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Land Capability Classification for Non-Rice Crops in Soils of the Sandy Terrain of Tram Kak District, Takeo Province.

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Abstract
The expansion of crop diversification in Cambodia in lowlands and in uplands could be facilitated by a process for the assessment of land capability for non-rice crops. Maize, soybean, mung bean, sesame and peanut appear to be the crops of most interest initially for land capability assessment, together with cassava and sugar cane. Land capability was determined for the above field crops in predominantly sandy terrain of Tram Kak district, Takeo province. Limiting factors for crops were identified, and land qualities rated for the soil types identified previously in a soil survey of the district. The main Soil groups on the siliceous uplands are Prey Khmer and Prateah Lang. The deep sandy Prey Khmer soils have fair capability for cropping with low soil water storage and Al toxicity being the most likely limiting factors. By contrast, the Prateah Lang soil has poor capability due to waterlogging and low soil water storage, and the Bakan soil was not recommended for non-rice crops due to waterlogging and inundation risk

Key words: Aluminium toxicity, deep sand**,** field crops, land capability, land resource assessment, limiting factors, lowlands, soil types, uplands, waterlogging.

Introduction
Upland agriculture is beginning to expand rapidly in many part of Cambodia with maize, cassava, and soybean the most commonly grown crops. Proximity to markets in Vietnam and Thailand appear to be a driving force behind the expansion which at present favours development in the border regions of Cambodia. Rising population in the more densely settled lowland rice producing areas may be another trigger for the expansion of agriculture on uplands. Expansion of upland cropping in the border areas, 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 the Cambodia Agronomic Soil Classification, and in the development of appropriate soil management technologies for soil groups (Dobermann and White, 1999: 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).

By contrast with the border areas of Cambodia where clayey soils of moderate to high fertility are encountered, much of the rest of the uplands of Cambodia is dominated by siliceous geology (Workman 1972; Seng et al. 2005). This report assesses land capability for the main soils and landscapes in Tram Kak district, Takeo province, Cambodia as a representative of sandy terrains that cover large areas of the uplands of Cambodia. The district of Tramkak comprises a range of landforms from sloping colluvial land to the seasonally inundated lowlands used for rice (Hin et al. 2005). Developing sustainable farming systems for the sandy upland landscapes of Cambodia is an urgent need and the following land capability classification will provide a basis for matching crops to soils and for identifying key soil constraints on which further research and development is needed to develop soil management technologies.

This report should be read in conjunction with three background papers which provide an overview of land capability classification and of soils in Tram Kak district:

- Assessing Land Suitability for Crop Diversification in Cambodia (Bell et al. 2006)", and
- Land Capability Classification for Non-Rice Crops in Cambodia (Bell et al. 2005), and
- Soil and Landscapes of Sandy Terrain in Tram Kak District, Takeo Province, Kingdom of Cambodia. (Hin et al. 2005).

The land qualities selected for assessing land capability for crop diversification in Cambodia are shown in Table 1. Land qualities and the definitions of ratings were based on van Gool et al. (2006). The rating of the land qualities has been modified for the soils and environment of Cambodia based on descriptions of soil properties and limiting factors in White et al. (1997), a recent soil survey (Hin et al. 2005), field trials and published information for the field crops of interest. In particular, the depth of assessment of land qualities has been limited to 50 cm, in keeping with the approach of the Fertility Capability Classification (FCC) (Sanchez et al. 2003).

Land capability in Tram Kak district, Takeo

A preliminary assessment of the land capability of soils of Takeo province was developed based on detailed studies in Tram Kak district, which lies to the west of Takeo, the province centre and also to the west of National Road No. 3. This district was chosen because it had a range of upland soils fringing the quartzite Domrey Romeal mountain on its western border in addition to the typical lowland soils of the province (Hin et al. 2005).

In the district of Tram Kak, about 66 % of the lowland area is used for paddy rice fields in the main wet season (Table 2). Some areas in the south-east of the district are flooded by the Tonle Bassac River and its tributaries during the wet season: these may grow a dry season rice crop on the receding floodwaters. Other important crops in the lowlands include soybean, mungbean, peanut, watermelon and gourd. In the lowland areas, two crops may be grown per year with field crops grown before rice in the early wet season or after rice sown in the dry season. In the upland areas, field crops such as maize, mungbean and peanut are commonly grown in the early wet season, soybean and peanut in the main wet season and watermelon is sown in the beginning of the dry season utilising residual soil water from the wet season rainfall. Recently areas of the uplands have been planted to mango and other fruit trees. The mountain areas are still under native forest. Since they contain steep land with mostly shallow sandy soils that should not be disturbed for agriculture, they are not considered further here.

Table 1. Land qualities and their rating for land capability classification for field crops in Cambodia based on van Gool et al. (2006).
Note: For specific crops the ratings below may vary.

Land qualities	**Rating**				
	1. Very high capability	2. High Capability	3. Fair capability	4. Low capability	5. Very low capability
Soil workability*	Good, fair		Poor		Very poor
Surface condition	Loose, soft, firm, self-mulching	Few stones	Crusting, common stones	Hard-setting, many stones	Abundant stones, boulders
Surface soil structure decline susceptibility	Low	Moderate	High		
pH ($CaCl_2$) (0-20 cm)	5-7.5	4.6-5	4.3-4.5	<4.3, >8.5	
pH ($CaCl_2$) (20-50 cm)	5-7.5	4.6-5	4.3-4.5	<4.3, >8.5	
Nutrient availability	Low leaching risk	Moderate leaching, moderate P retention	High leaching High P retention		
Waterlogging	Nil, very low	Low	Mod	High	Very high
Inundation	Nil, low		Mod		High
Soil water storage (mm/m)	>70	35-50	35-50	<35	
Rooting depth (cm)**	>50	35-50	25-35	15-25	<15
Water erosion risk	Low	Mod	High	Very high	Extreme
P export	Low	Mod	High		

* Assessed for tractor draft, but for animal draft the limitation may be more severe
* *Modified depth ranges to align with the FCC (White et al. 1997; Sanchez et al. 2003).

Soil types and their properties

In the rice soils map for Cambodia, Tram Kak district is shown to have Prey Khmer, Prateah Lang and Orung soils (Oberthür et al. 2000). The Orung unit of the rice soils map appears to be an error in interpretation since firstly it has not been identified by

Hin et al. (2005) in many locations where it is mapped and secondly, the map unit covers the mountains. The analysis below focuses on Prey Khmer and Prateah Lang soils and discusses those properties that will affect land capability, and in particular those that will result in a very different set of limiting factors for crops apart from lowland rice.

Table 2. Map unit descriptions - Soil-landscape map of Tram Kak district, Takeo province (Hin et al. 2005).

Mapping unit	Area (%)	Description
Tk1	3.1	High quartzite ridge of the Domrey Romeal mountain. Steeply sloping land. Shallow sandy soils (soil type not yet defined). Evergreen forest.
Tk2	5.3	Colluvial sloping uplands. Deep fine sandy soils (Prey Khmer, fine sandy phase). Upland crops.
Tk3	19.7	Gently sloping area surrounding colluvial sloping uplands. Deep sandy soil (Prey Khmer). Paddy rice fields and upland crops.
Tk4	47.2	Very gently sloping to flat plain. Shallow sandy soil with a loamy or clayey subsoil (Prateah Lang) and deeper sandy soils, usually with clay at depth (Prey Khmer). Paddy field.
Tk5	3.5	Level treeless plain with seasonal flooding as part of a regional flood plain system. Pale brown loamy to clayey surface soil with mottled subsoil (Bakan) Flooded rice.
Tk6	3.9	Low rise (possibly a sandstone bedrock high) with deep sandy soils (Prey Khmer). Upland crops.
Tk7	11.0	Seasonally flooded plain. Loamy fine sand surface soil with grey clayey subsoil. (Prateah Lang soils and minor Bakan soils). Flooded rice.
Tk8	1.7	Minor alluvial plains. (Prateah Lang soils).
Tk9	4.7	Sandy alluvial terrace next to small river. (Prey Khmer soils). Upland crop and paddy field.

The Prey Khmer soil is defined for rice production as having a sandy layer > 50 cm deep, but the deep sandy forms of the profile are unsuitable for rice unless the surrounding landform supports a shallow water table during the main wet season. Prey Khmer Soil group with deep sandy soils were encountered around the base of the Domrey Romeal mountain in Tram Kak district with sandy layers to 110 cm and more. These soils have potential for non-rice crops.

For rice, three phases of Prateah Lang are recognised: shallow A horizon, loamy sub-soil and clay sub-soil (White et al. 1997). Each of these phases is also considered to have significant differences in capability for non-rice crops. The shallow phase has a hard layer of clay or ironstone within 20 cm of the surface and is the most restrictive of the Prateah Lang phases for non-rice crops. The loamy sub-soil phase has a gradual increase in clay content with depth and no distinctive hard layer that would restrict root growth.

Substantial differences in pH were evident in the profiles (Table 3). The Prateah Lang loamy sub-soil phase has neutral to alkaline pH below 10-30 cm but can be strongly acidic in the surface layer. By contrast the clayey sub-soil phase appears to become strongly acidic in the sub-soil. Mapping has not yet defined the distribution of the most strongly acid forms of the Prey Khmer or Prateah Lang soils.

Table 3. Soil pH and exchangeable Al in soils of Tram Kak district, Takeo.

Soil Type	Depth (cm)	Phase	pH $CaCl_2$	Al (cmol/kg)	ECEC (cmol/kg)
Prateah Lang	0-8	clayey	5.2	0.01	2.07
	8-23	subsoil	4.9	0.11	1.69
	23-82	phase	4.3	0.85	2.8
	82-110		4.3	1.45	3.8
Prateah Lang	0-10	loamy	4.8	0.1	1.9
	10-40	subsoil	6.5	0	5.81
	40-70	phase	8	0	11.2
	70-110		7.9	0	11.2
	110-120		8.2	0	8.7
Prateah Lang	0-12	loamy	4.2	0.4	1.57
	12-30	subsoil	4.2	0.48	1.66
	30-70	phase	5.7	0	2.83
	70-110		8.2	0	5.6
Prey Khmer	0-6		4.3	0.14	0.45
	6-20		4.3	0.29	0.56
	20-60		4.5	0.32	0.65
	60-85		4.1	3.24	5.6
	85-100		6.4	0	10.7
Prey Khmer	0-12	fine sandy	4.5	0.28	1.83
	12-60	phase	4.2	1.57	1.81
	60-100		4.1	1.4	1.6
	100-120		4.2	1.32	1.48

Prey Khmer

In lowland rainfed ecosystems of Cambodia, Prey Khmer is a low productivity soil for rice due to low nutrient status, poor nutrient retention and excessive drainage of water (White et al. 1997). In Tram Kak district, Prey Khmer profiles were observed in lowland fields, on low rises within the seasonally flooded plain and on elevated sloping land on the footslopes of the Damrey Romeal Mountain (Hin et al. 2005). The following discussion refers mostly to the Prey Khmer soil on elevated and sloping land where it is unsuited to padi rice cultivation. These occurrences of Prey Khmer are presently not defined in the CASC due to land slope and elevation, but the profile form is consistent with the Soil group concept of Prey Khmer (White et al. 1997). Hence a modification of the Key in White et al. (1997) is needed in Question 32, to allow grouping of the deep sandy soils on sloping lands as Prey Khmer soil, or else a new Key for Upland soils needs to be created.

Both fine and medium sand forms of the Prey Khmer soil profiles were present in Tram Kak district. The fine sandy phase was most prevalent on the colluvial sloping uplands suggesting that it was a textural characteristic derived from the quartzite parent rock of the Domrey Romeal mountain. In addition, variation in depth to clay was found, ranging from 60 cm to over 110 cm depth. The depth of clay in the sub-soil layers is likely to be a significant factor in determining soil water storage and nutrient retention against leaching. The Prey Khmer soil from Site 5 contained surprisingly high levels of smectite clay and talc mineral, up to 5 % in the root zone and up to 15 % at depth. The origin of the smectite, its prevalence in other profiles of the soil, and its implications for management of the Prey Khmer soil are not well understood.

Levels of carbon and most nutrients on the Prey Khmer soil were low (Table 4). At present little is known about optimal fertiliser rates for the Prey Khmer soils for non-rice crops. However, N and K deficiencies can appear during the growing season even when reasonably high basal fertiliser rates were applied. This suggests that the soil has low inherent supply of these elements and that it is prone to losses by leaching.

Generally the Prey Khmer soil was strongly acid at the surface but the pH trend with depth varied with some profiles reaching pH ($CaCl_2$) as low as 4.1 while another profile showed increased pH ($CaCl_2$) to 6.4 below 85 cm depth (Tables 3, 4). Exchangeable Al saturation reached > 86 % of ECEC in one profile. Hence Al toxicity is likely to be a major limiting factor for production of most species on some Prey Khmer soils, and on most other profiles for sensitive species. Sanchez et al. (2003) reported that > 60 % Al saturation was toxic to most plants whereas the impact of 20-60 % Al saturation depends on species tolerance to Al. However, greater understanding is needed of the factors controlling variation in Al saturation in Prey Khmer profiles so that the locations where Al toxicity is limiting to crop growth can be more readily recognised. While the Prey Khmer soils on the sandy rise (Tk6) in the south-east of Tram Kak district had low exchangeable Al, so too did some of the profiles examined from the colluvial slopes of Damrey Romeal mountain. Besides high Al saturation in the strongly acid forms of Prey Khmer, Mn toxicity is a risk for crop production based on high DPTA extractable Mn on two sites, and leaf symptoms of Mn toxicity on mung bean and peanut at one site (Hin et al. 2005). The elevated Mn levels were in surface horizons and hence potentially treatable with lime if it were available, but high Al levels were also found in sub-soils which would make it more difficult to treat.

Prey Khmer soils may contain < 10 % clays to 60 cm depth or more. Clearly this, along with low organic matter content limits plant available soil water. On profiles that have high soluble Al, restriction in roots growth may further limit plant access to stored water. The low clay content will also limit the retention of plant available nutrients and NO_3-N, K, SO_4-S and B in particular would be prone to leaching. Hence even with fertiliser supply, maintaining an adequate pool of plant available nutrients will be difficult on Prey Khmer soils. The significant of the smectite clays and talc detected in the Prey Khmer soils by XRD analysis (Hin et al. 2005) for water and nutrient retention is not clear.

Based on typical soil properties, the land capability class for Prey Khmer soil was 3-4, depending mostly on acidity, leaching and low water storage (Tables 5, 6).

Table 4. Soil limiting factors for crop production in soils of Tram Kak district. Site numbers refer to soil surveys reported by Hin et al. (2005).

Land characteristics	**Prey Khmer** Fine sand phase (Site 6)	**Prey Khmer** Medium sand phase (Sites 5, 52)	**Prateah Lang** Clay sub-soil phase (Site 1)	**Prateah Lang** Loamy sub-soil phase (Sites 2, 4, 60)
Soil chemical properties	Low in N, P, K, S, Mg, B, Zn, and Cu from soil analysis. Low in CEC & OM	Low in N, P, K, S, Mg, B, Zn, and Cu from soil analysis. Low in CEC & OM	Low in N, P, K, S from soil analysis; Low in CEC & OM	Low in N, P, K, S, Zn, and B from soil analysis. Low in CEC & OM
pH	Acidic and poorly buffered, risk of Al toxicity from 12 cm depth. High soluble Mn in surface horizon.	Very strongly acidic and poorly buffered, risk of Al toxicity below 6 cm depth. High soluble Mn in surface horizon of Site 52 but not Site 6.	Strongly acidic in sub-soil, risk of Al toxicity below 23 cm depth. High soluble Mn in surface horizon.	Some profiles very strongly acid and poorly buffered in topsoil, risk of Al toxicity but not strongly acid in sub-soil. Indeed some profiles have alkaline sub-soil below 40 cm. High soluble Mn in surface horizon.
Texture in A and B horizon, presence of pans	Severe leaching risk for N, S, and K. Clay subsoil at 60 cm may limit loss.	Very severe leaching risk for N, S, and K. Clay subsoil at 60 cm may limit loss.	Leaching may be significant for early growth when roots are shallow. Clay subsoil may prevent loss.	Leaching may be significant for early growth when roots are shallow. Increased clay in subsoil may limit loss.
Sesquioxides and pH	Low P sorption, but potential for P toxicity and P leaching from soluble P fertilisers.	Low P sorption, potential for P toxicity and P leaching from soluble P fertilisers.	Low P sorption, but potential for P toxicity from soluble P fertilisers.	Low P sorption, but potential for P toxicity from soluble P fertilisers
Soil strength, texture class	Potential for hard setting when dry	Generally friable or loose when dry	Generally hard setting when dry	Generally hard setting when dry
Soil texture and organic matter	Weak crusting when dry	Weak crusting when dry	Potential crusting when dry and after slaking occurs.	Potential crusting when dry and after slaking occurs.
Soil texture and organic matter	Low potential for dispersion.	Low potential for dispersion.	High potential for dispersion	High potential for dispersion
Infiltration rate	Surface ponding after heavy rain	Minimal surface ponding	Moderate to severe surface ponding after heavy rain	Moderate surface ponding after heavy rain
Sub-soil	Potential for temporary	Low potential for waterlogging	Severe waterlogging, depending	Moderate to severe

permeability, perched watertable	waterlogging in heavy rain and flood. Soil is well drained	except below 60 cm, soil is well drained except in clay layers > 60 cm depth	on elevation and depth of regional watertable.	waterlogging, depending on elevation, bunding of field, texture and depth of regional watertable.
Previous land use, soil strength	Possible weak pan if under cultivation for padi rice.	No plough pan except when texture is sandy loam.	Well developed plough pan (8-23 cm), massive.	Well developed plough pan (10-40 cm), massive except where there is a deep sandy A horizon to 30 cm. Sub-soil massive and may be sodic.
Dense sub-soil, ferricrete in sub-soil, parent rock	No serious limitations to root depth except Al toxicity.	No serious limitations to root depth except Al toxicity.	Root growth is strongly restricted due to plough pan, and clay sub-soil.	Root growth is restricted due to plough pan, but roots recorded to 110 cm
Profile texture	Poor water holding capacity. Limitations would depend on subsoil water storage and root access to subsoil.	Poor water holding capacity. Limitations would depend on subsoil water storage and root access to subsoil due to Al toxicity.	Poor water holding capacity in the surface soil (effects on crop establishment and growth). For plant growth, available water holding capacity limited by the clay sub-surface and acid sub-soil	Poor water holding capacity in the surface soil (effects on crop establishment and early growth). For plant growth water holding capacity would depend on ability for roots to penetrate the subsurface plough pan.
Slope, dispersion, structure	Water erosion risk, depending on the slope.	Water erosion risk, depending on the slope and bunding around field.	Water erosion risk, dependent on the clay dispersion, slope and bunding around the field	Water erosion risk, dependent on the clay dispersion, slope and bunding around the field
Stoniness, soil strength	No problems with ease of cultivation	No problems with ease of cultivation	Requirement for moist soil to plough.	Requirement for moist soil to plough.

Table 5. Land qualities and their rating for typical properties of Prey Khmer soil (fine sand phase) based on assessments in Tram Tak district, Takeo province. Note the ratings for land qualities may vary with plant species and varieties and with the natural range of soil properties.

Land qualities	Values	Capability
Soil workability	Good, fair	Very high
Surface condition	Soft, firm	Very high
Surface soil structure decline susceptibility	Moderate	High
pH($CaCl_2$) (0-20 cm)	4.3-4.5	Fair
pH ($CaCl_2$) (20-50 cm)	**<4.3**	**Low**
Nutrient availability	High leaching, low PRI	Fair
Waterlogging	Very low	Very high
Inundation	Low	Very high
Soil water storage (mm/m)	35-50	High
Rooting depth	>50 cm	Very high
Water erosion risk	Moderate to high	High-fair
P export	High	Fair
Overall land capability	**Sub-soil acidity**	**Low**

At present, insufficient field evidence has been assembled to clearly differentiate the fine sand from the medium sand phases of Prey Khmer soil in terms of land capability differences, or to map the distribution of the most acid-forming of the Prey Khmer soils, that are expected to be most limiting. Similarly, there may be differences in texture, and depth to clay that significantly alter the water storage of the root zone, but the extent of such variation, and its geographical distribution, and its impact on land capability have not yet been defined.

Prateah Lang

Prateah Lang Soil group is the most prevalent soil in Tram Kak district, covering about 58 % of the district, and is predominantly used for lowland rice. Clay and loamy sub-soil phases were observed (White et al. 1997), but insufficient sampling was undertaken to be able to map the spatial distribution of the two phases. The loamy sub-soil phases in Tk 4 of Hin et al. (2005) were characterised by alkaline sub-soil pH (at 70 cm depth and greater) whereas Prateah Lang in Tk7 map unit did not show this pH trend. However, at this stage it is not known how repeatable those differences are.

Non-rice crops on Prateah Lang soil would generally be restricted to the early wet season. In slightly elevated positions, non-rice crops are also grown on the Prateah Lang soil in the main wet season. In addition, raised beds and raised platforms (1 m high or more) of Prateah Lang soil are commonly constructed to minimise the risk of waterlogging in the root zone of non-rice crops. However, these profiles contain mixed soil materials and are difficult to characterise.

Table 6. Land qualities and their rating for Prey Khmer Soil group (medium sand phase) based on assessments in Tram Kak district, Takeo province. Note the ratings for land qualities may vary with plant species and varieties and with the natural range of soil properties.

Land qualities	Values	Capability
Soil workability	Good, fair	Very high
Surface condition	Soft, firm	Very high
Surface soil structure decline susceptibility	Moderate	High
pH($CaCl_2$) (0-20 cm)	**4.6-5 or 4.3-4.5**	**High-fair**
pH ($CaCl_2$) (20-50 cm)	**4.6-5 or 4.3-4.5**	**High-fair**
Nutrient availability	**High leaching, low P retention**	**Fair**
Waterlogging	Nil, very low	Very high
Inundation	Nil, low	Very high
Soil water storage (mm/m)	**35-50**	**Fair**
Rooting depth	>50 cm	Very high
Water erosion risk	Moderate	High
P export	High	Fair
Overall land capability	**High leaching, low soil water storage and acidity**	**Fair**

The Prateah Lang soil contained surprisingly high levels of smectite clay, up to 15 % at depth (Hin et al. 2005). The origin of the smectite and its implications for management of the Prateah Lang soil are not well understood. Similarly, the origin and significance of increases in pH to 8.2 at > 70 cm in some profiles, and the associated sodicity, remains unclear. Dispersion of clay is a common property of the Prateah Lang soil (White et al. 1997) and may be related to its sodicity.

The risk of Al toxicity varied greatly amongst profiles of Prateah Lang soil. In some profiles, Al saturation was 26-29 % in the surface but decreased to zero below 30 cm. In another profile belonging to the clay sub-soil phase, Al saturation below 23 cm exceeded 31 % but the surface layers had negligible exchangeable Al. Finally, other profiles of the Prateah Lang soil had negligible exchangeable Al throughout the profile. Hence the levels of Al saturation are not high enough to impair the growth of all species but may be toxic to sensitive species. Seng et al. (2006) found that lime increased the growth of upland rice on an acid Prateah Lang (pH $CaCl_2$ 4.7) from Syay Rieng, however, this soil contained 80 % Al saturation, much higher than levels found in Tram Kak district so far.

All the profiles analysed in the present study had low N, P, K and S levels. As noted above, there is limited experimental evidence on which to base fertiliser recommendations for non-rice crops on Prateah Lang soils. A preliminary set of recommendations derived from several sources is reported in Seng et al. (2005). However, even with these recommended fertiliser rates, we observed low yields of crops on Prateah Lang soils (Table 10), suggesting that other major limiting factors such as water logging and drought were more severe limiting factors. Hence, while yields remain very low for non-rice crops, due to non-nutritional constraints, there is little advantage in applying the rates of fertilisers suggested by Seng et al. (2005) for Prateah Lang soils.

Possibly the most acute limiting factors in Prateah Lang soils for non-rice crops relate to plant-available water storage and root depth. In the clay sub-soil phase and where a dense plough pan has developed in padi fields, water logging of the surface horizon occurs readily after rainfall and the soil does not drain as freely as Prey Khmer. When plough pans or clay sub-soil limit root depth, low plant-available water storage will by a major limiting factor resulting in a high drought risk.

Overall, the land capability class for Prateah Lang soil was 3-4, depending mostly on waterlogging, risk of inundation, hardsetting of soils, and low water storage (Tables 7,8). Very strong acidity may be a limiting factor on some profiles. Hence Prateah Lang profiles have a range of significant limiting factors that collectively are difficult to overcome.

At present, insufficient field evidence has been assembled to clearly differentiate the clayey from the loamy phases of Prateah Lang soil in terms of land capability differences, or to map their distribution. Similarly, there may be differences in texture, and depth to clay that may significantly alter the water storage of the root zone, but the extent of such variation, and its geographical distribution, and its impact on land capability have not yet been defined.

Table 7. Land qualities and their rating for Prateah Lang (clay sub-soil phase) based on assessments in Tram Kak district, Takeo province. Note the ratings for land qualities may vary with plant species and varieties and with the natural range of soil properties.

Land qualities	**Values**	**Capability**
Soil workability	Good-poor	Fair
Surface condition	**Hardsetting**	**Low**
Surface soil structure decline susceptibility	High	Fair
pH($CaCl_2$) (0-10 cm)	4.6-5	High
pH ($CaCl_2$) (50-80 cm)	4.3-4.5	Fair
Nutrient availability	Moderate leaching	High
P retention	Moderate	Fair
Rooting depth	>50 cm	Very high
Waterlogging	**High**	**Low**
Inundation	**Moderate- High**	**Fair-Low**
Soil water storage	Very low	Fair
Water erosion risk	Low -Moderate	High
P export	Moderate	High
Overall land capability	**Hardsetting, waterlogging and inundation**	**Low**

Table 8. Land qualities and their rating for Prateah Lang (loamy sub-soil phase) based on assessments in Tram Tak district, Takeo province. Note the ratings for land qualities may vary with plant species and varieties and with the natural range of soil properties.

Land qualities	Values	Capability
Soil workability	Good- poor	Very high-fair
Surface condition	**Hardsetting**	**Low**
Surface soil structure decline susceptibility	High	Fair
pH($CaCl_2$) (0-20 cm)	**4.6-5 to <4.3**	**High to low**
pH ($CaCl_2$) (20-50 cm)	5-8 to 4.3-4.5	Very high to fair
Nutrient availability	Moderate leaching	High
Waterlogging	**Moderate to high**	**Fair to low**
Inundation	Moderate	High
Soil water storage		**Low**
Rooting depth (cm)	>50 cm	Very high
Water erosion risk	Low	Very high
P export	Low to moderate	Very high to high
Overall land capability	**Hardsetting, waterlogging, acidity and low soil water storage**	**Low**

Bakan

Bakan Soil group occurs on treeless plains subject to seasonal flooding. The risk of flooding, or inundation is generally too high on this soil for non-rice crops even in the early wet season (White et al. 1997) unless raised beds or platforms approximately 1 m high are constructed to prevent waterlogging (Tables 9, 10). However, the dispersion of clays that occurs on Bakan soils may limit the effectiveness of raised beds and result in high costs of their maintenance. Bakan soils, like the Prateah Lang and Prey Khmer soils, has low levels of carbon and extractable nutrients. While strongly acid, the exchangeable Al level and extractable Mn level on this soil were too low to be harmful to crops.

General Discussion

A summary of the participants ranking of the soils for different crops is shown in Tables 11-13. Based on trials conducted on farmers' fields with fertiliser supplied at rates considered to be adequate and with attention to pest and weed control, crop performance was ranked for eight soils in Cambodia (Table 11). The relative yield of all crops on Prey Khmer soil were moderate, with the exception of mung bean which gave highest yields on this soil. By contrast, relative crop yields were consistently low on Prateah Lang soils.

In Tram Kak district, farmers and agronomy technicians ranked the Prateah Lang soil lower in land capability than Prey Khmer. Depending on the crop species the land capability raking for Prateah Lang soils was high to low for non-rice crops (Table 13). They ranked peanut as most suited to this soil, and mung bean least suited which varies from the relative performance in on-farm trials (Table 11). On the deep sandy Prey Khmer soils, all crops were rated as high to very high in suitability. Overall in Tram Kak district peanut was consistently rated as very highly suitable on all soils, whereas other crops had high to fair suitability. Mung bean suitability varied from very high to low, suggesting that choice of soil could be more important for the productivity of this crop than others. There are several limitation in using the farmers' and agronomy technicians' ranking of soils for crop performance. Firstly, the farmers and technicians were only asked to rank the two soils against one another whereas the land capability classification and the on-farm trials (Table 11) were based on a wider assessment of soils across Cambodia. Also as farmers tend to use little fertiliser on field crops whereas the on-farm trials use an optimal fertiliser rate, this difference may have influenced the ranking. Finally it was clear how much weight farmers and technicians placed on crop performance in the current season (main wet season of 2005) rather than performance generalised over a number of seasons and sites.

Table 9. Limiting factors for crop production Bakan Soil group in the early wet season.

Land characteristics	Bakan Soil
Soil chemical properties	Low N, P, K, S, Zn and B from soil analysis. Low CEC and OM. Rice on this soil responds well to fertilizer applications
pH	Acidic but only moderate to low Al and Mn toxicity risk
Texture in A and B horizon, presence of pans	Low nutrient leaching risk after soil wets up but moderate risk through cracks when soil is dry.
Sesquioxides and pH	Low to moderate P sorption
Soil strength, texture class	Hard setting when dry.
Soil texture and organic matter	Severe crusting, highly dispersive soil.
Infiltration rate	Major surface ponding problem after rain.
Sub-soil permeability, perched watertable	Major waterlogging problem from low lying elevation.
Previous land use, soil strength	Plough pan at 15 to 25 cm in padi fields.
Dense sub-soil, ferricrete in sub-soil, parent rock	Low water holding due to plough pan that restricts root depth.
Profile texture	High water holding capacity if roots able to penetrate through plough pan.
Slope, dispersion, structure	Low water erosion risk but risk of selective clay loss due to dispersion. Difficulty with creating raised beds or drains due to dispersion.
Stoniness, soil strength	Low ease of cultivation, ploughing effectiveness decreased by wet or dry conditions

Table 10. Land qualities and their rating for Bakan Soil group based on assessments in Tram Tak district, Takeo province. Note the ratings for land qualities may vary with plant species and varieties and with the natural range of soil properties.

Land qualities	Values	Capability
Soil workability	Poor	Fair
Surface condition	Hardsetting	Low
Surface soil structure decline susceptibility	High	Fair
pH($CaCl_2$) (0-20 cm)	4.3-4.5	Fair
pH ($CaCl_2$) (20-50 cm)	>5 to 4.3-4.5	Very high to fair
Nutrient availability	Low leaching risk, moderate P retention	Very high to fair
Waterlogging	**High, very high**	**Very low**
Inundation	**High, very high**	**Very low**
Soil water storage (mm/m)	High, moderate	Very high
Rooting depth (cm)	30-50	High
Water erosion risk	Low	Very high
P export	Moderate	High
Overall land capability	**Waterlogging and inundation**	**Very low**

The rating of land qualities presumes that no technology has been applied to alleviate or overcome the limitation. Clearly there are often opportunities to do so. Waterlogging, for example can be alleviated by raised beds and shallow drains: when this is done, the severity of the limitation is decreased, and the land class increased accordingly. Similarly, with erosion control measures implemented, the capability of land for sloping soil will be upgraded. Hence land qualities are not fixed properties of soils.

Table 11. Ranking of yield performance of crops on soils. Ranks were determined as follows: firstly relative yield for each crop on each soil was calculated as a % high input yield as defined in Table 12; secondly, relative yields across soils were ranked from 1 (highest) to 8 (lowest) for each crop; finally, ranks were summed across crop species to determine mean soil ranking.

Soil group, phase	**Soil rank**	Maize	Mung bean	Soybean	Peanut	Sesame
Kompong Siem	**2.3**	2	2	3	2	-
Kien Svay	**2.4**	2	5	2	1	2
Labansiek, non-petroferric	**3**	1	7	1	3	-
Toul Samrong	**3.8**	4	2	6	3	-
Prey Khmer	**3.8**	6	1	5	5	2
Ou Reang Ov	**4.3**	4	2	4	7	-
Prateah Lang	**5.8**	8	-	6	8	1
Kompong Siem, calcareous	**6.3**	6	6	8	5	-

Table 12. High input yields and average farmers' yields (t/ha) of various crops. Average national yields are reported for 2002, and the on-farms trials in Tram Kak district for 2004.

	Maize	Mung bean	Peanut[B]	Sesame	Soybean
High input [A]	6-9	2-2.7	2-3	1.2-1.5	1.5-2.5
Average Cambodia yield [C]	2.8	0.6	0.8	0.5	0.9
Average on-farm trials [D]	1.0	0.6	1.5	0.5	0.6

[A] Source: Sys et al. (1993) except for mung bean values from Ahn and Shanmugasundram (1989).
[B] Unshelled pods
[C] Data from Agricultural Statistics, MAFF (2002-2003).
[D] From ACIAR Report of 2004 On-farm Trials

Table 13. Land capability for field crops in Tram Kak District, Takeo Province. Result from field workshop of farmers and agronomy technician to consider sandy soils of Tram Kak district on 18 Oct. 2005.

Rating scale: 1: Very high, 2 : High, 3: Fair, 4: Low, 5: Very low

Crops	Prey Khmer (Sites 51& 5)	Prey Khmer (Site 52 & 6)	Prateah Lang (Site 60)
Peanut	1	1	2
Soybean	1	2	3
Maize	2	2	3
Seasame	2	2	3
Mung bean	2	1	4

The differences in rainfall distribution between the early wet and main wet seasons, and the reliance on stored soil water or irrigation in the dry season will interact with several land qualities. Land qualities such as water erosion risk and leaching may need to be rated for a particular soil separately for the early wet season, main wet season and dry season.

Species and cultivar differences may also alter the apparent ranking of land capability (Bell et al. 2005). For many limiting factors there will be genotypic variation in tolerance, at species and variety levels, which if identified and present in adapted varieties can be exploited to decrease the severity of the stress. Tolerance of Al toxicity is a case where a severe limitation in acid soils could be alleviated to increase overall land capability on both soils.

The ratings of capability above for each soil (Tables 5-8 and 9) were based on typical soil properties (Tables 3, 4 and 8- see also Hin et al. 2005). However, there is a natural range of variation in properties for all soils. In the present cases, the typical properties of soils were derived from White et al. (1997), supplemented by a relatively small number of field profile observations and fewer sets of detailed chemical analysis in the Tram Kak district (see Hin et al. 2005). Hence there is some uncertainty about the modal soil properties for each soil type and the natural range of variation. Secondly, the overall rating of capability cannot be expected to apply to all fields of a particular soil. A capability rating for a particular field can be assessed by using Table 1 and assessing each land quality for the site.

The land capability classification is a bio-physical assessment, and lacks the critical socio-economic inputs that also influence crop selection for particular soils. Hence the land capability assessment in the current project will be combined with an assessment of the land use pressure and availability of markets for crops to determine overall land suitability. The output of this assessment is a ranking of crop options at a commune- to provincial-scale according to both biophysical and socio-economic constraints. The products of the research will be maps showing land suitability for particular crops in the study areas and a report describing for each of the main soil groups, their major constraints for crop production, their capability ranking, environmental degradation hazards and overall suitability for different crop options. The project will also describe a methodology for land suitability assessment that will be applicable to other provinces of Cambodia where upland and lowland crop diversification shows promise.

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