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Soil and Landscapes of Basaltic Terrain in Ou Reang Ov District, Kampong Cham Province, Kingdom of Cambodia

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Abstract

Cambodia has an old national soil map and a more recent map of rice soils, but little is known about soil distribution and properties in the uplands. Such soil information is needed to support moves towards crop diversification in Cambodia in particular for the production of crops other than rice. This investigation was to identify the range and distribution of soil types in the Ou Reang Ov district, Kampong Cham province and to determine the limiting factors of these soils. The study area was on uplands of mid Pleistocene basaltic flows and associated lowland paddy soils of old and recent alluvium/colluvium. Soil classification was completed by detailed profile descriptions using FAO descriptors. These were combined with digital air photos, a digital elevation model, Landsat TM satellite images and expert knowledge to create 10 soil-landscape map units. Chemical and mineralogical properties of the detailed soil profiles were analysed. Soils on the basaltic terrain follow a toposequence from the Labansiek Soil group on the undulating surfaces of the plateau to the Kompong Siem Soil group on the lower slopes with an intermediate gravel-rich, brown clayey soil on the mid-slopes. The Ou Reang Ov Soil group is a newly proposed group for the mid-slope soils of the basaltic terrain. The abundance of gravel in the profile limits soil water storage which can be a constraint for crops under the erratic rainfall regimes of Cambodia. Although the soil occurs on hilly and sloping land, due to high permeability it is not prone to waterlogging or water erosion. The surface is prone to be hard when dry, but the sub-soil is generally friable and root penetration to 60 cm or deeper was observed. The Labansiek non-petroferric phase is a well-structured, acid red soil, with potentially deep root penetration and high soil water storage except where Al toxicity inhibits sub-soil root growth. A significant proportion of these soils are already used for rubber plantations in Ou Reang Ov. Kompong Siem is a deep black soil with no significant impeding layers. Slopes are low, and fields are often bunded so erosion risk is negligible. The soil has self-mulching properties so soil structure re-forms after tillage through wetting and drying cycles. Nutrient availability is not limiting as levels of most nutrients are satisfactory and pH is only moderately to slightly acid. Despite the high clay content, the Kompong Siem soil in the upland areas appears to drain well in the early wet season. However, its location on relatively flat, low-lying landforms results in shallow watertables (10-60 cm) during the main wet season. In conclusion, the clayey soils of the hills and slopes of Ou Reang Ov district have high potential for non-rice cropping. Their relative proximity to markets and good-quality all-weather roads adds to the potential for crop diversification.

1 Introduction

Upland agriculture is beginning to expand rapidly in Kampong Cham province in the east of Cambodia where cassava, peanut, and soybean are the most prevalent field crops (Statistics Office MAFF 2003). Proximity to markets in Vietnam appears to be a driving force behind the expansion. Rising population in the more densely settled lowland rice producing areas may be another trigger for the settlement of upland areas and their increasing use for cropping. Expansion of upland cropping in Kampong Cham province and elsewhere is occurring on soils whose properties are poorly known. The concentration of research in Cambodia over the last 15 years has been on rice producing soils, and substantial progress has been made both in the development of a Cambodian Agronomic Soil Classification (CASC), and in the development of appropriate soil management technologies for soil groups (White et al. 1997, 2000). However, knowledge of the upland soils has stagnated with little new information being reported since the study of Crocker (1962).

Pleistocene basalt flows are quite extensive in eastern Cambodia (Workman 1972). Similar aged basalt flows occur in southern Laos and the central highlands of Vietnam, and to a minor extent in Northeast Thailand. In Cambodia, the greatest area of basaltic terrain occurs as a series of lava sheets with elevations up to about 300 m above sea level in Kampong Cham province and extending west to Kampong Thom province and north to Kratie. Additional large areas of basalt occur in southeast Mondulkiri and in eastern Ratanakiri, bordering Vietnam.

Basaltic soils were recognised as two groups in the CASC for rice (White et al. 1997). The Kompong Siem soil is distinguished by its black to very dark grey colour, and cracking clays. It is a significant rice growing soil in Kampong Cham and Kampong Thom where is occurs *in situ* on low elevation sheets of lava flows, and on the alluvial/colluvial outwash of these sheets. The Labansiek soil is only a minor rice growing soils because its higher elevation on the basaltic plateau and free draining characteristics make it less favourable for padi rice: it is used for upland rice.

Basaltic terrain is common in other tropical regions, including those with a similar monsoonal savannah climate to that which occurs in much of Cambodia (e.g. Isbell et al. 1976, 1977; D'haeze et al. 2001). The basaltic terrain of the central highlands of Vietnam has been the focus of significant agricultural development in the past 20 years (D'haeze et al. 2001) where a major coffee production centre has been developed in Dac Lac province. Coffee is grown on a range of basaltic soils in this province, but is most suited to the well drained Rhodic Ferralsols which occur on the crests of the basaltic plateau, and not suited to the poorly drained and shallow Phaeozem and Vertisols. In Cambodia, deeply weathered red soils on the crests of the basaltic plateau were selected for rubber plantations during the French colonial administration. About 43,000 ha of these soils support rubber in Kampong Cham and there is a potential for a threefold expansion of the area under rubber (FAO 1999; OPCV 2002; Statistics Office MAFF 2004). Because of the high potential agricultural productivity of the soils developed on basalt, their distribution and properties should be the subject of more thorough research in Cambodia. The basaltic soils may have considerable potential for the development of a productive diversified and sustainable upland agriculture in eastern Cambodia.

The aims of the present study were to study a broad range of soils on basaltic terrain of Kampong Cham and determine the key properties of the soils that would act as constraints to agricultural development. The present pilot study was conducted in Ou Reang Ov district about 20 km southeast of Kampong Cham town. The present study documents the main soils and landscapes in Ou Reang Ov district, and the methods used to delineate them. This information will assist agronomists and land resources planners in the identification of different soils and landscapes in the district, and assist research into determining the best agronomic practices in the district. The soil-landscape units will form the basis for land capability assessment for the soils of the basaltic terrain of eastern Cambodia. The general soil-landscape relationships identified in Ou Reang Ov district are expected to have relevance to other districts in Kampong Cham, and in parts of Kampong Thom and Kratie where basaltic terrain occurs, although the relative prevalence of the soil-landscape mapping units may vary from place to place.

2 District overview

Location

The district of Ou Reang Ou in the province of Kompong Cham is located north east of Phnom Penh. The Mekong River flows through the province of Kampong Cham separating the district of Ou Reang Ov from the provincial city (Figure 1). Ou Reang Ov is about 165 km from Phnom Penh. Figure 2 shows the Ou Reang Ov district with roads, rivers, commune offices and boundaries.

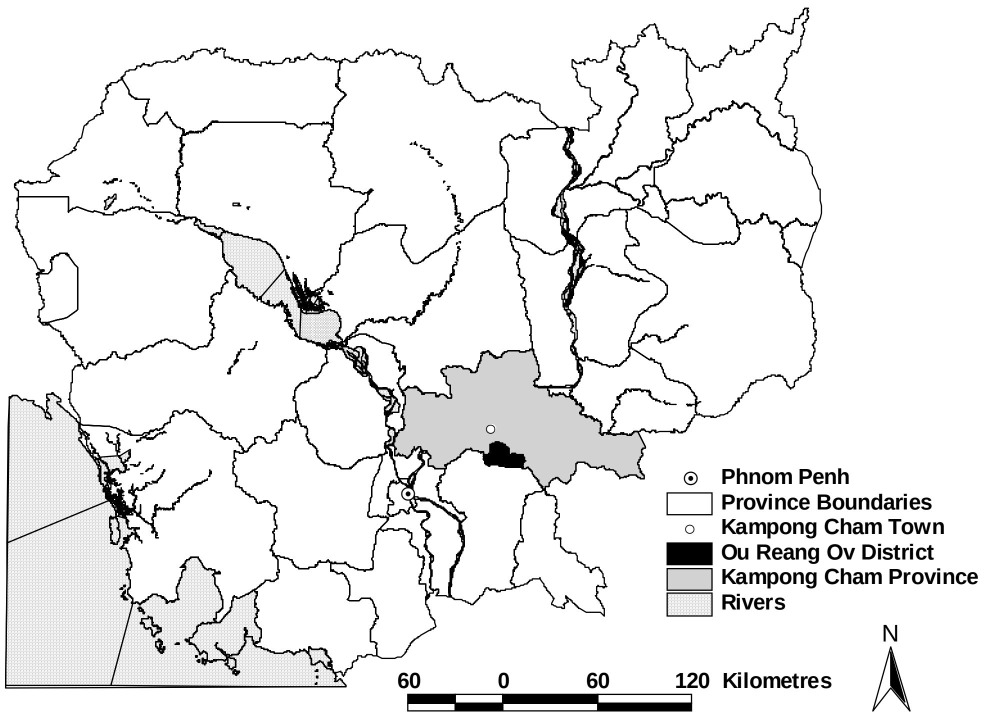

Fig. 1. Map of Ou Reang Ov district in the Province of Kampong Cham.

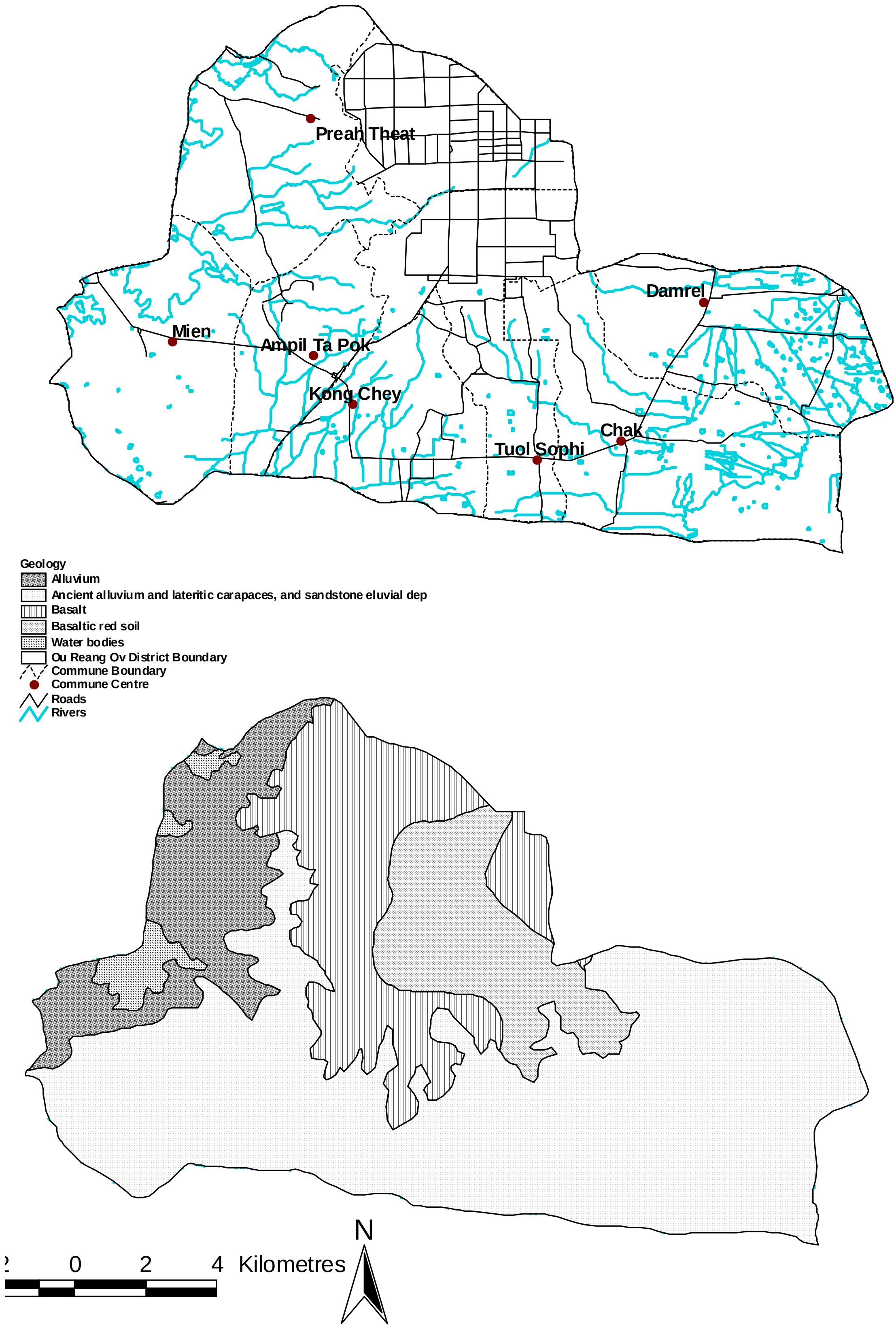

Fig. 2. Map of Ou Reang Ov district showing communes, roads and rivers and the geology of the district.

Climate

Cambodia has a monsoonal climate, which is characterised by distinct wet and dry seasons. The dry season starts in November, with the early wet season beginning in April and the main wet season beginning in July. There are no rainfall records yet for Ou Reang Ov district, however, the average annual rainfall ranges between 1500 and 1750 mm (Nesbitt 1997). At Chup in Tbong Khmum district, the closest rainfall monitoring station to Ou Reang Ov district, average monthly rainfall for the last 10 years was fairly consistent between May and October at 240-270 mm (Figure 3). Daily temperatures range from 21 to 35 ^{o}C. Highest maximum temperatures are reached in April to May with the coolest time of the year being from October to January.

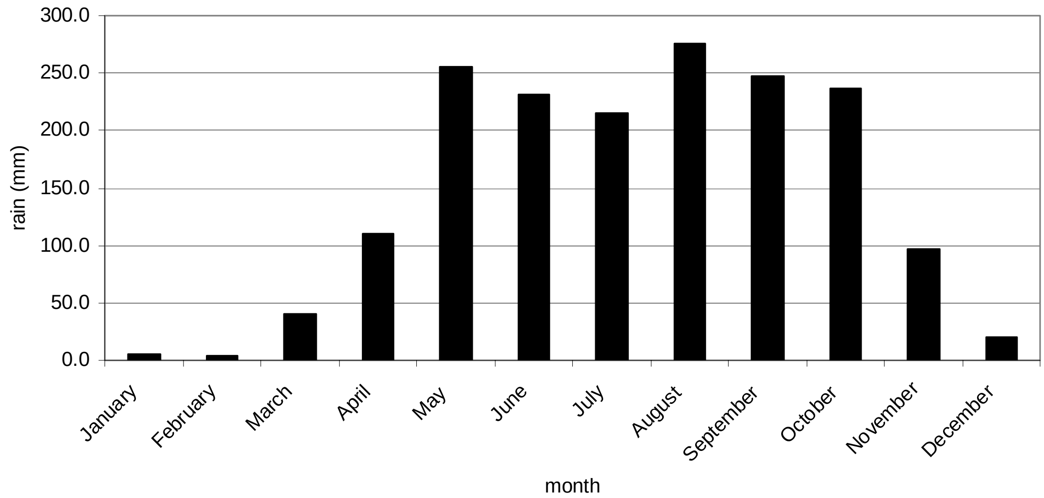

Fig. 3. Average monthly rainfall for Chup station, Tbong Khmum District, Kampong Cham Province (10 years of data) (Vance *et al.* 2004). Mean annual rainfall for Chup is 1740 mm.

Geology

The study area comprises uplands of mid Pleistocene basaltic flows in the northern half of the district, surrounded by associated lowland paddy soils of old and recent alluvium. Ou Reang Ov district is on the southern margin of the basaltic flows in eastern Cambodia (Workman 1972). The uplands rise to 80-100 m above sea level in Ou Reang Ov, but are higher in other parts of Kampong Cham (Ovens 2005).

Land use

The uplands are currently dominated by rubber plantation, the lowlands by mixed land use for paddy rice and non-rice crops (Department of Agricultural Extension 2003). Rice is produced in the wet and dry seasons. Groundwater seepage water is collected in reservoirs in a number of places in Ou Reang Ov district and this water is used for irrigation, supporting mostly early and main wet season rice with supplementary irrigation and limited vegetation and fruit tree production all year round (Ovens 2005). Field crops produced in the district are peanut, soybeans, sesame, maize, mungbean, chilli and cassava. These are grown mainly in the wet season in the upland areas not used for rubber plantations. Vegetable crops are also produced in the district where irrigation is possible, and some lowlands that retain significant stored moisture after rice harvesting, are used for watermelon and cucumber production in the dry season.

3 Method of soil-landscape survey

Soil survey

Detailed soil profile descriptions were completed on 11 soil pits, in areas of the landscape which were deemed to represent the different soil-landscape units. An additional 10 less detailed soil observations were made in the district. In Ou Reang Ov district, the following resources were used to guide soil sampling location: rice soils map for the district (Oberthur et al. 2000); a geology map (supplied by Mekong River Commission -MRC); digital elevation models (MRC); US Army Corp topography maps (1:50,000 1967) and digital ortho-rectified aerial photographs (Department of Geography 1:50,000 1992). However, locations of soil pits were constrained being predominantly at locations used for crop trials. Soil classification was completed by detailed profile descriptions using FAO descriptors (FAO-ISRIC 1990). Data from all soil profile observations was recorded in the CARDI Soil Profile Database of Cambodia, using Microsoft Access software.

Soil chemical analyses

At each soil pit, samples of soil were taken from each horizon. These samples were analysed for electrical conductivity (1:1 soil:water) and pH (1:1 soil:water) in the CARDI laboratory. Analyses of soil chemical characteristics were also completed at CSBP laboratory in Western Australia. These analyses included: nitrogen concentrations as ammonium, nitrate, and total nitrogen; concentrations of extractable phosphorus and potassium, sulphur, copper, zinc, manganese, iron and boron; exchangeable calcium, magnesium, sodium, potassium and aluminium; organic carbon and the electrical conductivity, $pH_{(CaCl2)}$ and $pH_{(water)}$ of the soil (Rayment and Higginson 1992). Data from soil chemical analyses were recorded in the CARDI Soil Profile Database of Cambodia.

Soil-landscape map production

A soil-landscape map of Ou Reang Ov district was completed by combining the soil survey information (detailed pits and observations) with digital air photos, a digital elevation model and Landsat TM satellite images (1989) and expert knowledge to create a land unit map. Arcview software was used to combine these data layers. Polygons of the new soil-landscape map units were digitised. The soil-landscape map was ground-truthed by further observation of the soil-landscapes in the district to determine if the observed soil types were as predicted in the soil-landscape map. The soil-landscape map was modified as required.

4 Soil-landscape overview

The main influence on soil-landscape pattern was the broad basaltic rises that occur in the northern half of the district. The digital elevation model indicates that these rises may be built up of more that one flow which may help explain the occurrence of different soils on the top of the flow versus the steeper side slopes. Rasmussen and Bradford (1977) also concluded that several basalt flows make up the present plateau with the older flows contemporaneous with the Pleistocene alluvial formations in the southern half of the district.

The basalt rises (60- 80 m above sea level) are more or less undulating on top, limiting erosion and allowing for the development of deeply weathered, red, structured clays (KC1: Labansiek, non petroferric phase after White et al. 1997). The distinctive composition of the top basalt flow may be a contributing factor to the development of the deep red clay soils. These soils are favoured for the growth of rubber trees, but would also have significant agricultural or agro-forestry potential.

The side-slopes of the basalt rises are generally much steeper and dissected leading to generally shallower soils and rock outcrop/surface stones and boulders (KC2). It is also likely that the basalt hills are composed of more that one lava flow (Rasmussen and Bradford 1977; Ovens 2005), and the underlying flows exposed at the edge of the hills may have different chemical compositions and weather to different soils. This hypothesis has not been tested. The soils associated with the basalt slopes are invariably brown, and may contain significant amounts of ferruginous gravels and rock fragments. There is no suitable group for these soils in the Cambodian Agronomic Soil Classification (CASC) (White et al. 1997), and a new *Ou Reang Ov* Soil group has been proposed (Seng et al. 2005). A low-relief finger of the basalt extends out to the north-west of the main basalt area, and this has a mixture of Ou Reang Ov and Kompong Siem soils (KC10). Small groundwater seepage areas (KC9) are common near the exposed interface of basalt flows or between the basalt flow and underlying ancient alluvium (Oven 2005). The seepage areas (KC9) did not have distinctive soils, rather their identification as a separate mapping unit was on account of the groundwater seepage and its implications for local water use and irrigation.

The lower colluvial slopes and adjoining plain is influenced by the basaltic parent material, and comprises deep, dark, cracking clay soils (Kompong Siem) (KC3, KC4). These clays may contain basalt floaters in the profiles near to the hills, but floaters become less common with distance from the rises. A broad and seasonally flooded plain to the south and east of the district is dominated by deep Kompong Siem soils free of rock or ironstone gravel (KC5).

In the south-west, the plains are derived from Recent Mekong River alluvium, and paler-surfaced soils (Bakan, Prateah Lang) derived from old Pleistocene alluvium (KC8). Permanent swamps and associated seasonal swamps are also common between the basalt uplands and the Mekong River in the west of the district (KC6, KC7).

Table 1 describes each of the map units outlined above. Figure 4 is a map that shows where in the landscape of Ou Reang Ov district each map unit occurs.

Table 1. Map unit descriptions - Soil-landscape map of Ou Reang Ov district, Kampong Cham province.

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Map Unit	% of district covered	Summary description of soil-landscape unit
KC1	13.5	Very gently undulating to undulating uplands on basalt with red clay soils (Labansiek, non-petroferric phase). Rubber plantations and upland crops
KC2	13.1	Gentle to moderately sloping fringes of basalt uplands and low basaltic rises with rocky or gravelly red or brown soils (Ou Reang

		Ov). Upland crops.
KC3	20.5	Very gently sloping areas surrounding basalt uplands. Dark clayey soils with basalt boulders at depth. (Kompong Siem, gravelly and non-gravelly). Paddy field rice and upland crops
KC4	14.9	Flat area surrounding basalt uplands and often at lower elevation than map unit KC3. Dark clayey soils with basalt boulders at depth. (Kompong Siem, non-gravelly). Paddy field rice
KC5	24.3	Alluvial plains, flooded 2-4 months per year. Dark, clayey soils, not rocky (Kompong Siem). Flooded rice
KC6	4.4	Swamps with vegetation
KC7	2.8	Permanent water
KC8	4.8	Alluvial plains, flooded 2-4 months per year. Yellow to brown sandy to clayey soils (Bakan, Prateah Lang). Flooded rice
KC9	0.3	Groundwater seeps out of basalt hills/rises. Opportunistic irrigation and cropping. Tree crops, reservoirs and native vegetation.
KC10	1.5s	Low and often linear rises emanating from basalt uplands. Kompong Siem, gravelly and non-gravelly and Ou Reang Ov. Paddy field rice and upland crops.

Fig. 4. Map of Ou Reang Ov district indicating the location of each soil- landscape unit. See Table 1 for map unit descriptions.

5 Soil Profiles

The Kompong Siem and Labansiek Soil groups have been previously described in detail by White et al. (1997) and those descriptions will not be repeated here. The Ou Reang Ov Soil group is a newly proposed Soil group for the CASC (Seng et al. 2005).

The Ou Reang Ov Soil group is a dark brown to very dark brown soil with a high proportion of gravel. It is derived from weathering of basalt and is commonly found on mid to upper slopes of the hills. Its position in the landscape is above where the Kompong Siem Soil group is found, and below the Labansiek. It differs significantly in profile characteristics and in chemical and physical properties from both these Soil groups. Its dark brown surface colour can lead to mis-identification as Kompong Siem, and its red sub-soil may lead to mis-identification with the Labansiek soils. Currently, only the gravelly form of this soil is proposed. Intergrade profiles have been observed between Ou Reang Ov and Kompong Siem and between Labansiek and Ou Reang Ov Soil groups but it is not yet clear whether these need to be recognised as separate phases. The Ou Reang Ov Soil group has been observed elsewhere in Kampong Cham province and in Kampong Thom, and is likely to be common in Kratie province but this is yet to be confirmed by survey.

The profile is moderately deep (> 1 metre) with abundant ferruginous gravel in sub-surface layers. The surface horizon is 12 to 18 cm deep, dark brown to very dark brown, clay to clay loam texture, with many fine ferruginous nodules. The surface is generally hard when dry. The sub-surface layers are dark brown to dark red, extend generally to 120 cm depth or more, have clay to clay loam texture, and are characterised by abundant medium to coarse size ferruginous gravel. It also contains very few coarse fragments of sub-rounded basalt.

Colour in the surface can vary from very dark greyish brown to dark brown and dark reddish brown. Sub-soil is generally dark brown but can vary to reddish brown. Combined depth of the A and B horizons was mostly > 95 cm, and usually > 120 cm. However, shallow profiles, 60 cm deep on weathered basalt, were observed on hill slopes. Ferruginous gravel (varying in composition to iron-manganese gravels) is a distinctive characteristic of the Ou Reang Ov Soil group. The surface has variable amounts of fine gravel (from none to many). Medium to coarse gravel becomes abundant below 15 cm depth extending to 90 or greater than 120 cm. The profile shows very little mottling and does not form cracks when dry. Ou Reang Ov Soil group contains very few coarse fragments of sub-rounded basalt although on low linear ridges a mapping unit of mixed Kompong Siem and Ou Reang Ov Soil groups was identified (KC10) which did have abundant basalt boulders. Small areas of KC10 occur within the KC2 mapping unit but were too small to identify at the present mapping scale.

Ou Reang Ov Soil group occurs in less elevated positions than Labansiek soil, below the top of the basalt plateau, and is less reddish in colour especially at the surface, with medium sized blocky peds. There is more gravel in Ou Reang Ov than Labansiek Soil group. When using the CASC, the Ou Reang Ov Soil Group does not key to Labansiek Soil Group due to the dark brown colour and the lack of stable granular[1] structure.

Ou Reang Ov soil occurs higher in the landscape and on greater slopes than Kompong Siem Soil group. The fields where the Ou Reang Ov Soil group occurs are almost

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[1] Although described by White et al. (1997) as having a crumb structure, it is more correctly a granular structure and will be referred to as such hereafter.

always too well drained for rice cultivation. It has a greater abundance of fine to medium ferruginous gravel fragments than in Kompong Siem Soil group (the gravelly phase of Kompong Siem may contain many fine ferruginous and manganiferous gravel). It does not key to Kompong Siem due to its dark brown colour and also due to its non-cracking behaviour.

Typical soil profiles for the upland soil-landscape units are shown below. A more complete list is available from the soil database maintained at CARDI. Lowland soil groups (KC5, KC8) are not described below as a detailed description of their profiles is reported in White et al. (1997).

Kompong Siem, non gravelly phase

Project & Site Code: ACIAR 0013
Described by: Noel Schoknecht **Date:** 11/6/03
Location: Datum: IND60 Zone: 48 556130 mE 1309430 mN GPS measurement
Current Classification
World Reference Base: (FAO -ISRIC- ISSS 1998) Gleyic Phaeozem

Horizon	Depth (cm)	Description
Ap	0-10	very dark grey (10YR 3/1 moist) clay; fine faint brown (7.5YR 4/4 moist) mottles; hard dry consistence; weak, medium, sub-angular blocky structure; few segregations, fine iron (ferruginous) nodules rounded reddish brown hard; common roots, very fine; few coarse fragments sub-angular fine gravel quartz; pH 6.37 (1:1 water); EC 0.3 mS/m (1:1); very fine, medium porosity, vughs void; clear, smooth boundary.
A	10-40	very dark greyish brown (10YR 3/2 moist) clay; fine faint brown (7.5YR 4/4 moist) mottles; friable moist consistence; weak, medium, granular structure; few segregations, fine ferruginous nodules rounded reddish brown hard; few roots, fine; few coarse fragments sub-angular fine gravel quartz; pH 6.82 (1:1 water); EC 0.3 mS/m (1:1); fine and medium, high porosity, vughs void; gradual, wavy boundary.
BC	40-75	dark greyish brown (10YR 4/2 moist) clay; fine distinct strong brown (7.5YR 4/6 moist) mottles; friable moist consistence; moderate, fine, angular blocky structure; common cutans, faint clay; few segregations, fine manganese (manganiferous) soft segregation rounded black soft and many segregations, fine ferruginous nodules irregular reddish brown hard; no roots; few coarse fragments sub-angular fine gravel quartz; pH 6.82 (1:1 water); EC 0.3 mS/m (1:1); fine and medium, low porosity, vughs void; diffuse, wavy boundary.
Cg	75-115+	grey (2.5Y 5/1 moist) clay; fine prominent strong brown (7.5YR 4/6 moist) mottles; firm moist consistence; weak, fine, angular blocky structure; common segregations, fine manganese (manganiferous) soft segregation rounded black soft and common segregations, fine ferruginous nodules irregular reddish brown hard; no roots; pH 7.02 (1:1 water); EC 0.6 mS/m (1:1); fine and medium, low porosity, vughs void.

Note: the depth to grey clay may be only 60 cm in some profiles.

Ou Reang Ov

Project & Site Code: ACIAR 0014
Described by: Noel Schoknecht **Date:** 11/6/03
Location: Datum: IND60 Zone: 48 560347 mE 1306195 mN GPS measurement
Site notes: Gentle slope. Soil with abundant ironstone gravels. Not clear if gravels are pedogenic in origin.
Surface and Hydrological Properties
Surface coarse fragments: common sub-rounded igneous rock gravel
Physical properties: hardsetting surface
Geology/parent material
Soil parent material: basalt
Geology: basalt
Current Classification
The above profile was classified as a Skeletal Phaeozem (FAO ISRIC ISSS 1998). By contrast, profiles recognised as Kompong Siem Soil group from nearby were classified as Gleyic Phaeozom. A more oxidised variation of the Ou Reang Ov Soil group was provisionally classified as a Nitosol (i.e. related to the typical Lanansiek Soil group) and a shallower profile was provisionally classified as a Regosol.

Horizon	Depth (cm)	Description
Ap	0-12	very dark greyish brown (10YR 3/2 moist) clay loam; slightly hard dry consistence; massive structure; many segregations, fine ferruginous rounded reddish brown hard; common roots, fine; moderate permeability; pH 6.53 (1:1 water); EC 0.3 mS/m (1:1); fine, medium porosity, vughs void; clear, smooth boundary.
BC1	12-85	dark brown (10YR 3/3 moist) clay; friable moist consistence; moderate, fine, angular blocky structure; abundant segregations, fine ferruginous irregular yellowish brown hard; few roots, fine; very few coarse fragments sub-rounded stones of basalt; moderate permeability; pH 6.63 (1:1 water); EC 0.3 mS/m (1:1); fine, vughs void; diffuse, wavy boundary.
BC2	85-120+	brown (10YR 4/3 moist) clay; fine distinct light brown (7.5YR 6/4 moist) mottles; friable moist consistence; weak, fine, angular blocky structure; abundant segregations, medium ferruginous irregular brown hard; no roots; moderate permeability; pH 6.87 (1:1 water); EC 0.3 mS/m (1:1); fine, vughs void.

Labansiek, non petroferric phase

Project & Site Code: ACIAR 0015
Described by: Noel Schoknecht **Date:** 12/6/03
Location: Datum: IND60 Zone: 48 560659 mE 1306847 mN GPS measurement
Surface and Hydrological Properties
Surface coarse fragments: no gravel, no stones
Physical properties: self-mulching surface
Current Classification
World Reference Base: (FAO-ISRIC-ISSS 1998) Eutric Nitisol

Horizon	Depth (cm)	Description
Ap	0-15	dark reddish brown (2.5YR 3/3 moist) clay; slightly hard dry consistence; weak, fine, granular structure; very few segregations, very fine ferruginous nodules rounded reddish brown hard; common roots, very fine; pH 5.43 (1:1 water); EC 0.1 mS/m (1:1); fine, medium porosity, vughs void; gradual, smooth boundary.
B1	15-60	dark reddish brown (2.5YR 3/4 moist) clay; friable moist consistence; moderate, fine, sub-angular blocky structure; no segregations; few roots, very fine; pH 5.55 (1:1 water); EC 0.1 mS/m (1:1); fine, medium porosity, vughs void; diffuse, wavy boundary.
B2	60-120+	dark red (2.5YR 3/6 moist) clay; fine faint light red (2.5YR 6/8 moist) mottles; friable moist consistence; moderate, fine, angular blocky structure; no segregations; few roots, very fine; pH 5.55 (1:1 water); EC 0.1 mS/m (1:1); fine, low porosity, vughs void.

Note: the depth of the B2 horizon may be 200+ cm

6 Soil Chemical Properties of Profiles

Interpretation of the soil chemical analysis is based on Peverill et al. (1999).

6.1 Labansiek, non petroferric

Three profiles were analysed (Table 2, 3 and 4).

Soils contained low to moderate levels of organic carbon in the surface horizon and very low total N. Site 16 differed from other profiles in having very high extractable NO_3-N.

All three soil profiles were strongly acidic throughout with pH ($CaCl_2$) less than or equal to 4.6. However, Al saturation was always less than 30 %. Site 16 had the highest Al saturation at 24-27%.

Exchangeable Ca and Mg levels in Labansiek Soil group were moderate, but there were very low exchangeable Na and low to very low K levels.

Bicarbonate extractable P was low to moderate with high values in sub-soils of Sites 15 and 61. Although the high surface layer P may reflect, in part, long term P fertiliser use for rubber, the high P at 40-120 cm was probably innate. Extractable S levels were moderate to low. DTPA extractable Cu and Zn levels were moderate, as was B, but extractable Mn was very high especially in surface horizons. Pot experiments at CARDI have demonstrated Mn toxicity on this soil and its alleviation with lime (Seng personal communication).

6.2 Ou Reang Ov

Five profiles were sampled and analysed.

Ou Reang Ov soil contained low to moderate (> 1.5 %) organic C levels and total N also very low (Tables 2 and 3).

Soil pH was generally moderately acid in the surface horizon but decreased on some profiles to strongly acid at depth (> 18-25 cm) (Table 2). Among the profiles there was some variation in sub-soil pH- Site 17 was uniformly acid and Site 14 did not have strongly acid sub-soils. Only one of the profiles (Site 11) had significant Al in sub-soil with Al saturation about 40 % below 45 cm (Table 3).

Exchangeable Ca levels in the Ou Reang Ov soils were moderate to high except in sub-soil layers of the most acidic profile (Table 3). Exchangeable Mg was uniformly high. Unlike in Kompong Siem soils, there was negligible exchangeable Na throughout. Exchangeable K levels were generally moderate to high except in Site 17, the most oxidised of the Ou Reang Ov profiles which had low exchangeable K especially in the sub-soil.

Extractable P levels were generally high except at Site 17 (Table 4). Extractable S was generally low but there were moderate levels in sub-soils of two profiles (Sites 11 and 18).

Ou Reang Ov soils contained moderate levels of the extractable micronutrients, B, Cu, Zn and Mn (Table 4).

6.3 Kompong Siem

Three profiles were analysed (Tables 2, 3 and 4).

The organic C levels in Kompong Siem soils were low to moderate and total N was very low (Table 2 and 3).

Kompong Siem soils were moderately acid throughout rising to near neutral at depth in some profiles (Table 2). Consequently all contained negligible exchangeable Al. Soils contained moderate to high exchangeable Ca and Mg, and high exchangeable Na in lower horizon of two profiles (Table 3). Exchangeable K was very low throughout in all three profiles. Effective CEC levels were moderate to high.

Extractable P levels were low throughout the profile (although bicarbonate extractable P in Site 27 was moderate), as were levels of extractable S (Table 4). Soils contained moderate DTPA extractable Cu, moderate to low DTPA Zn, high Mn levels in some layers of the profile and low hot $CaCl_2$ extractable B.

A Kompong Siem profile on basalt parent rock, from Baray district in Kampong Thom, showed similar chemical properties to those above.

6.4 Other Soils

The alluvial plains, KC5 and KC8 in Figure 4, are used for rice and hence their physical and chemical properties are as described in White et al. (1997). The seepage areas (KC9) did not have distinctive soils (Ovens 2005) and hence the properties described above for Ou Reang Ov and Kompong Siem soils will probably apply also to the KC9 soil-landscape mapping unit.

Table 2. Organic carbon and pH of soils of Ou Reang Ov district.

Site	Cambodian Soil Group		Depth	Organic	pH	pH
	Group	Phase		carbon	$CaCl_2$	H_2O
			(cm)	(%)		
10	Kompong Siem	non gravelly	0-10	1.39	5.1	6.1
			10-25	0.91	5.4	6.5
			25-43	0.47	5.2	6.3
			43-78	0.21	5.4	6.4
			78-115	0.23	6.9	7.9
13	Kompong Siem	non gravelly	0-10	1.03	5.6	6.5
			10-40	0.63	6.1	6.9
			40-75	0.43	5.9	7.1
			75-115	0.09	6.3	7.4
27	Kompong Siem	gravelly	0-50	0.94	5.7	6.5
11	Ou Reang Ov		0-18	1.54	6.1	7.1
			18-45	0.83	4.7	5.7
			45-88	0.53	4.4	5.5
			88-120	0.37	4.3	5.4
14	Ou Reang Ov		0-12	1.79	5.7	6.7
			12-85	0.63	5.5	6.6
			85-120	0.64	5.4	6.5
17	Ou Reang Ov		0-20	1.35	4.6	5.3
			20-60	0.86	4.4	5.5
			60-95	0.5	4.6	5.6
29	Ou Reang Ov		0-10	1.58	5.5	6.5
			10-25	0.97	5.2	6.1
			25-60	0.93	4.7	5.7
18	Ou Reang Ov		0-10	1.1	5.5	6.6
			10-30	0.82	5.8	6.6
			30-75	0.56	4.5	5.4
			75-120	0.37	4.6	5.6
15	Labansiek	non petroferric	0-15	1.2	4.4	5.3
			15-60	0.64	4.5	5.3
			60-120	0.38	4.4	5.5
16	Labansiek	non petroferric	0-18	1.04	4.3	4.7
			18-50	1.23	4.6	5.3
			50-100	0.48	4.4	5.3
61	Labansiek	non petroferric	0-10	1.29	4.3	5.2
			10-40	0.65	4.4	5.3
			40-120	0.45	4.3	5.2

7 Mineralogy

Only one Labansiek profile was assessed for mineralogy of the bulk horizon samples (Table 5). It revealed a strongly weathered profile with a predominance of kaolinitic clays comprising nearly 50 % of the sample. It was also contained 15-20 % Fe oxides, mainly goethite. Surprisingly for a basaltic soil, relatively high quartz levels were also found, especially in the topsoil layer, but even at 60-120 cm depth 20 % of the soil material was quartz. Since quartz is rarely found in basalt, the quartz present may to be a secondary mineral forming in the soil.

The single Kompong Siem profile assessed for mineralogy was distinctly different from the Labansiek soil profile (Table 5). Smectite was a major mineral in Kompong Siem soil, comprising 10 % of soil mass to 78 cm depth and 15 % from 78 to 115 cm. Kaolinite was a major soil mineral in Kompong Siem soil comprising 30-40 % of soil mass. Quartz was the major mineral in the Kompong Siem profile being most prevalent at the surface and decreasing with depth, the converse of kaolinite. Only traces of Fe oxides were found in the Kompong Siem soil, except for a minor amount at 78-115 cm in the C horizon, and only traces of feldspar were found.

Two profiles of Ou Reang Ov were analysed (Table 5). Site 14 has the more typical Ou Reang Ov soil profile form. Ou Reang Ov Soil group contains significant smectite clays, indeed about the same content as Kompong Siem except in the more oxidised profile at Site 17. The latter profile contained 20-25 % Fe oxides whereas Site 14 contained only 5 %. The dominant minerals in Ou Reang Ov profiles were kaolinite and quartz. The levels of kaolinite were higher and quartz lower in the more oxidised profile at Site 17. Traces of ilmenite were found in Ou Reang Ov soils, and traces of feldspar only at Site 17. Hence the mineralogy of the Ou Reang Ov Soil group indicates that it is intermediate between that of the Labanasiek and Kompong Siem Soil groups.

Table 3. Exchangeable cations, effective cation exchange capacity (ECEC) and Al saturation in soils of Ou Reang Ov district.

Site	Cambodian Soil Group	Phase	Depth	Ca	Mg	Na	K	Al	ECEC	Al saturation
	Group	Phase								
			(cm)	(cmol/kg)						(%)
10	Kampong Siem	non gravelly	0-10	5.94	5.8	0.15	0.05	0.07	12.0	1
			10-25	6.44	6.07	0.12	0.03	0.03	12.7	0
			25-43	3.22	6.51	0.27	0.03	0.02	10.1	0
			43-78	2.23	6.51	0.55	0.04	0.02	9.4	0
			78-115	3.49	16.9	2.23	0.09	0	22.7	0
13	Kampong Siem	non gravelly	0-10	7.04	6	0.1	0.19	0	13.3	0
			10-40	4.76	3.92	0.09	0.05	0	8.8	0
			40-75	4.92	6.87	0.3	0.04	0	12.1	0
			75-115	5.61	16.11	1.36	0.07	0	23.2	0
27	Kompong Siem	gravelly	0-50	13.9	10.5	0.22	0.08	0	24.7	0
11	Ou Reang Ov		0-18	7.5	3.16	0.03	1.74	0	12.4	0
			18-45	2.3	2.32	0.02	0.4	0.36	5.4	7
			45-88	0.69	1.58	0.03	0.84	1.82	5.0	37
			88-120	0.62	1.43	0.04	0.78	2.22	5.1	44
14	Ou Reang Ov		0-12	13.0	5.37	0.05	1	0	19.4	0
			12-85	10.5	9.67	0.07	0.44	0	20.7	0
			85-120	10.8	9.1	0.08	0.5	0.03	20.5	0
17	Ou Reang Ov		0-20	7.05	3.2	0.02	0.26	0.49	11.0	4
			20-60	6.05	2.92	0.06	0.09	1.42	10.5	13
			60-95	6.49	2.87	0.08	0.08	0.41	9.9	4
18	Ou Reang Ov		0-10	6.8	2.35	0.01	0.62	0	9.8	0
			10-30	6.13	2.47	0.02	0.27	0	8.9	0
			30-75	3.16	2.33	0.02	0.4	0.55	6.5	9

			75-120	3.73	2.2	0.03	1.01	0.45	7.4	6
29	Ou Reang Ov		0-10	9.34	5.04	0.06	0.42	0	14.9	0
			10-25	8.4	5.51	0.1	0.28	0.01	14.3	0
			25-60	7.74	7.59	0.2	0.34	0.08	16.0	1
15	Labansiek	non	0-15	2.58	1.12	<0.01	0.26	0.65	4.6	14
		gravelly	15-60	2.4	1.39	0.02	0.15	0.45	4.4	10
			60-120	1.5	1.03	0.01	0.35	0.82	3.7	22
16	Labansiek	non	0-18	1.7	1.03	0.02	0.15	1.07	4.0	27
		gravelly	18-50	7.12	3.17	0.02	0.26	0.56	11.1	5
			50-100	1.32	1.11	<0.01	0.03	0.78	3.2	24
61	Labansiek	non	0-10	1.77	1.11	0.02	0.18	0.2	3.3	6
		gravelly	10-40	2.39	0.94	0.02	0.06	0.11	3.5	3
			40-120	1.18	0.68	0.02	0.08	0.37	2.3	16

Table 4. Extractable nutrient levels in soils of Ou Reang Ov district.

Site	Cambodian Soil Group		Depth	Nitrogen			Bicarb. P	KCl-S	DTPA	DTPA	DTPA	Hot $CaCl_2$
	Group	Phase		NO_3	NH_4^+	Total N			Cu	Zn	Mn	B
			(cm)	(mg/kg)	(mg/kg)	(%)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
10	Kampong Siem	non	0-10	6.0	7.0	0.02	14	1.7	3.6	1.02	52.3	0.3
		gravelly	10-25	3.0	5.0	0.07	11	<1	2.79	0.72	37.7	0.3
			25-43	3.0	4.0	0.06	16	<1	1.58	0.48	8.08	0.3
			43-78	4.0	7.0	0.02	29	2.1	0.78	0.68	66.6	0.3
			78-115	2.0	5.0	<0.02	4	1.2	0.72	0.79	6.74	0.2
13	Kampong Siem	non	0-10	2.0	9.0	0.09	16	2.4	3.1	0.86	40.0	0.3
		gravelly	10-40	<1.0	4.0	0.04	11	1.0	1.72	0.37	8.82	0.3
			40-75	1.0	4.0	0.04	8	1.0	0.97	0.29	6.64	0.3
			75-115	2.0	4.0	<0.02	6	1.5	1.03	0.33	4.79	0.2
27	Kompong Siem	gravelly	0-50	6.0	11.0	0.1	31	4.2	5.05	1.15	97.2	0.3
11	Ou Reang Ov		0-18	1.0	7.0	0.12	132	4.6	1.25	5.18	40.0	0.7
			18-45	2.0	4.0	0.07	96	3.6	0.94	1.47	20.1	0.4
			45-88	4.0	6.0	0.07	54	9.4	0.57	1.14	14.2	0.4
			88-120	7.0	5.0	0.07	23	13.8	0.43	1.03	8.31	0.4
14	Ou Reang Ov		0-12	7.0	7.0	0.12	191	3.5	2.21	4.2	26.2	0.6
			12-85	2.0	5.0	0.07	27	5.2	2.06	0.69	15.4	0.4
			85-120	2.0	4.0	0.07	22	5.5	2.14	0.73	13.0	0.4
17	Ou Reang Ov		0-20	22.0	8.0	0.13	21	3.0	3.01	2.58	59.2	0.5
			20-60	5.0	8.0	0.09	12	4.8	1.61	0.84	11.2	0.4
			60-95	5.0	4.0	0.09	14	5.0	1.22	0.58	8.21	0.4
18	Ou Reang Ov		0-10	5.0	10.0	0.08	129	2.5	1.52	3.99	33.6	0.5
			10-30	7.0	1.4	0.08	106	1.3	1.36	1.47	22.8	0.5

			30-75	13.0	<1	0.07	50	13.5	1.12	0.74	29.0	0.4
			75-120	11.0	<1	0.05	37	7.9	1.59	1.12	62.5	0.4
29	Ou Reang Ov		0-10	6.0	16.0	0.14	26	3.3	2.3	3.36	77.9	0.3
			10-25	4.0	31.0	0.1	21	5	2.37	0.96	50.7	0.4
			25-60	3.0	16.0	0.1	13	6.5	2.47	0.92	60.8	0.3
15	Labansiek	non	0-15	8.0	6.0	0.13	44	4.3	1.06	1.7	97.2	0.5
		petroferric	15-60	14.0	3.0	0.09	98	3.2	0.5	0.36	17.1	0.5
			60-120	5.0	5.0	0.04	108	8.9	0.3	0.41	5.53	0.4
16	Labansiek	non	0-18	53.0	5.0	0.11	26	8.4	1.08	2.27	144	0.5
		petroferric	18-50	24.0	5.0	0.12	22	3.2	2.84	2.47	56.8	0.5
			50-100	9.0	3.0	0.07	36	1.4	0.37	0.51	14.0	0.4
61	Labansiek	non	0-10	4.0	5.0	0.12	68	2.4	1.72	2.92	97.1	0.4
		petroferric	10-40	1.0	3.0	0.06	135	5.4	0.81	0.65	27.8	0.4
			40-120	1.0	1.0	0.04	155	12.6	0.63	0.5	12.2	0.3

Table 5. Mineralogy of soil profiles from X-ray diffraction of powder preparations of horizon samples from each of four profiles.

Site	Cambodian Soil group Group	Phase	Depth (cm)	Smectite (%)	Kaolinite	Quartz	Fe-oxide	Feldspar	Ilmenite
10	Kampong Siem	non gravelly	0-10	10	30	60	traces	traces	
			10-25	10	35	55	traces		
			25-43	10	35	55	traces		
			43-78	10	40	50	traces		
			78-115	15	40	40	5	traces	
14	Ou Reang Ov		0-12	10	15	55	5		5
			12-85	15	25	55	5		traces
			85-120	15	30	50	5		traces
17	Ou Reang Ov		0-20	5	40	35	20	traces	traces
			20-60	5	55	15	25		
			60-95	5	65	5	25		
15	Labansiek	non petroferric	0-15		40	45	15		traces
			15-60		50	35	15		traces
			60-120		60	20	20		traces

8 Soil Management

Labansiek

Labansiek non-petroferric phase is a deep red clay soil that occurs on very gently undulating to undulating uplands of the basaltic plateau. These landforms occupy significant areas of eastern Cambodia (White et al. 1997) and hence the Labansiek properties described here have broader relevance. Labansiek Soil group is not a significant padi rice soil (White et al. (1997), but has potential for other field crops. A significant proportion of these soils are already used for rubber plantations in Ou Reang Ov as well as other districts in Kampong Cham province. During replanting of rubber trees there are 2-3 years when annual field crops such as peanut, soybean and mung bean are increasingly grown in the inter-row. The present comments apply to the non-petroferric phase of Labansiek since the petroferric phase was not observed in Ou Reang Ov district. The shallow ferricrete layer in the Labansiek petroferric phase would be a major constraint for field crops. By contrast the non-petroferric phase is a deep soil, with potentially deep root penetration and high soil water storage except where Al toxicity inhibits sub-soil root growth.

The Labansiek soil has moderate leaching potential on account of its porosity and low effective cation exchange capacity. Leaching especially of nitrate may be significant on this soil due to its porous nature, on the other hand if the soil contains significant anion exchange capacity (which is conceivable given its low pH and mineralogy see Donn et al. 2004) nitrate and sulfate may be retained in the sub-soil, and be available for use by deep-rooted crops.

Low pH was the major limiting factor on the Labansiek non-petroferric soil. Non-petroferric phases of Labansiek soil were generally strongly acidic with a risk of Al toxicity in species with low tolerance (e.g maize, mung bean and soybean). Manganese toxicity has also been confirmed in Labansiek soil in pot experiments where a lime application alleviated the symptoms of Mn toxicity in mung bean and increased plant growth (Seng personal communication). For legumes, molybdenum may deficient and restrict nitrogen fixation on acid Labansiek soils.

Low pH would commonly limit nutrient availability, but the Labansiek soil has moderate to high extractable P levels, even in sub-soils. However, it also has high P retention index (PRI), which would prevent risk of P leaching.

Erosion risk depends on slope and soil exposure. On sloping land, moderate water erosion risk is predicted. Rill formation has been observed on bare slopes, despite the high infiltration rates and stable soil structure.

Most of the land qualities for Labansiek soils were rated as favourable, and generally non-limiting. Overall land capability was rated as fair to good (Class 2-3), depending mostly on soil pH and perhaps erosion risk. The fair capability of Labansiek is perhaps lower than is perceived by many agronomists in Cambodia. Cassava which is increasingly grown on Labanbsiek soil is highly tolerant of Al toxicity (Dierolf et al. 2001). Similarly, rubber which occupies large areas of the Labansiek non-petroferric soil is tolerant of Al toxicity (Sys et al. 1993; Sanchez et al. 2003). Hence the use of

Labansiek soil for production of these Al tolerant crops may mask the severity of limitations for other crops.

Ou Reang Ov

Ou Reang Ov soil is well drained throughout. The surface is prone to be hard when dry. Although the soil occurs on hilly and sloping land, due to high permeability it is not prone to water erosion. The sub-soil is generally friable and root penetration to 60 cm or deeper was observed. The abundance (40- 80 % by volume) of medium to coarse ferruginous gravel in the sub-soil may limit soil water storage and make crops on this soil prone to drought.

The soil appears to have naturally high extractable P levels even in the sub-soil. Sulfur supply in the surface soil may be limiting for early growth but as roots penetrate deeper they access greater available S supplies. Other nutrients appear to be in adequate supply from soil analysis.

Ou Reang Ov soils are generally too shallow for rubber plantations. Given the low yield of upland rice (<1 t/ha) and landforms on which the soil occurs, growing other field crops may be more economical than rubber or upland rice. Overall capability for non-rice crops is fair to good. Major limiting factors are low soil water storage, and possible Al toxicity in the sub-soil. The soil appears to drain well and is not prone to soil erosion even on slopes, but nevertheless protection of the soil from water erosion should be practiced. Crop yields on this soil with fertiliser added are generally inferior to those on Kompong Siem and Labansiek Soil groups. By contrast, farmers in Ou Reang Ov district ranked Ou Reang Ov soil above both Labansiek and Kompong Siem soils in terms of suitability for a range of crops. Possibly this was because farmers do not generally use fertiliser on such crops, and secondly the Ou Reang Ov profile type observed by the farmers had little gravel in it. On the profile types with appreciable sub-soil Al, tolerant crops like peanut, cassava may be more productive than soybean, maize, sesame and mung bean. Overall land capability was rated as fair to good (Class 3-2), depending mostly on low soil water storage.

Kompong Siem

Kompong Siem has few limiting factors. It is a deep soil with no significant impeding layers. Slopes are low, and fields are often bunded so erosion risk is negligible. The soil has self-mulching properties so soil structure re-forms after tillage through wetting and drying cycles. Nutrient availability is not limiting as levels of most nutrients are satisfactory and pH is only moderately to slightly acid. Extractable P levels are lower than Ou Reang Ov and Labansiek soils, but added P is expected to be readily available since the soil has moderate pH, moderate PRI and low Fe oxide content. Low K and S, and marginal B levels may limit production unless appropriate fertiliser is added on these soils.

Waterlogging risk is perhaps the most severe limiting factor, but despite the high clay content, the Kompong Siem soil in the elevated KC3 and KC4 areas appears to drain well in the early wet season. Crop yields in trials on this soil with fertiliser applied outstrip those of Ou Reang Ov and Labansiek soil groups, both of which have better internal and external drainage. However, its location on relatively flat, low-lying landforms results in shallow watertables (10-60 cm) during the main wet season. It is hard when dry and sticky when wet making it difficult to prepare land for sowing.

Overall land capability was rated as good to fair (Class 2-3), depending mostly on waterlogging.

9 General Discussion

The clayey soils of the hills and slopes of Ou Reang Ov district have high potential for non-rice cropping. Their relative proximity to markets and good-quality all-weather roads adds to the potential for crop diversification. The availability of groundwater seepage around the fringes of the basalt plateau represents a significant but somewhat limited water resource for supplementary irrigation in Ou Reang Ov district and similar resources exist in other districts of Kampong Cham (Ovens 2005). However, most of this groundwater seepage water is presently used for early wet season rice production (Ovens 2005). Hence farmers are still reluctant to diversify to non-rice crops even when a supplementary water resource exists. This may reflect the strong market demand for rice in Kampong Cham province since this province generally has a rice shortage (FAO 1999). In the Central Highlands of Vietnam, irrigation of coffee on basaltic uplands is heavily reliant on pumping groundwater supplies (D'haeze et al. 2001). Indeed over exploitation of the groundwater for irrigation is causing significant declines in water levels. Groundwater is used in the rubber plantation in Ou Reang Ov district for household use by staff, for irrigation of the rubber seedlings in the nursery and for processing latex. Some of the groundwater is acquired from groundwater seepage areas, and some by pumping from a groundwater bore. Since annual flows from groundwater seepages areas is reported to vary, it appears that the groundwater resource in Ou Reang Ov may be a limited resource, and could be prone to over exploitation. Hence it would be wise not to plan on a significant increase in irrigation from this source although there are prospects for re-allocation of it over time to high value crops.

The Ou Reang Ov Soil group appears to have the most significant limiting factors for crop production. The abundance of gravel in the profile limits soil water storage which can be a severe constraint under the erratic rainfall regimes of Cambodia. The Ou Reang Ov Soil group is a newly proposed group, not previously described in CASC, although White et al. (1997) do refer to intermediate brown gravelly soils in the mid-slopes of the basaltic terrain that are now classified as the Ou Reang Ov Soil group.

Waterlogging is the main constraint for non-rice crops on Kompong Siem, and the severity of this limiting factor will vary with groundwater levels that are higher in the main wet season and in years of above average rainfall.

Soil acidity is also a limiting factor, but the extent of limitation varies among sites. More research is needed to more reliably identify the most severely acid profiles of Labansiek soil, and to determine the extent of limitation on Ou Reang Ov soil where sub-soil acidity exists. Further the maximum depth at which sub-soil Al can cause significant loss in crop production needs to be determined. The extent and severity of Mn toxicity and possibly Mo deficiency on the acid soils needs better definition also.

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