Assessing Land Suitability for Crop Diversification in Cambodia

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Abstract

Opportunities for poverty alleviation in Cambodian agriculture are emerging in diversification from traditional wet season lowland rice (*Oryza sativa*) production to double-cropped, rice-based production systems and to upland cropping. The potential for double-cropping rice-based production will depend on understanding land capability for a range of non-rice crops in the lowlands of Cambodia. In addition, there are relatively large areas of land available for the expansion of upland cropping especially since the establishment of improved security and roads in rural Cambodia. The process of crop diversification in Cambodia could be facilitated by assessment of land suitability for field crops in lowlands and in uplands.

Land capability needs to be assessed for a range of field crops with realistic prospects for specific agro-ecosystems in Cambodia. Maize, soybean, mung bean, sesame and peanut appear to be the food crops of most interest initially, together with cassava and sugar cane. Usually soil constraints are assessed for land capability classification from published land resource studies. Such information is generally unavailable for uplands in Cambodia at an appropriate scale. Hence further land resource assessment in the upland areas is needed to undertake a more comprehensive land suitability assessment. Whilst a soil map for lowland rice has been published, soil constraints for non-rice crops have not been assessed for these soils.

Land suitability is currently being determined for selected field crops that are relevant to landscapes in the study areas in Takeo, Kampong Cham and Battambang provinces. Toposequences in these provinces will be surveyed to characterise soils based on a variety of parent materials. In the lowlands, the focus will be on the identification of land suitability for double cropping (e.g. legume-rice, rice-legume) in rice-based systems. In the uplands, the focus will be on rainfed field crops that can be introduced into or expanded in Cambodia. The highest priority will be assigned to those crops that are already well established in Cambodia, including maize, soybean, and mung bean. Socio-economic input to land suitability assessment will be in the form of a GIS approach that will adjust land capability values spatially according to three key drivers of crop diversification: market access factors, population pressure, and poverty indicators.

Key words: Aluminium toxicity, basalt, field crops, land capability, land resource assessment, land suitability, limiting factors, lowlands, soil types, uplands.

Introduction

Production of all crops in Cambodia is currently dwarfed by that of wet season lowland rainfed rice (Nesbitt, 1997). The main non-rice field crops in Cambodia are maize, mung bean, soybean, cassava and sugar cane (Fig. 1). Rubber is also an important crop in eastern Cambodia. Table 1 summarises the range of other field crop options apart from rice, currently grown in Cambodia. Presumably all these crops are suitable for growing in Cambodia, but not all are equally suited, and not necessarily in the same place. Diversification of agriculture in Cambodia will largely involve the development of one or more of these existing crops, but may also involve the development of animal-based industries, including aquaculture. A key knowledge gap for crop diversification in Cambodia is to identify those conditions that suit each crop and the most probable locations of such conditions. The rate and scale of diversification are likely to depend, in addition to bio-physical factors, on a number of market factors including: a) whether export opportunities for rice can be developed by increased production of higher quality grain; b) export opportunities that emerge for other crops; c) development of local markets for non-rice field crops, vegetables and tree crops, and; d) the demand for increased household income nation-wide. Diversification can be achieved by intensification of production through double- or triple-cropping of lowland soils that currently grow only the wet season rice. This can involve early wet season production of crops such as mung beans, peanut or sesame. In addition, dry season cropping with rice, vegetables or short duration crops is an option for lowland soils if adequate irrigation or stored water is available. Most of the rainfed lowlands are underlain by relatively shallow perched aquifers that are considered to have prospects for exploitation as a resource for supplementary irrigation during the early wet season and dry season, using small scale technologies based on pumps and tubewells (Hunter et al. 1998). However, the areas with high water yields and high annual recharge rates may be more restricted than suggested by earlier authors (Briese 1996; Kokusai Kogyo 2002; Rickman et al. 2004; Ovens 2005). There has been little attempt to systematically assess land suitability for diversification on the lowlands or to define and ground truth the soil and hydrological requirements for non-rice crops in the diversified rice-based cropping systems.

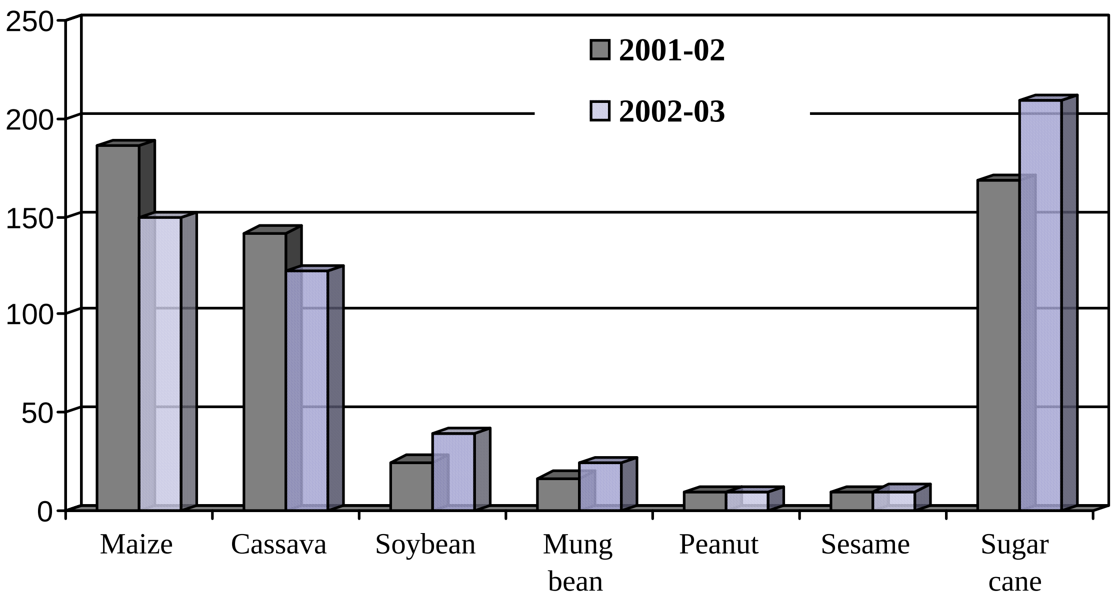

Figure 1. Production (x 1000 tonnes) of field crops in Cambodia in 2001-2 and 2002-3. MAFF Statistics.

Table 1 Current non-rice crop production areas in Cambodia, factors affecting future development of these crops and priority for land suitability assessment.

Crop	Area '000ha[A]	Main production area-Province[A,B]	Soils and landscapes[D]	Markets[B,D,E]	Notes[D,E]	Priority[E]
Maize	72	Battambang Thai border districts – wet season Kandal- early wet and dry season	Unknown, fertile uplands Fertile low river terraces	Thailand Export grain and local fresh cob	Decreased production by 35 % since 1967; International buyers reported to have markets for increased production	High
Rubber	60[B]	Kampong Cham	Upland red basaltic soils	Export	Potential for 300,000 ha (FAO, 1994)	Low
Mungbean	35	Battambang, Kampong Cham, Kandal, Banteay Meanchey	Unknown, fertile uplands Black clay, red basaltic, young alluvial high fields	Local/ export	Decreased production since 1967 by 20 %. Potential for pre- and post-rice. Existing CARDI and ACIAR research.	High
Soybean	29	Kampong Cham Battambang	Black clay, red basaltic, fertile low river terraces after flood Unknown, fertile uplands	Local/ export to Vietnam and Thailand	Increased production since 1993 by 50 %. Previous CARDI research.	High
Cassava	19	Kampong Cham, Siem Reap, Kampong Speu, Battambang, Kampong Thom	Upland red basaltic and sandy soils	Flour export to Vietnam	Increased production since 1967	Medium
Sesame	18	Kampong Cham, Kratie, Prey Veng	Black clay and red basaltic, alluvial (Deepwater rice areas post-rice)	Export/ local		Medium
Tobacco	18[B,F]	Kampong Cham	Fertile low river levee banks after flood	Local cigarette manufacture		Low
Peanut	12	Battambang, Kampong Cham, Kampot	Black clays and sandy upland soils	Snack foods/ local	23,000 ha planted in 1967	Medium
Sweet potato	10/ 50[C,F]	Kampong Cham, Kampot, Takeo	Varied			
Sugar cane	9	Kampong Cham, Kandal, Kratie, Kampot	Black clay Fertile river levee Sandy upland soils	Vietnam/ local		Medium
Oil palm	5?[B]	Sihanouk Ville	Sandy coastal terraces	Cooking oil	Single large plantation run by investors	Low
Jute/ kenaf	2[B,F]	Battambang		Local processing		

A. Data from Agricultural Statistics, MAFF. (2002-2003).
B. Data from Men et al. (2001).
C. Small plots in home gardens are ignored in this assessment
D. Sources: Dr Seng Vang (personal communication), Nesbitt (1997), Hunter et al. (1998)
E. Workshop held at CARDI, 27 Sept 2001
F. 1993 area planted- Nesbitt (1997), quoting Govt Statistics

Uplands and high fields with marginal water supply for rice can also be considered for crop diversification. Based on Landsat imagery of 1993, 1.25 million ha of land is potentially available for crops other than rice, and another 2.3 million ha of shrublands may also have potential (World Bank/ UNDP/ FAO 1996). Since only about 0.2 million ha is currently used for upland crops (Table 1), this preliminary assessment suggests the potential for a 6-20 fold increase of upland cropping, agroforestry and grazing. Security considerations have until recently limited the utilisation of these areas. Now that those concerns have eased, and the standard of roads have improved, population pressure and market access factors are likely to be key drivers of the expansion of upland cropping as they were in northern and north-eastern Thailand in the 1960-70s (Chiang Mai University/ Chulalongkorn Social Research Unit 1983; Ruaysoongnern and Suphanchaimart 2001). However, the land suitability of these areas has not been assessed, apart from an estimate of the area that could be suited to rubber production (FAO 1999).

Land use is dependent on climate. Rainfall in Cambodia varies markedly from less than 1100 mm, in low lying south-eastern provinces like Prey Veng, to 4000 mm on the south coast. Most of the lowlands and uplands of interest for crop diversification in Cambodia are reported to have mean annual rainfall from 1250 to 2000 mm (Nesbitt 1997), but recent analysis of these rainfall records suggest that the rainfall isohyets previously reported may over report annual rainfall in many locations by 50-700 mm (Vance and Bell 2004). Regional variations in rainfall will have a significant bearing on which crops are suitable for each area. However, long term climatic data is relatively sparse in Cambodia (Nesbitt 1997) and would have to be supplemented where possible with local knowledge. Some gene-ecological classification of tree growing environments has been undertaken by Dummer (2003), and could be calibrated for field crops.

Land Capability Classification for Field Crops in Cambodia

Land suitability assessment is the process of determining the best land use options for particular parcels of land (FAO 1976; FAO 1984). This process has three main data inputs:

- assessment of soil constraints;
- determination of crop requirements, and;
- determination of the economics of the different options (Rossiter and van Wambeke, 1991)

The first two stages of land suitability assessment, dealing with the bio-physical resources, are known as land capability classification (Fig. 2). A more complete of set of definitions of land evaluation terminology is provided in an Appendix to the present Proceedings.

Most formal modern land suitability classifications are based on the semi-quantitative FAO approach which generates a land suitability rating on a 5-point scale for each of the alternative land uses under consideration for a particular parcel of land (FAO 1996, 1998). Land is rated as unsuited, moderately suited and highly suited. Soil constraints for a particular crop option are usually assessed from information in a soil or land resource survey. However, there is limited soil survey coverage of the agricultural soils of Cambodia with the exception of soils for lowland rice (White et al. 1997). Hence it is essential that additional field surveying be undertaken, particularly in the upland areas, to establish a framework for landscape and soil classification in Cambodia. The soil-landscape survey is also needed for the identification of soil constraints, and development of a landscape model from which broader-scale mapping of land capability and suitability can be made.

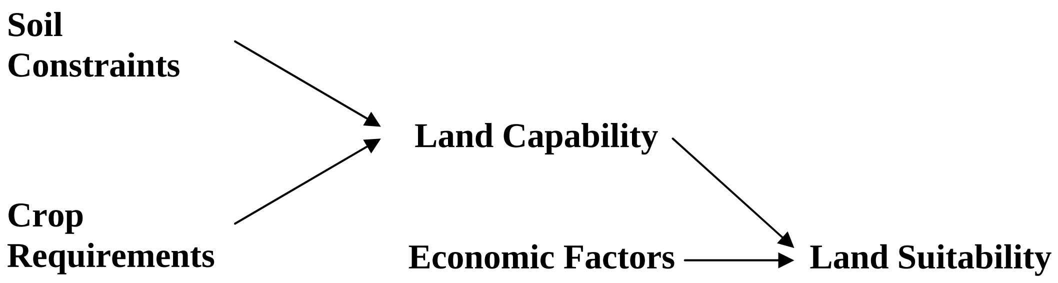

Figure 2. A schema for assessing land capability and suitability. See also the Appendix for definitions of land capability and suitability.

In the empirical land suitability approach, expert knowledge is also used in the assessment and ranking of soil constraints. This input will be essential in Cambodia because of the relative paucity of land resource information. However, in addition to seeking the expert opinion of experienced land resource personnel and agronomists, it is possible to elicit from farmers their knowledge of soil constraints and their severity for different crops using interview techniques tested previously (e.g. Ieng et al. 2002). Messing and Hoang Fagerstrom (2001) also found that farmers' knowledge of soil constraints, elicited through semi-structured interviews was reliable in defining limiting biophysical land properties in a study catchment in northern China. Probabilistic modelling using EXPECTOR has the capacity to integrate empirically derived data with expert opinion (Cook et al. 1996). Hence, the expected performance of a crop on a parcel of land can be modified based on the farmers' (and other experts') local knowledge and experience.

Land capability classification is a systematic process for organising land resource information for the purpose of assessing land use potential. It aims to evaluate options for land use, and to rank them according to their potential for profitable and sustainable production (Fig. 2; Table 2). By convention, the lowest ranking land is not recommended for the assessed use. The highest ranked land has no significant limitations for the proposed use. One or more intermediate classes are used to categorise land with slight to severe limitations for the proposed use. The limitations may relate to productivity of the land use proposed or to the risk of land degradation when used for that purpose.

The basis of land capability classification is the selection of land qualities, which are complex land attributes having a distinctive influence on land capability for use. The rating of these land qualities will clearly vary from crop to crop according to their tolerances of different limiting factors. In addition, soil attributes that impose limitations on land development or those that influence land degradation hazards are assessed, so that both productivity and sustainability of proposed land uses are considered in the rating of land capability.

Table 2. Land capability classes for given land use types (Source: van Gool et al. 2004).

Capability class	*General description*
1 Very high	Very few physical limitations present and easily overcome. Risk of land degradation is negligible.*****
2 High	Minor physical limitations affecting either productive land use and/or risk of degradation. Limitations overcome by careful planning.
3** Fair	Moderate physical limitations significantly affecting productive land use and/or risk of degradation. Careful planning and conservation measures required.*******
4 Low	High degree of physical limitation not easily overcome by standard development techniques and/or resulting in high risk of degradation. Extensive conservation measures required.*******
5 Very low	Severe limitations. Use is usually prohibitive in terms of development costs or the associated risk of degradation.

***** Experience has shown that very few land use developments have no negative effect expressed as land degradation, hence capability class 1 will not occur for many land uses employing broadly accepted management and development techniques.

** Class 3 is often the largest category of land. It is often highly productive agricultural land which requires improved land management to avoid slowly increasing effects of land degradation.

***** Conservation or planning requirements likely to involve ongoing management.

The first step in selecting land qualities is to determine the likely land use options. Land use types have their own requirements, so that the same parcel of land will be assigned a different capability for different uses. Such differences are the basis of choice by decision-makers or managers about land use. In this paper, we will focus on land capability and suitability for field crops. The principles discussed are applicable to other potential land uses for Cambodia including paddy rice, fruit trees, pastures, rubber, trees, and vegetables.

Limiting factors

Limiting factors comprise any crop, soil or landscape constraint that limits a proposed use (see also Appendix 1). Most emphasis is placed on those limiting factors that are difficult to modify. By contrast, nutrient supply in the soil is usually not assessed as a limiting factor since in principle fertiliser use allows such limitations to be economically corrected. However, soil properties such as acidity may well affect the availability of nutrients whether supplied by fertiliser or from soil reserves, and these soil properties can be assessed as land qualities.

Since limiting factors will vary within landscapes, the usual starting point for identifying limiting factors is an analysis of the land resources and the properties of the soils within landscapes. Soil survey and mapping produces a primary data set for this purpose since it indicates the range of soils that are encountered, and their relative importance. The assessment of land capability would normally concentrate on the most common soils. From soil surveys, the profile characteristics can be interpreted to assess a range of the limiting factors that relate to land preparation, crop establishment, and crop growth (Tables 2 and 3). Indeed the default source of information for limiting factors is the soil survey and the typical properties described for each soil. Soil chemical and physical (and biological) properties should be determined in addition, where possible, for a number of land qualities, but in their absence proxy values are used from soil survey information. For example, P retention could be determined as a relatively definitive value from a soil chemical test, but where this information is unavailable, sesquioxide levels, clay content, and pH of the soils can be interpreted to provide an approximate understanding of relative P retention (van Gool et al. 2004). In addition, the opinions of farmers who cultivate the soils, and scientists and advisers who have local knowledge of the potential and behaviour of the soils can be very valuable in identifying and rating limiting factors. Finally, it is important to calibrate and validate the interpretation of limiting factors by trials designed to test the impact of the limiting factors on crop growth, and land sustainability (Fig. 3).

Table 3. Land qualities for assessing land capability for non-rice field crops in Cambodia. Land qualities are related primarily to productivity potential (P), or degradation hazards (D, based on van Gool et al. (2004). Land characteristics are defined as those attributes that are measurable and can be used to assess land qualities.

Land quality	Assessed for	Land characteristics	Primary source of data
pH (0-10 cm and 50-80 cm)	P	pH, exchangeable Al	Soil type, soil analysis
Nutrient availability (NPKSMgZnCuB Mo)	P	Soil chemical properties, texture in A and B horizon, presence of pans	Soil type, pot trials, field trials, rice fertilizer recommendations, soil analysis
Surface condition	P	Soil structure, organic matter level, % gravel	Soil type, Soil properties in A horizon
Surface soil structure decline susceptibility	P	Soil strength, texture class and organic matter	Soil type, texture analysis
Sub-surface compaction susceptibility	P	Soil strength, texture class and organic matter	Soil type, texture analysis
Rooting depth	P	Dense sub-soil, ferricrete in sub-soil, bedrock, previous land use, soil strength, chemical constraints	Soil profile, pans, soil depth, prior land use, soil analysis
Waterlogging	P	Sub-soil permeability, perched watertable	Slope, landform, soil profile texture, pans
Inundation	P	Infiltration rate, slope, elevation	Topography, texture B horizon, dispersion
Soil water storage	P	Profile texture, soil water measurements	Soil profile type, soil water monitoring
Soil workability	P	Stoniness, soil strength, ferricrete in sub-soil	Soil profile
Water erosion risk	D	Slope, dispersion, structure	Slope, dispersion, structure
P export	D	Texture, sesquioxides and pH	Soil type

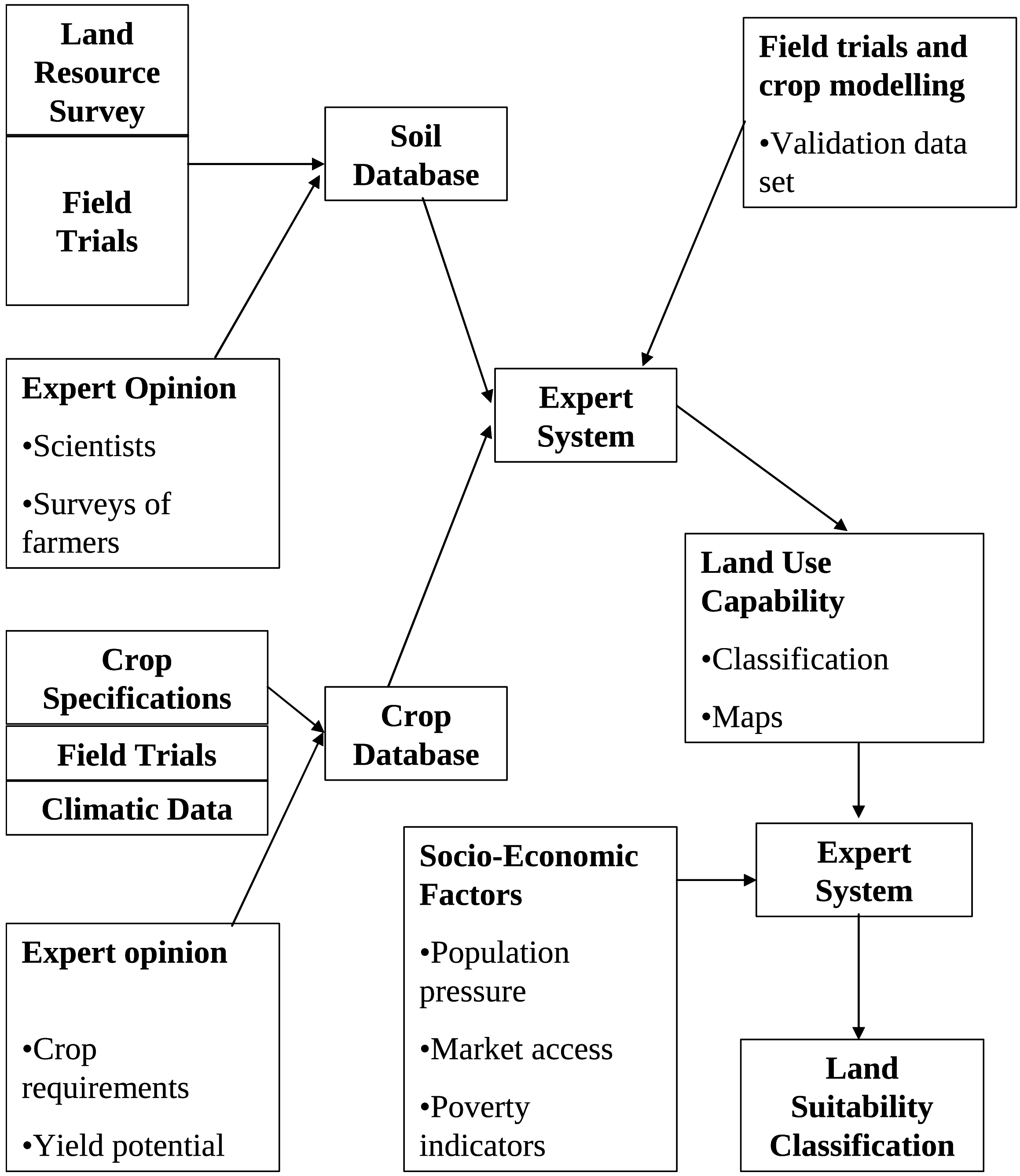

Figure 3. Schema for the information used to assess land capability and suitability for crop diversification in Cambodia.

Limiting factors will vary with land use and crop species. Hence the requirements of a particular crop need to be determined in order to rate the limiting factors according to degree of severity. For example, waterlogging is not a constraint for paddy rice, but it is to varying degrees for other field crops.

In a current project, we are assessing land capability for food crops with potential for expanded production in the lowlands and uplands of Cambodia. Maize and soybean have good market prospects as components of feeds used in the expanding livestock industries of Thailand and Vietnam. They are already produced in significant areas of

Cambodia (Table 1; Fig. 1). Mung bean, peanut and sesame are relatively common field crops and were also included in the assessment. Other important field crops not considered in the present study include: upland rice, cassava, and sugar cane. For most crop species of interest to this project (maize, mung bean, peanut, sesame and soybean), their requirements are reported in Sys et al. (1993) and in EcoCrop (2000). However, it is important to note that cultivar differences exist in tolerance of limiting factors such as waterlogging, alkalinity and Al toxicity. Hence the ratings for individual species should be treated with caution since for different combinations of cultivars different rankings of the species may be made.

The primary current source of information on limiting factors for Cambodian soils is White et al. (1997). Whilst it is limited to rice soils, and is focussed on lowland environments, it remains the most comprehensive analysis of soils information in Cambodia, and because it is an agronomic soils classification it focuses on limiting factors. Some of the limiting factors for rice will be common to those for field crops. Others such as waterlogging, soil pH or rooting depth could have very different interpretations. In particular the sub-soil properties are commonly not assessed when considering rice cultivation except to the extent that they affect percolation rates of water, but these could impose significant constraints for the production of other field crops. Other sources of information include the soils surveys undertaken in a present project in Ou Reang Ov district, Kampong Cham; Tram Kak district, Takeo; and Banan district, Battambang (ACIAR Project LWR1/2001/051), special purpose surveys conducted in Cambodia (e.g. Stung Chinit soil survey- Sanyo Corporation 1971) and surveys of the Agricultural Soils Unit of Ministry of Agriculture, Fisheries and Forestry conducted in conjunction with the Mekong River Commission (MRC, 2002).

Land use requirements

Land use requirements refer to the pre-requisites for the proposed land use. In this case, we consider requirements for growth of non-rice field crops, determined by climatic requirements or landscape/ soil factors (Sys et al. 1993). In Cambodia, the main climatic factors likely to limit crop production are those related to rainfall, either drought or excessive rainfall depending on the time of the year (Table 4).

Low temperature is rarely a limiting factor for crop production in Cambodia, but high temperatures, which can exceed 38 ^{o}C in the later part of the dry season (March-April) (Pheav et al. 2003), may be. While high temperature during the end of the dry season may be a limiting factor for crop production (Ahn and Shanmugasundram 1989; Sys et al. 1993; Ecocrop 2000)., it is not clear how much it varies spatially within most parts of Cambodia considered for field crops. Nevertheless, variability from year to year, and even from place to place in a particular year may affect crop performance especially when high temperature episodes coincide with sensitive phases of crop growth like flowering or emergence. Hence heat tolerance may well be a character that needs to be introduced to germplasm of field crops released for use in the dry and early wet seasons in Cambodia, but it need not be assessed for parcels of land in the land capability assessment process.

Land capability involves a rating of likely yield of crops relative to climatic potential. High input crop yields usually outstrip averages achieved on farmers' fields (Table 5). Averages across Cambodia are comparable to international averages for farmers' production, with the exception of maize. The maize yields of Cambodia are inflated by the very high yields currently achieved in the western border districts of Battambang. On-farm trial yields elsewhere in Cambodia in 2003 did not achieve a high potential yield. In addition, no success was obtained with planting sesame in June or July. However, since all 2003 early wet season trials were sown in June- July, unlike farmer practice (which is to plant on the first or second substantial rains in March- early April) caution should be exercised in reading too much into the 2003 results for sesame.

Table 4. Effect of growing season rainfall (mm) on performance of field crops. Source: Sys et al. (1993) unless otherwise stated. Severe inhibition is equivalent to a 40-60 % decrease in yield; prohibitive indicates > 60 % decrease in yield. In addition, total growing season rainfall was estimated for 2002 from Takeo and Kampong Cham records.

	Maize	Mung bean[A,B]	Peanut	Sesame	Soybean
Optimum	500-1200	750-875	400-1100	350-800	500-1100[A]
Severe Inhibition	300-400	200-400	200-300	200-350	180-250
Prohibitive	<300	<200	<200	<200	<180
2002 Growing season estimate [C]	382-504	319-359	424-498	402	415-477

[A] EcoCrop (2000)
[B] Ahn and Shanmugasundram (1989).
[C] Calculated from 2002 records of rainfall at Takeo and Kampong Cham for the following sowing dates: sesame- 1 April; maize, mung bean, peanut and soybean- 20 April

Previous trials by CIAP and CARDI on mung bean and soybean have been completed in all seasons. Average yields across all years and seasons are reported in Table 5. The maximum yields reported for mung bean and soybean were 2.8 and 4 t/ha, respectively, well above the average values.

The preference of most field crops is for fertile, well drained loamy soils. Hence, the differences among crop species are expressed in their tolerance of non-ideal edaphic conditions. These are summarised in Table 6. Whilst these generalisations are useful, they should be treated with some caution. Firstly, different literature sources provide different tolerance limits for a particular species. This may be related to cultivar variation that exists for many of these tolerances so that species rankings can change depending on the cultivars grown. The adaption of cultivars grown in Cambodia to adverse soil properties is still not well known so generalised estimates are drawn from international literature for the time being.

Aluminium toxicity is a common constraint for non-rice crops on acid upland soils in SE Asia (Dierolf et al. 2001). The most Al tolerant of the crops grown in Cambodia are cassava, cowpea, upland rice and rubber (Dierolf et al. 2001). Amongst the major field crops, peanut has low-moderate Al tolerance, whereas mung bean, maize and soybean are generally low in Al tolerance. However, all these species exhibit genotypic variation in Al toxicity tolerance so that the species ranking depends on tolerances of the specific varieties under consideration. Moreover, it is feasible to overcome a severe limitation due to Al toxicity by selecting more Al tolerant germplasm for the species of interest.

Table 5. High input yields and average farmers' yields (t/ha) from international studies of various crops. Average national yields are also reported for Cambodia in 2002, from past trials of CIAP and CARDI, and from the on-farms trials of the ACIAR project in 2003.

	Maize	Mung bean	Peanut[B]	Sesame	Soybean
High input	6-9	2-2.7[E]	2-3	1.2-1.5	1.5-2.5
Average international farmers' yield[A]	0.5-1.5	0.33-0.90 [F]	1-2	0.5-0.6	0.8-1.3
Average Cambodia yield [C]	2.8	0.6	0.8	0.5	0.9
Average for research trials[D]		0.9			1.5
Upper 25 % of yields in on-farm trials	1.9	1.1	0.9	0.1	1.4
Average on-farm trials	1.2	0.5	0.6	0.1	0.7

[A] Source: Sys et al. (1993).
[B] Unshelled pods
[C] Data from Agricultural Statistics, MAFF. (2002-2003).
[D] From Annual Reports of CIAP and CARDI 1991-2001
[E] With irrigation
[F] Ahn and Shanmugasundram (1989).

Table 6. Tolerance of adverse soil properties by field crops. Source: Sys et al. (1993) unless otherwise stated.

	Maize	Mung bean	Peanut	Sesame	Soybean
Al toxicity[A]	Poor	Poor	Fair	Poor	Poor
Low P[A]	Fair	Fair	Fair-poor	-	Poor
Alkalinity	Good	Fair	Poor	Poor	Fair
Waterlogging	Poor-fair[B]	Poor	Poor	Poor-fair	Fair-good
Inundation	Poor	Poor	Poor	Poor	Poor
Low soil water	Poor [E]	Fair	Good	Good	Poor
Minimum root depth	20- 60 cm[E C]	20 cm [C]	20- 60 cm[E C]	30- 60 cm[E]	20- 60 cm[E C]
Sandy	Poor	Fair	Good	Fair	Poor
Heavy clay	Poor	Poor [D]	Poor	Poor	Fair [D]

[A] Dierolf et al. (2001)
[B] Tolerant of water logging after tasselling (Zaidi et al. 2004)
[C] Ecocrop (2000)
[D] Reasonable growth can be achieved if drainage is good
[E] Landon (1984)

Extremely low extractable P levels are common in rice soils in Cambodia (White et al. 1997). Of the crops used in the present study, soybean is least likely to tolerate such low P levels (Dierolf et al. 2001). Hence either the lack of P fertiliser or the use of low levels will limit soybean more than other crops on these soils.

Alkalinity is not likely to be a significant limitation in Cambodia, except on the soils of Battambang and the west of Cambodia that are developed from calcareous marl and limestone (White et al. 1997). On these soils, maize is likely to be well adapted, but peanut and sesame are prone to Fe deficiency on such soils. Unlike most nutrient deficiencies, Fe deficiency is difficult to correct with fertilisers and the best prospects usually come from selection of suitable cultivars or species for growth on such high pH soils.

Sesame, mung bean and peanut are all very sensitive to waterlogging or inundation events (Sys et al. 1993). Maize tolerance is lowest at the tasselling stage (Zaidi et al. 2004). Soybean is regarded as being better adapted to wet soils and waterlogging than other crops; however even this crop has poor adaption compared to rice. The sensitivity to waterlogging and inundation makes most crops prone to failure when extreme rainfall events occur in the early wet season and main wet season. Shallow groundwater levels especially towards the end of the early wet season may also be a risk for non-rice crops. Hence it is important to select freely-drained soils for field crops. Lowland rice soils pose an extra waterlogging risk due both to bunding of fields that limits surface drainage and to the development of a plough pan at 10-20 cm depth which limits drainage within the profile. For example, the Bakan soil which has a loamy to clayey texture and occurs in the low lying parts of the old terrace is particularly risky for field crops in the dry season (White et al. 1997).

Crops vary in drought tolerance with soybean and maize generally less tolerant that sesame, mung bean and peanut. Hence low soil water storage is a more severe constraint for soybean and maize that other crops, and probably explains when farmers' tend to growth these crops in the main wet season.

Land qualities for crop diversification in Cambodia

The land qualities selected for assessing land capability for crop diversification in Cambodia are shown in Table 7. Land qualities and the definitions of ratings were based on van Gool et al. (2004). The rating of the land qualities has been modified for the soils and environment of Cambodia (Table 7) based on descriptions of soil properties and limiting factors in White et al. (1997), field trials and published information for the field crops of interest to this project.

Broadly, land qualities for land capability assessment can be categorised into those for:

- Tillage- hard setting, soil strength, stoniness, stickiness when wet
- Germination and emergence- crusting, soil strength
- Growth- nutrient availability, acidity, water supply (drought), waterlogging, inundation
- Land and resource degradation risk – slope, dispersion, leaching

Land qualities that relate to tillage are particularly significant in Cambodia where draft animals are still used to prepare land for most cropping. When dry, many of the soils of Cambodia have high strength or are hard setting. They are therefore difficult to plough until the first one or two rainfall events moistens and softens the soils (White et al. 1997). The lowland Prateah Lang soil has high strength even when moist despite its sandy surface texture. On the other hand after rains fall, clay soils may be too sticky for efficient tillage. Increasingly tractors are being used for land preparation, especially in upland areas of Cambodia, and so some revision of the ratings of limiting land qualities for tillage may be necessary for tractor tillage. High soil strength and hard setting may be less of a limitation for tractor drawn ploughs, and may allow earlier sowing in the early wet season. On the other hand, excessive wetness of clayey soils may be more of a limitation for tractor tillage than for draft animals.

Table 7. Land qualities and their rating for land capability classification for field crops in Cambodia based on van Gool et al. (2004) with modifications. For specific crops these ratings will vary.

Land qualities	Rating				
	1 Very high capability	2 High Capability	3 Fair capability	4 Low capability	5 Very low capability
pH ($CaCl_2$) (0-10 cm)	5-7.5	4.6-5	4.3-4.5	<4.3, >8.5	
pH ($CaCl_2$) (50-80 cm)	5-7.5	4.6-5	4.3-4.5	<4.3, >8.5	
Nutrient availability	Low leaching risk	Moderate leaching	High leaching		
Surface condition	Loose, soft firm, self-mulching	Few stones	Crusting, common stones	Cracking, hardsetting, many stones	Abundant stones, boulders
Surface soil structure decline susceptibility	Low	Moderate	High		
Rooting depth (cm)	>80	50-80	30-50	15-30	<15
Waterlogging	Nil, very low	Low	Mod		High, very high
Inundation	Nil, low		Mod		High
Soil water storage (mm/m)	>70	35-70	<35		
Soil workability	Good, fair		Poor		Very poor
Water erosion risk	Low	Mod	High	Very high	Extreme
P export	Low	Mod	High		

The erratic rainfall over most of Cambodia creates difficulties for crop emergence. April rainfall is critical for dry season sowing of field crops and is shown in Fig. 4 to be extremely variable. Intense rainfall coupled with low soil structural stability causes slaking of surface soils making them prone to form hard crusts as they dry. Crusting will impede seedling emergence. Sesame emergence and early establishment appears to be especially sensitive to intense rainfall and farmers tend to sow it very early before frequent heavy rainfall is likely. Crusting probably relates to low organic matter levels and lack of retention of crop residues, but in addition clays of Prateah Lang and Prey Khmer soils exhibit dispersion (White et al. 1997). If the seedbed dries the hard setting and dispersive tendency of soils is expressed as high soil strength that further limits crop establishment. Poor soil structure on paddy fields reflects the repeated tillage of wet soils designed to break down soils structure to improve soil water retention during the rice crop.

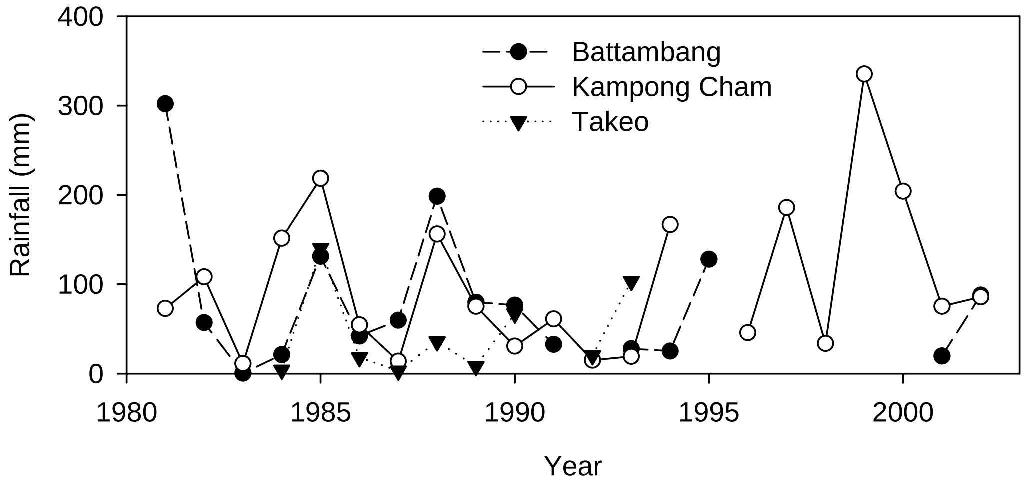

Figure 4. Rainfall (mm) in April at Battambang, Kampong Cham, and Takeo over the period 1980-2002.

The constraints of intense rainfall and poor soil structure are exacerbated by the use of low quality seed. Farmers commonly report that soybean seed has to be re-sown if moisture conditions are less than ideal after sowing since the seeds have low vigour and cannot tolerate either excess moisture or drying of the seedbed during emergence. In on-farm trials in 2003, poor emergence and establishment of sesame and variable establishment of soybean, maize and mung bean were observed. Only peanut reliably established under all conditions with crop failure occurring on only 1 out of 12 experiments.

As mentioned above, soil nutrient supply, *per se*, is not considered as a land quality, since fertiliser application enables these constraints to be overcome. However, this approach may need review so long as fertiliser use on non-rice crops remains very low. The land qualities related to nutrient supply are generally those which are more difficult change, and which affect the availability of nutrients, such as pH, Al toxicity, P sorption capacity and nutrient leaching.

Soil acidity is likely to be a significant limiting factor for field crops on many Cambodian soils. It has been largely overlooked previously because flooding of soils for rice production neutralises acidity. However, Seng et al. (2004) showed strong responses by upland rice to lime application on the acid Prateah Lang and Koktrap soils (pH $CaCl_{2\ =}$ 4; Al saturation = 80 %) when maintained in an aerated state whereas no response was found when these soils were flooded. Flooding increased soil pH to 5.5 or greater regardless of lime application, whereas only the highest lime rate in this experiment increased soil pH to 5.5 and the unlimed, unflooded soil had pH < 5. From preliminary analysis of a range of upland soils from Kampong Cham and Takeo, Al toxicity appears to be a significant limiting factor for a range of field crops (Fig. 5; Table 8). Among the four main upland soils in Ou Reang Ov district in Kampong Cham, Al saturation was > 20 % in the Kampong Siem gravely phase and the Labansiek non-gravelly phase (Fig. 5). In the Labansiek non-gravelly soil, high Al was present in the surface layers, whereas in the Kampong Siem gravelly phase, it was in the sub-soil. These soils are likely to be quite common in the basaltic uplands of eastern Cambodia (Kampong Cham, Kampong Thom, Kratie Provinces) suggesting that Al toxicity may be quite widespread and a significant limiting factor for field crop production. In Prey Khmer soils in uplands of western Takeo province, Al saturation values of 50-80 % were found in the sub-soil (Table 8).

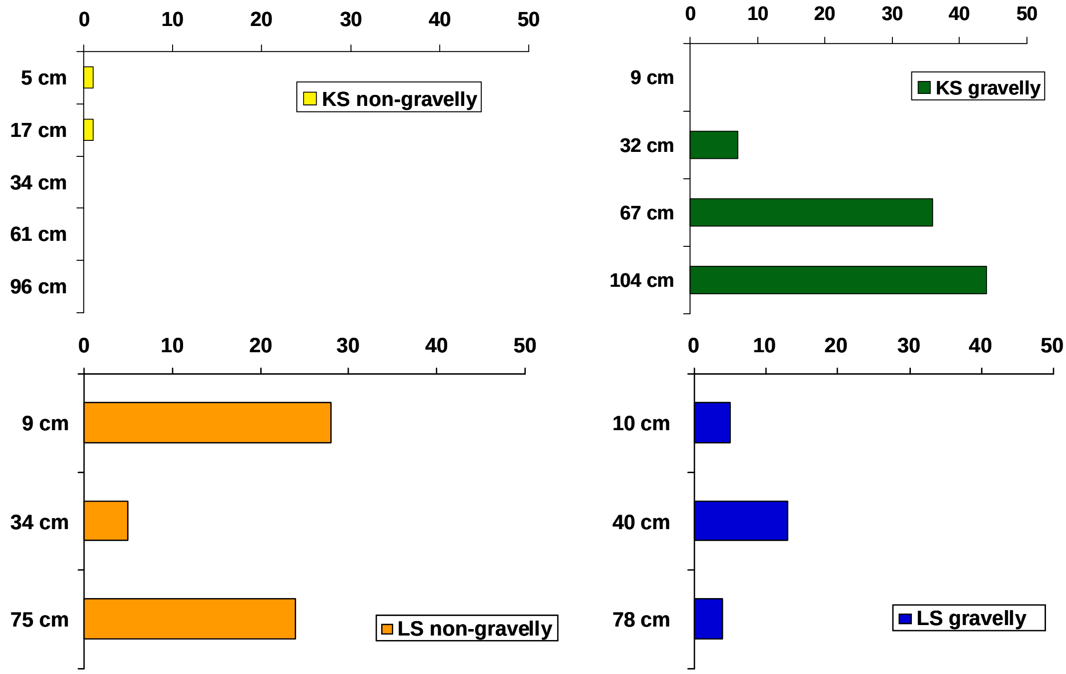

Figure 5. Aluminium saturation (as a % of effective cation exchange capacity) values for down profile samples collected in four main upland soils in Ou Reang Ov district, Kampong Cham: KS- Kompong Siem soil; LS- Labansiek soil. Note: it is proposed to re-name Labansiek gravelly soil as Ou Reang Ov Soil group.

Water supply (drought) is a key limiting factor for most areas of Cambodia because of the monsoonal rainfall pattern and the erratic rainfall distribution during the wet season (Fig. 4). Most of the field crops grown in the early wet season and main wet season receive less than optimal rainfall in total (Table 4). Hence the water storage capacity of the soil would have a large bearing on the regulation of water availability to crops especially during periods of little or no rainfall. Water supply may be quite different for crops other than for rice on the same soils. Deep sands are generally considered unsuitable or of low productivity for paddy rice because water is not retained in the shallow root zone of rice, and because a plough pan does not readily form to retain water (White et al. 1997). Whereas paddy rice is very shallow rooted and cannot exploit water stored deeper in the sandy profiles, this may not be a limitation for other crops. Hence deep sands (75-100 cm) will have a higher potential for production of deep rooted field crops than for rice. By contrast, soils like the Prateah Lang that may have a dense sub-soil are favourable for rice because water is retained in the root zone (White et al. 1997). For field crops the dense sub-soil may impede root penetration so that the available stored water is very low, making these crops very prone to either waterlogging following intense rain, or drought following a period without rain. Plough pans that form in paddy fields may exacerbate the problem of soil water storage. Hence the growth of field crops in paddy fields during the early wet season may be particularly prone to water shortages. Sub-soil Al may also impede root growth and act as a limit on access to stored sub-soil water.

Table 8. Soil pH, exchangeable Al, effective cation exchange capacity (ECEC) and Al saturation in soils of Tramkak District, Takeo.

Soil Group	Depth (cm)	Phase	pH $CaCl_2$	Al (cmol/kg)	ECEC (cmol/kg)	Al saturation (%)
Prateah Lang	0-8	clayey	5.2	0.01	2.07	0
	8-23	subsoil	4.9	0.11	1.69	7
	23-82	phase	4.3	0.85	2.8	30
	82-110		4.3	1.45	3.8	38
Prateah Lang[A]	0-10	loamy	4.8	0.1	1.9	5
	10-40	subsoil	6.5	0	5.81	0
	40-70	phase	8	0	11.2	0
	70-110		7.9	0	11.2	0
	110-120		8.2	0	8.7	0
Prateah Lang[A]	0-12	loamy	4.2	0.4	1.57	25
	12-30	subsoil	4.2	0.48	1.66	29
	30-70	phase	5.7	0	2.83	0
	70-110		8.2	0	5.6	0
Prey Khmer	0-6		4.3	0.14	0.45	31
	6-20		4.3	0.29	0.56	52
	20-60		4.5	0.32	0.65	49
	60-85		4.1	3.24	5.6	58
	85-100		6.4	0	10.7	0
Prey Khmer	0-12	fine sandy	4.5	0.28	1.83	15
	12-60	phase	4.2	1.57	1.81	87
	60-100		4.1	1.4	1.6	88
	100-120		4.2	1.32	1.48	89

[A]Two profiles of Prateah Lang had distinctly different pH between 10 and 70 cm depth.

Intense rainfall events will often lead to waterlogging in both the early wet and main wet season because the infiltration rate for soils is much less than rainfall rates. This is beneficial for rice cultivation because it stores water than can be used later by the crop. For other crops waterlogging is usually harmful, especially if prolonged, and within 30 cm of the soil surface. Inundation involves ponding of water on the soils surface either from intense rainfall, or from river flooding. Risks of the latter for more than a few days would usually prohibit the use of a parcel of land for non-rice crops. Hence, for example the prospects for growing non-rice crops on the low lying Bakan soil during the early wet season are considered to be low (White et al. 1997) because inundation and waterlogging risk are very high.

The key land degradation hazard that needs to be assessed in upland soils is erosion potential. Slope and slope length in landscape segments are the main properties that should be assessed for erosion risk. Soil properties that affect erosion include infiltration characteristics and surface soil structural stability. Anecdotal evidence suggests that sandy upland soils on slopes are at high risk of severe erosion if cleared and left bare in the wet season. By contrast, the upland Labansiek soil has strong stable soil structure (White et al. 1997) and would represent a much lower erosion risk for land of similar slope to the sandy soils. Similar conclusions were reached regarding erosion risk of upland soils developed on basalt *vs* metamorphic rocks in the Central Highlands of Vietnam (D'haeze et al. 2005). Hence it is important that erosion risk be assessed in land capability classification to ensure that unsustainable land uses for field crops are not proposed.

Phosphorus leaching potential is also selected as a land quality since the export of P into water bodies may cause eutrophication that has harmful effects on food harvesting from these water bodies (Bell et al. 2001).

Case study for Labansiek non-gravelly soil

The Labansiek non-gravelly phase is a deep red clay soil that occurs on very gently undulating to undulating uplands of the basaltic plateau that occupies significant areas of eastern Cambodia (White et al. 1997). While described by White et al. (1997), Labansiek non-gravelly is not a significant rice growing soil, but has potential for other field crops although a significant proportion of these soils are already used for rubber plantations. In this case, its land capability was assessed based on field investigation in Ou Reang Ov district, Kampong Cham. Most of the land qualities were rated as favourable, with no limiting factors (Table 9). The soil has moderate leaching potential, and on sloping land, moderate water erosion risk. Low pH was the major limiting factor on the Labansiek non-gravelly soil. Aluminium toxicity will be a limiting factor for many field crops. The moderate capability of Labansiek non-gravelly is perhaps lower than it is perceived to be by many agronomists in Cambodia. Cassava which is increasingly grown on Labanbsiek non-gravelly soil is highly tolerant of Al toxicity (Dierolf et al. 2001). Similarly, rubber which occupies large areas of the Labansiek non-gravelly soil is tolerant of Al toxicity. For crops that are not Al tolerant, land capability on the Labansiek non-gravelly is only moderate.

General Discussion

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.

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.

Table 9. Rating of land qualities for the Labansiek non-gravelly soil in Ou Reang Ov district, Kampong Cham.

Land qualities	1 Very high capability	2 High Capability	3 Fair capability	4 Low capability
pH ($CaCl_2$) (0-10 cm)			4.3-4.5	
pH ($CaCl_2$) (50-80 cm)			4.3-4.5	
Nutrient availability		Moderate leaching		
Surface condition	soft, self-mulching			
Surface soil structure decline susceptibility	Low			
Rooting depth (cm)	>80			
Waterlogging	Very low			
Inundation	Nil			
Soil water storage (mm/m)	>70			
Soil workability	Good			
Water erosion risk		Moderate		

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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