The Soils Used for Rice Production in Cambodia

A MANUAL FOR THEIR IDENTIFICATION AND MANAGEMENT

EDITED BY
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Cambodia-IRRI-Australia Project
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Preface

A workshop designed to examine the classification of the soils on which rice is grown in Cambodia was held in Phnom Penh in May 1995. The workshop brought national soil scientists, agronomists, extension workers, and soil surveyors together with soil experts from the Philippines, Germany, and Australia. Participants concluded that there was a strong need to reappraise the classification of Cambodian soils and gave a mandate for the development of this manual.

Scientists from The Cambodia-IRRI-Australia Project developed this manual as part of the Project's role in developing the agriculture sector in Cambodia. The Cambodia-IRRI-Australia Project is a collaborative project utilizing resources from both the International Rice Research Institute (IRRI) and the Department of Agronomy within the Ministry of Agriculture, Forestry and Fisheries. Funding for the IRRI portion of the project is provided by the Australian Agency for International Development (AusAID).

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INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)

AUSTRALIAN AGENCY FOR INTERNATIONAL DEVELOPMENT (AUSAID)

Foreword

Recognizing soils is difficult for most people under the best of circumstances. In Cambodia the task is made even more complex by the lack of available information. *The Soils Used for Rice. Production in Cambodia* represents the first major work on Cambodian soils in the last 30 yr and goes a long way to satisfying a growing demand for basic information to guide planning and management decisions in agriculture.

The manua1 provides a simple method for identifying the main rice growing soils. The key is very easy to use and the major soils have been grouped into a manageable number of units. General profile descriptions are also provided as a final check if there is any doubt over a particular classification. With this manual, agronomists do nor require detailed maps or complex laboratory analysis to classify a soil. The manual provides information suitable for a range of potential users and, furthermore, complements international soil taxonomic classifications. Undoubtedly, agricultural technicians working in the field will come to rely on this manual.

The manual has been printed in both Khmer and English. In addition ro Provincial Agricultural Officers and district technicians using their copies ro assist farmers with developing soil management practices, the manual will also be useful at universities, colleges, and agricultural schools. We congratulate the authors and donors on their vision for the future development of Cambodia.

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The important contributions of Mr. Mike Bolton and Dr. Harry Nesbitt in Cambodia and Mr. Gene Hettel in thc Philippines during the editing of this manua1 are also gratefully acknowledged. Mr. Tim Sothor, Mr. Pheav Sovuthy, Mr. Lor Bunna, and Mr. Mot Sana translated the manual into Khmer. Ms. Yim Vuthong and Mr. Juan Lazaro IV constructed all original diagrams and adapted Figure 6 from Moormann and van Breemen (1978), and Ms. Doris Rifareal did the map of Cambodia and the page layout.

Introduction

P.F. White

Improving the production and efficiency of Cambodian agriculture demands an understanding of the country's soil resources. Fertilizer rates, tillage practices, varieties, cropping rotations, conservation and management systems, and even pest management strategies can all be affected by the soil type occurring at any particular location. The soils of Cambodia are diverse across its 19 provinces and Kompong Som and Phnom Penh municipalities (Fig. 1). Large areas of sandy, infertile, fragile soils, which require careful management, occur alongside highly reproductive soils that have the potential to support a wide range of cropping systems. Scientists, extension workers, and farmers need to be able to recognize and communicate this diversity.

Currently, agriculturists in Cambodia have little information about soils on which to rely. The first comprehensive inventory of the soil resources in the country was published by Crocker (1962) in his *Exploratory Survey ofthe Soils of Cambodia.* Mmost studies since then have been commissioned on an *ad hoc* basis producing a disjointed database of varying quality. (White *et al* 1995). Even Crocker’s classification is rarely used by agronomists or is used inappropriately; its usefulness being limited by the small scale of the map and the difficulty for nonexperts to recognize the soil units in the field.

Cambodian agriculture, nevertheless, is beginning a phase of rapid development. The research infrastructure is being rehabilitated, important research has been started and many projects are in preparation. These developments need better soil information to enable good planning, accurate interpretation of data, and the extension of results to new areas. This manual will aid these developments by serving as a tool for easy and improved communication about soils. It will, hopefully, also enable the development of a cohesive and comprehensive darabase on Cambodian soils.

This manual has the dual aims of providing a guide tor people who deal with soils only at a simple level, while also providing more comprehensive information for the experienced soil scientist. The classification relies mostly on the topsoil properties that affect crop production and is conceptually built on rhe soil series approach. A soil map is not provided nor envisaged. In the first instance, the classification allows nonspecialists to classify the soil on which they are standing, in the field, without the aid of a laboratory. Importantly, the system is not designed to replace more formal soil taxonomic classifications but to complement them. An avenue for correlation to international classifications has been incorporated through the third component of the system, the Fertility Capability Classification (Sanchez et al 1982).

Modifications will be needed. Appendix 3 sets out the protocol for further enhancing the manual as the agriculture sector in the country develops and more information becomes available. The key to the success of the manual will be its usefulness to agriculturalists working in the field.

Geomorphology and Hydrology of Cambodian Ricelands

P.F. WHITE AND T. OBERTHÜR

Geomorphology

The rice growing areas of Cambodia can be divided into three easily recognizable physiographic regions (Figs. 2-4: Saeki et al 1959, Crocker 1962, Kawaguchi and Kyuma 1974, Thach 1985):

- Soils developed on the old alluvial and/or colluvial plains;
- Soils developed *in situ* from underlying parent material;
- Soils developed on the active flood plains of rivers and lakes that receive annual alluvial deposits.

Soils derived from old alluvium and/or colluvium

Old alluvial terraces. These landforms, which occur in all rice-growing provinces of Cambodia, are former river, lake, or marine floodplains that are now above the level of regular flooding (Fig. 2; Plates 1 and 2). The soils are derived from alluvial material carried in the waters of the old rivers that once flooded these areas. Now the soils are flooded principally by rainwater only;

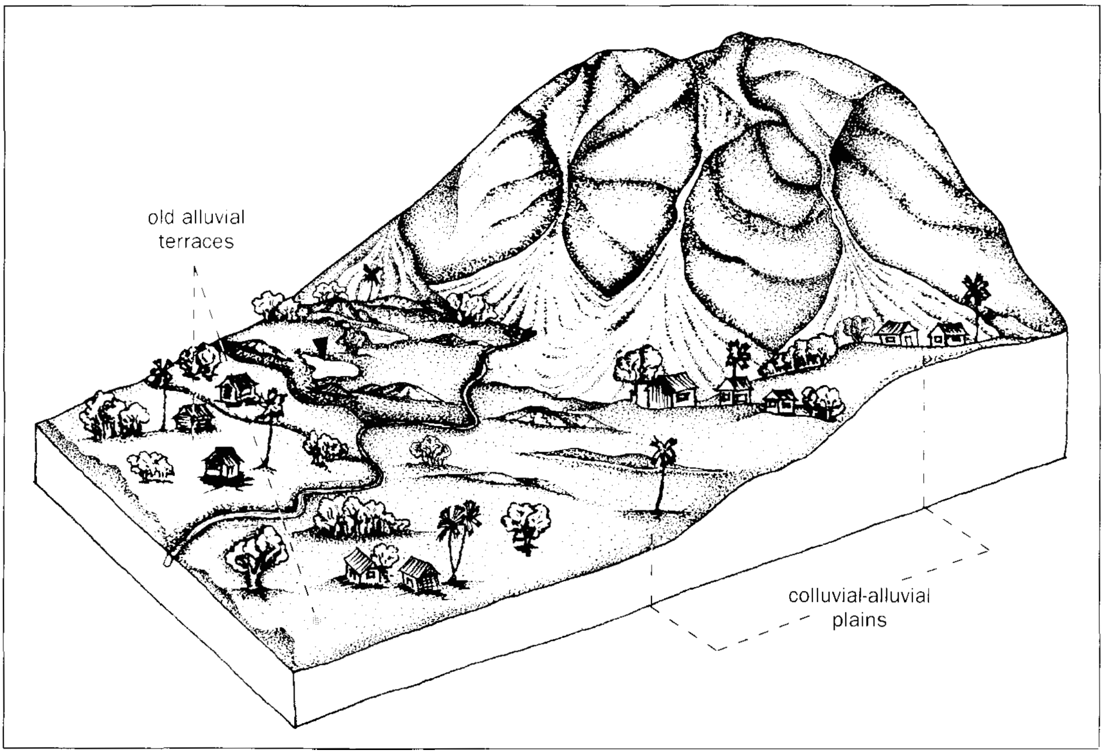

Figure 2. Old alluvial terraces and a series of colluvial-alluvlal plains extending from the base of hills and mountains.

soil nutrients are not replenished by annual alluvial deposits, and the soils undergo alternate reduction and oxidation with leaching that causes a net loss of nutrients and clay movement down the profile. Occasionally, in years of exceptional flooding, some of these areas may be flooded with water from nearby rivers but for only short periods by relatively fast flowing water. Some of these soils may also be located on the fringes of lake or river floodplains. They may be flooded for intermittent periods each year depending on seasonal conditions. The water reaching them contains little silt load and the length of inundation, never exceeds three months. Ferrolysis (Brinkmann 1970) resulting in clay dissolution and chloritization may also be a feature of these soils.

Soils on the alluvial terraces vary widely depending on age and erosion level. Older, relatively higher terraces may be dissected, usually forming wide flat valleys, giving the terrace an undulating topography. Very young terraces that only recently caused to be part of the active, present-day floodplains, are flat and may show transitional soil characteristics between the floodplain and the older terraces.

Colluvial-alluvial plains. These landforms result from erosion of the surrounding hills and mountains and the movement of the eroded material to the lowlands, initially forming a fan (Plate 3). Where several fans overlap, gently sloping plains extending from the base of hills are formed (Fig. 2). Wetland rice grown on the colluvial-alluvial plains is found mainly in the lower areas of the landform where the soils generally have a finer texture. Alluviation, which is washing of sediments from the hills by rivers and creeks, probably plays a more dominant role than colluviation in the formation of these plains in Cambodia. Colluviation, which is the movement of soil down slopes through gravitational action, although important, particularly in the initial stages ofthe process, will transport material to a lesser degree. The colluvial-alluvial plain generally grades into the old alluvial terraces.

In Cambodia, the formation of colluvial-alluvial plains are important in most rice-growing areas, but particularly in Battambang, Banteay Meanchy, Siem Reap, and parts of Pursat, Kompong Thom, Kompong Cham, and Svay Rieng. In some areas, the original hills or mountains have been completely eroded forming vast gently undulating plains.

Soils developed in situ from underlying parent material

These soils, which develop through weathering and decomposition ofthe underlying rock from which they are formed. In some cases, where these soils are found in lower slopes of hills, degrees of colluviation and alluviation may also have contributed to their formation (Fig. 2).

In Cambodia, these soils are derived from two main sources of parent material: 1) sandstones and shales of the Palaeozoic era, which form much of the mountains surrounding the country, and 2) extruded magma. The sandstone itself is formed from previously weathered material. The magma materials were extruded from volcanoes or fissures in the sandstone rock during relatively recent periods of geological activity. Both acid (e.g., granites) and basic (e.g., diorites) rocks were extruded giving rise to a range of soils with various pHs. Soils formed from these materials are relatively young and fertile, particularly the soils formed on basic rocks. Only the soils developed from recently extruded magma materials form a significant part of the rice-growing area, mainly in Kompong Cham, Kompong Thom, Ratnakiri, Stung Treng, and Battambang.

Soils of the active floodplains

Three major types of active floodplains can be distinguished in Cambodia.

Meander floodplains. These occur along the middle stretch of the rivers and are comprised of river channel, natural levees, backslopes, and basin (Fig. 3 and 5, Plate 4). Water is usually contained in the channel by the natural levees. When too much water is supplied, and the river overflows its levees, the basins are flooded. Sedimentation takes place at various rates depending on the water flow. The coarsest sediments (coarse sand and graivel) are deposited in the channel, fine sand and silt are deposited on the levees while clay is deposited in the basins.

In Cambodia, the levees and backslopes are mainly used for housing, vegetable and cash crop farmings or, very occasionally for rice production. Backslopes may be considered as the transition zone between levee and the basin. Soils in the basins show distinct hydromorphic properties, and are used mainly for rice production as water in the basin recedes. Peat may accumulate in the basin areas that do not drain.

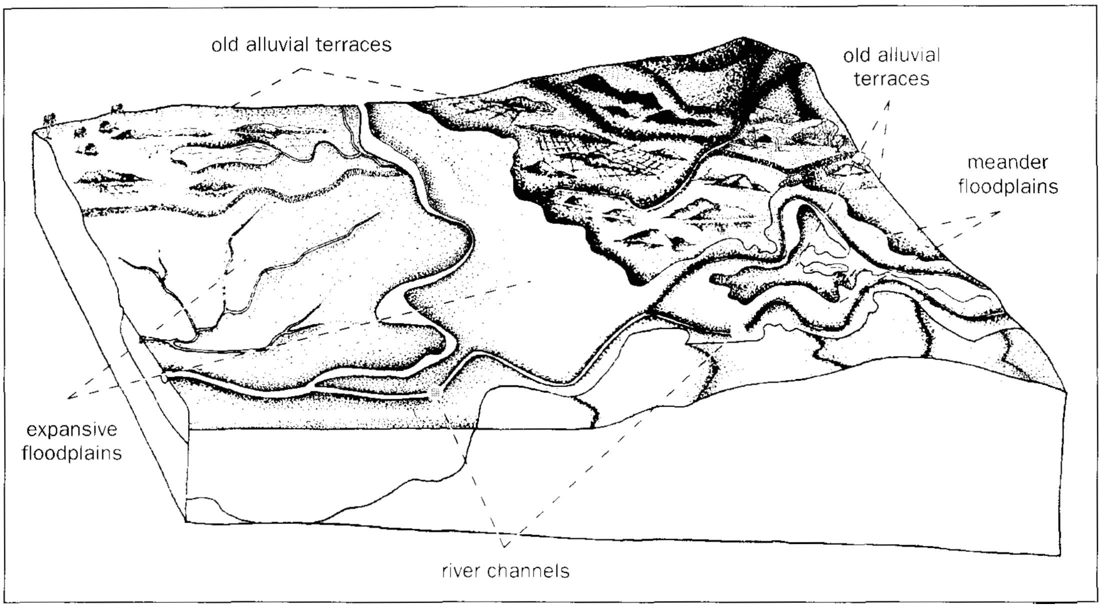

Figure 3. Expansive floodplains in relation to old alluvial terraces.

Meandering rivers migrate laterally, changing the sedimentary pattern as it moves. Levees break causing the channel to be cut off and later to be filled with sedimentary material. This creates a system of old and new levees and abandoned meanders (Fig. 5). The Mekong-Bassac river system has formed many such patterns.

Shorter rivers with steeper gradients may not develop real basins or have developed only shallow, minor basins.

The meander floodplains are observed along much of the Mekong River and parts of the Bassac River as wel1 as along other rivers of the country. This landform meets the expansive floodplains in the southern half of Kandal, Takeo and Prey Veng and the Lacustrine floodplains of the Tonle Sap.

Expansive flood plains. These are important landforms in Cambodia that are related to but, need to be distinguished from the meander floodplains. The expansive floodplains occur along the lower stretch of the river. These areas are characterized by a main river channel, a levee of medium or heavy-textured soil, behind which extends a wide, flat extensive basin with few features (Fig. 3, Plate 5). The basin may extend up to several kilomerers from the river channel in some areas of Takeo and Kandal. The basin is also traversed by shallow secondary channels without levees in which water flows during periods of low water water levels. The basins, as well as much of the levees, are covered by more than 2 m of water for exntended periods each year. These areas predominate in the southern half of Takeo, Kandal, and Prey Veng, around the Mekong-Bassac river system.

Marine floodplains also occur in the coastal areas of the country. Rice grown in these areas is affected by tidal movements and the intrusion of sea water. These areas, however, are only minor rice-growing areas in Cambodia.

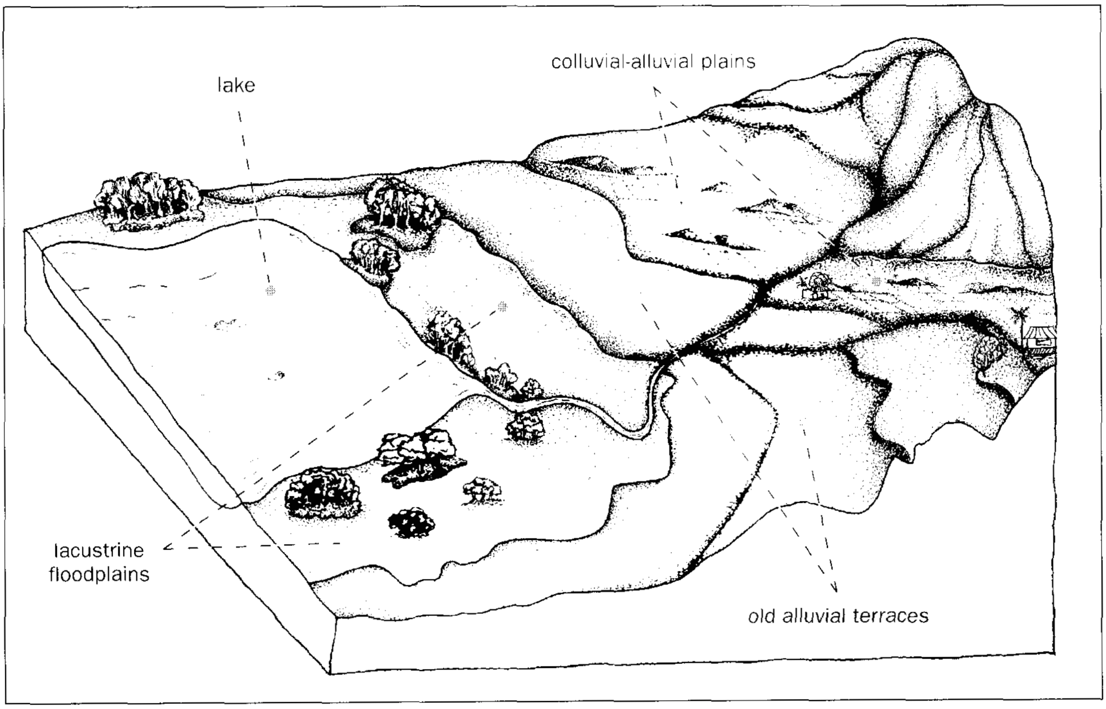

Figure 4. Lacustrine floodplains in relation to old alluvial terraces and colluvial-alluvial plains.

Lacustrine floodplains. In Cambodia, these landforms have much in common with the expansive floodplains. The plain surrounding Tonle Sap Lake is an example of a well developed Lacustrine floodplain (Fig. 4). Such floodplains are generally flat and featureless with fine-textured sediments. The nature of the sediments, however, depends on the lithology of the surrounding area and the occurring watershed pattern of rivers entering the lake. The hydrological situation of the Tonle Sap Lake, in particular, is unique with the floodwaters of the Mekong River backing into the Tonle Sap each year allowing sediments to be deposited in the

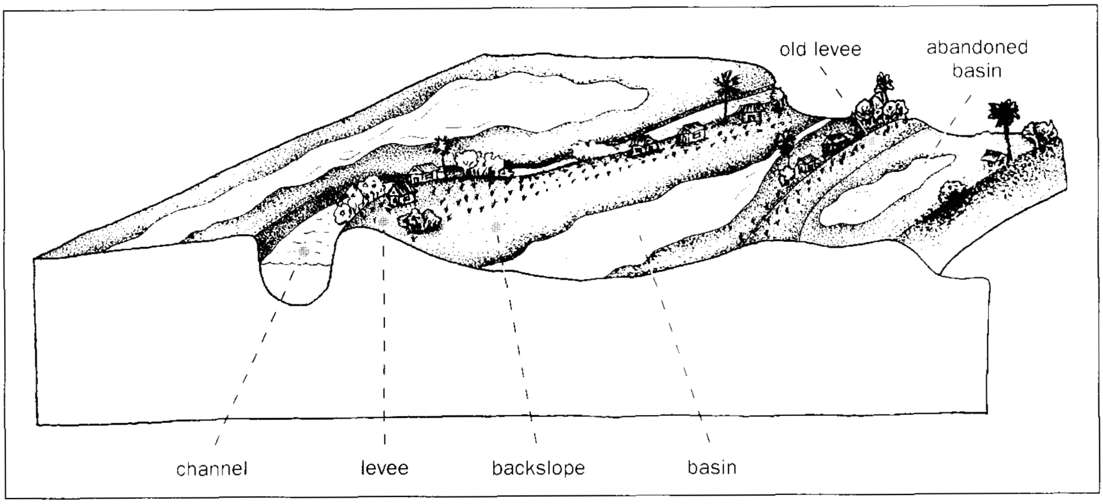

Figure 5. The river levee system.

lake. In addition, there are many small- and medium-sized rivers emptying into the lake. Small deltas form that are affected by the annual rising and falling of the water levels of the lake. A complex soil pattern has resulted with coarse-textured material being deposited near the wide mouth of the river as it enters the lake. Over time, with the changing direction of rivers. soils with succeeding layers of coarse and fine material have also developed.

Hydrology

Soil type and land use are intimately linked with hydrology. A simple means to describe the hydrology in any particular area is therefore needed to effectively communicate about soils and extend research to new areas. Moormann and van Breemen (1978) developed a convenient terminology for describing the hydrology of rice land. They divided riceland into pluvial, phreatic, and fluxial land (Fig. 6).

Pluvial ricelands

Water on pluvial ricelands is exclusively from rain. Excess water leaves the soil by percolation or as runoff. In the landscape, pluvial lands occur on gently to steeply sloping terrain and at relatively high levels in respect to the levels of groundwater or surface water.

Where the natural hydrology of the land has been altered through building bunds and puddling to retain more water and create a more aquatic water regime, then the term *anthraquic* is used. Hence, an area of pluvial land that has been bunded and puddled for paddy rice cultivation but, which retains only the rainwater that falls on it, would be termed anthraquic pluvial land.

Phreatic ricelands

In phreatic lands, rice plants are fed by rainwater and by groundwater (phreatic water), which is at a shallow depth during at least part of the cropping season. During heavy rains, phreatic lands may also receive some runoff water from higher parts of the surrounding local area. Phreatic

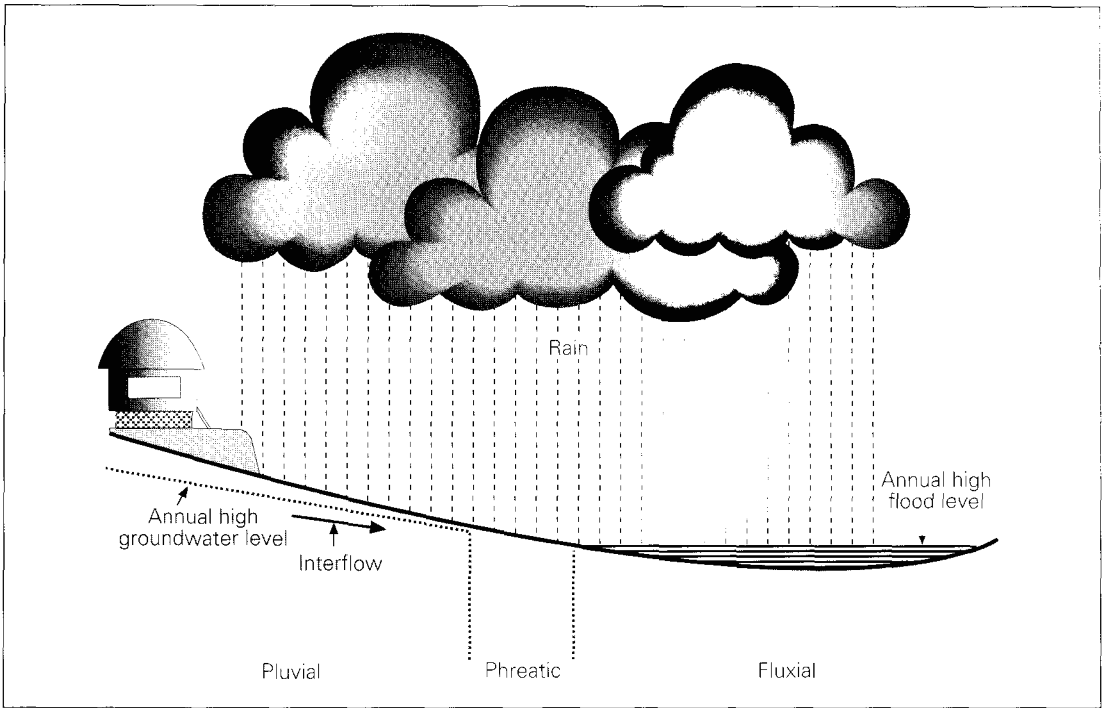

Figure 6. Terminology of Moormann and Van Breemen (1978) for describing the hydrology of ricelands.

ricelands commonly occur on foot slopes of hills and in depression areas in the landscape. These lands are also found on level and relatively high aspects of the landscape where impervious layers in the subsoil cause the formation of a temporary, suspended water table in periods when rainfall exceeds evapotranspiration and runoff.

As with pluvial lands, the hydrology of phreatic lands can be altered by human activity. The term *anthraquic phreatic* applies to phreatic land where the hydrology has been altered to create a more aquatic water regime.

Fluxial ricelands

Fluxial ricelands receive water wholly or partly from streams, rivers, or lakes. Fluxial ricelands are consistently inundated with this water for an extended period for at least part of every year during which a rice crop is grown. Landforms in which which fluxial ricelands occur are always in the lower parts of the landscape, such as valleys, closed depressions, or river or lake floodplains. Drainage, whether internal by percolation or by external runoff, is sufficiently slow so that ricefields remain flooded for at least part of the time that rice is grown.

An anthraquic hydrological regime is redundant in fluxial lands because by definition fluxial lands are aquatic for part of the growing season.

Classification System Used for Cambodian Rice Soils

T. OBERTHUR, P.F. WHITE, AND A. DOBERMANN

General Concept

The classification system used here consists of three levels: soil groups, soil phases, and the fertility capability classification (FCC). Soil groups are based on pedogenic criteria and use mainly morphological characteristics of the soil. The soil phase level is agronomically based and uses soil characteristics which affect crop production as criteria for separating phases. The FCC is a quantitative assessment of the soil fertility constraints and provides guidelines for management.

The classification is based on only two diagnostic layers of the soil. Unless specified differently, the upper layer coincides with the top 20 cm of the soil. This layer is referred to as the topsoil (or 'type' in FCC; see Table A1.1). The soil below the upper layer is referred to as the subsoil (or 'substrara type' in FCC). Unless specified differently, the subsoil is considered to a depth of 50 cm.

Emphasis is placed on features that are easily detectable in the field, such as texture. color, depth of horizons, presence or absence of cracks gravel, and compacted layers. Soil analytical laboratory data are only used to support the classification if available. This approach was chosen to enable people with little practical experience in pedology to easily identify soils in rhe field and classify them into one of the broad groups or phases. For the more experienced user, the FCC enables morc accurate quantitative classification at specific locations.

The strength of this system of classification is its ease of use, which allows the soil to be classified at several locations simply and quickly. The reliance on subjective criteria, however, may cause some difficulty in classification at any one location, particularly if it occurs at the border between two groups. Classification of the soil in any one area, therefore, should he based on several observations at different locations within the study area.

Soil Groups

Soil groups are defined as a unit of morphologically similar soils, which occur at the same position in the landscape. Hence, a black, cracking clay occurring on an old alluvial terrace is classified separately from a black, cracking clay occurring on an expansive floodplain. Similarly, all soils with a deep sandy profile occurring on old alluvial terraces are grouped together. The broad criteria assume a link between topographic location and morphology with pedogenic processes.

Each soil group is named and identified by a central concept, which is a one-line statement highlighting the soil's main features. The occurrence and genesis of rhe soil is described followed by a general description of the morphological properties of the group.

The generalized soil profiles given for each group are compilations of rhe previously published profile descriptions of Crocker (1962) and Reyes (1995), and unpublished data from the Cambodia-IRRI-Australia Project.

The number of soil groups is not fixed. As more information becomes available through soil surveys and general observations, additional groups may he established. Furthermore, the central concepts of groups may also be revised if necessary (see Appendix 3).

Soil Phases

Soil phases subdivide soil groups. They are defined primarily on soil properties having significance for crop production. Local experience and expertise were important in determining the number and type of phases existing within a group. Class limits for the phases are based on data gained from the scientific literature.

Soil phases, once defined, receive a name based on the dominant property identifying the phase. More phases may be identified if agronomically relevant soil properties are encountered in the future.

Fertility Capabilty Classification for Cambodia

FCC is a technical system for grouping soils according to the kinds of problems they present for agronomic management (Buol et a1 1973, Sanchez et a1 1987, Sanchez and Buol 1985, Smith 1989). The FCC provides a checklist of identifiable properties that have been found by previous research and experience to influence the effectiveness of crop management (Appendix 1). For any particular soil, the classification is presented as a code (e.g., *L(0-1%)* or *Lehk).* The interpretation ofthe code then provides information to guide the user in choosing the right practices for the classified soil (Dobermann 1995).

FCC is based on quantitative topsoil and subsoil parameters (termed *soil type* and *substrata type*) and condition modifiers, directly relevant to plant growth. Most ofthe class limits are borrowed from *Soil taxonomy* (Soil Survey Staff 1994) or the FAO/UNESCO soil classification system (FAO 1974). As with the soil groups and phases, the FCC is open-ended, allowing for additional features of local importance to be added to the condition modifier as superscript plus ($^+$) or minus ($^-$). In Cambodia, it has been necessary to define some additional condition modifiers (low available soil P and low soil organic matter content) to family cover the range of soils occurring. The topsoil and subsoil parameters and the condition modifiers of the FCC, which have relevance to Cambodia, have therefore been assembled *as the Fertility Capability Classification for Cambodia* (FCC-C; see Table A1.2). More parameters will probably be added as research provides a better understanding of the relationship between management recommendations and the FCC-C parameters.

When using FCC-C, soils are classified by determining the topsoil and subsoil texture classes first (type and substrata) and then whether a condition modifier is present. The final FCC-C code lists the type and the substrata type in capital letters, the modifiers in lower case letters, the gravel modifier as a prime (‘) and the slope, if desired, in parentheses. Interpretation of the code is then based on individual guidelines for each type, substrata type, and modifier. Sanchez and Buol (1 985) provided guidelines of interpretation of the FCC codes for wetland rice cultivation. General guidelines for upland agriculture can be found in Sanchez et a1 (1982) and Boul (1987). Smith (1989) further elaborated on both upland crops and rice cultivation. Guidelines for the interpretation of the FCC-C codes are presented in Appendix 1 (Tables A1.3, A1.4, and A1.5).

The FCC-C classifies the soil in greater detail than the soil groups and phases and provides more specific management recommendations. The FCC-C also provides a link with other international soil classification system. Most of the data needed for FCC-C can be found in classical soil surveys, can be measured directly in the field, or can be obtained from relatively simple laboraltory analysis. FCC units can also easily be obtained from data used to classify soils using *Soil taxonomy* or the FAO/UNESCO soil classification.

The FCC-C code for each of the soil phases is presented in Table 1 as a guide. It should be noted, however, that not all the condition modifiers for a soil phase may occur at all locations. Nevertheless, experience has shown that these FCC-C codes will generally apply to the soil phases listed. In the absence of more information they may be used as a guide to management of the soil phases. For more accurate classification at specific locations the user must determine the FCC-C for each site individually.

Table 1. General FCC-C codes for each soil group and phase.

Soil group	Soil phase	FCC-C code
Prey Khmer	*Coarse sandy*	S *d h e k o p*
	Fine sandy	S *d h e k o p*
Prateah Lang	*Shallow*	Sc *or* R^{-} *d g h e k o p*
	Loamy subsoil	SL *d g h e k o p (i+)*[4]
	Clayey subsoil	SC *d g h e k o p*
Labansiek	*Nonpetroferric*	C *d a e* i^{-} *k*
	Petroferric	CR *d a e* i^{-} *k*
Orung		LS *gdkepo*
Krakor	*Noncracking*	LC *g or* C *g*
	Cracking	*C g (g+) v*
Bakan		LC *gekpo*
Kbal Po	*Thionic*	C *g (g +) c (a)*
	Nonthionic	*C g (g+)*
Kein Svay		L *dg (p)*
Toul Samroung	*Brown*	C *g d (v) (o) i*
	Gray	C g d (v) (o) i
Koktrap	*Fertile*	LC or C *g (g+) d k i*
	Nonfertile	LC (R+) *g (g+)d h (a) k v i* or C (R+) *g (g+) d h (a) k v i*
Kampong Siem	*Gravelly*	C *g (d) p v*
	Nongravelly	C *g (d b) p v*

Modifiers enclosed in parentheses indicate uncertainty in the application of the modifier.

Procedure for Classifying Soils

P.F WHITE, T. OBERTHUR, A. DOBERMANN, AND R.T. REYES

Identifying soil groups and phases using the *Key to the major soil of the rice-growing areas* beginning on page 15 is the first step in classifying soils. The key suggests a probable classification which must then be compared with the group concept and general description of the soil. Experienced users can classify the soil further using the FCC-C parameters listed in Appendix 1. For less experienced users, the FCC-C codes for each group and phase have been listed in Table 1. It should be noted, however, that these codes are only a guide. Appendix 1 must be consulted if the FCC-C codes are to be accurately assigned to the soil at a specific site.

The following procedure should be followed to classify a soil.

1. Key the soil out to the group and phase by answering the questions listed in the key.
2. Compare the group and phase suggested by the key with the group concept and soil phase description (Table 2).
3. If the soil exactly matches the group concept and phase description then compare the soil with the general description of the soil in the section on *Major soils of the rice-growing areas.* If the group concept or phase description does not match the soil, then consult Appendix 3.
4. If the soil fits the general description of the soil, then considered it classified under that particular group and phase. It is important that the overall picture of the soil outlined in the general description matches the soil king studied, however, not all the features listed in the general description need to he present in the soil to obtain a classification. If the general description does not match the soil, then consult Appendix 3.
5. Regardless of whether the soil can be classified at the group and phase levels, determine the FCC-C type and substrata type by using Table A1.1 in Appendix 1.
6. Assign any condition modifiers to the soil based on Table A1.2.
7. Interpret the FCC-FC codes to provide additional guidance for management using Tables Al.3, A1.4, and A1.5.

Table 2. Group concept, phase description, and the estimated proportion of the total rice area in Cambodia occupied by each group. [a]

Group concept and phase description	Percentage of rice area
Group 0 - Prey Khmer A soil occurring on the old alluvial terraces or the colluvial-alluvial plains. which has a sandy textured profile extending deeper than 50 cm. *Fine sandy phase: the sand is predominantly fine sand (<0.5 mm).* *Coarse sandy phase: the sand is predominantly coarse sand (>0.5 mm).*	10 - 12%
Group 1 - Prateah Lang A soil occurring on the old alluvial terraces or the colluvial-alluvial plains, which has a sandy topsoil less than 40 cm thick over a subsoil that has a loamy or clayey texture. *Shallow phase:* the depth of the topsoil IS 20 cm or less and the texture of the subsoil is clayey or a very hard layer occurs within 20 cm of the surface. The very hard layer is a plow pan or a consolidated iron pan. *Clayey subsoil phase:* the depth of the topsoil IS 20 cm or greater, a very hard layer is not present within the top 20 cm of the profile, and the texture of the subsoil is clayey. *Loamy subsoil phase:* the subsoil has a loamy texture and a very hard layer is not present within 20 cm of the surface.	25 - 30%
Group 2 - Labansiek Soils occurring on the sides of hills or mountains with a red, clayey surface soil with a crumb structure and a clayey subsoil. *Petroferric phase:* a hard consolidated ironstone layer several centimeters thick is present within the top 50 cm of soil. *Nonpetroferric phase:* a hard consolidated ironstone layer is not present within the top 50 cm of soil.	1%
Group 3 - Orung A soil occurring on the old alluvial terraces that has a loamy to clayey textured topsoil less than 40 cm thick over a sandy subsoil layer that is thicker than 10 cm. *Orung phase:* separate phases have not been defined.	1· 2%
Group 4 - Krakor A soil with a gray to brown but not dark gray, very dark brown or black, loamy or clayey textured topsoil over a sandy, loamy or clayey subsoil occurring on the active floodplains. *Cracking phase:* moderate to large cracks form in the soil surface when it dries. The cracks penetrate deeper than 5 cm into the soil when it dries. *Noncracking phase:* cracks are not formed in the soil surface when it dries or there are only surface cracks, which do not penetrate more than 5 cm into the soil.	15%
Group 5 - Bakan A soil occurring on the colluvial-alluvial plains or the old alluvial terraces, which has a loamy or clayey topsoil that does not crack or has only shallow surface cracks occurring over a mottled loamy or clayey subsoil. *Bakan phase:* separate phases have not been defined.	10 - 15%

Table 2. Continued.

Group concept and phase description	Percentage of rice area
Group 6 - Kbal Po A soil with a dark gray, very dark brown to black, clayey topsoil, which forms large deep cracks over a clayey subsoil, occurring on the active floodplains. Sandy strata in the subsoil may occur. *Thionic phase:* the subsoil pH is below 4.5. *Nonthionic phase:* the subsoil pH is above 4.5.	13%
Group 7 - Kein Svay A brown, loamy or clayey textured soil (topsoil and subsoil) with a weakly developed profile formed on the river levees and the associated backslopes. *Kein svay phase:* separate phases have not been defined.	2%
Group 8 - Toul Samroung A soil occuring on the old alluvial terraces or the colluvial-alluvlal plains, which has a clayey or loamy topsoil that forms wide cracks that penetrate deeper than 5 cm into the soil over a clayey or loamy subsoil. The topsoil is gray or brown, but not dark gray or black. *Brown phase:* when wet, the surface soil is brown or light brown *Gray phase:* the color of the surface soil when wet is gray or light gray.	7 - 10%
Group 9 - Koktrap A soil occurring on the old alluvial terraces, which has a dark gray, very dark brown to black topsoil with a clayey or loamy texture over a light gray or light brown, loamy or clayey subsoil. *Infertile phase:* unfertilized yields on farmers' fields are less than 1,200 kg rice ha^{-1}, generally around 500 to 800 kg ha^{-1}. Slight to severe bronzing of the leaves of rice grown on these soils frequently occurs. *Fertile phase:* unfertilized yields on farmers' fields are more than 1,200 kg rice ha^{-1}, generally more than 1,500 kg ha^{-1} and leaf bronzing does not occur.	5%
Group 10 - Kompong Siem Soils on which calcimorphic limestone or bassalt stones or boulders are clearly visible within the profile or on the soil surface and that have a black or dark gray, clayey textured topsoil, which forms deep, wide cracks over a clayey textured subsoil. *Gravelly phase:* abundant small, round black and brown ferro-manganese concretions are present throughout the profile. Gravel can be clearly seen in the surface soil; a handful of topsoil will most often contain gravel. *Nongravelly phase:* gravel is not present throughout the profile or only a few scattered concretions are formed or the gravel is only concentrated in a part of the subsoil and is not present in the surface soil.	1.2%

[a] It should be noted that the groups have been named arbitrarily. The occurence of the soils is not restricted to the area indicated by the name. All soils can be found in many provinces.

Key to the Major Soils of the Rice-Growing Areas

P.F. White, R.T Reyes T. Obretür and H Obermann

1 The soil is flooded for at least 3 months or longer for at least 4 out of every 5 years by river or lake water? — YES ► Go to 38

NO ▼

2 The soil occurs on the sides of hills or mountains? — YES ► Go to 32

NO ▼

3 The soil occurs on an area of undulating topography? — YES ► Go to 25

NO ▼

4 The soil occurs on a river levee or associated backslope? — YES ► Go to 35

NO ▼

5 The soil occurs on an extensive flat area? — NO ► Review the geomorphology on pages 3-7 or go to 46

YES ▼

6 The soil has a sandy topsoil extending deeper than 50 cm? — NO ► Go to 9

YES ▼

7 The sand grains are coarse? — YES ► Prey Khmer group — Coarse sandy phase

NO ▼

8 The sand grains are fine? — YES ► Prey Khmer group — Fine sandy phase

9 The soil has a sandy topsoil over a loamy or clayey subsoil? — NO ► Go to 13

YES ▼

10 A clayey subsoil occurs at less than 20 cm or a very hard layer occurs within 20 cm from the surface?	—YES →		Prateah Lang group	Shallow phase
NO ↓				
11 A clayey subsoil occurs deeper than 20 cm from the surface and a very hard layer is not present within the top 20 cm?	—YES →		Prateah Lang group	Clayey subsoil phase
NO ↓				
12 The subsoil is loamy and a very hard layer is not present within the top 20 cm?	—YES →		Prateah Lang group	Loamy subsoil phase
13 The soil has a loamy or clayey topsoil and a loamy or clayey subsoil?	— NO →	Go to 24		
YES ↓				
14 The color of the topsoil is dark gray, very dark brown or black?	— NO →	Go to 19		
YES ↓				
15 Basalt or calcimorphic limestone rocks, stones or boulders can be seen on the soil surface or in the soil profile or occur in the general area and are known to be associated with this soil?	— YES →	Go to 29		
NO ↓				
16 Hills are nearby on which the red, Labansiek soils occur?	— YES →	Go to 29		
NO ↓				
17 Unfertilized yields on farmers' fields are less than 1.2 t/ha?	— YES →		Koktrap group	Infertile phase
NO ↓				
18 Unfertilized yields on farmers' fields are more than 1.2 t/ha?	— YES →		Koktrap group	Fertile phase

19	Cracks occur in the surface soil when the soil dries?	NO ►		Bakan group	Bakan phase
	YES ▼				
20	When the soil dries, there are only small surface cracks in the surface soil that do not penetrate deeper than 3-4 cm into the soil?	YES ►		Bakan group	Bakan phase
	NO ▼				
21	When the soil dries, there are large cracks in the surface that penetrate deeper than 3-4 cm into the soil?	NO ►	Go to 46		
	YES ▼				
22	The top soil is brown?	YES ►		Toul Samroung group	Brown phase
	NO ▼				
23	The top soil is gray?	YES ►		Toul Samroung group	Gray phase
	NO	►	Go to 46		
24	The soil has a loamy or clayey topsoil over a sandy subsoil?	YES ►		Orung group	Orung phase
	NO	►	Go to 46		
25	The soil has a loamy or clayey topsoil and a loamy or clayey subsoll?	NO ►	Go to 46		
	YES ▼				
26	Basalt or calcimorphic limestone rocks, stones, or boulders can be seen on the soil surface or in the soil profile or occur in the general area and are known to be associated with this soil?	YES ►	Go to 28		
	NO ▼				
27	There is clear profile development so that the topsoil has either a different texture, color or structure to the subsoll?	NO ►	**Go** to 36		
	YES	►	**Go to** 14		

28 The soil color is dark gray to black?	— NO →	Go to 32		
YES ↓				
29 When the soil dries, large cracks extending 3-4 cm or deeper form in the surface?	— NO →	Go to 46		
YES ↓				
30 Abundant gravel occurs in the profile?	— YES →		Kompong Siem group	Gravelly phase
NO ↓				
31 Gravel does not occur in the profile?	— YES →		Kompong Siem group	Nongravelly phase
32 The color of the surface soil is red to brown and the soil has a crumb structure?	— NO →	Go to 46		
YES ↓				
33 The soil has a hard consolidated ironstone layer within the top 50 cm of the soil?	— YES →		Labansiek group	Petroferric phase
NO ↓				
34 The soil does not have a root restricting layer within the top 50 cm of the soil?	— YES →		Labansiek group	Nonpetroferric phase
35 The soil has a loamy or clayey topsoil and a loamy or clayey subsoil.	— NO →	Go to 46		
YES ↓				
36 The top 50 cm of soil is very uniform; color, structure, and texture are similar (ignoring mottles)?	— YES →		Kein Svay group	Kein Svay phase
NO ↓				
37 When the soil dries, cracks occur in the surface soil, which penetrate deeper than 3-4 cm?	— YES →	Go to 22		
NO →		Go to 46		

38 The soil has a loamy or clayey topsoil and a sandy, loamy or clayey subsoil? — NO ► Go to 46

YES ▼

39 The soil has a dark gray to black colored surface horizon, which forms cracks on drying whlch penetrate 3-4 cm or deeper. — NO ► Go to 42

YES ▼

40 The subsoil has a pH below 4.0 or farmers report problems with the growth of rice if they plow too deeply? — YES ► Kbal Po group — Thionic phase

NO ▼

41 The subsoil has a pH above 4.0 or farmers do not report problems with the growth of rice if they plow too deeply? — YES ► Kbal Po group — Nonthionic phase

NO ▼

42 The surface soil color is gray to brown? — NO ► Go to 46

YES ▼

43 When the soil dries, cracks occur in the soil surface, which penetrate deeper than 3-4 cm? — YES ► Krakor group — Cracking phase

NO ▼

44 When the soil dries, small cracks appear in the surface soil but the cracks do not penetrate deeper than 3-4 cm into the soil? — YES ► Krakor group — Noncracking phase

NO ▼

45 Cracks do not appear in the surface soil when it dries? — YES ► Krakor group — Noncracking phase

NO ▼

46 The soil has not yet been defined and cannot be classified. See Appendix 3 for the protocol for adding new soil groups or phases to the classification.

Major Soils of the Rice-Growing Areas

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Group 0—Prey Khmer Soil (Plate 6)

Group concept

A soil occurring on the old alluvial terraces or the colluvial-alluvial plains with a, sandy textured profile extending 50 cm or deeper.

Occurrence

Soils of this group have developed from sandy alluvial or colluviall material. The soils occur predominantly on the old alluvial terraces and some of the colluvial-alluvial fans and piedmont plains. The soils are above the level of natural flooding of local rivers and lakes, but may become inundated for short periods in years of exceptional flooding. This soil type is located on both anthraquic pluvial lands and anthraquic phreatic lands.

Small areas of this soil type can be found in most provinces, but more significant areas occur in Pursat, Kompong Chhnang, Kompong Speu, and Siem Reap. This soil type is estimated to occur on 10 to 12% of the rice-growing area.

General description

The prominent feature of this soil is its deep sandy nature. In some profiles, the sandy horizon extends beyond 2 m. The color of the surface soil can vary but is usually lighter shades of gray or brown often with a pinkish tinge. There is no soil structure or hardpan development and few, if any, ironstone concretions. The small amount of clay in the surface soil is usually dispersed. Orange and yellow mottling may occur below 30 cm but plinthite, does not occur. In soils where there is some subsoil horizon development, this is usually indicated by a slightly lighter color and slightly higher clay content.

Soils in this group are derived from two sources. Somc soils have developed on beaches and point bars of ancient rivers. The soil in this case has developed on coarse sandy alluvium and is highly leached with little evidence of clay movement within the profile. These soils are generally found in the flat, lower parts of the landscape. Other soils have developed on a mixture of alluvial deposits and coarse colluvial material and occur mostly on slightly undulating terrain. In these cases, there is some evidence of clay movement from the sandy surface to the lower horizons, although, the amount of clay in the profile nevertheless remains small. In both cases, water infiltrates easily through the profile. Water standing on the surface only occurs for a short period during the height of the rainy season when the entire surface profile is saturated.

Profile description

Surface layer

Depth	10-40 cm.
Texture	Sandy
Color	Dry: varies but is most often pale gray to pale brown, often with pinkish tinge. Moist: varies but is most often pale or light brown or pale or light gray.
Mottles	A few mottles may occur.
Consistency	Dry: loose but sometimes firm. Moist: loose.
Structure	Structureless.

Subsoil

Texture	Sandy (a loamy or clayey textured layer can occur deeper than 50 cm, i.e., beyond the profile described here).
Color	Dry: varies but is most often light brown to light gray. Wet: varies but is most often light brown to gray
Mottles	A few may occur, usually orange to pale brown.
Consistency	Dry: loose but sometimes firm. Moist: loose.
Structure	Structureless.
Plinthire	Does not occur within the 50-cm profile.

Synonyms

The Prey Khmer soils correlate with some of the Red-Yellow Podzols and occasionally Planosols of Crocker (1962). Where the sandy topsoil extends deeper than 1 m, *Keys to soil taxonomy* (Soil survey staff 1994) would classify this group in the Entisol order (suborder Psamments) otherwise the group would fall into the Ultisol order. This group would also be classified as (Dystric) Fluvisols or occasionally Arenosols using the FAO/UNESCO soil classification system (FAO 1974).

Division in phases

Two phases of the Prey Khmer group have been defined based on the size of the sand fraction in the surface horizon:

Fine sandy phase. There is a dominance of fine sand in the sand fraction. Most of the sand grains are less than 0.5 mm in size but usually less than 0.3 mm. The feel of the surface soil may be likened to good quality table salt. The fine sandy surface layer frequently overlays a B horizon, which, although sandy, has a slightly higher clay content than the surface horizon.

Coarse sandy phase. The sand fraction is predominantly coarse, with sand grains of over 0.5 mm dominating the feel of the soil, which may be likened to good quality table sugar (see Fig. A2.3).

Soil management

This soil is difficult to manage for rice production. There is little potential for achieving high rice yields on this soil.. Yields are likely to vary substantially from year to year depending on the prevailing seasonal conditions. The coarse sandy phase of this group is likely to present more problems than the fine sandy phase. This soil type is not suitable for irrigation.

The fertility of this soil is very low. Glasshouse experiments have shown the soil to be potentially deficient in N, P, K, S, and Mg (CIAP 1994, Lor et al 1996). The cation exchange capacity (CEC) and organic matter levels are very low. Fertilizer management is very difficult with nutrients being easily leached and there is difficulty in matching nutrient supply to crop demand. Farmers have been known to commonly apply sea salt as a fertilizer on this soil type. The *e, k, o,* and *p* modifiers from FCC-C always apply.

The soil pH is acidic but is not strongly buffered and reaches a favorable value for rice production when the soil is flooded; the *h* modifier generally applies. Proglems with sulfur toxicity may occur when large amounts of organic manures are applied in one application. Similarly, applying inorganic fertilizer containing large amount\ of S,e.g., $(NH_4)_2SO_4$, may also cause S toxicity. Where the soil is situated on phreatic lands the *g*+ and *i*+ modifiers are likely to apply. Salt toxicity problems have been reported on small areas of this soil in which case the *n* or *n* modifiers would apply.

Limitation of rooting depth is not a problem in this soil. Low water holding capacities, however, present problems. Flooding generally only occurs when the entire profile is saturated. As the soil dries, plants tend to run into drought stress it they are unable to tap the water stored deeper in the profile. The S type and substrata type apply as does the *d* modifier.

The soil is excessively drained, particularly in the coarse sandy phase. Water infiltrates easily into the soil and lateral flow of water within the profile can occur. If this soil occurs on pluvial lands, it is only able to support rice production if an impermeable layer occurs in the profile (below the top 50 cm described here) that prevents deep percolation of water. A plow pan cannot be effectively established in the coarse sandy phase of this soil but can sometimes occur in the fine sandy phase.

Tillage is relatively easy, but, the sand grains settle quickly after plowing or harrowing, which makes transplanting difficult. The sand grains pack more rightly with the fine sandy phase and hence transplanting is more difficult in this phase than with the coarse sandy phase. Harrowing is not always necessary.

The soil is structureless and, hence, does not cause problems when rice is rotated with upland crops. Upland crops can be easily grown after a rice crop if moisture conditions allow.

Recommendations

- Use urea rather than of ammonium sulfate fertilizer.
- Apply N and K in small, frequent doses.
- Avoid applying large amounts of organic matter in a short period.
- Use deep-rooting rice varieties.
- Compact the soil to reduce water infiltration, if possible. This is likely to be more successful in the fine sandy phase than in the coarse sandy phase.
- Transplant within a few hours of harrowing or plowing.

- Consider direct seeding to take greater advantage of available water.
- Ensure the field is level.
- If Fe toxicity is a problem, use resistant varieties and transplant 1 or 2 months after flooding or transplant at the time of flooding.
- Include deep rooting legumes in a rotation after rice where water is available deeper in the profile.
- If salt is a problem, flushing the soil to leach the salt may be an option, otherwise grow tolerant varieties.
- Apply cow manure or inorganic fertilizer to the nursery at the following rates (do not apply large amounts of cow manure immediately before sowing): 50 kg cow manure/100 m^2, 0.5 kg each of N, P_2O_5, and K_2O/100 m^2.
- Organic and inorganic fertilizer should be applied to the main field to provide the following nutrient rates: 78-52 kg N, 12-15 kg P_2O_5, 0-20 kg K_2O. and 0-10 kg S/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a constraint on yields. The higher rates are recommended for modern varieties and where water is less of a constraint on yields.

Group 1—Prateah Lang Soil (Plate 7)

Group concept

A soil occurring on the old alluvial terraces or the colluvial-alluvial plains, which has a sandy topsoil less than 40 cm deep over a subsoil, which has a loamy or clayey texture

Occurrence

This soil makes up a substantial part of the old alluvial terraces and some of the colluvial-alluvial fans and piedmont plains. This group occurs on anthraquic pluvial and anthraquic phreatic ricelands. The Prateah Lang group does not occur on fluxial ricelands, although in years of exceptionally high floods, floodwaters may reach these lands for short periods. This soil type is very common and is estimated to occupy about 25 to 30% of the rice-growins area. Where it has not been used for rice production, the soil supports grassland or low-grade tropical forest.

General description

A prominent feature of this soil group is the sandy textured surface soil overlying a loamy or clayey textured subsoil. The surface layer, in which sand grains can be distinctly felt, is overlying a more compact subsoil of heavier texture in which the sand grains cannot be as easily distinguished. The topsoil, which is structureless, is firm or hard when dry. The small amount of clay in the topsoil is highly dispersed and generally leaves a very thin layer of clayey material coating the surface of the soil when the standing water evaporates. The color of the soil ranges from very pale brown or gray (which appears almost white in some cases) to lighter shades of brown or gray In some cases, the soil surface may have a pinkish tinge.

The effective rooting depth is often restricted by a firm to extremely hard plow pan occurring within the top 15 to 20 cm. The subsoil shows clay accumulation together with red and yellowish orange mottles. In many cases, it is dominated by plinthite, which is shown by characterisric red streaking when struck with a spade. The plow pan and the clayey subsoil also restricts internal drainage. Ironstone gravel can occur in the whole profile, and in some cases large ironstone boulders or hardpans can outcrop the surface (Plate 8). In most cases, however, gravel is mostly scattered in the subsoil.

The Prateah Lang group has developed from previously weathered alluvium deposited by rivers and/or colluvium derived mostly from sandstone and clay shale. The alluvium was deposited on ancient river, lake, or marine floodplains, the hydrology of which changed, leaving the soils above the level of natural flooding by rivers or streams. The colluvium, often mixed with the alluvial material, was washed down from the surrounding hills and mountains. The soils were subsequently weathered and leached by rainwater with clay movement down the profile giving the characteristic sandy surface over a clayey or loamy subsoil.

Profile description

Surface Layer

Depth	15-40 cm.
Texture	Sandy.
Color	Dry: varies but is most often pale brown or pale gray, with a pinkish tinge; sometimes almost white. Moist: pale to light brown or pale to light gray.
Mottles	Few may occur.
Consistency	Dry: hard but sometimes loose. Moist: loose.
Structure	Structureless.

Subsoil

Texture	Loamy or clayey.
Color	Dry: pale to light brown or light gray. Moist: mostly light brown, sometimcs light gray or gray.
Mottles	Many often occur.
Consistency	Dry: firm to very hard. Moist: firm to hard.
Structure	Blocky or massive.
Plinthite	Often present; a hard ironstone layer may develop.

Synonyms

Some soils classified as Red-Yellow Podzols, Plinthite Podzols or Cultural Hydromorphs (Crocker 1962) would fall into this group. The Prateah Lang soil also correlates with the immature surface water gley soils developed on poorly drained level terrace and old floodplain landscapes (Brammer and Brinkmann 1977). The Gray or Gray Leached soils (Thach 1985, Sinh 1986, Hung 1988) also fall into this group. Using *Keys to soil taxonomy* (Soil survey staff 1994), the Prateah Lang soils would be assigned to the Alfisol order (e.g., Plinthustalfs, Haplusalfs) or Uitisol order (e.g., Hapludults, Plinthustults, Plinthaquulrs. Kanhaplustlt) depending on the base saturation. The FAO/UNESCO soil classification system (FAO 1374) would classify this group mainly as Luvisols, Acrisols, or Planosols.

Division in phases

Three phases of Prateah Lang soil have been defined based on characteristics of the subsoil that affect root penetration and water drainage.

Shallow phase. The depth of the topsoil is 20 cm or less and the texture of the subsoil is clayey or a very hard layer occurs within 20 cm of the surface. The compacted layer is a plow pan or a consolidated ironstone pan. Drainage and root penetration through the profile are restricted by the clayey subsoil or the compacted layer.

Clayey subsoil depth. The depth of the topsoil to between 20 to 40 cm deep, a very hard layer is not present within the top 20 cm of the profile and the texture of the subsoil clayey. There is usually a sharp boundary between the sandy topsoil and the clayey subsoil. Drainage through the profile is restricted by the clayey subsoil.

Loamy subsoil phase. The subsoil has a loamy texture and a very hard layer is not present within 20 cm of the surface. The sandy topsoil tends to grade into the loamy subsoil. The contrast between the sandy topsoil and loamy subsoil is not distinct at the boundary but a distinct difference occurs between the middle of each layer. Water tends to infiltrate more rapidly through the subsoil of this phase than through the subsoil of the shallow or clayey subsoil phase.

Soil management

This soil is difficult to manage for rice production. There is little potential to achieve high yields.; yield-response to improved management varies substantially from year to year depending on the prevailing seasonal conditions. The benefit from irrigating this soil is limited because of its inherent fertility problems. If structures for water harvesting and supplementary irrigation can be developed cheaply, then profitable yield increases may be expected on these soils.

The fertility of this soil is very low. Glasshouse experiments have shown the soil to be potentially deficient in N, P, K, S, Mg, and B (Lip et al 1960, CIAP 1994, Lor et al 1996). The CEC and organic matter levels are very low. Fertilizer management is very difficult with nutrients being easily leached or drained in surface runoff (loss of nutrients through leaching occurs more in the loamy subsoil phase while all phases loose nutrients through surface runoff). There is difficulty in matching nutrient supply to crop demand. After the soil has been flooded for a week or more, however, the CEC increases slightly, which will allow the soil to retain more nutrients from added fertilizers. The *e, k, o,* and *p* modifiers always apply.

The soil pH is acidic but is not strongly buffered and reaches a favorable value for rice production when the soil is flooded, the *h* modifier generally applies. Problems with sulfur toxicity may occur with the application of large amounts of organic manure and inorganic fertilizer, which contain a high percentage of S. Where the soil is situated in phreatic land and receives runoff from adjacent higher lands the *g+* and *i+* modifiers are likely to apply. This tends to occur with the clayey subsoil or the shallow phases more so than the loamy subsoil phase. This is particularly relevant where the flat plains are surrounded by weathered upland soils rich in iron such as in the Labansiek group. In small areas, salt toxicity is a problem on this soil type, in which case the *n* or *n* modifier applies.

Rooting depth in the shallow and clayey subsoil phases is limited in this soil by the hardpan or by the firm clayey subsoil. Water holding capacities are very low because of both the sandy surface texture and the limited soil volume that the roots can explore. Drought stress is a common problem on these soils, although less so in the loamy subsoil phase. The *S* type applies to the upper layer as does the *d* modifier. The *L, C,* and sometimes the *R* or R^+ substrata type applies depending on the phase. Most commonly the R^+ substrata class is assigned when shallow plowing by farmers has established a hard plow pan only 15 cm from the surface. The R^+ substrata class indicates an extremely limited rooting space.

Internal drainage is often restricted on these soils because of the clayey subsoil or the hard plow pan, which makes the soil suitable for flooded rice production. Water infiltrates to a greater extent into the loamy subsoil Phase than the Clayey Subsoil Phase.

Tillage is relatively easy on this soil, although with animal-pulled plows only shallow tillage is possible on the shallow phase. The sand is generally fine and the grains pack together tightly after plowing or harrowing flooded soil, making transplanting difficult unless seedlings are transplanted within a few hours of harrowing. Some sites may have excessive amounts of ironstone gravel or boulders near the surface which can cause turther problems with plowing and transplanting. Harrowing is not always necessary.

The restricted drainage and shallow rooting volumc of these soils, particularly in the shallow phase, makes it difficult to grow nonrice crops during the wet season unless good drainage is supplied. Even during the early part of the wet season, after a short downpour, the soil will remain saturated for periods of up to a week, which is sufficient to kill many waterlogging-sensitive species. This, however, is less of a problem for the subsoil phase, which generally occurs on the higher fields. It may be possible to grow a nonrice crop during the early part of the wet season on these soils.

Recommendations

- Use urea rather than ammonium sulfate fertilizer.
- Avoid applying large amounts of organic manure in a short period.
- Apply N and K fertilizers in small frequent doses.
- Apply inorganic fertilizers after cow manure application and after the soil has been flooded for at least a week.
- If salt toxicity is a problem, provide drainage for the area if possible and use resistant varieties.
- Where possible, plow to 20 cm or deeper to increase the soil volume available to the plants.
- Use water harvesting and supplementary irrigation to reduce drought periods.
- If possible, transplant within a few hours of harrowing or plowing.
- Ensure the field is level.
- If Fe toxicity is a problem, use resistant varieties and transplant 1 or 2 months after flooding or transplant at the time of flooding.
- Apply cow manure or inorganic fertilizer to the nursery at the following rates (do not apply large amounts of cow manure immediately before sowing): 50 kg cow manure/100 m^2, 0.5 kg each of N, P_2O_5, and K_2O/100 m^2.
- Organic and inorganic fertilizers should be applied to the main field to provide the following nutrient rates: 40-60 kg N, 23-29) kg P_20_5, 20-30 kg K_20, and 0-10 kg S/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a constraint on yields. The higher rates are recommended for modern varieties and where water is less of a constraint on yields.

Group 2—Labansiek Soil (Plates 9 and 10)

Group concept

Soils occuring on the sides of hills or mountains with a red colored, clayey textured surface soil with a crumb structure and a clayey subsoil.

Occurrence

The Labansiek soils are pluvial lands and do not occur in the flooded valleys. They occur on the sides of hills and mountains that were once ancient volcanoes. The soils are developed from the underlying basalt rock. These soils are related to the Kompong Siem soils and hence both soil types often occur in association. The Labansiek soils occupy the upper freely draining parts of the toposequence, while the Kompong Siem soils occur in the lower areas which are regularly flooded.

Significant areas of this soil type occur in Kompong Cham, Kratie, Mondulkiri, Ratanakiri, and smaller areas occur in Battambang. Upland rice is mainly grown on this soil. They are estimated to cover less than 1% of the rice area. Apart from rice, dense tropical forest typically occur on these soils and siginificant areas have been cleared or rubber or teak plantations and small areas of fruit and vegetable production.

General description

These soils have a distinctive red color and a uniform deep profile. The surface soil has a crumb structure with a high degree of aggregate stability and is usually friable. The soil texture is clayey throughout the profile, but, by touch, the surface gives the impression of being more sandy than it is, because of the stable microstructure of the mainly kaolinitic clays, iron and aluminum oxides and hyrdoxides. The soil is very sticky and slippery when wet.

The subsoil is clayey, usually has a deeper red color than the topsoil and is usually friable with a crumb structure.

Profile description

Upper layer

Depth	20-30 cm.
Texture	Clayey.
Color	Dry; red; sometimes brown.
	Moist: most often dark red, sometimes brown.
Mottles	None.
Consistentcy	Dry: hard.
	Moist: loose.
Structure	Crumb.

Subsoil

Texture	Clay.
Color	Dry: red to brown.
	Moist: dark red to brown.

Mottles	None.
Consistency	Dry: hard.
	Moist: loose.
Structure	Crumb.
Plinthite	Development of a petroferric iron pan is possible but not usual.

Synonyms

Most of the Labansiek soils were classified by Crocker (1962) as Latosols. In the FAO/UNESCO classification system (FAO 1974), they would fall into the Nitisols (not yet as weathered as the Ferrasols, having no plinthite in the upper 125 cm) or Ferrasols or if a petroferric layer occurs, into the Plinthosols. The soil would mainly be in the Ultisol, or possibly Oxisol order, if classified according to *Keys to soil taxonomy* (Soil survey staff 1994).

Division in phases

Two phases have been described based on the presence or absence of a petroferric layer:

Petroferric phase. A hard consolidated ironstone layer several centimeters thick is present within the top 50 cm of the soil. The petroferric layer is generally about 30-40 cm below the soil surface but can outcrop the surface in places. This has sometimes been observed in areas continuously grown to upland crops, such as in Kompong Cham. The petroferric layer acts as a barrier impeding root and water penetration. These lands can also form relief inversions, where the petroferric layer shields the underlying horizons from further erosion.

Nonpetroferric phase. A hard consolidated ironstone layer is not present within the top 50 cm of the soil.

Soil management

This soil has a moderately potential and responds well to improved management. The soil occurs on the sides of hills and is well suited to upland rice production.

The fertility of this soil is moderate. Glasshouse experiments have shown the soil to be potentially deficient in N, P, K, and S (CIAP 1994, Lor et al 1996). Rice is likely to respond to application of N, P, and K in the field. The CEC and organic matter levels are moderate to high, which aids fertilizer management. The *p and k* modifiers generally apply. The *a* and *e* modifiers sometimes apply and high P-fixation generally occurs (*i*+).

The soil pH is slightly acidic, although it may be slightly alkaline in some cases; both situations are favorable for upland rice production. Root or water penetration is not limited unless a petroferric layer occurs. Soil water holding capacity is good. The *C* type applies.

Tillage is generally possible in a wide range of soil moisture conditions and a variety of implements without affecting structure. When wet, however, the soils can become very slippery and sticky so that traction and plowing become difficult.

Recommendations

- Fertilizer should be applied at the following rates: 48-94 kg N, 46-63 kg P_2O_5, and 0-22 kg K_2O/ha. The lower rates are recommended for traditional varieties and the higher rates are recommended for modern varieties.

Plate 1. Old terrace showing a generally flat landscape but with slight changes in field level. The slightly higher region in the background is not used for rice cultivation.

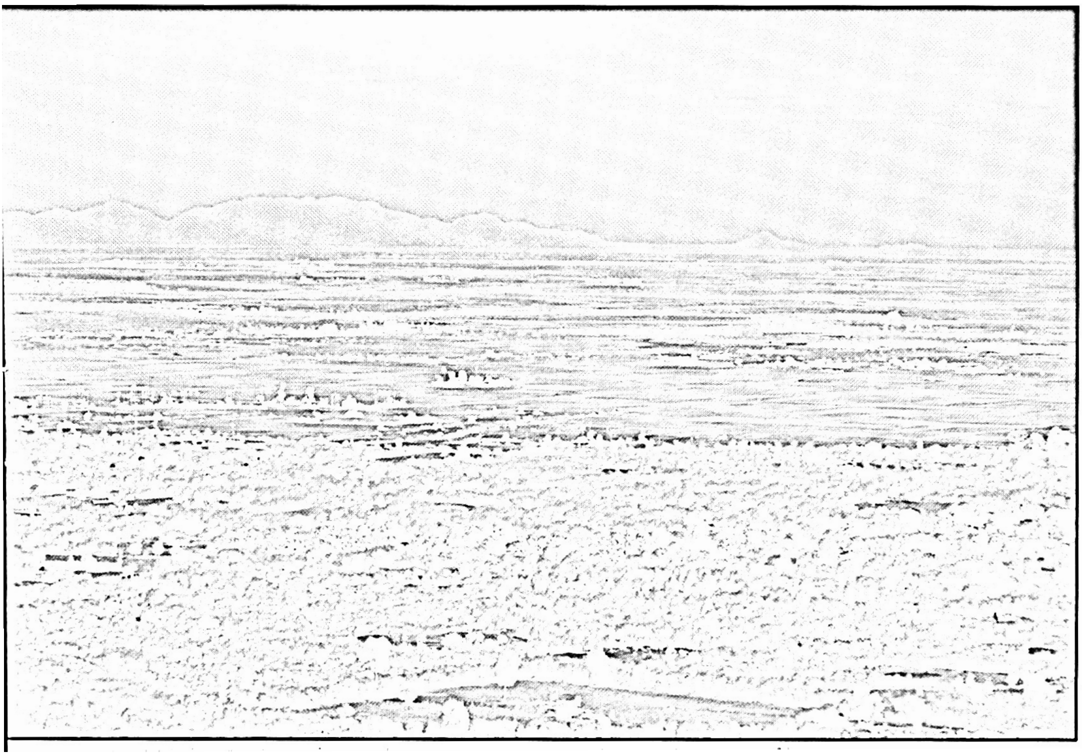


Plate 2. The wide open landscape of the old terraces and the colluvial-alluvial plains dominate the rainfed lowland rice-growing areas.

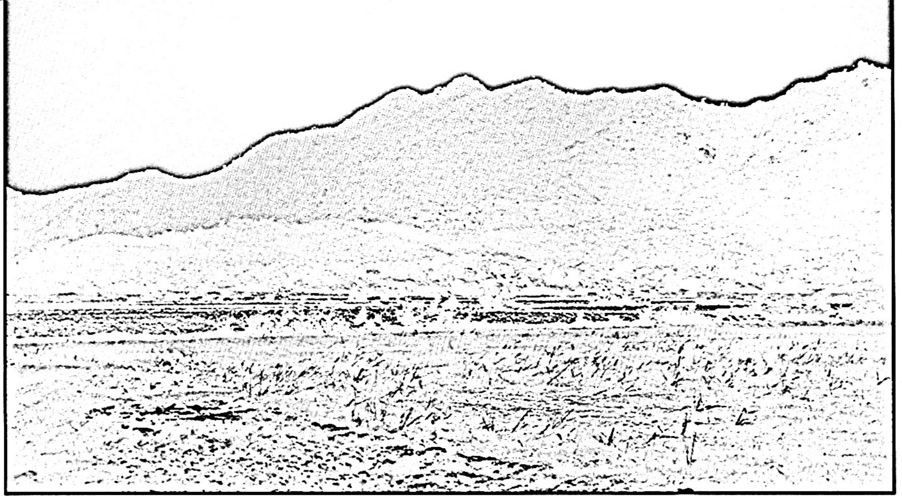


Plate 3. The colluvial-alluvial plains at the base of limestone hills.

Plate 4. The back slopes of river levee where receding rice is being grown. At this location, the soil in: the Kein Svay group occurred on the levee crest and backslopes (left side), soil in the Krakor group occurred on the low part of the backslopes, and soil in the Kbal Po group occurred in the water-filled basin (right side).

Plate 5. The flat, featureless expansive floodplains during the dry season where much of Cambodia's irrigated rice is grown.

Plate 6. Coarse sandy textured surface soil characteristic of the Coarse sandy phase of the Prey Khmer group.

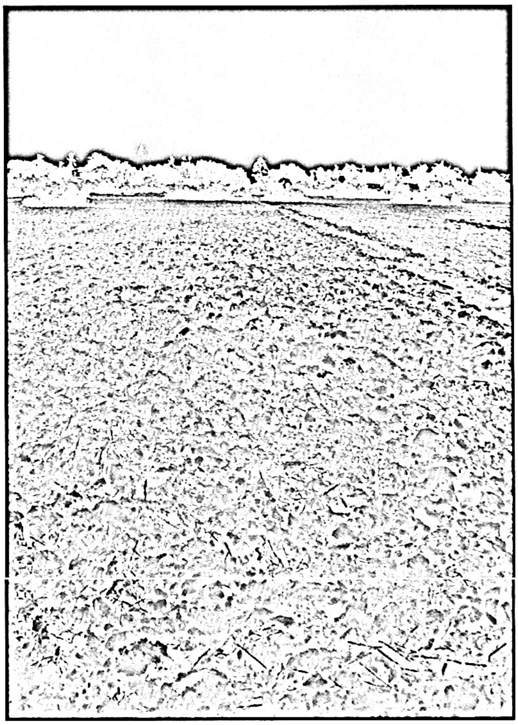


Plate 7. The sandy surface texture of soils of the Prateah Lang group showing a light brown color when wet and a pale brown color when dry.

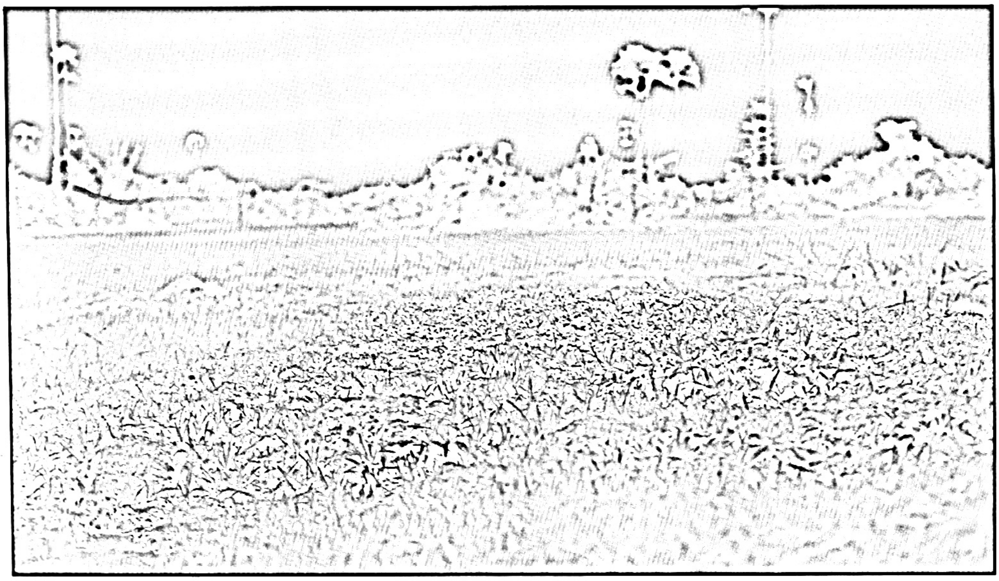


Plate 8. Ironstone gravel, rocks, and boulders are common features in many soils and can outcrop the soil surface as shown here.

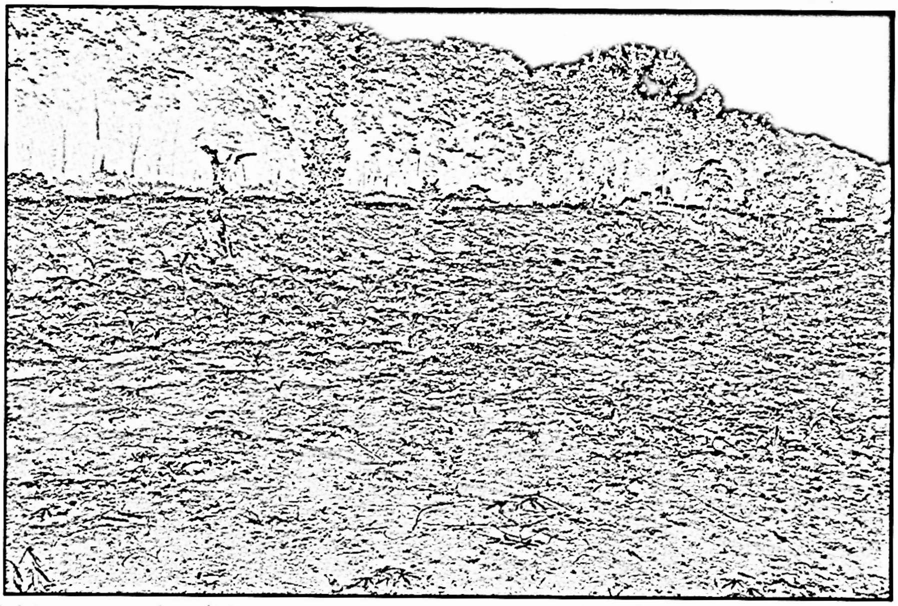


Plate 9. The characteristic red color of the Labansiek group occurring on the side a small hill A rubber plantation is shown in the background and maize inter-cropped with local oil papaya is shown in the foreground.

Plate 10. Upland rice grow on soil from the Labansiek group. The surface shows the granular structure and red color characteristic of this group.

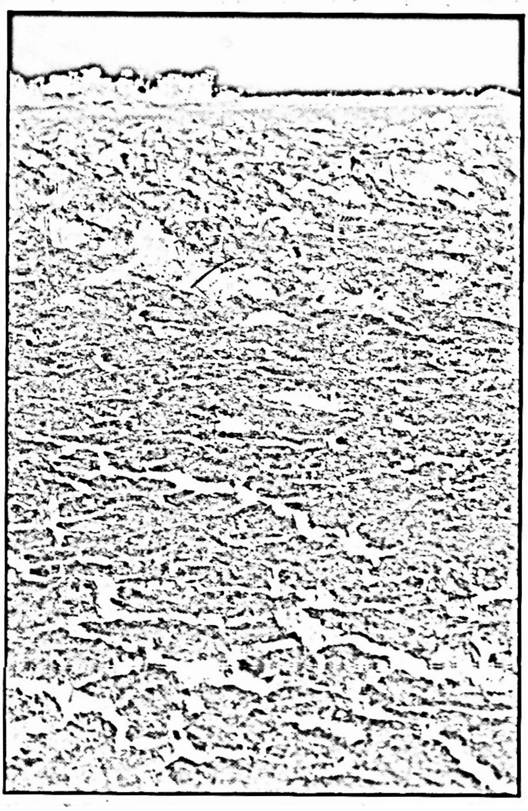


Plate 11. Soils of the Krakor group showing deep cracking upon drying.

Plate 13. Soil from the Bakan group located on a lower paddy of the old terrace.

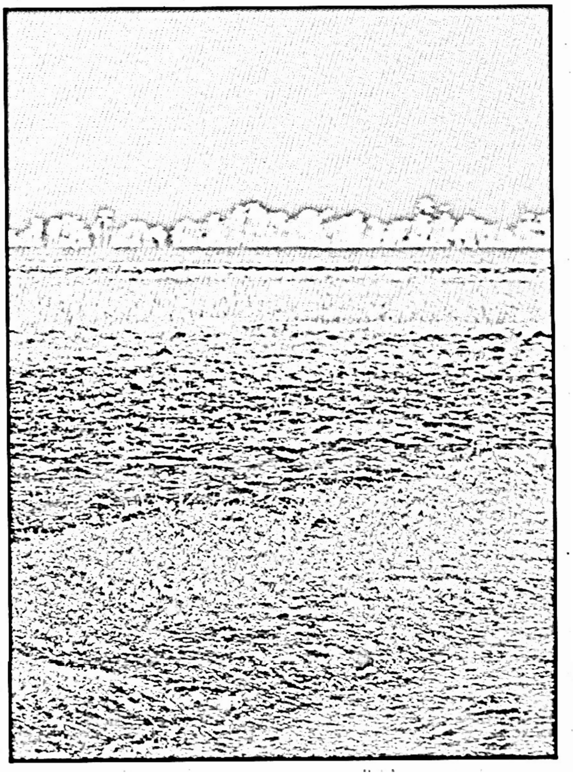
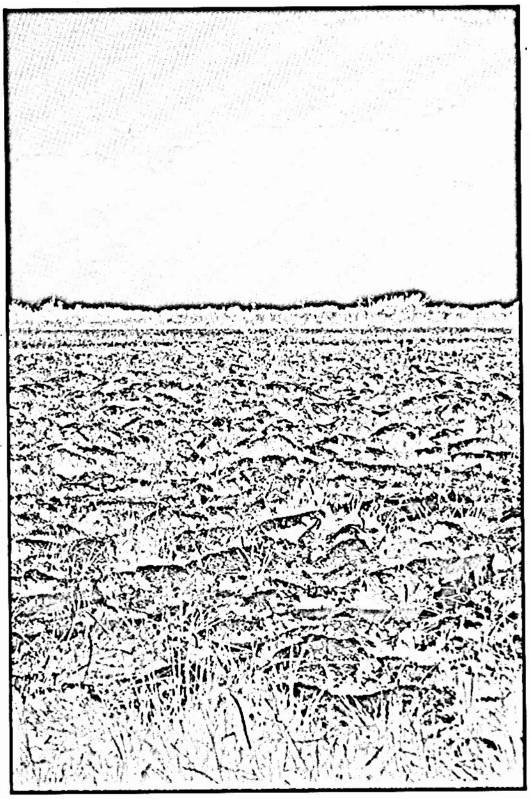


Plate 12. A freshly plowed field in the deepwater rice-growing areas showing soils of the Krakor group.



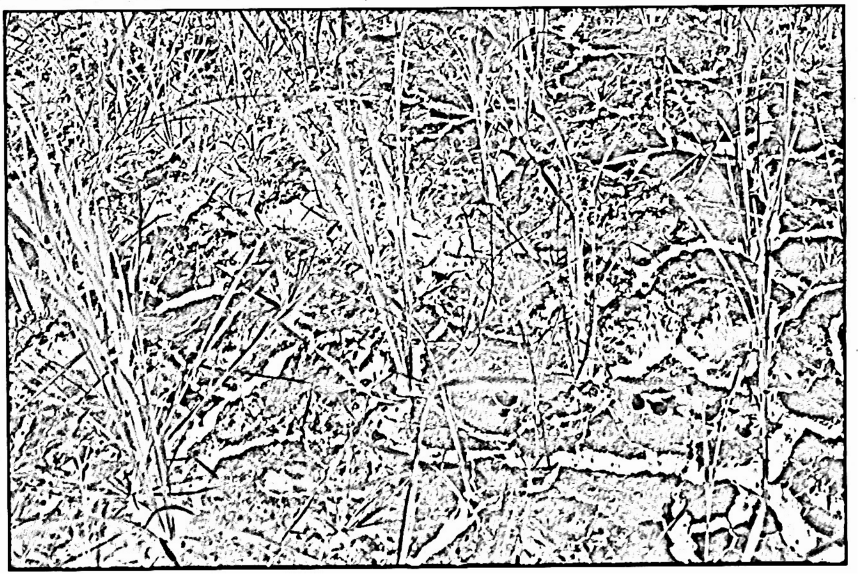


Plate 14. Soil from the Kbal Po group showing distinct cracking upon drying.

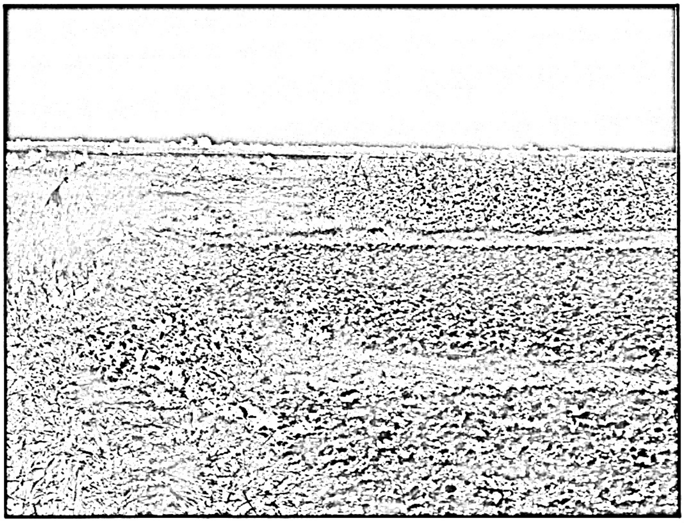


Plate 16. Soil of the Kein Svay group occurring on the backslope of the river levee. A variety of crops are grown including, rice, longbean, and mungbean. The flooded basin is visible in the background.

Plate 15. A newly cleared area of the expansive floodplain showing soils of the Kbal Po group.

Plate 17. The characteristic brown color and blocky structure of the Brown phase. of the Toul Samroung group.

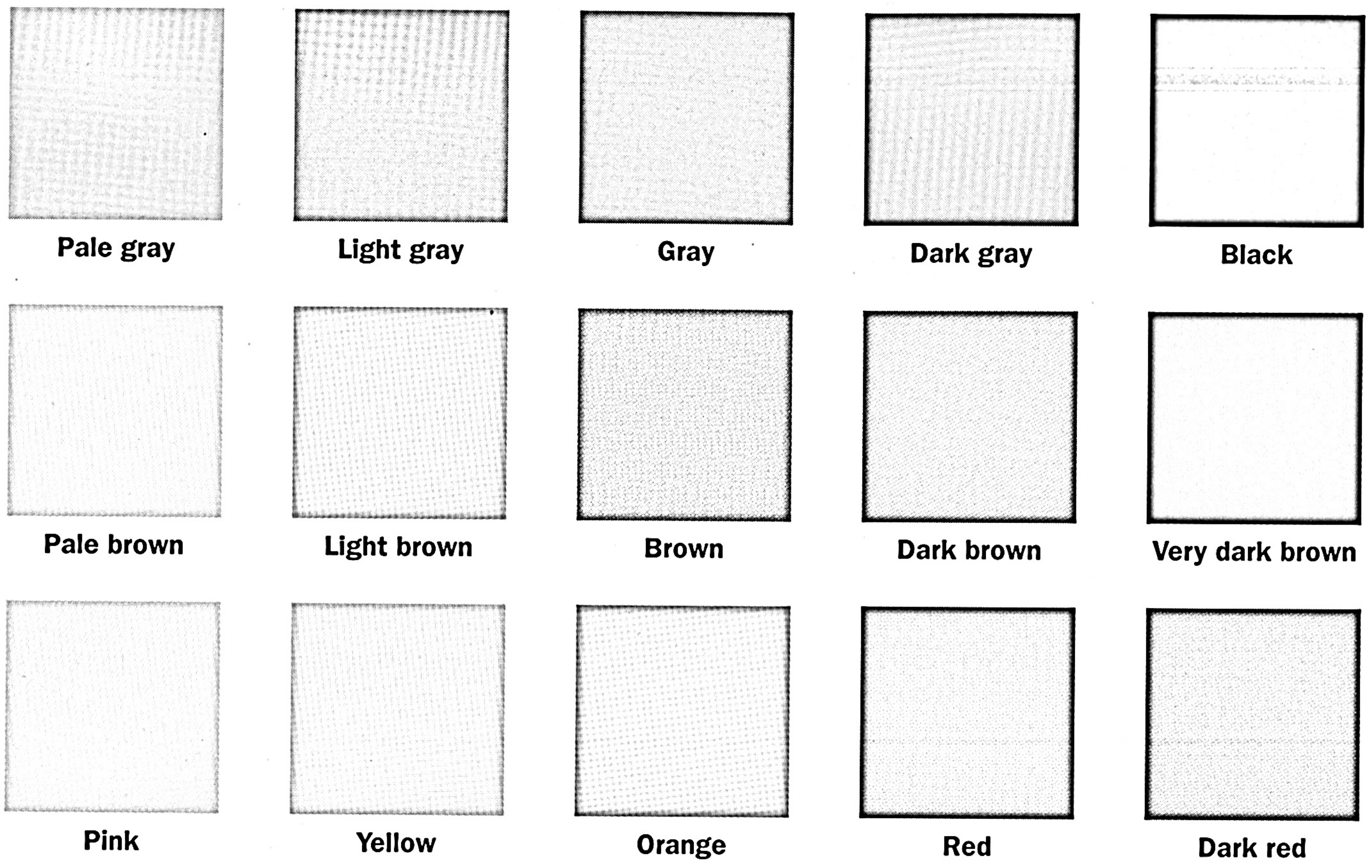
Plate 18. Soil of the Koktrap group showing the distinctive dark gray to black surface soil color.

Plate 19. Orange and red mottling characteristic of plinthite development occurring in the subsoil of the Koktrap group.

Plate 20. Basalt boulders outcropping the surface of the soil in the Kompong Siem group.

Plate 21. Soil of the Kompong Siem group showing the very dark topsoil color and wide cracks upon drying.

Soil Color Guide



Group 3—Orung Soil

Group concept

A soil occurring on the old alluvial terraces which has a loamy to clayey textured topsoil less than 30 cm thick over a sandy subsoil layer which is thicker than 20 cm.

Occurrence

This soil is mostly associated with present or ancient river systems. The soils may have been formed as the loops of meandering rivers migrated laterally or where rivers abruptly changed their direction. These changes caused finer material to be laid over come material, which is sometimes referred to as 'fining upwards' (see Driessen and Dudal 1991). The nature of the alluvium deposited depends on the source of its origin. The different topsoil and subsoil strata usually have different parent materials.

These soils are found on phreatic lands of the old alluvial terraces. The soil occurs in localized areas mainly around Kompong Chhnang, Pursat, and Siem Reap but may also occur in other areas. This soil type is estimated to occur on about 1 to 2% of the total rice area. Most areas have moderately dense tropical forest or have been cleared for rice production.

General description

This soil is characterized by the sharp boundary between a loamy or clayey textured, surface soil and the sandy textured subsoil. Generally, the thickness of the fine textured surface horizon is greatest toward the lower paddies while it is thinnest in the upper paddies. In rare cases, there may be two or three further layers, alternating between fine and coarse textured marerial. The surface soil color is generally lighter shades of gray or brown and some mottling occurs. The soil has a similar appearance to the Bakan group from the surface.

The structure is usually blocky or massive. The clay particles are highly dispersed and the soil sets hard when dry. Shallow surface cracks may appear in the surface when it dries. A plow pan may occur where the surface horizon is greater than 20 cm deep, but it is usually nor strongly developed. Internal drainage is restricted by the surface clayey layer. Where the sandy subsoil occurs on top of a clay layer deeper in the profile, then the sandy layer is saturared and water flows laterally within it.

The sand, subsoil is gray or light gray with slight orange and yellow mottling and streaking. Plinthire development does not occur.

Soils with clayey or loamy surface soils over sandy subsoils also occur in the Krakor and Kbal Po groups. The soils in these groups, however, are flooded annually by river or lake water and hence, have been classified separately.

Profile description

Surface layer

Depth	10-30 cm.
Texture	Loamy or clayey.
Color	Dry: pale gray or pale brown.
	Moist: light gray to gray.

Mottles	Few sometimes occur.
Consistency	Dry: hard.
	Moist: loose to firm.
Structure	Massive or blocky.

Subsoil

Texture	Sandy.
Color	Dry: light gray or pale gray.
	Moist: light gray to gray.
Mottles	Few often occur; usually orange or red in color.
Consistency	Dry: loose to firm.
	Moist: loose.
Structure	Structureless.
Plinthite	No plinthite occurs within the sandy subsoil layer.

Synonyms

This soil is not recognized by Crocker (1962). Using *Keys to soil taxonomy* (Soil survey staff 1994), this soil would be classified an Inceptisol or an Entisol (e.g. Fluvent). Following the FAO/ UNESCO soil classification system (FAO 1974), the soil would be described as a Fluvisol.

Division in phases

No phases have yet been identified for the Orung soils.

Soil management

This soil is difficult to manage for rice production. It has a low to moderate potential, response to improved management and yields are likely to vary substantially from year to year, depending on the thickness of the surface clayey or loamy layer and on prevailing seasonal conditions. Benefits from full or supplementary irrigation similarly vary depending on the depth of the surface soil.

The fertility of this soil is low. Glasshouse experiments have shown the soil to be potentially deficient in N, P, K, and S (CIAP 1994, Lor et al 1996). The CEC and organic matter levels are very low. Fertilizer management is difficult with nutrient being leached into the subsoil and or drained through surface runoff. There is difficulty in matching nutrient supply to crop demand. The *e, o,* and *p* modifiers always apply and the *k* modifier sometimes applies.

Rooting depth is generally not limited in this soil by a hard plow pan or by the firm clayey subsoil. Water holding capacity of the topsoil is good and water in the sandy subsoil is also available to the plants, although, storage capacity is low and lateral flow of water reduces the amount of water available. The *C* or *L* type most often applies as does the d modifier. The *S* substrata type applies.

Drainage through the topsoil is restricted on these soils, hut if the soil is saturated, water will drain into the sandy subsoil.

Tillage is relatively difficult on this soil. The soil sets hard on drying and must be thoroughly wet before plowing is possible with animal traction. If it is plowed dry with a tractor, then large clods are formed, which require several additional passes with the plow and harrow to prepare the soil for sowing or transplanting. With four-wheeled tractors, it may be difficult to obtain an even cultivation depth if the soil is cultivated when it is too wet.

The restricted drainage on these soils makes it difficult to grow waterlogging-sensitive crops during the wet season unless good drainage is supplied. Even during the early part of the wet season, after a short downpour, the soil will remain saturated for periods of up to a week or more.

Recommendations

- Use urea rather than ammonium sulfate fertilizer.
- Avoid applying large amounts of organic matter in a short period.
- If Fe toxicity is a problem, use resistant varieties and transplant 1 or 2 months after flooding or transplant at the time of flooding.
- If salt toxicity is a problem, provide drainage for the area if possible and use resistant varieties.
- If feasible, use water harvesting and supplementary irrigation to reduce drought periods.
- Ensure the field is level.
- If the sandy subsoil occurs near the surface, avoid deep plowing that may cause the soil to become excessively drained.
- Apply cow manure or inorganic fertilizer to the nursery at the following rates (do not apply large amounts of cow manure immediately before sowing): 50 kg cow manure/100 m^2, 0.5 kg each of N, P_2O_5, and K_2O/100 m^2.
- Organic and inorganic fertilizer should be applied to the main field to provide the following nutrient rates: 36 to 70 kg N, 23 to 40 kg P_2O_5, 0 to 30 kg K_2O, and 0 to 15 kg S/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a constraint on yields. The higher rates are recommended for modern varieties and where water is less of a constraint for yields.

Group 4—Krakor Soil (Plates 11 and 12)

Group concept

A soil with a gray to brown but not dark gray, very dark brown or black, loamy or clayey textured topsoil over a sandy, loamy or clayey subsoil occurring on the active floodplains.

Occurrence

This soil type occurs on the floodplains of lakes and rivers, which are inundated for 3 months or longer. The main sources of parent material are colluvial-alluvial outwash from the surrounding terraces and mountains or alluvial materials carried by river water. The nature of these materials differ depending on their source. Limestone and basalt parent materials dominate towards the northwest of rhe Tonle Sap Lake, whereas sandstone. shale, gneiss, and granite contribute most on the river floodplains and elsewhere.

This soil is generally used for deep water rice cultivation during the wet season or for receding or fully irrigated rice cultivation in the dry season. Significant areas are still occupied by flooded forest or secondary bushland. Small areas of upland crops are also grown in the dry season. The soil occurs in all provinces and is estimated ro occupy about 15% of the land area grown to rice in Cambodia.

General description

The soil surface is gray or brown when wet and generally light gray to light brown when dry. The soil does not have the distinctive dark gray, very dark brown to black surface soil of the Kbal Po group. The soil may or may not form moderate to large cracks in the surface when it dries. The cracks penetrate deeper than 2-3 cm. The texture is usually loamy bur sometimes clayey and the soil structure is usually friable but can be blocky. Internal drainage is slow and a plow pan does not generally occur.

The subsoil has a firm consistency, usually with a loamy or clayey texture and a light brown, brown, gray or light gray color with red and orange or sometimes dark gray mottling. A sandy subsoil can occur in some areas, but it is unusual. If a sandy layer occurs, it is usually 10 to 30 cm thick and is generally followed by a clayey or loamy horizon. The contrast between the color of the surface soil and the subsoil is not marked. Plinthite or ironstone gravel can occur but are not abundant. Iron concretions can be present in the forms of brittle cubes formed around roots.

Profile description

Surface layer

Depth	20-40 cm.
Texture	Clayey or loamy.
Color	Dry: light gray, gray or light brown. Wet: gray or brown.
Mottles	None.
Consistency	Dry: friable to hard. Moist: friable.
Structure	Blocky or crumb.

Subsoil

Texture	Clayey or loamy, sometimes sandy.
Color	Dry: Light browm to light gray. Wet: Light brown to gray or light gray.
Mottles	Often common; red or orange and few dark gray in color.
Consistency	Dry: hard. Moist: firm.
Structure	Blocky.
Plinthite	Sometimes present.

Synonyms

The soil would mainly be an Entisol or Inceptisol if classified according to *Keys to soil taxonomy* (Soil survey staff 1994). Applying the FAO/UNESCO soil classification system (FA0 1974), this soil would either be a Fluvisol or Gleysol. Crocker (1962) classified the soil as lacustrine alluvial or alluvial soils.

Division in phases

Two phases have been defined for the Krakor soil, noncracking and cracking. It is expected that the group will be further subdivided into a number of phases following more detailed work.

Noncracking phase. Cracks are not formed in the soil surface when it dries or only surface cracks which do not penetrate more than 2-3 cm into the soil are formed.

Cracking phase. Moderate to large cracks form in the soil surface when it dries. The cracks penetrate deeper that 5 cm into the soil when it dries.

Soil management

The soil has a good potential to produce high rice yields. The soil responds well to improved management. It has a high suitability for irrigation if water can be managed effectively. The inherent fertility of the soil is good. Glasshouse and field trials have shown responses to only N and sometimes P fertilizer application (CIAP 1994, Lor et al 1996).

Root growth is generally not limited in this soil. Significant areas of this soil have a low bearing capacity and if four-wheel tractors are used, land preparation must occur before the soil gets too wet. For the cracking phase, large clods will be formed it the soil is plowed when it is too dry.

The FCC-C modifiers indicate a high suitability of this soil for rice production. Some soils may have an *L* type and an *C* substrata type indicator (mainly the noncracking phase), while others have *C* type and substrata type (cracking phase often with *v* modifier).

Recommendations

- Ensure the field is level.
- Plan field operations carefully to ensure that plowing occurs at the right moisture content.
- Develop water storage and irrigation structures to enable dry season rice production if feasible.
- If rice is wet direct-seeded, ensure soil does not cover the weds.
- Fertilizer should be applied at the following rates: 66 to 120 kg N and 23 to 34 kg $P_2 0_5$/ha. The lower rates are recommended for situations where water availability is likely to be a constraint on yields. The higher rates are recommended for situations where water is less of a constraint on yields. No fertilizer is recommended for traditional varieties grown on this soil.

Group 5—Bakan Soil (Plate 13)

Group concept

A soil occurring on the colluvial-alluvial plains or the old alluvial terraces that has a loamy or clayey topsoil, which does not crack or has only shawllowsurface cracks occurring over a mounted loamy or clayey subsoil.

Occurrence

This soil occurs on colluvial plains and old alluvial terraces. It is generally derived from previously weathered material of colluvial and/or alluvial origin. The soils occur in the lower paddies ,md depressions of the landscape and receive fine material from the upper paddies. During years of exceptionally high flooding, these areas may also receive and amounts of alluvium deposited by floodwater from rivers or lakes. This soil group comprise mainly anthraquic phreatic land.

The soil can be found in all rice-growing areas of Cambodia and is estimated to occur on 10-15% of the rice growing area. Where it has not been cleared for rice production, it supports moderately dense tropical forest.

General description

The topsoil has a loamy or clayey texture with a degraded massive structure, the clay being highly dispersed. When the soil has been plowed and puddled for transplanted rice production the topsoil is usually soft and is sometimes slippery. The surface sets extremely hard when dry. Water infiltrates slowly into the soil, a plow pan is present.

The color is usually lighter shades of gray or brown when wet and very pale gray or brown when dry. Small to medium sized cracks often, but not always, form in the surface when the soil dries. When cracks form, however, they are only surface cracks that do penetrate more than 2-3 cm into the soil.

The subsoil has a loamy or clayey texture; it is very firm and generally has a light gray to light brown color with orange, red and sometimes black mottles. Plinthite generally occurs and there are frequently abundant ironstone gravel scattered throughout the subsoil.

Profile description

Upper layer

Depth	10-20 cm.
Texture	Loamy or clayey.
Color	Dry: varies, most often gray to pale or light brown.
	Moist: varies, most often light gray or gray to light brown or brown.
Mottles	Few may occur.
Consistency	Dry: very hard.
	Moist: firm to very hard.
Structure	Massive.

Subsoil

Texture	Clayey or loamy.
Color	Dry: pale gray to pale brown.
	Wet: light brown to light gray or gray.
Mottles	Often many; orange or red common; few black.
Consistency	Dry: hard to very hard.
	Moist: firm.
Structure	Blocky or massive.
Plinthite	Often present.

Synonyms

Soil classified as Cultural Hydromorphs and Gray Hydromorphs by Crocker (1962) would fit into the Bakan Group. According to the criteria of *Keys to soil taxonomy* (Soil survey staff 1994), the group would mainly be classified as an Alfisol, sometimes as an Ultisol. According to FAO/ UNESCO soil classification guidelines (FAO 1974), the soil would be assigned to the Luvisols, sometimes to the Planosols or Acrisols. Vietnamese workers identified the soil as gray, gray elluvial and leached gray soil (Sinh 1986, Phong 1987, Hung 1988).

Division in phases

No phases have yet been identified for the Bakan soil group.

Soil management

This soil is well suited to rice production; it has low, to moderate potential, but where water conditions are favorable, yields respond well to improved management. These soils are suitable for irrigation.

Soil fertility is low to moderate. Glasshouse experiments have shown the soil to be potentially deficient in N, P, K, and possibly S (CIAP 1994, Lor er al 1996). Rice grown on this soil is likely to respond to N, P and K fertilizer application in the field. The CEC and organic matter levels are low and care must be taken with fertilizer management. The *o, p, and k* modifiers generally apply.

The soil ranges from slightly acid to acid and but generally reaches a favorable value for rice production when flooded. Where the soil occurs in the depressions of the landscape. the *g* modifier applies. Rooting depth is generally limited by a very hard plow pan or by the firm clayey subsoil. Water holding capacity of the topsoil is good. The *C* type and substrata type most often apply

The surface seals when it dries. The surface seal, together with the clayey or loamy topsoil and subsoil and the hard plow pan, severely restricts internal drainage especially with the early rains at the onset of the season. Excess water drains from the surface which removes nutrients in the runoff water.

Tillage is very difficult; the soil sets hard on dryig and must be saturated before plowing is possible with animal traction. Plowing is also difficult with a tractor. It the soil is plowed when it is too dry, then large clods are formed, which are difficult to manage later. If it is plowed when it is very wet but nor flooded, a lack of sufficient traction causes tractor wheels to slip. If plowed when saturated, it can be difficult to obtain an even plowing depth, particularly in areas where the plow pan has been broken. Once puddled the surface soil is very soft. Seed broadcast into the soft surface soil often sinks into the poorly oxygenated layers. Germination is inhibited and a poor plant stand results.

The restricted drainage on these soils, the poor physical properties and its generally low position in the landscape prevents cultivation of waterlogging-sensitive crops on this soil during any part of the wet season.

Recommendations

- Use urea rather than ammonium sulfate.
- Use water harvesting and supplementary irrigation to reduce drought periods where feasible and consider developing structures for full irrigation.
- Ensure the field is level.
- Do not broadcast into freshly puddled soil. Delay sowing until a few days after the final harrow to allow the soil to settle.
- If seeds are sown into soft soil, increase the seeding rate or drain the field until the seedlings have established.
- Plow 20 cm or deeper to increase the soil-rooring volume.

- If rice straw is not required for grazing, plow the soil soon after harvest to aid land preparation for the following season.
- Apply cow manure or inorganic fertilizer to the nursery to the follwoing rates (do not apply large amounts of cow manure immediately before solving): 50 kg cow manure/100 m^2, 0.5 kg each of N, P_2O_5 and K_2O/100 m^2.
- Organic and inorganic fertilizer should be applied to the main field to provide the following nutrient rates: 36 to 70 kg N, 23 to 40 kg P_20_5, 20 to 30 kg K_20, and 0 to 15 kg S/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a constraint on yields. The higher rates are recommended for modern varieties and where water is less of a constraint for yields.

Group 6—Kbal Po Soil (Plates 14 and 15)

Group concept

A soil with a dark gray, very dark brown to black, clayey topsoil, which forms large deep cracks over a clayey subsoil, occurring on the active floodplains.

Occurrence

This soil is formed of recent alluvial material on broad flat basins, of the expansive floodplains of the Mekong-Bassac River system, and on the broad flat Lacustrine floodplain surrounding the major lakes. The soils may also be found within some wider river basins of meander floodplains of some of the medium-sized and smaller rivers of the country.

This soil type is always located on fluxial lands. It occurs mainly in Kandal, Takeo, and Prey Veng Provinces and the provinces surrounding Tonle Sap Lake. It is estimated to occur on 15% of the rice growing area. Thc soil generally supports deep water rice production during the wet season and receding or fully irrigated rice during the dry season. Where it is not sown to rice. it is occupied by flooded tropical forest or regenerated, flooded bushland.

General description

This soil is young, and poorly, differentiated; with the primary difference between the subsoil and the topsoil, being restricted to color. The surface soil is dark gray or very dark brown to black when wet and gray or dark gray when dry. The surface soil develops wide cracks on drying which extend deeper than 2-3 cm. The soil surface is usually hard when dry and the structure blocky although significant areas have a friable surface structure. The depth of the dark upper layer varies from about 20 cm to more than 50 cm (often more than 100 cm). The depth decreases with distance from the main river channel or permanent water of the lake. On the edge of the floodplain, the surface layer is only about 20 cm deep. The fertility of the soil also tends to decrease with distance from the river channel or permanent water of the lake. A plow pan does not occur.

Where the dark surface horizon is shallower than 50 cm, there is a distinct transition between the dark upper horizon to the pale to light gray or pale to light brown subsoil. Apart from color, profile differentiation is not strong. Soil texture in the subsoil is the same as the topsoil but is has red, orange, yellow (in the thionic phase) and sometimes black mottles and distinct gleyic properties. Iron concretions may occur in the shape of plates or tubes, caused mainly by oxidation zones around roots. The submit generally remains wet year round.

Very occasionally sandy layers may occur beneath the subsoil in localized areas. These layers may be 10 cm or thicker. The sandy strata are generally light to pale gray, but have not been widely observed.

The soil receives fresh sediments each year, which maintains fertility. The amount of alluvium deposited, however, varies greatly with position. The soil remains inundated by water for more than 3 months each year.

Occasionally, this soil may be confused with the Koktrap or the Kompong Siem soils. However, the Koktrap or Kompong Siem groups do not received annual deposits of fresh alluvium and are not inundated by river water for extended periods.

Profile description

Surface layer

Depth	20-50.
Texture	Clayey.
Color	Dry: gray to dark gray.
	Moist: dark gray, very dark brown to black.
Mottles	None.
Consistency	Dry: firm to hard.
	Moist: loose to firm.
Structure	Crumb or blocky

Ssubsoil

Texture	Clayey, sandy strata sometimes occurs.
Color	Dry: light gray.
	Wet: light gray to light brown or sometimes brown.
Mottles	Often common; red, orange-yellow (thionic phase) common, black few.
Consistency	Dry: firm.
	Moist: friable to firm.
Structure	Blocky.
Plinthite	Sometimes occurs.

Synonyms

Soil in this group is classified as Alluvial Soil (Crocker 1962, Sinh 1986, Phong 1987, Hung 1988) or Eutric Gleysols (Ceruse 1977). The soil would be an Inceptisol or Entisol, if classified in accordance with the criteria of *Keys to soil taxonomy* (Soil survey staff 1994). The FAO/UNESCO soil classification system (FAO 1974) would allocate this soil to the Fluvisols or Gleysols.

Division in phases

Two phases of the Kbal Po soils are recognized based on soil chemical properties: nonthionic and thionic.

Thionic phase. The thionic phase of the Kbal Po soils are similar to acidic sulphate soils. This phase has a subsoil pH below 4.5. The presence of bright yellow mottle or stains in the light gray to grayish brown subsoil is generally a distinguishing feature of these soils, but may not always be present. This phase is acidic and problems with rice production occur if the soil is plowed too deeply. Rice may develop a bronzing discoloration of the leaves.

Nonhionic phase. The nonthionic phase of the floodplain soils is distinguished by a subsoil pH above 4.5 and absence of bright yellow mottles in the top 50 cm of the soil.

Soil management

This soil is relatively easy to manage. It has a high potential for rice production and responds well to management. Some precautions, however, must be taken with the thionic phase of this soil. These soils are well suited to irrigation.

Soil fertility is good. Glasshouse experiments have shown the soil to be potentially deficient in only N and P (CIAP 1994, Lor et al 1996). The response to P fertilizer application in the field, however, is variable. Where the soil is located very close to the main river channel or permanent water of the lake, a response to P fertilizer is unlikely. The organic matter content and CEC of these soils are moderate to high, which aids in fertilizer management. Both phases would receive the *p* modifier in some instances.

The soil pH of the nonthionic phase of this soil is slightly acid to neutral and is well suited to rice growth. The subsoil of the thionic phase however is acid (<pH 4.5), which will affect plant growth if the soil is brought to the surface by deep plowing. The *a* and *c* modifiers would apply to the thionic phase of this soil. The *g* modifier applies to all phases of this soil and, where rice is grown during the wet season on this soil, the *g+* modifier is likely to apply, indicating constant saturation by a high water table.

Root growth is restricted by the acidic subsoil in the thionic phase of this soil. Water holding capacity is good except if sandy strata occupy a significant proportion of the subsoil. In the nonthionic phase of this soil. considerable water can he stored within the profile that is available to plants. The *C* type and *C* substrata type apply generally.

The first rains drain rapidly into these soils but as the soil swells and the cracks close then internal drainage is restricted because of the clayey topsoil.

The Kbal Po soils are very sticky when moist, which causes problems for plowing, particularly when animal traction is used. The stickiness is reduced when the soil is saturated. The soils have a low bearing capacity, particularly in newly cleared land and it may be difficult to plow with four-wheeled tractors or even with animal traction in some areas when the soil gets too wet.

Recommendations

- Plow less than 20 cm deep on the thionic phase.
- For the thionic phase, flush the soil with fresh water to remove the acidity prior to transplanting rice.
- For the thionic phase, maintain a high water table to ensure the acidic subsoil is reduced, particularly during the growing season.
- Ensure the field is level.

- Develop water storage and irrigation strucrures to allow for irrigated rice production.
- Plan land preparation well in advance, particularly in newly cleared areas.
- Fertilizer should be applied at the following rates: 66 to 120 kg N and 23 to 34 kg P_2O_5/ha. These rates are recommended for modern varieties only. The lower rates are for situations where water availability is likely to be a constraint on yields. The higher rates are recommended for situations where water is less of a constraint on yields. For traditional varieties no fertilizer is recommended.

Group 7—Kein Svay Soil (Plates 4 and 16)

Group concept

A brown, loamy or clayey textured soil (topsoil and subsoil) ir11 a weakly developed profile formed on the river levees and the associated backslopes.

Occurrence

This soil occupies the river levees and parts of the backslopes. It occurs typically on the meander floodplain systems and occupies phreatic and anthraquic phreatic lands. The backslopes where most of the rice is cultivated are usually flooded each year (though for less than 3 months), receiving fresh alluvium, whereas the levee crests are inundated for only short periods, if at all. In the larger systems of the Mekong and Bassac Rivers, where the river has frequently changed course, there are many abandoned levees and channels forming a large undulating area of this soil type. This soil group may be found in association with the Krakor and Kbal Po soil groups, which occupy part of the basins. In more simple systems, the soils of this group grades into soils of the Toul Samroung, Bakan, and Prateah Lang groups wirth increasing distance from the river channel.

This soil occurs mainly in Kandal, Phnom Penh, Kompong Speu, Prey Veng, Kompong Cham, Kompong Thom, Kratie, and Stung Treng. It is estimated to occupy less than 2% of the rice-growing area. Apart from rice, these soils are mainly used for fruit and vegetable production or support dense forest.

General description

Soils in this class are distinguished by a deep, relatively uniform profile with a brown surface soil. Soil texture ranges from loamy to clayey. The loamy soil tends to occur on the crests of the levees while the clayey soil occurs on the backslopes. Sandy textured soils also occur on the river levees, however, the sandy textured soils are not used for rice production and are nor classified here. Most rice is grown on the soils with a clayey texture. Water infiltration into the loamy soils is good, but somewhat poorer on the clayey soils on the backslopes. Soil structure is generally friable in the loamy textured soils toward the levee crests and becomes blocky for the clayey soils. Wide cracks penetrating more than 2-3 cm into the soil surface occur on the soils with a clayey textured surface. A plow pan generally does not occur.

The subsoil has a similar color and texture to the surface soil but, in some cases, there may be a few faint red or orange mottles. Plinthite does not occur.

Profile description

Surface Layer

Depth	20 cm.
Texture	Loamy or clayey.
Color	Dry: Light brown or brown. Moist: brown.
Mottles	None.
Consistency	Dry: friable to hard. Moist: loose to firm.
Structure	Blocky.

Subsoil

Texture	Loamy or clayey.
Color	Dry: light brown to brown. Wet: brown but may be slightly more gray than upper layer.
Mottles	Sometimes few mottles; red or orange and sometimes dark gray.
Consistency	Dry: firm to hard. Moist: firm.
Structure	Blocky.
Plinthite	None.

Synonyms

Soils in this group have been classified as brown Alluvials by Crocker (1962). The soil would be classified as an Inceptisol (e.g., Humaquept) or Entisol, in *Keys to soil taxonomy* (Soil survey staff 1994) or a Fluvisol or Cambisol using the FAO/UNESCO soil classification system (FAO 1974).

Division in phases

Different phases of the Kein Svay soils have not been recognized.

Soil management

This soil is relatively easy to manage and it has a high potential for agricultural production. The soil responds very well to improved management. If used for rice production, the soil generally requires irrigation.

Glasshouse experiments have shown the soil to be potentially deficient in only N and P (CIAP 1994, Lor et al 1996). The response to P fertilizer application in the field, however, is variable and P fertilizer application is frequently not required. The moderate organic matter content and CEC of these soils are helpful in fertilizer management. The soil would receive the *p* modifier in some instances.

The soil pH is slightly acidic to neutral and is well suited to rice growth. Root growth is generally not restricted on the Kein Svay soil group. Often the *LC, C* or *L* type apply to the soil. The internal drainage is good to moderate on the loamy soils but poor on the clayey textured soils.

On the backslopes and levees, the these soils are well suited to a wide variety of crops. This is indicated where both the *d* and *g* modifiers can be assigned.

Recommendations

- Ensure the field is level for flooded rice production.
- Develop structures for irrigation if water is available.
- Fertilizer should be applied at the following rates: 66 to 120 kg N and 0 to 34 kg $P_2 0_5$/ha. These rates are recommended for modern varieties only. The lower rates are for situaitions where water availability is likely to be a constraint on field. The higher rates are recommended for situations where water is less of a constraint on yields. For· traditional varieties, no fertilizer is recommended.

Group 8—Toul Samroung Soil (Plate 17)

Group concept

A soil occurring on the old alluvial terraces or the colluvial-alluvial plains that has a clayey or loamy topsoil, which forms wide cracks that penetrate deeper than 3-4 cm into the soil over a clayey or loamy subsoil. The color of the topsoil is gray or brown but not dark gray or black.

Occurrence

This soil is primarily found on the slightly undulating plains formed from colluvium and alluvium of mixed origin; mainly basic (basalts) and partly acidic rocks (granite, sandstone, and shale), washed from surrounding hills and mountains. In some areas, the soil has developed in slight depressions on relatively flat terrain derived from old alluvium. The soil is moderately weathered and has undergone some leaching and movement of materials out of the surface horizons to follow positions in the profile. In some areas, the soil occasionally receives local alluvium deposited through minor creeks and rivers but soil is not flooded for extended periods. The soil is found on anthraquic pluvial and anthraquic phreatic ricelands. Large areas are used for dry direct-seeded rice cultivation and transplanted rice. Small areas of upland crops are planted on this soil type and small areas of dense tropical forest also remain.

The soil occupies about 7-10% of the rise area and is found mainly in Battambang, Banteay Meachey, Kompong Speu, Pursat, Kompong Thom, and Kompong Cham.

General description

Soil in this group is characterized by the brown or gray clayey or loamy topsoil that develops moderate to large cracks on drying. The cracks extend deeper than 3-4 cm into the profile. The topsoil has a blocky structure and is very hard when dry. Internal drainage is slow. A plow pan is common.

The subsoil usually has a slightly higher clay content than the surface horizon and a lighter brown or gray color sometimes with a distinct yellowish tinge. Red, orange, or black mottles are clearly visible in the subsoil and iron and manganese concretions are common. Plinthite is often present.

In somc cases, the Toul Samroung group may be similar to the Bakan group, however, the Bakan soils have a clearly degraded massive structure compared to the blocky structure of the Samroung soils. Cracks occurring in the Bakan soil are only shallow surface cracks. In other cases, the Toul Samroung group may also be confused with the Koktrap group. The Koktrap group, however, has a much darker surface soil color being dark gray, very dark brown or black compared to the grate or brown of the Toul Samroung soil.

Profile description

Upper Layer

Depth	10-20 cm.
Texture	Loamy or clayey.
Color	Dry: light brown to brown or light gray to gray.
	Moist: brown to gray
Mottles	Few sometimes occur.
Consistency	Dry: hard to very hard.
	Moist: friable to firm.
Structure	Blocky.

Subsoil

Texture	Loamy or clayey.
Color	Dry: light brown or light gray.
	Wet: light brown to brown or light gra!. [o y+-.
Mottles	Often common; red, orange, or black.
Consistency	Dry: hard to very hard.
	Moist: firm.
Structure	Blocky.
Plinthite	Sometimes occurs.

Synonyms

The Samroung soil group is classified by Crocker (1 962) in the Brown, Gray, or Cultural Hydromorphic soil units. Moormann (1961) assigned this soil type to the low humic gley soil. The soil would be Vertisol or Alfisol (e.g., Endoaqualf), if classified using *Keys to soil taxonomy* (Soil survey staff 1994) or a Luvisol or Vertisol using the FAO/UNESCO soil classification system (FAO 1974).

Division in phases

Two phases of the Toul Samroung group have been identified.

Brown phase. The surface soil of this phase is brown or light brown. The subsoil is usually light brown, often with a yellowish tinge. The subsoil has frequent orange, red, and black mottles and iron or manganese gravel is common. Plinthite sometimes occurs. The brown phase of the Toul Samroung soil generally has a higher fertility than the Gray phase.

Gray phase. The surface soil of this phase is gray when wet and light gray when dry. The subsoil is light or pale gray with frequent orange and red mottles. Plinthite often occurs.

Soil management

This soil is well suited to rice production. It has moderate to high potential and yields respond well to improved management. The soil is well suited to irrigation.

Glasshouse experiments have shown the soil to be potentially deficient in N, P, and K, however, field responses have only been observed with N and P fertilizer application (CIAP 1994, Lor et al 1996). The CEC and organic matter levels are low to moderate. The *o* and *i* modifiers may apply.

The soil pH ranges from slightly acidic to neutral aid reaches a favorable value for rice production when the soil is flooded. Where the soil occurs in the depressions of the landscape, the *g* modifier applies. Rooting depth is generally limited in this soil by a hard plow pan or by the firm clayey subsoil. Water holding capacity of the topsoil is good. The *C* type most often applies.

The first rains drain rapidly into these soils, but as the soil swells and the cracks close then internal drainage is restricted because of the clayey subsoil and the hard plow pan. The *v* modifier sometimes applies to this soil.

Tillage is moderately difficult on this soil. The soil sets hard on drying and it must be saturated before plowing is possible with animal traction. The soil can be plowed dry with four wheeled tractors, but requires two further workings with the plow and harrow prior to sowing or transplanting. In areas where direct seeding into dry soil is practiced, it is very important to have a level seedbed to ensure consistent germination. If dry-direct seeding is not practiced then plowing should he delayed until the soil is moist.

The restricted drainage on these soils makes it difficult to grow waterlogging-sensitive crops on this soil during the wet season unless good drainage is supplied.

Recommendations

- Use water harvesting or develop full irrigation structures where feasible.
- Ensure the field is level.
- Plow deeper than 20 cm to increase the soil rooting volume.
- Apply cow manure or inorganic fertilizer to the nursery at the following rates (do not apply large amounts of cow manure immediately before sowing): 50 kg cow manure/100 m^2 , 0.5 kg each of N and P_2O_5/100 m^2.
- Organic and inorganic fertilizer should be applied to the main field to provide the following nutrient rates: 62 to 100 kg N and 40 to 52 kg P_2O_5/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a yield constraint. The higher rates are recommended for modern varieties and where water is less of a yield constraint.

Group 9—Koktrap Soil (Plates 18 and 19)

Group concept

A soil occurring on the old alluvial terraces, which has a dark gray, very dark brown to black topsoil will a clayey or loamy texture over a light gray or light brown, loamy or clayey subsoil.

Occurrence

The soil in this group occupies land on the old alluvial terraces, mostly on the lower fields or in depressions. This soil occurs on anthraquic phreatic lands, never in fluxial lands, although in years of exceptional flooding, they may become inundated for short times with water from nearby rivers or lakes. The soil occurs in the southern provinces, mainly in Prey Veng and Svay Rieng with smaller areas in Kandal and Takeo. The soils are almost exclusively used for lowland rice production. They are estimated to occur on about 5% of the rice growing area.

General description

The surface soil of this group is usually clayey, but sometimes loamy, with a strong blocky structure. Small to large cracks usually appear in the surface when the soil dries. The cracks are not always deep; they may or may not penetrate more than 3-4 cm in the surface soil. The soil color is dark gray, very dark brown to black when were and is dark gray or gray when dry. A hard plow pan occurs within the top 15-20 cm of the soil, which restricts root penetration and water infiltration. The surface soil is very hard when dry.

The subsoil has a clayey or loamy texture with abundant red and yellow mottles; plinthite is often a prominent feature and ironstone gravel is common. The subsoil is usually gray or light gray and contrasts with the dark surface soil. Scattered iron concretion may occur. The subsoil usually remains moist for a good part of the year and has distinct gleyic properties although the subsoil will dry out during the dry season.

Soils in this group have been mistaken as acid sulfate soils by some authors (Crocker 1962, Thach 1985, Hung 1988). It is possible that some of these soils are remnants of acid sulfate soils, which have been leached of much of their acid and sulfuric materials. In their present state, these soils are no more acidic than other soils in Cambodia and there is an absence of jarosite or pyrite mottles in the profile.

The Koktrap soils have a similar appearance to the Kbal Po soils. However, unlike Kbal Po soils, the Koktrap soils are flooded only by rainwater and runoff from nearby lands, the soils are not situated on the active floodplains, and they do not receive fresh alluvium each year. The Toul Samroung group may sometimes be confused with the Koktrap group. however, the soils in the Toul Samroung group are gray or brown and never dark gray or black. The Kompong Siem group may also be confused with the Koktrap group, however, the Kompong Siem soils contain stones or boulders of basalt or calcimorphic limestone, which are not present in the Koktrap soil.

Profile description

Surface layer

Depth	10-20 cm.
Texture	Loamy or clayey.
Color	Dry: gray to dark gray. Moist: dark gray, very dark brown to black.
Mottles	None.
Consistency	Dry: very hard. Moist: firm to friable.
Structure	Blocky.

Subsoil

Texture	Clayey.
Color	Dry: light gray. Wet: gray to light gray.
Mottles	Many often.
Consistency	Dry: hard to very hard. Moist: firm.
Structure	Blocky.
Plinthite	Often occurs.

Synonyms

Some of the soils mapped by as Alumisol (Crocker 1962), fall into this group. The soils would be classified as Utisols or Alfisols using *Keys to soil taxonomy* (Soil survey staff 1994). e.g., Plinthaquult or Plinthaualf. Using the FAO/UNESCO soil classification system (FAO 1974), the Koktrap soil would be classified as Acrisols (e.g.. Plinthic Acrisols, Gleyic Acrisols).

Division in phases

Extensive field work and visual field evaluation could not clearly reveal any distinct morphological differences to subdivide this group. Nevertheless, interviews with farmer clearly indicated that there were distinct phases of the Koktrap group. Very large differences in unfertilized yields occur between the two phases. Limited chemical analysis of the soil indicate that these differences are possibly related to the P content of the soil. Based on this information, soil phases are defined primarily on the present fertility.

Infertile phase. The infertile Koktrap soil has unfertilized yields of less than 1,200 kg rice ha^{-1}, generally around 500 to 800 kg ha^{-1} . Slight to severe bronzing of the leaves of rice grown on these soils occurs at least once every 2 or 3 yr. Farmers generally regard these soils as the worst in their area.

Fertile phase. The Koktrap soil has unfertilized yield of more than 1,200 kg rice ha^{-1}, generally more than 1,500 kg ha^{-1}, and rice-bronzing does not occur. Farmers usually regard these soils as some of the better ones in their area. The contrast in color between the dark gray to black topsoil and the light gray subsoil is less marked in the fertile phase of this group.

Soil management

This soil is relatively easy to manage. It has a moderate-to-high potential and responds well to management. Fertility varies greatly between the fertile and infertile phases. Farmers generally regard the infertile phase as a poor soil. With correct fertilizer application, however, high yields can be obtained and the soil becomes one of the better soils of the rainfed areas. The fertile phase of this soil is similarly regarded as one of the better soils of the rainfed areas. These soils are well suited to irrigation.

Glasshouse experiments have shown both phases to be potentially deficient in N, P, and K (CIAP 1994, Lor et al 1996). The response to P fertilizer application on the infertile phase, however, is very marked. The limited soil data available indicate that this phase has a very low, available P content; the *i* modifier always applies. Nitrogen application alone, without P on the Infertile Phase of the Koktrap group, will reduce yields and sometimes kill crops. The organic matter content and CEC of these soils are moderare, which aids in fertilizer management. Both phases would receive the *k* and *p* modifiers.

The soil pH is strongly buffered with the pH increasing only slowly on flooding. A bronzing disease, which causes a patchy brown discoloration of the leaves, often occurs on plants grown on the infertile phase of this soil, which may indicate Fe toxicity. The infertile phase may receive the *h* or occasionally the *a* modifier. The soil occurs in the lower parts of the landscape and generally remains flooded for extended periods, hence the *g,* g^+ or i^+ modifiers may apply, although during the dry season, the subsoil dries so that the *d* modifier would apply,

Rooting depth is limited by a hard plow pan and by the firm clayey subsoil. Water holding capacity of the soil is good and the soil is not as susceptible to drought as the sandier soils. The *L* or *C* type applies for the surface layer and the *C* substrata type applies to the subsoil. In many cases, shallow plowing by farmers has established a hard plow pan only 15 cm from the surface. In these cases, the R^+ substrata class is assigned, indicating an extremely limited rooting space.

The soil surface sets hard when dry, however, it requires only a moderate amount of moisture before the soil becomes soft enough to plow. After plowing and harrowing, the soil can remain very soft in some areas, which causes transplanted seedling to lodge if transplanting is not delayed.

The restricted drainage on these soils and their low position in the landscape prevent cultivation of waterlogging-sensitive crops during the wet season. If irrigation is provided during the dry season, then upland crops can be grown, but it may be difficult to regenerate the soil structure after the soil has been puddled for rice production and hence careful management of water is essential.

Recommendations

- Where possible, plow to a 20-cm depth to increase the soil volume available to the plants.
- Do not apply urea alone to the Infertile phase; ensure that P is applied together with N for the basal dressing. Urea can be topdressed alone later during crop growth if P is applied basally.
- Use water harvesting and supplementary irrigation where feasible.
- Develop irrigation structures where water is available.
- Wait 3 days after the final harrow before transplanting in areas where the topsoil is soft.
- Ensure the field is level.
- If Fe toxicity is a problem, use resistant varieties and transplant one or two months after flooding or transplant at the time of flooding.
- Apply inorganic fertilizer to the nursery at the following rates, 0.5 kg each of N, P_2O_5 and K_2O/ 100 m^2.
- Organic and inorganic fertilizer should be applied to the main field to provide the following nutrient rates: infertile phase—42 to 94 kg N, 35 to 63 kg P_2O_5 and 15 to 22 kg K_2O/ha; infertile phase—62 to 100 kg N, 23 to 34 kg P_2O_5/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a constraint on yields. The higher rates are recommended for modern varieties and where water is less of a constraint for yields.

Group 10—Kompong Siem Soil (Plates 20 and 21)

Group concept

Soils on which stones or boulders of basalt or calcimorphic limestone are clearly visible in the profile or on the soil surface and which have a black or dark gray. clayey textured topsoil, which forms deep, wide cracks over a clayey textured subsoil.

Occurrence

This soil is found in low, areas of a varied undulating landscape of small hills and rises, or at the footslopes of larger hills or mountains. The soil occurs on flat land, but the associated small hills and mountains are usually but not always, visible in the vicinity. Bassaltic or limestone rocks or boulders are always present within the profile or on the soil surface. If stones or boulders are not present at the actual site where the soil is being examined, but, from observation or from reports of farmers, are present in the general vicinity, when the soil may still be classified within the Kompong Siem group.

The Kompong Siem soil has developed from underlying parent material and from colluvial-alluvial outwash from higher areas and partly by the alluvial deposits of local rivers and creeks. This soil primarily comprise anthraquic phreatic land.

The soils of this type used for rice production are mainly located in Kompong Cham, Kratie, Ratanakiri, and, to a minor extent, Battambang. Parent material is either partially weathered basic basalt rock or calcimorphic limestone (usually in the form of calcaerous marl). These soils are, pedogenically, fairly young. They are estimated to occupy about 2% of the rice area.

The Kompong Siem soils occur in association with soils of the Labansiek group, which occupy the slopes of hills and mountains. These red Labansiek soils of the hill slopes gradually change to the dark brown soils of the lower slopes and the slight rises, and then to the dark gray or black Kompong Siem in the low, flat depression areas.

General description

The distinctive criteria for this soil group are the dark color, clayey soil texture, and deep wide cracking. The surface soil is very dark gray or black even when dry, it remain very dark. The texture is clayey; the clay being very plastic and sticky when wet, and very hard when dry. There is considerable shrinking and swelling in this soil with large cracks appearing in the surface when it dries. The surface soil has a self-mulching, granular structure. Water infiltrates rapidly into the dry soil. Once the soil has swelled and the crack close, the internal drainage is poor.

The subsoil has a lighter color than the topsoil; it is usually gray or light gray. The texture is clayey. There is often less than 1 m of soil overlying the parent rock, although some profiles can be much deeper. Large rocks and boulders can often, but not always be seen on the surface of these soils and abundant small gravel can occur throughout the profile.

The Labansiek soils and the Kompong Siem soils are derived from the same parent materials. As weathering of the soil on the upper slopes proceeds, the base cations are removed, leaving Fe compounds to predominate giving the red soil color characteristic of the Labansiek group. Poor drainage and accumulation of cations in the lower depressed areas lead to smectite clay development with associated vertic properties and the dark color characteristic of the Kompong Siem group. The dark brown soils are intermediate in the landscape between the Labansiek and Kompong Siem soils; rice is rarely grown on these soils.

Profile description

Surface layer

Depth	10-30 cm.
Texture	Clayey.
Color	Dry: dark gray or black. Moist: black.
Mottles	None.
Consistency	Dry: very hard. Moist: firm.
Structure	Crumb or blocky.

Subsoil

Texture	Clay.
Color	Dry: gray to light gray. Moist: gray.
Mottles	A few sometimes occur; red or brown in color.
Consistency	Dry: very hard. Moist: firm.
Structure	Crumb or blocky.
Plinthite	Absent.

Synonyms

The soils of the Kompong Siem group are classified as Regurs (Crocker 1962). Some of Crocker's Basic Lithosols may also belong to this class. Moormann (1961) designated this soil in Vietnam as Regurs or Grumusols. Other names have been coined, such as black cotton soil, rendzinas, tirs, magallitic soils, densinigra soils, or vertisols. Dudal (1963) counted about 40 names for this soil. The soil would be a Vertisol if classified according to *Keys to soil taxonomy* (Soil survey staff 1994). Regurs low in the toposequence form the aquert suborder. The better drained regurs in undulating land would be assigned to the ustert suborder. According ro FAO/UNESCO soil classification guidelines (FAO 1974), the soil would also be assigned to the Vertisols.

Division in phases

Two phases of the Kompong Siem group are recognized had on the presence or absence of gravel. Further subdivision, based on parent material (calcimorphic or basaltic), is likely to be needed in the future as more information becomes available.

Gravelly phase. Abundant small, round black and brown ferro-manganese concretions are present throughout the profile. The gravel ranges in size from 1 to 2 mm to more than 1 cm in diameter. The abundance of gravel is such that it can be clearly seen in the surface soil and when a handful of topsoil is taken it will most often contain gravel.

Nongravelly phase. Gravel is not present throughout the profile, or only a few scattered concretions are formed, or the gravel is only concentrated in a part of the subsoil and cannot be seen in the surface soil. When a handful of soil is taken, most often it does not contain gravel.

Soil management

These soils are fertile soils and well suited to rice production; yields increase with improved management. Glasshouse experiments have shown the soil to be potentially deficient in N and P Rice is likely to respond to application of both of these nutrients in the field. The CEC and organic matter levels are high. The *p* modifier generally applies.

The soil ranges from slightly acidic to slightly alkaline. The soil in some areas (developed on calcimorphic parent material), however, may have a high pH, which causes P and Zn deficiency. In these cases, the soil would receive the *b* modifier. Rice grown on this soil type, which has a moderately acidic pH and remains flooded for most of the cropping season, may suffer from Fe toxicity. A period of dying or flushing of the soil with fresh warer is required to prevent the toxicity.

Rooting depth is generally not limited in this soil, although the soil may be shallow. Water holding capacity of the topsoil is good, but during periods of little rain the soils are drought-prone because water is held tightly in the soil. The *C* type applies and the *v* modifier is assigned.

Internal drainage is initially very rapid because of the large cracks in the surface. These cracks generally close slowly, which extend percolation losses. However, once the soil swells and the cracks close, drainage is restricted.

The soil is extremely sticky when moist and is very difficult to plow with a four-wheeled tractor. Tillage is easiest by animal traction when the soil is saturated. Generally, several passes with the plow and harrowing are necessary.

The soil structure is relatively stable and can recover from puddling for rice production allowing easier transition from rice in the wet season to upland crops in the dry season. This soil is well suited to upland crops if irrigation water is available during the dry season.

Recommendations

- Use water harvesting and supplementary irrigation if feasihle.
- Develop irrigation structures where water is available.
- Ensure the field is level.
- If four-wheeled tractors are used, timely planning is required to ensure that operations occur at the correct soil moisture content.
- If Fe toxicity is a problem, drain and dry the soil druing the dry season or flush the soil with fresh water. If this is not possible, use resistant varieties, and transplant 1 or 2 months after flooding or transplant at the time of flooding.
- Fertilizer should be applied at the following rates: 66 to 110 kg N and 23 to 40 kg P_2O_5/ha. The lower rates are recommended for traditional varieties or where water availability is likely to be a constraint on yields. The higher rates are recommended for modern varieties and where water is less of a constraint for yields.

Cited references

Boul SW. 1987. Fertility Capability classification system and its utilization In: ASIALAND: Soil management under humid conditions in Asia. Bangkok (Thailand):IBSRAM. p 317-331.

Buol SW, Sanchez PA, Cate Jr PA, Granger MA. 1973. Soil fertility capability classification. In: Bornemisza E, Alvarado A, editors. Soil management in tropical America. Raleigh (USA): North Carolina State University. p 126-141.

Brammer H, Brinkmann R. 1977. Surface-water gley soils in Bangladesh: Environment, landforms and soil morphology. Geoderma 17:91-109.

Brinkmann R. 1970. Ferrolysis, a hydromorphic soil forming process. Geoderma 3:199-206.

Ceruse J. 1977. Pedogeomorphologic map of the Lower Mekons Basin, descriptive legend and map. Bangkok (Thailand): Mekong Secretariat.

[CIAP] Cambodia-IRRI-Australia Project. 1994. Annual research report 1993. Phnom Penh (Cambodia): CIAP.

Crocker CD. 1962. The general soil map of the Kingdom of Cambodia and the exploratory survey of the soils of Cambodia. Joint publication. Phnom Penh (Cambodia): Royal Cambodian Government Soil Commission/USAID.

Dobermann A. 1995. Options for classifying soils in Cambodia. In: Classifying Cambodian soils from an agronomic perspective. Proceedings of an in-country workshop, 8-12 May 1995. Phnom Penh (Cambodia): Cambodia-IRRI-Australia Project.

Driessen PM, Dudal R. 1991. The major soils of the world. Lecture notes on their geography, formation, properties, and Use. Leuven, Wageningen, Leuven (The Netherlands): Agricultural University of Wageningen, Katholieke. Universiteit.

Dudal R. 1963. Dark clay soils of tropical and subtropical region.;. Soil Sci. 95(4):264-270.

[FAO] Food and Agriculture Organization. 1974. FAO-UNESCO soil map of the world. 1:5,000,000. Vol. 1, Legend. Paris (France): UNESCO.

Hung NH. 1988. Agricultural zoning and planning in the Province of Takeo. Phnom Penh (Peoples Republic of Kampuchea): Ministry of Agriculture. [French].

Kawaguchi K, Kyuma K. 1974. Paddy soils in tropical Asia. Part I. Description of fertility characteristics. Southeast Asian Studies 12:3-24.

Lip TL, Siteck E, Litzenberger SC. 1960. Results of soil fertility studies with lowland rice in Cambodia. In: 7th International Congress of Soil Science. Transactions V. III, p 276-284.

Lor B, White PF, Chan P. 1996. Nutrient requirements for the growth of rice on Cambodian soils. In: Maximizing Sustainable Rice Yields through Improved Soil and Environmental Management. Bangkok (Thailand): Soils and Fertilizer Society of Thailand. p 45-56.

Moormann FR. 1961. The soils of the Republic of Vietnam, Saigon (Vietnam): Ministry of Agriculture, Directorate of Studies and Research in Agronomy, Forestry, and Animal Husbandry, 66 p.

Moormann FR, van Breemen N. 1978. Rice: soil, water, land. Manila (Philippines): International Rice Research Institute. 185 p.

Phong TA. 1987. Planning possibilities and agricultural mapping in the Province of Prey Veng. Phnom Penh (Peoples Republic of Kampuchea): Ministry of Agriculture. *[French].*

Reyes R. 1995. Soils of Cambodia. In: Classifying Cambodian soils from an agronomic perspective proceedings of an in-country workshop, 8-12 May 1995. Phnom Penh (Cambodia): Cambodia-IRRI-Australia Project.

Saeki H, Masao O, Junzo A, Hirofumi I, Masahiro T, Hiroshi T. 1959. Investigation5 on Cambodian soils. Soil and Plant Food. 5:16-22.

Sanchez PA, Buol SW. 1985. Agronomic taxonomy for wetlands. In: Wetland Soils: Characterization, Classification, and Utilization. Manila (Philippines): International Rice Research Institute. p 207-228.

Sanchez PA, Couto W, Buol SW. 1982. The fertility capability classification system: interpretation. applicability, and modification. Geoderma 27:283-309.

Sinh NK. 1986. Explanatory report of the soils of Kandal with map at scale 1:50,000. Sub-Institute for Agricultural Management. Saigon (Vietnam): Ministry of Agriculture. [French].

Smith CW. 1989. The fertility capability classification system—the 3rd approximation. Ph.D. thesis. Raleigh (USA): North Carolina Stare University, Department of Soil Science.

Soil survey staff. 1994. Keys to soil taxonomy 6th ed. Washington DC (USA): United States Department of Agriculture, Soil Conservation Service.

Thach TK. 1985. Pedogeomorphology map 1:500 000 of the Peoples Republic of Kampuchea and Explanatory Report. Ho Chi Minh City (Vietnam): Sub-National Institute of Planning and Projection. *[French].*

White PF, Oberthür T. Domingo LV. 1995. Classifying Cambodian soils from an agronomic perspective. Phnom Penh (Cambodia): Cambodia-IRRI-Australia Project.

Appendix 1. FCC-Cambodia

The term "FCC-Cambodia" is used to indicate adapatation of the Fertility Capability Classification, as developed by Sanchez and Buol (1985), to the soil and growing conditions present in Cambodia. The pertinent parts of the classification, which have relevance to rice growing, are described below.

Table A1.1. Definitions for the FCC type and substrate types for the FCC-Cambodia. (Sanchez and Buol 1985, Smith 1989).

Type (texture of plow layer or surface 20 cm, whichever is shallower)		
S	sandy topsoils	loamy sands and sands (USDA definition)
L	loamy topsoils	< 35% clay but not a loamy sand or sand.
C	clayey topsoils	> 35% clay
O	organic soils	> 20% organic matter to a depth of 50 cm or more
Substrata type (texture of subsoil up to 50 cm) [1]		
S	sandy subsoils	loamy sands and sands (USDA definition)
L	loamy subsoils	< 35% clay but not lS or S
C	clayey subsoils	> 35% clay
R	rock or hard root-restricting layer,	
R+[2]	rock or hard root-restricting layer within the upper 10 cm.	

[1] Used only if there is marked textural change from the surface or if a hard-root restricting layer is encountered within the 50 cm.
[2] Added for the classification of Cambodian rice soils.

Two new modifiers, which are not contained within the FCC of Sanchez and Buol (1985), have been described. The *p* modifier signals extremely low total phosphorus content and the *o* modifier signals extremely low soil organic matter. The *p* modifier has been included because the extremely low available P levels in Cambodian soil are not described adequately by the current *i* modifier of Sanchez and Buol (1985). The low available P levels in some Cambodian soils appear to be present where P fixation levels are not high. The *p* modifier signals that large responses to small additions of P are likely—given adequate N supply. The *o* modifier was included to signal a low contribution of nutrients or CEC from organic matter. Therefore, the *o* modifier indicates that a response to N fertilizer is likely and that there are potential problems with fertilizer management in terms of maintaining a constant supply of nutrients to the plant.

Table A1.1 defines the type and substrata type for the textural classes used in the classification and Table A1.2 defines the condition modifiers. Tables A1.3, A1.4, and A1.5 provide sample interpretations and suggested management practices for the parameters defined in Tables A1.1 and A1.2. At present, the potential of the FCC-C cannot be fully realized due to the limited quantitative information available. The FCC-C needs relatively little data to work effectively, but even this amount of information is still lacking in Cambodia. Nevertheless, it still provides a powerful tool for interpreting soil information and malting management decisions. As more information becomes available the usefulness of the FCC-C will concomitantly increase.

Table A1.2. The definition of the FCC condition modifiers for the FCC-Cambodia (Sanchez and Buol 1985, Smith 1989).

Condition modifiers [1]

g + ***Constant saturation,*** a high water table is continously maintained during the growing season at or near the surface for wetland crop production, or reducing conditions as shallow as 5 cm to at least as 50 cm from the soil surface to prevent any wetness-sensitive crop being grown in most years without artificial drainage, or an 0 surface type and soil saturation for a long enough period to prevent the growth of an upland crop without artificial drainage.

g' ***Paddy rice terraces,*** paddy soils on upland terraces, usually drained for part of the year to allow upland crop production.

g ***Gley,*** soil or mottles <2 chroma within 60 cm of the soil surface and below all A-horizons, or soil water saturated for 60 d in most years.

d ***Dry,*** ustic or xeric soil moisture regimes (subsoil dry >90 cumulative days in most years).

k ***Low K reserves,*** <10% weatherable minerals in silt and sand fraction within 50 cm of the soil surface. or exch. K < 0.20 cmol kg^{-1}, or K < 2% of S bases, If bases <10 cmol kg

e ***Low CEC,*** applies only to plow layer or surface 20 cm. whichever IS shallower; CEC <4 cmol kg^{-1} by S bases + KCl extractable Al (effective CEC), or CEC <7 cmol kg^{-1} by S cations at pH 7, or CEC <10 cmol kg^{-1} soil by S cations + Al + H at pH 8.2.

b ***Basic reaction,*** free $CaC0_3$ within 50 cm of the soil surface [HCl test) or pH >7.3.

h ***Acid.*** 10-60% Al saturation of the ECEC within 50 cm soil surface. or pH in 1:1 H_2O between 5.0 and 6.0.

a ***Al toxicity,*** >60% Al saturation of the ECEC within 50 cm of the soil surface, or 67% acidity saturatlon of CEC by xcations at pH 7, or > 86% acidity saturation of CEC by pH 8.2. or pH <5.0 in 1:1 H_2O.

i ***High P fixation by iron,*** %free Fe_2O_3/% clay >0.15 and more than 35% clay. or hues of 7.5YR or redder and granular structure. This modifier IS used only in clay (C) types: it applies only to plow layer or surface 20 cm, whichever is shallower.

i + ***Potential Fe toxicity,*** any of the blue, gray, or green colors in the soil change color to become more yellow or reddish if a fresh saturated sample IS exposed to the air for 15-30 min (only if a *g* modifier exists and surface type is not 0). It applies only to plow layer or surface 20 cm, whichever is shallower.

x ***X-ray amorphous,*** pH >10 in 1N NaF, or positive to field NaF test, or other indirect evidences of allophane dominance in the clay fraction,

p ***Low inherent P content*** [3]***,*** (as long as no other data are available) if pH > 6 and Olsen P < 2 mg kg^{-1} soil, or if pH < 6 and Bray-II P < 10 mg kg- soil. It applles only to plow layer or surface 20 cm, whlchever IS shallower.

o ***Low organic matter status*** [3]***,*** the soil receives annually less than 5 t organic material ha^{-1} (such as cow manure), or has less than 0.75% organic C kg soil (wet digestion].

v ***Vertisol,*** very sticky plastic clay: >35% clay and >50 % of 2:1 expanding clays. or severe topsoil shrinking (cracks) and swelling.

s ***Severe salinity,*** >4 mmhos cm^{-1} of electrical conductivity of saturated extract at 25ºC within 1 m of soil surface.

s- ***Potential salinity,*** between 2 and less than 4 mmhos cm^{-1} of electrical conductivity of saturated extract at 25 ºC within 1 m of soil surface.

Table A1.2. Continued.

Condition modifiers [1]

n ***Natric,*** >15% Na saturation of CEC within 50 cm of the soil surface.

n*⁻** ***Potential natric, between 6 and less than 15% Na saturation of CEC within 50 cm of the soil surface. (Caution: If carbonates or gypsum are present, only SAR values should be used. The n modifier is not assigned with an s or s modifier.)

c ***Cat clay,*** pH 1:1 H_2O is <13.5 after drying and jarosite mottles with hues of 2.5Y or yellower and chromas of 6 or more are present within 60 cm of the soil surface.

' ***Gravel,*** a prime (') denotes 15.35% gravel or coarser (>2 mm) particles by volume to any type or substrata type texture; two prime ('') marks denote >35% gravel or particles by volume.[2]

(%) ***Slope,*** where it is desirable to show slope with the FCC-C, the slope % can be placed in parentheses after the last condition modifier.

[1] When more then one criterion is listed for each modifier, only one must be met. The criterion listed first is the most desirable one.
[2] Example: S'L =gravelly sand over loamy; L'C'' = gravelly loam over clayey skeletal.
[3] These modifiers were only established for the Cambodian ricelands.

Table A1.3. Nutritional disorders with relevance to rice production for the FCC (Sanchez and Buol 1985).

Soil		Soil condition	Disorder
Very low pH	High in active Fe	Acid sulfate soil	Fe toxicity
Low pH	High in active Fe	Low in organic matter High in organic matter	P deficiency combined with Fe toxicity
Low pH	High in active Fe	High in Mn	Mn toxicity
Low pH	Low in active Fe and exchange cations	Low in K	Fe toxicity interacted with K deficiency
High pH		High in Ca	P deficiency Fe deficiency Zn deficiency
High pH		High in Ca and low in K	K deficiency associated with high Ca
High pH		High in Na	Salinity problem Fe deficiency B toxicity

Table A1.4. Sample interpretations for the FCC type and substrata types for rice cultivation (Sanchez and Buol 1985, Smith 1989).

Type	Interpretation
S	High in infiltration; low water-holding capacity: more difficult to do thorough puddling: traffic pans infrequent: relatively easy to regenerate structure for rotation with other crops: level of management (nutrients and water) required for high rice yields is higher than in L or C soils; split of N fertilizer required; H_2S toxicity possible if sulfate fertilizer used particularly in conjunction with organic material; high amounts of organic material or N fertilizer may result in toxic accumulation of ammonium; often Zn-deficient.
L	Medium Infiltration; medium water-holding capacity, usually easy to puddle: medium difficulty in regeneration structure; traffic pans important in these soils; L soils are generally more productive for rice than S soils and less than C soils, provided condition modifiers are similar; if texture is silty and traffic pan is broken very low load bearing capacity.
C	Low infiltration rates; high water holding capacity (except Ci); easy to puddle and difficult to regenerate previous structure (except Ci): traffic pans not common, generally more productive for rice than L or S soils, provided condition modifiers are similar.
O	Deep organic or peat soils, with little to no potential for rice production.
OC, OL, OS	Shallow organic soils with a mineral layer in less than 50 cm depth: potential for rice production depends on depth and properties of mineral layer; low bearing capacity: Cu, Mo, and K deficiencies common, often Zn-deficient: hydrogen sulfide toxicity possible, use fertilizer without sulfur; incorporate underlying material in the upper layer to better support the plant.
SL, SC	Somewhat better water holding capacity and thus better suitability for rice production than S soils.
R or R$^+$	Suttability depends on the water availability: suitable with *g* or g^+.

Table A1.5. Sample interpretations of FCC condition modifiers for rice cultivation (Sanchez and Buol 1985, Smith 1989).

Modifier	Limitations or management requirements
g	Defines wetland soils, preferred moisture regime for rice cultivation.
g$^+$	Prolonged submergence causes Zn deficiency.
	N loss increased if soil is intermittently flooded and drained; ammonia volatilization is excessive if *b* or *n* modifier are assigned: N fertilization 2 wk after flooding: mollusk shells indicate Zn deficiency.
d	Topsoil moisture limited during dry season unless irrigated; generally only one rainfed rice crop can be grown annually; irrigated rice during the dry season has higher yield potential and responds to higher N rates.
k	Low Inherent fertility because of low inherent reserves of weatherable minerals; potential K deficiency depending on base contents of irrigation water.

Table A1.5. Continued.

Modifier	Limitations or management requirements
e	Low ECEC reflects less gradual N release, fast built up of mineralized N levels in the solution: more exacting N management needed; identifies degraded paddy soils with SLa or LCa and low organic matter contents; if so potential H_2S toxicity can occur if $(NH_4)_2SO_4$ is used as N source; potential Fe toxicity if adjacent uplands have Fe rich soils; in S soils often Mn-deficient; application of large organic material keeps pH low even after flooding.
a	Aluminum toxicity will occur in aerobic layers; soil test for Identifying P deficiency recommended; liming; in L and C soils continous flooding increases the P availability.
b	High pH may induce Fe deficiency when aerobic and Zn deficiency when waterlogged; high N volatilization loss potentlal from broadcast N application: mollusk shells are Indicative of Zn deficiency.
i	High P fixation by Fe; P deficiency likely; Fe toxicity potential, soils difficult to puddle and will regenerate original structure rapidly; interflow from C *i* uplands may cause Fe toxicity to e soils with lower topographic positions; transplant 1 to 2 mo after flooding or transplant at time of flooding; grow seedlings in flooded nurseries.
i +	P deficiency likely; Fe toxicity potential particularly in S soils with *e* and during high rainfall; Zn-deficiency potential; transplant 1 to 2 mo after flooding or transplant at time of flooding; grow seedlings in flooded nurseries.
o	N deficient; response to N fertilization very likely; low ECEC or sandy soils; N fertilizer should be applied in frequent, small doses.
p	Plant available P deficient; response to small additions of P fertilization very likely.
x	Volcanic materials indicate high inherent fertility with no potentlal Si deficiency; N and P deficiencies common and soil may fix large quantities of P: soils difficult to puddle and will regenerate original structure rapidly.
V	Soils will shrink and crack when dry, causing excessive percolation losses afterwards; easy to puddle but difficult to regenerate structure; P and S deficiency suspect and should be determined by soil test; soils fix applied NH_4 and release later to the rice crop (positive effect); cracks may not close after drying and subsequent flooding, increasing percolation and exacerbating N losses.
S	Defines saline soils; drainage needed but must consider. conductivity of irrigation water.
N	Defines alkali soils; reclaiming with drainage and gypsum applications may be needed; Zn deficiency common.
C	Acid-sulfate soils causing Fe and S toxicity when anaerobic and Al toxicity when aerobic: depth at which c modifier occurs determines feasibility of rice production; strong P deficiency likely and Al toxicity when aerobic; Zn deficiency common: prevent seepage from this areas.
‘	Presence of gravel limits land preparation and water holding capacity.
‘’	Skeletal soils with limited potential for rice production.
%	The higher the slope the narrower the paddies and the higher the rise between the terraces.

Appendix2. Glossary

By necessity the methods used in this manual to identify a soil has been kept general and simple. For example, the use of color charts is avoided because these are not regularly available. Similarly, texture has been limited to three classes and is defined using field test methods only, because laboratory facilities are not readily accessible in the country. This approach leads to some imprecision in the boundaries between classes so that, at times, the user will have to rely on discretion as to which class is applied. Unfortunately, this cannot be avoided in a system of soil classification such as this. It should be emphasised, however, this imprecision is compensated for by the ease of classifying the soil. Hence a soil can be quickly and easily classified at three or four locations in one area allowing a more complete and accurate classification, than if the classification were based on just one profile described in detail at one location.

Soil layers

It is necessary to dig a soil pit of about 60 cm in depth. Only the upper 50 cm of the soil are of interest for this soil classification. We are interested in identifying the two primary layers that make up rhe top 50 cm. The upper layer is termed the topsoil (or type in the FCC-C) and the lower layer is termed the subsoil (or substrata type in the FCC-C). Sometimes more than two layers can be seen, in which case only the top two layers are of interest.

The most important criterion for separating layers is soil texture. If two sections of the profile differ in their soil texture, then these should be classed as separate layers. In the absence of a difference in soil texture, layers can be separated on the basis of a change in color, structure, or consistency. Gravel content is not used to distinguish soil layers when classifying soil groups or phases but is used to distinguish soil layers in the FCC-C. Hence, the Prateah Lang group may or may not contain a gravelly layer in the subsoil. The FCC-C, however, would distinguish between soil with or without a gravelly layer by means of a prime (') or two primes ("). In the absence of these distinguishing characteristics layers are simply defined by depth, with the top 20 cm being designated the upper layer.

Soil texture

Only three classes are defined for soil texture (Fig A2.1):

Sandy — thesoil is compsed of more than 70% sand and less than 15% clay.

Loamy — the soil contains less than 35% clat, but does not have a sandy texture as described above.

Clayey — soil contains more than 35% clay.

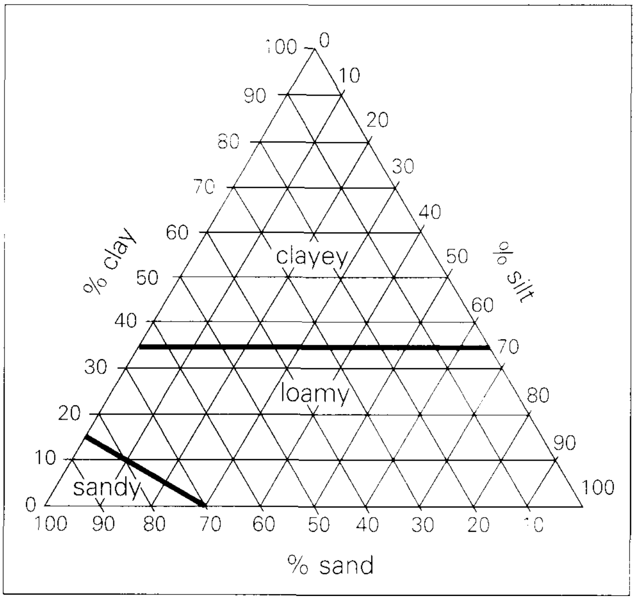


Figure A2.1. Triangle for determining soil texture.

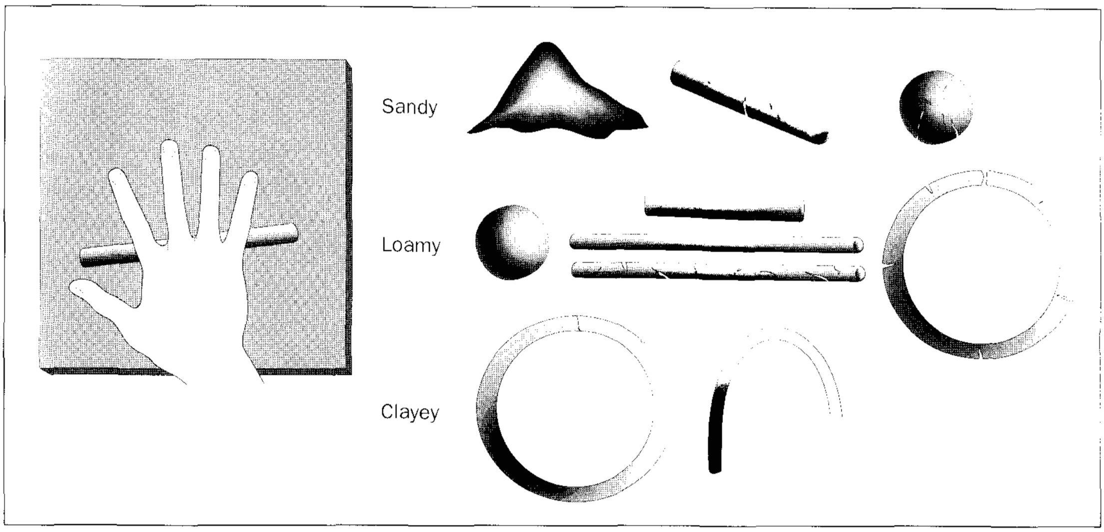


Figure A2.2. "Feel" method for determining soil texture.

In the field, soil texture is determined using the 'feel' method. The following procedure should be followed (Fig. A2.2):

1. Take a sample of soil sufficient to fit comfortably into the palm of the hand (quarter handful).
2. Remove foreign bodies (e.g., roots, seeds, insects) and soil material greater than 2 mm (e.g., gravel).
3. Moisten the sample with water, a little at a time, knead the soil till it just begins to stick to your fingers; the so-called sticky point. The soil must be uniformly moist and must be broken down into its individual particles so that no aggregates remain. Some soils need much working.
4. Work the soil in your hand and squeeze the soil between thumb and forefinger to determine if it is one of the following:
   - Sandy—The soil has nil to very little coherence **or** a rough ball can be formed, which breaks easily when squeezed lightly between the thumb and fingers **or** a rough cylinder (about 5 cm long, 1.5 cm diameter) can be formed out of the soil but the cylinder is not smooth and cracks form **and** the soil has a sandy feel, which predominates **and** it is not very sticky.
   - Loamy—The soil forms a smooth ball or cylinder that is coherent **or** the ball or cylinder can ball can be rolled into a thread (about 13 cm long, 0.6 cm diameter) **and** the soil can be easily worked between the thumb and forefinger and the thread can be formed into a 'U' or ring and when formed into a 'U' or ring cracks are formed **and** the soil sticks to the fingers **and** it has a silky/soapy feel which predominates but it may sometimes also have a slightly sandy feel.
   - Clayey—The soil can be formed into a ball, which is smooth and plastic, **and** the soil is stiff to work between the thumb and forefinger and the soil can be rolled into a ribbon, which forms a ring without cracking, **and** the soil takes on polish when moist **and** the soil is very sticky when wet **and** has a silky soapy feel, which predominates but sometimes a few sand grains may also be felt.

Sand is further divided into coarse or fine (Fig. A2.3).

- Fine sand—The individual grains can just be seen with the naked eye and have a feel similar to good quality imported white table salt.
- Coarse sand—The grains are easily visible by the naked eye. They appear similar in size to good quality table sugar.

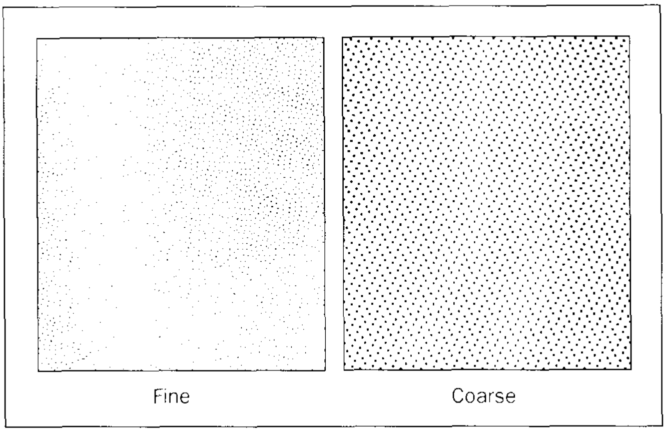


Figure A2.3. Size of sand fraction.

Soil color

Soil color can comprise two components: 1) the soil matrix, which is the main body of the soil and 2) mottles, which are stains or discoloration distinct from the main body of the soil. In some cases mottles may be so numerous that they tend to dominate the impression of the soil color. Nevertheless, it should be remembered that soil color refers to the soil matrix color only. Mottles are described below.

In this manual, the following adjectives arc used to describe color: white, gray, black, yellow, orange, red and brown. Examples of the colors are given in the soil color guide on p. 36. An exact match of the soil color with example colors is not required. If a soil is described as brown, it means that the soil is essentially brown and does not exclude a slight tinge to the soil. Hence a brown soil which has a slightly grayish or yellowish tinge would still be described as brown. If a soil is described as gray or brown the soil color ranges from essentially brown to essentially gray and may appear any combination of the two colors, such as brownish gray or grayish brown. Only the two main colors are important.

To further describe the shade of color the following terms are used: pale, light and dark. Pale signifies a very hint color, light signifies a slightly lower intensity of the main color, while dark signifies a greater intensity of the main color (refer to the soil color guide).

Mottles

Mottles are described in terms of their color and abundance. Color uses the same adjectives as listed above while abundance is described as either:

- Few: Mottles occupy less than about 2% of the exposed surface.
- Common: Mottles occupy about 2 to 20% of the exposed surface.
- Many: Mottles occupy more than 20% of the exposed surface.

Pans

Pans are horizons or layers in the soil, which are strongly compacted, indurated, or very high in clay content. There are many different types of pans such as duripans, fragipans or ironpans. However in this manual we refer only to compacted layers. We expect to that very hard layers in the soil will either be a plow layer or a consolidated ironstone layer. A soil layer is considered a pan if it severely limits or prevents the movement of water or more down the profile.

To detect a plow plow in the field a sharp object, such as a knife or stick can be gently prodded into soil along the face of a profile pit. It can be considered a plow pan if there is a marked change to the ease with which the knife can be produced into the soil compared to the ease with which the stick can be prodded into the soil a few can above or below the layer, then this can be considered a plow pan.

Plinthite

Plinthite is a highly weathered mixture of iron and aluminum oxides with quartz and other diluents. It occurs as red mottles; the soil shows characterisric red streaking when struck with a spade (Plate 19). Plinthite may gradually harden and form ironstone upon alternating wetting and drying.

Soil structure

Soil structure is the arrangement of the primary soil particles intro aggregates which may be called peds. The size and shape and the degree of ped development can be described in detail. In this manual, we use only a few terms to describe structure:

- Structureless—The soil has no structure and particles do not hold together to form peds. Soil particles are present only as loose grains.
- Blocky—The soil naturally forms aggregates, which have either a regular or irregular block shape. The size of the blocks can vary from a few centimetres to more than 20 centimetres in diameter. The larger blocks naturally break into smaller block-shaped aggregates.
- Crumb—The soil naturally forms small rounded or many sided, angular aggregates with the appearance of crumbs. The aggregates range in size from a few millimeters to about 1 cm.
- Massive—The soil does not form natural aggregates but adheres together in a large consolidated mass. Large blocks can be dug from the soil, which can be broken into smaller aggregates but there are no natural breakage lines in the blocks.

Soil consistency

Consistency describes the resistance of the soil to crushing or being moulded:

- Loose—The soil is soft, it does not adhere strongly together. The soil can be easily squeezed between the thumb and fingers.
- Friable—The soil adheres together into distinct aggregates, but the aggregates are easily crushed between the thumb and fingers.
- Firm—The soil holds together strongly but can be crushed between the thumb and forefinger by applying strong pressure.
- Hard—The soil holds together very strongly and cannot be crushed by hand, but can be crushed with a spatula or trowel
- Very hard—The soil holds together very strongly and is very difficult to crush even with a spatula or trowel.
- Plastic—The soil olds together strongly and can be moulded and shaped between the thumb and forefinger.

Basalt and calcimorphic limestone stones and boulders

Break a rock or stone in half or try to chip part of its surface away so that a fresh surface of the rock can be examined.

Calcimorphic limestone in Cambodia is a sedimentary rock. It generally comes in pieces ranging from less that 1 cm to about 10 cm in diameter in the soil. When the rock is chipped, the color is pale gray to dark gray, white, sometimes brown. The rock is often made up as a conglomerate of smaller bodies (1 to 5 mm diameter) with a regular fine structure. Limestone is easily readily scratched by steel; and will dissolves withh effervescence in cold HCL.

Basalt in Cambodia is an igneous rock which can be found as two distict types: 1) Nonvesicular—the chipped surface of this type has a gray to dark gray color. It is very hard and it is difficult to scratch with steel. It has a dense, fine crysatline structure. It occurs as boulders or gravel, though gravel is more common. 2) Vesicular—the chipped surface of this type has a gray to dark gray color. It has a loose structure with many holes. It is quite soft and easily scratched by steel. It is generally present as boulders and small pieces of rock (Plate 20).

Appendix 3. System Modifications

If a soil cannot be adequately classified into one of the soil groups or phases described in this manual, then it is possible to create a new group or phase. This manual has been left *'open ended'* to accommodate such modifications in the future. The Agricultural Soil Unit (ASU) within the Ministry of Agriculture, Forestry and Fisheries is responsible for collecting and collating further information on soils and has the responsibility for updating this manual. The following are some simple guidelines for recognising and describing new soil group,

- Any new group should occur on an area, which is significantly important for Cambodian rice production. If the manual is extended beyond rice soils, then the soil must be of significance to agricultural production in general.
- Any new soil group should be significantly different from the other groups already described, in term of its morphlogy or agricultural potential and limitations.
- A new phase of an existing soil group should identified by a soil property that significatly affects management of the soil for agricultural production. A new phase can not be distinguished solely on morphological differences.
- New soil groups should have significance to the agricultural in general. Soils that occur in small isolated pockets should not be identified as new groups. It is possible, however, to identify these soils as new phases of existing groups.

Once a new group or phase has been identified, a short justification for its inclusion into the manual should be written. A detailed description of a representative profile should be included in the soil group or phase definition. This information should be forwarded to the ASU. The ASU will examine the new soil and determine whether it is necessary to create a new soil group or phase or whether changes to the existing groups and phases can accommodate the new findings. Responsibility for fully describing new soil groups and phases rests with the ASU.