and when weeding such land, the farmer leaves trash and dead weeds in the hollows and furrows between the mounds. This diminishes or eliminates the erosive effect of run-off water, and little or no erosion occurs. It is assumed that the same technique will be used under improved management and that as far as erosion control is concerned the two levels are identical. No other erosion control measures are included.

Water management. Two kinds of water management are considered: intense water management in the case of rice, and drainage in the case of other crops.

Water management is crucial for improved rice cultivation (Moormann and Veldkamp 1977). The main benefits of improved water management are a sufficient supply of water to the plants, a diminished loss of nitrogen by denitrification, and a better control of weeds when the land is flooded. Under traditional management, farmers plant rice (either by direct sowing or by transplanting) after weeding and turning over the surface soil. In the improved management, water can be conserved by making bunds around small fields and by levelling the fields. If water is available in streams or from springs, simple diversion may supplement the rainfall supply. Drainage of the bunded and levelled land may be required, for instance, in cases of interflow iron-toxicity. The best way of draining land suffering from interflow iron-toxicity (cf. Section 5.3.1) is to intercept the interflow water on the upper-slope side of the paddies by intercept ditches. Direct drainage by furrows that lead surface water to streams is fairly effective against iron toxicity, but leaves the problem of severe denitrification. The latter form of drainage, in a simple way, is included in the traditional management level. Taken altogether, the improvements in water management remain simple; the water supply to fields is semi-regular, and fields are not levelled completely.

If crops other than rice are to be grown on hydromorphic land, drainage is very important. Ridges, mounds, and ditches alter the water regime by creating a locally less wet environment for the plant (Figs. 6.1 and 6.2). Improvement depends on the height of the ridges or mounds and the depth and flow-efficiency of the ditches. Under traditional management, the ridges or mounds are between 20 and 30 cm high; under the improved management, considered here, they are up to 50 cm high. It may be mentioned that locally in Africa, e.g. in the lowlands of eastern Nigeria, mounds of up to 1.5 metre are made. This, however, alters the hydromorphic land to such an extent that new land types, on a detailed scale, are created. This practice was therefore not considered in this study.

Fig. 6.1. Large unplanted mounds in valley bottom land; Eastbank area I.

Fig. 6.2. Same mounds as in Fig. 6.1, planted with yam (on stakes), cocoyam and sweet potato.

6.2.3 Specification of management practices

The management practices for the two management levels are specified in Table 6.1, fertilizer application and water management on hydromorphic land being the main practices. Management practices differ per crop or management group of crops. A number of management groups (T_1, T_2, I_1, I_2, I_3) were established, each group having its own combination of management practices, as considered relevant for the study area. Groups T_1 and T_2 cover the traditional management level, groups I_1, I_2 and I_3 the improved management level.

6.3 THE EFFECT OF MANAGEMENT ON THE LAND QUALITIES

In Chapter 5 the land qualities of the studied soil units and groundwater classes were determined without considering any influence of management on the qualities. However, some of the management practices involved (i.e. fertilizer application and water management) will certainly have an effect on land qualities.

The application of fertilizers is included in management groups T_1, I_1, and I_2 (Table 6.1). This will affect the land qualities *availability of nutrients (fertility)* and *response to applied N*. The small quantity of N-fertilizer as applied in management group T_1 will only affect the latter land quality. Within group I_2 two kinds of fertilizer applications are specified; however, the influence on both land qualities is considered to be equal for both kinds of application. The influence of NPK fertilization in groups I_1 and I_2 is given in Table 6.2(A); it is assumed that the originally medium or higher grades of *availability of nutrients (fertility)* will not be influenced by the applied quantity of fertilizer, but that the lower grades will be raised somewhat (cf. Table 5.18). In management groups T_1, I_1 and I_2, the land quality *response to applied N* will be changed by the application of fertilizers containing nitrogen. Groups T_2 and I_3 receive no nitrogen and the grading remains unchanged (cf. Table 5.14). Groups T_1, I_1, and I_2 have

Table 6.1. Management practices as applied to the studied crops; the crops have been grouped into management groups according to the management practices in each of the two management levels.

management level		traditional		improved			
management group of crop(s)		T_1	T_2	I_1	I_2		I_3
crop(s)		rice	maize root crops grain legumes tomato, celosia okra, sweet pepper, banana, plantain	rice	maize	tomato celosia sweet pepper banana/ plantain	root crops grain legumes okra
management practices	fertilizer application	low N-top-dressing	none	moderate basal dressing of P and K; high N-top-dressings	moderate basal dressing of NPK with moderate N-top-dressing on second and latter maize crops after clearing	regular small NPK-dressings	none
	water management on hydromorphic land	none, except some drainage by furrows in the case of iron toxicity	ridges or mounds (except for cocoyam)	bunding, partial levelling, irrigation by diversion; drainage in the case of iron toxicity	higher ridges or mounds, some drainage ditches		higher ridges or mounds, some drainage ditches (except for cocoyam)

Table 6.2. A. Qualitative grading of the land quality *availability of nutrients (fertility)* for the soil units, as applied to five management groups of crops; the NPK-fertilization in management groups I_1 and I_2 influences the lower grades only: the grades vl, vl-l, l and l-m become, respectively, l, l, l-m and m (for soil unit 9, eroded phase, l becomes m).

soil unit	management group of crops T_1, T_2, I_3	 I_1, I_2	remarks
1	h	h	
2	l-m	m	
3	l-m	m	
4	l	l-m	in the case of groundwater class 1, 2 and 4
	vl	l	in the case of groundwater class 3, 5-11
5	m	m	
6	vl-l	l	
7	m	m	
8	m	m	
9	h	h	if not eroded
	l	m	if eroded
A	m	m	
B	m	m	
C	l-m	m	
D	l-m	m	

B. Qualitative grading of the land quality *response to applied N* for the groundwater classes, as applied to five management groups of crops; the grades are raised depending on the quantity of N-fertilizer.

quantity of applied N relevant management group of crop(s) groundwater class	none T_2, I_3	low T_1	moderate I_2	high I_1
1	vh	vh	vh	vh
2	vh	vh	vh	vh
3	h	vh	vh	vh
4	m-h	h	vh	vh
5	m	m-h	h	h-vh
6	l	l-m	m	m- h
7	vl	vl	l	l- m
8	l-m	l-m	m	m- h
9	l	l	l-m	m
10	l-m	l-m	m	m- h
11	h	h	h	h-vh

higher grades, related to the quantity of N-fertilizer applied. The resulting grades are presented in Table 6.2(B).

Water management influences three land qualities: *the availability of water*, *the availability of oxygen*, and *the probability of occurrence of iron-toxicity*. In the land quality *availability of water*, rice has to be considered separately. The aim of water management for rice is to increase the quantity of water in or on the soil. Hence, the originally prevailing groundwater class may be changed into a wetter one. The groundwater classes resulting from improved water management of rice are shown in Table 6.3. The

Table 6.3. Effect of water management on the groundwater class in rice cultivation; applicable in the major first and the second season only (cf. Fig. 4.7).

traditional management (without raising the highest groundwater level)		improved management (including raising of the highest groundwater level, especially in groundwater classes 4 to 11)	
highest groundwater level (depth in cm)	groundwater class	highest groundwater level (depth in cm)	groundwater class
more than 75	1	more than 75	1
25 - 75	2	25 - 75 if 0 - 25	2 4 or 5
	3	25 - 75 if 0 - 25	3 5,6 or 7
less than 25	4	less than 25	4
0 - 25	5 6 7	less than 0	8 9 10
less than 0	8 9 10 11		8 9 10 11

grading of the land qualities of a particular location under these conditions is then found under the new groundwater class.

Water management for crops other than rice generally means drainage measures. In other words, the land quality *availability of water* does not limit the growth of crops. Therefore, the influence of water management on this land quality can be omitted when determining the suitability of these crops, and the original grades of *availability of water* can stand.

The land quality *availability of oxygen* can be strongly influenced by water management, especially by drainage measures. Management groups T_1 and I_1 (both intended for rice only) are not relevant because the suitability of rice, as single crop in both groups, is not influenced by this land quality. Nor are the water management practices directed towards a higher availability of oxygen. For management groups T_2, I_2 and I_3, however, the availability of oxygen increases with water management and especially with drainage (Table 6.4(A)). In management group T_2, under traditional management where some minor drainage is provided, the increase is moderate. In management groups I_2 and I_3, under improved management with more intensive drainage practices, the increase is higher. In Table 6.4(B), the effect of water management on the land quality *availability of oxygen* is shown for the soil units in which groundwater classes of 4 or higher occur. For the soil units in which groundwater classes 1, 2, and 3 occur, the availability of oxygen remains unchanged (cf. Table 5.11(C and D)).

The land quality *probability of occurrence of iron-toxicity in rice* can be influenced by water management. Under traditional management, some drainage by field ditches can improve the situation, but whether it can be solved partially or completely, depends on the cause and extent of the iron-toxicity problems. At the improved management level, the construction of intercept ditches will help overcome interflow iron-toxicity. In Table 6.5, the qualitative grading of the probability of occurrence of iron-toxicity is given, assuming somewhat higher grades with improved management than with traditional management.

Table 6.4. A. The effect of the height of ridges or mounds on the original grades of *availability of oxygen* for relevant management groups of crop(s); groundwater classes 4-11 only.

original grade of availability of oxygen	grade when height is 20/30 cm (management group T_2)	grade when height is 50 cm (management groups I_2 and I_3)
vh	vh	vh
h-vh	vh	vh
h	h-vh	vh
m-h	h	h-vh
m	m-h	h
l-m	m	m-h
l	l-m	m
vl-l	l	l-m
vl	vl-l	l

B. The grades of the *availability of oxygen* changed by water management for management group T_2 (traditional management level) and for management groups I_2 and I_3 (improved management level).

management group	soil units	groundwater class 4	5	6	7	8	9	10	11
T_2	1	h	m-h	m	l-m	m	l-m	l	vl-l
	2,3,4 and D	h-vh	m-h	m	l-m	m	l-m	l	vl-l
I_2 and I_3	1	h-vh	h	m-h	m	m-h	m	l-m	l
	2,3,4 and D	vh	h	m-h	m	m-h	m	l-m	l

Table 6.5. Grading[1] of the *probability of occurrence of iron-toxicity in rice* for the groundwater classes under the two management levels.

groundwater class	management level: traditional		improved	
9	+	(low)	-	(improbable)
10	++	(moderate)	+	(low)
11	+++	(high)	++	(moderate)
others	-	(improbable)	-	(improbable)

Note: [1] the grading is expressed by the frequency of the symbol +.

7. THE PERFORMANCE OF CROPS ON TOPOSEQUENCES WITH EMPHASIS ON HYDROMORPHIC LAND AND THE ECOLOGICAL SUITABILITY CLASSES IN RELATION TO CROP REQUIREMENTS

7.1 PROCEDURE FOR DETERMINING THE ECOLOGICAL SUITABILITY

In Fig. 7.1 the procedure for determining the ecological suitability of a management unit is given; a management unit is defined by the soil unit, the phase if any, and, per season, the groundwater class; the management level is also specified.

The soil units have been discussed in Chapter 3; in Chapter 4 the seasons and groundwater classes to be determined for each season were defined; the land qualities and their grading were considered in Chapter 5. Chapter 6 described the management levels and the influence of a specified management level on the grading of the land qualities. In the present chapter, two determinations will be made for each crop: the expected yield per groundwater class (per season) and the suitability classes in relation to crop requirements. These two determinations will be used in the final step in the ecological land evaluation, discussed in Chapter 8, which is the determination of the ecological crop suitability. In this process, the land qualities of the soil units (and phases) and the groundwater classes per season for a specified management level in a specified season are matched with the requirements of the suitability classes. This matching process results in the "calculated ecological suitability of a crop". This "calculated ecological suitability" is then compared with the expected yield per groundwater class per season; if the two values are equal or almost equal, the ecological crop suitability, as final value, is equal to the calculated ecological suitability. If the difference is too large, the average value is considered to represent the ecological crop suitability. In this way, the available yield data are used to check the calculated suitability value.

The expected yield per groundwater class for each crop per specified season and per management level is discussed in Section 7.2. The suitability classes in relation to the crop requirements are determined for each crop in Section 7.3. As each suitability class is determined by the grading of the land qualities, the discussion on the suitability classes is done according to the relevant land qualities.

7.2 EXPECTED YIELD PER GROUNDWATER CLASS PER SEASON

7.2.1 Introduction

In this section, a number of crops will be discussed with respect to their ecological suitability for different locations, using the methodology described by Moormann, Veldkamp, and Ballaux (1977).

For five years (1972-1976) several crops were grown on eight toposequences in Eastbank area I (Fig. 7.2 and 7.3). These toposequences were sequences of well-drained to very

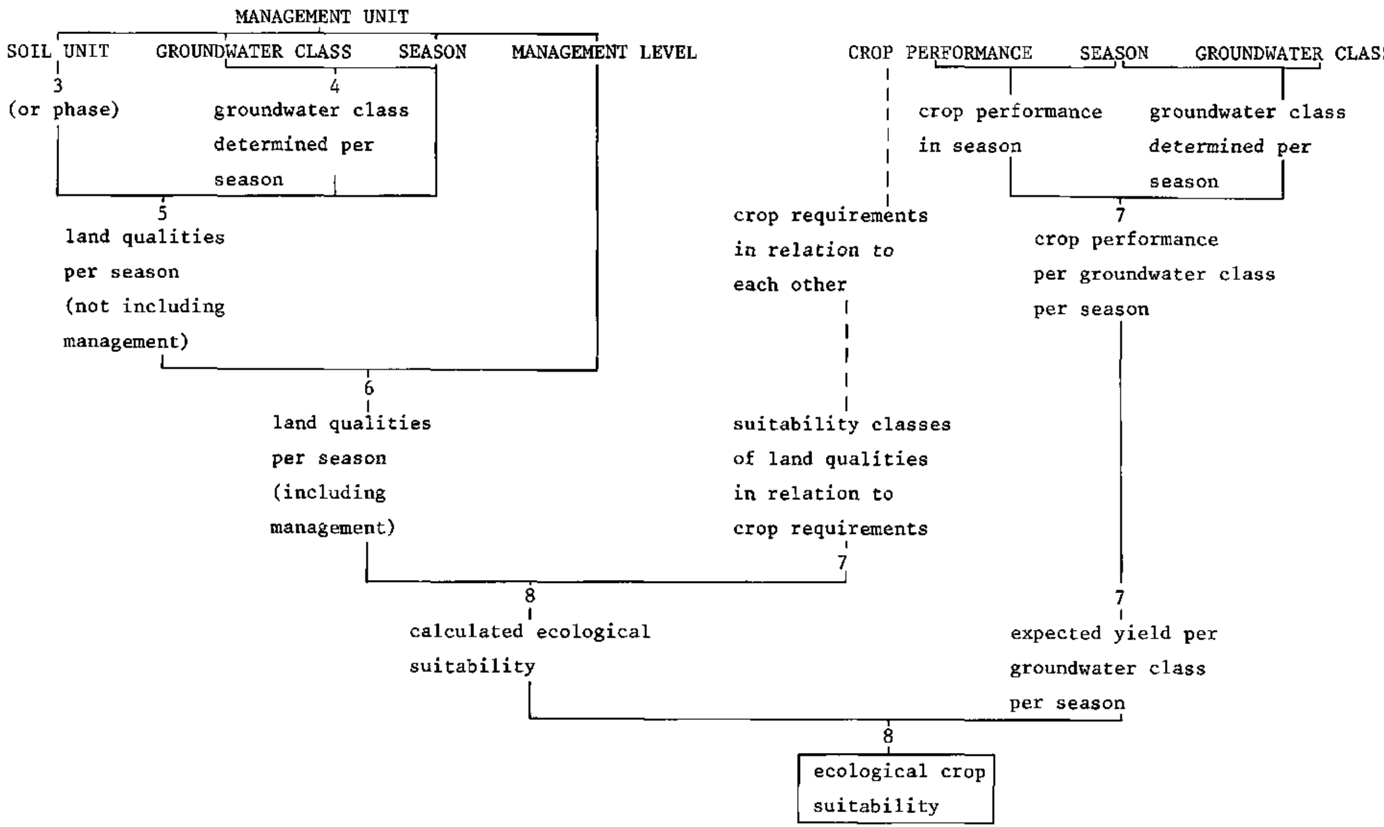


Fig. 7.1. Procedure for determining the ecological crop suitability of a management unit for a season or on a yearly basis; a management unit consists of a soil unit, a phase, the groundwater class for each season, and a specified management level. Numbers refer to chapters.

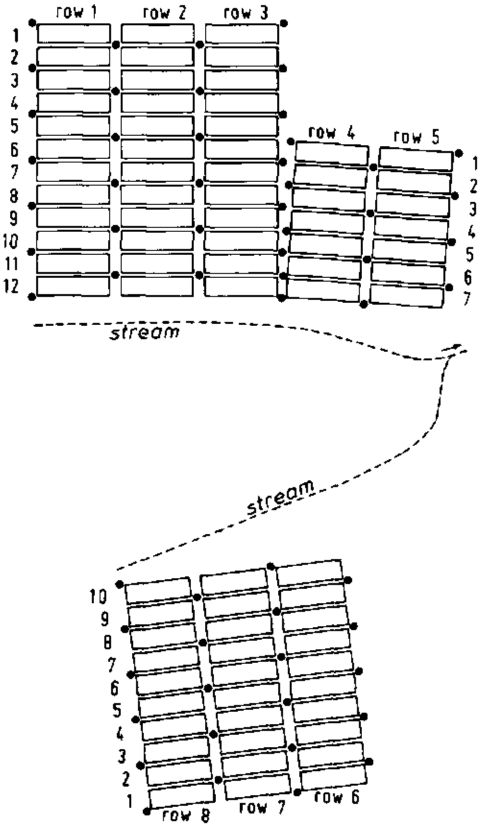


Fig. 7.2. Experimental area lay-out in Eastbank area; thick points represent the groundwater tubes (width of strips is 5 m).

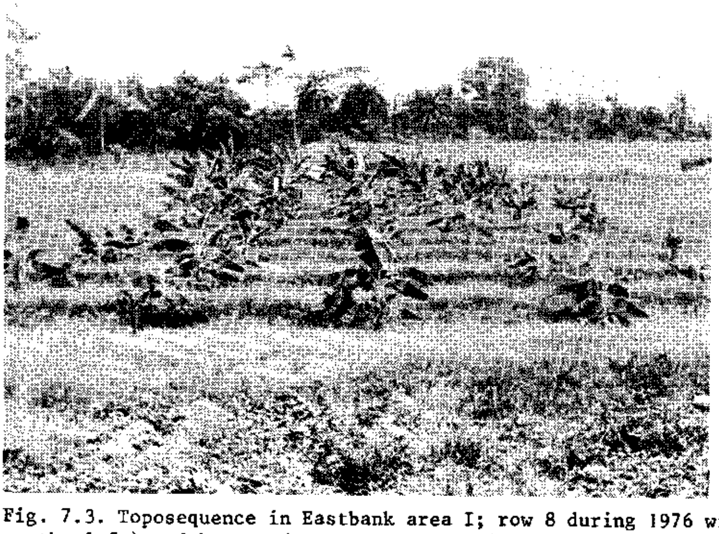


Fig. 7.3. Toposequence in Eastbank area I; row 8 during 1976 with plantain (four rows on the left) and banana (two rows on the right).

poorly drained soils. Their length on the lower slope ranged from 35 to 60 m. Each sequence was subdivided into strips, roughly parallel to the contour lines, 5 m wide (along the slope) and 16 to 18 m long (perpendicular to the slope). The strips were separated by low bunds, planted with a protective cover of *Paspalum notatum*. (For more information on the soils and hydrology of Eastbank area I, see Section 3.2.3 and Chapter 4).

The toposequences were cultivated with several crops of which rice, maize, cowpea, and soybean were studied intensively; other crops, with the exception of cocoyam, were planted only once (Table 7.1). The treatment of a crop on a toposequence was similar all along the sequence in order to study the effect of soil and water characteristics on crop performance. The level of management applied differed per crop; the four most intensively observed crops were cultivated on a management level that can be compared to the defined improved management level although it differed in the following respects: the only drainage applied on the lower strips was by planting on ridges or mounds without the use of any small drainage ditches; a higher quantity of fertilizers was sometimes applied than was described in Table 6.1; more than one cultivar was used, although during later years cultivation was limited to one useful cultivar.

Several soil and water characteristics of the toposequences in Eastbank area I were correlated with yields of rice, maize, cowpea, and soybean. As these toposequences run from well-drained to very poorly drained soils, it could be expected that the groundwater depth would dominate crop performance. On the other hand, there are other factors such as texture, amount of gravel and several soil chemical factors, that form a complex of factors related to yield. As such a complex was nearly always related to the water regime, a clear influence of any separate factor in the complex could hardly, if ever, be detected. In fact, a toposequence of well to very poorly drained soils is not suitable to study the effect of non-groundwater factors on crop performance. It was concluded from the correlation study that the groundwater class per season could serve as the major factor representing the groundwater fluctuation, related to crop performance. For more details reference is made to Appendix G.

The expected yield per groundwater class per season was based, as far as possible, on actual yield data. Most of these data were obtained from the toposequence experiments in Eastbank area I during the years 1972 to 1976, supplemented with some experimental data from Eastbank area II and the valley bottom of Eastbank area I. Groundwater depths were measured biweekly in groundwater tubes on both sides of each toposequence (cf. Section 4.1.2). Groundwater classes were determined for the whole period of cultivation of each crop with the exception of maize, for which the first eight weeks were found to be more appropriate. For the harvesting of crops, each strip on a toposequence was divided into four plots. The average of the two plots closest to a groundwater tube was used to determine the relation yield-groundwater class. In Appendix H, the yield data per groundwater class per season are given for rice, maize, cowpea, and soybean.

The expected yield per groundwater class per season is expressed in four classes: high, moderate, restricted, and low, represented in the Tables as 1, 2, 3, and 4, respectively; intermediate values (1-2, 2-3 and 3-4) were also used. The available data on the relation yield-groundwater class were interpreted for each growing season. For rice, maize, cowpea and soybean the average yields, the number of yield data and the number of rela-

Table 7.1. Summary of location and season of crops, grown on the toposequences in Eastbank area I from 1972 to 1976 (see Fig. 7.2).

year	season	crop	cultivar	row	strips
1972	second	cowpea	Prima	4	all
		soybean	Kent	5	all
1973	major first	rice	IR 20/IR 305	1	all
		maize	TzB	2	all
		rice	IR 20/IR 305	3	all
		soybean	Bossier	4	all (left side)
		cowpea	Pale green	4	all (right side)
		soybean	Kent	5	all (left side)
		cowpea	Prima	5	all (right side)
		rice	IR 20	6	all
		maize	TzB	7	all
		rice	IR 20	8	all
1973	second	rice	IR 20/IR 305	1	all
		maize	TzB	2	all
		rice	IR 20/IR 305	3	all
		soybean	Bossier/Kent	4	all
		cowpea	Prima/Pale green	5	all
		rice	IR 20/IR 305	6	all
		maize	TzB	7	all
		rice	IR 20/IR 305	8	all
1973/74	dry	maize	TzB	2	7-12
		soybean	Bossier	4+5	4-7
		maize	TzB	7	5-10
1974	major first	rice	IR 20	1	all
		maize	TzB	2	all
		rice	Tos 2300/2328	3	all
		cowpea	TVU 1190	4	all
		soybean	Bossier	5	all
		pigeon pea	8104	6	all
		rice	Tos 2405	7	all
		maize	TzB	8	all
1974	second	rice	Tos 2328	1	all
		maize	TzB	2	all
		rice	IR 20	3	all
		soybean	Bossier	4	all
		cowpea	TVU 1190	5	all
		pigeon pea	8104	6	all
		soybean	Bossier	7	all
		maize	TzB	8	all
1975	early first	maize	TzB	6	6-10
1975	major first	rice	Tos 2378/2382	1	all
		maize	TzB	2	1-9
		rice	IR 20	2	10-12
		rice	IR 20	3	all
		maize	TzB	6	1-5
		rice	Tos 4019	6	6-10
		cassava	local (Ojunkaiye)	7	1-6
		rice	IR 20	7	7-10
		okra	local	8	all
1975	second	maize	TzpB	2	all
		maize	TzB	6	3-5
		soybean	Bossier	6	3-10
		cowpea	TVU 1190	6	1-2
		cassava	local (Ojunkaiye)	7	1-6
		celosia	local	8	all
1975/76	dry	tomato	11-12-6	6	7-10
		sweet pepper	Yolo wonder	7	7-10
		banana	Dwarf Cavendish	8	all (right side)
		plantain	False Horn	8	all (left side)

year	season	crop	cultivar	row	strips
1976	major first	yam	local	2	all
		cassava	local (Ojunkaiye)	7	1-6
		banana	Dwarf Cavendish	8	all (right side)
		plantain	False Horn	8	all (left side)
1976	second	yam	local	2	all
		sweet potato	-	7	all
		banana	Dwarf Cavendish	8	all (right side)
		plantain	False Horn	8	all (left side)

tively low yields were compared for the groundwater classes in relation to each other. There can be a large difference in the number of yield data per groundwater class; some groundwater classes occur more often than others, while some do not occur at all. Moreover with a higher number of observations, a higher number of relatively low yields might be expected. For the other crops, which were cultivated only once, yield data were merely used as indicative values. The expected yield per groundwater class for all crops was, as far as possible, extrapolated in a qualitative way from the available data. The determination of the expected yield per groundwater class was made for each of the two management levels. In many cases, the expected yield was higher for the improved management level, considering any of the management practices as represented in Table 6.1. However, as more management practices are to be applied under the improved management level, a high yield expectation (class 1) in the case of improved management is considered to represent a higher expected yield level compared to the high yield expectation class in the case of traditional management. The difference in expected yield between improved and traditional management was applied to compensate for the costs of improvements; moreover, a higher yield level is required as an incentive for the farmer to change from traditional to improved management.

In Appendix K reference yields are mentioned for each crop. These reference yields are considered to be "high yields" (indicated in the Tables as expected yield class 1). Yields of rice, maize, cowpea, and soybean, as obtained in the toposequence experiments in Eastbank area I, are usually higher than the reference yields. For the determination of the expected yield per groundwater class for these four crops, yields have to be compared for the groundwater classes in relation to each other.

7.2.2 Rice

Rice (*Oryza sativa* L.) was grown on toposequences twelve times during the major first season (1973 to 1976) and six times during the second season (1973 to 1974); furthermore rice was planted twice in the valley bottom of Eastbank area I during the second season (1975 and 1976). Before planting a basal dose of P and K was applied and rice was directly sown afterwards; on flooded strips direct sowing did not always succeed and then it was transplanted from other strips. During the first eight weeks N was applied in 3 to 4 applications (total of 40 kg N/ha). No water management (drainage, bunding, levelling, irrigation) was applied. In Table 7.2 the yields, averaged per groundwater class and the number

Table 7.2. Average yield of rice (in q/ha), the number of yield data, the number of low yields (less than 5 q/ha) and the expected yield per management level, as determined per groundwater class during three seasons.

season	major first					second					dry	
groundwater class	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.	expected yield trad.	expected yield imp.
1	18	16	2	3	2-3	0	19	19	4	4	4	4
2	21	30	6	3	2-3	1	14	13	4	4	4	4
3	11	2	1	2-3	2	0	2	2	4	3-4	4	4
4	7	1	0	3	2-3	0	2	2	4	4	4	4
5	29	12	0	1	1	4	5	3	3	2	3	2-3
6	29	5	0	1	1	17	6	1	2	1	2-3	2
7	nd	0	0	1	1	13	5	0	2	1	2	2
8	nd	0	0	1	1	11	4	1	2	2	3	2-3
9	32	12	0	1	1	17	8	1	1	1	2	2
10	23	12	0	1	1	19	13	2	1	1	1	1
11	21	4	0	1-2	1	20	9	2	2	1-2	1-2	1-2

Notes: 1 q/ha = 100 kg/ha; nd. = no data; trad. = traditional; imp. = improved management; expected yield: 1 = high, 2 = moderate, 3 = restricted, 4 = low.

of yield data and low yields (taken as being lower than 500 kg/ha) are indicated, together with the expected yield per groundwater class for each management level. More detailed yield-groundwater class data can be found in Appendix H. Although yield data were not available for the dry season, the expected yields for this season were extrapolated from data of the other two seasons.

For the major first season the classes 5 to 11 have a high expected yield; with class 11 the occurrence of iron-toxicity caused somewhat lower yields. With classes 1 to 4, the water supply was limited during drought periods causing low yields; the expected yields for these classes are lower than those of classes 5 to 11. Although the obtained average yield for class 3 is relatively low, the expected yield is somewhat higher than those of the classes 1, 2, and 4, because of the low number of yield data and because a more regular water supply by the groundwater table is expected to result in lower yield losses by drought periods.
As the rainfall period of the second rainy season is too short for rice, only the classes with relatively shallow groundwater levels can supply rice with sufficient water during the whole growing period and especially the classes 1 to 4 have therefore a low expected yield. The expected yield for the classes 6 to 11 are differentiated, depending on average yields and percentage of low yields. Class 5 is considered as being intermediate between the two groups of groundwater classes; although the obtained average yield is low, the yields are expected to be restricted to moderate.
In the dry season only the more hydromorphic groundwater classes are expected to give a reasonable yield; the wettest classes (10 and 11) are best suited.

7.2.3 Maize

Maize (*Zea mays* L.) was grown on toposequences twice during the dry season (1973/74), once during the early first season (1975), six times during the major first season (1973 to 1975) and six times during the second season (1973 to 1975); furthermore maize was cultivated in the valley bottom of Eastbank area I during the dry season (1974/75) and the early first season (1976). Before planting a basal dose of NPK was applied, followed by one application of N (of 25 kg N/ha) six weeks after planting. The used management can be compared to the improved management level, although no drainage measures were taken in the lower strips. Planting was done without the use of ridges or mounds. In Table 7.3 the yields, averaged per groundwater class and the number of yield data and low yields (taken as being lower than 600 kg/ha) are indicated, together with the expected yield per groundwater class for each of the two management levels. More detailed yield-groundwater class data can be found in Appendix H.

High groundwater levels severely reduced the yield, especially during the early (vegetative) growth of maize (IITA 1976) (Fig. 7.4). This was also shown in the correlation study, Appendix G; the first eight weeks after planting was found to be a more appropriate period for the calculation of the groundwater class than the whole growing period. This implies, that damage by high groundwater after the first eight weeks was not included in the expected yield determination. It was observed that maize plants in later (generative) stages of growth and cultivated on soils with high groundwater levels, were more easily blown over by wind than plants on well-drained soils; another feature was the occurrence of N-deficiency in such plants. In spite of these forms of yield loss, the determination of the groundwater class was based on the first eight weeks after planting.

Table 7.3. The determination per groundwater class[1] for four seasons of the average yield of maize (in q/ha), the number of yield data, the number of low yields (less than 6 q/ha) and the expected yield per management level.

season	dry					early first				
groundwater class	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.
1	7	1	0	4	4	nd	0	0	4	4
2	17	1	0	3-4	3-4	nd	0	0	3-4	3
3	20	3	1	3	2-3	26	4	1	2	2
4	nd	0	0	4	3	nd	0	0	3	2-3
5	nd	0	0	2	2	nd	0	0	2	1
6	24	3	0	2-3	2	27	10	0	2	2
7	28	11	0	3	2	29	9	0	3	2-3
8	nd	0	0	3	2	nd	0	0	2	2
9	nd	0	0	4	3	nd	0	0	3	2-3
10	3	1	1	4	4	24	2	0	3-4	3
11	nd	0	0	4	4	0	1	1	4	4

season	major first					second				
groundwater class	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.
1	42	26	0	1	1	14	3	0	3-4	3
2	53	11	0	1	1	20	18	0	3	2-3
3	42	10	0	1	1	22	2	0	2-3	2
4	nd	0	0	1-2	1-2	nd	0	0	3-4	2-3
5	40	4	0	2	2	19	6	0	3	2
6	28	8	1	3	2-3	17	1	0	3-4	2-3
7	nd	0	0	4	3	0	3	3	4	4
8	8	1	0	3-4	2-3	nd	0	0	3-4	3
9	18	4	0	4	3	3	6	5	4	4
10	7	7	5	4	4	1	13	12	4	4
11	nd	0	0	4	4	0	6	6	4	4

Note: [1] groundwater class determined for the first eight weeks after planting.

Fig. 7.4. Sequential transition in maize performance; with better drained (left) and poorly drained (right) conditions.

For the dry season only few yield data were available; only for classes 3, 6, and 7 an average yield could be calculated out of more than one yield date. The classes 6 and 7 are expected to give restricted to moderate yields, depending on management, instead of high yields, compared to the higher yield levels obtained in the major first season. With class 3 slightly lower yields than those of classes 6 and 7 are expected. The classes with relatively low (1 and 2) and those with relatively high (9, 10, and 11) groundwater levels are expected to give low yields.
As in the dry season, also few yield data were available for the early first season. Compared to the dry season, the expected yields, apart from classes 1 and 11, are generally somewhat higher for the early first season.
The major first season is a suitable season for maize and high yields are expected for the groundwater classes 1 to 5. From class 6 onwards, yields decline depending on the height of the groundwater levels and classes 9 to 11 are expected to give low yields. Improvement of the drainage conditions by higher ridges or mounds results in higher expected yields with classes 5 to 9.
High groundwater levels in the second season, compared to those of the major first season, are more likely to reduce the yield of maize, as the groundwater level rises more rapidly after planting; therefore the expected yields in the second season for the classes 5 to 11 are lower than those of the major first season. Although the yields obtained with classes 1, 2, and 3 are relatively good, the expected yield for these classes is given as restricted to moderate in relation to the high yields of the major first season and because of possible drought stress in later stages of growth after the regular rains of the second season have ended.

7.2.4 Root crops

The root crops involved were yam (*Dioscorea* spp.), cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* (L.) Lam), and cocoyam (*Aracea* spp. such as *Colocasia esculenta* D. Schott and *Xanthosoma sagittifolium* (L.) Schott). Yam, cassava, and sweet potato were planted on mounds in the traditional way. Drainage, by means of high mounds and drainage ditches (as are to be used under improved management) was not applied, in order to be able to study the effect of high groundwater levels on crop performance. Fertilizers were not applied.

Yam (*Dioscorea rotundata* Poir.).

White yam (*D. rotundata*) is the common yam species in south-western Nigeria.

On one of the toposequences in Eastbank area I, yam was cultivated during the major first and the second seasons of 1976. Pieces of locally bought yams were planted in May on mounds about 20 cm high; harvesting was in December. The following observations were made:

- the percentage of living plants on the strips.
- the mean rating of crop performance on two dates: 16th September, just after the short dry season and 4th November, just after the second rainy season. Plants were rated as follows: very poor = 1, poor = 2, medium = 3, and good = 4; the values were averaged per strip.
- the yield.
- the estimated value (in N) of the tubers, based on the size.

Results are illustrated in Fig. 7.5. It can be seen that the percentage of living plants decreases gradually towards the wetter end of the toposequence. With strip no. 1 being the highest and strip no. 12 the lowest, strip no. 9 with groundwater class 6 showed a sharp decrease in the two ratings of crop performance; there, the presence of a spring level caused high groundwater levels. The ratings measured after the second rainy season show a better crop performance than those just after the short dry season. The yield is

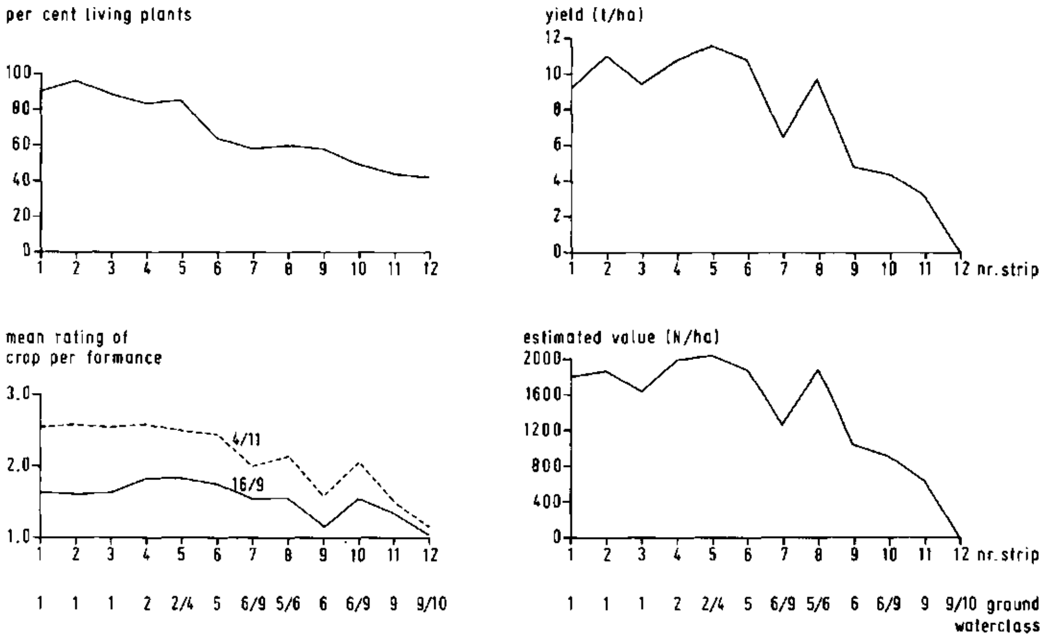


Fig. 7.5. The relation between groundwater class and percentage of living plants, mean ratings of crop performance, yield, and estimated value of yam, cultivated on a toposequence in Eastbank area I, 1976.

Table 7.4. The expected yield per groundwater class for two management levels for yam, cassava, sweet potato (major first and second season) and cocoyam.

crop	yam		cassava		sweet potato				cocoyam	
season	major first + second		annual		major first	second	major first	second	major first + second	
management level	trad.	imp.	trad.	imp.	trad.		imp.		trad.	imp.
groundwater class										
1	1	1	1	1	1	3	2	3	3-4	3-4
2	1	1	1	1	1	2	2	2	2-3	2-3
3	1	1	1	1	1	1	1	1	1	2
4	1	1	1	1	1	2	2	2	1-2	2
5	1-2	1-2	3	2	1	1	1	2	1	2
6	2	2	4	3	2	1	2	1	1	1
7	4	4	4	4	2	2	2	2	1	1
8	1-2	1-2	4	3	2-3	2	2	2	1	1-2
9	3	2	4	4	3	2	2	2	1	1
10	4	4	4	4	4	3	3	2	1	1
11	4	4	4	4	4	4	4	4	1	1

in accordance with the ratings of crop performance. The upper strips with groundwater classes 1 to 5 gave good yields. Strip no. 8 did relatively well because of somewhat better drainage than the other wet strips. The estimated values of the tubers agree well with the yield data.

Based on the information of this experiment and on other observations made in yam experiments at IITA, the expected yield of yam per groundwater class was considered for the period of the major first and second season (Table 7.4).

The groundwater classes 1 to 4 are expected to give high yields. With higher groundwater levels within a depth of 25 cm, expected yields decrease: class 5 and 8 moderate to high, class 6 moderate and class 9 restricted or moderate, depending on management; classes 7, 10, and 11 are too wet for yam and have a low expected yield.

Cassava (*Manihot esculenta* Crantz).

Cassava was grown on the six upper strips on one of the toposequences (consisting of ten strips) in Eastbank area I in 1975 and 1976. No differences were found among the upper five strips on which yields of 206 to 229 q/ha were obtained with groundwater class 1 or 2. The lowest (sixth) strip had higher groundwater levels with consequently lower yields.

No yield was obtained with groundwater class 9. Groundwater at less than 25 cm depth severely affected the growth of cassava; the "wetter" groundwater classes have therefore been given a low yield expectation (Table 7.4); the expected yield for groundwater classes 1 to 4 was considered "high". The intermediate groundwater classes (5 and to a minor extent 6 and 8) were interpolated.

Sweet potato (*Ipomoea batatas* (L.) Lam).

Although sweet potato is not an important food crop in the study area, it was included in the evaluation because of its general importance as a tropical root crop. On a toposequence in Eastbank area I, sweet potatoes were grown during the second rainy season of 1976. As the rainfall period of this season was rather short, drought stress occurred in the upper strips. The sweet potatoes were grown on 30 cm high ridges along the sequence, without fertilizer application. Yield and percentage of weevil-attacked tubers as related to the groundwater class over the whole growing season are given in Table 7.5. The yield in the upper strips was fairly low, with about 70 per cent of tubers attacked by weevils, which are common pests in sweet potatoes. The middle strips had higher yields, but 70 to 90 percent of the tubers were damaged. The sweet potatoes in the lower strips were not affected by weevils and gave fairly good yields, although the tubers were small. No determinations were made as to whether the tubers of the hydromorphic strips were tuberous or fibrous (cf. Section 7.3.3). The observations suggest that weevils cannot survive in hydro-

Table 7.5. Yield of sweet potato and percentage of tubers attacked by weevils in relation to the groundwater class; Eastbank area I, second season 1976.

strip	groundwater class	yield q/ha	percentage of tubers attacked by weevils
1	1	33	74
2	1	109	64
3	2	107	94
4	2	153	91
5	2/4	150	78
6	8	170	51
7	9	189	0
8	10	190	0
9	10	106	0
10	10	144	0

morphic soils and that plants not affected by drought stress have more resistance to weevil attacks. The expected yield for the second season was extrapolated from this experiment; the data for the major first season were interpreted from those of the second season (Table 7.4).

As the rainfall period is longer in the major first season than in the second season, expected yields of sweet potato in the second season are relatively lower. The groundwater classes 3 and 6 and, with traditional management, class 5 are expected to result in high yields in the second season. In classes 1, 2, and 4 the occurrence of drought stress is more likely and compared to class 3, they have lower expected yields: classes 2 and 4 moderate and class 1 restricted. Improvements in the drainage condition with class 5 is not expected to result in a sufficient yield increase; therefore with improved management only moderate yields are expected. Towards the wetter classes expected yields levels decrease: classes 7, 8, and 9 moderate, class 10 restricted or moderate, depending on management and class 11 low.

Cocoyam (*Colocasia esculenta* D. Schott and *Xanthosoma sagittifolium* (L.) Schott).

Cocoyam forms a common food crop in areas with a high rainfall such as the Cameroons. Within the study area, this crop (and in particular *Xanthosoma*) is only important in the eastern part, but was considered for the whole study area.

Unfortunately, cocoyam was not cultivated on a toposequence, but observations were made in other experimental areas at IITA. It was observed that no mounds are needed for this crop; farmers always plant cocoyam on the flat, usually as an intercrop. The expected yield was estimated based on these observations (Table 7.4).

For cocoyam, the "wetter" groundwater classes are expected to give generally higher yields than the "better drained" groundwater classes. As *Xanthosoma* aroids prefer non-waterlogged soils, the expected yield is based on *Colocasia* aroids. The expected yield for groundwater class 1 and to a minor extent class 2, is dependent on the amount and distribution of the rainfall; with relatively long drought periods yields may decrease considerably.

7.2.5 Grain legumes

Grain legumes involved in the study were cowpea (*Vigna unguiculata* (L.) Walp.), soybean (*Glycine max* (L.) Merr.), and pigeon pea (*Cajanus cajan* (L.) Millsp.). Especially cowpea is popular in the study area. All grain legumes are sensitive to waterlogging, although variation occurs among species. Soybean was less sensitive to waterlogging than cowpea; pigeon pea is more sensitive (IITA 1976). The legumes were cultivated under improved management conditions, but without drainage. Inoculated seed was used and a basal dose of P and K was applied before planting; these two practices were not included in the improved management level as described in Table 6.1. Cowpea and soybean were cultivated many times; detailed yield-groundwater class data can be found in Appendix H.

Cowpea (*Vigna unguiculata* (L.) Walp.).

Cowpea was grown on toposequences twice during the major first season (1973 and 1974) and three times during the second season (1972 to 1974). In Table 7.6 the yields are averaged per groundwater class and the number of yield data and low yields (taken as being less than 200 kg/ha) are indicated, together with the expected yield per groundwater

Table 7.6. The determination per groundwater class for several seasons of the average yield of cowpea and soybean (in q/ha), the number of yield data, the number of low yields (less than 2 (cowpea) and 3 (soybean) q/ha) and the expected yield per management level for cowpea, soybean and pigeon pea.

crop	cowpea												pigeon pea	
season	major first					second					dry			
groundwater class	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.	average yield	number of data	number of low yield	expected yield trad.	expected yield imp.	expected yield trad.	expected yield imp.	expected yield trad.	expected yield imp.
1	13	4	0	1	1	nd	0	0	1	2	4	4	1	1
2	13	4	0	1	1	9	9	0	1	2	4	4	2-3	2-3
3	13	3	0	1	1	nd	0	0	1	1-2	1	2	3-4	3
4	nd	0	0	1	1	8	2	0	2	2	3-4	3	3	3
5	16	1	0	2	1-2	7	3	0	3	2	2-3	2	4	3
6	4	1	0	3	2-3	3	7	5	4	3-4	2	2	4	4
7	nd	0	0	4	3	nd	0	0	4	4	3	2	4	4
8	nd	0	0	3	2	17	1	0	4	3-4	3	2-3	4	4
9	8	3	0	4	2-3	0	1	1	4	4	4	3-4	4	4
10	nd	0	0	4	4	0	1	1	4	4	4	4	4	4
11	nd	0	0	4	4	nd	0	0	4	4	4	4	4	4

crop	soybean														
season	major first					second					dry				
groundwater class	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.	average yield	number of data	number of low yield	expected yield trad.	expected yield imp.	average yield	number of data	number of low yields	expected yield trad.	expected yield imp.
1	18	1	0	1	2	6	2	0	1-2	2	14	1	0	4	4
2	21	7	0	1	1-2	17	16	0	1	2	nd	0	0	3	2-3
3	27	2	0	1	1	6	1	0	1	2	20	5	0	2	2
4	nd	0	0	1	2	nd	0	0	2	2	nd	0	0	2	2
5	33	1	0	2	1	16	5	0	3	2	nd	0	0	1	1-2
6	33	4	0	2	1-2	11	5	1	4	3	16	2	0	3	2
7	nd	0	0	3	2	nd	0	0	4	3	7	6	0	4	3
8	nd	0	0	2	2	22	1	0	4	3	nd	0	0	2	2
9	30	1	0	2-3	2	12	4	1	4	3	nd	0	0	3	2-3
10	nd	0	0	4	2-3	4	10	5	4	4	nd	0	0	4	3-4
11	nd	0	0	4	4	nd	0	0	4	4	nd	0	0	4	4

Note: 1 q/ha = 100 kg/ha; nd = no date; trad. = traditional; imp. = improved management.

class for each management level. Although no yield data were available for the dry season, an estimate was made for this season on the basis of the expected yields per groundwater class of the other two seasons.

For the major first season classes 1 to 4 are expected to result in high yields. The expected yields decrease towards class 10 and 11, where low yields are expected. For the intermediate groundwater classes 5 to 9 moderate to low yields are expected, depending on the degree of wetness and on management.
With classes 1 to 4 lower yields were obtained in the second season compared to the major first season and therefore expected yields are generally lower. Class 3 is considered somewhat better than classes 1, 2, and 4, because of a better water supply by the groundwater at the end of the growth period. The other classes 5 to 11 are expected to give lower yields compared to those of the major first season because groundwater rises more quickly after planting. For class 5 restricted to moderate yields are expected, depending on management. Classes 6 to 11 result in low expected yields, although for classes 6 and 8 higher ridges may improve yields to some extent.

Soybean (*Glycine max* (L.) Merr.).

Soybean was cultivated on toposequences twice during the dry season (1973/74), twice during the major first season (1973 and 1974) and five times during the second season (1972 to 1975); furthermore soybean was cultivated in the valley bottom of Eastbank area I during the dry season (1975/76). In Table 7.6 the average yield, the number of yield data and the number of low yields (being taken as lower than 300 kg/ha) are given per groundwater class, together with the expected yield per groundwater class for each of the two management levels.

Only few yield data are available for the dry season; they are limited to the classes 3, 6, and 7. The single yield obtained with class 1 is exceptional; this class is considered to result in low yields during the dry season. Class 3 is expected to result in moderate yields; class 6 and 7 in restricted to moderate or low to restricted yields respectively, depending on management. Class 5 is considered to result in high yield levels. From class 8 towards class 11 expected yields decrease with the degree of wetness, although with the improved management level higher yields can be expected compared to the yield levels obtained with the traditional management level.
In the major first season, the expected yield for the classes 1 to 6 is high or moderate; for some of these classes (notably 1, 2, and 4) the expected yield for the traditional management level is higher than the one for the improved level, as the defined improvements, which do not include irrigation, are assumed not to result in sufficient yield increases. The average yield given for class 9 is based on only one value, which is exceptionally high for this class. Groundwater class 11 is expected to result in low yields under both management levels, while with class 10 restricted to moderate yields are expected only with improved management.
The yields obtained in the second season are generally lower than those of the major first season; therefore, especially with improved management, expected yields are also lower. Few yield data were available for the classes 1 and 3; even so, their expected yield levels are considered to be about similar to that of class 2. Although relatively high yields were obtained with classes 8 and 9, the classes 6 to 11 are expected to result in low yields in the case of traditional management and in restricted (classes 6 to 9) and low (classes 10 and 11) yields in the case of improved management.

Pigeon pea (*Cajanus cajan* (L.) Millsp.).

Pigeon pea was cultivated in Eastbank area I in 1974 and 1975. On locations where groundwater rose above a depth of 25 cm, growth of pigeon pea was nil. In general, pigeon pea is not a suitable crop for hydromorphic soils. Only for those classes in which groundwater remains below 25 cm depth, apart from intensive drainage in class 5, can some yield be expected (Table 7.6).

Class 1 is expected to give high yields; the expected yields for the classes 2, 3, and 4 are intermediate: class 2 restricted to moderate, class 3 low to restricted and class 4 restricted.

7.2.6 Vegetables

The vegetables included in the study were: tomato (*Lycopersicon esculentum* Mill.), okra (*Hibiscus esculentus* L.), celosia (*Celosia cristata* L.), and sweet pepper (*Capsicum annuum* L.). Many more vegetables are grown by the farmers, but those mentioned, with the exception of sweet pepper, are the more important ones. Vegetables are usually grown in the compound area of villages and scattered in the fields among other food crops. Cultivation of vegetables on a larger scale involves a more intensive approach, including insecticide spraying and timing of harvesting, while the presence of a nearby market becomes important. Furthermore, growing of vegetables as cash crops involves storage, packing, and transport to the market. This aspect is not included in the two management levels under investigation and vegetable cultivation is considered to be for home consumption only. Under both management levels, vegetables are cultivated on small plots. Higher applications of fertilizer and better water management (drainage) differentiates the improved level from the traditional level (cf. Table 6.1). Directly after transplanting tomato and sweet pepper, in the dry season, watering may be needed during the first 1 to 2 weeks. This initial hand irrigation was included for both management levels. This was possible because of the relatively small number of plants involved (small plots) and the presence of water nearby.

Yield data of tomato and sweet pepper are only available for the dry season and those of okra and celosia for the major first and the second season, respectively. Because of scarcity of data only the dry season was considered and expected yields for okra and celosia were extrapolated from the data of other seasons.

Tomato (*Lycopersicon esculentum* Mill.).

Tomato was grown on four hydromorphic strips in Eastbank area I during the dry season of 1975-1976 and in the valley bottom of Eastbank area II during the dry season of 1976-1977. Although only few yield-groundwater class data were available, the expected yield per class was determined (Table 7.7). The intermediate classes are expected to give the highest yields. Even with the wettest class (11), yield can be expected if enough drainage is applied and if seedlings are planted on relatively high ridges.

Okra (*Hibiscus esculentus* L.).

Okra was cultivated on a toposequence in Eastbank area I during the major first season of 1975. Plants were grown on ridges on all strips. No clear difference in yield were found between the upper, relatively dry strips and the lower, relatively wet strips. Only on local depressions on the lower strips, in which the groundwater reached the top of the ridges, did okra yield 30 to 50 per cent less.

Table 7.7. The expected yield per groundwater class for two management levels of tomato, okra, celosia, and sweet pepper; dry season only.

crop	tomato		okra		celosia		sweet pepper	
management level	trad.	imp.	trad.	imp.	trad.	imp.	trad.	imp.
groundwater class								
1	4	4	4	4	4	4	4	4
2	4	4	4	4	4	4	4	4
3	3	2-3	3-4	3-4	3	3	4	4
4	4	4	3	2-3	4	4	4	4
5	1	1	1	1	1	1	1	1
6	1	1	1-2	2	2	2	2	2
7	2	1	3	2	4	3-4	4	3
8	3	1	1	1-2	2	2	3	2
9	3	2	2	2	3	2	4	3
10	3	2	2-3	2	4	3	4	4
11	4	3	4	3	4	4	4	4

The expected yield per groundwater class for the dry season is interpreted from the major first season data. The driest groundwater classes 1 and 2 are not expected to give a sufficient yield in the dry season as the availability of water will be too low. Class 5 is considered an ideal groundwater class for the cultivation of okra. Class 11 may still give some yield with intense drainage. The expected yields for the other classes were interpolated (Table 7.7).

Celosia (*Celosia cristata* L.).

Celosia was grown on a toposequence in Eastbank area I during the second season of 1975. The expected yield per groundwater class for the dry season was extrapolated from the second season data. While the upper strips gave satisfactory yields, the quality of the leaves of the plants grown on the lower, wetter strips was bad and the rate of growth much slower than for the upper drier strips; classes 10 and 11 therefore have a low expected yield. As with okra, class 5 is expected to give the highest yields. Severe drought stress will occur in the dry season with groundwater classes 1 and 2 (Table 7.7).

Sweet pepper (*Capsicum annuum* L.).

Sweet pepper was cultivated on four hydromorphic strips on a toposequence in Eastbank area I during the dry season of 1975-1976. Sweet pepper cultivation was best with the intermediate groundwater classes (Table 7.7). Excess of water (classes 7, 10, and 11) or severe drought (classes 1, 2, 3, and 4), will reduce the yield severely. The expected yields of sweet pepper are more restricted to the intermediate groundwater classes than those of tomato.

7.2.7 *Plantain and banana*

Plantain and banana (*Musa* spp.) are grown by the local farmers on a small scale. These plants can be found scattered in the fields and around housing areas, but not as plantation crops. Yields and rate of growth are often low. Plantains and bananas are more important in areas with a higher rainfall such as Eastern Nigeria and the Cameroons.

A toposequence in Eastbank area I was planted in the rainy season of 1975 with plantain (False Horn) and banana (Dwarf Cavendish) (cf. Fig. 7.3); a number of plants in the hydromorphic part of the toposequence had to be replanted in the following dry season. Every six months, 300 g of a 15:15:15 NPK-fertilizer per plant was applied. The obtained yields, however, were still low, due to excess water, drought stress, or to the generally low soil fertility status of that particular toposequence (Table 7.8); the time from planting up to the first harvest is rather long, especially on the wetter strips (P. Devos, personal communication). The relation between the height of the tallest sucker of plantain and the groundwater class is very obvious. Some of the plantains were damaged by wind.

On the basis of these data, the expected yield per groundwater class was determined for plantain and banana (Table 7.9). The expected yield per groundwater class for plantain differs slightly from that of banana for some groundwater classes. Plants

Table 7.8. The relation between the groundwater class and the first yield of plantain and banana, the number of days to the first harvest, and several other relevant data (toposequence Eastbank area I, 1975 to 1977).

strip	groundwater class	plantain						
		yield (bunch-weight)	days to harvest	plants re-planted in dry season	plants felled by storm March '77	non-established plants	established but not flowering after 640 days	mean height of the tallest sucker
		q/ha	days	number out of eight plants				cm
1	1/2	91	451	-	1	-	-	175
2	2	119	463	-	2	-	-	134
3	2/4	89	414	-	5	-	-	185
4	2/4	87	443	-	1	-	-	157
5	4	92	439	1	2	1	3	164
6	4/8	79	434	5	-	2	-	91
7	9	57	437	6	1	1	-	85
8	9/10	69	517	5	-	1	-	72
9	9	77	570	1	2	-	1	79
10	9	64	540	1	-	1	1	90

strip	groundwater class	banana					
		yield (bunch-weight)	days to harvest	plants re-planted in dry season	plants felled by storm March '77	not-established plants	established but not flowering after 640 days
		q/ha	days	number out of four plants			
1	1/2	190	407	-	-	-	-
2	2	158	432	-	-	-	-
3	2/4	139	454	-	-	-	-
4	2/4	104	553	2	-	1	1
5	4	253	484	2	-	-	3
6	4/8	232	479	3	-	-	2
7	9	144	546	3	-	-	3
8	9/10	0	-	4	-	-	4
9	9	112	411	3	-	-	1
10	9	0	-	4	-	-	4

Table 7.9. The expected yield per groundwater class for two management levels for plantain and banana.

crop	plantain		banana	
management level groundwater class	traditional	improved	traditional	improved
1	1-2	2	2	2
2	1	1-2	1-2	2
3	1-2	2	1	1-2
4	1-2	2	1-2	2
5	2-3	2	2-3	2
6	3-4	2-3	4	3-4
7	4	3-4	4	4
8	3	2	3	2
9	4	3	4	3
10	4	4	4	4
11	4	4	4	4

on "poorly drained" groundwater classes are late bearing and the risk of failure is high on soils with groundwater classes 9, 10, and 11. On the other hand, drought may also reduce yields; therefore, groundwater class 1 has expected yield levels indicated as moderate (2) or moderate to high (1-2). For plantain, groundwater class 2 and for banana groundwater class 3 are expected to give the highest yields. The other groundwater classes were interpolated.

7.3 DETERMINATION OF THE ECOLOGICAL SUITABILITY CLASSES IN RELATION TO CROP REQUIREMENTS

7.3.1 Introduction

In this section the requirements for the crop will be discussed which are concerned with the land qualities (cf. Chapter 5). For each crop, the grades of the relevant land qualities for each ecological suitability class was determined. Climatic factors such as light and temperature are not included; generally speaking they are suitable for the studied crops in south-western Nigeria.

Four ecological suitability classes were introduced: high, moderate, restricted, and low. The determination of the ecological suitability classes for each crop was based on the mainly qualitative grading as used in Chapter 5. Therefore, the grading of the ecological suitability classes is also qualitative and limited to the study area. A clear definition of the ecological suitability classes cannot be given, but reference is made to the four classes of the expected yield per groundwater class (cf. Section 7.2), which are considered to have the same meaning as the four classes used for the determination of the requirements in relation to the crop performance.

For the determination of the ecological suitability classes the crops, with respect to their requirements, have to be compared in relation to each other. As most crops are discussed separately in literature, comparisons among crops with respect to their requirements of different land qualities can only be made to a minor extent[1]. In this study the

[1] Research into comparisons among crops with respect to a number of soil characteristics is being done by Sys cs.

qualitative requirements for the ecological suitability classes were determined on the basis of the data mentioned in literature, with the addition of observations made by the author in experimental areas at IITA. As both the grading of the land qualities and the ecological suitability classes was qualitative, the requirements for the crops should not be used in other studies, unless the same system of grading for the land qualities is applied.

With four ecological suitability classes and five grades, there is a limited number of possible sequences of grades for each (group of) crop(s). Going from one class to another, the required grade is changed by not more than one grade, except for the very high (vh) grade, where the difference is not more than two grades. Except for the very low grade (vl), the other grades only appear in one or two classes; the very high grade (vh) only appears in the high ecological suitability class. The total number of possible sequences of grades for each (group of) crop(s) is limited to eighteen by these restrictions. The most suited sequence was chosen for each (group of) crop(s).

7.3.2 Availability of water (Table 7.10)

Among the studied crops there is a large variation in requirements concerning the availability of water during the growing period. These requirements vary in the total quantity of available water during the growing period, but also in the availability of water in specific critical periods within the growing period; in these specific periods, shortage of water may reduce yields more severely than in other periods. However, an exact comparison among crops with respect to the availability of water is not possible, as the variation among crops is too complex. Therefore, a more qualitative differentiation is made among the studied crops with respect to their requirements concerning the availability of water.

Group a. *Cassava* and *pigeon pea*. Cassava and pigeon pea are regarded as crops that can withstand drought best. Except at planting, *cassava* can withstand prolonged periods of drought and is a valuable crop in regions of low or uncertain rainfall (Kay 1973). Cassava, being a relatively tall woody shrub, is associated with perennial growth in which the secondary thickened stem, from which the majority of leaves are shed, is capable of with-

Table 7.10. The land quality *availability of water* as criterion for the division of the four ecological suitability classes.

		ecological suitability class			
group	crops	high (1)	moderate (2)	resticted (3)	low (4)
a	cassava, pigeon pea	l	vl	vl	vl
b	sweet potato, cowpea	m	m	l	vl
c	maize, yam, soybean, okra, sweet pepper	h	m	l	vl
d	tomato, celosia	h	m	m	l
e	cocoyam, banana/plantain	h	h	m	l
f	rice	vh	h	m	l

Note: vl = very low, l = low, m = medium, h = high and vh = very high.

standing dry periods (Wilson 1977). The root system of cassava ramifies in the soil during the first few months, but when massive tuber growth occurs at depth of between 0 and 30/40 cm, the production of absorptive roots declines. Although the whole root system is reported to be fairly superficial and located in the upper 60 cm (Williams 1975), the evidence of cassava surviving dry seasons, which are even more severe than the one at Ibadan (e.g. South Togo, Forbes 1975), seems to indicate that this crop can draw considerable soil moisture, even when other crops, with exception of pigeon pea, are succumbing to drought. According to Fujise and Tsuno (1967) there is some evidence that cassava roots, concerned with water and ion uptake, are deep seated, but that tuberous roots are shallow. Such a root distribution would seem to be a desirable drought-tolerant characteristic.

Pigeon peas are drought-resistant. Their deep root system permits good growth under semi-arid conditions with less than 635 mm of rain per year (Purseglove 1968).

In Table 7.10 the requirements for the availability of water for cassava and pigeon pea are considered to be low for the high ecological suitability class; their ecological suitability is limited to the moderate suitability class in the case of a very low availability of water. The other studied crops have higher requirements for the availability of water.

Group b. *Sweet potato* and *cowpea*. With a medium availability of water, the ecological suitability class would be high or moderate; with a low availability of water the ecological suitability would be restricted. As with cassava, there is some evidence that the roots of *sweet potato*, concerned with water and ion uptake, are deep-seated, while the tuberous roots are shallow (Fujise and Tsuno 1967). At least 500 mm of rain is required during their growing seasons, but they can tolerate considerable periods of drought, although yields are much reduced if water shortage occurs 50 to 60 days after planting, i.e. at the onset of tuber bulking (Kay 1973, Wilson 1977).

Cowpea can stand drought periods fairly well, and the normal drought periods in the rainy seasons in the study area do not form real problems on well-drained soils, unless they have a very low water-holding capacity. The drought tolerance of cowpea is somewhat better than for soybean.

Group c. *Maize*, *yam*, *soybean*, *okra*, and *sweet pepper*. Compared with group b a high, instead of a medium availability of water is needed for the high ecological suitability class.

Maize has a relatively deep root system of up to 2.5 m. The roots grow very rapidly and can reach a depth of 60 cm in only four weeks (Berger 1962). Purseglove (1972) mentions a water requirement of 600 to 900 mm for tropical circumstances. Although maize has a fairly low water requirement per unit of dry matter produced, it has a low drought tolerance (Ignatieff and Page 1958).

For *yam* Coursey (1967) states that at least 1000 mm is needed for a growth period of 7-8 months. Yams can withstand periods of severe drought, but reduction in yield could be serious. Wilson (1977) states that yam requires more than 1150 mm of water for growth and development.

According to De Geus (1973) the climatic and soil requirements for *soybean* are similar to those of maize, although soybean is somewhat more drought-resistant. Ignatieff and Page (1958) remark that soybeans are successfully grown on soils commonly used for maize.

No data were found for *okra*; for *sweet pepper* a requirement of 600 to 1250 mm was mentioned by Purseglove (1968). On the basis of observations made in the toposequence experiments in Eastbank area I, the water requirements of okra and sweet pepper were considered to be similar to maize and soybean.

Group d. *Tomato* and *celosia*. Compared to group d, a medium instead of a low availability of water is needed for a restricted suitability. *Tomato* and *celosia* are known to have a relatively high water requirement for satisfactory growth.

Group e. *Cocoyam* and *banana/plantain*. The water requirements of the aroids are higher than those of the other studied root crops (Wilson 1977). In the *Colocasia aroids*, higher yields were obtained under lowland paddy field conditions than under drier conditions; *Xanthosoma* aroids also have high water requirements (but not paddy field conditions) for high yields (de la Peña and Plucknett 1967).

According to Champion (1963), the water demands of *banana* are high; 25 mm/week was found to be the minimum for satisfactory growth. Its drought resistance is low.

Group f. *Rice*. For rain-fed *rice*, Moomaw and Vergara (1964) stated that 1200 to 1500 mm in one rainy season is enough for a rice crop. However, in a bimodal rainfall pattern as in south-west Nigeria, 1500 mm would be the lowest limit (Colonna 1967). Rice can be grown on a wide range of soils and water regimes, varying from purely rain-fed to waterlogged. It cannot withstand prolonged drying out of the soil, because of its higher water requirements and a generally more shallow root system than dryland cereals (Moormann 1973). Water is generally stated as the most important factor in rice production (Grist 1959, Moomaw and Vergara 1964). Its importance overshadows or changes the relative importance of other production-determining soil characteristics (Moormann and Dudal 1968, Kilian and Teissier 1972). As the soils of the study area generally have low water-holding capacities, the commonly occurring dry spells within the rainy seasons severely affect rice cultivation on well-drained soils. A drought period of five days or longer in a critical growth stage is bound to depress the yield considerably in most freely drained soils (Moormann 1973). A critical growth stage is the period of 10 days before flowering (Matsushima 1962); since the response is irreversible, an adequate supply of water at later stages is totally ineffective; on the other hand, water stress during the vegetative stage may reduce several plant characteristics, but the plant can recover from the retarded growth if water is supp ed to the plant in time to permit its recovery before flowering (Yoshida 1977). Apart from drought stress, the appearance of blast (*Pyricularia oryza*) was found to be connected to the lenght of the drought stress period of the rice crop (IITA 1973). The difference between rice and the former group (cocoyam and banana/plantain) is the very high requirement of availability of water for the high ecological suitability class.

7.3.3 Availability of oxygen (cf. Table 7.11)

With respect to the availability of oxygen, there is a lot of variation among the studied crops. Generally, a low availability of oxygen restricts growth most severely in the early growth stages. For two crops, rice and cocoyam, this land quality is not considered, both crops being adapted to wet soil conditions by way of an aerenchym system

Table 7.11. The land quality *availability of oxygen* as criterion for the division of the eco... ...al suitability classes.

group	crops	ecological suitability class			
		high (1)	moderate (2)	restricted (3)	low (4)
a	rice, cocoyam	vl	vl	vl	vl
b	okra	m	m	l	vl
c	cassava, sweet pepper, banana/plantain	h	m	l	vl
d	soybean, tomato	h	m	m	l
e	maize, yam, sweet potato, cowpea and celosia	h	h	m	l
f	pigeon pea	vh	h	h	m

that provides the roots with atmospheric oxygen (Alberda 1953, Fujii 1974, Wilson 1977). Moreover for rice a superficial root system is formed in the oxidized surface layer of a flooded soil at the end of the tillering period. Unlike *Colocasia*, *Xanthosoma* aroids cannot withstand prolongued waterlogging; for the evaluation *Colocasia* was taken as representative of the cocoyam species.

Group b. *Okra*. From the toposequence experiments, a comparison could be made between the yield of *okra* on the upper and the lower side of the toposequence; when planted on ridges, the lower hydromorphic part yielded about the same as the upper well-drained part (cf. Section 7.2.6). A medium availability of oxygen was therefore considered sufficient for the high ecological suitability class; with a low availability of oxygen, the ecological suitability class would be restricted.

Group c. *Cassava*, *sweet pepper* and *banana/plantain*. This group differs from group b by the high instead of a medium requirement of availability of oxygen for the high ecological suitability class.

Cassava grows well under wet conditions (Wilson 1977), but complete waterlogging reduces the yield to nil. It was observed in the toposequence experiments in Eastbank area I that cassava plants are not killed by waterlogging; their growth in minimal, but when the aeration condition of the soil is improved by drainage the growth increases. Whether a plant under these conditions is able to give a satisfactory yield is not known. Cassava bacterial blight, a common cassava disease, appeared less on the hydromorphic strip in the toposequence experiment than on the well-drained strips (G. Persley, personal communication).

Sweet pepper cannot withstand complete waterlogging, as it causes the leaves to shed after a short time (Purseglove 1968). In the toposequence experiments, satisfactory yields were obtained with drainage and planting on ridges, even on severely hydromorphic soils.

For the planting of *banana* and *plantain* a groundwater level of 30 cm is necessary, although Lassoudiere (1973) recommended drainage up to 40/50 cm as minimal. In later growth stages, higher groundwater levels are tolerated, but these will have a negative effect on yield and especially on the time period between harvests. For commercial growth of bananas, though not included in this study, the requirement for the availability of oxygen is considered relatively high with a high requirement for the availability of water.

Group d. *Soybean* and *tomato*. This group differs from group c by a medium instead of a low requirement for the availability of oxygen for the restricted ecological suitability class.

Compared with other grain legumes such as cowpea and pigeon pea, *soybean* is less sensitive to waterlogging (cf. Section 7.2.5). According to De Geus (1973), the climatic and soil requirements for soybean are similar to those of maize. However, from observations in the toposequence experiments in Eastbank area I, the requirement for maize was considered to be somewhat higher than for soybean. On hydromorphic soils, soybean must be planted on ridges. The growth of young seedlings is reduced with groundwater levels above 20 to 30 cm (IITA 1975a). Waterlogging severely reduces growth, but it takes more than 2 days before the plants die off. Flooded soybean plants may develop aerenchym tissues, which serve to aerate the underground structures and increase the tolerance to flooding, as was found in pot-experiments by Fukui (1956) and Arikado (1954). As stated by Hopkins et al. (1950), soybeans, grown in pots, were able to maintain growth processes at oxygen levels as low as 1.5 per cent. An important factor in the tolerance of soybean to temporary high groundwater levels, or even flooding, is thought to be the capacity of the plant to form, under such conditions, very superficial roots, even on the surface of the flooded soil. The oxygen in the floodwater and in the upper few mm of the soil, which decreases with depth, may be assumed to be sufficient for survival. According to Ignatieff and Page (1958), excess moisture does not kill the soybean plant, but promotes profuse vegetative growth at the expense of seed production. Also, the fixation of atmospheric nitrogen by *Rhizobia* bacteria is known to be reduced by waterlogging of the soil.

Tomato is considered to have a somewhat higher requirement for the availability of oxygen than sweet pepper. The tomato plants must be staked on hydromorphic soils but with heavy yields, unharvested fruits may still lie on the soil surface. To avoid quick rotting of these fruits, a moderate or higher availability of oxygen represents soil conditions in which tomato can yield satisfactory.

Group e. *Maize*, *yam*, *sweet potato*, *cowpea* and *celosia*. Compared with group d, a high instead of a medium availability of oxygen is needed for the moderate ecological suitability class.

Waterlogging during early growth stages of *maize* (before tasseling) impedes its growth severely or even totally (IITA 1975a). Young maize can only sustain high groundwater levels for a very limited period. In later growth stages waterlogging may cause some reduction in yield.

Yams cannot tolerate waterlogging (Coursey 1967), as the tubers are likely to rot. When tubers are in groundwater for more than one week, their quality is lowered; if such conditions last for 2 to 3 weeks, very poor quality tubers, subject to rotting, are obtained.

According to Ignatieff and Page (1958) *sweet potato* and yam are usually grown under the same conditions and their drainage requirements, etc. are very similar. The deleterious effects of an over-supply of water on tuberization in tropical root crops are due to restriction of the oxygen supply, which is critical for tuberization in sweet potato (Togari 1950). According to Hahn (1977), oxygen deficiency in the soil at an early growth stage results in young roots developing into fibrous roots instead of tuberous roots. Lack of oxygen and excess moisture in the soil have an adverse effect on fleshy root formation and enlargement; on the other hand (cf. Section 7.2.4) weevil damage in sweet potato was reduced to nil on hydromorphic land.

Cowpea is less sensitive to waterlogging than pigeon pea, but more sensitive than soybean (cf. paragraph 7.2.5). Good drainage is of primary importance for the cowpea crop (Ignatieff and Page 1958), although fair to good crops are found over a wide range of drainage conditions. Good aeration in the root zone is conducive to more efficient fixation of nitrogen by the nodule bacteria and free drainage is therefore necessary. Nodule functioning is known to be less with groundwater levels close to the soil surface; for a number of cowpea cultivars, optimal functioning of nodules was measured with groundwater levels around 40/50 cm depth (IITA 1975a). On wet soils cowpea is planted on ridges, providing at least 20 cm, but preferably 30 cm, of aerated soil (IITA 1975a) for good germination and early growth. The seedlings are very sensitive to waterlogging, especially in the first few weeks after planting. Severe damage in the first three weeks was observed when groundwater rose above 10 cm depth in one day, above 20 cm in 2 to 3 days, or above 30 cm in 9 to 10 days. Also in later stages of growth, high groundwater levels may kill the cowpea plants, but at a slower rate. An older plant is more easily affected because of its more extended root system, but on the other hand the stress can be overcome by the non-affected part of the root system. Approximately 2 days of complete waterlogging may kill fully grown cowpea plants (C. Wien, personal communication).

Hydromorphic conditions were found to be even less favourable for *celosia*, especially in view of the poor quality of the leaves and the slow rate of growth, even when planted on ridges.

Group f. *Pigeon pea.* Of the three studied grain legumes, *pigeon pea* was found to be the one most sensitive to waterlogging. In a toposequence experiment, a groundwater level of less than 25 cm severely damaged the plants, which yielded either very badly or not at all.

7.3.4 Availability of nutrients and the response to applied nitrogen (cf. Tables 7.12 and 7.13)

The *availability of nutrients or fertility* (cf. Section 5.2.3) was considered for the studied crops irrespective of crop factors such as mixed cropping practices. Ignatieff and Page (1958) stated that the differences in the nutrient requirements of crops depend upon: a) the actual nutrient uptake of mineral nutrients; b) the ability of crops to obtain nutrients from the soil; and c) symbiotic relationships. In the first case, the total removal of nutrients with each harvest was considered. Reference is made to Appendix I where these figures for some of the studied crops are presented. For each crop, the average removal of N, P, and K was calculated and multiplied by the reference yield (cf. Appendix K). Although these figures indicate remarkable differences in removal of the three elements, they do not indicate the differences in requirements with respect to the availability of nutrients during the growth period. Differences among crops in their ability to absorb nutrients from the same medium may depend on the size of the root system and the inherent characteristics of the roots themselves. Moreover, well-inoculated legumes may be independent of soil nitrogen for satisfactory growth. Another important factor is

Table 7.12. The land quality *availability of nutrients* as criterion for the division of the four ecological suitability classes.

group	crops	ecological suitability class			
		high (1)	moderate (2)	restricted (3)	low (4)
a	cassava	m	l	vl	vl
b	cowpea, pigeon pea, okra	m	l	l	vl
c	rice, yam, sweet potato, cocoyam, soybean, celosia and sweet pepper	m	m	l	vl
d	maize, tomato and banana/plantain	h	m	l	vl

the normal situation of the crop in the shifting cultivation pattern; whether a crop is planted soon after the clearing of natural vegetation or is cultivated as the last crop, implies differences in requirements of availability of nutrients during the growth period. Although qualitative, four groups, with respect to the requirements of the availability of nutrients, were distinguished among the studied crops (Table 7.12).

For the response to applied N, consideration was restricted to those crops for which the application of nitrogen forms part of the management practices of the two defined management levels (cf. Table 6.1); those crops are rice, maize, tomato, celosia, sweet pepper, and banana/plantain. The requirements of the availability of nutrients will first be discussed, followed by the differences in requirements of the response to applied N.

Group a. *Cassava.* According to Jones (1959), *cassava* thrives on soils too poor for most crops. Purseglove (1968), stated that cassava will produce an economic crop on impoverished soils unsuitable for other production, and that it is consequently often the last crop in the rotation in shifting cultivation. In Appendix I, the demands of N, P, and K for cassava are presented; a crop of 20 tons/ha removes 200 kg (N+P+K)/ha, of which K is especially important. Although a relatively large amount of nutrients are removed, cassava is considered to have a relatively low requirement of soil fertility; it has probably a root system that is very effective in nutrient uptake. Moreover, its growing season is relatively long.

Group b. *Cowpea*, *pigeon pea* and *okra*. Compared with group b a low instead of a very low availability of nutrients is needed for the restricted ecological suitability class.

Cowpea production is generally confined to less fertile soils, and good growth occurs under these conditions. The crop will, however, respond to nominal dressings of P and K fertilizers, where the soil is low in these elements, even though the specific requirements of the crop are not well defined. When properly inoculated, it is self-sufficient, as far as nitrogen is concerned (Ignatieff and Page 1958). On newly cleared land, two locations in the study area (Ikenne and Ibadan) gave no response to either N or P. On Basement Complex soils with low fertility as a result of continuous cropping with maize and root crops, responses to small applications of N and P were observed (IITA 1974).

According to Gooding (1962), even though only limited work has been done on the fertility requirements of *pigeon pea*, it gives little response, except occasionally to phosphates.

Okra can be grown on any type of soil (Purseglove 1968). No data are known about its requirements for the availability of nutrients, but it was considered to have a relatively low requirement.

Group c. *Rice*, *yam*, *sweet potato*, *cocoyam*, *soybean*, *celosia* and *sweet pepper*. Compared to group b a medium instead of a low availability of nutrients is needed for the moderate suitability class.

In comparison with other cereal crops, *rice* has only moderate requirements for plant nutrients and makes better use of soil nutrients. This crop, therefore, can give moderate yields on soils of low fertility (Ignatieff and Page (1958). In Appendix I, the removal of (N+P+K) by the grains is remarkably lower than the value for maize.

Yam and *sweet potato* are usually grown under the same conditions and their needs in terms of nutrient requirements are similar. Yam and sweet potato have long been considered rather moderate in their soil nutrient demands and to need only a somewhat low level of soil fertility, above which there is relatively little yield increase. This is a misleading assumption. Although these crops can succeed at low levels of fertility and with a low nutrient supply, for really good crops, especially sweet potato, a better level of nutrition is necessary (Ignatieff and Page 1958).

Soil fertility requirements are higher for yam than for cassava; in West Africa, yams are therefore usually grown as the first crop after the clearing of the bush fallow in shifting cultivation. In this way the crop benefits from the mineral nutrients accumulated in the surface soil as a result of the burning of the bush cover, with the exception of nitrogen which disappears in the process of burning (De Geus 1973). Fertilization of yam on two soil series at IITA and one at Ikenne did not significantly affect the yield; the size of the mounds was more important to yield (IITA 1974).

Cocoyam needs a rich soil for optimum development. When grown under less ideal conditions, it has been found to respond well to applications of N, P, and K, especially N (Hodnett 1958, de la Peña and Plucknett 1967). The exact requirement for cocoyam in comparison to other crops is unknown, but it is considered similar to that of yam and sweet potato.

The nutrient requirement of *soybeans* is high in comparison with many other crops. In general, P and K are top priorities, but calcium is also important. Although it is a legume, the soybean nevertheless often responds to nitrogen application, especially in the earlier stages of growth. It is important that the appropriate strain of nitrogen-fixing bacteria (*Rhizobium*) is present in the soil to supply the bulk of nitrogen needed by the crop (Ignatieff and Page 1958). Response curves obtained by Bray (1961) showed that the response curves of soybean for P and K closely approximated those of maize.

Celosia is a leaf vegetable and therefore especially needs nitrogen (De Geus 1973). The requirement for the availability of nutrients is unknown, but it is considered to be moderate.

Sweet pepper can be grown on a variety of soils; fertilization of sweet pepper is very effective (Purseglove 1968). De Geus (1973) stated that the best fertilizer practices for chillies and pimento are similar to those used for tomato; sweet pepper can probably also be compared to those crops. In this study, however, a separation was made between the requirements of tomato and sweet pepper mainly because of the somewhat lower reference yield of sweet pepper (see Appendix K), resulting in a somewhat lower total removal of nutrients than by tomato.

Group d. *Maize*, *tomato* and *banana/plantain*. Compared to group c, a high instead of a medium availability of nutrients is needed for the high ecological suitability class.

Besides a high N requirement, a high level of nutrients, particularly P and K, is required for *maize* (Ignatieff and Page 1958, Purseglove 1972). In Appendix I, the relatively high removal of (N+P+K), compared to rice, is indicated.

The requirements of availability of nutrients are high for *tomato*, especially when grown commercially. Fertilizers are effective, N during the whole growing season and K during fruit setting (De Geus 1973).

Banana is a heavy feeder on nitrogen, and even with high soil fertility it responds to this plant nutrient. Little response has been reported from P, and heavy P dressings have even depressed yield in certain cases. Potassium is considered quite important in many banana-producing areas; the crop is known to be a heavy user of available soil potassium (Appendix I) (Ignatieff and Page 1958, Champion 1963).

For the requirement of the response to applied N two groups were distinghuised (Table 7.13):

Group a. *Rice*, *tomato*, *sweet pepper* and *banana/plantain*.

If the response of these crops to applied N is high, medium, low, and very low, respectively, the implication to the ecological suitability class is considered to be high, moderate, restricted, and low, respectively. The application of N is important to these crops; when the response to applied N is relatively low, the ecological suitability class is also considered to be relatively low.

Group b. *Maize* and *celosia*.

Because of the high requirements for N of maize and celosia (the latter because of its being a leaf vegetable) (De Geus 1973), these crops have been singled out as a group by way of a very high requirement of the response to applied N for the high ecological suitability class. Thus, if the response to applied N is high only, the highest ecological suitability class will be the moderate one.

7.3.5 The probability of occurrence of soil erosion (cf. Table 7.14)

The occurrence of soil erosion as a limiting factor in crop performance was considered for the studied crops, taking into account for the four ecological suitability

Table 7.13. The land quality *response to applied N* as criterion for the division of the four ecological suitability classes for rice, maize, tomato, celosia, sweet pepper and banana/plantain.

		ecological suitability class			
group	crop	high (1)	moderate (2)	restricted (3)	low (4)
a	rice, tomato, sweet pepper and banana/plantain	h	m	l	vl
b	maize and celosia	vh	m	l	vl

Table 7.14. The land quality *probability of occurrence of soil erosion* for the division of the four ecological suitability classes.

crops	ecological suitability class			
	high (1)	moderate (2)	restricted (3)	low (4)
rice, maize, yam, cowpea, soybean, tomato, okra, celosia and sweet pepper	-	-	+	++
cassava and cocoyam	-	-	++	+++
sweet potato	+	++	+++	++++
pigeon pea and banana/plantain	+	++	++++	-

classes, the length of the growing season, the rate of establishment after planting, the degree and rate of covering of the soil surface, and the depth of the root system. The requirements for the probability of soil erosion are indicated in Table 7.14 with crosses; the more crosses the more intensive the soil erosion (cf. Section 5.3.2). For most crops, soil erosion severely restricts the ecological suitability. For the vegetables (tomato, okra, celosia and sweet pepper) the ecological suitability was only determined for the dry season. The requirement of the probability of soil erosion was omitted in the determination for the dry season, since an unseasonal rain may be able to cause soil erosion, but these rains are exceptional.

Cassava and *cocoyam* have relatively long growing seasons; their degree of covering of the soil surface is relatively good. The result for these two crops is a somewhat lower restriction. *Sweet potato*, although having a shorter growing season, is able to cover the soil surface rather quickly and very effectively. Soil erosion can be limited by this crop, although after harvesting the loose soil is again easily subject to soil erosion. *Pigeon pea* and *banana/plantain* both have a long growing season; they only partly cover the soil surface. Furthermore, pigeon pea has a deep root system. These two crops can be planted on steep hills. The ecological suitability class for these crops is restricted with serious soil erosion, otherwise a moderate or high ecological suitability class was considered for these crops.

7.3.6 The impediment of root development (cf. Table 7.15)

The (mechanical) impediment of root development is expressed for two depths in the following way: ++ = 50 to 80 cm, and +++ = 30 to 50 cm (cf. Section 5.3.4). The impedimen of root development above a depth of 30 cm only occurs very locally in the study area and has been omitted from the evaluation. The impediment of root development deeper than 80 cı is considered not to limit the performance of the studied crops.

For sweet potato, cocoyam, tomato, okra, celosia, sweet pepper and banana/plantain, the impediment of root development deeper than 30 cm is not considered to seriously limit crop performance (Table 7.15). For rice, cowpea and soybean, impediment at 30 to 50 cm results in a moderate or lower ecological suitability class; for yam and cassava such an impediment may cause misformation of the tubers and this is considered to result in a restricted or low ecological suitability class. These five crops are not limited by an

Table 7.15. The land quality *impediment of root development* for the division of the four ecological suitability classes.

crops	ecological suitability class			
	high (1)	moderate (2)	restricted (3)	low (4)
sweet potato, cocoyam, tomato, okra, celosia, sweet pepper and banana/ plantain	-	-	-	-
rice, cowpea and soybean	++	+++	-	-
yam and cassava	++	++	+++	-
maize and pigeon pea	-	++	+++	-

Note: ++: 50 to 80 cm depth, +++: 30 to 50 cm depth.

impediment at 50 to 80 cm depth. Maize and pigeon pea, with their relatively deep root systems, are more restricted by any impediment: if occurring at 50 to 80 cm, the ecological suitability class is moderate or lower; if occurring at 30 to 50 cm, the ecological suitability class is reduced to the restricted one.

7.3.7 The probability of occurrence of iron toxicity in rice (cf. Table 7.16)

This land quality is only considered for rice (cf. Section 5.3.1). Table 6.5 showed the severity of iron toxicity in relation to the groundwater classes, the severity being expressed by the number of crosses. The requirements of rice for the four ecological suitability classes are given in Table 7.16.

Table 7.16. The land quality *probability of occurrence of iron toxicity in rice* for the division of the four ecological suitability classes.

ecological suitability classes			
high (1)	moderate (2)	restricted (3)	low (4)
-	+	++	+++

Note: probability of occurrence of iron toxicity: - = none, + = low, ++ = moderate and +++ = high (cf. Table 6.5).

8. DETERMINATION OF THE ECOLOGICAL CROP SUITABILITY

8.1 ACTUAL PROCEDURE OF THE DETERMINATION

As was indicated in Fig. 7.1, the ecological suitability of a soil unit, phase, and groundwater class combination for a specific crop under a specified management level in a specific season or for more seasons, is determined by the conversion of the calculated ecological suitability of a soil unit, phase, and groundwater class combination and the expected yield per groundwater class. In determining the ecological crop suitability, the following tables were used:

- a. the determined land qualities as prevailing under a specified management level and specified for seasons only for the land quality *availability of water* (Tables 5.8, 5.11 (C and D), 5.21, 5.22, 6.2, 6.3, 6.4 (B) and 6.5).
- b. the requirements of the crops, with respect to the land qualities, for four suitability classes, possibly specified for a management level (Tables 7.10, 7.11, 7.12, 7.13, 7.14, 7.15 and 7.16).
- c. the expected yield per groundwater class (Tables 7.2, 7.3, 7.4, 7.6, 7.7 and 7.9).

The calculated ecological suitability was determined from the tables mentioned under a and b. The most limiting land quality prevailing within a soil unit, phase, and grounwater class combination under a specific management level (management unit) determines the calculated ecological suitability class as indicated in the requirement tables.

For crops with a relatively long growing season, the land quality *availability of water* as one of the possible limiting land qualities was considered in the determination of the calculated ecological suitability as follows:

- the availability of water during the *major first* season for yam and cocoyam.
- the availability of water during the *dry* season for cassava, pigeon pea, plantain, and banana.

Both the calculated ecological suitability and the expected yield per groundwater class were expressed in a four class system, in which 1 = high, 2 = moderate, 3 = restricted, and 4 = low. For the matching process the intermediate values, being 1-2, 2-3, and 3-4 were used as $1\frac{1}{2}$, $2\frac{1}{2}$, and $3\frac{1}{2}$ respectively. The ecological crop suitability was then determined according to the formula:

$$\frac{1}{3}\ (2 \times \text{calculated ecological suitability} + 1 \times \text{expected yield per groundwater class})$$

The procedure is meant to result in whole numbers for the resulting ecological crop suitability only. This formula was therefore chosen instead of the arithmetic mean. When using the mean, rounding off the resulting fractions would be too complex a procedure. By using the formula this could be avoided partially by giving a slight dominance to the calculated ecological suitability in the determination of the ecological crop suitability, due to the more fundamental nature of this value compared to the expected yield per groundwater class (cf. Section 7.1). Moreover, the groundwater class as determined for the relation yield - groundwater class (cf. Section 7.2) was based on the whole growing period of crops (except maize); the length of these periods may differ from the defined seasons. Rounding off of fractions is done in the usual way, but for a result of a whole number + ½ the outcome depends on whether the calculated ecological suitability and the expected yield per groundwater class are:

unequal, then the result is rounded off towards the next whole number towards the number of the expected yield per groundwater class (e.g.
calc. ecol. suit. 3 - exp. yield per grw. class 1-2 results in 2.
calc. ecol. suit. 1 - exp. yield per grw. class 2-3 results in 2).

equal, then the result is rounded off towards the higher number or, in other words, a lower ecological crop suitability (e.g.
calc. ecol. suit. 1-2 - exp. yield per grw. class 1-2 results in 2.
calc. ecol. suit. 3-4 - exp. yield per grw. class 3-4 results in 4).

Exceptional cases may occur where the ecological crop suitability under the improved management level is higher than the one under the traditional management level, although the most limiting land quality was not improved by management. If such a case occurred, the ecological crop suitability under the improved management level remained the same as under the traditional management level. This situation may occur when any of the following land qualities are involved:

- *availability of water* (w), only in the case of rice with groundwater classes 1, 2, and 3.
- *probability of occurrence of soil erosion* (e).
- *impediment of root development* (i).

8.2 THE DETERMINATION OF THE ECOLOGICAL CROP SUITABILITY

In Table 8.1, the abbreviation of the crop names and the seasons in which the ecological crop suitability was determined are given.

The determination for all combinations of soil unit, phase, and groundwater class (or management units) can be found in Appendix J; for all these combinations, the calculated ecological suitability and the expected yield per groundwater class were determined. These two values were then matched to find out the ecological crop suitability. The

Table 8.1. Abbreviation of crop names and the growing seasons as used in the suitability determination.

crop	abbreviation	growing seasons				
		dry	early first	first	second	yearly
rice	ric	+		+	+	
maize	mai	+	+	+	+	
yam	yam					+
cassava	cas					+
sweet potato	spo			+	+	
cocoyam	ccy					+
cowpea	cop	+		+	+	
soybean	soy	+		+	+	
pigeon pea	pip					+
tomato	tom	+				
okra	okr	+				
celosia	cel	+				
sweet pepper	spe	+				
plantain	pla					+
banana	ban					+

Table 8.2. An example of the determination of the ecological suitability of rice, maize, and cowpea for soil unit 1 (no specific phase) and groundwater classes 2, 2, 5, and 6 (dry, early first, major first, and second seasons respectively).

		traditional management level				improved management level			
crop	season	calculated ecological suitability	expected yield per ground-water class	ecological crop suitability	most limiting land quality"	calculated ecological suitability	expected yield per ground-water class	ecological crop suitability	most limiting land quality"
rice	dry	3-4	4	4	w	3-4	4	4	w
	major first	1-2	1	1	n	1-2	1	1	n
	second	2-3	2	2	n	2	1	2	n
maize	dry	2-3	3-4	3	w	2-3	3-4	3	w
	early first	2	3-4	3	w	2	3	3'	w
	major first	2-3	2	2	o	2	2	2	n
	second	3	3-4	3	o	2-3	2-3	3	o
cowpea	dry	2-3	4	3	w	2-3	4	3	w
	major first	2-3	2	2	o	1	1-2	1	-
	second	3	4	3	o	2-3	3-4	3	o

Note': the ecological crop suitability should really be 2, but the availability of water has not been increased by improved management, resulting in an ecological crop suitability equal to the one of the traditional management level.

Note": w = availability of water; o = availability of oxygen; n = response to applied N.

most limiting land qualities are also mentioned. An example of the determination is given in Table 8.2.

The outcome of the determination of the ecological crop suitability for all management units is shown in Table 8.3; only the "highly" and "moderately" suitable crops were represented. This table shows the suitable crops for each management unit and the suitable combinations for each crop. As some of the soil units have identically graded land qualities, they have been combined in Table 8.3; these soil units 2, 3 and D; 7 and 8; A and B.

Table 8.3. The crops with high and moderate ecological suitability per soil unit, phase, and groundwater class combination per management level (or management unit) per season of for more seasons.
For abbreviations of the crop names, see Table 8.1.
trad. = traditional
imp. = improved
suit. = ecological suitability
med. = moderate
If no crop is mentioned, there are no "highly" or "moderately" suitable crops as far as the studied crops and growing seasons are concerned.

Explanation of abbreviation of phases:

abbreviation of phase	meaning of phase	occurrence of phase	relevant land quality	abbreviation of land quality
cl	clayey phase	soil unit 1	availability of water	w
cs	coarse sandy phase	soil unit 4	availability of water	w
ir	iron toxicity	in rice with groundwater classes 9, 10, and 11	probability of occurrence of iron-toxicity in rice	t
i_s	impediment of root development at shallow depth (30-50 cm)	soil units 6, 7, and 9	impediment of root development	i
i_d	impediment of root development at depth of 50-80 cm	soil units 6, 7, and 9	impediment of root development	i
er	eroded phase	soil unit 9	availability of water	w
se	soil erosion hazard	soil units 7, 8, 9, A and B	probability of occurrence of soil erosion	e

season	man. level	suit.	1 1 -	1 1 cl	1 2 -	1 2 cl	1 3 -	1 3 cl	1 4 -	1 4 cl	1 5 -	1 5 cl	1 6 -	1 6 cl	1 7 -	1 7 cl
annual	trad.	high	yam cas pip	yam cas pip	yam cas	yam cas	ccy	ccy	yam cas ccy	yam cas ccy	ccy	ccy	ccy	ccy	ccy	ccy
		med.		ccy	ccy pip	ccy ban pip pla	yam ban cas pla	yam ban cas pla	pip	pip pla ban	yam ban cas pla	yam ban cas pla				
	imp.	high	yam cas pip	yam cas pip	yam cas	yam cas	ccy	ccy	yam cas ccy	yam cas ccy	yam pla cas ban ccy	yam pla cas ban ccy	ccy	ccy	ccy	ccy
		med.		ccy	ccy pip	ccy pip pla	yam ban cas pla	yam ban cas pla	pip	pip	pip	pip	yam cas pla	yam cas pla		
dry	trad.	high									soy spe tom okr	soy spe tom okr	okr	okr		
		med.				cop soy	ric tom cop okr soy	ric tom cop okr soy	soy	cop soy okr	ric mai cel	ric mai cel	soy tom spe	soy tom spe		
	imp.	high									cop okr soy cel tom spe	cop okr soy cel tom spe	okr	okr	okr	okr
		med.				cop soy	ric tom soy okr	ric tom soy okr	soy	cop soy okr	ric mai	ric mai	ric soy mai tom cel cop spe	ric soy mai tom cel cop spe	ric soy tom	ric soy tom
early first	trad.	high														
		med.				mai			mai	mai	mai	mai				
	imp.	high														
		med.				mai			mai	mai	mai	mai	mai	mai		
major first	trad.	high	mai soy spo cop	mai soy spo cop	mai soy spo cop	mai soy spo cop			spo cop soy	spo cop soy	ric	ric				
		med.		ric	ric	ric	ric cop mai soy spo	ric cop mai soy spo	ric mai	ric mai	mai soy spo cop	mai soy spo cop	ric soy	ric soy		
	imp.	high	mai spo cop	mai soy spo cop	mai soy spo cop	mai soy spo cop	ric	ric	mai soy spo cop	mai soy spo cop	ric soy spo cop	ric soy spo cop				
		med.	soy	ric	ric	ric	mai soy spo cop	mai soy spo cop	ric	ric	mai	mai	ric spo soy	ric spo soy	ric soy	ric soy
second	trad.	high	cop soy	cop soy	spo cop soy	spo cop soy			spo cop soy	spo cop soy						
		med.	mai spo	ric mai spo	ric mai	ric mai	ric soy spo cop	ric soy spo cop	ric	ric	ric spo soy	ric spo soy	ric spo	ric spo		
	imp.	high	cop soy	cop soy	spo cop soy	spo cop soy			spo cop soy	spo cop soy	spo cop soy	spo cop soy				
		med.	mai spo	ric mai	ric mai	ric mai	ric soy spo	ric soy spo	ric mai	ric mai	ric mai	ric mai	ric spo	ric spo	ric soy	ric soy

season	man. level	suit.	soil unit 1, groundwater class 8, phase –	1, 8, cl	1, 9, –	1, 9, cl	1, 9, ir	1, 10, –	1, 10, cl	1, 10, ir	1, 11, –	1, 11, cl	1, 11, ir	2,3,D, 1, –	2,3,D, 2, –	2,3,D, 3, –
annual	trad.	high	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy		cas	cas
		med.	yam pla ban	yam pla ban										yam cas pip	yam pip	yam ban ccy pla
	imp.	high	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy	ccy		cas	cas
		med.	yam ban cas pla	yam ban cas pla										yam cas pip	yam pip	yam ban ccy pla
dry	trad.	high	okr	okr							ric	ric				
		med.	soy tom spe	soy tom spe	okr	okr	okr	ric	ric	ric						cop soy okr
	imp.	high	okr	okr	okr	okr	okr	ric	ric		ric	ric				
		med.	ric tom mai cel soy spe	ric tom mai cel soy spe	ric soy tom	ric soy tom	ric soy tom	okr	okr	ric okr			ric			ric tom cop okr soy spe
early first	trad.	high														
		med.														mai
	imp.	high														
		med.	mai	mai												mai
major first	trad.	high									ric	ric			cop	
		med.	ric soy	ric soy	ric	ric	ric	ric	ric	ric				mai soy spo cop	mai spo soy	mai soy spo cop
	imp.	high	ric	ric				ric	ric		ric	ric			cop	
		med.	spo cop soy	spo cop soy	ric soy	ric soy	ric soy			ric			ric	mai soy spo cop	mai spo soy	ric cop mai soy spo
second	trad.	high									ric	ric		cop	cop	
		med.	ric	ric	ric	ric	ric	ric	ric	ric				soy	spo soy	spo cop soy
	imp.	high						ric	ric		ric	ric		cop		
		med.	ric spo soy	ric spo soy	ric soy	ric soy	ric soy			ric			ric	mai soy	mai soy spo cop	ric cop mai soy spo

season	man. level	suit.	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	2,3,D	4	4	4
groundwater class			4	5	6	7	8	9	9	10	10	11	11	1	1	2
phase			-	-	-	-	-	-	ir	-	ir	-	ir	-	cs	-
		high	cas													
annual	trad.	med.	yam ccy pip	yam cas ccy	ccy	ccy	yam ccy	ccy	ccy	ccy	ccy	ccy	ccy	cas pip	cas pip	cas pip
		high	cas													
	imp.	med.	yam ccy pip	yam cas ccy	yam pla cas ccy	ccy	yam pla cas ban ccy	ccy	ccy	ccy	ccy	ccy	ccy	cas pip	cas pip	cas pip
		high		okr			okr									
dry	trad.	med.		mai cel soy spe tom	tom okr spe		soy	okr	okr	ric	ric	ric				
		high		okr cel spe						ric		ric				
	imp.	med.		mai tom cop soy	ric tom mai okr cop cel soy spe	ric tom okr	ric tom mai okr soy cel spe	ric tom okr	ric tom okr	okr	ric okr		ric			
		high														
early first	trad.	med.		mai												
		high														
	imp.	med.		mai	mai		mai									
		high	cop													
major first	trad.	med.	mai spo cop soy	ric cop mai soy spo	ric soy		ric soy	ric	ric	ric	ric	ric				spo cop soy
		high	cop		ric					ric		ric				
	imp.	med.	mai spo soy	ric cop mai soy spo	spo soy	ric soy	ric soy spo cop	ric soy	ric soy		ric		ric			cop soy
		high														
second	trad.	med.	spo cop soy	spo	ric spo		ric	ric	ric	ric	ric	ric		cop soy		cop soy
		high			ric					ric		ric				
	imp.	med.	mai soy spo cop	ric cop mai soy spo	spo	ric	ric spo	ric	ric		ric		ric			cop

season	man. level	suit.	4 2 cs	4 3 –	4 3 cs	4 4 –	4 4 cs	4 5 –	4 5 cs	4 6 –	4 6 cs	4 7 –	4 7 cs	4 8 –	4 8 cs	4 9 –
annual	trad.	high														
		med.	cas pip	cas	cas	yam cas pip	cas pip									
	imp.	high														
		med.	cas pip	cas ban	cas	yam cas pip	cas pip									
dry	trad.	high														
		med.														
	imp.	high														
		med.						spe		tom	tom	tom	tom	tom		
early first	trad.	high														
		med.														
	imp.	high														
		med.						mai								
major first	trad.	high														
		med.				mai soy spo cop										
	imp.	high														
		med.				mai cop soy		ric	ric	ric	ric	ric	ric	ric	ric	ric
second	trad.	high														
		med.				cop soy										
	imp.	high														
		med.				cop soy				ric	ric	ric	ric			ric

season	man. level	suit.	soil unit 4, groundwater class 9, phase cs	4, 9, ir	4, 10, -	4, 10, cs	4, 10, ir	4, 11, -	4, 11, cs	4, 11, ir	5, 1, -	6, 1, -	6, 1, i_s	6, 1, i_d	6, 2, -	6, 2, i_s
annual	trad.	high														
		med.									yam cas pip	cas	cas	cas	cas	cas
	imp.	high														
		med.									yam cas pip	cas	cas	cas	cas	cas
dry	trad.	high														
		med.														
	imp.	high														
		med.			ric	ric	ric	ric	ric	ric						
early first	trad.	high														
		med.														
	imp.	high														
		med.														
major first	trad.	high														
		med.									mai soy spo cop					
	imp.	high														
		med.	ric	ric	ric	ric	ric	ric	ric	ric	mai soy spo cop					
second	trad.	high									cop					
		med.									spo soy					
	imp.	high									cop					
		med.	ric	ric	ric	ric	ric	ric	ric	ric	spo soy					

soil unit groundwater class phase			6 2 i_d	7,8 1 –	7 1 i_s	7 1 i_d	7,8 1 se	9 1 –	9 1 er	9 1 i_s	9 1 i_d	9 1 se	A,B 1 –	A,B 1 se	C 1 –	C 2 –
season	man. level	suit.														
annual	trad.	high						yam cas			yam cas				cas pip	cas
		med.	cas	yam cas pip	yam cas pip	yam cas pip	cas pip	pip	yam cas pip	yam cas pip	pip	pip	yam cas pip	pip	yam	yam pip
	imp.	high						yam cas			yam cas				cas pip	cas
		med.	cas	yam cas pip	yam cas pip	yam cas pip	cas pip	pip	yam cas pip	yam cas pip	pip	pip	yam cas pip	pip	yam	yam pip
dry	trad.	high														
		med.														
	imp.	high														
		med.														
early first	trad.	high														
		med.														
	imp.	high														
		med.														mai
major first	trad.	high						mai soy spo cop		spo	spo cop soy				cop	cop
		med.		mai soy spo cop	mai soy spo cop	mai soy spo cop	spo		mai soy spo cop	mai cop soy	mai		mai soy spo cop	spo	mai spo soy	mai spo soy
	imp.	high						mai spo cop		spo	spo cop				cop	cop
		med.		mai soy spo cop	mai soy spo cop	mai soy spo cop	spo	soy	ric mai cop	mai cop soy	mai soy		mai soy spo cop		mai spo soy	ric soy mai spo
second	trad.	high		cop		cop		cop soy			cop soy		cop		cop	cop
		med.		spo soy	spo cop soy	spo soy	spo	mai spo	cop soy	spo cop soy	spo		spo soy		soy	spo soy
	imp.	high		cop		cop		cop soy			cop soy		cop			
		med.		spo soy	spo cop soy	spo soy	spo	mai spo	ric mai cop	spo cop soy	spo		spo soy		mai cop soy	ric cop mai soy spo

9. EVALUATION OF ECOLOGICAL CROP SUITABILITIES, SOCIO-ECONOMIC AND OTHER CONSTRAINTS AND THE APPLICATION TO SOME COMMON MANAGEMENT UNITS IN THE STUDY AREA

9.1 INTRODUCTION

Apart from the ecological suitability of a crop, economic and social factors determine whether a crop will be cultivated or not. These factors are usually site-specific and also depend on the farmer's (or his family's) personal preferences. Feasible land utilization types are the organisational units to be determined in this context (Beek 1972, 1978). A land utilization type has several key attributes such as the type of produce, the land tenure system, the size of farm(s), the labour intensity, the capital intensity, the level of technical know-how, and the type of farm power used. Besides these factors, others are also important in characterizing a land utilization type: the status of the infrastructure, the location, the degree of commercialization, the availability of credit, and the availability of markets.

In Chapter 6, the traditional and improved management levels were described; the description did not include the availability of credit, the size of the farm and the separate plots, etc. The labour intensity on the farms is high, whereas the capital intensity is low. Technical implements consist of simple tools such as the hoe, matchet, and axe; mechanization was not considered in this study.

The type of produce for each management unit was derived from Table 8.3. An ecological crop suitability index was then calculated to compare the ecological crop suitabilities among management units. After considering several socio-economic constraints, 27 management units, divided into 11 groups were derived and used to evaluate the crop suitability.

9.2 THE ECOLOGICAL CROP SUITABILITY INDEX (E.C.S.I.)

The ecological suitability for crops of a management unit can be expressed quantitatively by calculating an ecological crop suitability index (e.c.s.i.) including, for each suitable crop, factors such as the suitability and importance of a crop, the number of possible cultivation seasons, the length of the growth cycle of the crops, and the decreasing order of importance with an increasing number of suitable crops. The index has an indicative nature and can be used to compare management units on their ecological crop suitability, irrespective of relative crop differences in total labour requirement, yield, and net income from yield. The index was calculated for both management levels.

The index was calculated with respect to the following characteristics of each suitable crop:

a. The ecological suitability of a crop.

Only "highly" and "moderately" suitable crops were considered. Although crops with a restricted suitability may determine land use if there are clear socio-economic reasons for doing so, a better basis is obtained by considering "highly" and "moderately" suitable crops only. The differentiation of a "high" and a "moderate" ecological suitability for the calculation of the index should be based on agro-socio-economic data concerning, for example, yield data, prices, and labour input data. These data were not available, but from the data in Appendix K (assuming a yield level of 80 to 100 per cent of the reference yield with a high suitability and a yield level of 60 to 80 per cent with a moderate suitability) a high suitability is given a general loading of twice that of a moderate suitability. Thus, a crop with a high suitability will give the farmer an additional net income or increased yield level per unit of labour or per unit of land which is twice that of a moderate suitability.

b. The frequency of growing seasons in which suitable crops can be cultivated.

When a suitable crop was determined for one season only, this was considered to result in a lower index than when a crop was suitable for more growing seasons. Crops with a long growth cycle (cassava, pigeon pea, plantain, banana, yam, and cocoyam) were counted once; crops with a growth cycle not extending beyond a defined growing season were counted for each season in which they were found to be highly or moderately suited.

For rice and sweet potato, the second season is too short to cover the whole growth cycle of these crops. In these cases, the calculated ecological suitability was based on land qualities as they appeared during the second season, while the expected yield per groundwater class for rice and sweet potato was based on yields obtained in toposequence experiments during the second and at the beginning of the dry season (cf. Section 7.2.2 and 7.2.4). In this way, the ecological crop suitability was determined for these two crops for the second season.
The early first season, being the period in which groundwater levels start to rise from the low dry-season level to the first peak of the major first season (cf. Section 4.2.2), is considered to be an exceptional season; it is too short for any of the studied crops. Yet, it was used for maize, because the first 6 to 8 weeks after planting are decisive in determining the suitability for maize. These 6 to 8 weeks can usually be included within the early first season on soils on lower slope positions with slowly rising groundwater levels after the dry season.

c. The dietary importance of a crop.

Cereals and root crops, as main food crops, were considered of primary importance for food crop production. Other crops, such as grain legumes, vegetables, plantain, and banana were considered of secondary importance, being supplementary to the primary crops (Table 9.1). The crops were also distinguished into preferred and not-preferred; this was not considered in the e.c.s.i., but was involved in the evaluation of suitable crops, as will be discussed in Section 9.4. The net labour productivity of the primary crops is

Table 9.1. The dietary importance and the preference of the studied (food) crops.

dietary importance	primary		secondary	
preference	preferred	not preferred	preferred	not preferred
crops	rice maize yam cassava cocoyam	sweet potato	cowpea tomato okra celosia plantain banana	soybean pigeon pea sweet pepper

generally higher than those of the secondary crops (cf. Table 9.7). Although the labour productivity of tomato cultivation is fairly high, this crop is considered of secondary importance for the study area in general. However, if tomato were to be grown in the vicinity of a big town, the importance could well be primary. Arbitrary coefficients of importance were chosen: the primary crops were given a loading twice that of the secondary crops.

d. The length of the growth cycle.

The e.c.s.i. was determined on a yearly basis. For crops with a growth cycle of more than one year, as mentioned under b, a reduction of the e.c.s.i. was applied.

For cassava the growth cycle varies between 1 and 3 years; the average of 2 years was used, resulting in a reduction of the index by 50 per cent. For pigeon pea, the growth cycle was taken as the period from planting to the second (ratoon) harvest; as this was assumed to last about one year, no reduction was applied for this crop. For plantain and banana, the growth cycle is longer than one year, but it may be assumed that one harvest can be expected per year, so no reduction was applied for these crops; in the toposequence experiments, however, the time from planting to the first harvest was found to be longer than one year. Yam and cocoyam have a growth cycle covering the major first and the second season; therefore no reduction was necessary.
Another implication in determining the e.c.s.i. for crops with a growth cycle exceeding a normal growing season was partly discussed in Section 8.1. For cassava, pigeon pea, plantain, and banana, the suitability determination was based on the consideration of the calculated ecological suitability for the dry season in relation to shortage of water, and for the second season in relation to excess of water. For yam and cocoyam, the major first and the second season were considered, in relation to shortage and excess of water, respectively.

e. The number of suitable crops.

A large number of "highly" and "moderately" suitable crops increased the e.c.s.i. of a management unit, but there is a decreasing order of importance with an increasing number of suitable crops. The importance of a tenth crop in addition to nine other suitable crops in a season is less than that of a second crop additional to the first one. On the other hand, each crop might have its own importance depending on crop diversification in the farming system to obtain sufficient amounts of preferred food. Coefficients have been given which represent a trend of decreasing importance with an increasing number of suitable crops (Table 9.2). The second crop has been given a coefficient of an equal importance to the first, as this additional crop gives the farmer the opportunity of choosing or possibly mixing his crops. From the third to the seventh crop, the importance decreases proportionately; any suitable crop in addition to seven others has a progressively decreasing order of importance. A tenth crop would have no importance.

For the calculation of the e.c.s.i., the suitable crops must be numbered for each growing season. This numbering takes place according to the following order of crop categories:
- "highly" suitable primary crops
- "highly" suitable secondary crops
- "moderately" suitable primary crops
- "moderately" suitable secondary crops

Crops with a long growth cycle, however, if suitable for two or more seasons, may interfere with the numbering of those crops with a short growth cycle. In that case, the crop with a long growth cycle is counted first. For example, if yam is highly suited (major first and second season), while maize and sweet potato are also highly suited in the second season, then yam is counted first. When more crops with a short

Table 9.2. Summary of the effect of five characteristics on the determination of the ecological crop suitability index.

a. Ecological crop suitability. Coefficient in the determination: high = 2, moderate = 1.

b. Frequency of growing seasons in which "highly" or "moderately" suitable crops can be cultivated. For the long growth-cycle crops (cassava, pigeon pea, plantain, banana, yam, and cocoyam) any suitability is counted once. For the short growth-cycle crops, each season for which such a crop is found suitable, is counted. If maize is found suitable in the early first season, this is counted as a separate season.

c. Importance of crop. Coefficient in the determination: primary = 2, secondary = 1.

d. Lenght of growth cycle. Only with cassava is a reduction of 50 per cent applied.

e. Number in the list of highly and moderately suited crops. The numbering is to be determined by the suitability (first highly suitable crops then moderately suitable crops) and then by the importance of the crop (first primary crops then secondary crops). The coefficients for each number to be used in the determination are as follows:

number	coefficient
1	1.00
2	1.00
3	0.95
4	0.85
5	0.75
6	0.65
7	0.55
8	0.40
9	0.25
10	0.00

growth cycle appear in the same category, the numbering depends on the index of the crop in the determination (Table 9.2). The crop with the highest index is counted first.

It is assumed that the production factors, land and labour are scarce. Where sufficient labour is available, the surface of cultivated land might be extended and then each crop, irrespective of the number, should be considered.

The effect of each of the five characteristics (a-e) on the e.c.s.i. is summarized in Table 9.2.

It should be noted that the ecological suitability is based on the cultivation of sole crops. The mixed cropping system is incorporated in the farming system for which the ecological suitabilities have been determined. However, the ecological suitability might be slightly different from the determined one, for instance, if a wide plant density is applied. In such a case the suitability of the separate crops can be determined first, followed by some alterations with respect to the practices used in the mixed cultivation.

A summary of the calculation of the e.c.s.i. for a management unit per management level is as follows:

- 1. The calculation of the e.c.s.i. per season for the crops with a relatively short growth cycle.

- 2. The calculation of the e.c.s.i. for the crops with a relatively long growth cycle depending on the lowest suitability of one of the relevant seasons.

- 3. Numbering of the suitable crops per season and multiplying each index by the coefficient as indicated in Table 9.2.

- 4. Addition of the ecological suitability indices of all highly and moderately suited crops, resulting in the e.c.s.i. per management unit.

Table 9.3 gives an example of how the e.c.s.i. of a management unit is calculated. The index can also be graded, e.g.: less than 5: very low; 5-10: low; 10-20: moderate; and more than 20: high.

9.3 SOCIO-ECONOMIC AND OTHER CONSTRAINTS

The actual farming system, as practiced by a farmer, is dependent on more aspects than the suitability of crops. These aspects are mainly socio-economic or are related to the cultivation of a specific crop; the latter aspects were not included in any of the land qualities studied, but certainly play important roles in the determination of land use. The most important aspects are the development of hydromorphic land types and the crop choice.

The development of hydromorphic and adjacent land types generally involves the opening-up of land which has hardly if ever been used before. Important aspects for the development are:

- the accessibility of the valley and the clearing of the vegetation
- the more (semi-) permanent nature of land use on these land types.

The accessibility of valleys in the study area is poor. Some footpaths may lead along or across the valleys, but any development must start with the laying of footpaths across the valleys and on both sides along the valleys. As transport to and from the valley is by head-loading, no special roads are needed, but with the introduction of machines, such as a motor-thresher and for the transport of large quantities of produce by lorries, an all-weather road will be needed.

The clearing of the vegetation on hydromorphic land is more time-consuming and more unpleasant than the usual way of clearing on well-drained land. Specific difficulties lie in the removal and burning of the vegetation, and in the presence of standing water and the fact that more insects are present. The dry season is the best period for clearing if the groundwater level is low. The use of heavy machinery for clearing is limited to those periods when soils are dry enough to bear the weight of the machinery. Chain-saws and winches can be very useful for accelerating the removal of trees. Table 9.4 shows the costs and labour requirements of clearing one hectare of well-drained and poorly drained land. The clearing of poorly drained land takes more time and is therefore more costly; the cost ratio is about 3:1. When land has been in use for three years, an equal area of hydromorphic land should have been in use for about 9 years to have the same clearing costs. The labour requirement of 2560 hours, which is based on IITA-labour, may be an overestimation; the labour requirement if done by a contractor, would certainly be less. The estimated costs of clearing poorly drained land by IITA-labour or by contractor are about equal. The costs of clearing palms and large trees increase the total costs by 2 to 4 times, unless a chain-saw is used. No herbicides were used in the clearing, although they would probably have been very effective, especially for the last stage of clearing (minor clearing) (Fig. 9.1, 9.2, 9.3 and 9.4).

Cultivation on hydromorphic land differs from the traditional way of cultivation on well-drained land, for example, by its (semi-) permanent nature in contrast to the traditional shifting of cultivation every 2 to 3 years. In Asia, hydromorphic land has been

Table 9.3. An example of the calculation of the ecological crop suitability index for the management unit consisting of soil unit 3 (no specific phase) and groundwater classes 3,3,6,6 (dry, early first, major first, second respectively).

<u>Traditional management level</u>

<u>short</u> growth cycle crops.

season[1]	*crop*	*ecological suitability*[2]	*dietary importance*[3]	*number of suited crop per season*[4]	*coefficient of number*[5]	*index*[6]
		a.	b.		c.	a.b.c
d	cowpea	1	1	1	1.00	1.00
	soybean	1	1	2	1.00	1.00
	okra	1	1	3	0.95	0.95
ef	maize	1	2	1	1.00	2.00
mf	rice	1	2	2	1.00	2.00
	soybean	1	1	3	0.95	0.95
s	rice	1	2	2	1.00	2.00
	sweet potato	1	2	3	0.95	1.90
<u>long</u> growth cycle crops.[7]						
d	–					
ef	–					
mf	cocoyam	1	[illegible]	[illegible]	1.00	2.00
s	cocoyam	1	2	–		
					e.c.s.i.	13.80

<u>Improved management level</u>

<u>short</u> growth cycle crops.

season[1]	crop	ecological suitability[2]	dietary importance[3]	number of suited crop per season[4]	coefficient of number[5]	index[6]
		a.	b.		c.	a.b.c
d	rice	1	2	2	1.00	2.00
	cowpea	1	1	4	0.85	0.85
	soybean	1	1	5	0.75	0.75
	tomato	1	1	6	0.65	0.65
	okra	1	1	7	0.55	0.55
	sweet pepper	1	1	8	0.40	0.40
ef	maize	1	2	2	1.00	2.00
mf	rice	2	2	1	1.00	4.00
	sweet potato	1	2	5	0.75	1.50
	soybean	1	1	7	0.55	0.55
s	rice	2	2	1	1.00	4.00
	sweet potato	1	2	5	0.75	1.50
<u>long</u> growth cycle crops.[7]						
d	cassava	1	2	1	–	
	plantain	1	1	3	–	
ef	cassava	1	2	1	–	
	plantain	1	1	3	–	
mf	yam	1	2	2	1.00	2.00
	cocoyam	1	2	3	0.95	1.90
	cassava	1	2	4	0.85	0.85[8]
	plantain	1	1	6	0.65	0.65
s	yam	1	2	2	–	
	cocoyam	1	2	3	–	
	cassava	1	2	4	–	
	plantain	1	1	6	–	
					e.c.s.i.	24.15

Notes:

1 : abbreviation of seasons: d = dry, ef = early first, mf = major first, s = second.

2 : high = 2, moderate = 1.

3 : primary = 2, secondary = 1.

4 : numbering traditional management level: d: cowpea, soybean, okra; ef: maize; mf: cocoyam, rice, soybean; s: <u>cocoyam</u>, rice, sweet potato.
numbering improved management level: d: <u>cassava</u>, rice, <u>plantain</u>, cowpea, soybean, tomato, okra, sweet pepper; ef: <u>cassava</u>, maize, <u>plantain</u>; mf: rice, yam, cocoyam, cassava, sweet potato, plantain, soybean; s: rice, <u>yam</u>, <u>cocoyam</u>, <u>cassava</u>, sweet potato, <u>plantain</u>.
For the calculation of the ecological crop suitability index the underlined items are omitted, because the numbering of the major first season is used (for long growth cycle crops only).

5 : the coefficient of the number is found in Table 9.2.

6 : the index is the multiplication of columns a, b, and c.

7 : The suitability of cassava, pigeon pea, plantain and banana depends on the dry and second season: for the traditional management level none of these crops is highly or moderately suited; for the improved management level cassava and plantain have a moderate suitability. The suitability of yam and cocoyam depends on the major first and second season: for the traditional management level cocoyam has a moderate suitability; for the improved management level cocoyam and yam have a moderate suitability.

8 : for cassava a reduction of 50 per cent is applied, due to its long growth cycle (cf. paragraph 9.2 (d)).

Table 9.4. Costs and labour requirements per hectare for the clearing of two different land types.

land type	well-drained land[1]		poorly drained land[2]		
			A[3]		B[3]
type of clearing (without stumping)	hours/ha	₦/ha	hours/ha	₦/ha	₦/ha
traditional manual clearing (all vegetation, except big trees and palms)	244	115	2560[4]	688	625
complete manual clearing (all vegetation)	864[5]	225	nd	nd	1375

Notes:

nd: no data available

1 The figures for well-drained land were derived from a study by Dibbits (1975); the original costs of clearing are given, but in the meantime wages have doubled making secondfold values a fairly good estimate. The vegetation cleared is a representative secondary forest.

2 The poorly drained land in this case is the valley bottom of Eastbank area II, covered by a secondary forest vegetation with oil palm and bamboo.

3 A: IITA-labour, costs of labour are based on 8 hour working day at ₦ 2.15 per day.
B: estimation of costs by a contractor.

4 A chain-saw was used for 5 days but the method of clearing remained traditional. The labour requirement can be subdivided into:

		hours/ha
- clearing of main stream		300
- major clearing (felling of most trees, except oil palms, rough clearing of underbrush and burning)		1725
- minor clearing (removal and burning of remaining vegetation)		535
	total	2560

5 With the use of a chain-saw, the labour requirement was reduced to 266 hours/ha.

made productive for many centuries, even under relatively poor soil conditions by the development of bunded and levelled fields (paddies) in which water management is applied. With sufficient high groundwater, the same system can be applied in the study area.

Besides the development of hydromorphic land types, the crop choice is an important socio-economic aspect. The crop choice (of food crops) depends on the following factors (Flinn, personal communication):

- the supply of food over time and the risk of crop failure
- food preferences and traditions
- the regular supply of cash and the desire for larger amounts of it
- the price ratio's among crops
- the labour requirements of crops

The supply of food over time is important in avoiding shortages; this is the subsistence element in the agricultural system in which only the surplus above family needs of food crops is sold (Flinn et al. 1974). In this respect, storage of produce and the flexibility of harvesting time are relevant factors. The risk of crop failure is closely connected to the supply of food over time. The use of reliable crops and crop cultivars,

Fig. 9.1. Eastbank area II after raking of the slope; high trees and oil palms on lower slope and valley bottom are left standing. Some bamboo in the valley bottom remains to be cleared. On the left is the central lake of IITA.

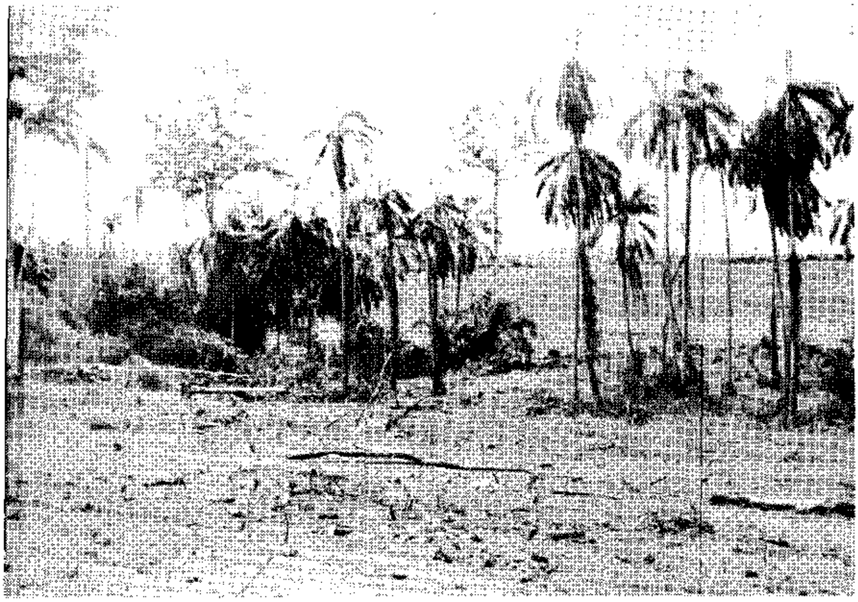


Fig. 9.2. Close-up of valley bottom and lower slope of Eastbank area II.

and the method of mixed cropping, decrease the risk of food shortages. The inclusion of the use of hydromorphic land would probably also reduce this risk. A greater diversion of land types within a farm provides more favourable conditions under which crops can be grown and in some cases more growing seasons for food crop production.

Fig. 9.3. Main stream, cleared of debris, in valley bottom of Eastbank area II after major clearing of the vegetation.

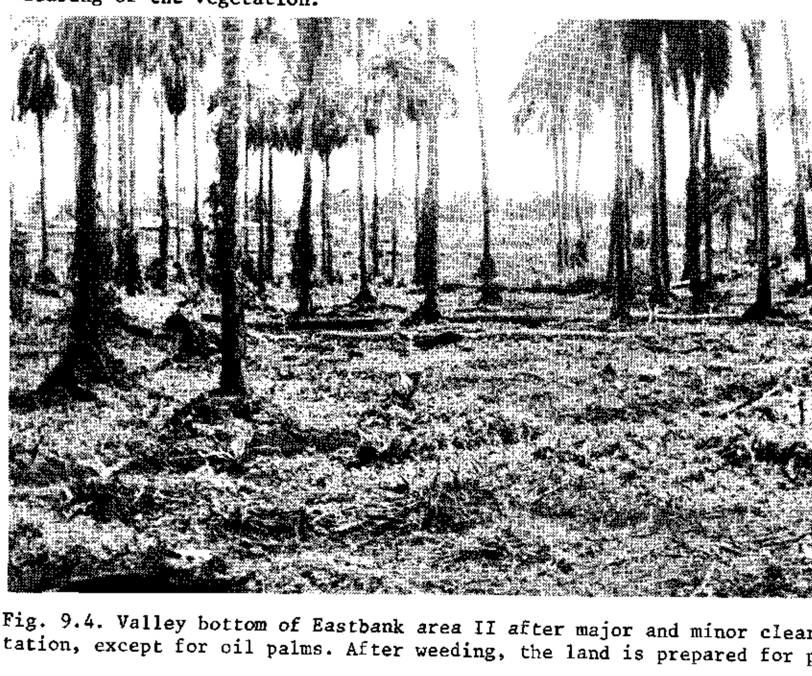


Fig. 9.4. Valley bottom of Eastbank area II after major and minor clearing of the vegetation, except for oil palms. After weeding, the land is prepared for planting.

Traditionally grown crops and those crops assumed to be suited to the study area, were discussed in Chapter 7. Of the main crops, maize, yam, and cassava are grown traditionally. Rice is cultivated only in certain parts of the study area. There is, however, an increasing demand for rice in urban centres and also, particularly with the younger generation, in the rural areas; the trend has been for rice to gradually displace yam and cassava (Mabogunje and Gleave 1964). Cocoyam, in particular *Xanthosoma* is more important in the eastern part of the study area. Sweet potato, although a generally suited crop, is hardly eaten. Of the grain legumes, cowpea is especially important; pigeon pea is more common in the area north of the study area and soybean is hardly known at all. Tomatoes, okra, and celosia are common vegetables, but sweet pepper is hardly known. Plantains and bananas are grown occasionally, but do not form an important part of the daily diet. Studied crops have been separated into preferred and not preferred food crops, and into primary and secondary crops (cf. Table 9.1).

A regular supply of cash is needed to buy items such as clothes, tools, etc., if they cannot be made by the family itself. Larger amounts of cash are required at certain times, e.g. to pay school fees, to buy planting material (especially for yam), or to buy a motorcycle. As credit is not always available or is not received on time, the farmer has to sell produce to pay for these items (second season maize can serve this purpose). Cash crops such as cocoa and kola, if included in the farming system, will of course be more important in this respect than food crops.

The labour requirements are important in the choice of crop, but also in the type of cultivation (hydromorphic land versus well-drained land cultivation). Labour returns are often more important than land returns (Robinson 1974). Farmers may be willing to work more hours if highly profitable innovations are introduced, but they will often not adopt such innovations if these require the employment of additional labour (Flinn et al. 1974).

The labour requirement determines the choice of crop in two ways, namely by labour peaks in certain periods and by the relative labour requirements among crops and among ways of cultivation. An important labour peak occurs in April (beginning of the major first season) for land preparation and planting. The cultivation of hydromorphic land (valley bottom and lower slope) and non-hydromorphic land, can offer the possibility of avoiding this peak; planting can be advanced or delayed. In general, the inclusion of hydromorphic land in the traditional farming system will allow a greater flexibility in the use of farm labour.

In Table 9.5, the specified labour requirement of some crops and crop combinations can be compared. The data are derived from Eastbank area II, where in 1976 these crops were grown traditionally, or with some relevant simple improvements; for comparison the data are calculated per hectare, resulting in relatively high values for the small vegetables plots. The labour requirements of improved rice cultivation on hydromorphic land are high, mainly because of the intensive preparation of land. On the better drained land 40 to 50 per cent of the total labour is spent on weeding crops such as yam/maize and cassava/maize(/cowpea). Once the (semi-) permanent fields for improved rice cultivation are established on hydromorphic land, the labour requirement is strongly reduced, less labour being required for land preparation, but also for weeding.

The net labour productivity (gross margin/man-hours labour) of the crops and crop combinations, mentioned in Table 9.5, is given in Table 9.6. Either average prices were used, or the value of the produce was estimated in the field. The values for the returns per man-hour are only indicative; there are many factors causing variation in yield, and consequently variation in labour productivity, such as date of planting, regularity of weeding, occurrence of drought periods and, for rice, water management. The labour produc-

Table 9.5. The labour requirement of some crops and crop combinations in the Eastbank area II (1976).

crop(s)	rice								yam/maize				cassava/maize				cas/mai/cop		tomato		okra	
specification	A		B		C		D		E		F		G		H		I		J		K	
	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent	hours	per cent
land preparation, bunding, levelling, ridging, drainage	1647	54.7	717	26.5	3245	45.8	1283	21.6	618	16.5	484	12.4	618	27.0	503	25.3	739	25.9	2703	27.3	1386	39.0
nursery, planting, trans-planting	569	18.9	711	26.3	920	13.0	957	16.1	338	9.0	278	7.1	103	4.5	116	5.8	128	4.5	2239	22.6	602	16.9
fertilization	7	0.2	40	1.5	145	2.0	339	5.7	-	-	41	1.1	-	-	8	0.4	13	0.5	104	1.1	-	-
staking	-	-	-	-	-	-	-	-	700	18.7	937	24.1	-	-	-	-	-	-	1354	13.7	-	-
weeding	499	16.6	757	28.0	847	11.9	860	14.5	1727	46.1	1792	46.0	1191	52.0	1031	51.9	1364	47.8	1615	16.3	602	16.9
water management	-	-	-	-	645	9.1	1501	25.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
harvesting, threshing of rice	288	9.6	478	17.7	1290	18.2	995	16.8	362	9.7	360	9.2	379	16.5	328	16.5	611	21.4	1875	19.0	964	27.1
total	3010		2703		7092		5935		3745		3892		2291		1986		2855		9890		3554	

Specification of location, season, soil unit(s), groundwater class(es), plot size, crop and name of cultivar and management specifications.
A. Valley bottom, major first season, soil units 1 and 4, groundwater class 10-11; plot size 0.04 ha; OS 6 rice, transplanted, 53 kg urea/ha; no bunds, no levelling, no surface drainage; several places with bronzing; great variation in yield within plot.

B. Valley bottom, dry season, soil units 1 and 4, groundwater class 10-11; plot size 0.02 ha; IR 20 rice, transplanted, 98 kg ammonium sulphate nitrate/ha, 133 kg ammonium sulphate/ha; no bunds, no levelling; parallel furrows to drain surface soil in order to avoid bronzing; only slight bronzing in some places; less variation in yield within plot than A.

C. Valley bottom, major first season, soil units 1, 3 and 4, groundwater class 10-11; plot size 0.03 ha; IR 20 rice, transplanted, 200 kg 15:15:15/ha, 87 kg urea/ha; paddies with bunds and partly levelled, irrigation by direct diversion of main stream, but still poor water management; hardly any bronzing.

D. Valley bottom, dry season, soil units 1, 3 and 4, groundwater class 10; plot size 0.03 ha; IR 20 rice, transplanted, 290 kg ammonium sulphate/ha; paddies with bunds and partly levelled, irrigation by direct diversion of main stream, but poor water management; hardly any bronzing; severe yield losses by rodents (estimated yield without losses 1930 kg/ha).

E. Upper part of lower slope, major first and second season, soil units 3 and 4, groundwater classes 2, 3, 5 and 6; plot size 0.08 ha; yam/maize; as planting material for yam locally brought white yams were used, which were cut into several pieces, depending on the size of each yam; about 2000 yams per ha were used; two varieties of maize: TZB and local mixture; maize harvested green.

F. Same as E and 150 kg 15:15:15/ha.

G. Upper slope, major first, second and dry season, soil units 6, 7 and 8, groundwater class 1 throughout; plot size 0.1 ha; cassava/maize; local cassava variety Isu-Nikan Kiy two varieties of maize: TZB and local mixture; maize harvested dry.

H. Same as G and 91 kg 15:15:15/ha.

I. Upper slope, major first, second and dry season, soil units 6, 7 and 8, groundwater class 1 throughout; plot size 0.1 ha; cassava/maize/cowpea; local cassava variety Isu-Nikan Kiyan, two varieties of maize; TZB and local mixture, Ife Brown cowpea; maize harvested dry; 125 kg 15:15:15/ha.

J. Valley bottom, dry season, soil unit 1, groundwater classes 6 and 7; plot size 0.01 ha; tomatoes; transplanted from nursery on ridges; staked on pools; 400 kg 15:15:15/ha.

K. Valley bottom, dry season, soil unit 1, groundwater classes 6 and 7; plot size 0.01 ha; okra; planted on ridges.

Table 9.6. The calculation of the net labour productivity (as returns per man hour) of some crops and crop-combinations (Eastbank area II, 1976).

crops and specifications	price (K/kg)[2]	yield (kg)	gross revenue (₦)	cash costs (₦)	gross margin (₦)	man hours labour	returns per man hour (K)[2]
A. rice	41	764	313	17	296	3010	10
B. rice	41	1206	493	31	462	2703	17
C. rice	41	2370	972	27	945	7092	13
D. rice, with loss by rodents	41	937	384	31	353	5935	6
without loss by rodents[3]		1930	791		760		13
E. yam	x	6289	1209				
maize, TZB, green	x	4747	266				
yam + TZB maize			1475	587	888	3745	24
maize, local, green	x	3840	188				
yam + local maize			1397	587	810	3745	22
F. yam	x	8187	1553				
maize, TZB, green	x	5852	284				
yam + TZB maize			1837	579	1258	3892	32
maize, local, green	x	2385	172				
yam + local maize			1725	579	1146	3892	29
G. cassava	9	3970	357				
maize, TZB, dry	18	683	123				
cassava + TZB maize			480	2	478	2291	21
maize, local, dry	18	492	89				
cassava + local maize			446	2	444	2291	19
H. cassava	9	3140	283				
maize, TZB, dry	18	551	99				
cassava + TZB maize			382	5	377	1986	19
maize, local, dry	18	324	58				
cassava + local maize			341	5	336	1986	17
I. cassava	9	3800	342				
maize, TZB, dry	18	775	140				
cowpea	x	42	12				
cassava + TZB - maize + cowpea			494	10	484	2855	17
maize, local, dry	18	461	83				
cassava + local maize + cowpea			437	10	427	2855	15
J. tomato	32	6240	1997	28	1969	9890	20
K. okra	30	394	118	10	108	3554	3

Notes: x price for yam, green maize and cowpea estimated in the field.
[2] 1 K = 0.01 ₦ = $ 0.016
[3] estimated.

tivity of crop combinations on well-drained land was generally higher than that of rice on hydromorphic land. The use of the improved TZB maize variety was more profitable than the local maize variety. Whereas the cultivation of tomatoes resulted in a fairly good labour productivity, the cultivation of okra was poor, owing to low yield.

To compare the studied crops, the net labour productivity (gross margin/man days labour) was compiled in Table 9.7, based on a moderate to high suitability. The details of the calculation are given in appendix K. The calculation and the resulting average and extreme values are based besides a "moderate" to "high" suitability on a wide range of prices, a relevant range of cash costs, and a relevant range of labour requirements. In Table 9.7 three figures are represented:

- an average figure, representing the average net labour productivity with a yield

Table 9.7. Estimated average and extreme returns per man day for the studied crops under moderate to high suitability, divided into cultivation on hydromorphic and well-drained land (₦ 1 = $ 1.6) (cf. Appendix K).

Hydromorphic land	average (₦)	range (₦)
rice, trad. management	2.0	1.1 - 3.6
imp. management	0.9	0.4 - 1.6
maize, early first season, green	3.0	1.8 - 4.7
sweet potato	1.2	0.3 - 2.8
cocoyam	3.8	1.0 -14.5
cowpea	0.5	0.2 - 0.9
soybean	0.2	0.1 - 0.2
tomatoes, dry season	3.0	0.4 -13.5
okra, dry season	1.7	0.3 -12.0
celosia, dry season	2.1	0.3 -16.7
sweet pepper, dry season	0.9	0.3 - 2.7
plantain, up to first harvest	0.6	0.2 - 1.1
banana, up to first harvest	0.5	0.1 - 1.1
Well-drained land		
rice	3.0	1.8 - 4.7
maize	2.7	1.1 - 5.1
yam, incl. costs of planting material	2.2	0.0 - 7.8
excl. costs of planting material	3.5	1.2 - 8.3
cassava	9.6	1.2 -30.0
sweet potato	1.5	0.4 - 3.4
cocoyam	4.6	1.2 -17.4
cowpea	0.6	0.2 - 1.2
soybean	0.2	0.2 - 0.3
pigeon pea	0.3	0.1 - 0.6
plantain, up to first harvest	1.4	0.5 - 3.2
banana, up to first harvest	1.2	0.2 - 3.2

level of 80 per cent of the reference yield, an average (1976) price, average costs, and an average labour requirement.

- a low and a high extreme figure, representing the lowest and the highest net labour productivity, respectively using yield levels of 60 and 100 per cent of the reference yield and lowest-highest price, relatively high-relatively low costs, and high and low labour requirement, respectively.

  The marginal labour productivity, which is actually more important than the average net labour productivity, is within this range.

The variation in labour requirement can be high due to site-specific factors; no comparison can therefore be made between the net labour productivity among management levels per crop, except for rice on hydromorphic land, where a wide difference in labour requirement among the two management levels exists.

A separation was made between hydromorphic land (valley bottom and lower slope) and well-drained land (upper slope); the labour requirement on hydromorphic land is generally higher due, for example, to more intensive weed growth and the faster erosion of the ridges and mounds than on well-drained land. Besides an increase in labour requirement because more weeding is necessary, yields will also be reduced; both factors cause a lower net productivity. The faster erosion of ridges and mounds cause more maintenance work than on well-drained land, especially under the improved management when higher ridges and mounds have to be made. As can be seen in Table 9.7 the net labour productivities on hydromorphic land are somewhat lower than on well-drained land.

Relatively high net labour productivities can be obtained for primary food crops such as rice, maize, cassava, and cocoyam; the price for cassava is relatively high. Yam and improved rice cultivation on hydromorphic land have lower net labour productivities due to the high labour requirements. However, with a strong reduction in required labour after the establishment of the levelled and bunded fields, improved rice cultivation on hydromorphic land may have a higher net labour productivity than indicated in Table 9.7; the one mentioned in this table should only be considered for the first year after clearing of the vegetation. Afterwards a higher net labour productivity can be expected. Vegetables, apart from sweet pepper, are profitable on hydromorphic land in the dry season. Cowpea, plantain, and banana form additional crops with a relatively good net labour productivity under a moderate to high suitability. The cash costs, mainly for seed and fertilizers, are generally very low compared to the gross revenues obtained with yields under a moderate to high crop suitability, except for yam if planting material has to be purchased.

For rice, when it is past the heading stage, bird scaring is essential, especially when it is introduced into a new area. It is not included in the figures of Table 9.7. The labour requirement for bird scaring depends on the size of the rice fields; children are often used as bird scarers.

9.4 QUALITATIVE EVALUATION OF A NUMBER OF COMMON MANAGEMENT UNITS (CASE STUDIES)

As pointed out in the introduction of this chapter, Table 8.3 is considered as the basis for the crop suitabilities for any of the management units. Apart from a soil unit and possibly a phase, a management unit is defined by the groundwater classes in all seasons[1]. Soil units which had equal grades in all studied land qualities, were grouped in one unit. The very large number of possible sequences of groundwater classes per season makes it impossible to discuss all possible management units. A reduction was made by considering those management units commonly occurring in the three study areas. These areas are: 1) on the Basement Complex, on which soil units 1-9 are important, the Westbank area (which is under forest vegetation), and the Eastbank area II (its vegetation has been recently cleared; its valley bottom is much wetter than the one of the Westbank area); 2) on the sedimentary formations, with soil units A-D, the Ikenne area. Twenty-seven management units will be evaluated in a qualitative way. The management units with specifications about the soil unit(s), the phase(s), and the groundwater class per season, the occurrence in any of the three study areas, and the calculated ecological crop suitability index (e.c.s.i.) for both management levels are indicated in Table 9.8. An example of the calculation of the e.c.s.i. (the one of management unit m) was shown in Section 9.2, Table 9.3.

Besides the distinction in geology (Basement Complex versus sedimentary formations), the management units have been grouped into eleven groups (I-XI) according to the topographic position and the groundwater regime (the latter is indicated by the seasonal groundwater classes) (Fig. 9.5). The grouping is given in Table 9.9.

[1] The management level is not specified here, as the best management level will be chosen in the following discussion.

Table 9.8. List of specifications and ecological crop suitability indices per management level of common management units in three study areas, grouped into eleven groups of management units.

group of management units	management units	soil unit	phase(s)	groundwater class per season: dry	early first	major first	second	study area[1]: WB	EBII	IK	ecological crop suitability index: traditional management	improved management
I	a	1	–	1	1	9	10	+			8.00	8.95
	b	4	–	1	1	9	10	+			0.00	4.00
II	c	1	–,cl	9	9	10	10		+		9.00	17.80
	d	1	–,cl	10	10	11	11		+		14.00	17.00
	e	1	ir	10	10	11	11		+		6.00	11.00
	f	3	–	9	9	10	10		+		7.00	13.95
	g	4	–,cs,ir	9	9	10	10		+		0.00	4.00
	h	4	–,cs,ir	10	10	11	11		+		0.00	6.00
III	i	D	–	10	10	11	11			+	8.00	15.00
	j	D	ir	10	10	11	11			+	2.00	9.00
IV	k	2,D	–,ir	1	1	5	9	+		+	11.00	11.00
	l	4	–	1	1	5	6	+			0.00	4.00
V	m	3	–	3	3	6	6		+		13.80	24.15
	n	4	–,cs	3	3	6	6		+		0.00	4.00
VI	o	1	–	1	1	3	6	+			14.90	18.35
	p	2,3	–	1	1	3	6	+			11.40	15.90
VII	q	3	–	2	2	3	3		+		13.40	16.80
	r	4	–	2	2	3	3		+		1.00	1.00
VIII	s	4	–	1	1	2	2	+	+		7.30	5.60
IX	t	C	–	1	1	2	2			+	16.15	18.25
X	u	4	–	1	1	1	1	+	+		3.80	2.00
	v	6	i_s,i_d	1	1	1	1	+	+		1.00	1.00
	w	7,8	–,i_d	1	1	1	1	+	+		12.90	12.90
	x	9	–	1	1	1	1	+			22.95	22.30
	y	9	se	1	1	1	1	+			1.00	1.00
	z	7	i_s	1	1	1	1		+		11.85	11.85
XI	&	A,B	–	1	1	1	1			+	12.90	12.90

Note:

[1] WB: Westbank area
EBII: Eastbank area II
IK: Ikenne area

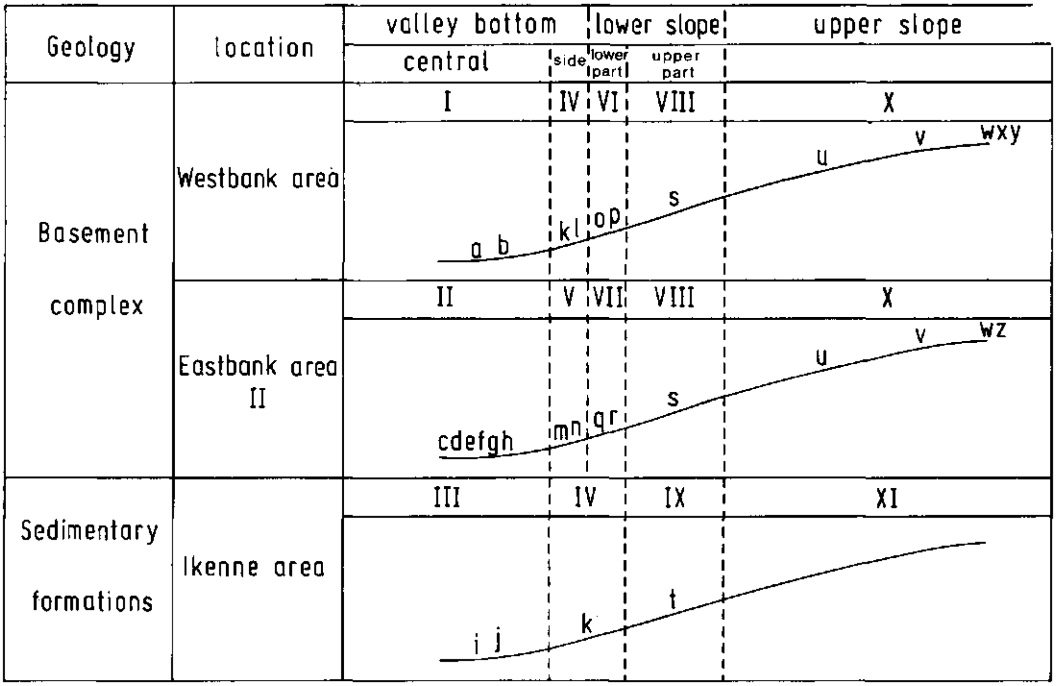


Fig. 9.5. The occurrence of common management units in three study areas and their topographic position. For explanation of the figures, refer to Table 9.8.

Table 9.9. The topographic position and the groundwater regime with respect to the distinction of groups of management units.

primary topographic position	secondary topographic position	groundwater regime	groups of management units
valley bottom	central	groundwater class 9 or higher in major first and second season	I, II, III
	side	groundwater class 9 or higher in one or none of the major first and second season	IV, V
lower slope	lower part	groundwater class 3 or higher in major first and second season	IV, VI, VII
	upper part	groundwater class 2 in major first and second season	VIII, IX
upper slope	-	groundwater class 1 throughout the year	X, XI

For each group of management units, only the "highly" and "moderately" suited crops, as resulting from the ecological suitability determination (cf. Section 8.2) are discussed; this means that only those crops are considered from which yield levels of more than 50 per cent of the reference yield are expected to be obtained (cf. Appendix K) and that a restricted crop suitability (expected to result in yield levels of 30-50 per cent of the reference yield) is not considered in the evaluation.

To show all highly and moderately suited crops for all management units in each of the three study areas, schematic representations are given for four seasons (early first, major first, second and dry season) (Tables 9.10, 9.11, and 9.12). The highest ecological

Table 9.10. Westbank area. Schematic representation of the highly and moderately suited crops for four seasons (early first, major first, second and dry).

primary topographic position	valley bottom				lower slope			upper slope				
secondary topographic position	central		side		lower part		upper part					
management unit	a	b	k	l	o	p	s	u	v	w	x	y
soil unit	1	4	2	4	1	2,3	4	4	6	7,8	9	9
phase	–	–	–,ir	–	–	–	–	–	i_s,i_d	–,i_d	–	se
EARLY FIRST SEASON												
groundwater class	1	1	1	1	1	1	1	1	1	1	1	1
highly suited crops	–	–	–	–	–	–	–	–	–	–	cas	–
moderately suited crops	–	–	–	–	cas	cas	cas pip	cas pip	cas	cas pip	pip	pip
MAJOR FIRST SEASON												
groundwater class	9	9	5	5	3	3	2	1	1	1	1	1
highly suited crops	ccy	–	–	–	ric ccy	–	–	–	–	–	mai yam cas spo cop soy	–
moderately suited crops	ric soy	ric	ric mai spo ccy cop soy	ric	mai yam cas spo cop soy	ric mai yam cas spo ccy cop soy	cas spo cop soy pip	cas pip	cas	mai yam cas spo cop soy pip	pip	pip
SECOND SEASON												
groundwater class	10	10	9	6	6	6	2	1	1	1	1	1
highly suited crops	ric ccy	–	–	–	ccy	ric	–	–	–	cop	yam cas cop soy	–
moderately suited crops	–	ric	ric ccy	ric	ric yam cas spo soy	yam cas spo ccy	cas cop soy pip	cas cop soy pip	cas	yam cas spo soy pip	mai spo pip	pip
DRY SEASON												
groundwater class	1	1	1	1	1	1	1	1	1	1	1	1
highly suited crops	–	–	–	–	–	–	–	–	–	–	cas	–
moderately suited crops	–	–	–	–	cas	cas	cas pip	cas pip	cas	cas pip	pip	pip

Explanation of abbreviation: ric = rice, mai = maize, yam = yam, cas = cassava, spo = sweet potato, ccy = cocoyam, cop = cowpea, soy = soybean, pip = pigeon pea, tom = tomato, okr = okra, cel = celosia, spe = sweet pepper, pla = plantain, ban = banana.

Table 9.11. Eastbank area II. Schematic representation of highly and moderately suited crops for four seasons (early first, major first, second and dry).

primary topographic position	valley bottom								lower slope			upper part			
secondary topo-graphic position	central						side		lower part		upper part				
management unit	c	d	e	f	g	h	m	n	q	r	s	u	v	w	z
soil unit	1	1	1	3	4	4	3	4	3	4	4	4	6	7,8	7
phase	-,cl	-,cl	ir	-	-,cs,ir	-,cs,ir	-	-,cs	-	-	-	-	i_s,i_d	-,i_d	i_s
EARLY FIRST SEASON															
groundwater class	9	10	10	9	9	10	3	3	2	2	1	1	1	1	1
highly suited crops	-	-	-	-	-	-	-	-	cas	-	-	-	-	-	-
moderately suited crops	-	-	-	-	-	-	mai cas pla	-	-	cas	cas pip	cas pip	cas	cas pip	cas pip
MAJOR FIRST SEASON															
groundwater class	10	11	11	10	10	11	6	6	3	3	2	1	1	1	1
highly suited crops	ric ccy	ric ccy	ccy	ric	-	-	ric	-	cas	-	-	-	-	-	-
moderately suited crops	-	-	ric	ccy	ric	ric	yam cas spo ccy soy pla	ric	ric mai yam spo ccy cop soy	cas	cas spo cop soy pip	cas pip	cas	mai yam cas spo cop soy pip	mai yam cas spo cop soy pip
SECOND SEASON															
groundwater class	10	11	11	10	10	11	6	6	3	3	2	1	1	1	1
highly suited crops	ric ccy	ric ccy	ccy	ccy	-	-	ric	-	cas	-	-	-	-	cop	-
moderately suited crops	-	-	ric	ccy	ric	ric	yam cas spo ccy pla	ric	ric mai yam spo ccy cop soy	cas	cas cop soy pip	cas cop soy pip	cas	yam cas spo soy pip	yam cas spo cop soy pip
DRY SEASON															
groundwater class	9	10	10	9	9	10	3	3	2	2	1	1	1	1	1
highly suited crops	okr	ric	-	-	-	-	-	-	cas	-	-	-	-	-	-
moderately suited crops	ric soy tom	okr	ric okr	ric tom okr	-	ric	ric cas cop soy tom okr spe pla	-	-	cas	cas pip	cas pip	cas	cas pip	cas pip

Table 9.12. Ikenne area. Schematic representation of the highly and moderately suited crops for four seasons (early first, major first, second and dry).

primary topographic position	valley bottom		lower slope		upper slope
secondary topographic position	central		lower side part	upper part	
management unit	i	j	k	t	&
soil unit	D	D	D	C	A,B
phase	-	ir	-,ir	-	-
EARLY FIRST SEASON					
groundwater class	10	10	1	1	1
highly suited crops	-	-	-	cas	-
moderate suited crops	-	-	-	pip	cas pip
MAJOR FIRST SEASON					
groundwater class	11	11	5	2	1
highly suited crops	ric	-	-	cas cop	-
moderately suited crops	ccy	ric ccy	ric mai spo ccy cop soy	ric mai yam spo soy pip	mai yam cas spo cop soy pip
SECOND SEASON					
groundwater class	11	11	9	2	1
highly suited crops	ric	-	-	cas cop	cop
moderately suited crops	ccy	ric ccy	ric ccy	ric mai yam spo soy pip	yam cas spo soy pip
DRY SEASON					
groundwater class	10	10	1	1	1
highly suited crops	ric	-	-	cas	-
moderately suited crops	okr	ric okr	-	pip	cas pip

crop suitability in any of the two management levels was chosen. Crops with a relatively long growth cycle are indicated for any season to which they are suited.

The discussion about the "highly" and "moderately" suited crops will cover three locations:

- central valley bottom
- side part of lower slope and upper slope
- upper part of lower slope and upper slope

This separation was made as the crop possibilities are more comparable within, and also among these groups.

For each management unit, the management level with the highest suitability is chosen and indicated in the tables as *t* (traditional) or *i* (improved). When the suitability under both management levels is equal, it is indicated as *t*/*i*. In the case of equal suitability under both levels the best management level was chosen by considering five factors: the crop, the period of time between clearing of the vegetation and cultivation, the frequency of cultivation, the intensity of weed growth, and the cultivation on hydromorphic or well-drained land. Table 9.13 shows the results. The five factors mentioned were considered as follows:

- crops: the same management groups of crop(s) were used as in the determination of the management practices for each management level (cf. Table 6.1).
- intensity of weed growth: this factor was applied for rice only, as the improved management includes bunding and levelling; in this way water is conserved on the fields, strongly reducing weed growth.
- frequency of cultivation: a higher frequency of cultivation may imply a greater part of the produce to be marketed; if so, production very likely involves some improvements in the management if the marginal costs are covered by the marginal benefits.
- period of time between clearing of the vegetation and cultivation: directly after clearing, fertilizers are not always effective; their effect increases with time.
- cultivation on hydromorphic or well-drained land: this factor was applied for rice only. For rice on well-drained land the traditional management level is thought to be more suited in the case of irregular cultivation shortly after clearing; in the other cases, the improved management level, especially by higher applications of fertilizers, is

Table 9.13. The best management level in the case of equal crop suitability under both management levels (t = traditional, i = improved).

hydromorphic/well-drained land[1]			hydromorphic		well-drained	
period of time between clearing and cultivation			short	long	short	long
group of crop(s)	frequency of cultivation[2]	weedgrowth				
rice	regular	intensive	i	i	i	i
		not intensive	t	i		
	irregular	intensive	t	i	t	i
		not intensive	t	t		
maize, tomato, celosia, sw. pepper, plantain, banana	regular		i	i	i	i
	irregular		t	i	t	i
yam, cassava, sw. potato, cocoyam, cowpea, soybean, pig. pea, okra	regular		t	t	t	t
	irregular		t	t	t	t

Notes:

1 hydromorphic: valley bottom, lower slope
well-drained: upper slope

2 regular: more than one crop in one year or cultivation of crop almost every year
irregular: only one crop in one year and cultivation not every year.

probably better, especially if the net labour productivity under the improved management level is going to be higher than under the traditional management level (cf. Section 9.3). For rice on hydromorphic land the intensity of weed growth, the frequency of cultivation, and the period of time between clearing and cultivation were taken into account.

Central valley bottom (cf. Table 9.8)

For the central valley bottom location, three groups of management units (I, II, and III) will be discussed. Groups I and II are situated on the Basement Complex, group III on sedimentary formations. Another important distinction is that group I has groundwater class 1 in the dry and in the early first season, while groups II and III remain wet to very wet (class 9 or higher) during these seasons. On the Basement Complex, three soil units were considered: soil unit 4 is a sandy soil, soil unit 3 a loamy soil without a clayey texture at less than 1 m depth, and soil unit 1 a loamy soil with a clayey texture at less than 50 cm. On sedimentary formations only soil unit D, a loamy soil, was considered. Especially in group II more than one phase was considered per management unit; if more phases are mentioned with a soil unit, it means that the ecological suitability of crops for that management unit, as far as highly and moderately suited crops are concerned, is equal for all mentioned phases. Exceptions are management units *e* and *j* where the suitability of the crops is influenced by a particular phase; in these cases the ecological suitability of crops is reduced by iron toxicity (phase ir).

A comparison of the ecological crop suitability indices (Table 9.8) shows higher indices for the heavier textured soil units, reflecting more crop possibilities and higher crop suitabilities on these soil units. The indices for the sandy soil (soil unit 4) is rather low and even nil for the traditional management level. This means that in the case of the traditional management level, not a single crop was found to be highly or moderately suited for these management units; such a management unit might be cultivated under the traditional management level with crops of a restricted suitability (e.g. cocoyam). However, with the improved management level, rice and sometimes cocoyam are suitable. As already stated, the occurrence of iron toxicity (management units *e* and *j*) reduced the index to some extent. The absence of high groundwater levels in the dry and in the early first season, as occurring in group I, results in a lower index, especially for the improved management level. Management unit *i*, on sedimentary formations, has indices comparable to management unit *f* on the Basement Complex. Improvement of management clearly increases the ecological crop suitability index for all management units, although the increase for management unit *a* is only slight.

Table 9.14 gives a summary of the highly and moderately suited crops for the management units *a*-*j*, together with specifications about the dietary importance and crop preference, the best management level, and the season. The main crops for all three groups of management units are rice and cocoyam. Due to the high groundwater levels in the dry season, rice was found suitable for this season in groups II and III, but not in group I. The improved management level usually results in a higher ecological suitability for rice cultivation; exceptions are management unit *a* in the major first season and management unit *f* in the dry season. For the latter two cases the choice of the best management level must be made according to Table 9.13. Rice was found highly suited in the dry season to

Table 9.14. Central valley bottom, groups of management units I, II, and III. Summary of highly and moderately suited crops and specifications about the preference and dietary importance of crops, the best management level and the season.

group of management units	crop preference	dietary importance of crop	crop	specification of season	specification of management unit(s)[1]	management level with highest suitability[2]	ecological suitability
I	preferred	primary	rice	major first	a	t/i	moderate
					b	i	moderate
				second	a	i	high
					b	i	moderate
			cocoyam	major first + second	a	t/i	high
		secondary	-				
	not preferred	primary	-				
		secondary	soybean	major first	a	i	moderate
II	preferred	primary	rice	dry	d	i	high
					f	t/i	moderate
					c,e,h	i	moderate
				major first, second	c,d,f	i	high
					e,g,h	i	moderate
			cocoyam	major first + second	c,d,e	t/i	high
					f	t/i	moderate
		secondary	tomato	dry	c,f	i	moderate
			okra	dry	c	i	high
					f	t/i	moderate
					d,e	i	moderate
	not preferred	primary	-				
		secondary	soybean	dry	c	i	moderate
III	preferred	primary	rice	dry, major first, second	i	i	high
					j	i	moderate
			cocoyam	major first + second	i,j	t/i	moderate
		secondary	okra	dry	i,j	i	moderate

Note: [1] The management units (a - &) are specified in Table 9.8.

[2] Management levels: t = traditional
i = improved
t/i= equal suitability under both management levels; the best management level can be found in Table 9.13.

Fig. 9.6. Bunded and partly levelled rice (IR 20) fields on valley bottom land during the first year after clearing; Eastbank area II (management units c, d, and f).

Fig. 9.7. Rice (IR 20) grown on valley bottom land at Ikenne (management units i and j). Some drainage is applied to avoid iron toxicity. In the background Rapphia palms along a stream.

management units *d* and *i*, in the major first season to management units *c*, *d*, *f* and *i*, in the second season to management units *a*, *c*, *d*, *f* and *i* (Figs. 9.6 and 9.7). Cocoyam, with a somewhat higher average net labour productivity than rice, is suited for all three groups of management units; it is best cultivated under the traditional management level (cf. Table 9.13). Cocoyam (major first and second season) was found to be highly suited to management units *a*, *c*, *d* and *e*. Some vegetables can be grown in the dry season: tomato in group II and okra in groups II and III. Okra is highly suited to management unit *c* especially. These vegetables can form an attractive alternative to rice, as their net labour productivities are rather high (cf. Table 9.7). Of the least preferred crops, soybean is suited in groups I and II.

Side of valley bottom and lower part of lower slope (cf. Table 9.8)

Four groups of management units (IV, V, VI and VII) will be discussed for these sites, which form the transition zone between the hydromorphic valley and the well-drained upper slope. The width of this zone is different on each slope and along each slope, but usually ranges from 1 to 20 m. Several groundwater classes may occur within a few metres. A number of common sequences of groundwater classes have been included in the studied management units. A main distinction is formed by the occurrence of groundwater class 1 in the dry and early first season in groups IV and VI, while this is not the case in groups V and VII (which have groundwater classes of 3 and 2, respectively, in these seasons). Proceeding from group IV to group VII, the highest groundwater levels in the major first and in the second season decrease. Apart from soil unit D (management unit *k* in group IV), a loamy soil, the other soil units are situated on the Basement Complex. Soil unit 2 is added to soil units 1, 3, and 4, as discussed in the evaluation of the central valley bottom. Soil unit 2 represents a soil with characteristics that are between soil units 1 and 3; although a loamy soil, it has a clayey texture between 50 and 100 cm depth. No distinction among management units was made with respect to phases. The additional phases in management units *k* and *n* are added, as no effect on the suitability of crops was found.

The ecological crop suitability index (cf. Table 9.8) for soil unit 4, occurring in management units *l*, *n* and *r*, is remarkably lower than for the more heavier textured soil units. Under the traditional management level, only management unit *r* is suited for cassava; under improved management, management units *l* and *n* become suited for rice. Soil unit 1, being the most clayey one, shows indices that differ only slightly from the other loamy soils (soil units 2, 3 and D). The index for management unit *m* (improved management level) is the highest of all studied management units. Although groundwater class 1 occurs in the dry and early first season (groups IV and VI), the ecological crop suitability indices are similar to those of groups V and VII, as far as the heavier textured soil units are concerned. Improvement of management increases the ecological crop suitability index for all the management units, except *k* and *r*. For the latter management units, a remarkable yield increase can not be expected by the improvements indicated in Table 6.1.

Table 9.15 gives a summary of the highly and moderately suited crops for management units *k*-*r*, together with specifications about the dietary importance and crop preference, the best management level, and the season. Compared to the groups of management units of the central valley bottom, as far as the heavier textured soils are concerned, a much

Table 9.15. Side of valley bottom and lower part of lower slope, groups of management units IV, V, VI and VII. Summary of highly and moderately suited crops and specifications about the preference and dietary importance of crops, the best management level and the season.

group of management units	crop preference	dietary importance of crop	crop	specification of season	specification of management unit(s)	management level with highest suitability	ecological suitability
IV	preferred	primary	rice	major first, second	k	t/i	moderate
					l	i	moderate
			maize	major first	k	t/i	moderate
			cocoyam	major first + second	k	t/i	moderate
		secondary	cowpea	major first	k	t/i	moderate
	not preferred	primary	sweet potato	major first	k	t/i	moderate
		secondary	soybean	major first	k	t/i	moderate
V	preferred	primary	rice	dry	m	i	moderate
				major first, second	m	i	high
					n	i	moderate
			maize	early first	m	t/i	moderate
			yam	major first + second	m	i	moderate
			cassava	annual	m	i	moderate
			cocoyam	major first + second	m	t/i	moderate
		secondary	cowpea	dry	m	t/i	moderate
			tomato	dry	m	i	moderate
			okra	dry	m	t/i	moderate
			plantain	annual	m	i	moderate
	not preferred	primary	sweet potato	major first	m	i	moderate
				second	m	t/i	moderate
		secondary	soybean	dry, major first	m	t/i	moderate
			sweet pepper	dry	m	i	moderate
VI	preferred	primary	rice	major first	o	i	high
					p	i	moderate
				second	p	i	high
					o	t/i	moderate
			maize	major first	o,p	t/i	moderate
			yam	major first + second	o,p	i	moderate
			cassava	annual	o,p	i	moderate
			cocoyam	major first + second	o	t/i	high
					p	t/i	moderate
		secondary	cowpea	major first	o,p	t/i	moderate
	not preferred	primary	sweet potato	major first, second	o,p	t/i	moderate
		secondary	soybean	major first	o,p	t/i	moderate
				second	o	i	moderate
VII	preferred	primary	rice	major first, second	q	i	moderate
			maize	major first	q	t/i	moderate
				second	q	i	moderate
			yam	major first + second	q	t/i	moderate
			cassava	annual	q	t/i	high
					r	t/i	moderate
			cocoyam	major first + second	q	t/i	moderate
		secondary	cowpea	major first, second	q	t/i	moderate
	not preferred	primary	sweet potato	major first, second	q	t/i	moderate
		secondary	soybean	major first, second	q	t/i	moderate

wider crop choice is apparent. Suitable crops appearing in all four groups are rice, maize, sweet potato, cocoyam, cowpea, and soybean. Yam and cassava appear as suitable crops in groups V, VI and VII. Group V, and in particular management unit *m*, shows the widest crop choice, as was already indicated by the high ecological crop suitability index; for this management unit, additional suited crops are tomato, okra, sweet pepper, and plantain.

The improved management level is usually more appropriate for rice cultivation; exceptions are management unit *k*, major first and second season, and management unit o, second season. For these two cases the choice of the best management level has to be made according to Table 9.13. Rice was found to be highly suited in the major first season to management units *m* and *o*, and in the second season to management units *m* and *p*. Maize is suited in the early first season to management unit *m*, in the major first season to units *k*, *o*, *p* and *q* (management level according to Table 9.13), and in the second season to unit *q* (improved management level). For yam and cassava the improved management level is considered more appropriate, except for management unit *q* (yam) and *q* and *r* (cassava). Management unit *q* is especially suited to cassava. For sweet potato, cocoyam, cowpea, and soybean, the traditional management level is good (according to Table 9.13), except for sweet potato, in the major first season, in management unit *m*, and for soybean in the second season, in management unit *o*. Management unit *o* was also found highly suited to cocoyam.

The average net labour productivities of the suitable crops can be compared according to the values in Table 9.7. The zone of the side of the valley bottom and the lower part of the lower slope is situated between the hydromorphic and the well-drained land; therefore, the average net labour productivities of the crops are intermediate between the values given for hydromorphic and well-drained land. Cassava shows a high value; rice, maize, yam, cocoyam, tomato, and okra have moderate values; sweet potato and plantain have lower values, while those of cowpea, soybean, and sweet pepper are the lowest. Not only labour productivity data are decisive in the wide pattern of crop possibilities, but also other factors such as preferences, crops on other parts of the farm area, and the narrowness of this transition zone on the slope. Although there is a variation on a detailed scale in groundwater regime, the transition zone offers many possibilities for cultivation and should not be left unused or only used for storing remnants of the cleared vegetation from the valley bottom and lower slope.

Upper part of lower slope and upper slope (cf. Table 9.8)

Four groups of management units (VIII, IX, X and XI) will be discussed for these locations. The four groups differ from each other in the following way: group VIII and X are situated on the Basement Complex, groups IX and XI on the sedimentary formations; groups VIII and IX represent the soils on the upper part of the lower slope (groundwater class 2 in the major first and second season), while groups X and XI represent the soils of the upper slope (groundwater class 1 throughout the year). Differences occur among these four groups by way of the soil units and their phases (cf. Table 9.8). For the Basement Complex, the soil units 4, 6, 7, 8, and 9 are considered. Soil unit 4 (management units *s* and *u*) is a sandy soil which also occurs in other parts of the land-scape. Soil unit 6 (management unit *v*) is a very gravelly soil. Management units *w* and *z* consist of loamy soils (soil units 7 and 8), the soil of unit *z* being gravelly (phase i_s). Management units *x* and *y* consist of clayey soils (soil unit 9), the soil of unit *y* being the erodible phase due to its occurrence on moderately steep or steep slopes. For the sedimentary formations, the soil units A, B, and C are considered. Soil unit C (management unit *t*) is a loamy soil with a mottled subsoil. Unit *&* consists of clayey and loamy soils (soil units A and B respectively).

The ecological crop suitability index of management units *v* and *y* is very low under both management levels. Only one crop was found suitable for each unit: cassava for unit *v* and pigeon pea for unit *y*. Crops with a restricted suitability or other forms of land use, e.g. forestry, might possibly be taken into consideration. However, unit *v* was found to be barely suitable for forestry (Forestry Research Dept., Ibadan, personal communication). The ecological crop suitability index for units *s* and *u* (both consisting of soil unit 4) is clearly lower than for the other units with heavier textured soils. An even lower index is obtained with improved management than with traditional management. Management units *w* and *&* have equal indices and equal crop possibilities. Management unit *z* differs only very slightly from these units. Management unit *x* represents the soils with the most crop possibilities and the higher crop suitabilities. The influence of management improvements in all four groups of management units is obvious. Actually it is only unit *t* that shows a higher ecological crop suitability index with improved management.

No suitable crops were found for the dry and the early first season; therefore, vegetables do not appear in the list of suitable crops. Table 9.16 gives a summary of the highly and moderately suited crops for management units *s*-*&*, together with specifications about dietary importance and crop preference, the best management level, and the season. Rice was only found suited to management unit *t*. Among the management units *s*, *t*, *u*, *w*, *x*, *z* and *&* there is a variation in other crop possibilities and crop suitabilities, mainly due to variation in factors such as the occurrence of groundwater class 2 in the major first and in the second season, differences in texture, occurrence of gravels and soil erosion. Suitable crops, appearing in all four groups, are cassava, sweet potato, cowpea, soybean and pigeon pea. Maize and yam are suited only in groups IX, X, and XI. High ecological crop suitabilities were found for cassava on management units *t* and *x*, for yam on management unit *x*; for the major first season for maize and sweet potato on management unit *x*, for cowpea on management units *t* and *x*, for soybean on management unit *t* only; for the second season for cowpea on management units *t*, *w* and *x*, for soybean on management unit *x* only.

Apart from the less preferred crops such as sweet potato, soybean, and pigeon pea, the other crops are traditionally grown by the farmers of the study area. Although cocoyam was found of restricted suitability only, due to an insufficient availability of water, further ast in the study area with somewhat higher and more reliable rainfall, a moderate suitability might apply. Maize is grown traditionally on all management units on well-drained land, but from this evaluation maize was found suited in the major first and second season only on management units *t*, *x* and *&* and in the major first season on management units *w* and *z*. The cultivation of maize in the second season was found restricted for some management units, such as *w* and *z*.

The average net labour productivities of the highly and moderately suited crops can be compared in Table 9.7. Cassava has a relatively high value; rice, maize and yam have

Table 9.16. Upper part of lower slope and upper slope, groups of management units VIII, IX, X and XI. Summary of highly and moderately suited crops and specifications about the preference and dietary importance of the crops, the best management level and the season.

group of management units	crop preference	dietary importance of crop	crop	specification of season	specification of management unit(s)	management level with highest suitability	ecological suitability
VIII	preferred	primary	cassava	annual	s	t/i	moderate
		secondary	cowpea	major first, second	s	t/i	moderate
	not preferred	primary	sweet potato	major first	s	t	moderate
		secondary	soybean	major first, second	s	t/i	moderate
			pigeon pea	annual	s	t/i	moderate
IX	preferred	primary	rice	major first, second	t	i	moderate
			maize	major first, second	t	t/i	moderate
			yam	major first + second	t	t/i	moderate
			cassava	annual	t	t/i	high
		secondary	cowpea	major first, second	t	t/i	high
	not preferred	primary	sweet potato	major first, second	t	t/i	moderate
		secondary	soybean	major first, second	t	t/i	moderate
			pigeon pea	annual	t	t/i	moderate
X	preferred	primary	maize	major first	x	t/i	high
					w,z	t/i	moderate
				second	x	t/i	moderate
			yam	major first + second	x	t/i	high
					w,z	t/i	moderate
			cassava	annual	x	t/i	high
					u,v,w,z	t/i	moderate
		secondary	cowpea	major first	x	t/i	high
					w,z	t/i	moderate
				second	x,w	t/i	high
					z	t/i	moderate
					u	t	moderate
	not preferred	primary	sweet potato	major first	x	t/i	high
					w,z	t/i	moderate
				second	x,w,z	t/i	moderate
		secondary	soybean	major first	x	t	high
					w,z	t/i	moderate
				second	x	t/i	high
					w,z	t/i	moderate
					u	t	moderate
			pigeon pea	annual	u,w,x,y,z	t/i	moderate
XI	preferred	primary	maize	major first	&	t/i	moderate
			yam	major first, second	&	t/i	moderate
			cassava	annual	&	t/i	moderate
		secondary	cowpea	major first	&	t/i	moderate
	not preferred	primary	sweet potato	major first, second	&	t/i	moderate
		secondary	soybean	major first, second	&	t/i	moderate
			pigeon pea	annual	&	t/i	moderate

moderate values; those of sweet potato are rather low, while those of the grain legumes (cowpea, soybean and pigeon pea) are the lowest.

Very remarkable is that the traditional management level is the best for all four groups, except for maize on units *t*, *w*, *z*, *x* and *&*; in those cases, the best management level is to be found according to Table 9.13. An increase of the ecological suitability of crops has to be found by other means such as breeding, plant protection, irrigation, and by a more effective application of fertilizers. Although the emphasis in this study has been placed on the hydromorphic soils, the evaluation reveals that the most suitable land use on the upper part of the lower slope and upper slope positions, apart from the least preferred crops, is almost identical with the current land use. It may be stated, therefore, that the land use potential of hydromorphic and adjacent land was studied in the context of the present conditions.

A management level of a higher order, with more and probably costlier improvements than those of the improved management level discussed in this study, would cause difficulties in evaluation. Many experiments still have to be done not only to find out what influence other improvements have on the yield of crops, but also their influence on the land qualities. Apart from significant changes in land qualities, improvements of a higher order than the ones in this study will certainly include additional improvements as found in modern agricultural areas. These improvements have a complex influence on the yield level. A great variation in yield due to management can be expected: for example, the effect of fertilizer application depends on the type and quality of the fertilizer, the time and method of application and the period between the last weeding and the application. It will be necessary, therefore, to define such higher management levels in a detailed way.

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Appendix A. Range in characteristics of the nine (1-9) map units of the soil survey in the Westbank area, IITA (total surface 39.1 ha; for each map unit the surface of each drainage phase is given).

Map unit 1. An often thin (5-10 cm) very dark grey to dark brown, in recent depositions often yellowish-red, sandy loam to clay surface soil covers grey to very dark greyish-brown sandy clay loam to clay, sometimes interlayered with thin sandier layers, on better drained places with brownish yellow mottles and few to many concretions. Below 50 cm depth several layers of different textures occur with a bluish-grey or grey colour (very poorly drained 0.55 ha, poorly drained 0.85 ha).

Map unit 2. A thin (10-20 cm) black to dark brown loamy sand to sandy loam surface soil covers a dark grey to brown loamy sand to sandy loam subsurface horizon with few to common yellowish-brown mottles. Light grey to pale brown sand to sandy loam, occasionally gravelly, with yellowish-brown to brownish-yellow mottles occurs underneath. Below 50 cm depth, but not deeper than 1 m, heavier textures up to sandy clay or clay occur with bluish-grey, grey to pale brown matrix colours, prominent brownish-yellow to yellowish-red mottles and containing few to common gravels and concretions (very poorly drained 0.04 ha, poorly drained 1.02 ha, imperfectly drained 0.57 ha).

Map unit 3. A thin (5-10 cm) black to dark brown and, in recent depositions, reddish-brown loamy sand to sandy loam surface soil covers a grey to dark yellowish-brown loamy sand to sandy clay loam subsurface horizon, which may have yellowish-brown mottling. Below 20 cm depth textures range from sand to sandy clay loam. The special characteristic of this unit is the absence of a clayey texture within 1 m depth. In the subsoil colours differ from grey to brown, usually with reddish-yellow to yellowish-brown mottles, increasing with depth (very poorly drained 0.08 ha, poorly drained 0.35 ha, imperfectly drained 0.51 ha).

Map unit 4. This map unit occurs in all drainage phases and therefore has a wide range of characteristics. The poorly and very poorly drained soils in this unit have a thin (5-10 cm) black to dark brown sandy loam surface soil covering a grey to dark greyish-brown sand to sandy loam subsurface horizon. Below 20 cm depth, sand to loamy sand, and occasionally over a depth of less than 20 cm within 1 m sandy loam occurs with bluish-grey, dark grey to light yellowish-brown matrix colours and yellowish-brown to brownish-yellow mottles. Few to common concretions are found in the subsoil. The better drained soils in this unit have a thin (5-10 cm) very dark greyish-brown to brown loamy sand to sandy loam surface soil, which covers dark brown to dark yellowish-brown sand to loamy sand. Below 20 cm depth the same textures as in the poorly drained soils of this unit occur, but the matrix colours range from light brownish-grey to dark yellowish-brown with dark yellowish-brown to brownish or reddish-yellow mottles. Concretions are present in small quantities below 50 cm depth (very poorly drained 0.29 ha, poorly drained 3.07 ha, imperfectly drained 3.56 ha, moderately well and well drained 2.31 ha).

Map unit 5. In this map unit a thin (about 5 cm) dark brown loamy sand to sandy loam surface soil covers brown loamy sand. Below 20 cm depth loamy sand to sandy loam textures occur with occasionally, in small parts of the profile, sandy clay loam. The colour can be brown to strong brown (in the 7.5 YR hue), but also brownish-yellow or yellowish-red.

There are hardly any gravels or concretions (only well drained).

Map unit 6. A thin (5 cm) very dark grey to dark yellowish-brown loamy sand to sandy loam surface soil covers a very dark greyish-brown to dark yellowish brown loamy sand subsurface horizon. The main characteristic of this map unit is the very frequent occurrence of concretions starting from a depth of 30 to 80 cm depth, which vary within short distances. The concretions are partly cemented. The soil material in between has a loamy sand to sandy loam texture, usually increasing somewhat with depth and has several colours ranging from yellowish-brown to yellowish-red. Below the concretionary horizon the texture may be as heavy as sandy clay (imperfectly drained 0.88 ha, moderately well and well drained 5.72 ha).

Map unit 7. A thin (5-10 cm) very dark greyish-brown to dark yellowish-brown loamy sand to sandy loam surface soil covers strong brown, dark yellowish-brown to reddish-brown (often in the 5 or 7.5 YR hue) loamy sand to sandy loam. The texture is increasingly heavier with depth up to sandy clay loam, while the colour becomes more reddish (reddish-brown to yellowish-red or red). Between 25 and 80 cm depth the soil is gravelly to very gravelly, mainly quartz gravels and some concretions (only well drained).

Map unit 8. A thin (5-10 cm) very dark greyish-brown to dark yellowish-brown loamy sand to sandy loam surface soil covers very dark greyish, strong, reddish or yellowish-brown loamy sand. The texture increases in heaviness with depth up to sandy clay loam and has dark to strong or reddish-brown to yellowish-red colours. Strong brown to yellowish-red clay occurs within 25 to 80 cm depth, often with reddish and yellow spots, which continue up to the saprolitic material (only well drained).

Map unit 9. A thin very dark greyish-brown to dark reddish-brown loamy sand to sandy clay loam surface soil (sandy clay loam if eroded) covers a greyish-brown to dark reddish-brown slightly gravelly sandy loam to sandy clay loam subsurface horizon. Below this horizon and up to *in situ* weathered material (usually at a depth of 75-150 cm) a (very) gravelly horizon exists with a dark reddish-brown to yellowish-red colour and a sandy clay loam to clay texture. The gravels mainly consist of subrounded and angular quartz gravels, occasionally mixed with some concretions. In some places a 5-10 cm thick stoneline was observed at a depth of 10-30 cm. Below the gravelly layer, multi-coloured clay often with a yellowish-red or red matrix with yellow spots occurs, which is *in situ* weathered material. This clayey material may contain some gravel of varying composition (mainly quartz, but also feldspar or partly weathered rock pieces) (only well drained).

Appendix B, profile descriptions (the methods used for the analytical data can be found in appendix C).

Profile no. 1, map unit 9, G, IITA no. 55.
Name: Iwo series.
Soil classification: Oxic Paleustalf (USDA), Ferric Luvisol (FAO), Sol ferrallitique faiblement desaturé, remanié, faiblement rajeuni ou pénévolué (CPCS).
Family: clayey, kaolinitic, isohyperthermic.
Date examination: 8 February 1973 by F.R. Moormann and E. Chijioke.
Location: 7°29'N, 3°53'E, Ibadan, Nigeria; IITA-site, Westbank area, at CP 108.
Elevation: 223 m.
Landform: upper convex slope on side of small plateau; topography is rolling with V-shaped valleys in a trellis pattern.
Slope: 4 per cent south, long straight slightly convex across the slope.
Vegetation: neglected cocoa grove, now secondary forest with oil palms.
Parent material: gravelly slope colluvium over weathered banded gneiss with a biogenetic surface layer of less than 20 cm.
Drainage: well drained.
Moisture conditions: dry surface layers; slightly moist subsoil.
Groundwater: none at less than 2 m throughout the year.
Biological activity: many earthworm casts on the surface.
General aspect: deep reddish clayey soil with a sandier brownish surface soil and a distinct gravelly layer.
Profile description:

A_1 0-12 cm; dark brown (7.5 YR 3/2 moist, 7.5 YR 5/2 dry); sandy loam; moderate fine crumb structure; slightly hard; many fine interstitial pores, common fine tubular pores; many fine, common medium roots; clear wavy boundary.

A_3 12-20 cm; dark reddish-brown (5YR 3/3 moist, 5 YR 5/3 dry); slightly gravelly sandy (clay) loam; weak fine subangular blocky; slightly hard; many fine tubular pores; common fine and medium roots; clear smooth boundary.

IIB_1 20-42 cm; yellowish-red (5YR 4/6); very gravelly sandy clay loam; moderate fine subangular blocky; slightly sticky, slightly plastic, hard; thin patchy cutans; many fine tubular pores, some larger voids; subangular quartz gravels, some quartz stones (8-10 cm); common fine subrounded iron-manganese concretions; common fine roots; gradual smooth boundary.

IIB_2t 42-92 cm; yellowish-red (5YR 4/6); gravelly clay; moderately strong fine subangular blocky; slightly sticky, slightly plastic, hard; moderately thick broken cutans; many fine random tubular pores; subangular quartz gravels, usually less than 1 cm diameter; common fine subrounded iron-manganese concretions; common fine roots; clear wavy boundary.

$IIIB_2t$ 92-117 cm; yellowish-red (5YR 4/6); common fine and medium faint mottles, both darker and lighter than matrix; gravelly clay; moderately strong fine subangular blocky; slightly plastic, firm; moderately thick broken cutans; common fine tubular pores; fine angular quartz gravels, locally a tilted angular quartz vein, descending in the underlying horizons; fine, soft, to slightly hard iron-manganese concretions; common fine roots;

gradual wavy boundary.

$IIIB_3$ 117-160/180 cm; multi-coloured with yellowish-red (5 YR 4/6) matrix; many fine and medium distinct mottles, mainly reddish-yellow (weathered feldspar), red and black soft iron-manganese concretions; slightly gravelly clay; moderate fine and medium angular and subangular blocky; slightly sticky, slightly plastic, firm; moderately thick broken cutans; common fine tubular pores; fine quartz gravels; some saprolite, increasing in size and number with depth; few fine roots; gradual wavy boundary.

IIIC 160/180+ cm; multi-coloured with strong brown (7.5 YR 4/4) matrix; many medium and coarse distinct reddish and yellowish mottles; slightly gravelly sandy clay; saprolite with faint rock structure, increasing with depth; moderate medium subangular blocky in non-saprolite material; firm (friable in saprolitic material); moderately thick patchy cutans in matrix; common fine tubular pores; few fine quartz gravels; few soft iron-manganese concretions; many very fine mica flakes; few fine roots.

Table B-1. Analytical data of profile no. 1, map unit 9, Oxic Paleustalf.

horizon	A_1	A_3	IIB_1	IIB_2t	$IIIB_2t$	$IIIB_3$	IIIC
depth (cm)	0-12	12-30	20-42	42-92	92-117	117-160/180	160/180+
0-2 μ (per cent)	16	21	35	55	55	49	38
2-20 μ (per cent)	18	8	8	8	12	14	15
20-2000 μ (per cent)	66	71	57	37	33	37	47
> 2 mm (per cent)	3	9	54	44	23	19	20
bulk density (g/cm^3)	1.09	1.36	nd	1.38	1.49	1.43	nd
$pH(H_2O)$	6.2	6.2	6.0	6.0	5.9	6.1	6.2
pH(KCL)	5.5	5.4	5.2	5.3	5.4	5.6	5.7
org. C (per cent)	2.08	0.77	0.58	0.45	0.48	0.57	0.33
exch. Ca (me/100 g)	6.19	3.09	2.50	3.39	3.29	3.39	2.79
exch. Mg (me/100 g)	3.37	1.60	1.53	1.23	1.20	1.30	1.14
exch. K (me/100 g)	0.41	0.22	0.18	0.22	0.16	0.13	0.11
exch. Na (me/100 g)	0.15	0.14	0.14	0.15	0.14	0.14	0.14
exch. Mn (me/100 g)	0.57	0.27	0.40	0.22	0.13	0.04	0.05
exch. acidity (Al+H) (me/100 g)	0.10	0.06	0.04	0.05	0.05	0.05	0.04
sum of cations (me/100 g soil)	10.79	5.38	4.79	5.26	4.97	5.05	4.27
(me/100 g clay)	67	26	14	10	9	10	11
base saturation (per cent)	99	99	99	99	99	99	99

Profile no. 2, map unit 7, FG 1, IITA no. 65.

Name: Ibadan series.

Soil classification: Oxic Plinthustalf (USDA), Ferric Luvisol (FAO), Sol ferrallitique faiblement desaturé remanié (CPCS).

Family: loamy-skeletal, kaolinitic, isohyperthermic.

Date examination: 5 May 1973 by F.R. Moormann.

Location: 7°29'N, 3°53'E, Ibadan, Nigeria; IITA-site, Westbank area, at CP 109.

Elevation: 213 m.

Landform: regular middle slope between small plateau and valley.

Slope: 4 per cent south-west, almost straight across and along the slope.

Vegetation: thicket, at least five years old after shifting cultivation; some larger trees and oil palms.

Parent material: slope colluvium, gravelly in lower part, over colluviated gravel, with sedentary weathered banded gneiss in the subsoil.

Drainage: well to moderately well drained, some impedance on clayey subsoil.

Moisture conditions: moist to about 60 cm depth after rains, subsoil dry.

Groundwater: not observed; deeper than 1.5 m in the rainy season.

General aspect: deep soil with brownish sandy upper part and gravelly, clayey mottled subsoil, with continuous plinthite and hardened Fe/Mn-concretions.

Profile description:

A_1 0-12 cm; dark greyish-brown (7.5-10 YR 4/2); loamy sand; moderate fine crumb structure; very friable; many fine interstitial and tubular pores; abundant fine and common medium roots; clear smooth boundary.

A_3 12-32 cm; dark brown (7.5 YR 4/4); coarse sandy loam; weak fine subangular blocky, crumb in spots; very friable; common fine interstitial pores, many fine tubular pores; few small (0.5-1 cm) subrounded quartz gravels; many fine and common medium roots; gradual smooth boundary.

B_1 32-60 cm; dark brown to reddish-brown (5-7.5 YR 4/4); slightly gravelly coarse sandy loam; moderate fine subangular blocky; friable; thin patchy cutans, more distinct in pores; many fine tubular pores; few subrounded quartz gravels, some larger gravels (3-5 cm); many fine and common medium roots; clear wavy boundary.

B_2tcn 60-71 cm; yellowish-red (5 YR 5/6); very gravelly sandy clay loam; moderate fine subangular blocky; friable; moderately thick broken cutans on peds, more distinct in pores; many fine tubular pores; 50 per cent subrounded quartz gravels, mainly between 0.5 and 2 cm; 50 per cent iron-manganese moderately soft to hard, mainly reddish and some black concretions; common fine roots; clear wavy boundary.

IIB_2t 71-105 cm; yellowish-red (5 YR 5/6); many fine and medium distinct diffuse and clear yellowish-brown and strong brown mottles in a reticulate pattern; very gravelly sandy clay loam; moderate fine subangular blocky; hard; moderately thick broken cutans on peds, more distinct in pores; common fine tubular pores; many angular and subrounded quartz (0.5-5 cm) gravels and common fine reddish and blackish concretions; patches of weathered feldspar; few fine roots; clear gradual boundary.

IIIBC 105-150 cm; yellowish-red (5YR 4/6); many fine and medium distinct, mainly red and dark yellowish-brown, some pale brown (weathered feldspar) mottles; gravelly sandy clay loam; weak coarse angular blocky; hard; thin patchy cutans; many fine angular quartz gravels; common fine reddish and blackish concretions, which are softer than in previous horizons; friable weathered feldspar.

Table B-2. Analytical data of profile no. 2, map unit 7, Oxic Plinthustalf.

horizon	A_1	A_3	B_1	B_2tcn	IIIB_2t	IIIBC
depth (cm)	0-12	12-32	32-60	60-71	71-105	105-150
0-2 μ (per cent)	12	14	12	22	22	24
2-20 μ (per cent)	7	15	10	6	9	11
20-2000 μ (per cent)	81	71	78	72	69	65
> 2 mm (per cent)	9	14	23	60	69	50
bulk density (g/cm^3)	1.15	1.48	1.51	1.65	1.70	nd
pH(H_2O)	6.0	5.8	5.7	5.7	5.9	6.0
pH(KCl)	5.3	4.2	4.6	4.8	5.3	5.7
org. C (per cent)	1.50	0.46	0.30	0.30	0.30	0.27
exch. Ca (me/100 g)	1.10	0.70	0.78	1.24	1.82	4.04
exch. Mg (me/100 g)	0.49	0.23	0.14	0.26	0.43	0.46
exch. K (me/100 g)	0.13	0.08	0.05	0.06	0.06	0.05
exch. Na (me/100 g)	0.21	0.19	0.17	0.21	0.21	0.21
exch. Mn (me/100 g)	0.03	0.06	0.04	0.02	0.01	0.00
exch. acidity (Al+H) (me/100 g)	0.10	0.18	0.18	0.09	0.08	0.04
sum of cations						
(me/100 g soil)	2.06	1.44	1.36	1.88	2.61	4.80
(me/100 g clay)	17	10	11	9	12	20
base saturation (per cent)	95	88	87	95	97	99

Profile no. 3, map unit 4, Dd4, IITA no. 140.

Name: Apomu series.

Soil classification: (Aquic) Ustorthent (USDA), Eutric Gleysol (FAO), Sol peu évolué non climatique d'apport colluvial hydromorphe (CPCS).

Family: sandy, mixed, isohyperthermic.

Date of examinations: 16 May 1975 by W.J. Veldkamp.

Location: $7^{o}29'$N, $3^{o}53'$E, Ibadan, Nigeria; IITA-site, Westbank area, 150 m north-west of CP 102.

Elevation: 211 m.

Landform: convex to straight middle slope; undulating topography.

Slope: 6-8 per cent south, sloping.

Vegetation: thicket with some oil palms.

Parent material: sandy colluvial material.

Drainage: moderately well drained, rapid permeability in upper 1.5 m, medium permeability below.

Moisture conditions: moist throughout.

Groundwater: at time of observation groundwater was deeper than 1.8 m; most of the time there is no groundwater within 2 m depth, only at the height of the rainy season impedance on the deep clayey subsoil occurs with a probable rise of groundwater up to 70 cm depth.

General aspect: deep moderately well drained yellowish-brown sandy soil covering at 1.5 m clayey material.

Profile description:

A_1 0-18 cm; dark brown (10 YR 3/3); loamy coarse sand; weak fine subangular blocky to medium crumb structure; very friable; many very fine and fine tubular pores, many fine, common medium and few coarse interstitial pores; frequent very fine and fine, few medium and coarse roots; clear wavy boundary.

AC 18-40 cm; dark yellowish-brown (10 YR 4/4); loamy coarse sand; very weak fine subangula blocky; loose; common very fine and fine tubular pores, common fine and few medium interstitial pores; common very fine and fine roots; many medium oil palm roots; clear wavy boundary.

C_1 40-70 cm; yellowish-brown (10 YR 5/6); loamy coarse sand; very weak fine to medium subangular blocky; very friable; common very fine and fine tubular pores, few fine interstitial pores; few very fine and very few medium roots; gradual wavy boundary.

C_2g 70-102 cm; light yellowish-brown (10 YR 6/4); many medium and coarse diffuse distinct yellowish-brown mottles; loamy coarse sand; weak fine angular blocky; friable; few very fine and fine tubular pores, common fine interstitial pores; very few fine, medium and coarse roots; gradual wavy boundary.

C_3g 102-150 cm; very pale brown (10 YR 7/3); many coarse diffuse faint brownish-yellow anc common medium clear distinct yellowish-brown mottles; coarse sandy loam; weak fine and medium angular blocky; very friable; few fine interstitial pores; very few fine and mediur roots; gradual wavy boundary.

C_4g 150+ cm (boring): slightly gravelly sandy clay loam.

Table B-3. Analytical data of profile no. 3, map unit 4, (Aquic) Ustorthent.

horizon	A_1	AC	C_1	C_2g	C_3g	C_4g
depth (cm)	0-18	18-40	40-70	70-102	102-150	150+
0-2 μ (per cent)	6	6	8	8	16	36
2-20 μ (per cent)	12	8	8	8	8	10
20-2000 μ (per cent)	82	86	84	84	76	54
> 2 mm (per cent)	0	4	18	10	44	36
bulk density (g/cm^3)	1.08	1.39	1.52	1.60	nd	nd
pH(H_2O)	6.4	6.2	5.9	6.0	6.0	6.0
pH(KCl)	5.2	4.6	4.3	4.6	4.8	4.3
org. C (per cent)	1.60	0.34	0.14	0.06	0.10	0.14
exch. Ca (me/100 g)	3.59	0.92	0.56	0.35	1.20	4.59
exch. Mg (me/100 g)	1.22	0.40	0.21	0.23	0.53	2.90
exch. K (me/100 g)	0.19	0.06	0.07	0.02	0.04	0.06
exch. Na (me/100 g)	0.13	0.12	0.11	0.11	0.12	0.28
exch. Mn (me/100 g)	0.07	0.09	0.04	0.02	0.02	0.02
exch. acidity (Al+H) (me/100 g)	0.04	0.08	0.24	0.04	0.08	0.20
sum of cations						
(me/100 g soil)	5.24	1.67	1.23	0.77	1.98	8.05
(me/100 g clay)	87	28	15	10	12	22
base saturation (per cent)	99	95	80	95	96	98

Profile no. 4, map unit 6, Ed3, IITA no. 144.

Name: Gambari series.

Soil classification: Oxic Haplustalf (USDA), Ferric Luvisol (FAO), Sol ferrallitique faiblement desaturé typique induré (CPCS).

Family: loamy-skeletal, mixed, isohyperthermic, shallow.

Date of examination: 13 May 1975 by W.J. Veldkamp.

Location: 7°29'N, 3°53'E, Ibadan, Nigeria; IITA-site, Westbank area, 75 m north-east of CP 110.

Elevation: 207 m.

Landform: convex to straight lower slope; undulating topography.

Slope: 4-5 per cent south-west, gently sloping.

Vegetation: thicket with grasses; no oil palms or other trees; probably in use 6-7 years ago.

Parent material: sandy and loamy very concretionary colluvial material and *in situ* weathered clayey material, probably derived from banded gneiss.

Drainage: moderately well drained, rapid permeability above the clayey subsoil.

Moisture conditions: moist; below 1 m depth wet.

Groundwater: at time of observation 1.3 m; maximum rise probably 1 m.

Human influence: pieces of charcoal in relatively thick A-horizon.

General aspect: deep, moderately well drained brown very concretionary sandy soil covering at 1.2 m depth *in situ* weathered clayey material.

Profile description:

A_1 0-24 cm; brown (10 YR 4/3); loamy sand; weak fine and medium subangular blocky; very friable; many very fine and fine and common medium interstitial pores, common fine tubular pores; frequent very fine, common fine, few medium and very few coarse roots; clear smooth boundary.

A_3 24-36 cm; dark yellowish-brown (10 YR 4/4); slightly gravelly loamy coarse sand; weak fine subangular blocky; very friable; many very fine, common fine and few medium interstitial pores, few fine tubular pores; very few very small and small rounded quartz gravels; few hard ironstone concretions; common very fine, few fine and medium and very few coarse roots; clear wavy boundary.

IIB_1cn 36-73 cm; brown (7.5 YR 5/4); very gravelly loamy coarse sand; very weak fine subangular blocky; very friable; moderately thick patchy cutans; many very fine and fine tubular pores, many fine and few medium interstitial pores; very frequent small and large hard knobbly ironstone concretions; very few small (0.2-0.5 cm) angular quartz gravels; weakly cemented; few very fine and very few fine, medium and coarse roots; gradual irregular boundary.

$IIB_{21}tcn$ 73-106 cm; brown (7.5 YR 4/4); very gravelly coarse sandy loam; very weak medium subangular blocky; very friable; thick broken cutans; many fine, common medium and few coarse interstitial pores; very frequent small and large hard knobbly ironstone concretions; very few small angular quartz gravels; weakly cemented; few very fine and very few fine roots; clear wavy boundary.

$IIB_{22}tcn$ 106-124 cm; brown (7.5 YR 4/4); common fine clear distinct yellow mottles; very gravelly sandy clay loam; moderate fine angular blocky; sticky, plastic; thick continuous cutans; few fine, medium and coarse interstitial pores; dominant small and large hard knobbly ironstone concretions; very few quartz gravels; moderately cemented; few very fine and very few fine roots; clear wavy boundary.

$IIIC_1g$ 124+ cm; light brown (7.5 YR 6/4); many fine diffuse distinct yellow and many medium and coarse clear prominent red mottles; gravelly sandy clay loam; strong fine and medium angular blocky; sticky, plastic; thick continuous cutans; few fine interstitial pores; frequent small quartz gravels.

$IIIC_2g$ 190+ cm; weathered rock.

Table B-4. Analytical data of profile no. 4, map unit 6, Oxic Haplustalf.

horizon	A_1	A_3	IIB_1cn	$IIB_{21}tcn$	$IIB_{22}tcn$	$IIIC_1g$
depth (cm)	0-24	24-36	36-73	73-106	106-124	124+
0-2 μ (per cent)	10	10	13	18	25	32
2-20 μ (per cent)	9	9	4	7	11	12
20-2000 μ (per cent)	81	81	83	75	64	56
> 2 mm (per cent)	7	10	75	76	81	41
bulk density (g/cm^3)	1.16	1.47	1.55	1.60	nd	nd
$pH(H_2O)$	5.7	5.8	6.1	6.2	6.1	6.2
pH(KCl)	4.7	4.5	4.6	4.6	4.7	4.3
org. C (per cent)	0.60	0.46	0.32	0.36	0.40	0.34
exch. Ca (me/100 g)	2.00	1.80	2.00	2.79	3.79	6.00
exch. Mg (me/100 g)	0.61	0.46	0.30	0.72	1.48	2.83
exch. K (me/100 g)	0.09	0.07	0.07	0.08	0.08	0.07
exch. Na (me/100 g)	0.13	0.14	0.14	0.14	0.16	0.22
exch. Mn (me/100 g)	0.03	0.04	0.01	0.00	0.00	0.00
exch. acidity (Al+H) (me/ 100 g)	0.08	0.08	0.08	0.08	0.08	0.12
sum of cations (me/100 g soil)	2.94	2.59	2.60	3.81	5.59	9.24
(me/100 g clay)	29	26	20	21	22	29
base saturation (per cent)	97	97	97	98	99	99

Profile no. 5, map unit 3, Cdl, IITA no. 124.
Name: Ikire series.
Soil classification: (Typic) Tropaquent (USDA), Eutric Gleysol (FAO), Sol hydromorphe peu humifère à pseudogley à nappe perché (CPCS).
Family: loamy, mixed, isohyperthermic.
Date examination: 22 April 1975 by W.J. Veldkamp.
Location: 7°29'N, 3°53'E, Ibadan, Nigeria; IITA-site, Westbank area, 105 m west-north-west of CP 102.
Elevation: 208 m.
Landform: valley bottom; flat topography.
Slope: 1 per cent, flat.
Vegetation: secondary forest with oil palms and some bananas.
Parent material: sandy and loamy alluvial material, partly colluvial, probably covering at 2.5 m depth *in situ* weathered clayey material, derived from granitic or banded gneiss.
Drainage: poorly drained, rapid permeability; soil remains wet for a considerable part of the year during and somewhat after the rainy season.
Moisture conditions: soil is moist up to 1 m depth and downwards wet (after several rains).
Groundwater: at time of observation groundwater at 1.2 m; high groundwater in the rainy season with maximum rise up to the surface.
General aspect: deep poorly drained light greyish sandy and loamy soil; a thin loamy surface layer covers a sandy and a loamy layer and a sandy subsoil; the groundwater stagnates somewhat on the loamy layer.
Profile description:
A_1 0-4 cm; reddish-brown (5 YR 4/4); many fine clear faint reddish-grey mottles; coarse sandy loam; moderate very fine and fine subangular blocky; slightly sticky, slightly plastic, friable; many very fine and fine and few medium interstitial pores, common very fine and fine tubular pores; frequent very fine, common fine, few medium and very few coarse roots; clear wavy boundary.
C_1g 4-25/37 cm; light brownish-grey (10 YR 6/2); few fine diffuse yellowish-brown mottles; slightly gravelly coarse sandy loam; very weak fine and medium subangular blocky; loose; common very fine and fine interstitial pores, few very fine and fine tubular pores, few fine vesicular pores; very few very fine and fine, few medium and common coarse roots; very few small angular quartz gravels; clear irregular boundary.
C_2g 25/37-70 cm; grey (10 YR 6/1); many medium and coarse clear prominent strong brown and common fine and medium diffuse faint yellow mottles; slightly gravelly coarse sandy loam; weak coarse angular blocky; slightly sticky, slightly plastic, firm; common very fine and fine and few medium interstitial pores, few very fine tubular pores; very few very fine, fine and medium roots; clear wavy boundary.
C_3g 70-150 cm; light grey (10 YR 7/1); common fine clear distinct strong brown and few fine and medium diffuse faint very pale brown mottles; gravelly loamy coarse sand; single grain structure; loose; broken thin sesquioxide cutans in medium pores; common very fine and fine and few medium interstitial pores, common fine vesicular pores and few fine tubular pores; very few small angular quartz gravels; very few very fine, fine and medium roots; gradual wavy boundary.

CG_1 150-230 cm (boring); light grey (2.5 Y 7/1, wet); sand with very coarse sandy and gravelly layers.

CG_2 230+ cm (boring); grey (2.5 Y 6/1, wet); loamy coarse sand.

Table B-5. Analytical data of profile no. 5, map unit 3, (Typic) Tropaquent.

horizon	A_1	C_1g	C_2g	C_3g
depth (cm)	0-4	4-25/37	25/37-70	70-150
0-2 µ (per cent)	14	12	18	9
2-20 µ (per cent)	28	9	10	5
20-2000 µ (per cent)	58	79	72	86
> 2 mm (per cent)	0	12	9	26
bulk density (g/cm^3)	0.71	1.61	1.64	1.73
pH(H_2O)	5.1	6.2	5.8	6.0
pH(KCl)	4.2	5.0	4.4	4.5
org. C (per cent)	2.26	0.16	0.12	0.08
exch. Ca (me/100 g)	2.00	1.65	1.50	0.60
exch. Mg (me/100 g)	1.60	0.63	1.00	0.44
exch. K (me/100 g)	0.16	0.05	0.06	0.04
exch. Na (me/100 g)	0.40	0.25	0.44	0.28
exch. Mn (me/100 g)	0.07	0.01	0.02	0.06
exch. acidity (Al+H) (me/100 g)	0.40	0.12	0.08	0.04
sum of cations (me/100 g soil)	4.63	2.71	3.10	1.46
(me/100 g clay)	33	23	17	16
base saturation (per cent)	91	96	97	97

Profile no. 6, map unit 2, Adl, IITA no. 130.

Name: Ikire series.

Soil classification: (Typic) Tropaquent (USDA), Eutric Gleysol (FAO), Sol hydromorphe peu humifère à pseudogley à nappe perché (CPCS).

Family: loamy, mixed, isohyperthermic.

Date examination: 16 April 1975 by W.J. Veldkamp.

Location: 7°29'N, 3°53'E, Ibadan, Nigeria; IITA site, Westbank area, 50 m south-west of CP 102, 15 m from stream.

Elevation: 206 m.

Landform: valley bottom; flat topography.

Slope: 1-2 per cent south-west, almost flat.

Vegetation: secondary forest with bamboo, oil palms and a few cocoa and cola trees; few shrubs in lower storey.

Parent material: sandy and loamy alluvial material, covering at 65 cm *in situ* weathered clayey material probably from granitic gneiss; saprolitic material at 1.7 m depth.

Drainage: poorly drained, rapid permeability in upper horizons; soil remains wet for a considerable part of the year during and somewhat after the rainy season.

Moisture conditions: dry surface layer, the rest of the profile is moist (after a drought period of one week).

Groundwater: at time of observation the groundwater was deeper than 2 m, but in the rainy season high groundwater levels occur with a maximum rise up to 0/10 cm depth.

General aspect: deep light greyish sandy soil with a clayey subsoil; thin organic matter rich surface soil contains many bamboo roots.

Profile description:

A_{11} 0-6 cm; very dark greyish-brown (10 YR 3/2 moist, 10 YR 4/2 dry); coarse sandy loam; moderate fine and medium crumb structure; slightly sticky, slightly plastic, friable, slightly hard; many very fine and fine, few coarse tubular pores, common medium interstitial pores; few wormcasts on surface; abundant very fine, frequent fine, few medium and very few coarse roots, mainly bamboo roots; clear smooth boundary.

A_{12} 6-10 cm; brown (10 YR 5/3); slightly gravelly coarse sandy loam; weak fine subangular blocky; very friable; common very fine and medium tubular pores; frequent very fine, common fine, few medium and coarse roots, mainly bamboo roots; clear wavy boundary.

C_1 10-25 cm; light grey (10 YR 7/1); slightly gravelly loamy coarse sand; weak fine subangular blocky; very friable; many very fine and fine, few medium tubular pores; frequent very fine, common fine, few medium and coarse roots; gradual wavy boundary.

C_2g 25-65 cm; white (10 YR 8/1); many coarse diffuse distinct brownish-yellow and many coarse common medium clear prominent strong brown mottles; slightly gravelly loamy coarse sand; weak medium and coarse subangular blocky; friable; common very fine and fine tubular pores, common fine interstitial pores; very few small hard irregular reddish-brown ironstone concretions; few fine and very few fine and medium roots; clear wavy boundary.

IIC_3g 65-95 cm; grey (10 YR 6/1); many medium diffuse faint yellowish-brown and many sharp prominent strong brown mottles; gravelly sandy clay loam; weak coarse angular blocky; sticky, plastic, very firm; patchy moderately thick cutans; common very fine tubular pores, few fine interstitial pores; very few irregular quartz gravels; few small hard irregular ironstone concretions; very few small hard spherical iron-manganese concretions; very few very fine and fine roots; gradual wavy boundary.

IIC_4g 95-170 cm; grey (10 YR 6/1); many medium sharp prominent strong brown mottles; slightly gravelly sandy clay; moderate coarse angular blocky; sticky, very plastic, extremely firm; patchy moderately thick cutans; few very fine and very few fine tubular pores, very few fine interstitial pores; few irregular quartz and weathered feldspar gravels; very few small hard ironstone concretions; very few very fine and fine roots.

IIC_5g 170+ cm (boring); weathered rock.

Table B-6. Analytical data of profile no. 6, map unit 2, Typic Tropaquent.

horizon	A_{11}	A_{12}	C_1	C_2g	IIC_3g	IIC_4g
depth (cm)	0-6	6-10	10-25	25-65	65-95	95-170
0-2 μ (per cent)	8	10	6	8	26	39
2-20 μ (per cent)	34	19	12	10	8	7
20-2000 μ (per cent)	58	71	82	82	66	54
> 2 mm (per cent)	12	6	5	11	16	12
bulk density (g/cm^3)	0.90	nd	1.61	1.61	1.81	nd
pH(H_2O)	5.8	5.5	5.9	6.2	6.9	7.7
pH(KCl)	5.2	4.5	5.0	4.9	5.3	6.1
org. C (per cent)	3.70	0.76	0.10	0.10	0.12	0.10
exch. Ca (me/100 g)	7.19	1.80	0.62	0.62	3.59	5.89
exch. Mg (me/100 g)	2.83	0.72	0.23	0.20	2.27	4.85
exch. K (me/100 g)	0.32	0.15	0.05	0.01	0.04	0.05
exch. Na (me/100 g)	0.28	0.14	0.14	0.14	0.49	0.98
exch. Mn (me/100 g)	0.04	0.01	0.00	0.01	0.00	0.00
exch. acidity (Al+H) (me/100 g)	0.12	0.10	0.10	0.04	0.04	0.04
sum of cations (me/100 g soil)	10.78	2.92	1.14	1.02	6.43	11.81
(me/100 g clay)	135	29	19	13	25	30
base saturation (per cent)	99	97	91	96	99	100

Profile no. 7, map unit 1, Bd2, IITA no. 57.

Name: Adio series.

Soil classification: Aeric Tropaqualf (USDA), Eutric Gleysol (FAO), Sol hydromorphe peu humifère à pseudogley à nappe perché (CPCS).

Family: loamy, mixed, isohyperthermic.

Date examination: 12 February 1973 by F.R. Moormann and E. Chijioke.

Location: 7°29'N, 3°53'E, Ibadan, Nigeria; IITA site, Westbank area, at CP 110.

Elevation: 204 m.

Landform: valley bottom, locally wider valley, which is V-shaped both up and downstream; the local topography is flat in surroundings with a rolling topography.

Slope: 1 per cent south-east, straight slope.

Vegetation: secondary forest with oil palms, big trees and shrubs, but no grass in lower storey.

Parent material: colluvial and alluvial materials covering at about 1 m depth *in situ* weathered clayey material, probably from banded gneiss; saprolite material at 1.6 m depth.

Drainage: poorly drained, slow permeability; soil remains wet for a considerable part of the year during and after the rainy season.

Moisture conditions: dry surface layers, moist subsoil.

Groundwater: high groundwater level after the start of the rains, no free groundwater at less than 2 m at time of observation; the absence of groundwater in the dry season is probably due to the presence of the forest; under cleared conditions similar depressions are known to have groundwater during most of the dry season.

Biological activity: numerous wormcasts on the surface.

General aspect: deep greyish mottled clayey profile with sandy brown surface layer.

Profile description:

A_1 0-10 cm; dark greyish-brown (10 YR 3/2 moist, 10 YR 5/2 dry); sandy loam; moderate fine and medium crumb structure; soft; many fine and medium interstitial pores, common fine tubular pores; many fine, common medium and some coarse roots; gradual smooth boundary.

A_3 10-30 cm; brown (10 YR 4/3 moist, 10 YR 5/3 dry); few fine and medium strong brown mottles; slightly gravelly coarse sandy loam; weak fine and medium subangular blocky; hard; common fine tubular pores; common fine and medium roots; gradual wavy boundary.

B_1 30-45 cm; brown (10 YR 4/3 moist, 10 YR 6/3 dry); many medium faint and few fine distinct yellowish brown mottles; slightly gravelly sandy loam; moderate fine subangular blocky; many fine tubular pores; common fine and medium roots; in this horizon slightly greyer streaks can be observed accompanying root-channels and in some cases forming ped surfaces; clear wavy boundary.

B_{21}tg 45-55 cm; greyish-brown (2.5 Y 5/2); many fine and medium distinct yellowish-brown mottles; slightly gravelly sandy clay loam; moderate fine subangular blocky; very hard; few patchy thin cutans in root-channels only; common fine tubular pores; iron-manganese concretions increasing with depth; common fine and few medium roots; clear wavy boundary.

B_{22}tg 55-80 cm; greyish-brown (2.5 Y 5/2) matrix with many fine and medium distinct and prominent yellowish-brown mottles; very gravelly sandy clay; moderately strong fine subangular blocky; extremely firm; broken thin cutans on many peds; distinct clay movement in root-channels and pores; few fine tubular pores; vertical cracks, 20 to 40 cm apart and less than 1 cm wide; many dark iron-manganese concretions, both soft and hard; some infiltration in vertical streaks of more humiferous material from upper horizon; gradual wavy boundary.

B_3g 80-103 cm; olive (5 Y 3/2); common fine and medium distinct brownish mottles, prominent in patches; gravelly sandy clay loam; moderate fine angular and subangular blocky; extremely firm; broken thin cutans on some peds, distinct clay movement in some pores; common soft to somewhat hardened subrounded blackish iron-manganese concretions; angular quartz fragments, usually less than 1 cm; few fine and medium roots; gradual wavy boundary.

IIC_1g 103-160 cm; light grey (10 YR 7/2); many medium promiment mainly yellowish-brown mottles, grouped in patches and streaks; gravelly sandy clay loam; moderate fine angular blocky; firm; no cutans visible on peds; few fine tubular pores; few soft subrounded blackish iron-manganese concretions; angular quartz fragments, usually less than 1 cm; few fine roots.

IIC_2g 160+ cm (boring); weathered rock.

Table B-7. Analytical data of profile no. 7, map unit 1, Aeric Tropaqualf.

horizon	A_1	A_3	B_1	B_{21}tg	B_{22}tg	B_3g	IIC_1g
depth (cm)	0-10	10-30	30-45	45-55	55-80	80-103	103-160
0-2 μ (per cent)	11	15	19	26	41	29	21
2-20 μ (per cent)	22	14	12	9	8	10	12
20-2000 μ (per cent)	67	71	69	65	51	61	67
> 2 mm (per cent)	0	3	4	15	57	22	26
bulk density (g/cm^3)	0.66	1.49	1.55	1.66	1.69	1.83	1.87
pH(H_2O)	5.8	5.9	5.5	5.7	6.5	6.8	6.9
pH(KCl)	5.3	5.0	4.2	4.5	5.2	5.3	5.2
org. C (per cent)	2.17	0.58	0.27	0.28	0.22	0.18	0.12
exch. Ca (me/100 g)	5.58	3.89	3.12	5.63	10.64	11.24	8.33
exch. Mg (me/100 g)	2.99	1.51	1.38	2.66	5.67	6.66	6.09
exch. K (me/100 g)	0.28	0.07	0.06	0.08	0.09	0.10	0.08
exch. Na (me/100 g)	0.18	0.15	0.15	0.49	0.55	0.71	1.00
exch. Mn (me/100 g)	0.50	0.20	0.11	0.09	0.01	0.01	0.00
exch. acidity (Al+H) (me/100 g)	0.15	0.04	0.08	0.08	0.08	0.04	0.02
sum of cations (me/100 g soil)	9.68	5.86	4.90	9.03	17.04	18.76	15.52
(me/100 g clay)	88	39	26	35	42	65	74
base saturation (per cent)	98	99	98	99	100	100	100

Profile no. 8, unit A, IITA no. 80.

Name: Alagba series.

Soil classification: Oxic Paleustalf (USDA), Eutric Nitosol (FAO), Sol ferralitique peu desaturé appauvri modal (CPCS).

Family: clayey, kaolinitic, isohyperthermic.

Date examination: 12 July 1973 by F.R. Moormann and P. Le Mare.

Location: $6^{o}50'$ N, $3^{o}41'$ E, Ikenne, Nigeria; IART station, near south-west corner of Block 27.

Elevation: 55 m.

Landform: gently undulating Pleistocene terrace.

Slope: 4 per cent south-west; the profile is situated on the lower part of a long straight slope.

Vegetation: dense re-growth of Eupatorium odoratum after clearing and several years of cultivation.

Parent material: weathered clayey sediments, uniform in lithology and texture to a depth of at least 4 m.

Drainage: well drained, rapid permeability; no visible impedance in any layer or horizon to depth of observation.

Moisture conditions: moist profile throughout; wet in upper 40 cm after heavy rains.

Groundwater: no groundwater at any time of the year to profile depth.

Biological activity: wormcasts on the surface; subterranean termite chambers, up to 15 cm in several places in the profile.

Human activity: pieces of pottery scattered through upper 50 cm.

General aspect: deep red clayey soil with sandy surface soil up to 30 cm.

Profile description:

A_1 0-13 cm; dark reddish-brown (5 YR 3/3); sandy loam; moderate fine crumb; slightly sticky, very friable; many fine and medium interstitial pores, common fine tubular pores; many fine and medium roots; gradual smooth boundary.

A_3 13-30 cm; dark reddish-brown (5 YR 3/4); sandy loam; weak medium subangular blocky, fine crumb in spots; slightly sticky, very friable; many fine and few medium tubular pores, common fine and medium interstitial pores; few large voids; many fine and common medium roots; gradual smooth boundary.

B_1 30-45 cm; dark reddish-brown (2.5 YR 3/4); sandy clay loam; weak to moderate fine subangular blocky; slightly sticky, slightly plastic, friable; patchy thin cutans in some ped surfaces, clear clay movement in larger pores; many fine, common medium tubular pores; common fine, few medium roots; gradual smooth boundary.

$B_{21}t$ 45-105 cm; dark red (2.5 YR 3/6); sandy clay; moderate fine subangular blocky; slightly sticky, plastic, firm; broken thin cutans on most peds, more distinct in pores; many fine tubular pores; few larger voids and channels; common fine and few medium roots; diffuse smooth boundary.

$B_{22}t$ 105-150+ cm; dark red (2.5 YR 3/6); sandy clay; moderate fine subangular blocky; slightly sticky, plastic, firm; broken thin cutans, locally moderately thick, very distinct clay movement in pores; common fine tubular pores, gradually diminishing; few faunal channels; few fine roots.

Table B-8. Analytical data of profile no. 8, unit A, Oxic Paleustalf.

horizon	A_1	A_3	B_1	$B_{21}t$	$B_{22}t$
depth (cm)	0-13	13-30	30-45	45-105	105-150+
0-2 μ (per cent)	13	16	31	45	36
2-20 μ (per cent)	15	4	4	2	18
20-2000 μ (per cent)	72	80	65	53	46
> 2 mm (per cent)	2	3	2	1	1
bulk density (g/cm^3)	1.24	1.46	1.57	1.64	1.73
pH(H_2O)	6.1	5.6	5.0	5.1	5.1
pH(KCl)	5.6	5.0	4.3	4.3	5.0
org. C (per cent)	1.56	0.70	0.44	0.30	0.22
exch. Ca (me/100 g)	5.36	1.82	1.42	1.60	1.87
exch. Mg (me/100 g)	2.89	0.72	0.68	0.57	0.49
exch. K (me/100 g)	0.25	0.04	0.03	0.04	0.06
exch. Na (me/100 g)	0.16	0.14	0.13	0.13	0.13
exch. Mn (me/100 g)	0.16	0.10	0.09	0.05	0.03
exch. acidity (Al+H) (me/100 g)	0.22	0.08	0.48	0.45	0.30
sum of cations (me/100 g soil)	9.04	2.90	2.83	2.84	2.88
(me/100 g clay)	70	18	9	6	8
base saturation (per cent)	98	97	75	84	90

Profile no. 9, unit B, IITA no. 69.

Name: Owode series.

Soil classification: Oxic Haplustalf (USDA), Ferric Luvisol (FAO), Sol ferralitique faiblement desaturé appauvri hydromorphe (CPCS).

Family: loamy, mixed, isohyperthermic.

Date examination: 31 May 1973 by F.R. Moormann and G. Murdoch.

Location: $6^{o}50'$ N, $3^{o}41'$ E, Ikenne, Nigeria; IART station, west of road to meteorological station, 450 m south of Adade bridge in block 33.

Elevation: 29 m.

Landform: upper part across a wide valley in a gently undulating terrace landscape; the profile is situated on a local weakly pronounced rise.

Slope: 1 per cent west, long gentle straight slope.

Vegetation: dense re-growth of Eupatorium odoratum and some shrubs after two years of monoculture of maize on completely cleared land.

Parent material: loamy material over clayey sediments of Tertiary or Secondary age, containing a few rounded weathered iron-sandstones at 50-75 cm.

Drainage: well drained; mottles in subsoil are probably fossile.

Moisture conditions; moist throughout, except sporadic superficial patches under old cultivation ridges.

Groundwater: no groundwater at time of observation; temporary groundwater in deeper mottled horizons during or immediately after peak of rainy season.

Human influence: surface soil shows the effect of deep mechanized ploughing in which the subsoil was mixed with the A-horizon and is visible as lighter coloured patches.

General aspect: deep reddish clayey profile with brownish loamy surface layers and strongly mottled lighter textured subsoil.

Profile description:

A_p 0-15/20 cm; very dark greyish-brown (10 YR 3/2); sandy loam; weak fine crumb; very friable; many fine tubular and interstitial pores; few faunal voids; charcoal fragments; many fine and few medium roots; clear wavy boundary.

A_3 15/20-55 cm; brown (10 YR 4/3 moist, 10 YR 6/3 dry); faintly mottled in lower part; sandy loam; weak fine and medium subangular blocky; very friable; many fine common medium tubular pores; few charcoal fragments; common fine roots diminishing with depth; clear smooth boundary.

$B_{21}t$ 55-90 cm; reddish-brown (5 YR 4/4); common fine faint and few fine distinct reddish mottles, increasing with depth; sandy clay loam; moderate fine subangular blocky; firm, very hard; thin broken cutans around most peds, locally moderately thick on vertical ped surfaces and pores; slight clay-humus infiltration along vertical ped surfaces with a chroma of 1 lower than matrix; many fine, common medium tubular pores; some faunal voids; common fine, few medium roots; gradual smooth boundary.

Table B-9. Analytical data of profile no. 9, unit B, Oxic Haplustalf.

horizon	A_p	A_3	$B_{21}t$	-	-	-
depth (cm)	0-15/20	15/20-55	55-90	90-120	120-175	175-190
0-2 μ (per cent)	14	38	33	33	25	13
2-20 μ (per cent)	12	18	9	13	2	14
20-2000 μ (per cent)	74	44	58	54	73	73
> 2 mm (per cent)	1	1	2	2	5	1
bulk density (g/cm^3)	1.34	1.45	1.85	1.76	1.82	nd
pH(H_2O)	7.7	6.9	6.5	6.6	5.2	5.0
pH(KCl)	7.2	6.1	5.5	5.7	4.3	4.0
org. C (per cent)	0.57	0.20	0.23	0.23	0.17	0.07
exch. Ca (me/100 g)	8.98	1.73	3.49	2.60	1.58	1.39
exch. Mg (me/100 g)	0.63	0.23	0.84	1.55	0.98	0.79
exch. K (me/100 g)	0.42	0.16	0.42	0.60	0.96	1.13
exch. Na (me/100 g)	0.18	0.11	0.13	0.13	0.13	0.11
exch. Mn (me/100 g)	0.09	0.02	0.01	0.01	0.02	0.03
exch. acidity (Al+H) (me/100 g)	0.00	0.00	0.00	0.01	0.32	0.84
sum of cations (me/100 g soil)	10.30	2.25	4.89	4.90	3.99	4.29
(me/100 g clay)	74	6	15	15	16	33
base saturation (per cent)	100	100	100	100	80	74

Profile no. 10, unit C, IITA no. 79.

Name: Atan series.

Soil classification: (Aquic oxic) Plinthustult (USDA), Plinthic Acrisol (FAO), Sol hydromorphe peu humifère à pseudogley à nappe perché (CPCS).

Family: loamy, mixed, ixohyperthermic.

Date examination: 11 June 1973 by F.R. Moormann and E. Chijioke.

Location: 6°50' N, 3°41' E, Ikenne, Nigeria; IART station, 25 m from meteorological station.

Elevation: 26 m.

Landform: middle part across a wide valley in a flat to gently undulating Pliocene-Pleistocene terrace landscape.

Slope: less than 1 per cent, generally south, long straight slope.

Vegetation: re-growth of Eupatorium odoratum on completely cleared land previously used for monoculture of maize; nearby young rubber plantation with poor growth.

Parent material: loamy material over clayey sediments of Tertiary or Cretacious age.

Drainage: imperfectly drained, slow permeability.

Moisture conditions: moist throughout.

Groundwater: no groundwater during most of the year, but saturation and temporary watertable during and immediately after peak of the rainy season at approximately 1 m or deeper.

General aspect: brownish sandy soil over increasingly prominently mottled greyish subsoil with plinthite.

Profile description:

A_p 0-20 cm; dark greyish-brown (10 YR 4/2); sandy loam; weak fine crumb on surface, structureless single grained below; very friable; common fine interstitial pores in upper part, common fine tubular pores below; many fine and common medium roots; clear wavy boundary.

A_3 20-38 cm; brown (10 YR 5/3); loamy sand to sandy loam; weak fine subangular blocky; very friable; many fine, common medium tubular pores; many fine and few medium roots; clear wavy boundary.

B_1 38-61 cm; brown (7.5 YR 5/4); common fine and medium faint mottles, somewhat redder than matrix and becoming more distinct with depth; sandy clay loam; moderate fine subangular blocky; slightly sticky, slightly plastic, firm; patchy thin cutans on many peds, more distinct in larger pores and root channels; clay-humus infiltration along old root or termite channels; many fine, common medium and few large tubular pores; common faunal voids up to 2 cm in diameter; many fine roots; clear wavy boundary.

B_2t 61-93 cm; brown (10 YR 5/3); strongly mottled with many fine and medium prominent sharp red mottles; sandy clay loam; moderate fine subangular blocky; slightly sticky, slightly plastic, firm; thin patchy cutans, more distinct in pores; clay-humus infiltration along old root or termite channels; many fine, few medium tubular pores; common faunal voids; common fine and few medium roots; gradual wavy boundary.

B_3 93-180+ cm; light brownish-grey (10 YR 6/2), matrix passing to grey (10 YR 6/1) with depth; many medium and coarse prominent sharp dark red mottles with browner fringes, which harden upon alternate wetting and drying (plinthite); slightly gravelly sandy clay; weak medium subangular blocky; slightly sticky, slightly plastic, firm; thin patchy cutans on some peds, more distinct in pores and root channels; some clay-humus infiltration along old root or termite channels; common fine tubular pores, diminishing with depth; few moderately hard Fe-concretions, usually less than 1.5 cm in diameter; common fine roots, diminishing with depth.

Table B-10. Analytical data of profile no. 10, unit C, (Aquic oxic) Plinthustult.

horizon	A_p	A_3	B_1	B_2t	B_3
depth (cm)	0-20	20-38	38-61	61-93	93-180
0-2 μ (per cent)	9	7	25	29	27
2-20 μ (per cent)	18	17	12	13	9
20-2000 μ (per cent)	73	76	63	58	64
> 2 mm (per cent)	1	3	3	4	10
bulk density (g/cm^3)	1.41	1.60	1.77	1.78	1.86
pH(H_2O)	5.7	5.3	4.7	4.6	4.8
pH(KCl)	5.1	4.3	3.8	3.8	3.8
org. C (per cent)	0.50	0.20	0.24	0.18	0.10
exch. Ca (me/100 g)	2.50	0.50	1.00	0.91	0.30
exch. Mg (me/100 g)	0.88	0.20	0.57	0.56	0.21
exch. K (me/100 g)	0.25	0.05	0.08	0.07	0.05
exch. Na (me/100 g)	0.18	0.13	0.16	0.15	0.16
exch. Mn (me/100 g)	0.08	0.03	0.00	0.00	0.00
exch. acidity (Al+H) (me/100 g)	0.14	0.19	1.30	1.59	2.59
sum of cations (me/100 g soil)	4.03	1.10	3.11	3.28	3.31
(me/100 g clay)	45	16	12	11	12
base saturation (per cent)	98	83	58	52	22

Profile no. 11, unit D, IITA no. 161.

Name: Oji series.

Soil classification: (Typic) Tropaquent (USDA), Dystric Gleysol (FAO), Sol hydromorphe peu humifère à gley peu profond (CPCS).

Family: loamy, mixed, isohyperthermic.

Date examination: 18 January 1977 by W.J. Veldkamp.

Location: 6°51'N, 3°41'E, Ikenne, Nigeria; IART station, behind rubber factory, 50 m below dam.

Elevation: 23 m.

Landform: transition of valley bottom and lower slope in a V-shaped valley.

Slope: 4 per cent west, gentle straight slope.

Vegetation: two years ago secondary forest with Raphia palm and bamboo, now under non-irrigated rice.

Parent material: loamy sedimentary materials.

Drainage: poorly drained.

Moisture conditions: moist to 50 cm depth, wet below.

Groundwater: presently at 70 cm depth, but rises close to the surface in rainy season.

General aspect: deep greyish-brown mottled sandy loam soil with a thin brown sandy clay loam surface layer.

Profile description:

A_1 0-11 cm; dark brown (7.5 YR 4/4); common fine faint clear strong brown mottles; sandy clay loam; weak medium subangular blocky; friable, slightly sticky, plastic; common fine and few medium tubular pores, few fine vesicular pores; many very fine and fine, few medium roots; clear smooth boundary.

C_1g 11-18 cm; pale brown (10 YR 6/3); common fine and medium faint and distinct clear yellowish-red mottles usually around roots; loamy sand; single grain; loose; few fine and medium tubular pores; common fine, few medium roots; clear wavy boundary.

C_2g 18-29 cm; dark greyish-brown (10 YR 4/2); common medium prominent clear yellowish-red mottles around roots; loamy sand; single grain; very friable; few fine and medium tubular pores; common fine and few medium roots; gradual wavy boundary.

C_3g 29-70 cm; greyish-brown (10 YR 5/2); many medium faint clear yellowish brown-mottles; sandy loam; very weak coarse angular blocky; friable, slightly sticky, slightly plastic; few fine and medium tubular pores, few fine vesicular pores; common fine, few medium roots; gradual wavy boundary.

CG 70+ cm; grey (10 YR 5/1); sandy clay loam; very weak coarse angular blocky to structureless; slightly sticky, slightly plastic; few fine and medium roots.

Table B-11. Analytical data of profile no. 11, unit D, (Typic) Tropaquent.

horizon	A_1	C_1g	C_2g	C_3g	CG
depth (cm)	0-11	11-18	18-29	29-70	70+
0-2 μ (per cent)	30	8	13	25	33
2-20 μ (per cent)	7	12	3	4	6
20-2000 μ (per cent)	63	80	84	71	61
> 2 mm (per cent)	0	0	0	0	0
bulk density (g/cm^3)	0.58	1.54	1.60	1.54	1.43
pH(H_2O)	4.7	5.4	5.1	5.1	5.0
pH(KCl)	4.2	4.3	4.0	3.7	3.7
org. C (per cent)	3.68	0.21	0.35	0.29	0.36
exch. Ca (me/100 g)	3.40	0.25	0.21	0.16	0.31
exch. Mg (me/100 g)	1.33	0.07	0.06	0.05	0.12
exch. K (me/100 g)	0.26	0.10	0.10	0.10	0.13
exch. Na (me/100 g)	0.21	0.09	0.09	0.10	0.15
exch. Mn (me/100 g)	0.04	0.00	0.00	0.00	0.00
exch. acidity (Al+H) (me/100 g)	0.58	0.22	0.62	1.48	2.28
sum of cations (me/100 g soil)	5.32	0.73	1.08	1.89	2.99
(me/100 g clay)	18	9	8	8	9
base saturation (per cent)	89	70	43	22	24

Appendix C. Methods.

The analytical methods used are those published in IITA (1975b), Jackson (1958), Amer. Soc. of Agron. (1965) and Amer. Pub. Health Ass. (1971).

The soil moisture content of fresh soil samples was determined gravimetrically. Bulk density was determined by sampling 98.15 cm^3 of soil from a vertical wall. Soil moisture retention characteristics were determined as follows: pF 0, 1 and 2 by tension cups; samples were saturated with water; after 24 hours under a tension of 0, 10 and 100 cm water, respectively, moisture content was determined gravimetrically. pF 2.5 and 4.2 by pressure extraction; after equilibrium the moisture content was determined gravimetrically.

Particle size analysis was done by the hydrometer method (Bouyoucos 1951). Organic carbon was determined by the Walkley-Black method. The pH was determined potentiometrically using a glass electrode in a 1:1 ratio of soil with water and also in a 1:1 ratio of soil with 1N KCl. Exchangeable bases were removed by extraction with 1N NH_4OAc pH 7.0; Ca, K and Na were measured by flame photometry and Mg and Mn by atomic absorbtion spectrometry. Exchange acidity was determined by extraction with 1N KCl and measured by titration with 0.1N NaOH, according to McLean (1965). The effective CEC was determined as the sum of exchangeable bases and exchange acidity. Total N was determined by the macro Kjeldahl method. NH_4-N was determined by extraction with 2N KCl and steam distillation with MgO. NO_3 was determined by the phenoldisulphonic acid method.

CEC (according to Kyuma and Kawaguchi 1973): extraction with $CaCl_2$, pH 7.0, displacement with NaCl and titrimetric determination with EDTA.

Total N in plant tissue material was determined by the micro Kjeldahl method. Extractable Fe, Mn, Zn, P and K were extracted by perchloric acid digestion; Fe, Mn and Zn were determined by atomic absorbtion, P by the colorimetric vanado-molybdate method and K by a flame photometer. S in plant material was determined by a Leco-sulphur-determinator.

Mineralogical determinations were done at the University of Louvain, Belgium and at the Rothemsted Experimental Station, Harpenden, England. For X-ray diffraction, clay-samples were saturated with magnesium. A microscope was used to identify the fine sand fraction.

Sampling of soil solution: The sampling of the soil solution was done in the following way. Four perforated plastic bags were fixed to the outside of a waterproof asbestos tube which had a diameter of 25 cm and was open at the top. The bags were filled with a perforated plastic centrifuge tube and glasswool. The centrifuge tube was connected to the inside of the asbestos tube by a rubber tube and fixed to the wall of the asbestos tube by a waterproof stopper. Hydraulic pressure in a wet soil causes the water to pass through the glasswool into the rubber tube. On the inside of the asbestos tube a clear soil solution can be tapped at each of the four depths. This method is based on the one described by Williams (1971). Using the soil solution samples, the pH was measured in the field directly after sampling. Other analyses were performed in the laboratory.

In soil solution samples, NO_3 was determined by the brucine method; SO_4 by the turbidimetric method; HCO_3 by potentiometric titration, assuming the alkalinity to represent bicarbonate when the phenolphthalein alkalinity is less than half the total alkalinity; Fe and Mn by atomic absorbtion. The electric conductivity was measured on an electric conductivity meter.

NH_3-volatilization was determined by absorption with boric acid; the boric acid was put in a petri dish 25 cm above the soil surface and covered by a plastic bucket to accumulate volatilizised NH_3; the determination of ammonium borate was done every 6 hours by titration with 0.005 N H_2SO_4.

Measurements of the composition of the soil atmosphere were made using simple gas chromatographic equipment. Samples were obtained using a diffusion-equilibrium reservoir at 15 cm depth with low dead-volume connecting tubes to the above ground sampling point (after Burford 1976).

The determination of the height of the capillary rise in the soil samples was done according to the method described by Emerson and Bond (1963). A vertical glass tube was filled with a disturbed air-dried soil sample and put into a container with water. The upper level of the water-saturated zone above the water level in the container (x) and the time (t) were recorded. Darcy's law was used for the saturated water movement:

$$dx/dt = K/S((h + L)/(x + L) - 1)$$

in which K = hydraulic conductivity, S = fractional water-filled pore space behind the wetting front, assumed to be constant for $x \leq h + 1$, L = height of constant external water level above the bottom of the column and h = maximum height of capillary rise of water in a soil column below which the water-filled pore space is constant and equal to S. Plotting dx/dt against 1/x gives a linear relation. For dx/dt = 0, x = h + L. With L as known value h can be calculated.

Appendix D. Determination of the difference in moisture content at pF 2 and pF 4.2 per horizon for all soil units.

Table D-1. Calculation of the difference in moisture content at pF 2 and 4.2 per horizon of the soil units 1-9 according to the formula Y = 34.54 - 0.34 (per cent sand) + 1.93 (per cent organic C).

soil unit	profile number	horizon	per cent sand	per cent organic C[1]	Y
1	7	A_1	67	2.06	15.7
		A_3	71	0.57	11.5
		B_1	69	0.27	11.6
		$B_{21}tg$	65	0.28	13.0
		$B_{22}tg$	51	0.22	17.6
2	6	A_{11}	58	3.51	21.6
		A_{12}	71	0.72	11.8
		C_1	82	0.10	6.9
		C_2g	82	0.10	6.9
		IIC_3g	66	0.12	12.3
3	5	A_1	58	2.15	19.0
		C_1g	79	0.16	8.0
		C_2g	72	0.12	10.3
		C_3g	86	0.08	5.5
4	3	A_1	82	1.53	9.6
		AC	86	0.34	6.0
		C_1	84	0.14	6.3
		C_2g	84	0.06	6.1
6	4	A_1	81	0.58	8.1
		A_3	81	0.46	7.9
		IIB_1cn	83	0.32	6.9
		IIB_2tcn	75	0.36	9.7
7	2	A_1	81	1.42	9.7
		A_3	71	0.46	11.3
		B_1	78	0.30	8.6
		B_2tcn	72	0.30	10.6
		IIB_2t	69	0.30	11.7
8	1	A_1	66	1.98	15.9
		A_3	71	0.76	11.9
		IIB_1	57	0.58	16.3
		IIB_2t	37	0.45	22.8

Note: [1] per cent organic C was corrected for the surface soil, see paragraph 5.2.1.

Table D-2. Calculation of the difference in moisture content at pF 2 and pF 4.2 per horizon for the soil units A-D, based on actual measurements.

soil unit	profile number	horizon	moisture content at pF 2	moisture content at pF 4.2	difference
A	8	A_1	29.5	13.3	16.2
		A_3	8.9	5.0	3.9
		B_1	16.5	10.8	5.7
		$B_{21}t$	23.6	12.9	10.7
B	9	A_p	14.5	4.5	10.0
		A_3	12.8	3.5	9.3
		$B_{21}t$	25.2	12.6	12.6
C	10	A_1	17.2	3.5	13.7
		A_3	11.9	2.6	9.3
		B_1	21.0	9.6	11.4
		B_2t	24.5	11.1	13.4
D	11	A_1	45.5	26.6	18.9
		C_1g	9.8	4.1	5.7
		C_2g	15.6	8.4	7.2
		C_3g	22.2	11.4	10.8
		CG	8.4	2.1	6.3

Appendix E. Determination of the available water-holding capacity AW in volume percentage per horizon for the soil units 1-9 (IITA) and A-D (Ikenne).

soil unit	horizon	depth (cm)	difference in moisture content at pF 2 and pF 4.2	bulk density	per cent gravel	AW
1	A_1	0-10	15.7	1.4	0	21.9
	A_3	10-30	11.5	1.5	3	16.7
	B_1	30-45	11.6	1.6	4	17.7
	$B_{21}tg$	45-55	13.0	1.7	15	19.2
	$B_{22}tg$	55-80	17.6	1.7	57	19.0
2	A_{11}	0- 6	21.6	1.4	12	27.0
	A_{12}	6-10	11.8	1.4	6	15.5
	C_1	10-25	6.9	1.6	5	10.5
	C_2g	25-65	6.9	1.6	11	9.9
	IIC_3g	65-95	12.3	1.8	16	19.9
3	A_1	0- 4	19.0	1.4	0	26.6
	C_1g	4-25/37	8.0	1.6	12	11.4
	C_2g	25/37-70	10.3	1.6	9	15.0
	C_3g	70-150	5.5	1.7	26	7.5
4	A_1	0-18	9.6	1.4	0	13.4
	AC	18-40	6.0	1.4	4	8.1
	C_1	40-70	6.3	1.5	18	7.9
	C_2g	70-102	6.1	1.6	10	8.8
6	A_1	0-24	8.1	1.4	7	10.5
	A_3	24-36	7.9	1.5	10	10.8
	IIB_1cn	36-73	6.9	1.6	75	6.2
	IIB_2tcn	73-106	9.7	1.6	76	8.8
7	A_1	0-12	9.7	1.4	9	12.5
	A_3	12-32	11.3	1.5	14	14.9
	B_1	32-60	8.6	1.5	23	10.5
	B_2tcn	60-71	10.6	1.7	60	11.2
	IIB_2t	71-105	11.7	1.7	69	11.7
9	A_1	0-12	15.9	1.4	3	21.6
	A_3	12-20	11.9	1.4	9	15.3
	IIB_1	20-42	16.3	1.6	54	17.0
	IIB_2t	42-92	22.8	1.4	44	22.1
A	A_1	0-13	16.2	1.4	0	22.7
	A_3	13-30	3.9	1.5	0	5.9
	B_1	30-45	5.7	1.6	0	9.1
	$B_{21}t$	45-105	10.7	1.6	0	17.1
B	A_p	0-15/20	10.0	1.4	0	14.0
	A_3	15/20-55	9.3	1.5	0	14.0
	$B_{21}t$	55-90	12.6	1.8	0	22.7
C	A_1	0-20	13.7	1.4	0	19.2
	A_3	20-38	9.3	1.6	0	14.9
	B_1	38-61	11.4	1.8	0	20.5
	B_2t	61-93	13.4	1.8	0	24.1
D	A_1	0-11	18.9	1.4	0	26.5
	C_1g	11-18	6.3	1.5	0	9.5
	C_2g	18-29	5.7	1.6	0	9.1
	C_3g	29-70	7.2	1.5	0	10.8
	CG	70+	10.8	1.4	0	15.1

Appendix F. NCSU fertility-capability classification and fertility evaluation for paddy soils according to Kyuma and Kawaguchi.

The fertility-capability classification of North Caroline State University (NCSU 1973).

The fertility-capability classification is based on the division of soils into types, substrata types and condition modifiers in order to assess their fertility and their response to fertilizer application. The soil criteria chosen are those that have a direct influence on the interactions of applied fertilizers and closely related fertilizer management practices. The type is the highest category which is determined by the average texture of the plough layer or upper 20 cm of the soil, whichever is shallower:

S = sandy surface soil

L = loamy surface soil

C = clayey surface soil

The substrata type is the second highest category, which is determined by the texture of the subsoil; used if textural change or hard root restricting layer is encountered within 50 cm:

S = sandy subsoil

L = loamy subsoil

C = clayey subsoil

R = rock or root restricting layer

The condition modifiers refer to chemical or physical properties of the plough layer or top 20 cm, whichever is shallower, unless otherwise specified. Relevant condition modifiers for the soil units in the study area are:

g: refers to a gley condition in the soil indicative of water saturation within 60 cm of the surface during some part of the year. It should be indicative of soils that could benefit from drainage practices.

d: refers to an annual dry season of more than 60 consecutive days. Its significance in fertility is not fully recognized, but might indicate different nitrogen relationships at the onset of rains following a dry period.

e: refers to a soil condition of very low cation exchange capacity in the plough layer.

h: refers to a moderate level of acidity at less than 50 cm depth that would retard the growth of some aluminum sensitive plants.

i: this modifier is intended for those soils in which phosphorus fixation by iron-compounds is of major importance.

k: this modifier attempts to delimit those soils where it is almost certain that potassium will be needed in an agronomic fertility programme.

Because all soil units in the study area would be given the modifier d, it has been omitted for obtaining a relative grading for the soil units. Modifier g is not used as limiting the soil fertility; its implicance is usually concerned with management.

Table F-1 shows the results of the fertility-capability classification. A relative grading has been given on the basis of the type, substrata type and condition modifiers.

Table F-1. Types, substrata types and condition modifiers of the soil units and the relative grade of each unit based on the fertility-capability classification categories.

soil unit	type/substrata	type of modifiers	grade	remarks
1	LC	e	high	
2	L	e(k)	medium	
3	L	e(k)	medium	
4	S	e	low	
		e(k)	very low	when poorly or very poorly drained
5	L	e	medium	
6	SR	e(k)	very low	
7	L	e	medium	
8	L	e	medium	
9	LC	i(e)	high	
A	LC	e(i)(k)	medium	
B	L	(e)	medium-high	
C	L	ehk	low	
D	L	ek	low-medium	

Fertility evaluation for paddy soils

Kyuma and Kawaguchi (1973) developed a method of fertility evaluation for paddy soils. Eleven soil characteristics are involved, which are related to the yield of rice. After transforming the data and using principle component analysis according to Seal (1964), four components were considered. These were interpreted as skeletal organic matter status, available phosphorus status, inherent potentiality and available nitrogen status. As distinct from the other three components, the inherent potentiality reflected the general base status, the clay content, the clay-mineral species of the soil and the available silica. The inherent potentiality is taken as a refined form of the fertility status, leaving the factors concerning the organic matter, nitrogen and phosphorus status out of consideration.

In this study, the final factor loadings for the inherent potentiality have been applied for a number of hydromorphic soils at IITA, according to the following formula:

inherent potentiality (IP) = 0.30 (per cent organic C) + 0.80 (CEC) + 0.85 (exch. Ca+Mg) + 0.77 (exch. K) - 0.59 (per cent sand) (1)

Due to lack of data and the generally low factor loadings, the characteristics of N, P and Si-status were omitted. An assumption was made for the total percentage N, which was taken as 0.1 per cent organic C, based on a C/N ratio of 10; in this case the coefficient for organic C in the formula rose from 0.27 to 0.30. Kyuma and Kawaguchi determined CEC as described in Appendix C. In order to calculate the effective CEC values of the profiles used in the calculation, a regression-equation given by Juo et al. (1976), was applied. This regression equation involves the base saturation calculated on the basis of effective CEC (b.s.1) and the base saturation calculated on the basis of the CEC determination by NH_4OAc, pH 7.0 (b.s.2). The latter is assumed to resemble the base saturation as calculated according to the method used by Kyuma and Kawaguchi. The regression equation is:

$$b.s.1 = 5.28 + 2.13\,(b.s.2) - 0.012\,(b.s.2)^2.$$

The CEC, as used in formula (1), is then calculated as follows:

CEC = (b.s.1). ECEC/(b.s.2) in which ECEC stands for effective CEC.

The soils from which the inherent potentiality were calculated and the resulting inherent potentiality per genetic horizon are given in Table F-2. Table F-3 shows the inherent potentiality for these soils, but calculated for the upper 30 cm of the soil according to the formula:

$$IP(total) = d_1.IP_1 + d_2.IP_2 + \ldots\ldots + d_n.IP_n$$

in which d_n is the thickness of the n^{th} horizon, IP_n the inherent potentiality of the n^{th} horizon. The 30 cm depth is taken as being most important for rice cultivation under paddy conditions.

The percentage of sand has a dominant influence in calculating the inherent potentiality according to formula (1), resulting in relatively high ratings for the clayey soils and low ratings for sandy soils.

Table F-2. Analytical data of nine hydromorphic soils on Basement Complex in order to calculate the inherent potentiality (IP) for the upper 30 cm according to formula (1).

soil unit[1]	IITA nr.	depth (cm)	per cent sand	per cent org. C	exch. (Ca+Mg) me/100 g soil	exch. K me/100 g soil	ECEC	b.s.1	CEC	IP
1	57	0-10	67	2.17	8.57	0.28	9.68	98	12.1	- 216.8
		10-30	71	0.58	5.40	0.07	5.86	99	6.5	- 637.8
1-5	31	0-18	58	1.46	8.66	0.19	9.19	98	11.5	- 306.9
		18-30+	54	(0.60)	7.28	0.10	7.67	98	9.6	- 212.9
2	130	0- 6	58	3.70	10.02	0.32	10.78	99	12.0	- 88.3
		6-10	71	0.76	2.52	0.15	2.92	98	3.9	- 145.2
		10-25	82	0.10	0.85	0.05	1.14	93	1.9	- 691.6
		25-30+	82	0.10	0.82	0.01	1.02	96	1.5	- 232.2
2	58	0- 8	67	2.33	6.49	0.26	7.25	99	8.1	- 212.6
		8-23	84	0.33	3.61	0.03	3.84	99	4.3	- 645.1
		23-30+	83	0.25	0.98	0.06	1.46	98	1.8	- 321.4
2	122	0- 9	72	2.08	7.86	0.24	8.31	99	9.2	- 249.5
		9-21	74	0.31	3.27	0.05	3.54	99	4.0	- 451.0
		21-30+	76	0.11	2.95	0.04	3.26	99	3.9	- 352.1
3	124	0- 4	58	2.26	3.60	0.16	4.63	88	7.7	- 96.6
		4-30+	79	0.16	2.28	0.05	2.71	77	3.9	-1078.3
3	x	0-19	78	1.75	10.88	0.82	12.40	98	15.5	- 440.5
		19-30+	78	0.20	4.42	0.06	4.83	100	5.4	- 416.0
3-4	34	0-30+	75	0.94	1.48	0.09	1.96	86	3.6	-1193.7
4	127	0- 7	60	2.06	5.76	0.23	6.61	96	9.4	- 154.7
		7-30+	89	0.16	0.90	0.07	1.43	91	2.4	-1143.5

[1]Explanation of the soil units: no. 57 is profile no. 7 in Appendix B; no. 31 is a deep imperfectly drained brown sandy clay loam soil with a brown sandy clay subsoil (Udic Haplustalf); no. 130 is profile no. 6 in Appendix B; no. 58 is poorly drained deep sandy to loamy sandy soil with *in situ* weathered clay at about 80 cm depth (Tropaquent); no. 122 is a deep poorly drained grey sandy to loamy soil covering mottled gravelly clay subsoil at 80 cm depth (Tropaquent); no. 124 is profile 5 in Appendix B; no. x is a dark brown to strong brown sandy loam soil covering a light yellowish-brown mottled sandy loam subsoil which covers (*in situ*) weathered clayey material, imperfectly drained (Aquic Ustorthent); no. 34 is a deep somewhat poorly drained greyish-brown to brown loamy sand to sandy loam soil with a grey clayey subsoil at 125 cm (Aeric Tropaquent); no. 127 is a deep poorly drained sandy soil, layered with coarse sandy layers and with a reddish-brown loamy surface soil (Tropaquent).

Table F-3. The inherent potentiality of nine hydromorphic soils and the average inherent potentiality for four soil units (upper 30 cm).

soil unit	IITA nr.	IP	soil unit	average IP	standard error
1	57	- 854.6	1	- 687	237
1-5	31	- 519.8			
2	130	-1157.3	2	-1130	68
2	58	-1179.1			
2	122	-1052.6			
3	124	-1174.9	3	-1075	131
3	x	- 856.5			
3-4	34	-1193.7	4	-1246	74
4	127	-1298.2			

ppendix G. Correlation of yield of rice, maize, cowpea and soybean to soil and water haracteristics.

Yield data of rice, maize, cowpea and soybean, obtained in the Eastbank area I from 972 to 1976, were correlated to a number of soil and water characteristics of the same rea. The determination of yield and groundwater data was discussed in paragraph 7.1. The verage of two subplots closest to a groundwater tube were used for this determination; rom the same subplots samples were taken for determining the soil data. A list of characteristics (or variables) is given in Table G-1. Each characteristic has been given a umber, while the yield variable is represented as no. 50. Some characteristics were used pecifically for one or two crops, others were used for all crops.

After calculating the correlation between the variables, they were listed according o the sum of the squares of the correlation coefficients (in decreasing order), followed y a grouping of variables showing strong inter-relations. The grouping is determined by correlation-threshold, concerning the largest portion of correlation coefficients on he horizontal line of each variable; each variable within the first group should have a orrelation-coefficient of 60 or more within the first larger portion of the coefficients n the horizontal line; for the next group a reduction by 10 is applied. The result of he grouping is a concentration of high correlation-coefficients close to the diagonal f the diagrams (see following figures). Each group formed in this way, represents a roup of variables, which are significantly correlated. Also, any indication of a relationhip between groups of variables is found in the relevant rectangle in the diagrams.

The results of rice, maize, cowpea and soybean will be considered successively. For ach crop, the resulting correlation-matrices for the relevant seasons are given, followed y matrices in which only those variables are represented that are significantly correlatd with yield.

ice.

The correlation-matrices for the major first and for the second season are given in ig. G-1 and G-2. From these matrices, two groups of variables can be derived, which are ignificantly correlated with the yield of rice. The correlation-coefficients between ield of rice and the variables significantly correlated with the yield and the correlation-coefficients between these variables are given in Fig. G-3 and G-4, for the major irst and for the second season, respectively.

The two groups of variables significantly correlated with rice yield in both seasons re:

- a group of variables concerning "water"-variables, representing shortage of water: variable no. 17 (the number of weeks with groundwater deeper than 65 cm) and no. 4 (the highest groundwater level during the whole growing season).
- a group of variables concerning soil fertility: variable no. 30 (the organic matter content of the surface soil) and no. 32 (the exchangeable Mg-content of the surface soil).

The variable no. 40, being the Ca/Mg-ratio, is related to yield to some extent, but s also significantly correlated with the two groups of variables mentioned above as far s the major first season is concerned and with the second group only in the second

Table G-1. List of variables used in the correlation studies.

No. variable	description
	Water
1	groundwater class[1] during whole growing season
2	groundwater class[1] during first six weeks after planting (maize)
3	groundwater class[1] during first week after planting (soybean)
4	highest groundwater level during whole growing season
5	highest groundwater level during first six weeks after planting (maize)
6	lowest groundwater level during whole growing season
7	lowest groundwater level during first six weeks after planting (maize)
8	number of weeks groundwater at less than 0 cm depth during first six weeks after planting (maize)
9	number of days groundwater at less than 0 cm depth during first week after planting (soybean)
10	number of weeks groundwater at less than 10 cm depth during first six week after planting (maize)
11	number of days groundwater at less than 10 cm depth during first week afte planting (soybean)
12	number of weeks groundwater at less than 10 cm depth during first three weeks (cowpea)
13	number of days groundwater at less than 20 cm depth during first week afte planting (cowpea)
14	number of weeks groundwater at less than 25 cm depth during first six week after planting (maize)
15	number of days groundwater at less than 25 cm depth during first week afte planting (soybean)
16	number of weeks groundwater between 40 and 65 cm depth (rice)
17	number of weeks groundwater deeper than 65 cm depth (rice)
18	occurrence of drought stress lasting more than 1 to 1½ weeks[2] (rice, maize
19	number of weeks drought in May-August[3] (rice)
	Texture
20	per cent sand in surface soil
21	per cent silt in surface soil
22	per cent clay in surface soil
23	texture class of subsurface soil[4]
24	depth of alluvial clay[5]
25	depth of *in situ* weathered clay[5]
26	depth of alluvial or *in situ* weathered clay, whichever is shallower[5] (soybean, cowpea)
	Gravels
27	depth of a very gravelly layer[5]
28	depth of a gravelly layer[5]
	Chemical factors
29	pH of surface soil
30	organic matter content of surface soil
31	exchangeable Ca-content of surface soil
32	exchangeable Mg-content of surface soil
33	exchangeable K-content of surface soil (not for rice)
34	exchangeable Na-content of surface soil (not for rice)
35	exchangeable Mn-content of surface soil (only rice)
36	available phosphate in surface soil
37	total acidity (only for rice)
38	Ca + Mg (rice and maize)
39	Ca + Mg + K + Na (soybean and cowpea)
40	Ca/Mg-ratio
	Yield
50	yield

Notes.

1 the number of groundwater classes were relisted in a logical way: 1=1; 2,3=2; 4,5,8 = 3; 6,9=4; 7,10=5; 11=6.

2 occurrence of drought stress as follows: yes=1, no=2.

3 number of weeks of drought determined by soil moisture determinations.

4 texture class subsurface soil as follows: sandy=1, loamy=2, clayey=3.

5 depth of clay or gravel as follows: 12 - d (in which d = depth in dm).

Fig. G-1. Correlation matrix for rice, major first season.
(significant values more than 27, highly significant values more than 34).

17																									
6	84																								
-1	77	92																							
4	79	73	84																						
-18	75	73	60	48																					
-20	37	38	92	73	73																				
19	67	60	52	51	78	60																			
23	67	55	51	58	56	55	52																		
22	52	52	55	50	35	52	13	51																	
21	14	18	11	1	12	18	-14	45	57																
38	1	-3	-5	0	-4	-3	-33	14	50	65															
31	9	3	0	7	5	3	-22	17	48	53	94														
32	-17	-16	-14	-16	-23	-16	-44	3	36	67	75	50													
30	-14	-4	-2	-8	-26	-4	-40	-21	24	46	52	32	74												
24	26	21	17	19	15	21	11	55	46	52	31	25	32	5											
28	57	57	44	38	66	57	51	50	20	14	9	23	-22	-28	0										
27	56	49	41	41	64	49	53	53	15	11	1	14	-25	-28	-14	85									
25	31	32	20	13	41	32	13	28	26	33	34	45	0	-2	10	69	66								
40	26	20	17	26	28	20	35	15	-4	-35	-16	14	-73	-59	-11	41	38	28							
35	41	41	47	34	35	41	33	38	47	22	-12	-20	-6	-9	15	14	12	-11	-20						
-29	25	34	42	32	13	34	24	32	21	4	-37	-39	-22	-6	0	1	9	-19	-2	56					
-50	29	14	17	37	20	14	33	32	-12	-21	-29	-18	-41	-41	8	28	38	15	32	0	24				
-36	22	27	19	7	40	27	34	13	14	-10	-15	-8	-74	-28	-6	34	26	21	24	18	-17	-26			
37	13	14	10	6	7	14	-11	0	25	18	14	14	9	9	18	11	2	25	-4	8	-3	-9	5		
16	-20	18	18	-9	9	18	-4	-2	2	10	-6	-5	-6	-2	0	18	9	14	0	5	9	-9	17	7	
var.	17	6	-1	4	-18	-20	19	23	22	21	38	31	32	30	24	28	27	25	40	35	-29	-50	-36	37	16

Fig. G-2. Correlation matrix for rice, second season.
(significant values more than 29, highly significant values more than 36).

6																								
-1	92																							
-18	84	76																						
17	83	75	79																					
4	74	83	70	79																				
-50	57	48	76	64	53																			
28	63	54	63	67	52	55																		
27	53	50	59	62	52	48	86																	
23	51	50	53	64	60	43	47	51																
-20	40	39	27	34	28	10	28	18	55															
21	20	17	11	16	5	-4	21	15	47	90														
22	53	55	41	45	47	25	26	17	48	86	59													
38	-4	-5	-16	-1	-6	-14	11	0	12	67	68	49												
31	0	-2	-8	8	0	0	26	13	13	60	58	46	95											
32	-12	-10	-27	-20	-16	-38	-20	-24	6	63	68	42	81	59										
24	13	8	11	21	13	11	0	-12	53	51	48	39	26	21	30									
30	-3	2	-26	-17	-13	-51	-21	-22	-23	38	42	26	59	42	74	-2								
35	45	46	39	38	46	27	15	12	41	41	26	51	-10	-18	8	14	-6							
25	38	26	36	42	19	32	71	67	29	37	35	29	35	48	1	10	0	-8						
-40	-12	-7	-21	-28	-19	-39	-40	-35	-8	29	37	14	26	-2	74	14	58	21	-27					
-29	42	47	37	29	36	13	16	19	39	20	9	28	-39	-44	-20	-2	-12	59	-9	3				
-36	31	31	36	26	31	26	22	22	0	-12	-35	19	-26	-18	-35	-17	-15	18	12	-26	27			
16	29	24	33	-12	-3	23	16	10	1	4	3	12	-11	-12	-7	-9	-5	12	4	6	16	19		
37	17	14	13	12	10	16	11	0	1	24	20	27	13	13	10	22	10	11	26	7	2	5	8	
var.	6	-1	-18	17	4	-50	28	27	23	-20	21	22	38	31	32	24	30	35	25	-40	-29	-36	16	37

Fig. G-3. Diagram showing the correlation-coefficients between the yield of rice and the variables significantly correlated with the yield and the correlation-coefficients between these variables, major first season (significant values more than 27, highly significant values more than 34).

variable											
number of weeks groundwater deeper than 65 cm (no. 17)											
highest groundwater level during the whole growing season (no. 4)	79										
number of weeks drought in May-August (no. 19)	67	51									
texture class of subsurface soil (no. 23)	67	58	52								
the depth of a gravelly layer (no. 28)	57	38	51	50							
the depth of a very gravelly layer (no. 27)	56	41	53	53	85						
Ca + Mg (no. 38)	1	0	-33	14	9	1					
the exchangeable Mg-content of the surface soil (no. 32)	-17	-16	-44	3	-22	-25	75				
the organic matter content of the surface soil (no. 30)	-14	-8	-40	-21	-28	-28	52	74			
Ca/Mg ratio (no. 40)	26	26	35	15	41	38	-16	-73	-59		
rice yield (no. 50)	-29	-37	-33	-32	-28	-38	29	41	41	-32	
variable no.	17	4	19	23	28	27	38	32	30	40	50

Fig. G-4. Diagram showing the correlation-coefficients between the yield of rice and the variables significantly correlated with the yield and the correlation-coefficients between these variables, second season (significant values more than 29, highly significant values more than 36).

variable													
lowest groundwater level during the whole growing season (no. 6)													
groundwater class during whole growing season (no. 1)	-92												
occurrence of drought stress lasting more dan 1-1½ weeks (no. 18)	-84	76											
number of weeks groundwater deeper than 65 cm depth (no. 17)	83	-75	-79										
highest groundwater level during whole growing season (no. 4)	74	-83	-70	79									
depth of a gravelly layer (no. 28)	63	-54	-63	67	52								
depth of a very gravelly layer (no. 27)	53	-50	-59	62	52	86							
texture class of the subsurface soil (no. 23)	51	-50	-53	64	60	47	51						
the depth of *in situ* weathered clay (no. 25)	38	-26	-36	42	19	71	67	29					
exchangeable Mg content in the surface soil (no. 32)	-12	10	27	-20	-16	-20	-24	6	1				
organic matter content in the surface soil (no. 30)	-3	-2	26	-17	-13	-21	-22	-23	0	74			
Ca/Mg ratio (no. 40)	12	-7	-21	28	19	40	35	8	27	-74	-58		
rice yield (no. 50)	-57	48	76	-64	-53	-55	-48	-43	-32	38	51	-39	
variable no.	6	1	18	17	4	28	27	23	25	32	30	40	50

season.

The difference in additional "water"-variables, concerning shortage of water between the major first and the second season, which is significantly correlated to yield, is as follows:

- additional in the major first season variable no. 19 (the number of weeks of drought in the period May-August).
- additional in the second season are the variables no. 6 (the lowest groundwater level during the whole growing season), no. 1 (the groundwater class during the whole growing season) and no. 18 (the occurrence of drought stress lasting more than 1-1½ weeks).

Some variables such as no. 23, 25, 27 and 28 (the texture class of the subsurface soil, the depth of *in situ* weathered clay, the depth of a very gravelly layer and the depth of a gravelly layer, respectively) are strongly correlated with the variables representing shortage of water; it is uncertain whether they are yield-determining factors.

Maize.

The correlation-matrices for the major first, the second and dry season are given in Fig. G-5, G-6 and G-7 respectively. From the first two matrices, one group of variables which is significantly correlated with yield of maize, can be derived. The diagrams showing the correlation-coefficients between the yield of maize and the variables significantly correlated with the yield and the correlation-coefficients between these variables are given in Fig. G-8 and G-9, for the major first and the second season respectively. For the few dry season data, in contrast to those of the major first and the second season, no variable was found that was significantly correlated with yield. The data for the dry season have not been considered any further.

The main group of variables significantly correlated with maize yield in the major first and the second season consists of three subgroups of variables:

- a subgroup of variables concerning an excess of water: variable no. 5 (the highest groundwater level during the first six weeks after planting), no. 8, 10 and 14 (the number of weeks with groundwater at less than 0 cm, 10 cm and 25 cm respectively) and no. 2 (the groundwater class during the first six weeks after planting).
- a subgroup of variables concerning shortage of water: variable no. 7 (the lowest groundwater level during the first six weeks after planting) and no. 18 (the occurrence of drought stress lasting more than 1-1½ weeks).
- a subgroup of variables concerning other characteristics. These variables are all correlated with the variables mentioned in the foregoing subgroups. It is uncertain whether the variables of this subgroup are yield-determining factors. For both the major first and the second season this subgroup includes the variable no. 20 (the percentage silt in the surface soil), no. 22 (the percentage clay in the surface soil) and no. 34 (the exchangeable Na content in the surface soil).

For the second season only additional variables are included in the subgroup:

- variable no. 23 (the texture class of the subsurface soil), being correlated with all other variables, except a weak correlation with variable no. 14.
- a sub-subgroup with variables 21, 24 and 31 (respectively, the percentage silt in

Fig. G-5. Correlation matrix for maize, major first season.
(significant values more than 37, highly significant values more than 46).

7																									
5	92																								
-14	90	79																							
-2	83	85	85																						
-34	79	81	81	75																					
23	73	79	79	69	71																				
33	75	75	75	69	67	72																			
22	73	69	69	66	59	61	57																		
-20	65	62	62	57	55	66	75	89																	
-18	75	70	70	72	55	52	53	64	56																
-10	77	64	64	59	48	41	47	51	41	57															
-8	65	56	56	51	42	35	40	45	35	50	92														
28	52	60	60	54	50	66	39	52	43	40	34	33													
50	65	44	44	47	38	28	37	45	39	62	70	58	9												
27	42	54	54	46	43	61	37	37	32	33	29	25	84	0											
24	52	51	51	39	42	63	61	46	58	22	30	28	18	22	4										
21	35	33	33	28	45	47	84	49	81	28	18	12	13	21	14	50									
40	41	54	54	47	41	45	28	39	23	22	29	27	67	-1	66	19	-8								
25	39	47	47	41	31	49	35	28	28	19	26	22	68	-6	81	17	18	72							
-32	23	33	33	32	48	19	-11	4	-24	8	23	20	41	0	38	-15	-49	69	35						
31	23	24	24	23	-12	24	35	52	58	23	13	16	38	0	33	28	38	45	46	-26					
38	10	7	7	6	-26	12	32	41	57	15	2	5	15	0	12	29	51	10	23	-61	92				
-29	44	47	47	37	47	33	36	49	29	36	32	17	28	28	23	10	-4	43	14	44	15	-4			
-30	9	15	15	13	-1	9	-48	-1	-33	10	13	17	30	0	25	-16	-65	35	3	64	-28	-48	13		
36	-9	-6	-6	0	-45	-4	-5	-1	-6	-7	9	15	7	-12	4	-2	-14	37	19	13	43	30	27	-9	
var.	7	5	-14	-2	-34	23	33	22	-20	-18	-10	-8	28	50	27	24	21	40	25	-32	31	38	-29	-30	36

Fig. G-6. Correlation matrix for maize, second season.
(significant values more than 37, highly significant values more than 46).

7																									
-10	93																								
-8	82	90																							
23	83	77	90																						
50	84	87	71	87																					
5	88	78	68	78	71																				
-34	77	80	61	80	78	67																			
33	73	76	57	76	79	68	67																		
22	74	75	62	75	76	59	59	57																	
-20	69	70	58	70	76	56	55	75	89																
-2	73	59	51	59	60	76	50	60	56	61															
28	62	59	53	59	54	59	50	39	52	43	57														
27	54	51	41	51	45	55	43	37	37	32	49	84													
25	48	43	36	43	32	47	31	35	28	28	43	68	81												
40	43	34	27	34	32	48	37	31	39	28	49	65	62	68											
21	40	41	31	41	51	33	45	84	49	81	39	13	14	18	0										
30	-14	-8	-9	-8	-3	-15	1	48	1	33	8	-30	-25	-3	-25	65									
32	-19	-18	-8	-18	-7	-22	-45	14	-3	26	5	-39	-37	-34	-53	51	65								
38	15	11	17	11	20	13	-16	34	39	57	47	18	14	23	31	52	49	60							
24	59	52	49	52	47	54	42	61	46	58	52	18	4	17	22	50	16	16	30						
31	26	20	23	20	27	24	-5	36	47	57	53	37	31	41	58	42	32	32	94	29					
-14	39	33	29	33	44	41	36	44	35	43	56	33	27	23	50	36	18	14	55	31	60				
-18	48	50	40	50	49	54	28	31	42	44	38	37	32	23	11	32	-5	1	10	23	11	26			
-29	34	35	20	35	33	30	47	36	49	29	27	28	23	14	38	-4	-13	-43	-4	10	11	12	6		
-36	22	16	11	16	18	13	45	5	1	6	2	-7	-4	-19	-32	14	-9	13	-24	2	-34	13	28	-27	
var.	7	-10	-8	23	50	5	-34	33	22	-20	-2	28	27	25	40	21	30	32	38	24	31	-14	-18	-29	-36

Fig. G-7. Correlation matrix for maize, dry season.
(significant values more than 67, highly significant values more than 79).

5																							
7	98																						
-2	82	81																					
-18	74	71	68																				
33	70	66	53	73																			
23	71	67	54	67	83																		
-20	71	73	50	55	77	81																	
21	61	61	38	64	88	82	89																
30	59	60	35	47	88	77	89	90															
22	62	68	57	38	42	60	86	58	58														
24	64	59	24	38	66	66	60	62	61	35													
32	48	38	20	28	71	57	59	58	66	32	69												
-34	54	58	66	65	42	48	30	34	31	26	7	-24											
-40	32	19	22	40	64	41	16	43	36	-22	43	62	8										
-14	65	62	52	41	32	28	9	2	7	8	46	28	34	30									
-10	65	65	39	33	27	22	34	35	26	22	37	19	19	21	34								
38	40	34	12	9	46	40	58	40	54	48	56	90	-41	24	21	14							
31	33	29	8	0	31	29	53	29	44	53	46	79	-46	4	16	11	97						
-29	40	54	35	36	24	30	56	49	33	65	20	-13	37	-31	7	31	-5	-1					
-28	-1	7	0	16	26	11	15	29	17	7	10	1	11	11	18	-15	-8	-12	57				
36	25	26	-13	8	29	25	43	42	39	27	69	41	-28	-7	1	30	49	49	30	2			
-8	46	45	24	20	18	13	34	37	22	23	23	19	0	19	2	92	17	14	29	-18	28		
-50	32	20	46	58	35	32	7	15	8	-1	3	13	47	50	22	-5	-8	-18	-28	-23	-40	-7	
var.	5	7	-2	-18	33	23	-20	21	30	22	24	32	-34	-40	-14	-10	38	31	-29	-28	36	-8	-50

Fig. G-8. Diagram showing the correlation-coefficients between the yield of maize and the variables significantly correlated with the yield and the correlation-coefficients between these variables, major first season (significant values more than 37, highly significant values more than 46).

variable	7	5	14	2	34	22	20	18	10	8	50
lowest groundwater level during first six weeks after planting (no. 7)											
highest groundwater level during first six weeks after planting (no. 5)	92										
number of weeks groundwater at less than 25 cm depth during first six weeks after planting (no. 14)	-90	-79									
groundwater class during first six weeks after planting (no. 2)	-83	-85	85								
exchangeable Na content of the surface soil (no. 34)	-79	-81	81	75							
per cent clay in the surface soil (no. 22)	73	69	-69	-66	-59						
per cent sand in the surface soil (no. 20)	-65	-62	62	57	55	-89					
occurrence of drought stress lasting more than 1-1½ weeks (no. 18)	-75	-70	70	72	55	-64	56				
number of weeks groundwater at less than 10 cm depth during first six weeks after planting (no. 10)	-77	-64	64	59	48	-51	41	57			
number of weeks groundwater at less than 0 cm depth during first six weeks after planting (no. 8)	-65	-56	56	51	42	-45	35	50	92		
maize yield (no. 50)	65	44	-44	-47	-38	45	-39	-62	-70	-58	
variable no.	7	5	14	2	34	22	20	18	10	8	50

the surface soil, the depth of alluvial clay and the exchangeable K content in the surface soil); these three variables are all correlated with all other variables, except with no. 18, 27 and 28.

- a sub-subgroup with variables 27 and 28 (respectively the depth of a gravelly and a very gravelly layer), correlated with all the mentioned variables, except no. 21, 24 and 33.

Summarizing the correlation studies with maize, it can be concluded that the "water"-variables play the most important role in determining (or limiting) maize yield, as obtained in the toposequence experiments. The other variables are all correlated with these "water"-variables and the separate importance of these variables is obscured within the whole correlative complex.

Cowpea

The correlation-matrices for the major first and the second season are given in Fig. G-10 and G-11. These matrices reveal only a few variables which are significantly correlated with the yield of cowpea. For the major first season the percentages silt and sand in the surface soil were found to be significantly correlated with yield. For the second

Fig. G-9. Diagram showing the correlation-coefficients between the yield of maize and the variables significantly correlated with the yield and the correlation-coefficients between these variables, second season. (significant values more than 37, highly significant values more than 46).

variable																	
lowest groundwater level during first six weeks after planting (no. 7)																	
number of weeks groundwater at less than 10 cm depth during first six weeks after planting (no. 10)	-93																
number of weeks groundwater at less than 0 cm depth during first six weeks after planting (no. 8)	-82	90															
texture class of subsurface soil (no. 23)	83	-77	-90														
highest groundwater level during first six weeks after planting (no. 5)	88	-78	-68	78													
exchangeable Na content of surface soil (no. 34)	-77	80	61	-80	-67												
exchangeable K content of surface soil (no. 33)	73	-76	-57	76	68	-67											
per cent clay in surface soil (no. 22)	74	-75	-62	75	59	-59	57										
per cent sand in surface soil (no. 20)	-69	70	58	-70	-56	55	-75	-89									
groundwater class during first six weeks after planting (no. 2)	-73	59	51	-59	-76	50	-60	-56	61								
depth of a gravelly layer (no. 28)	62	-59	-53	59	59	-50	39	52	-43	-57							
depth of a very gravelly layer (no. 27)	54	-51	-41	51	55	-43	37	37	-32	-49	84						
per cent silt in surface soil (no. 21)	40	-41	-31	41	33	-45	84	49	-81	-39	13	14					
depth of alluvial clay (no. 24)	59	-52	-49	52	54	-42	61	46	-58	-52	18	4	50				
number of weeks groundwater at less than 25 cm depth during first six weeks after planting (no. 14)	-39	33	29	-33	-41	36	-44	-35	43	56	-33	-27	-36	-31			
occurrence of drought stress lasting more than 1-1½ weeks (no. 18)	-48	50	40	-50	-54	28	-31	-42	44	38	-37	-32	-32	-23	26		
maize yield (no. 50)	84	-87	-71	87	71	-78	79	76	-76	-60	54	45	51	47	-44	-49	
variable no.	7	10	8	23	5	34	33	22	20	2	28	27	21	24	14	18	50

Fig. G-10. Correlation matrix for cowpea, major first season.
(significant values more than 61, highly significant values more than 73).

34																							
-33	75																						
-6	75	77																					
-27	64	86	86																				
-25	61	85	85	85																			
-28	68	76	76	70	64																		
-4	67	77	77	60	46	67																	
-36	62	79	79	60	57	54	66																
1	73	51	51	49	41	75	57	48															
-30	36	59	59	62	53	67	50	40	49														
21	70	54	54	45	43	58	27	41	48	5													
-20	70	29	29	23	20	52	20	37	71	9	77												
24	46	38	38	26	25	33	39	49	48	35	47	48											
26	46	23	23	13	12	23	23	33	48	19	56	61	94										
23	49	13	13	2	-7	14	20	35	39	3	53	61	66	77									
-31	-2	33	33	17	34	14	23	28	4	17	21	-6	56	44	15								
-39	-8	39	39	23	35	18	31	32	-2	28	10	-22	51	33	3	94							
13	54	20	20	19	17	38	29	29	74	35	10	62	23	26	23	-30	-38						
22	40	-6	-6	-6	-5	21	4	18	59	7	16	73	24	32	36	-32	-47	88					
32	20	-28	-28	-20	-13	-14	-34	-21	18	-35	19	50	-22	1	24	-43	-69	41	60				
-50	57	20	20	13	9	38	26	26	44	-11	65	67	40	45	44	-15	-21	19	38	24			
-40	23	2	2	0	20	0	-15	0	22	-16	42	47	30	44	41	40	9	15	32	63	13		
29	4	36	36	37	14	18	25	33	-6	57	-6	-10	0	-8	2	5	12	1	-10	-17	-32	-11	
var.	34	-33	-6	-27	-25	-28	-4	-36	1	-30	21	-20	24	26	23	-31	-39	13	22	32	-50	-40	29

Fig. G-11. Correlation matrix for cowpea, second season.
(significant values more than 51, highly significant values more than 62).

33																								
27	85																							
25	85	88																						
36	83	67	64																					
6	81	67	63	58																				
28	76	70	63	55	78																			
-34	73	60	54	64	72	66																		
-1	66	61	50	57	82	64	66																	
4	70	76	66	39	66	53	57	61																
30	66	65	55	49	65	71	39	60	61															
-21	53	46	41	38	73	63	67	58	30	18														
-24	44	33	31	49	45	41	46	40	25	53	39													
-26	28	19	15	32	45	30	47	42	18	36	49	93												
-23	15	5	-8	33	38	20	54	52	3	14	48	58	70											
20	24	21	13	28	52	51	64	45	6	12	77	36	50	54										
31	50	35	51	38	38	36	9	22	18	37	26	60	47	10	-5									
39	55	40	51	42	38	40	6	20	26	47	18	61	42	2	-16	96								
32	42	32	30	32	21	32	-5	6	31	53	-7	46	23	-12	-39	58	78							
22	14	11	14	-8	1	-11	-31	-3	21	2	-11	-11	-19	-29	-70	37	47	55						
-40	-4	-3	-22	0	-19	-2	-20	-20	8	17	-40	-13	-27	-29	-42	-33	-8	54	25					
-12	43	38	25	36	31	40	63	13	46	24	12	9	4	2	30	-22	-15	1	-37	25				
-13	41	41	17	35	20	36	53	3	41	17	11	5	-1	0	20	-19	-10	10	-21	34	91			
-50	-22	-31	-36	-1	-48	-16	-7	-52	-37	-37	-27	-13	-19	-13	-4	-26	-21	0	-25	37	42	48		
-29	46	41	22	45	44	26	15	45	35	58	8	6	-1	9	0	8	14	17	10	10	11	14	-28	
var.	33	27	25	36	6	28	-34	-1	4	30	-21	-24	-26	-23	20	31	39	32	22	-40	-12	-13	-50	-29

season the groundwater class during the whole growing season was found to be significantly correlated with yield. No clear conclusions can be drawn from these correlations.

Soybean.

The correlation matrices for the major first, the second and the dry season are given in Fig. G-12, G-13 and G-14. From these matrices, different group(s) of variables can be derived which are significantly correlated with yield; these groups differ per season. The diagrams showing the correlation-coefficients with the yield of soybean and the variables significantly correlated with the yield and the correlation-coefficients between these variables are given in Fig. G-15, G-16 and G-17, for the major first, the second and the dry season respectively. The group(s) of variables significantly correlated with yield consist(s) of:

- for the major first season one group of variables, divided into two subgroups:
    - variable no. 6 (the lowest groundwater level during the whole growing season) as representing limitation of yield by shortage of water.
    - variable no. 4 (the highest groundwater level during the whole growing season) as representing limitation of yield by excess of water.
- for the second season there are two groups of variables:
    - a group of variables concerning excess of water:
      variable no. 15 (the number of days during the first week after planting that groundwater is at less than 25 cm depth), no. 11 (the number of days during the first week after planting that groundwater is at less than 10 cm depth), no. 9 (the number of days during the first week after planting that groundwater is at less than 0 cm depth) and no. 3 (the groundwater class during the first week after planting) and shortage of water:
      variable no. 6 (the lowest groundwater level during the whole growing season). Significantly correlated with variables no. 3 and 6 are variable no. 25 (the depth of *in situ* weathered clay), no. 27 (the depth of a very gravelly layer) and no. 28 (the depth of a gravelly layer); it is uncertain whether these variables are yield-determining factors.
    - a group of variables concerning the exchangeable Ca-content of the surface soil: variable no. 31 (the exchangeable Ca-content of the surface soil) and no. 39 (the sum of Ca, Mg, K and Na); variables 31 and 39 are very closely related ($r = 0.96$).
- for the dry season there is one group of variables representing an excess of water: variable no. 15 (the number of days during the first week after planting that groundwater is at less than 25 cm) and no. 1 (the groundwater class during the whole growing season); related to these two variables is variable no. 22 (the percentage clay in the surface soil).

Fig. G-12. Correlation matrix for soybean, major first season.
(significant values more than 61, highly significant values more than 73).

6																							
28	87																						
-1	77	77																					
-34	78	68	73																				
33	74	76	51	75																			
4	73	74	54	74	90																		
27	66	70	49	64	86	87																	
-50	75	65	53	71	77	74	72																
25	60	64	42	61	85	77	85	85															
-21	83	58	54	70	54	42	45	61	43														
36	52	54	44	62	79	59	60	47	57	41													
-3	62	47	41	53	49	61	59	61	65	58	19												
20	73	52	76	70	29	27	23	48	20	77	37	39											
30	49	67	48	36	59	68	62	57	53	5	40	17	9										
-22	27	21	60	40	-6	0	-6	17	-5	16	18	5	73	7									
-24	42	33	41	46	38	26	26	48	25	47	49	-4	48	35	24								
-26	42	23	43	46	23	15	13	43	12	56	33	2	61	19	32	94							
-23	36	14	36	49	13	4	2	21	-7	53	35	-2	61	3	36	66	77						
31	14	14	0	-2	33	9	17	36	34	21	28	-10	-6	17	-32	56	44	15					
39	12	18	-7	-8	39	18	23	29	35	10	32	-14	-22	28	-47	51	33	3	94				
32	0	14	-22	-20	28	25	20	-3	13	-19	21	-21	-50	35	-60	22	-1	-24	43	69			
-40	-18	0	-23	-23	-2	11	0	-42	-20	-42	0	-22	-47	16	-32	-30	-44	-41	-40	-9	63		
-29	15	18	-3	4	36	41	37	23	14	-6	33	-3	-10	57	-10	0	-8	2	5	12	17	11	
var.	6	28	-1	-34	33	4	27	-50	25	-21	36	-3	20	30	-22	-24	-26	-23	31	39	32	-40	-29

Fig. G-13. Correlation matrix for soybean, second season.
(significant values more than 42, highly significant values more than 52).

6																										
-34	84																									
4	78	67																								
-1	75	65	72																							
-3	77	68	65	50																						
-15	73	64	66	50	77																					
-11	65	53	58	47	69	90																				
33	71	63	66	58	52	40	32																			
28	61	43	45	54	59	49	42	25																		
26	1	-24	21	9	18	23	34	-13	30																	
24	-3	-27	13	4	15	19	30	-20	19	96																
23	2	-14	27	22	12	24	35	-10	28	84	81															
-20	-20	-35	8	-3	0	10	28	-18	-2	82	77	78														
21	-34	-44	-3	-23	-16	8	20	-31	-17	70	67	66	84													
22	0	-14	16	15	15	9	29	-2	11	67	63	66	85	44												
32	-9	-40	5	6	-6	2	11	5	13	58	44	45	66	50	62											
39	-6	-31	3	-1	7	8	19	-1	24	56	42	38	60	40	62	79										
31	-5	-24	1	-5	11	10	20	-8	26	50	37	32	52	32	55	60	96									
-9	42	19	42	28	47	51	61	7	33	51	47	40	36	29	35	18	31	34								
50	53	32	30	32	56	65	65	21	65	41	33	26	21	4	31	37	52	52	43							
25	45	38	32	36	41	34	29	46	66	21	6	22	4	-16	18	22	38	39	17	61						
27	59	46	48	43	52	41	35	43	73	15	5	19	-2	-25	16	12	17	16	20	55	79					
36	31	14	21	3	17	14	7	45	32	2	-12	-25	-20	-20	-16	28	30	25	3	40	50	36				
29	-26	-34	-27	-5	-15	-2	0	-44	26	39	37	28	25	18	22	39	54	56	5	35	23	10	5			
30	21	5	15	9	19	18	13	52	16	17	8	6	16	29	0	41	28	17	0	25	32	18	40	-13		
40	11	28	1	-8	29	14	14	-10	18	-14	-12	-16	-21	-28	-9	-51	9	34	16	16	21	13	-8	13	-30	
var.	6	-34	4	-1	-3	-15	-11	33	28	26	24	23	-20	21	22	32	39	31	-9	50	25	27	36	29	30	40

Fig. G-14. Correlation matrix for soybean, dry season.
(significant values more than 86, highly significant values more than 94).

20																							
-3	85																						
-1	84	99																					
-15	79	95	97																				
-22	82	92	94	98																			
-50	83	55	99	95	92																		
-32	75	70	73	83	90	70																	
-39	54	80	80	79	80	80	65																
-34	78	74	74	72	72	74	70	71															
-31	34	67	66	61	59	67	36	94	56														
30	55	72	69	57	58	72	30	62	25	65													
6	82	69	64	47	48	69	31	44	68	40	62												
4	58	67	62	42	37	67	6	53	54	63	71	88											
36	69	52	52	47	55	52	64	56	84	41	25	67	43										
-23	69	33	34	33	42	33	63	24	73	2	0	57	18	89									
28	53	57	54	42	42	57	21	61	46	65	69	67	75	27	12								
-26	73	42	41	40	40	42	46	-5	55	-27	-3	56	21	50	72	-1							
27	52	48	43	24	23	48	5	48	60	57	54	88	91	62	41	74	20						
33	41	36	31	15	14	36	4	42	65	49	29	78	78	73	51	46	25	92					
-24	73	42	41	40	40	42	46	-5	55	-27	-3	56	21	50	72	-1	100	20	25				
-21	59	15	11	0	4	15	12	-15	43	-24	4	73	41	55	74	27	75	57	55	75			
40	42	7	10	22	31	7	59	-21	17	-52	-25	-1	-44	27	60	-36	69	-39	-33	69	38		
-29	1	1	-2	-13	-7	1	-11	6	-9	14	40	29	28	36	14	-9	-11	34	42	-11	13	-17	
var.	20	-3	-1	-15	-22	-50	-32	-39	-34	-31	30	6	4	36	-23	28	-26	27	33	-24	-21	40	-29

Fig. G-15. Diagram showing the correlation-coefficients between the yield of soybean and the variables significantly correlated with the yield and the correlation-coefficients between these variables, major first season (significant values more than 61, highly significant values more than 73).

variable								
lowest groundwater level during whole growing season (no. 6)								
highest groundwater level during whole growing season (no. 4)	73							
depth of *in situ* weathered clay (no. 25)	60	77						
exchangeable K-content of the surface soil (no. 33)	74	90	85					
depth of a very gravelly layer (no. 27)	66	87	85	86				
exchangeable Na-content of the surface soil (no. 34)	-78	-74	-61	-75	-64			
depth of a gravelly layer (no. 28)	87	74	64	76	70	68		
soybean yield (no. 50)	-75	-74	-85	-77	-72	71	-65	
variable no.	6	4	25	33	27	34	28	50

Fig. G-16. Diagram showing the correlation-coefficients between the yield of soybean and the variables significantly correlated with the yield and the correlation-coefficients between these variables, second season (significant values more than 42, highly significant values more than 52).

variable											
number of days groundwater at less than 25 cm during the first week after planting (no. 15)											
number of days groundwater at less than 10 cm during the first week after planting (no. 11)	90										
number of days groundwater at less than 0 cm during the first week after planting (no. 9)	51	61									
groundwater class during first week after planting (no. 3)	77	69	47								
lowest groundwater level during whole growing season (no. 6)	-73	-65	-42	-77							
depth of a gravelly layer (no. 28)	-49	-42	-33	-59	61						
depth of *in situ* weathered clay (no. 25)	-34	-29	-17	-41	45	66					
depth of a very gravelly layer (no. 27)	-41	-35	-20	-52	59	73	79				
Ca + Mg + K + Na (no. 39)	-8	-19	-31	-7	-6	24	38	17			
exchangeable Ca-content of the surface soil (no. 31)	-10	-20	-34	-11	-5	26	39	16	96		
soybean yield (no. 50)	-65	-65	-43	-56	53	65	61	55	52	52	
variable no.	15	11	9	3	6	28	25	27	39	31	50

Fig. G-17. Diagram showing the correlation-coefficients between the yield of soybean and the variables significantly correlated with the yield and the correlation-coefficients between these variables, dry season (significant values more than 86, highly significant values more than 94).

variable				
groundwater class during whole growing season (no. 1)				
number of days groundwater at less than 25 cm depth during first week after planting (no. 15)	97			
per cent clay in the surface soil (no. 22)	94	98		
soybean yield (no. 50)	99	95	92	
variable no.	1	15	22	50

Appendix H. Yield data of rice, maize, cowpea and soybean, obtained in toposequence experiments in Eastbank area I, 1972-1976.

Table H-1. Yield data (in q/ha) of rice per groundwater class for the major first and the second season (1973-1976).

MAJOR FIRST SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1973	23 28	29 20	21	-	26	30	-	-	31 42	25	-
	20 18	37 45			29	28			39	42	
	6 17	41 47			44				34	23	
	17 30	34 32			48				44		
	12 26	17 28			39				57		
	3 27	13 40			33				25		
	38	28							35		
1974	1	5 21	-	-	22	25	-	-	26	25 19	30
	10	3 20			22	28			21	27	7
	12	22 30			20				10	34	25
		18 31			19					22	
		1 8								18	
		1 11								12	
		29 17								15	
1975	-	0 0	0	7	22	34	-	-	24	12	23
		0			28						
total	288	628	21	7	352	145	0	0	388	274	85
number	16	30	2	1	12	5	0	0	12	12	4
average	18	21	11	7	29	29	-	-	32	23	21
no. < 5 q	2	6	1	0	0	0	0	0	0	0	0

SECOND SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1973	0 0	0 0	0	-	7	22	12	31	28	22 25	21
	0 0	0 18			0	20		10	23	23 23	14
	0 0	0 0			12	25			35	26	16
	0 0	0 0			0	28			26	17	
	0 0	0								28	
	0	0								31	
1974	0 0	0	0	0	0	2	-	4	1	0	2
	0 0	1		0					7	2	0
	0 0	0							7		
	0 0	0							5		
1975	-	-	-	-	-	-	-	-	-	21	31 38
											23 32
1976	- -		-	-	-	7	10 13	-	-	17	-
							19 11			10	
total	0	19	0	0	19	104	65	45	132	246	177
number	19	14	2	2	5	6	5	3	8	13	9
average	0	1	0	0	4	17	13	15	17	19	20
no. < 15 q	19	13	2	2	3	1	0	1	1	2	2

Table H-2. Yield data (in q/ha) of maize per groundwater class[1] for the dry, early first, major first and second season (1973-1976).

DRY SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1973/1974	7	17	28 30 2	-	-	35 19 19	11 20 35 23	-	-	3	-
1974/1975	-	-	-	-	-	-	40 29 32 33 28 12 46	-	-	-	-
total	7	17	60	0	0	73	309	0	0	3	0
number	1	1	3	0	0	3	11	0	0	1	0
average	7	17	20	-	-	24	28	-	-	3	-
no. < 6 q	0	0	1	0	0	0	0	0	0	1	0

EARLY FIRST SEASON	groundwater class										
year of cultviation	1	2	3	4	5	6	7	8	9	10	11
1975	-	-	38 3 41	-	-	23 40 44	-	-	-	31	-
1976	-	-	21	-	-	25 16 50 18 20 12 21	21 22 46 24 49 28 21 15 34	-	-	16	0
total	0	0	103	0	0	269	260	0	0	47	0
number	0	0	4	0	0	10	9	0	0	2	1
average	-	-	26	-	-	27	29	-	-	24	0
no. < 6 q	0	0	1	0	0	0	0	0	0	0	1

MAJOR FIRST SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1973	56 45 28 41 20 52 29 36 27 40	49 47	47 59 30 33 53	-	-	29 38 44 31 46	-	-	-	3	-
1974	34 65 38 44	50 79 54 61 69	42	-	39 61 30	8	-	-	11 31 13	5 2 21 8 5 3	-
1975	43 53 38 57 42 34 54 32 52 42 58 28	48 47 51 23	53 41 31 31	-	28	0 28	-	8	15	-	-
total	1088	578	420	0	158	224	0	8	70	47	0
number	26	11	10	0	4	8	0	1	4	7	0
average	42	53	42	-	40	28	-	8	18	7	0
no..< 6 q	0	0	0	0	0	1	0	0	0	5	0

SECOND SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1973	-	15 17 20 18 17 21 20 16 22	-	-	16	17	0	-	0 5	0 0 0 0	0 0 0 0 0
1974	10 11	19 30 16 13 13 20	-	-	26 15 22 6	-	0	-	1 9 0	0 0 1 0 0 0	0
1975	22	32 26 27	26 17	-	28	-	0	-	0	0 0 7	-
total number	43	362	43	0	113	17	0	0	15	8	0
number	3	18	2	0	6	1	3	0	6	13	6
average	14	20	22	-	19	17	0	-	3	1	0
no. < 6 q	0	0	0	0	0	0	3	0	5	12	6

Note: [1]groundwater class determined for the first eight weeks after planting.

Table H-3. Yield data (in q/ha) of cowpea per groundwater class for the major first and the second season (1972-1974).

MAJOR FIRST SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1973	17 13 9 11	15	12 13 14	-	-	-	-	-	-	-	-
1974	-	13 11 12	-	1	16	4	-	-	10 6 9	-	-
total	50	51	39	0	16	4	0	0	25	0	0
number	4	4	3	0	1	1	0	0	3	0	0
average	13	13	13	-	16	4	-	-	8	-	-
no. < 2 q	0	0	0	0	0	0	0	0	0	0	0

SECOND SEASON	groundwater class										
year of cultivation	1	2	3	4	5	6	7	8	9	10	11
1972	-	17 14 13	-	11	16	10 7	-	17	-	-	-
1973	-	5 5 5	-	-	2	0 0 0	-	-	-	0	-
1974	-	11 6 7	-	4	3	1 1	-	-	0	-	-
total	0	83	0	15	21	19	0	17	0	0	0
number	0	9	0	2	3	7	0	1	1	1	0
average	-	9	-	8	7	3	-	17	0	0	-
no. < 2 q	0	0	0	0	0	5	0	0	1	1	0

Table H-4. Yield data (in q/ha) of soybean per groundwater class for the dry, major first and second season (1972-1976).

DRY SEASON	groundwater class										
year cultivation	1	2	3	4	5	6	7	8	9	10	11
1973/1974	14	-	15 14 25 24 24	-	-	26	-	-	-	-	-
1975/1976	-	-	-	-	-	5	7 3 7 8 6 8	-	-	-	-
total	14	0	102	0	0	31	39	0	0	0	0
number	1	0	5	0	0	2	6	0	0	0	0
average	14	-	20	-	-	16	7	-	-	-	-
no. < 3 q	0	0	0	0	0	0	0	0	0	0	0

MAJOR FIRST SEASON	groundwater class										
year cultivation	1	2	3	4	5	6	7	8	9	10	11
1973	18	12 29 17	25 29	-	-	34 32	-	-	-	-	-
1974	-	26 15 21 25	-	-	33	31 33	-	-	30	-	-
total	18	145	54	0	33	130	0	0	30	0	0
number	1	7	2	0	1	4	0	0	1	0	0
average	18	21	27	-	33	33	-	-	30	-	-
no. < 3 q	0	0	0	0	0	0	0	0	0	0	0

SECOND SEASON	groundwater class										
year cultivation	1	2	3	4	5	6	7	8	9	10	11
1972	-	24 26 29 13 27	6	-	7	8	-	-	-	-	-
1973	-	24 26	-	-	19	21	-	22	10	3 3	-
1974	3	6 7 8 16 9 25	-	-	24 27	10 14	-	-	0 25 12	0 2 0 14 0	-
1975	9	12 9 9	-	-	5	2	-	-	-	2 6 5	-
total	12	270	6	0	82	55	0	22	47	35	0
number	2	16	1	0	5	5	0	1	4	10	0
average	6	17	6	-	16	11	-	22	12	4	-
no. < 3 q	0	0	0	0	0	1	0	0	1	5	0

Appendix I. The removal of N, P and K per reference yield of some of the studied crops (all numbers are indicated per hectare).

crop	ref.[1]	N	P	K	N+P+K	reference yield[2] (kg)	removal of N+P+K per ref. yield (kg)	average (kg)
		kg						
rice panicle	(1)	10.0	2.7	2.3	15.0			
grain	(2)	21.9	2.3	3.4	27.6			
grain	(3)	22.1	2.3	3.4	27.8			
grain	(4)	11.0	2.9	3.3	17.2			
			range		15 - 28	2000	30- 56	43
maize grain	(5)	13.7	3.3	4.1	21.1			
grain	(6)	27.9	10.3	20.5	58.7			
grain	(4)	16.9	3.0	4.0	23.9			
			range		21 - 59	2300	48-136	92
cassava								
tubers	(7)	2.1	0.7	5.8	8.6			
tubers	(2)	6.4	0.7	4.5	11.6			
tubers	(8)	1.7	0.6	6.1	8.4			
			range		8 - 12	20000	160-240	200
sweet potato								
tubers	(2)	4.7	0.6	6.1	11.4			
tubers	(8)	4.6	0.6	6.1	11.3			
			range		11	12000	132	132
soybean								
grain	(6)	82.4	26.5	39.4	148.3			
grain	(8)	62.6	6.3	15.7	84.6			
			range		85 -148	650	55- 96[3]	76[3]
tomato								
fruits	(9)	5.1	4.4	5.9	15.4			
fruits	(6)	5.0	1.7	8.8	15.5			
fruits	(8)	2.7	0.3	3.3	6.3			
fruits	(4)	1.6	0.3	2.7	4.6			
			range		5 - 16	10000	50-160	105
banana/ plantain								
fruits	(10)[4]	2.0	1.1	5.0	8.1			
fruits	(11)[4]	2.6	0.2	2.2	5.0			
fruits	(8)[5]	0.8	0.1	2.2	3.1			
			range		3 - 8	15000	45-140	93

Notes:

1 : (1). IRRI (1963)
(2). ILRI (1972)
(3). Gerboria (1954)
(4). Potash Inst. N. Amer. (1972), cited by Tisdale and Nelson (1975)
(5). Barber and Olson (1968)
(6). Ignatieff and Page (1958)
(7). Cours and Fritz (1961)
(8). Jacob and Uexküll (1963)
(9). Geraldson (1964)
(10). De Geus (1973)
(11). Champion et al. (1958)

2 : for these figures reference is made to Appendix K.

3 : root nodules supply a substantial amount of nitrogen.

4 : means of resp.: (1.3-3.8, 0.1-0.3 and 0.7-3.6).

5 : means of resp.: (0.6-1.0, 0.1-0.1 and 1.9-2.5).

Appendix J. The calculated ecological suitability, the expected yield per groundwater class (per season), the ecological crop suitability and the most limiting land qualities, determined for each management unit per crop per relevant season.

Notes:

Explanation of the method followed see Chapter 8.

Abbrevations:

suit. = calculated ecological suitability (calculated from requirements of crops and prevailing land qualities).

yield exp./yld exp. = expected yield per groundwater class (per season).

res. = result of matching process, ecological crop suitability.

suit., yield exp. and res. are expressed in four class system, in which 1 = high, 2 = moderate, 3 = restricted and 4 = low.

lim. fact. = most limiting factor(s); those land qualities which determine the calculated ecological suitability.

w = availability of water

o = availability of oxygen

f = availability of nutrients (fertility)

n = response to applied N

e = occurrence of soil erosion

i = impediment of root development

t = occurrence of iron toxicity (in rice)

Order of crops, as mentioned in this appendix:

rice, maize, yam, cassava, sweet potato, cowpea, soybean, pigeon pea, cocoyam, tomato, okra, celosia, sweet pepper, plantain and banana.

[1]: means that the ecological crop suitability with improved management is actually higher than indicated, but the most limiting land quality was not improved by management, so that the ecological crop suitability with improved management was reduced to the one with traditional management.

soil unit	ground-water class	phase	rice, dry season: traditional suit.	yld exp.	res.	lim. fact.	rice, dry season: improved suit.	yld exp.	res.	lim. fact.	rice, major first season: traditional suit.	yld exp.	res.	lim. fact.	rice, major first season: improved suit.	yld exp.	res.	lim. fact.	rice, second season: traditional suit.	yld exp.	res.	lim. fact.	rice, second season: improved suit.	yld exp.	res.	lim. fact.
4	1	-	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	4	4	4	w	4	4	4	w
4	1	cs	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	4	4	4	w	4	4	4	w
4	2	-	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	3-4	4	4	w	3-4	4	4	w
4	2	cs	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	4	4	4	w	4	4	4	w
4	3	-	4	4	4	f	3	4	3	f	4	2-3	3	f	3	2	3	f	4	4	4	f	3	3-4	3	f
4	3	cs	4	4	4	f	3-4	4	4	w	4	2-3	3	f	3-4	2	3	w	4	4	4	f	3-4	3-4	4	w
4	4	-	4	4	4	w	4	4	4	w	3-4	3	4	w	3-4	2-3	3	w	3-4	4	4	w	3-4	4	4	w
4	4	cs	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	3	w	4	4	4	w	4	4	4	w
4	5	-	4	3	4	f	3-4	2-3	3	w	4	1	3	f	3	1	2	f	4	3	4	f	3	2	3	f
4	5	cs	4	3	4	f	4	2-3	3	w	4	1	3	w,f	3	1	2	w,f	4	3	4	w,f	4	2	3	w
4	6	-	4	2-3	3	f	3	2	3	f	4	1	3	f	3	1	2	f	4	2	3	f	3	1	2	f
4	6	cs	4	2-3	3	f	3	2	3	f	4	1	3	f	3	1	2	f	4	2	3	f	3	1	2	f
4	7	-	4	2	3	f,n	3	2	3	f	4	1	3	f,n	3	1	2	f	4	2	3	f,n	3	1	2	f
4	7	cs	4	2	3	f,n	3	2	3	f	4	1	3	f,n	3	1	2	f	4	2	3	f,n	3	1	2	f
4	8	-	4	3	4	f	3	2-3	3	f	4	1	3	f	3	1	2	f	4	2	3	f	3	2	3	f
4	8	cs	4	3	4	f	3-4	2-3	3	w	4	1	3	f	3	1	2	w,f	4	2	3	f	3	2	3	w,f
4	9	-	4	2	3	f	3	2	3	f	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f
4	9	cs	4	2	3	f	3	2	3	f	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f
4	9	ir	4	2	3	f	3	2	3	f	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f
4	10	-	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f
4	10	cs	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f
4	10	ir	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f	4	1	3	f	3	1	2	f
4	11	-	4	1-2	3	f	3	1-2	2	f	4	1-2	3	f	3	1	2	f	4	2	3	f	3	1-2	2	f
4	11	cs	4	1-2	3	f	3	1-2	2	f	4	1-2	3	f	3	1	2	f	4	2	3	f	3	1-2	2	f
4	11	ir	4	1-2	3	f,t	3	1-2	2	f,t	4	1-2	3	f,t	3	1	2	f,t	4	2	3	f,t	3	1-2	2	f,t
5	1	-	4	4	4	w	4	4	4	w	3-4	3	3	w	3-4	2-3	3	w	3	4	3	w	3	4	3	w
6	1	-	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	4	4	4	w	4	4	4	w
6	1	i_s	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	4	4	4	w	4	4	4	w
6	1	i_d	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	4	4	4	w	4	4	4	w
6	2	-	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	3-4	4	4	w,f	3-4	4	4	w
6	2	i_s	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	3-4	4	4	w,f	3-4	4	4	w
6	2	i_d	4	4	4	w	4	4	4	w	4	3	4	w	4	2-3	4^+	w	3-4	4	4	w,f	3-4	4	4	w
7,8	1	-	4	4	4	w	4	4	4	w	3-4	3	3	w	3-4	2-3	3	w	3	4	3	w	3	4	3	w
7	1	i_s	4	4	4	w	4	4	4	w	3-4	3	3	w	3-4	2-3	3	w	3	4	3	w	3	4	3	w
7	1	i_d	4	4	4	w	4	4	4	w	3-4	3	3	w	3-4	2-3	3	w	3	4	3	w	3	4	3	w
7,8	1	se	4	4	4	w,e	4	4	4	w,e	4	3	4	e	4	2-3	4^+	e	4	4	4	e	4	4	4	e
9	1	-	4	4	4	w	4	4	4	w	2-3	3	3	w	2-3	2-3	3	w	2	4	3	w	2	4	3	w
9	1	er	4	4	4	w	4	4	4	w	3	3	3	f	1-2	2-3	2	w	3	4	3	f	1	4	2	-
9	1	i_s	4	4	4	w	4	4	4	w	2-3	3	3	w	2-3	2-3	3	w	2	4	3	w,i	2	4	3	w,i
9	1	i_d	4	4	4	w	4	4	4	w	2-3	3	3	w	2-3	2-3	3	w	2	4	3	w	2	4	3	w
9	1	se	4	4	4	w,e	4	4	4	w,e	4	3	4	e	4	2-3	4^+	e	4	4	4	e	4	4	4	e
A,B	1	-	4	4	4	w	4	4	4	w	3-4	3	3	w	3-4	2-3	3	w	3	4	3	w	3	4	3	w
A,B	1	se	4	4	4	w,e	4	4	4	w,e	4	3	4	e	4	2-3	4^+	e	4	4	4	e	4	4	4	e
C	1	-	4	4	4	w	4	4	4	w	2-3	3	3	w,f	2-3	2-3	3	w	2-3	4	3	f	2	4	3	w
C	2	-	3-4	4	4	w	3	4	4^+	w	2-3	3	3	f	2	2-3	2	w	2-3	4	3	f	1-2	4	2	w

soil unit	ground-water class	phase	rice, dry season: traditional: suit.	yld exp.	res.	lim. fact.	rice, dry season: improved: suit.	yld exp.	res.	lim. fact.	rice, major first season: traditional: suit.	yld exp.	res.	lim. fact.	rice, major first season: improved: suit.	yld exp.	res.	lim. fact.	rice, second season: traditional: suit.	yld exp.	res.	lim. fact.	rice, second season: improved: suit.	yld exp.	res.	lim. fact.
1	1	–	4	4	4	w	4	4	4	w	2-3	3	3	w	2-3	2-3	3	w	2	4	3	w	2	4	3	w
1	1	cl	4	4	4	w	4	4	4	w	1-2	3	2	w	1-2	2-3	2	w	1	4	2	–	1	4	2	–
1	2	–	3-4	4	4	w	3-4	4	4	w	1-2	3	2	w	1-2	2-3	2	w	1-2	4	2	w	1-2	4	2	w
1	2	cl	3	4	3	w	3	4	3	w	1-2	3	2	w	1-2	2-3	2	w	1	4	2	–	1	4	2	–
1	3	–	1	4	2	–	1	4	2	–	1	2-3	2	–	1	2	1	–	1	4	2	–	1	3-4	2	–
1	3	cl	1	4	2	–	1	4	2	–	1	2-3	2	–	1	2	1	–	1	4	2	–	1	3-4	2	–
1	4	–	3-4	4	4	w	3-4	4	4	w	1-2	3	2	w	1-2	2-3	2	w	1-2	4	2	w	1-2	4	2	w
1	4	cl	3	4	3	w	3	4	3	w	1	3	2	–	1	2-3	2	–	1	4	2	–	1	4	2	–
1	5	–	1-2	3	2	n	1	2-3	2	–	1-2	1	1	n	1-2	1	1	n	1-2	3	2	n	1-2	2	2	n
1	5	cl	1-2	3	2	n	1	2-3	2	–	1-2	1	1	n	1-2	1	1	n	1-2	3	2	n	1-2	2	2	n
1	6	–	2-3	2-3	3	n	1-2	2	2	n	2-3	1	2	n	2	1	2	n	2-3	2	2	n	2	1	2	n
1	6	cl	2-3	2-3	3	n	1-2	2	2	n	2-3	1	2	n	2	1	2	n	2-3	2	2	n	2	1	2	n
1	7	–	4	2	3	n	2-3	2	2	n	4	1	3	n	2-3	1	2	n	4	2	3	n	2-3	1	2	n
1	7	cl	4	2	3	n	2-3	2	2	n	4	1	3	n	2-3	1	2	n	4	2	3	n	2-3	1	2	n
1	8	–	2-3	3	3	n	1-2	2-3	2	n	2-3	1	2	n	1-2	1	1	n	2-3	2	2	n	1-2	2	2	n
1	8	cl	2-3	3	3	n	1-2	2-3	2	n	2-3	1	2	n	1-2	1	1	n	2-3	2	2	n	1-2	2	2	n
1	9	–	3	2	3	n	2	2	2	n	3	1	2	n	2	1	2	n	3	1	2	n	2	1	2	n
1	9	cl	3	2	3	n	2	2	2	n	3	1	2	n	2	1	2	n	3	1	2	n	2	1	2	n
1	9	ir	3	2	3	n	2	2	2	n	3	1	2	n	2	1	2	n	3	1	2	n	2	1	2	n
1	10	–	2-3	1	2	n	1-2	1	1	n	2-3	1	2	n	1-2	1	1	n	2-3	1	2	n	1-2	1	1	n
1	10	cl	2-3	1	2	n	1-2	1	1	n	2-3	1	2	n	1-2	1	1	n	2-3	1	2	n	1-2	1	1	n
1	10	ir	3	1	2	t	2	1	2	t	3	1	2	t	2	1	2	t	3	1	2	t	2	1	2	t
1	11	–	1	1-2	1	–	1	1-2	1	–	1	1-2	1	–	1	1	1	–	1	2	1	–	1	1-2	1	–
1	11	cl	1	1-2	1	–	1	1-2	1	–	1	1-2	1	–	1	1	1	–	1	2	1	–	1	1-2	1	–
1	11	ir	4	1-2	3	t	3	1-2	2	t	4	1-2	3	t	3	1	2	t	4	2	3	t	3	1-2	2	t
2,3,D	1	–	4	4	4	w	4	4	4	w	3-4	3	3	w	3-4	2-3	3	w	3	4	3	w	3	4	3	w
2,3,D	2	–	4	4	4	w	4	4	4	w	3	3	3	w	3	2-3	3	w	2-3	4	3	w,f	2-3	4	3	w
2,3,D	3	–	2-3	4	3	f	1-2	4	2	w	2-3	2-3	3	f	1-2	2	2	w	2-3	4	3	f	1-2	3-4	2	w
2,3,D	4	–	4	4	4	w	4	4	4	w	2-3	3	3	w,f	2-3	2-3	3	w	2-3	4	3	w,f	2-3	4	3	w
2,3,D	5	–	2-3	3	3	w,f	2-3	2-3	3	w	2-3	1	2	f	2	1	2	w	2-3	3	3	f	2	2	2	w,f
2,3,D	6	–	2-3	2-3	3	f,n	1-2	2	2	n	2-3	1	2	f,n	1-2	1	1	n	2-3	2	2	f,n	1-2	1	1	n
2,3,D	7	–	4	2	3	n	2-3	2	2	n	4	1	3	n	2-3	1	2	n	4	2	3	n	2-3	1	2	n
2,3,D	8	–	2-3	3	3	f,n	2	2-3	2	w	2-3	1	2	f,n	2	1	2	w	2-3	2	2	f,n	2	2	2	w,f
2,3,D	9	–	3	2	3	n	2	2	2	n	3	1	2	n	2	1	2	n	3	1	2	n	2	1	2	n
2,3,D	9	ir	3	2	3	n	2	2	2	n	3	1	2	n	2	1	2	n	3	1	2	n	2	1	2	n
2,3,D	10	–	2-3	1	2	f,n	1-2	1	1	n	2-3	1	2	f,n	1-2	1	1	n	2-3	1	2	f,n	1-2	1	1	n
2,3,D	10	ir	3	1	2	t	2	1	2	t	3	1	2	t	2	1	2	t	3	1	2	t	2	1	2	t
2,3,D	11	–	~~2-3~~	~~1-2~~	2	f	1	1-2	1	–	2-3	1-2	2	f	1	1	1	–	2-3	2	2	f	1	1-2	1	–
2,3,D	11	ir	4	1-2	3	t	3	1-2	2	t	4	1-2	3	t	3	1	2	t	4	2	3	t	3	1-2	2	t

soil unit	ground-water class	phase	maize, dry season											
			traditional				improved				traditional			
			suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
1	1	–	4	4	4	w	4	4	4	w	2–3	4	3	w
1	1	cl	4	4	4	w	4	4	4	w	2	4	3	w
1	2	–	2–3	3–4	3	w	2–3	3–4	3	w	2	3–4	3	w
1	2	cl	2	3–4	3	w	2	3–4	3	w	1	3–4	2	–
1	3	–	3	3	3	o	3	2–3	3	o	3	2	3	o
1	3	cl	3	3	3	o	3	2–3	3	o	3	2	3	o
1	4	–	2–3	4	3	w	2–3	3	3	w	2	3	2	o
1	4	cl	4	4	4	w	4	3	4	w	1	3	2	–
1	5	–	2–3	2	2	o	2	2	2	n	2	2	2	n
1	5	cl	2–3	2	2	o	2	2	2	n	2	2	2	n
1	6	–	3	2–3	3	o	2–3	2	2	o	3	2	3	o
1	6	cl	3	2–3	3	o	2–3	2	2	o	3	2	3	o
1	7	–	4	3	4	n	3	2	3	o,n	4	3	4	n
1	7	cl	4	3	4	n	3	2	3	o,n	4	3	4	n
1	8	–	3	3	3	o	2–3	2	2	o	3	2	3	o
1	8	cl	3	3	3	o	2–3	2	2	o	3	2	3	o
1	9	–	3–4	4	4	o	3	3	3	o	3–4	3	3	o
1	9	cl	3–4	4	4	o	3	3	3	o	3–4	3	3	o
1	10	–	4	4	4	o	3–4	4	4	o	4	3–4	4	o
1	10	cl	4	4	4	o	3–4	4	4	o	4	3–4	4	o
1	11	–	4	4	4	o	4	4	4	o	4	4	4	o
1	11	cl	4	4	4	o	4	4	4	o	4	4	4	o
2,3,D	1	–	4	4	4	w	4	4	4	w	4	4	4	w
2,3,D	2	–	4	3–4	4	w	4	3–4	4	w	4	3–4	4	w
2,3,D	3	–	2–3	3	3	o,f	2–3	2–3	3	o	2–3	2	2	o,f
2,3,D	4	–	4	4	4	w	4	3	4	w	2–3	3	3	w,f
2,3,D	5	–	2–3	2	2	o,f	2	2	2	f,n	2	2	2	f,n
2,3,D	6	–	3	2–3	3	o	2–3	2	2	o	3	2	3	o
2,3,D	7	–	4	3	4	n	3	2	3	o,n	4	3	4	n
2,3,D	8	–	3	3	3	o	2–3	2	2	o	3	2	3	o
2,3,D	9	–	3–4	4	4	o	3	3	3	o	3–4	3	3	o
2,3,D	10	–	4	4	4	o	3–4	4	4	o	4	3–4	4	o
2,3,D	11	–	4	4	4	o	4	4	4	o	4	4	4	o
4	1	–	4	4	4	w	4	4	4	w	4	4	4	w
4	1	cs	4	4	4	w	4	4	4	w	4	4	4	w
4	2	–	4	3–4	4	w	4	3–4	4	w	4	3–4	4	w
4	2	cs	4	3–4	4	w	4	3–4	4	w	4	3–4	4	w
4	3	–	4	3	4	f	3	2–3	3	f	4	2	3	f
4	3	cs	4	3	4	f	3–4	2–3	3	w	4	2	3	f
4	4	–	4	4	4	w	4	3	4	w	4	3	4	w
4	4	cs	4	4	4	w	4	3	4	w	4	3	4	w
4	5	–	4	2	3	f	3–4	2	3	w	4	2	3	f
4	5	cs	4	2	3	w	4	2	3	w	4	2	3	w
4	6	–	4	2–3	3	f	3	2	3	f	4	2	3	f
4	6	cs	4	2–3	3	f	3	2	3	f	4	2	3	f
4	7	–	4	3	4	f,n	3	2	3	o,f,n	4	3	4	f,n
4	7	cs	4	3	4	f,n	3	2	3	o,f,n	4	3	4	f,n
4	8	–	4	3	4	f	3	2	3	f	4	2	3	f
4	8	cs	4	3	4	f	3–4	2	3	w	4	2	3	f
4	9	–	4	4	4	f	3	3	3	o,f	4	3	4	f
4	9	cs	4	4	4	f	3	3	3	o,f	4	3	4	f
4	10	–	4	4	4	o,f	3	4	3	o	4	3–4	4	o,f
4	10	cs	4	4	4	o,f	3	4	3	o	4	3–4	4	o,f
4	11	–	4	4	4	o,f	4	4	4	o	4	4	4	o,f
4	11	cs	4	4	4	o,f	4	4	4	o	4	4	4	o,f
5	1	–	4	4	4	w	4	4	4	w	4	4	4	w
6	1	–	4	4	4	w	4	4	4	w	4	4	4	w
6	1	i_s	4	4	4	w	4	4	4	w	4	4	4	w
6	1	i_d	4	4	4	w	4	•4	4	w	4	4	4	w
6	2	–	4	3–4	4	w	4	3–4	4	w	4	3–4	4	w
6	2	i_s	4	3–4	4	w	4	3–4	4	w	4	3–4	4	w
6	2	i_d	4	3–4	4	w	4	3–4	4	w	4	3–4	4	w
7,8	1	–	4	4	4	w	4	4	4	w	4	4	4	w
7	1	i_s	4	4	4	w	4	4	4	w	4	4	4	w
7	1	i_d	4	4	4	w	4	4	4	w	4	4	4	w
7,8	1	se	4	4	4	w	4	4	4	w	4	4	4	w,e
9	1	–	4	4	4	w	4	4	4	w	2–3	4	3	w
9	1	er	4	4	4	w	4	4	4	w	3	4	3	f
9	1	i_s	4	4	4	w	4	4	4	w	3	4	3	i
9	1	i_d	4	4	4	w	4	4	4	w	2–3	4	3	w
9	1	se	4	4	4	w	4	4	4	w	4	4	4	e
A,B	1	–	4	4	4	w	4	4	4	w	4	4	4	w
A,B	1	se	4	4	4	w	4	4	4	w	4	4	4	w,e
C	1	–	4	4	4	w	4	4	4	w	2–3	4	3	w,f
C	2	–	3–4	3–4	4	w	3–4	3–4	4	w	2–3	3–4	3	f

maize, early first season				maize, major first season								maize, second season							
improved				traditional				improved				traditional				improved			
suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
2-3	4	3	w	1-2	1	1	w	1-2	1	1	w	1	3-4	2	-	1	3	2	-
2	4	3	w	1-2	1	1	o	1	1	1	-	1	3-4	2	-	1	3	2	-
2	3	3^+	w	1	1	1	-	1	1	1	-	1	3	2	-	1	2-3	2	-
1	3	2	-	1	1	1	-	1	1	1	-	1	3	2	-	1	2-3	2	-
3	2	3	o	3	1	2	o	3	1	2	o	3	2-3	3	o	3	2	3	o
3	2	3	o	3	1	2	o	3	1	2	o	3	2-3	3	o	3	2	3	o
1-2	2-3	2	w	2	1-2	2	o	1	1-2	1	-	2	3-4	3	o	1	2-3	2	-
1	2-3	2	-	2	1-2	2	o	1	1-2	1	-	2	3-4	3	o	1	2-3	2	-
2	1	2	o,n	2-3	2	2	o	2	2	2	n	2-3	3	3	o	2	2	2	o,n
2	1	2	o,n	2-3	2	2	o	2	2	2	n	2-3	3	3	o	2	2	2	o,n
2-3	2	2	o	3	3	3	o	2-3	2-3	3	o	3	3-4	3	o	2-3	2-3	3	o
2-3	2	2	o	3	3	3	o	2-3	2-3	3	o	3	3-4	3	o	2-3	2-3	3	o
3	2-3	3	o,n	4	4	4	n	3	3	3	o,n	4	4	4	n	3	4	3	o,n
3	2-3	3	o,n	4	4	4	n	3	3	3	o,n	4	4	4	n	3	4	3	o,n
2-3	2	2	o	3	3-4	3	o	2-3	2-3	3	o	3	3-4	3	o	2-3	3	3	o
2-3	2	2	o	3	3-4	3	o	2-3	2-3	3	o	3	3-4	3	o	2-3	3	3	o
3	2-3	3	o	3-4	4	4	o	3	3	3	o	3-4	4	4	o	3	4	3	o
3	2-3	3	o	3-4	4	4	o	3	3	3	o	3-4	4	4	o	3	4	3	o
3-4	3	3	o	4	4	4	o	3-4	4	4	o	4	4	4	o	3-4	4	4	o
3-4	3	3	o	4	4	4	o	3-4	4	4	o	4	4	4	o	3-4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o	4	4	4	o	4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o	4	4	4	o	4	4	4	o
4	4	4	w	2-3	1	2	w,f	2-3	1	2	w	2-3	3-4	3	f	2	3	2	w,f
4	3	4	w	2-3	1	2	f	2	1	2	w,f	2-3	3	3	f	2	2-3	2	f
2-3	2	2	o	2-3	1	2	o,f	2-3	1	2	o	2-3	2-3	3	o,f	2-3	2	2	o
2-3	2-3	3	w	2-3	1-2	2	f	2	1-2	2	f	2-3	3-4	3	f	2	2-3	2	f
2	1	2	o,f,n	2-3	2	2	o,f	2	2	2	f,n	2-3	3	3	o,f	2.	2	2	f,n
2-3	2	2	o	3	3	3	o	2-3	2-3	3	o	3	3-4	3	o	2-3	2-3	3	o
3	2-3	3	o,n	4	4	4	n	3	3	3	o,n	4	4	4	n	3	4	3	o,n
2-3	2	2	o	3	3-4	3	o	2-3	2-3	3	o	3	3-4	3	o	2-3	3	3	o
3	2-3	3	o	3-4	4	4	o	3	3	3	o	3-4	4	4	o	3	4	3	o
3-4	3	3	o	4	4	4	o	3-4	4	4	o	4	4	4	o	3-4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o	4	4	4	o	4	4	4	o
4	4	4	w	4	1	3	w	4	1	3	w	4	3-4	4	w	4	3	4	w
4	4	4	w	4	1	3	w	4	1	3	w	4	3-4	4	w	4	3	4	w
4	3	4	w	4	1	3	w	4	1	3	w	3	3	3	f	2-3	2-3	3	w,f
4	3	4	w	4	1	3	w	4	1	3	w	4	3	4	w	4	2-3	4^+	w
3	2	3	f	4	1	3	f	3	1	2	f	4	2-3	3	f	3	2	3	f
3	2	3	f	4	1	3	f	3-4	1	3	w	4	2-3	3	f	3	2	3	f
4	2-3	4^+	w	3	1-2	2	f	2-3	1-2	2	w,f	3	3-4	3	f	2-3	2-3	3	w,f
4	2-3	4^+	w	4	1-2	3	w	4	1-2	3	w	4	3-4	4	w	4	2-3	4^+	w
3	1	2	f	4	2	3	f	3	2	3	f	4	3	4	f	3	2	3	f
4	1	3	w	4	2	3	w,f	4	2	3	w	4	3	4	w,f	4	2	4^+	w
3	2	3	f	4	3	4	f	3	2-3	3	f	4	3-4	4	f	3	2-3	3	f
3	2	3	f	4	3	4	f	3	2-3	3	f	4	3-4	4	f	3	2-3	3	f
3	2-3	3	o,f,n	4	4	4	f,n	3	3	3	o,f,n	4	4	4	f,n	3	4	3	o,f,n
3	2-3	3	o,f,n	4	4	4	f,n	3	3	3	o,f,n	4	4	4	f,n	3	4	3	o,f,n
3	2	3	f	4	3-4	4	f	3	2-3	3	f	4	3-4	4	f	3	3	3	f
3	2	3	f	4	3-4	4	f	3	2-3	3	f	4	3-4	4	f	3	3	3	f
3	2-3	3	o,f	4	4	4	f	3	3	3	o,f	4	4	4	f	3	4	3	o,f
3	2-3	3	o,f	4	4	4	f	3	3	3	o,f	4	4	4	f	3	4	3	o,f
3-4	3	3	o	4	4	4	o,f	3-4	4	4	o	4	4	4	o,f	3-4	4	4	o
3-4	3	3	o	4	4	4	o,f	3-4	4	4	o	4	4	4	o,f	3-4	4	4	o
4	4	4	o	4	4	4	o,f	4	4	4	o	4	4	4	o,f	4	4	4	o
4	4	4	o	4	4	4	o,f	4	4	4	o	4	4	4	o,f	4	4	4	o
4	4	4	w	2-3	1	2	w	2-3	1	2	w	2	3-4	3	w	2	3	3^+	w
4	4	4	w	4	1	3	w	4	1	3	w	4	3-4	4	w	4	3	4	w
4	4	4	w	4	1	3	w	4	1	3	w	4	3-4	4	w	4	3	4	w
4	4	4	w	4	1	3	w	4	1	3	w	4	3-4	4	w	4	3	4	w
4	3	4	w	4	1	3	w	4	1	3	w	3-4	3	3	f	3	2-3	3	f
4	3	4	w	4	1	3	w	4	1	3	w	3-4	3	3	f	3	2-3	3	f
4	3	4	w	4	1	3	w	4	1	3	w	3-4	3	3	f	3	2-3	3	f
4	4	4	w	2-3	1	2	w	2-3	1	2	w	2	3-4	3	w,f	2	3	3^+	w,f
4	4	4	w	3	1	2	i	3	1	2	i	3	3-4	3	i	3	3	3	i
4	4	4	w	2-3	1	2	w	2-3	1	2	w	2	3-4	3	w,f,i	2	3	3^+	w,f,i
4	4	4	w,e	4	1	3	e	4	1	3	e	4	3-4	4	e	4	3	4	e
2-3	4	3	w	1-2	1	1	w	1-2	1	1	w	1	3-4	2	-	1	3	2	-
2	4	3	w,f	3	1	2	f	2	1	2	f	3	3-4	3	f	2	3	2	f
3	4	3	i	3	1	2	i	3	1	2	i	3	3-4	3	i	3	3	3	i
2-3	4	3	w	2	1	2	i	2	1	2	i	2	3-4	3	i	2	3	3^+	i
4	4	4	e	4	1	3	e	4	1	3	e	4	3-4	4	e	4	3	4	e
4	4	4	w	2-3	1	2	w	2-3	1	2	w	2	3-4	3	w,f	2	3	3^+	w,f
4	4	4	w,e	4	1	3	e	4	1	3	e	4	3-4	4	e	4	3	4	e
2-3	4	3	w	2-3	1	2	f	2	1	2	f	2-3	3-4	3	f	2	3	2	f
2	3	2	w,f	2-3	1	2	f	2	1	2	f	2-3	3	3	f	2	2-3	2	f

soil unit	ground-water-class	phase	yam traditional suit.	yam traditional yield exp.	yam traditional res.	yam traditional lim. fact.	yam improved suit.	yam improved yield exp.	yam improved res.	yam improved lim. fact.
1	1	-	1-2	1	1	w	1-2	1	1	w
1	1	cl	1	1	1	-	1	1	1	-
1	2	-	1	1	1	-	1	1	1	-
1	2	cl	1	1	1	-	1	1	1	-
1	3	-	3	1	2	o	3	1	2	o
1	3	cl	3	1	2	o	3	1	2	o
1	4	-	1	1	1	-	1	1	1	-
1	4	cl	1	1	1	-	1	1	1	-
1	5	-	2-3	1-2	2	o	1	1-2	1	-
1	5	cl	2-3	1-2	2	o	1	1-2	1	-
1	6	-	3	2	3	o	2-3	2	2	o
1	6	cl	3	2	3	o	2-3	2	2	o
1	7	-	3-4	4	4	o	3	4	3	o
1	7	cl	3-4	4	4	o	3	4	3	o
1	8	-	3	1-2	2	o	2-3	1-2	2	o
1	8	cl	3	1-2	2	o	2-3	1-2	2	o
1	9	-	3-4	3	3	o	3	2	3	o
1	9	cl	3-4	3	3	o	3	2	3	o
1	10	-	4	4	4	o	3-4	4	4	o
1	10	cl	4	4	4	o	3-4	4	4	o
1	11	-	4	4	4	o	4	4	4	o
1	11	cl	4	4	4	o	4	4	4	o
2,3,D	1	-	2-3	1	2	w,f	2-3	1	2	w
2,3,D	2	-	2-3	1	2	f	2-3	1	2	f
2,3,D	3	-	2-3	1	2	o,f	2-3	1	2	f
2,3,D	4	-	2-3	1	2	f	2-3	1	2	f
2,3,D	5	-	2-3	1-2	2	o,f	2-3	1-2	2	f
2,3,D	6	-	3	2	3	o	2-3	2	2	o
2,3,D	7	-	3-4	4	4	o	3	4	3	o
2,3,D	8	-	3	1-2	2	o	2-3	1-2	2	o
2,3,D	9	-	3-4	3	3	o	3	2	3	o
2,3,D	10	-	4	4	4	o	3-4	4	4	o
2,3,D	11	-	4	4	4	o	4	4	4	o
4	1	-	3-4	1	3	w	3-4	1	3	w
4	1	cs	4	1	3	w	4	1	3	w
4	2	-	3-4	1	3	w	3-4	1	3	w
4	2	cs	3-4	1	3	w	3-4	1	3	w
4	3	-	4	1	3	f	4	1	3	f
4	3	cs	4	1	3	f	4	1	3	f
4	4	-	3	1	2	f	3	1	2	f
4	4	cs	3-4	1	3	w	3-4	1	3	w
4	5	-	4	1-2	3	f	4	1-2	3	f
4	5	cs	4	1-2	3	w,f	4	1-2	3	w,f
4	6	-	4	2	3	f	4	2	3	f
4	6	cs	4	2	3	f	4	2	3	f
4	7	-	4	4	4	f	4	4	4	f
4	7	cs	4	4	4	f	4	4	4	f
4	8	-	4	1-2	3	f	4	1-2	3	f
4	8	cs	4	1-2	3	f	4	1-2	3	f
4	9	-	4	3	4	f	4	2	3	f
4	9	cs	4	3	4	f	4	2	3	f
4	10	-	4	4	4	o,f	4	4	4	f
4	10	cs	4	4	4	o,f	4	4	4	f
4	11	-	4	4	4	o,f	4	4	4	o,f
4	11	cs	4	4	4	o,f	4	4	4	o,f
5	1	-	2-3	1	2	w	2-3	1	2	w
6	1	-	3-4	1	3	w,f	3-4	1	3	w,f
6	1	i_s	3-4	1	3	w,f	3-4	1	3	w,f
6	1	i_d	3-4	1	3	w,f	3-4	1	3	w,f
6	2	-	3-4	1	3	f	3-4	1	3	f
6	2	i_s	3-4	1	3	f	3-4	1	3	f
6	2	i_d	3-4	1	3	f	3-4	1	3	f
7,8	1	-	2-3	1	2	w	2-3	1	2	w
7	1	i_s	3	1	2	i	3	1	2	i
7	1	i_d	2-3	1	2	w	2-3	1	2	w
7,8	1	se	4	1	3	e	4	1	3	e
9	1	-	1-2	1	1	w	1-2	1	1	w
9	1	er	3	1	2	f	3	1	2	f
9	1	i_s	3	1	2	i	3	1	2	i
9	1	i_d	1-2	1	1	w	1-2	1	1	w
9	1	se	4	1	3	e	4	1	3	e
A,B	1	-	2-3	1	2	w	2-3	1	2	w
A,B	1	se	4	1	3	e	4	1	3	e
C	1	-	2-3	1	2	f	2-3	1	2	f
C	2	-	2-3	1	2	f	2-3	1	2	f

il it	groundwater-class	phase	cassava traditional suit.	yield exp.	res.	lim. fact.	cassava improved suit.	yield exp.	res.	lim. fact.
	1	-	1	1,	1	-	1	1	1	-
	1	cl	1	1	1	-	1	1	1	-
	2	-	1	1	1	-	1	1	1	-
	2	cl	1	1	1	-	1	1	1	-
	3	-	2	1	2	o	2	1	2	o
	3	cl	2	1	2	o	2	1	2	o
	4	-	1	1	1	-	1	1	1	-
	4	cl	1	1	1	-	1	1	1	-
	5	-	1-2	3	2	o	1	2	1	-
	5	cl	1-2	3	2	o	1	2	1	-
	6	-	2	4	3	o	1-2	3	2	o
	6	cl	2	4	3	o	1-2	3	2	o
	7	-	2-3	4	3	o	2	4	3	o
	7	cl	2-3	4	3	o	2	4	3	o
	8	-	2	4	3	o	1-2	3	2	o
	8	cl	2	4	3	o	1-2	3	2	o
	9	-	2-3	4	3	o	2	4	3	o
	9	cl	2-3	4	3	o	2	4	3	o
	10	-	3	4	3	o	2-3	4	3	o
	10	cl	3	4	3	o	2-3	4	3	o
	11	-	3-4	4	4	o	3	4	3	o
	11	cl	3-4	4	4	o	3	4	3	o
3,D	1	-	2	1	2	w	2	1	2	w
3,D	2	-	1-2	1	1	w,f	1-2	1	1	w,f
3,D	3	-	1-2	1	1	o,f	1-2	1	1	f
3,D	4	-	1-2	1	1	w,f	1-2	1	1	w,f
3,D	5	-	1-2	3	2	o,f	1-2	2	2	f
3,D	6	-	2	4	3	o	1-2	3	2	o
3,D	7	-	2-3	4	3	o	2	4	3	o
3,D	8	-	2	4	3	o	1-2	3	2	o
3,D	9	-	2-3	4	3	o	2	4	3	o
3,D	10	-	3	4	3	o	2-3	4	3	o
3,D	11	-	3-4	4	4	o	3	4	3	o
4	1	-	2	1	2	w,f	2	1	2	w,f
4	1	cs	2	1	2	w,f	2	1	2	w,f
4	2	-	2	1	2	w,f	2	1	2	w,f
4	2	cs	2	1	2	w,f	2	1	2	w,f
4	3	-	3	1	2	f	3	1	2	f
4	3	cs	3	1	2	f	3	1	2	f
4	4	-	2	1	2	w,f	2	1	2	w,f
4	4	cs	2	1	2	w,f	2	1	2	w,f
4	5	-	3	3	3	f	3	2	3	f
4	5	cs	3	3	3	f	3	2	3	f
4	6	-	3	4	3	f	3	3	3	f
4	6	cs	3	4	3	f	3	3	3	f
4	7	-	3	4	3	f	3	4	3	f
4	7	cs	3	4	3	f	3	4	3	f
4	8	-	3	4	3	f	3	3	3	f
4	8	cs	3	4	3	f	3	3	3	f
4	9	-	3	4	3	f	3	4	3	f
4	9	cs	3	4	3	f	3	4	3	f
4	10	-	3	4	3	o,f	3	4	3	f
4	10	cs	3	4	3	o,f	3	4	3	f
4	11	-	3-4	4	4	o	3	4	3	o,f
4	11	cs	3-4	4	4	o	3	4	3	o,f
5	1	-	2	1	2	w	2	1	2	w
6	1	-	2-3	1	2	f	2-3	1	2	f
6	1	i_s	3	1	2	i	3	1	2	i
6	1	i_d	2-3	1	2	f	2-3	1	2	f
6	2	-	2-3	1	2	f	2-3	1	2	f
6	2	i_s	3	1	2	i	3	1	2	i
6	2	i_d	2-3	1	2	f	2-3	1	2	f
,8	1	-	2	1	2	w	2	1	2	w
7	1	i_s	3	1	2	i	3	1	2	i
7	1	i_d	2	1	2	w	2	1	2	w
,8	1	se	3	1	2	e	3	1	2	e
9	1	-	1	1	1	-	1	1	1	-
9	1	er	2	1	2	f	2	1	2	f
9	1	i_s	3	1	2	i	3	1	2	i
9	1	i_d	1	1	1	-	1	1	1	-
9	1	se	4	1	3	e	4	1	3	e
,B	1	-	2	1	2	w	2	1	2	w
,B	1	se	4	1	3	e	4	1	3	e
C	1	-	1-2	1	1	f	1-2	1	1	f
C	2	-	1-2	1	1	f	1-2	1	1	f

soil unit	ground-water-class	phase	sweet potato, major first season: traditional suit.	yield exp.	res.	lim. fact.	improved suit.	yield exp.	res.	lim. fact.
1	1	-	1	1	1	-	1	2	1	-
1	1	cl	1	1	1	-	1	2	1	-
1	2	-	1	1	1	-	1	2	1	-
1	2	cl	1	1	1	-	1	2	1	-
1	3	-	3	1	2	o	3	1	2	o
1	3	cl	3	1	2	o	3	1	2	o
1	4	-	1	1	1	-	1	2	1	-
1	4	cl	1	1	1	-	1	2	1	-
1	5	-	2-3	1	2	o	1	1	1	-
1	5	cl	2-3	1	2	o	1	1	1	-
1	6	-	3	2	3	o	2-3	2	2	o
1	6	cl	3	2	3	o	2-3	2	2	o
1	7	-	3-4	2	3	o	3	2	3	o
1	7	cl	3-4	2	3	o	3	2	3	o
1	8	-	3	2-3	3	o	2-3	2	2	o
1	8	cl	3	2-3	3	o	2-3	2	2	o
1	9	-	3-4	3	3	o	3	2	3	o
1	9	cl	3-4	3	3	o	3	2	3	o
1	10	-	4	4	4	o	3-4	3	3	o
1	10	cl	4	4	4	o	3-4	3	3	o
1	11	-	4	4	4	o	4	4	4	o
1	11	cl	4	4	4	o	4	4	4	o
2,3,D	1	-	2-3	1	2	w,f	2-3	1	2	w,f
2,3,D	2	-	2-3	1	2	f	2-3	2	2	f
2,3,D	3	-	2-3	1	2	o,f	2-3	1	2	o,f
2,3,D	4	-	2-3	1	2	f	2-3	2	2	f
2,3,D	5	-	2-3	1	2	o,f	2-3	1	2	f
2,3,D	6	-	3	2	3	o	2-3	2	2	o,f
2,3,D	7	-	3-4	2	3	o	3	2	3	o
2,3,D	8	-	3	2-3	3	o	2-3	2	2	o,f
2,3,D	9	-	3-4	3	3	o	3	2	3	o
2,3,D	10	-	4	4	4	o	3-4	3	3	o
2,3,D	11	-	4	4	4	o	4	4	4	o
4	1	-	3-4	1	3	w	3-4	2	3	w
4	1	cs	4	1	3	w	4	2	3	w
4	2	-	3	1	2	w	3	2	3	w
4	2	cs	3-4	1	3	w	3-4	2	3	w
4	3	-	4	1	3	f	4	1	3	f
4	3	cs	4	1	3	f	4	1	3	f
4	4	-	3	1	2	f	3	2	3	f
4	4	cs	3-4	1	3	w	3-4	2	3	w
4	5	-	4	1	3	f	4	1	3	f
4	5	cs	4	1	3	f	4	1	3	f
4	6	-	4	2	3	f	4	2	3	f
4	6	cs	4	2	3	f	4	2	3	f
4	7	-	4	2	3	f	4	2	3	f
4	7	cs	4	2	3	f	4	2	3	f
4	8	-	4	2-3	3	f	4	2	3	f
4	8	cs	4	2-3	3	f	4	2	3	f
4	9	-	4	3	4	f	4	2	3	f
4	9	cs	4	3	4	f	4	2	3	f
4	10	-	4	4	4	f	4	3	4	f
4	10	cs	4	4	4	f	4	3	4	f
4	11	-	4	4	4	f	4	4	4	f
4	11	cs	4	4	4	f	4	4	4	f
5	1	-	2-3	1	2	w	2-3	2	2	w
6	1	-	3-4	1	3	w,f	3-4	2	3	w,f
6	1	i_s	3-4	1	3	w,f	3-4	2	3	w,f
6	1	i_d	3-4	1	3	w,f	3-4	2	3	w,f
6	2	-	3-4	1	3	f	3-4	2	3	f
6	2	i_s	3-4	1	3	f	3-4	2	3	f
6	2	i_d	3-4	1	3	f	3-4	2	3	f
7,8	1	-	2-3	1	2	w	2-3	2	2	w
7	1	i_s	2-3	1	2	w	2-3	2	2	w
7	1	i_d	2-3	1	2	w	2-3	2	2	w
7,8	1	se	2-3	1	2	w	2-3	2	2	w
9	1	-	1	1	1	-	1	2	1	-
9	1	er	3	1	2	f	3	2	3	f
9	1	i_s	1	1	1	-	1	2	1	-
9	1	i_d	1	1	1	-	1	2	1	-
9	1	se	4	1	3	e	4	2	3	e
A,B	1	-	2-3	1	2	w	2-3	2	2	w
A,B	1	se	3	1	2	e	3	2	3	e
C	1	-	2-3	1	2	f	2-3	2	2	f
C	2	-	2-3	1	2	f	2-3	2	2	f

sweet potato, second season

traditional				improved			
suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
1	3	2	-	1	3	2	-
1	3	2	-	1	3	2	-
1	2	1	-	1	2	1	-
1	2	1	-	1	2	1	-
3	1	2	o	3	1	2	o
3	1	2	o	3	1	2	o
1	2	1	-	1	2	1	-
1	2	1	-	1	2	1	-
2-3	1	2	o	1	2	1	-
2-3	1	2	o	1	2	1	-
3	1	2	o	2-3	1	2	o
3	1	2	o	2-3	1	2	o
3-4	2	3	o	3	2	3	o
3-4	2	3	o	3	2	3	o
3	2	3	o	2-3	2	2	o
3	2	3	o	2-3	2	2	o
3-4	2	3	o	3	2	3	o
3-4	2	3	o	3	2	3	o
4	3	4	o	3-4	2	3	o
4	3	4	o	3-4	2	3	o
4	4	4	o	4	4	4	o
4	4	4	o	4	4	4	o
2-3	3	3	f	2-3	3	3	f
2-3	2	2	f	2-3	2	2	f
2-3	1	2	o,f	2-3	1	2	o,f
2-3	2	2	f	2-3	2	2	f
2-3	1	2	o,f	2-3	2	2	f
3	1	2	o	2-3	1	2	o,f
3-4	2	3	o	3	2	3	o
3	2	3	o	2-3	2	2	o,f
3-4	2	3	o	3	2	3	o
4	3	4	o	3-4	2	3	o
4	4	4	o	4	4	4	o
3	3	3	w,f	3	3	3	w,f
4	3	4	w	4	3	4	w
3	2	3	f	3	2	3	f
3-4	2	3	w	3-4	2	3	w
4	1	3	f	4	1	3	f
4	1	3	f	4	1	3	f
3	2	3	f	3	2	3	f
3-4	2	3	w	3-4	2	3	w
4	1	3	f	4	2	3	f
4	1	3	f	4	2	3	f
4	1	3	f	4	1	3	f
4	1	3	f	4	1	3	f
4	2	3	f	4	2	3	f
4	2	3	f	4	2	3	f
4	2	3	f	4	2	3	f
4	2	3	f	4	2	3	f
4	2	3	f	4	2	3	f
4	2	3	f	4	2	3	f
4	3	4	f	4	2	3	f
4	3	4	f	4	2	3	f
4	4	4	f	4	4	4	f
4	4	4	f	4	4	4	f
1	3	2	-	1	3	2	-
3-4	3	3	f	3-4	3	3	f
3-4	3	3	f	3-4	3	3	f
3-4	3	3	f	3-4	3	3	f
3-4	2	3	f	3-4	2	3	f
3-4	2	3	f	3-4	2	3	f
3-4	2	3	f	3-4	2	3	f
1	3	2	-	1	3	2	-
2	3	2	i	2	3	2	i
1	3	2	-	1	3	2	-
2	3	2	e	2	3	2	e
1	3	2	-	1	3	2	-
3	3	3	f	3	3	3	f
1	3	2	-	1	3	2	-
1	3	2	-	1	3	2	-
4	3	4	e	4	3	4	e
1	3	2	-	1	3	2	-
3	3	3	e	3	3	3	e
2-3	3	3	f	2-3	3	3	f
2-3	2	2	f	2-3	2	2	f

soil unit	ground-water class	phase	cowpea, dry season: traditional suit.	traditional yield exp.	traditional res.	traditional lim. fact.	improved suit.	improved yield exp.	improved res.	improved lim. fact.	cowpea, traditional: suit.	yield exp.	res.	lim. fact.
1	1	-	3	4	3	w	3	4	3	w	1	1	1	-
1	1	cl	3	4	3	w	3	4	3	w	1	1	1	-
1	2	-	2-3	4	3	w	2-3	4	3	w	1	1	1	-
1	2	cl	1	4	2	-	1	4	2	-	1	1	1	-
1	3	-	3	1	2	o	3	2	3	o	3	1	2	o
1	3	cl	3	1	2	o	3	2	3	o	3	1	2	o
1	4	-	2-3	3-4	3	w	2-3	3	3	w	1	1	1	-
1	4	cl	1	3-4	2	-	1	3	2	-	1	1	1	-
1	5	-	2-3	2-3	3	o	1	2	1	-	2-3	2	2	o
1	5	cl	2-3	2-3	3	o	1	2	1	-	2-3	2	2	o
1	6	-	3	2	3	o	2-3	2	2	o	3	3	3	o
1	6	cl	3	2	3	o	2-3	2	2	o	3	3	3	o
1	7	-	3-4	3	3	o	3	2	3	o	3-4	4	4	o
1	7	cl	3-4	3	3	o	3	2	3	o	3-4	4	4	o
1	8	-	3	3	3	o	2-3	2-3	3	o	3	3	3	o
1	8	cl	3	3	3	o	2-3	2-3	3	o	3	3	3	o
1	9	-	3-4	4	4	o	3	3-4	3	o	3-4	4	4	o
1	9	cl	3-4	4	4	o	3	3-4	3	o	3-4	4	4	o
1	10	-	4	4	4	o	3-4	4	4	o	4	4	4	o
1	10	cl	4	4	4	o	3-4	4	4	o	4	4	4	o
1	11	-	4	4	4	o	4	4	4	o	4	4	4	o
1	11	cl	4	4	4	o	4	4	4	o	4	4	4	o
2,3,D	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w
2,3,D	2	-	3-4	4	4	w	3-4	4	4	w	1-2	1	1	f
2,3,D	3	-	2-3	1	2	o	2-3	2	2*	o	2-3	1	2	o
2,3,D	4	-	3-4	3-4	4	w	3-4	3	4	w	1-2	1	1	f
2,3,D	5	-	2-3	2-3	3	o	1-2	2	2	f	2-3	2	2	o
2,3,D	6	-	3	2	3	o	2-3	2	2	o	3	3	3	o
2,3,D	7	-	3-4	3	3	o	3	2	3	o	3-4	4	4	o
2,3,D	8	-	3	3	3	o	2-3	2-3	3	o	3	3	3	o
2,3,D	9	-	3-4	4	4	o	3	3-4	3	o	3-4	4	4	o
2,3,D	10	-	4	4	4	o	3-4	4	4	o	4	4	4	o
2,3,D	11	-	4	4	4	o	4	4	4	o	4	4	4	o
4	1	-	4	4	4	w	4	4	4	w	3-4	1	3	w
4	1	cs	4	4	4	w	4	4	4	w	4	1	3	w
4	2	-	4	4	4	w	4	4	4	w	3	1	2	w,f
4	2	cs	4	4	4	w	4	4	4	w	3-4	1	3	w
4	3	-	4	1	3	f	4	2	3	f	4	1	3	f
4	3	cs	4	1	3	f	4	2	3	f	4	1	3	f
4	4	-	4	3-4	4	w	4	3	4	w	2-3	1	2	w
4	4	cs	4	3-4	4	w	4	3	4	w	3-4	1	3	w
4	5	-	4	2-3	3	f	4	2	3	f	4	2	3	f
4	5	cs	4	2-3	3	f	4	2	3	f	4	2	3	f
4	6	-	4	2	3	f	4	2	3	f	4	3	4	f
4	6	cs	4	2	3	f	4	2	3	f	4	3	4	f
4	7	-	4	3	4	f	4	2	3	f	4	4	4	f
4	7	cs	4	3	4	f	4	2	3	f	4	4	4	f
4	8	-	4	3	4	f	4	2-3	3	f	4	3	4	f
4	8	cs	4	3	4	f	4	2-3	3	f	4	3	4	f
4	9	-	4	4	4	f	4	3-4	4	f	4	4	4	f
4	9	cs	4	4	4	f	4	3-4	4	f	4	4	4	f
4	10	-	4	4	4	o,f	4	4	4	f	4	4	4	o,f
4	10	cs	4	4	4	o,f	4	4	4	f	4	4	4	o,f
4	11	-	4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
4	11	cs	4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
5	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w
6	1	-	4	4	4	w	4	4	4	w	3-4	1	3	w,f
6	1	i_s	4	4	4	w	4	4	4	w	3-4	1	3	w,f
6	1	i_d	4	4	4	w	4	4	4	w	3-4	1	3	w,f
6	2	-	4	4	4	w	4	4	4	w	3-4	1	3	f
6	2	i_s	4	4	4	w	4	4	4	w	3-4	1	3	f
6	2	i_d	4	4	4	w	4	4	4	w	3-4	1	3	f
7,8	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w
7	1	i_s	4	4	4	w	4	4	4	w	2-3	1	2	w
7	1	i_d	4	4	4	w	4	4	4	w	2-3	1	2	w
7,8	1	se	4	4	4	w	4	4	4	w	4	1	3	e
9	1	-	3	4	3	w	3	4	3	w	1	1	1	-
9	1	er	3	4	3	w	3	4	3	w	2	1	2	f
9	1	i_s	3	4	3	w	3	4	3	w	2	1	2	i
9	1	i_d	3	4	3	w	3	4	3	w	1	1	1	-
9	1	se	3	4	3	w	3	4	3	w	4	1	3	e
A,B	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w
A,B	1	se	4	4	4	w	4	4	4	w	4	1	3	e
C	1	-	3	4	3	w	3	4	3	w	1-2	1	1	f
C	2	-	2-3	4	3	w	2-3	4	3	w	1-2	1	1	f

major first season				cowpea, second season							
improved				traditional				improved			
suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
1	1	1	-	1	1	1	-	1	2	1	-
1	1	1	-	1	1	1	-	1	2	1	-
1	1	1	-	1	1	1	-	1	2	1	-
1	1	1	-	1	1	1	-	1	2	1	-
3	1	2	o	3	1	2	o	3	1-2	2	o
3	1	2	o	3	1	2	o	3	1-2	2	o
1	1	1	-	1	2	1	-	1	2	1	-
1	1	1	-	1	2	1	-	1	2	1	-
1	1-2	1	-	2-3	3	3	o	1	2	1	-
1	1-2	1	-	2-3	3	3	o	1	2	1	-
2-3	2-3	3	o	3	4	3	o	2-3	3-4	3	o
2-3	2-3	3	o	3	4	3	o	2-3	3-4	3	o
3	3	3	o	3-4	4	4	o	3	4	3	o
3	3	3	o	3-4	4	4	o	3	4	3	o
2-3	2	2	o	3	4	3	o	2-3	3-4	3	o
2-3	2	2	o	3	4	3	o	2-3	3-4	3	o
3	2-3	3	o	3-4	4	4	o	3	4	3	o
3	2-3	3	o	3-4	4	4	o	3	4	3	o
3-4	4	4	o	4	4	4	o	3-4	4	4	o
3-4	4	4	o	4	4	4	o	3-4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o
2-3	1	2	w	1-2	1	1	f	1-2	1	1	f
1-2	1	1	f	1-2	1	1	f	1-2	2	2	f
2-3	1	2	o	2-3	1	2	o	2-3	1-2	2	o
1-2	1	1	f	1-2	2	2	f	1-2	2	2	f
1-2	1-2	2	f	2-3	3	3	o	1-2	2	2	f
2-3	2-3	3	o	3	4	3	o	2-3	3-4	3	o
3	3	3	o	3-4	4	4	o	3	4	3	o
2-3	2	2	o	3	4	3	o	2-3	3-4	3	o
3	2-3	3	o	3-4	4	4	o	3	4	3	o
3-4	4	4	o	4	4	4	o	3-4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o
3-4	1	3	w	3	1	2	w	3	2	3	w
4	1	3	w	4	1	3	w	4	2	3	w
3	1	2	w,f	2-3	1	2	w	2-3	2	2	w
3-4	1	3	w	3-4	1	3	w	3-4	2	3	w
4	1	3	f	4	1	3	f	4	1-2	3	f
4	1	3	f	4	1	3	f	4	1-2	3	f
2-3	1	2	w	2-3	2	2	w	2-3	2	2	w
3-4	1	3	w	3-4	2	3	w	3-4	2	3	w
4	1-2	3	f	4	3	4	f	4	2	3	f
4	1-2	3	f	4	3	4	f	4	2	3	f
4	2-3	3	f	4	4	4	f	4	3-4	4	f
4	2-3	3	f	4	4	4	f	4	3-4	4	f
4	3	4	f	4	4	4	f	4	4	4	f
4	3	4	f	4	4	4	f	4	4	4	f
4	2	3	f	4	4	4	f	4	3-4	4	f
4	2	3	f	4	4	4	f	4	3-4	4	f
4	2-3	3	f	4	4	4	f	4	4	4	f
4	2-3	3	f	4	4	4	f	4	4	4	f
4	4	4	f	4	4	4	f	4	4	4	f
4	4	4	f	4	4	4	f	4	4	4	f
4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
2-3	1	2	w	1	1	1	-	1	2	1	-
3-4	1	3	w,f	3-4	1	3	f	3-4	2	3	f
3-4	1	3	w,f	3-4	1	3	f	3-4	2	3	f
3-4	1	3	w,f	3-4	1	3	f	3-4	2	3	f
3-4	1	3	f	3-4	1	3	f	3-4	2	3	f
3-4	1	3	f	3-4	1	3	f	3-4	2	3	f
3-4	1	3	f	3-4	1	3	f	3-4	2	3	f
2-3	1	2	w	1	1	1	-	1	2	1	-
2-3	1	2	w	2	1	2	i	2	2	2	i
2-3	1	2	w	1	1	1	-	1	2	1	-
4	1	3	e	4	1	3	e	4	2	3	e
1	1	1	-	1	1	1	-	1	2	1	-
2	1	2	f	2	1	2	f	2	2	2	f
2	1	2	i	2	1	2	i	2	2	2	i
1	1	1	-	1	1	1	-	1	2	1	-
4	1	3	e	4	1	3	e	4	2	3	e
2-3	1	2	w	1	1	1	-	1	2	1	-
4	1	3	e	4	1	3	e	4	2	3	e
1-2	1	1	f	1-2	1	1	f	1-2	2	2	f
1-2	1	1	f	1-2	1	1	f	1-2	2	2	f

soil unit	ground-water class	phase	soybean, dry season								soybean			
			traditional				improved				traditional			
			suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
1	1	-	3	4	3	w	3	4	3	w	1-2	1	1	w
1	1	cl	3	4	3	w	3	4	3	w	1	1	1	-
1	2	-	2-3	3	3	w	2-3	2-3	3	w	1	1	1	-
1	2	cl	2	3	2	w	2	2-3	2	w	1	1	1	-
1	3	-	2	2	2	o	2	2	2	o	2	1	2	o
1	3	cl	2	2	2	o	2	2	2	o	2	1	2	o
1	4	-	2-3	2	2	w	2-3	2	2	w	1	1	1	-
1	4	cl	2	2	2	w	2	2	2	w	1	1	1	-
1	5	-	1-2	1	1	o	1	1-2	1	-	1-2	2	2	o
1	5	cl	1-2	1	1	o	1	1-2	1	-	1-2	2	2	o
1	6	-	2	3	2	o	1-2	2	2	o	2	2	2	o
1	6	cl	2	3	2	o	1-2	2	2	o	2	2	2	o
1	7	-	3-4	4	4	o	2	3	2	o	3-4	3	3	o
1	7	cl	3-4	4	4	o	2	3	2	o	3-4	3	3	o
1	8	-	2	2	2	o	1-2	2	2	o	2	2	2	o
1	8	cl	2	2	2	o	1-2	2	2	o	2	2	2	o
1	9	-	3-4	3	3	o	2	2-3	2	o	3-4	2-3	3	o
1	9	cl	3-4	3	3	o	2	2-3	2	o	3-4	2-3	3	o
1	10	-	4	4	4	o	3-4	3-4	4	o	4	4	4	o
1	10	cl	4	4	4	o	3-4	3-4	4	o	4	4	4	o
1	11	-	4	4	4	o	4	4	4	o	4	4	4	o
1	11	cl	4	4	4	o	4	4	4	o	4	4	4	o
2,3,D	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w,f
2,3,D	2	-	3-4	3	3	w	3-4	2-3	3	w	2-3	1	2	f
2,3,D	3	-	2-3	2	2	f	2-3	2	2	f	2-3	1	2	f
2,3,D	4	-	3-4	2	3	w	3-4	2	3	w	2-3	1	2	f
2,3,D	5	-	2-3	1	2	f	2-3	1-2	2	f	2-3	2	2	f
2,3,D	6	-	2-3	3	3	f	2-3	2	2	f	2-3	2	2	f
2,3,D	7	-	3-4	4	4	o	2-3	3	3	f	3-4	3	3	o
2,3,D	8	-	2-3	2	2	f	2-3	2	2	f	2-3	2	2	f
2,3,D	9	-	3-4	3	3	o	2-3	2-3	3	f	3-4	2-3	3	o
2,3,D	10	-	4	4	4	o	3-4	3-4	4	o	4	4	4	o
2,3,D	11	-	4	4	4	o	4	4	4	o	4	4	4	o
4	1	-	4	4	4	w	4	4	4	w	3-4	1	3	w
4	1	cs	4	4	4	w	4	4	4	w	4	1	3	w
4	2	-	4	3	4	w	4	2-3	4^+	w	3	1	2	w,f
4	2	cs	4	3	4	w	4	2-3	4^+	w	3-4	1	3	w
4	3	-	4	2	3	f	4	2	3	f	4	1	3	f
4	3	cs	4	2	3	f	4	2	3	f	4	1	3	f
4	4	-	4	2	3	w	4	2	3	w	2-3	1	2	w,f
4	4	cs	4	2	3	w	4	2	3	w	3-4	1	3	w
4	5	-	4	1	3	f	4	1-2	3	f	4	2	3	f
4	5	cs	4	1	3	f	4	1-2	3	f	4	2	3	f
4	6	-	4	3	4	f	4	2	3	f	4	2	3	f
4	6	cs	4	3	4	f	4	2	3	f	4	2	3	f
4	7	-	4	4	4	f	4	3	4	f	4	3	4	f
4	7	cs	4	4	4	f	4	3	4	f	4	3	4	f
4	8	-	4	2	3	f	4	2	3	f	4	2	3	f
4	8	cs	4	2	3	f	4	2	3	f	4	2	3	f
4	9	-	4	3	4	f	4	2-3	3	f	4	2-3	3	f
4	9	cs	4	3	4	f	4	2-3	3	f	4	2-3	3	f
4	10	-	4	4	4	o,f	4	3-4	4	f	4	4	4	o,f
4	10	cs	4	4	4	o,f	4	3-4	4	f	4	4	4	o,f
4	11	-	4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
4	11	cs	4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
5	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w
6	1	-	4	4	4	w	4	4	4	w	3-4	1	3	w,f
6	1	i_s	4	4	4	w	4	4	4	w	3-4	1	3	w,f
6	1	i_d	4	4	4	w	4	4	4	w	3-4	1	3	w,f
6	2	-	4	3	4	w	4	2-3	4^+	w	3-4	1	3	f
6	2	i_s	4	3	4	w	4	2-3	4^+	w	3-4	1	3	f
6	2	i_d	4	3	4	w	4	2-3	4^+	w	3-4	1	3	f
7,8	1	-	4	4	4	w	4	4	4	w	2-3	1	2	w
7	1	i_s	4	4	4	w	4	4	4	w	2-3	1	2	w
7	1	i_d	4	4	4	w	4	4	4	w	2-3	1	2	w
7,8	1	se	4	4	4	w	4	4	4	w	4	1	3	e
9	1	-	3	4	3	w	3	4	3	w	1-2	1	1	w
9	1	er	3	4	3	w,f	3	4	3	w,f	3	1	2	f
9	1	i_s	3	4	3	w	3	4	3	w	2	1	2	i
9	1	i_d	3	4	3	w	3	4	3	w	1-2	1	1	w
9	1	se	3	4	3	w	3	4	3	w	4	1	3	e
A,B	1	-	4	4	4	w	4	4	4	w	2-3	1	2	f
A,B	1	se	4	4	4	w	4	4	4	w	4	1	3	e
C	1	-	3	4	3	w	3	4	3	w	2-3	1	2	f
C	2	-	2-3	3	3	w,f	2-3	2-3	3	w,f	2-3	1	2	f

major first season				soybean, second season							
improved				traditional				improved			
suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
1-2	2	2	w	1	1-2	1	-	1	2	1	-
1	2	1	-	1	1-2	1	-	1	2	1	-
1	1-2	1	-	1	1	1	-	1	2	1	-
1	1-2	1	-	1	1	1	-	1	2	1	-
2	1	2	o	2	1	2	o	2	2	2	o
2	1	2	o	2	1	2	o	2	2	2	o
1	2	1	-	1	2	1	-	1	2	1	-
1	2	1	-	1	2	1	-	1	2	1	-
1	1	1	-	1-2	3	2	o	1	2	1	-
1	1	1	-	1-2	3	2	o	1	2	1	-
1-2	1-2	2	o	2	4	3	o	1-2	3	2	o
1-2	1-2	2	o	2	4	3	o	1-2	3	2	o
2	2	2	o	3-4	4	4	o	2	3	2	o
2	2	2	o	3-4	4	4	o	2	3	2	o
1-2	2	2	o	2	4	3	o	1-2	3	2	o
1-2	2	2	o	2	4	3	o	1-2	3	2	o
2	2	2	o	3-4	4	4	o	2	3	2	o
2	2	2	o	3-4	4	4	o	2	3	2	o
3-4	2-3	3	o	4	4	4	o	3-4	4	4	o
3-4	2-3	3	o	4	4	4	o	3-4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o
2-3	2	2	w,f	2-3	1-2	2	f	2-3	2	2	f
2-3	1-2	2	f	2-3	1	2	f	2-3	2	2	f
2-3	1	2	f	2-3	1	2	f	2-3	2	2	f
2-3	2	2	f	2-3	2	2	f	2-3	2	2	f
2-3	1	2	f	2-3	3	3	f	2-3	2	2	f
2-3	1-2	2	f	2-3	4	3	f	2-3	3	3	f
2-3	2	2	f	3-4	4	4	o	2-3	3	3	f
2-3	2	2	f	2-3	4	3	f	2-3	3	3	f
2-3	2	2	f	3-4	4	4	o	2-3	3	3	f
3-4	2-3	3	o	4	4	4	o	3-4	4	4	o
4	4	4	o	4	4	4	o	4	4	4	o
3-4	2	3	w	3	1-2	2	w,f	3	2	3	w,f
4	2	3	w	4	1-2	3	w	4	2	3	w
3	1-2	2	w,f	3	1	2	f	3	2	3	f
3-4	1-2	3	w	3-4	1	3	w	3-4	2	3	w
4	1	3	f	4	1	3	f	4	2	3	f
4	1	3	f	4	1	3	f	4	2	3	f
2-3	2	2	w,f	2-3	2	2	w,f	2-3	2	2	w,f
3-4	2	3	w	3-4	2	3	w	3-4	2	3	w
4	1	3	f	4	3	4	f	4	2	3	f
4	1	3	f	4	3	4	f	4	2	3	f
4	1-2	3	f	4	4	4	f	4	3	4	f
4	1-2	3	f	4	4	4	f	4	3	4	f
4	2	3	f	4	4	4	f	4	3	4	f
4	2	3	f	4	4	4	f	4	3	4	f
4	2	3	f	4	4	4	f	4	3	4	f
4	2	3	f	4	4	4	f	4	3	4	f
4	2	3	f	4	4	4	f	4	3	4	f
4	2	3	f	4	4	4	f	4	3	4	f
4	2-3	3	f	4	4	4	o,f	4	4	4	f
4	2-3	3	f	4	4	4	o,f	4	4	4	f
4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
4	4	4	o,f	4	4	4	o,f	4	4	4	o,f
2-3	2	2	w	2	1-2	2	w	2	2	2	w
3-4	2	3	w,f	3-4	1-2	3	f	3-4	2	3	f
3-4	2	3	w,f	3-4	1-2	3	f	3-4	2	3	f
3-4	2	3	w,f	3-4	1-2	3	f	3-4	2	3	f
3-4	2	3	f	3-4	1	3	f	3-4	2	3	f
3-4	2	3	f	3-4	1	3	f	3-4	2	3	f
3-4	2	3	f	3-4	1	3	f	3-4	2	3	f
2-3	2	2	w	2	1-2	2	w	2	2	2	w
2-3	2	2	w	2	1-2	2	w,i	2	2	2	w,i
2-3	2	2	w	2	1-2	2	w	2	2	2	w
4	2	3	e	4	1-2	3	e	4	2	3	e
1-2	2	2	w	1	1-2	1	-	1	2	1	-
3	2	3	f	3	1-2	2	f	3	2	3	f
2	2	2	i	2	1-2	2	i	2	2	2	i
1-2	2	2	w	1	1-2	1	-	1	2	1	-
4	2	3	e	4	1-2	3	e	4	2	3	e
2-3	2	2	f	2	1-2	2	w	2	2	2	w
4	2	3	e	4	1-2	3	e	4	2	3	e
2-3	2	2	f	2-3	1-2	2	f	2-3	2	2	f
2-3	1-2	2	f	2-3	1	2	f	2-3	2	2	f

soil unit	ground-water class	phase	pigeon pea traditional suit.	yield exp.	res.	lim. fact.	improved suit.	yield exp.	res.	lim. fact.
1	1	-	1-2	1	1	o	1-2	1	1	o
1	1	cl	1-2	1	1	o	1-2	1	1	o
1	2	-	2	2-3	2	o	2	2-3	2	o
1	2	cl	2	2-3	2	o	2	2-3	2	o
1	3	-	4	3-4	4	o	4	3	4	o
1	3	cl	4	3-4	4	o	4	3	4	o
1	4	-	2	3	2	o	1-2	3	2	o
1	4	cl	2	3	2	o	1-2	3	2	o
1	5	-	3-4	4	4	o	2	3	2	o
1	5	cl	3-4	4	4	o	2	3	2	o
1	6	-	4	4	4	o	3-4	4	4	o
1	6	cl	4	4	4	o	3-4	4	4	o
1	7	-	4	4	4	o	4	4	4	o
1	7	cl	4	4	4	o	4	4	4	o
1	8	-	4	4	4	o	3-4	4	4	o
1	8	cl	4	4	4	o	3-4	4	4	o
1	9	-	4	4	4	o	4	4	4	o
1	9	cl	4	4	4	o	4	4	4	o
1	10	-	4	4	4	o	4	4	4	o
1	10	cl	4	4	4	o	4	4	4	o
1	11	-	4	4	4	o	4	4	4	o
1	11	cl	4	4	4	o	4	4	4	o
2,3,D	1	-	2	1	2	w	2	1	2	w
2,3,D	2	-	1-2	2-3	2	w,o,f	1-2	2-3	2	w,o,f
2,3,D	3	-	3-4	3-4	4	o	3-4	3	3	o
2,3,D	4	-	1-2	3	2	w,o,f	1-2	3	2	w,f
2,3,D	5	-	3-4	4	4	o	2-3	3	3	f
2,3,D	6	-	4	4	4	o	3-4	4	4	o
2,3,D	7	-	4	4	4	o	4	4	4	o
2,3,D	8	-	4	4	4	o	3-4	4	4	o
2,3,D	9	-	4	4	4	o	4	4	4	o
2,3,D	10	-	4	4	4	o	4	4	4	o
2,3,D	11	-	4	4	4	o	4	4	4	o
4	1	-	2	1	2	w,f	2	1	2	w,f
4	1	cs	2	1	2	w,f	2	1	2	w,f
4	2	-	2	2-3	2	w,f	2	2-3	2	w,f
4	2	cs	2	2-3	2	w,f	2	2-3	2	w,f
4	3	-	4	3-4	4	f	4	3	4	f
4	3	cs	4	3-4	4	f	4	3	4	f
4	4	-	2	3	2	w,f	2	3	2	w,f
4	4	cs	2	3	2	w,f	2	3	2	w,f
4	5	-	4	4	4	f	4	3	4	f
4	5	cs	4	4	4	f	4	3	4	f
4	6	-	4	4	4	o,f	4	4	4	f
4	6	cs	4	4	4	o,f	4	4	4	f
4	7	-	4	4	4	o,f	4	4	4	o,f
4	7	cs	4	4	4	o,f	4	4	4	o,f
4	8	-	4	4	4	o,f	4	4	4	f
4	8	cs	4	4	4	o,f	4	4	4	f
4	9	-	4	4	4	o,f	4	4	4	o,f
4	9	cs	4	4	4	o,f	4	4	4	o,f
4	10	-	4	4	4	o,f	4	4	4	o,f
4	10	cs	4	4	4	o,f	4	4	4	o,f
4	11	-	4	4	4	o,f	4	4	4	o,f
4	11	cs	4	4	4	o,f	4	4	4	o,f
5	1	-	2	1	2	w	2	1	2	w
6	1	-	3-4	1	3	f	3-4	1	3	f
6	1	i_s	3-4	1	3	f	3-4	1	3	f
6	1	i_d	3-4	1	3	f	3-4	1	3	f
6	2	-	3-4	2-3	3	f	3-4	2-3	3	f
6	2	i_s	3-4	2-3	3	f	3-4	2-3	3	f
6	2	i_d	3-4	2-3	3	f	3-4	2-3	3	f
7,8	1	-	2	1	2	w	2	1	2	w
7	1	i_s	3	1	2	i	3	1	2	i
7	1	i_d	2	1	2	w,i	2	1	2	w,i
7,8	1	se	2	1	2	w	2	1	2	w
9	1	-	2	1	2	o	2	1	2	o
9	1	er	2	1	2	o,f	2	1	2	o,f
9	1	i_s	3	1	2	i	3	1	2	i
9	1	i_d	2	1	2	o,i	2	1	2	o,i
9	1	se	3	1	2	e	3	1	2	e
A,B	1	-	2	1	2	w	2	1	2	w
A,B	1	se	3	1	2	e	3	1	2	e
C	1	-	1-2	1	1	o,f	1-2	1	1	o,f
C	2	-	2	2-3	2	o	2	2-3	2	o

soil unit	ground-water-class	phase	cocoyam traditional suit.				cocoyam improved suit.			
			suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
1	1	-	2-3	3-4	3	w	2-3	3-4	3	w
1	1	cl	1	3-4	2	-	1	3-4	2	-
1	2	-	1	2-3	2	-	1	2-3	2	-
1	2	cl	1	2-3	2	-	1	2-3	2	-
1	3	-	1	1	1	-	1	2	1	-
1	3	cl	1	1	1	-	1	2	1	-
1	4	-	1	1-2	1	-	1	2	1	-
1	4	cl	1	1-2	1	-	1	2	1	-
1	5	-	1	1	1	-	1	2	1	-
1	5	cl	1	1	1	-	1	2	1	-
1	6	-	1	1	1	-	1	1	1	-
1	6	cl	1	1	1	-	1	1	1	-
1	7	-	1	1	1	-	1	1	1	-
1	7	cl	1	1	1	-	1	1	1	-
1	8	-	1	1	1	-	1	1-2	1	-
1	8	cl	1	1	1	-	1	1-2	1	-
1	9	-	1	1	1	-	1	1	1	-
1	9	cl	1	1	1	-	1	1	1	-
1	10	-	1	1	1	-	1	1	1	-
1	10	cl	1	1	1	-	1	1	1	-
1	11	-	1	1	1	-	1	1	1	-
1	11	cl	1	1	1	-	1	1	1	-
2,3,D	1	-	3-4	3-4	4	w	3-4	3-4	4	w
2,3,D	2	-	3	2-3	3	w	3	2-3	3	w
2,3,D	3	-	2-3	1	2	f	2-3	2	2	f
2,3,D	4	-	2-3	1-2	2	w,f	2-3	2	2	w,f
2,3,D	5	-	2-3	1	2	f	2-3	2	2	f
2,3,D	6	-	2-3	1	2	f	2-3	1	2	f
2,3,D	7	-	2-3	1	2	f	2-3	1	2	f
2,3,D	8	-	2-3	1	2	f	2-3	1-2	2	f
2,3,D	9	-	2-3	1	2	f	2-3	1	2	f
2,3,D	10	-	2-3	1	2	f	2-3	1	2	f
2,3,D	11	-	2-3	1	2	f	2-3	1	2	f
4	1	-	4	3-4	4	w	4	3-4	4	w
4	1	cs	4	3-4	4	w	4	3-4	4	w
4	2	-	4	2-3	3	w	4	2-3	3	w
4	2	cs	4	2-3	3	w	4	2-3	3	w
4	3	-	4	1	3	f	4	2	3	f
4	3	cs	4	1	3	f	4	2	3	f
4	4	-	3-4	1-2	3	w	3-4	2	3	w
4	4	cs	4	1-2	3	w	4	2	3	w
4	5	-	4	1	3	f	4	2	3	f
4	5	cs	4	1	3	w,f	4	2	3	w,f
4	6	-	4	1	3	f	4	1	3	f
4	6	cs	4	1	3	f	4	1	3	f
4	7	-	4	1	3	f	4	1	3	f
4	7	cs	4	1	3	f	4	1	3	f
4	8	-	4	1	3	f	4	1-2	3	f
4	8	cs	4	1	3	f	4	1-2	3	f
4	9	-	4	1	3	f	4	1	3	f
4	9	cs	4	1	3	f	4	1	3	f
4	10	-	4	1	3	f	4	1	3	f
4	10	cs	4	1	3	f	4	1	3	f
4	11	-	4	1	3	f	4	1	3	f
4	11	cs	4	1	3	f	4	1	3	f
5	1	-	3-4	3-4	4	w	3-4	3-4	4	w
6	1	-	4	3-4	4	w	4	3-4	4	w
6	1	i_s	4	3-4	4	w	4	3-4	4	w
6	1	i_d	4	3-4	4	w	4	3-4	4	w
6	2	-	4	2-3	3	w	4	2-3	3	w
6	2	i_s	4	2-3	3	w	4	2-3	3	w
6	2	i_d	4	2-3	3	w	4	2-3	3	w
7,8	1	-	3-4	3-4	4	w	3-4	3-4	4	w
7	1	i_s	3-4	3-4	4	w	3-4	3-4	4	w
7	1	i_d	3-4	3-4	4	w	3-4	3-4	4	w
7,8	1	se	3-4	3-4	4	w	3-4	3-4	4	w
9	1	-	2-3	3-4	3	w	2-3	3-4	3	w
9	1	er	3	3-4	3	f	3	3-4	3	f
9	1	i_s	2-3	3-4	3	w	2-3	3-4	3	w
9	1	i_d	2-3	3-4	3	w	2-3	3-4	3	w
9	1	se	4	3-4	4	e	4	3-4	4	e
A,B	1	-	3-4	3-4	4	w	3-4	3-4	4	w
A,B	1	se	4	3-4	4	e	4	3-4	4	e
C	1	-	2-3	3-4	3	w,f	2-3	3-4	3	w,f
C	2	-	2-3	2-3	3	f	2-3	2-3	3	f

soil unit	ground-water class	phase	tomato traditional suit.	tomato traditional yield exp.	tomato traditional res.	tomato traditional lim. fact.	tomato improved suit.	tomato improved yield exp.	tomato improved res.	tomato improved lim. fact.	okra traditional suit.	okra traditional yield exp.	okra traditional res.	okra traditional lim. fact.
1	1	-	4	4	4	w	4	4	4	w	3	4	3	w
1	1	cl	4	4	4	w	4	4	4	w	3	4	3	w
1	2	-	3-4	4	4	w	3-4	4	4	w	2-3	4	3	w
1	2	cl	2	4	3	w	2	4	3	w	2	4	3	w
1	3	-	2	3	2	o	2	2-3	2	o	1	3-4	2	-
1	3	cl	2	3	2	o	2	2-3	2	o	1	3-4	2	-
1	4	-	3-4	4	4	w	3-4	4	4	w	2-3	3	3	w
1	4	cl	2	4	3	w	2	4	3	w	2	3	2	w
1	5	-	1-2	1	1	o	1	1	1	-	1	1	1	-
1	5	cl	1-2	1	1	o	1	1	1	-	1	1	1	-
1	6	-	2	1	2	o	2	1	2	n	1	1-2	1	-
1	6	cl	2	1	2	o	2	1	2	n	1	1-2	1	-
1	7	-	3-4	2	3	o	3	1	2	n	2-3	3	3	o
1	7	cl	3-4	2	3	o	3	1	2	n	2-3	3	3	o
1	8	-	2	3	2	o	2	1	2	n	1	1	1	-
1	8	cl	2	3	2	o	2	1	2	n	1	1	1	-
1	9	-	3-4	3	3	o	2-3	2	2	n	2-3	2	2	o
1	9	cl	3-4	3	3	o	2-3	2	2	n	2-3	2	2	o
1	10	-	4	3	4	o	3-4	2	3	o	3	2-3	3	o
1	10	cl	4	3	4	o	3-4	2	3	o	3	2-3	3	o
1	11	-	4	4	4	o	4	3	4	o	3-4	4	4	o
1	11	cl	4	4	4	o	4	3	4	o	3-4	4	4	o
2,3,D	1	-	4	4	4	w	4	4	4	w	4	4	4	w
2,3,D	2	-	4	4	4	w	4	4	4	w	3-4	4	4	w
2,3,D	3	-	2-3	3	3	f	2	2-3	2	f	1-2	3-4	2	f
2,3,D	4	-	4	4	4	w	4	4	4	w	3-4	3	3	w
2,3,D	5	-	2-3	1	2	f	2	1	2	f	1-2	1	1	w,f
2,3,D	6	-	2-3	1	2	f	2	1	2	f,n	1-2	1-2	2	f
2,3,D	7	-	3-4	2	3	o	3	1	2	n	2-3	3	3	o
2,3,D	8	-	2-3	3	3	f	2	1	2	f,n	1-2	1	1	f
2,3,D	9	-	3-4	3	3	o	2-3	2	2	n	2-3	2	2	o
2,3,D	10	-	4	3	4	o	3-4	2	3	o	3	2-3	3	o
2,3,D	11	-	4	4	4	o	4	3	4	o	3-4	4	4	o
4	1	-	4	4	4	w	4	4	4	w	4	4	4	w
4	1	cs	4	4	4	w	4	4	4	w	4	4	4	w
4	2	-	4	4	4	w	4	4	4	w	4	4	4	w
4	2	cs	4	4	4	w	4	4	4	w	4	4	4	w
4	3	-	4	3	4	f	3	2-3	3	f	4	3-4	4	f
4	3	cs	4	3	4	f	3-4	2-3	3	w	4	3-4	4	f
4	4	-	4	4	4	w	4	4	4	w	4	3	4	w
4	4	cs	4	4	4	w	4	4	4	w	4	3	4	w
4	5	-	4	1	3	f	3-4	1	3	w	4	1	3	f
4	5	cs	4	1	3	w,f	4	1	3	w	4	1	3	f
4	6	-	4	1	3	f	3	1	2	f	4	1-2	3	f
4	6	cs	4	1	3	f	3	1	2	f	4	1-2	3	f
4	7	-	4	2	3	f	3	1	2	f,n	4	3	4	f
4	7	cs	4	2	3	f	3	1	2	f,n	4	3	4	f
4	8	-	4	3	4	f	3	1	2	f	4	1	3	f
4	8	cs	4	3	4	f	3-4	1	3	w	4	1	3	f
4	9	-	4	3	4	f	3	2	3	f	4	2	3	f
4	9	cs	4	3	4	f	3	2	3	f	4	2	3	f
4	10	-	4	3	4	o,f	3-4	2	3	o	4	2-3	3	f
4	10	cs	4	3	4	o,f	3-4	2	3	o	4	2-3	3	f
4	11	-	4	4	4	o,f	4	3	4	o	4	4	4	f
4	11	cs	4	4	4	o,f	4	3	4	o	4	4	4	f
5	1	-	4	4	4	w	4	4	4	w	4	4	4	w
6	1	-	4	4	4	w	4	4	4	w	4	4	4	w
6	1	i_s	4	4	4	w	4	4	4	w	4	4	4	w
6	1	i_d	4	4	4	w	4	4	4	w	4	4	4	w
6	2	-	4	4	4	w	4	4	4	w	4	4	4	w
6	2	i_s	4	4	4	w	4	4	4	w	4	4	4	w
6	2	i_d	4	4	4	w	4	4	4	w	4	4	4	w
7,8	1	-	4	4	4	w	4	4	4	w	4	4	4	w
7	1	i_s	4	4	4	w	4	4	4	w	4	4	4	w
7	1	i_d	4	4	4	w	4	4	4	w	4	4	4	w
7,8	1	se	4	4	4	w	4	4	4	w	4	4	4	w
9	1	-	4	4	4	w	4	4	4	w	3	4	3	w
9	1	er	4	4	4	w	4	4	4	w	3	4	3	w
9	1	i_s	4	4	4	w	4	4	4	w	3	4	3	w
9	1	i_d	4	4	4	w	4	4	4	w	3	4	3	w
9	1	se	4	4	4	w	4	4	4	w	3	4	3	w
A,B	1	-	4	4	4	w	4	4	4	w	4	4	4	w
A,B	1	se	4	4	4	w	4	4	4	w	4	4	4	w
C	1	-	4	4	4	w	4	4	4	w	3	4	3	w
C	2	-	3-4	4	4	w	3-4	4	4	w	2-3	4	3	w

				celosia								sweet pepper							
improved				traditional				improved				traditional				improved			
suit.	yield exp.	res.	lim. fact	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.	suit.	yield exp.	res.	lim. fact.
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
2-3	4	3	w	3-4	4	4	w	3-4	4	4	w	2-3	4	3	w	2-3	4	3	w
2	4	3	w	2	4	3	w	2	4	3	w	2	4	3	w	2	4	3	w
1	3-4	2	-	3	3	3	o	3	3	3	o	2	4	3	o	2	4	3	o
1	3-4	2	-	3	3	3	o	3	3	3	o	2	4	3	o	2	4	3	o
2-3	2-3	3	w	3-4	4	4	w	3-4	4	4	w	2-3	4	3	w	2-3	4	3	w
2	2-3	2	w	2	4	3	w	2	4	3	w	2	4	3	w	2	4	3	w
1	1	1	-	2-3	1	2	o	1	1	1	-	1-2	1	1	o	1	1	1	-
1	1	1	-	2-3	1	2	o	1	1	1	-	1-2	1	1	o	1	1	1	-
1	2	1	-	3	2	3	o	2-3	2	2	o	2	2	2	o	2	2	2	n
1	2	1	-	3	2	3	o	2-3	2	2	o	2	2	2	o	2	2	2	n
1	2	1	-	3-4	4	4	o	3	3-4	3	o,n	2-3	4	3	o	3	3	3	n
1	2	1	-	3-4	4	4	o	3	3-4	3	o,n	2-3	4	3	o	3	3	3	n
1	1-2	1	-	3	2	3	o	2-3	2	2	o	2	3	2	o	2	2	2	n
1	1-2	1	-	3	2	3	o	2-3	2	2	o	2	3	2	o	2	2	2	n
1	2	1	-	3-4	3	3	o	3	2	3	o	2-3	4	3	o	2-3	3	3	n
1	2	1	-	3-4	3	3	o	3	2	3	o	2-3	4	3	o	2-3	3	3	n
2-3	2	2	o	4	4	4	o	3-4	3	3	o	3	4	3	o	2-3	4	3	o
2-3	2	2	o	4	4	4	o	3-4	3	3	o	3	4	3	o	2-3	4	3	o
3	3	3	o	4	4	4	o	4	4	4	o	3-4	4	4	o	3	4	3	o
3	3	3	o	4	4	4	o	4	4	4	o	3-4	4	4	o	3	4	3	o
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
3-4	4	4	w	4	4	4	w	4	4	4	w	3-4	4	4	w	3-4	4	4	w
1-2	3-4	2	f	2-3	3	3	o,f	2-3	3	3	o	3	4	3	f	1-2	4	2	o
3-4	2-3	3	w	4	4	4	w	4	4	4	w	3-4	4	4	w	3-4	4	4	w
1-2	1	1	w,f	2-3	1	2	o,f	1-2	1	1	w	2-3	1	2	f	1-2	1	1	w
1-2	2	2	f	3	2	3	o	2-3	2	2	o	2-3	2	2	f	2	2	2	n
1-2	2	2	f	3-4	4	4	o	3	3-4	3	o,n	2-3	4	3	o,f	3	3	3	n
1-2	1-2	2	f	3	2	3	o	2-3	2	2	o	2-3	3	3	f	2	2	2	n
1-2	2	2	f	3-4	3	3	o	3	2	3	o	2-3	4	3	o,f	2-3	3	3	n
2-3	2	2	o	4	4	4	o	3-4	3	3	o	3	4	3	o	2-3	4	3	o
3	3	3	o	4	4	4	o	4	4	4	o	3-4	4	4	o	3	4	3	o
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	3-4	4	f	4	3	4	f	3	3	3	f	4	4	4	f	3	4	3	f
4	3-4	4	f	4	3	4	f	3-4	3	3	w	4	4	4	f	3	4	3	f
4	2-3	4+	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	2-3	4+	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	1	3	f	4	1	3	f	4	1	3	f	4	1	3	f	3	1	2	f
4	1	3	f	4	1	3	f	4	1	3	f	4	1	3	f	3-4	1	3	w
4	2	3	f	4	2	3	f	4	2	3	f	4	2	3	f	3	2	3	f
4	2	3	f	4	2	3	f	4	2	3	f	4	2	3	f	3	2	3	f
4	2	3	f	4	4	4	f	4	3-4	4	f	4	4	4	f	3	3	3	f,n
4	2	3	f	4	4	4	f	4	3-4	4	f	4	4	4	f	3	3	3	f,n
4	1-2	3	f	4	2	3	f	4	2	3	f	4	3	4	f	3	2	3	f
4	1-2	3	f	4	2	3	f	3-4	2	3	w	4	3	4	f	3	2	3	f
4	2	3	f	4	3	4	f	4	2	3	f	4	4	4	f	3	3	3	f
4	2	3	f	4	3	4	f	4	2	3	f	4	4	4	f	3	3	3	f
4	2	3	f	4	4	4	o,f	4	3	4	f	4	4	4	f	3	4	3	f
4	2	3	f	4	4	4	o,f	4	3	4	f	4	4	4	f	3	4	3	f
4	3	4	f	4	4	4	o,f	4	4	4	o,f	4	4	4	f	3	4	3	o,f
4	3	4	f	4	4	4	o,f	4	4	4	o,f	4	4	4	f	3	4	3	o,f
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w,f	3	4	3	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w	4	4	4	w
3	4	3	w	4	4	4	w	4	4	4	w	3	4	3	w	3	4	3	w
2-3	4	3	w	3-4	4	4	w	3-4	4	4	w	2-3	4	3	w	2-3	4	3	w

soil unit	ground-water class	phase	plantain traditional suit.	yield exp.	res.	lim. fact.	plantain improved suit.	yield exp.	res.	lim. fact.	banana traditional suit.	yield exp.	res.	lim. fact.	banana improved suit.	yield exp.	res.	lim. fact.
1	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
1	1	cl	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
1	2	-	3-4	1	3	w	3-4	1-2	3	w	3-4	1-2	3	w	3-4	2	3	w
1	2	cl	3	1	2	w	3	1-2	2	w	3	1-2	2	w	3	2	3	w
1	3	-	2	1-2	2	o	2	2	2	o	2	1	2	o	2	1-2	2	o
1	3	cl	2	1-2	2	o	2	2	2	o	2	1	2	o	2	1-2	2	o
1	4	-	3-4	1-2	3	w	3-4	2	3	w	3-4	1-2	3	w	3-4	2	3	w
1	4	cl	3	1-2	2	w	3	2	3	w	3	1-2	2	w	3	2	3	w
1	5	-	1-2	2-3	2	o	1	2	1	-	1-2	2-3	2	o	1	2	1	-
1	5	cl	1-2	2-3	2	o	1	2	1	-	1-2	2-3	2	o	1	2	1	-
1	6	-	2	3-4	3	o	2	2-3	2	n	2	4	3	o	2	3-4	3	n
1	6	cl	2	3-4	3	o	2	2-3	2	n	2	4	3	o	2	3-4	3	n
1	7	-	2-3	4	3	o	3	3-4	3	n	2-3	4	3	o	3	4	3	n
1	7	cl	2-3	4	3	o	3	3-4	3	n	2-3	4	3	o	3	4	3	n
1	8	-	2	3	2	o	2	2	2	n	2	3	2	o	2	2	2	n
1	8	cl	2	3	2	o	2	2	2	n	2	3	2	o	2	2	2	n
1	9	-	2-3	4	3	o	2-3	3	3	n	2-3	4	3	o	2-3	3	3	n
1	9	cl	2-3	4	3	o	2-3	3	3	n	2-3	4	3	o	2-3	3	3	n
1	10	-	3	4	3	o	2-3	4	3	o	3	4	3	o	2-3	4	3	o
1	10	cl	3	4	3	o	2-3	4	3	o	3	4	3	o	2-3	4	3	o
1	11	-	3-4	4	4	o	3	4	3	o	3-4	4	4	o	3	4	3	o
1	11	cl	3-4	4	4	o	3	4	3	o	3-4	4	4	o	3	4	3	o
2,3,D	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
2,3,D	2	-	4	1	3	w	4	1-2	3	w	4	1-2	3	w	4	2	3	w
2,3,D	3	-	2-3	1-2	2	f	2	2	2	f	2-3	1	2	f	2	1-2	2	f
2,3,D	4	-	4	1-2	3	w	4	2	3_+	w	4	1-2	3	w	4	2	3_+	w
2,3,D	5	-	2-3	2-3	3	w,f	2-3	2	3^+	w	2-3	2-3	3	w,f	2-3	2	3^+	w
2,3,D	6	-	2-3	3-4	3	f	2	2-3	2	f,n	2-3	4	3	f	2	3-4	3	f,n
2,3,D	7	-	2-3	3-4	3	o,f	3	3-4	3	n	2-3	4	3	o,f	3	4	3	n
2,3,D	8	-	2-3	3	3	f	2	2	2	f,n	2-3	3	3	f	2	2	2	f,n
2,3,D	9	-	2-3	4	3	o,f	2-3	3	3	n	2-3	4	3	o,f	2-3	3	3	n
2,3,D	10	-	3	4	3	o	2-3	4	3	o	3	4	3	o	2-3	4	3	o
2,3,D	11	-	3-4	4	4	o	3	4	3	o	3-4	4	4	o	3	4	3	o
4	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
4	1	cs	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
4	2	-	4	1	3	w	4	1-2	3	w	4	1-2	3	w	4	2	3	w
4	2	cs	4	1	3	w	4	1-2	3	w	4	1-2	3	w	4	2	3	w
4	3	-	4	1-2	3	f	3	2	3	f	4	1	3	f	3	1-2	2	f
4	3	cs	4	1-2	3	f	3-4	2	3	w	4	1	3	f	3-4	1-2	3	w
4	4	-	4	1-2	3	w	4	2	3	w	4	1-2	3	w	4	2	3	w
4	4	cs	4	1-2	3	w	4	2	3	w	4	1-2	3	w	4	2	3	w
4	5	-	4	2-3	3	f	3-4	2	3	w	4	2-3	3	f	3-4	2	3	w
4	5	cs	4	2-3	3	w,f	4	2	3	w	4	2-3	3	w,f	4	2	3	w
4	6	-	4	3-4	4	f	3	2-3	3	f	4	4	4	f	3	3-4	3	f
4	6	cs	4	3-4	4	f	3	2-3	3	f	4	4	4	f	3	3-4	3	f
4	7	-	4	4	4	f	3	3-4	3	f,n	4	4	4	f	3	4	3	f,n
4	7	cs	4	4	4	f	3	3-4	3	f,n	4	4	4	f	3	4	3	f,n
4	8	-	4	3	4	f	3	2	3	f	4	3	4	f	3	2	3	f
4	8	cs	4	3	4	f	3-4	2	3	w	4	3	4	f	3-4	2	3	w
4	9	-	4	4	4	f	3	3	3	f	4	4	4	f	3	3	3	f
4	9	cs	4	4	4	f	3	3	3	f	4	4	4	f	3	3	3	f
4	10	-	4	4	4	f	3	4	3	f	4	4	4	f	3	4	3	f
4	10	cs	4	4	4	f	3	4	3	f	4	4	4	f	3	4	3	f
4	11	-	4	4	4	f	3	4	3	f	4	4	4	f	3	4	3	f
4	11	cs	4	4	4	f	3	4	3	f	4	4	4	f	3	4	3	f
5	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
6	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
6	1	i_s	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
6	1	i_d	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
6	2	-	4	1	3	w	4	1-2	3	w	4	1-2	3	w	4	2	3	w
6	2	i_s	4	1	3	w	4	1-2	3	w	4	1-2	3	w	4	2	3	w
6	2	i_d	4	1	3	w	4	1-2	3	w	4	1-2	3	w	4	2	3	w
7,8	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
7	1	i_s	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
7	1	i_d	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
7,8	1	se	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
9	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
9	1	er	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
9	1	i_s	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
9	1	i_d	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
9	1	se	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
A,B	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
A,B	1	se	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
C	1	-	4	1-2	3	w	4	2	3	w	4	2	3	w	4	2	3	w
C	2	-	3-4	1	3	w	3-4	1-2	3	w	3-4	1-2	3	w	3-4	2	3	w

Appendix K. Estimation of the average, lowest and highest returns per man-day of several crops.

For each crop the average, lowest and highest returns per man-day are calculated for yield levels prevailing under medium to high suitability of crops. The low yield level has therefore been taken as 60 per cent of the reference yield, an average yield level as 80 per cent of the reference yield and the high yield level as 100 per cent of the reference yield (Table K-1). Average prices and price ranges were obtained mainly from the Ministry of Agriculture and Natural Resources, Ibadan (April 1976) and from Lagemann (1977). If a price was not available, it was estimated by the author. The cash costs involve seed costs with or without costs of fertilizers (depending on the crop, as defined in Chapter 6); for yam, the expensive purchase of planting material was taken both inclusive and exclusive the total costs. Planting material for cassava, sweet potato and cocoyam was assumed to be free of charge. The range in cash costs is due to the two management levels. The labour requirement (in man-days/ha) is based on data gathered by Phillips (1964) or estimated by the author from experiments. Finally, three figures for the returns per man-day result; these are respectively the lowest, the highest and the average returns per man-day (Table K-2).

Table K-1. Reference yields of the studied crops, representing reasonably high yields under the defined management levels.

crop	reference yield (if not specified in kg/ha)	reference[1]
rice	2000	a.
maize (dry)	2300	a.
maize (green)	50000 cobs (± 15 ton)	b.
yam	12000	c.
cassava	20000	c.
sweet potato	12000	c.
cocoyam	6000	c.
cowpea	450	c.
soybean	650	c.
pigeon pea	650	c.
tomato	10000	d.
okra	3000	d.
celosia	20000	d.
sweet pepper	8000	d.
plantain/banana	15000	e.

[1] References:

a. 35 per cent of the highest yield obtained in toposequence experiments in Eastbank area I (1972-1976).
b. Average yield obtained in Eastbank area II (1976).
c. Average yield as given by Phillips (1964).
d. 30-40 per cent of the highest yield obtained at IITA (IITA 1974, 1975a).
e. 60 per cent of highest yields obtained in toposequence experiments in Eastbank area I (1975-1977).

Table K-2. Estimation of average, lowest and highest returns per man-day for several crops.

crop, hydromorphic/well drained, management level	price (K/kg) low, high, average	per hectare yield (kg) low, high, average	gross revenue (N)	costs (N) high, low, average	gross margin (N)	man-days (number) high, low, average	returns/ man-day (K) low, high, average
rice, hydromorphic land,	33 d)	1200	396	21	375	350 a)	107
traditional management	50	2000	1000	13	987	275 a)	359
	41	1600	656	17	639	313	204
improved management						887 b)	42
						625	158
						756	85
well drained land				19	377	212 a)	178
				13	987	212 a)	466
				16	640	212	302
maize, hydromorphic land,	1 K/cob)	30000 cobs	300	12	288	215 f)	134
early first season,	2 K/cob)	50000 cobs	1000	5	995	170 f)	585
harvested green	1½ K/cob)	40000 cobs	600	9	591	195	303
well drained land	11 d)	1380	152	10	142	125 a)	114
	25	2300	575	5	570	112 a)	509
	18	1840	331	8	323	119	271
yam, with costs of plan-	10 e)	7200	720	1430	neg.	600 a)	neg.
ting material	26	12000	3120	200	2920	375 a)	779
	18	9600	1728	675	1053	488	216
without costs of				0	720	600 a)	120
planting material				0	3120	375 a)	832
				0	1728	488	354
cassava	2 e)	12000	240	0	240	200 a)	120
	15 e)	20000	3000	0	3000	100 h)	3000
	9 m)	16000	1440	0	1440	150	960
sweet potato, hydromorphic land	1 h)	7200	72	0	72	260 i)	28
	5	12000	600	0	600	215 i)	279
	3	9600	288	0	288	238	121
well drained land						200 a)	36
						175 a)	343
						188	153
cocoyam, hydromorphic land	5 e)	3600	180	0	180	180 i)	100
	29 e)	6000	1740	0	1740	120	1450
	12 e)	4800	576	0	576	150	384
well drained land						150 h)	120
						100 h)	1740
						125	461
cowpea, hydromorphic land	15 e)	270	41	7	34	210 i)	16
	35 e)	450	158	3	155	165 i)	94
	25 e)	360	90	5	85	188	45
well drained land						150 a)	23
						125 a)	124
						138	62
soybean, hydromorphic land	6.6 j)	390	26	3	23	210 k)	11
	6.6	650	43	3	40	165	24
	6.6	520	34	3	31	188	16
well drained land						150 k)	15
						125	32
						138	22
pigeon pea	5 h)	390	20	2	18	150 a)	12
	10	650	65	1	64	100 a)	64
	8	520	42	2	40	125	32
tomato, hydromorphic land dry season	10 e)	6000	600	32	568	1300 b)	44
	54 e)	10000	5400	10	5390	400 b)	1348
	32 e)	8000	2560	21	2539	850	299
okra, hydromorphic land dry season	10 e)	1800	180	4	176	600 b)	29
	100 e)	3000	3000	1	2999	250 b)	1200
	30 e)	2400	720	3	717	425	169
celosia, hydromorphic land dry season	1 l)	12000	120	4	116	450 b)	26
	25	20000	5000	0	5000	300 b)	1667
	5	16000	800	2	798	375	213
sweet pepper, hydromorphic land dry season	5 h)	4800	240	18	222	800 b)	28
	20	8000	1600	1	1599	600 b)	267
	10	6400	640	10	630	700	90
plantain, hydromorphic land up to first harvest	4 d)	9000	360	22	338	1500 h)	23
	8	15000	1200	-	1200	1100	109
	6	12000	720	11	709	1300	55
well draind land up to first harvest						650 h)	52
						375	320
						512	138
banana, hydromorphic land up to first harvest	2 d)	9000	180	22	158	1500 h)	11
	8	15000	1200	-	1200	1100	109
	5	12000	600	11	589	1300	45
well drained land up to first harvest						650 h)	24
						375	320
						512	115

Notes:

a) according to Phillips (1964)

b) calculated from experiments by taking one man-day as 8 working hours

c) estimated from type D (table 9.5) with better water management and semi-permanent rather well levelled paddies in which weeding is reduced by 400 hours/ha and water management by 600 hours/ha; total reduction 1000 hours/ha, resulting in a total labour requirement of about 5000 hours/ha = 625 man-days/ha

d) prices according to Min. of Agric. and Nat. Res. (April 1976)

e) prices according to Lagemann (1977)

f) according to Phillips (1964): 110-125 man-days/ha for dry maize, but estimated at 170-215 man-days/ha for early first maize on hydromorphic land; the addition is due to ridging + drainage 20-30 man-days/ha and extra weeding 40-60 man-days/ha

g) according to Phillips (1964) 2-5.5 tons/ha planting material, which at extreme prices costs 2000 times ₦ 0.10 = ₦ 200 (low), 5500 times ₦ 0.26 = ₦ 1430 (high) and 3750 times ₦ 0.18 = ₦ 675 (average)

h) estimated by the author

i) estimated from labour requirement as given by Phillips (1964), but with an addition of 20-30 man-days/ha for ridging or mound-making (not for cocoyam) and also 20-30 man-days/ha for additional weeding

j) guaranteed price of ₦ 66/ton according to Robinson (1974)

k) taken as equal to cowpea

l) average price according to Lagemann (1977) is 25 K/kg, but grown on hydromorphic land the quality is generally poor, severely reducing the price; the low price (1 K/kg) and the average price (5 K/kg) are estimated by the author

m) personal communication J.M. Hoyoux, Agric. Economic subprogram, IITA; recent price, March 1977

₦ 1 = $ 1.6

CURRICULUM VITAE

Wietze Jan Veldkamp, geboren op 13 mei 1948 te Groningen, volgde de Dalton H.B.S.-B te Groningen, waarna hij in 1966 ging studeren aan de Landbouwhogeschool. In 1974 studeerd hij af in de tropische bodemkunde met als keuzevakken bemestingsleer, ontwikkelingseconomie en luchtfotointerpretatie.

Van 1974 tot 1977 was hij werkzaam, na aanstelling als promotie-assistent bij de Landbouwhogeschool, als research fellow op het International Institute of Tropical Agriculture (IITA) te Ibadan, Nigeria. Gedurende die tijd werd het onderzoek voor het proefschrift gedaan. In Nigeria en na terugkomst in Nederland werd het schrijfwerk voltooid.

Sinds maart 1979 is hij werkzaam in Liberia als assistent-deskundige van DTH.

Hij is getrouwd en heeft 2 kinderen.