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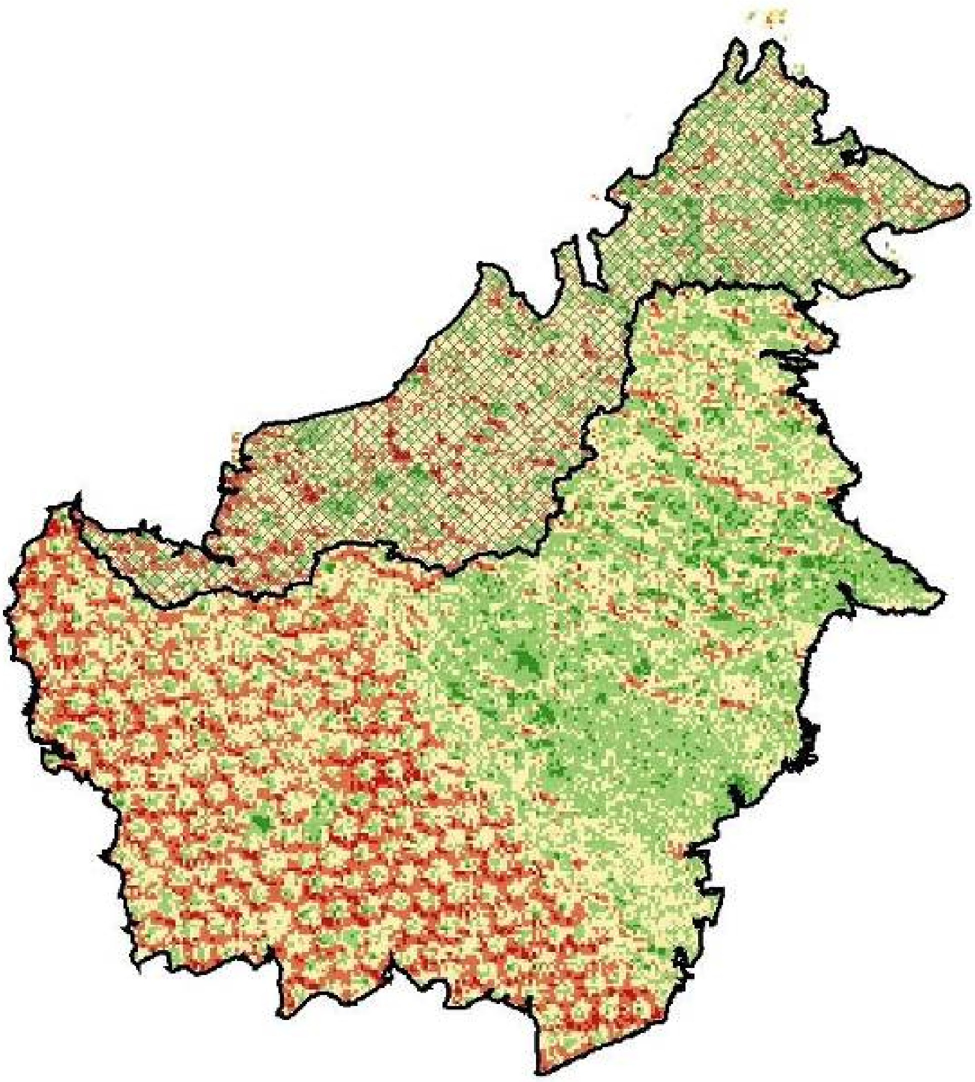
Biophysical Land Suitability for Oil Palm in Kalimantan, Indonesia

Stephan Mantel, Henk Wösten, and Jan Verhagen



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Front cover: The image within the boundaries of the Island of Borneo (including the Indonesian provinces of Kalimantan) is an artistic edit of a remote sensing image of an oil palm plantation (IKONOS 1-m resolution pan-sharpened color image). The image is 300 m across. In the altered image the area in the left part with red background and green dots is the oil palm plantation with matured palm trees (green dots). The other area (green with some red) is outside the plantation and represents trees, shrubs and grasses. [Prepared by Jan Huting, ISRIC]

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SUMMARY

On request of the Dutch Ministry of Agriculture, Nature and Food Quality (LNV), Wageningen University and Research Centre (WUR) partners, including ISRIC – World Soil Information, Alterra and Plant Research International, conducted a biophysically-oriented study on land suitability for oil palm in Kalimantan, Indonesia.

The following outputs were delivered:

- Maps at scale 1 : 250 000 indicating suitable areas for the cultivation of oil palm and limiting factors
- Recommendations and discussion on sustainable expansion or intensification of oil palm in relation to biophysical aspects of land and soil and related to spatial planning
- Analysis of constraints for oil palm, including factors such as soil anchorage, soil nutrient status, and water management
- Considerations for management in relation to spatial planning of oil palm plantations and relations with smallholder agriculture and land or forest management (e.g. buffer zone management).

The project contributes to the LNV objectives as it:

- Provided a sound, biophysically oriented basis for the allocation of new oil palm plantations or intensification of existing palm oil plantations, focusing on Kalimantan but other areas could be taken into account in the future
- Helped in discussions on expansion or intensification of oil palm cultivation that attracts international attention and raises wide public concern with respect to its environmental, social and economical impacts
- Provided factual, biophysically oriented inputs for decisions on expansion or intensification in the production of oil palm. Discussions often focus on biodiversity and social aspects, ignoring soil and land conditions that determine the feasibility for oil palm expansion or intensification
- Outside the scope of the study, but critically important for planning sustainable oil palm plantations, a spatial zonation for potential areas for oil palm expansion was made including legal land status, fragile land units, land tenure and biodiversity conservation protection areas.

Conclusions

- About half the area of Kalimantan is considered highly to moderately biophysically suitable for the cultivation of oil palm (~51% or 272 779 km^2). In about a third of Kalimantan (~37% or 198 405 km^2), the growth of oil palm is not possible/productive
- The dominant constraints are slope steepness and poor soil drainage. The latter can partly be overcome by management interventions
- Spatial planning including other factors than biophysical land suitability, such as legal status of land, actual land use, biodiversity conservation should also be considered
- Only limited areas are considered both physically suitable and without land use (land status) restrictions

- The land in Kalimantan adjacent to the border with Sarawak and Sabah is dominantly unsuited for oil palm cultivation.

Outlook / further research

- Methodology development/testing for regional planning of sustainable oil palm production (criteria and decision support system development)
- Assess sustainability issues (people, planet, profit)
- Consider management implications of land suitability/biophysical constraints at the plantation level *vis-à-vis* current exploratory scale of 1:250 000.

1 INTRODUCTION

Indonesia is a major producer of palm oil. World palm oil consumption is expected to grow considerably in the coming years and it is projected that Indonesia will be a major supplier. Growth in production will be both by expansion and intensification. The debate on oil palm expansion or intensification receives broad attention; there is public concern about the expansion of oil palm plantations in Kalimantan with regards to environmental and social issues. Expansion of oil palm to marginal lands increases investment and production costs and affects sustainability. Land suitability should therefore be taken into account in the decision making process.

In bilateral contacts, the Government of the Netherlands expressed concern to the Government of Indonesia with respect to the expansion of oil palm, in Kalimantan specifically, and offered to assist in provision of a regional evaluation of suitability of land in Kalimantan for oil palm as an input for decision making on sustainable expansion or intensification of oil palm. In this context, the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) requested ISRIC - World Soil Information and Wageningen UR to provide a regional land suitability assessment. The assessment will provide an input to the dialogue between the LNV and the Indonesian counterparts.

The objective of this assessment was to provide a biophysical basis for the discussion on large scale expansion of oil palm plantations or intensification of existing palm oil plantations in Kalimantan and to identify knowledge gaps. Although the assessment focused on Kalimantan, the developed methodology can be applied in other areas in Indonesia.

The report covers the following:

- Discussion of methodology
- Analysis of biophysical land suitability assessment for oil palm in Kalimantan
- Discussion on sustainable expansion or intensification of palm oil production based on data related to soil and land suitability
- Considerations for management in relation to spatial planning of oil palm plantations and relations with small-holder agriculture and land or forest management
- Recommendations.

2 DATA AND METHODS

2.1 Background

Oil palm (*Elaeis guineensis Jacq.)* grows in tropical lowlands and is one of the main vegetable oil crops in the world. Oil palm is assumed to have its origin in West Africa. The earliest record of oil palm in the Far East is the planting of four seedlings in the Botanic Gardens at Bogor in 1849. The first large commercial plantations were established around 1910 in Sumatra. Oil palm starts to yield about 3 to 4 years after planting and is in full production at an age of 8 to 10 years. The average economic lifetime is about 25 years. Oil palm yields vary. Well-managed plantations in Peninsular Malaysia have achieved yields of up to 30 t/ha (fresh fruit bunches, FFB), the average peak yield is in the order of 25–28 t/ha (Gurmit, 1999).

2.2 Approach

Kalimantan land suitability was assessed in five steps (Table 1). Land suitability was assessed irrespective of current land use, land status, or accessibility. The suitability assessment considered soil properties and geographic location (supply side), matched with crop and land management (e.g. level of inputs used, degree of mechanization) requirements (demand side). Suitability was assessed for a basic management level and adaptive (high-level) management.
The determination of land suitability for oil palm was computerized, but not automated because it relied on expert inputs at each stage of data processing.

To map areas with legal and environmental restrictions for use, an additional analysis was done to indicate the protected forest areas, the forest reserves, and the fragile lands. Overlay of this map with the land suitability map yielded a map that indicates the land area with potential for expansion for oil palm.

Table 1. Summary of steps involved in land evaluation

1. Environmental dataset preparation
   Soil data sets were prepared for each land unit (land facet);
   Climate data sets prepared;
2. Identification of crop requirements
   Crop requirement files prepared for oil palm
3. Data integration
   Soil, climate and elevation maps are overlaid using GIS to produce a batch file containing the data required for land evaluation
4. Suitability assessment
   The base analyses of suitability were carried out using PLANTGRO comparing crop requirements with the soil and climatic information. This identified the major constraints, and their level for the land facet. Management shift analysis assessed how management could improve yields
5. Creation of suitability maps
   All suitability results are reassessed for the management shift analysis to produce an overall rating for oil palm land suitability

2.3 Data Processing

1. *Environmental data*

Maps and data files were obtained from various sources. The land systems and land and forest status data were collected from the Regional Planning Programme for Transmigration project (RePPProT 1990) and the National Master Plan for Forest Plantations (NMFP 1994a). Additional information on land systems and soils in East Kalimantan was available from Berau regency, East Kalimantan (Mantel 2001). We followed the methodology and data structures for the land evaluation from the National Master Plan for Forest Plantations were followed (NMFP 1994a).

Climate

The climate database was compiled from using data from a variety of sources, including the Bureau of Meteorology and the NMFP data sets (NMFP 1994a). Monthly averages of nine climate factors have been extracted from the data sets:

1. Rainfall
2. Evaporation
3. Day length
4. Solar radiation
5. Temperature - Mean of daily maximum
6. Temperature - Mean of daily minimum
7. Temperature - Lowest, defined as the mean minimum and calculated as (mean minimum - absolute minimum) divided by 2
8. Average wind speed
9. Extreme wind speed

In equatorial regions, there is a strong correlation between elevation and temperature; Lapse rates have been used to modify the temperature values (-6°C per 1000 m). The contour maps of the area were used to derive the elevation at each site.

Elevation and slopes

Elevation and slope information was derived from the Shuttle Radar Topography Mission (SRTM, http://srtm.usgs.gov/) 90 m Digital Elevation model (Figure 1).

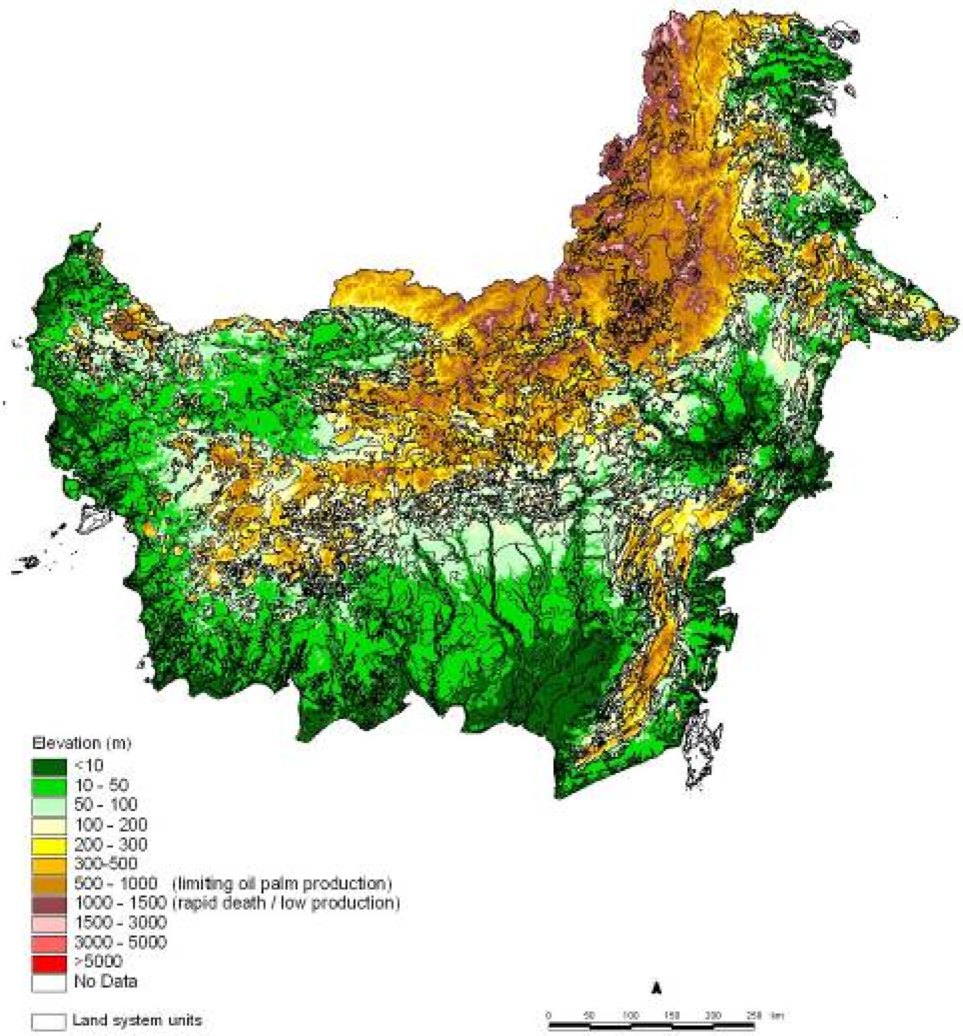


Figure 1. Elevation derived from the Shuttle Radar Topography Mission

Land units

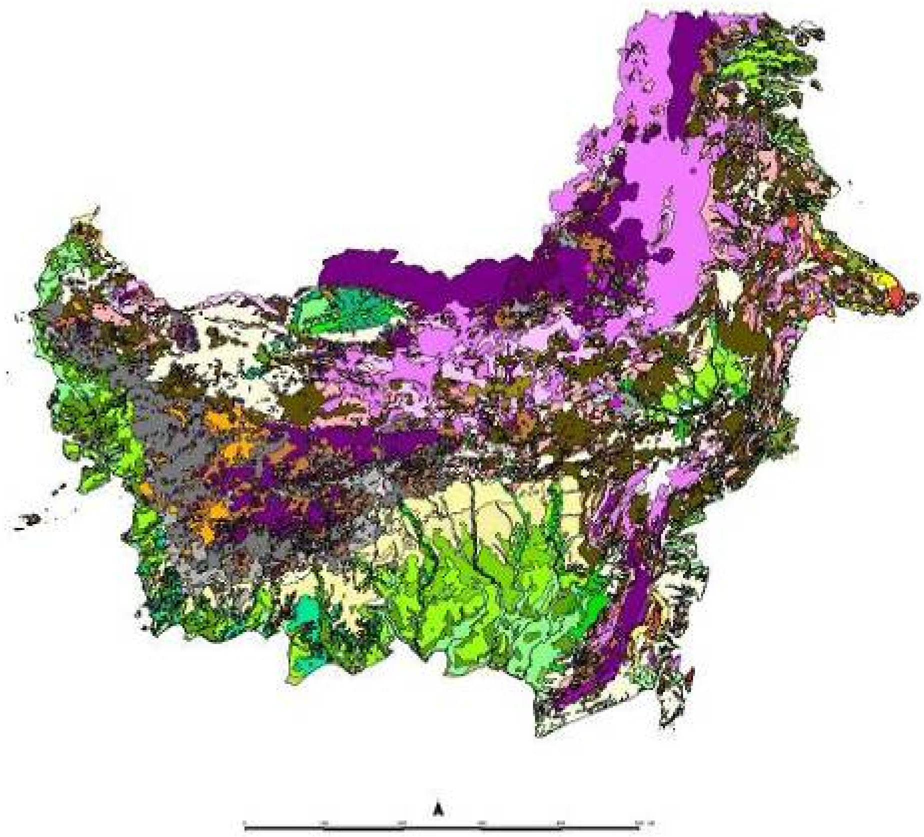
The base map was created from land systems maps (RePPProT 1987a, b, c, 1990). The available soils information varies in quality and there is no direct link between the land facet and soil components.
The Soils Data Base is an extract from data prepared for the National Masterplan for Forest Plantations (NMFP 1994a). Much of this information was derived from the reports by the Land Resources Department of the Overseas Development Administration for the Regional Physical Planning Program for Transmigration (RePPProT, 1987 a, b and c), with additional field checks. The land system concept is used to map the areas; a land system being an area, or group of areas, with a similar pattern of landform, soils and vegetation. For each land systems, RePPProT provides information on the resources including landforms, soils and vegetation. NMFP verified the land to soil correlation and assembled soils, climatic and topographic information from different sources, such as from the Land Resources Evaluation Project (LREP 1990), Department of Transmigration, and the Centre for Soil and Agroclimatic Research.

The database attributes are further subdivided into three land resource attributes (slope, % rock outcrop and flooding risk) and seventeen soils attributes such as soil reaction, and cation exchange capacity. The latter are further subdivided into chemical and physical attributes. The land systems are classified in four broad categories:

1. Flat land
2. Sloping land
3. Steep land
4. Mountains

Within each category, subcategories are identified (Figure 3). Landform and, to a lesser degree, undisturbed vegetation are major differentiating criteria. Within the land systems, smaller land facets are identified which, in turn represent one or more soil types. Figure 2 shows a view on a karst land system in East-Kalimantan (rugged limestone ridges and mountains).

Figure 2. View on karst landscape in a rainforest area in Berau, East Kalimantan (photo M.Steenis)



FLAT LANDS

Riverine sediments

- BKN - Floodplain over fluvial sediments (flat, wet)
- BLI - Swampy floodplain of narrow valleys (flat, wet)
- KHY - Coalescent, estuarine/riverine plains (flat/gently undulating, wet)
- KLR - Permanently waterlogged floodplains (flat, wet)
- PMG - Backswamps of inland floodplains (flat, wet)
- SBG - Meander belt of large rivers and broad levees (flat, wet)
- TNJ - Coalescent inland riverine plains (flat, wet)

Coastal systems

- KJP - Intertidal mudflats (flat, wet)
- PTG - Coastal beach ridges and swales over beach sand/gravels (flat, wet)

Peat soils

- GBT - Deep (>2 m) peat swamps (flat, wet)
- BRH - Flat sandy terraces, covered by peat (flat, wet)
- MDW - Shallow peat swamps (lat, wet)
- SRM - Peat filled valley within terraces (flat, wet)

Valleys and terraces

- MGH - Alluvial valley, wide valleys containing hillocks (flat, wet)
- SGT - Waterlogged sandy terraces (flat, wet)
- SHD - Flat, sandy terraces covered by deeper peat (flat, wet)

SLOPING LAND

Sloping land over basic parent rock

- SMD - Rolling volcanic plains over igneous basic rock (rolling)
- RGK - Undulating to rolling plains over metam./ultra-basic rock (undulating to rolling)
- BTK - Moderately dissected intermediate/basic lava flows (v. gently sloping, mod.steep)
- HJA - Hillocky plains over metamorphic/basic volcanic rock (moderately steep)

Sloping land over sedimentary rock

- LWW - Rolling plains over sedimentary stone (undulating to rolling)
- KRU - High sandstone plateaus (rolling)
- SPG - Very gently sloping terrace remnants (very gently sloping)
- BWN - Rolling sedimentary plains with sandy terrace remnants (gently sloping)
- PKU - Undulating, sandy terraces developed over old sands (undulating)
- PST - Marine terraces developed over old clays (gently) undulating
- SMI - Undulating to rolling riverine terraces (undulating to rolling)
- TDR - Sandstone cuestas with relatively gentle dipslopes (moderately steep)
- TWH - Hillocky sedimentary plains (moderately steep)

Sloping land over limestone with outcrops

- KPR - Undulating karstic plain with hums over limestone (undulating)
- GBJ - Hillocky karstic plain over limestone (mod. steep)

STEEP LANDS

(Very) steep ridges and hills over sedimentary rock

- MTL - Linear sedimentary ridge systems with steep dipslopes (steep)
- MPT - Medium gradient hills over sedimentary rocks (steep)
- TWB - Hillocky plains with steep parallel ridges (steep to very steep)
- LHI - Steep long-sided and narrow ridges over sandstone (very steep)

Extremely steep hills over igneous acidic rocks

- TBA - Extremely steepsided volcanic plugs (extremely steep)

(Very) steep ridges and hills over (ultra) basic and metamorphic rock

- PLN - Steep hills over basic and metamorphic rock (steep)
- SST - strongly dissected hills over ultrabasic rocks (steep)
- STB - Hillocky basaltic plain (steep)
- JLH - Metamorphic, sub-parallel ridge systems (very steep)

MOUNTAINS

Limestone mountains

- OKI - Rugged karst ridges and mountains (extremely steep)
- steep GDG

Mountains over sedimentary rock

- GDG - Extremely long karstic mountain ridges over marble
- PDH - Mountains over sedimentary and metamorphic rock (very steep)

Mountain systems over (ultra) basic and metamorphic rock

- BTA - Dissected volcanic cones over basic volcanic rock and tuff (very steep)
- LNG - Mountains over ultra-basic/volcanic rocks (very steep)
- BPD - Non-sedimentary mountain ridge systems (very steep)
- LPN - Eroded, moutainous stratovolcanoes (extremely steep)

Mountains over granite rock

- TWI - granite mountain ridge systems (steep)

Figure 3. Kalimantan land systems (RePPProT 1990)

2. *Identification of crop requirements*

Optimum conditions for the cultivation of oil palm are given by Hartley (1988) and DID (2001). The environmental requirements of oil palm are available in PLANTGRO files (Hackett 1991). The plant files contain information on the optima and limitations for a range of environmental conditions.

3. *Data integration*

Data integration is organized around the plant requirement information which is stored in PLANTGRO's plant, soil, and climate files. The computerized system uses PLANTGRO (Hackett 1991), a crop physiology-based system for assessing land suitability, customized database routines to evaluate land management constraints based on the expert judgement of soil and crop specialists, and a Geographical Information System (GIS) to handle the data, and to produce the final maps.

4. *Crop suitability assessment*

Matching of the land and soil information with the plant requirement information produces ratings that indicate the adequacy of land qualities for oil palm cultivation under predefined conditions of management and inputs. The most limiting factor was assumed to determine the overall suitability rating in accordance with Liebig's law of the minimum that states that crop growth is controlled not by the total of resources available, but crop performance is limited by the scarcest resource.

PLANTGRO soil and climate datasets were matched with the plant requirement files. This analysis identified biophysical constraints for oil palm production and their degree of limitation. Decision rules were used based on expert knowledge to adjust the land suitability analysis by assessing how plant growth can be enhanced, or constraints can be overcome through management interventions. Two management levels were considered; a base management level and a high management level. In chapter 3.3 the management levels and their implications for land suitability are discussed. The plant growth and management analysis were combined to give an overall rating of development potential.

5. *Creation of suitability maps*

Maps of land suitability and development potential were prepared. The analysis was based on complex mapping units; each component of which was assessed individually. This allowed for an estimate of the area covered by each land type. The maps represent associations of land types. Maps of suitability and ratings of development potential are for the dominant land type in a mapping unit. This provided an adequate indication of the potential, but the tabulated areas provide more details of development potential. Table 1 summarizes the steps used to arrive at the suitability assessment and soil limitation indications.

3 RESULTS

3.1 Environmental factors

Climate

Oil palm is adapted to a wide range of climates with rainfall varying from 1500 to 4000 mm per annum with both a marked or no dry season, and abundant sunshine. Ideally oil palm requires some 2000 mm of rainfall per annum, well distributed over the year. Cool temperatures, as observed at higher altitudes, will result in reduced yields. At altitudes higher between 500 to 1000 m sea level oil palm production is constrained, and at heights above 1500 m no or extremely low production can be expected. Figure 1 shows that the central core of steep lands that stretches almost from Pontianak in West Kalimantan up to the border with Sabah is at altitudes above 500 m and is therefore too cold (high altitudes) for oil palm production. Temperature/elevation lapse rates were used to modify the temperature values values (-6°C per 1000 m).

Land systems

Oil palm is grown commercially on a wide range of soils and landforms, with flat to steep slopes. Flat to gently undulating land is preferred for oil palm cultivation. Nonetheless, satisfactory yields can be obtained from hilly terrain; however, road construction and maintenance, harvesting and field maintenance, which are crucial for regular harvesting, are more expensive in hilly terrain. Management-related factors are thus important considerations when selecting land for the establishment of an oil palm plantation. Before considering soil related constraints, slope and erosion hazard are evaluated first which can pose clear limitations to the construction and exploitation of oil palm plantations.

Elevation and slopes

Slope steepness (Figure 4) may cause access and exploitation problems, and soil erosion with oil palm establishment.

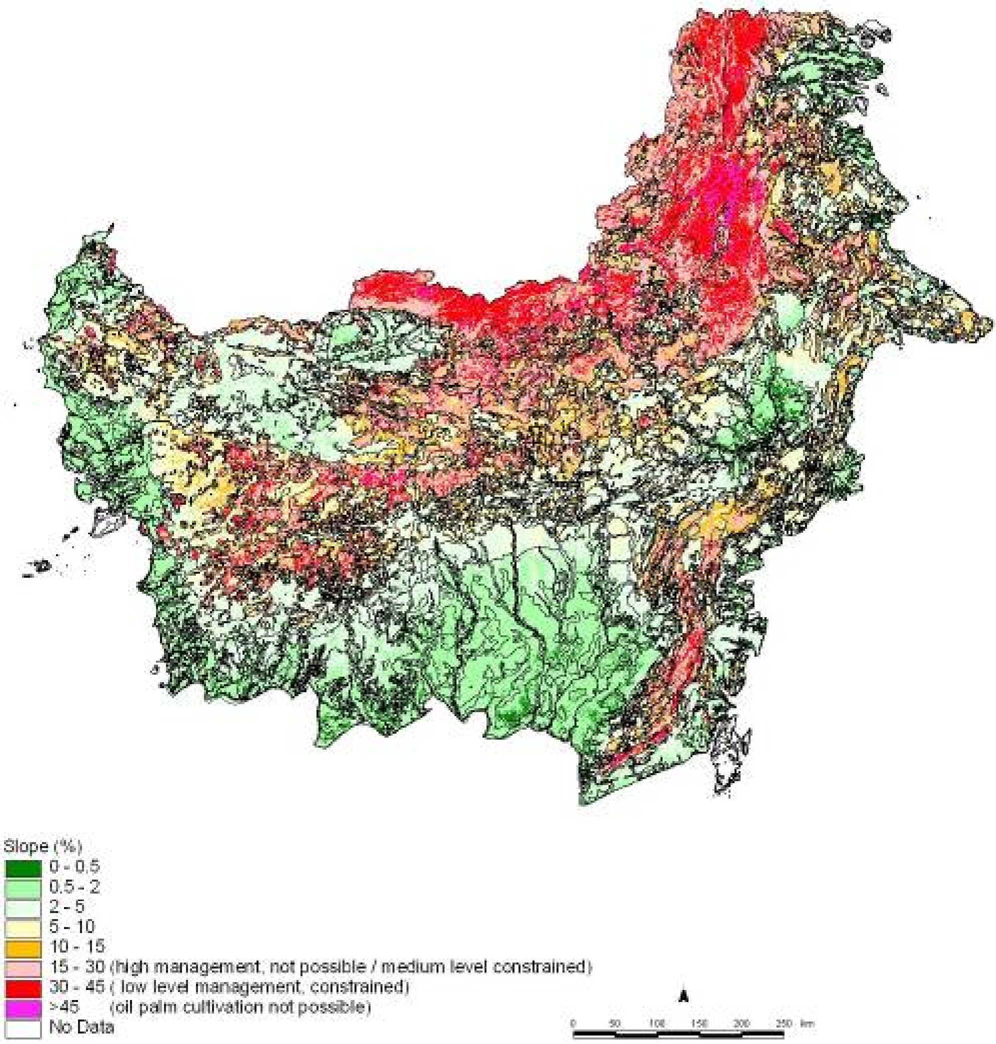


Figure 4. Slope map derived from the Shuttle Radar Topography Mission interpreted for suitability for oil palm cultivation

Terrain with slopes steeper then 40-45% is considered unsuitable for oil palm cultivation. Slopes less than 8% are optimal. For terrain with slopes between 9 and 30%, higher additional costs will be involved for land preparation. The slope map shows that the central (Iran) mountain range and Meratus and Sangkulirang mountain ranges and steep hills are not suitable oil palm plantations. Land above 500 and above 1000 m overlap with much of the areas with slopes steeper than 15 and 30% respectively.

Potential erosion hazard

Erosion hazard for bare land was calculated. The Universal water Soil Loss Indicator (USLI) is used to indicate the sensitivity of soils for water erosion under land cover change. This provides an indication of the potential impact of clearing land from its existing vegetation. The methodology is based on the universal soil loss equation (USLE) excluding the vegetation parameter, as reported by Tyrie and Gunawan

(1999) and NMFPb (1994b). If forest is cleared to be replaced by oil palm, then the period between vegetation clearing and oil palm establishment is critical. Soil erosion is a risk in that period; it may lead to irreversible decline in soil quality. Modelled soil loss over 180 t ha y^{-1} are considered too high; it renders these lands unsuitable for oil palm (Figure 5). The values for potential erosion hazard are almost exclusively found in the mountain and very steep land units.

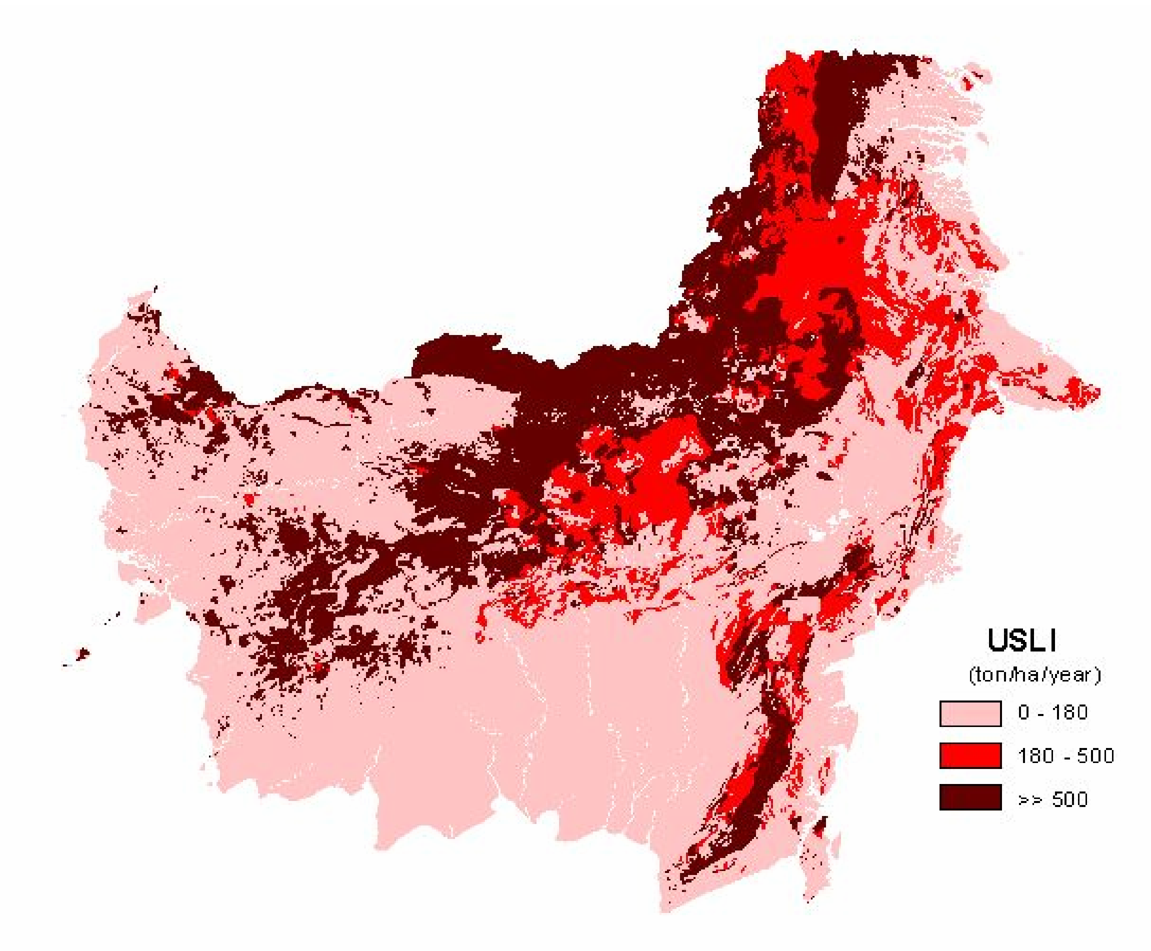


Figure 5. Soil erosion risk for bare soils modelled using Universal Soil Loss Indicator

Soils

Oil palm can grow on a wide variety of soils. Sufficient water supply to the roots is the most important requirement for crop development and production. The most unfavourable soil conditions for oil palm cultivation according to Hartley (1988), are:

- **Poor drainage**. Soils may be poorly drained due to low hydraulic conductivity, as is the case in soils with high clay content, or because of the topographical position. Soils in low-lying positions are normally poorly drained.

- **Low water holding capacity**. Gravelly and ironstone-rich soils are likely to have a low available moisture retention capacity and/or a lower effective soil depth, resulting in water stress during dry periods.
- **Adverse chemical conditions**. Oil palm does not grow very well on nutrient poor or acid soils.
- **Poor anchorage**. Oil palm requires a soil deep enough to develop a root system that can support the above-ground biomass.

The dominant soil types in Kalimantan (Table 2) are Tropudults (Soil Survey Staff 1996): strongly weathered, very acid, often overlying sedimentary rocks, found in upland areas. Tropudults have a dense clay subsoil and are moderately well to well drained, very deep, infertile and saturated with plant toxic aluminium. In general, they are not suitable for smallholder agriculture with low-input management. The only exception may be the traditional and nowadays almost non-existing, slash-and-burn system with long fallows. The undulating to hilly plains over Tertiary sediments can be planted with oil palm successfully if properly managed with adequate lime and fertilizer application.

Special attention was given to peat soils as they are particularly important in the discussion on expansion of oil palm and impacts on biodiversity and soil organic carbon stocks. Oil palm can be grown successfully –in agronomic terms- on 90 to 120 cm of peat overlying clayey subsoils. It is difficult to establish oil palm on deep peats (> 250 cm thick). Upon drainage, the peat shrinks and palms are unable to develop a root system for anchoring; palms lean in all directions and fall over. Deep peat soils cover several mapping units in Kalimantan and are particularly common in Central Kalimantan (Figure 6). There are several sustainability issues related to the cultivation of peat soils. These are discussed in paragraph 3.3.

Table 2. Main soil types of Kalimantan and their distribution

Soil type*	Description	Area	
		km^2	% total
Dystropepts	Shallow infertile soil	132559	24
Tropudults	Weathered, aluminium-saturated soils with dense subsoils	251507	45
Tropohemists	Peat soils	50543	9
Placaquods	Extremely weathered, infertile sands, with Fe and Al accumulation in subsoil ('podzols')	19225	3
Tropaquepts	Wet soil	30476	6
Other		73478	13
	Total	557788	100

*(Soil Survey Staff 1996)

Poor drainage conditions

To cultivate oil palm, it is best to maintain the water table at a depth of 0.60–0.75 m. For the drainage design, the maximum saturation period allowed is three days (stagnant water). Oil palm is tolerant of wetness if saturation does not persist more than two weeks, and/or if water is oxygen-rich. Poorly drained conditions prevail in coastal swamps, especially in Central and West Kalimantan (Figure 6). Peat soils should receive a priority in conservation. Draining peat soils for oil palm production is not sustainable and should be avoided.

The Mahakam, Berau, and Bulungan estuarine/deltaic swamps are located in East-Kalimantan. Inland riverine plains and peat soils are found in places such as along the Mahakam River and on the fringe of the footslopes of the Kapuas and Mueller mountains on the border with Malaysia.

Heavy textured (high clay content) soils may be difficult and costly to drain. Medium and coarse textured soils may also be poorly drained, particularly when found in low lying topographic positions, but these soils can be improved by shallow ditches.

Oil palm is sensitive to drought. Yields in areas with a moisture deficit of 400 mm per annum have been reported to be only half of yields obtained in zero-deficit areas. Because of the low-to-zero capillary rise in peat soils, dry spells lasting longer than 10 days will result in significant yield reductions on these soils.

Peat soils are found in the flooded and poorly drained plains and swamps. With appropriate management, oil palm can be grown on shallow peats. On deeper peat soils, there is not sufficient anchorage possible for oil palm tree roots and these soils are therefore not suitable for oil palm planting. Successful water management is the key to the productive cultivation of oil palm on peat soils. This demands systematic planning, organization and close control of drainage to maintain water levels. Peat decomposes when drained, resulting in CO_2 greenhouse gas emission to the atmosphere –often aggravated by peat fires- and irreversible soil loss. However, in deforested and already drained and degraded peatlands, agricultural cropping has the potential to reduce fire risks and annual greenhouse gas emissions. The case for sustainable agriculture on peats where the water levels are carefully regulated remains to be proven (Sargeant 2001).

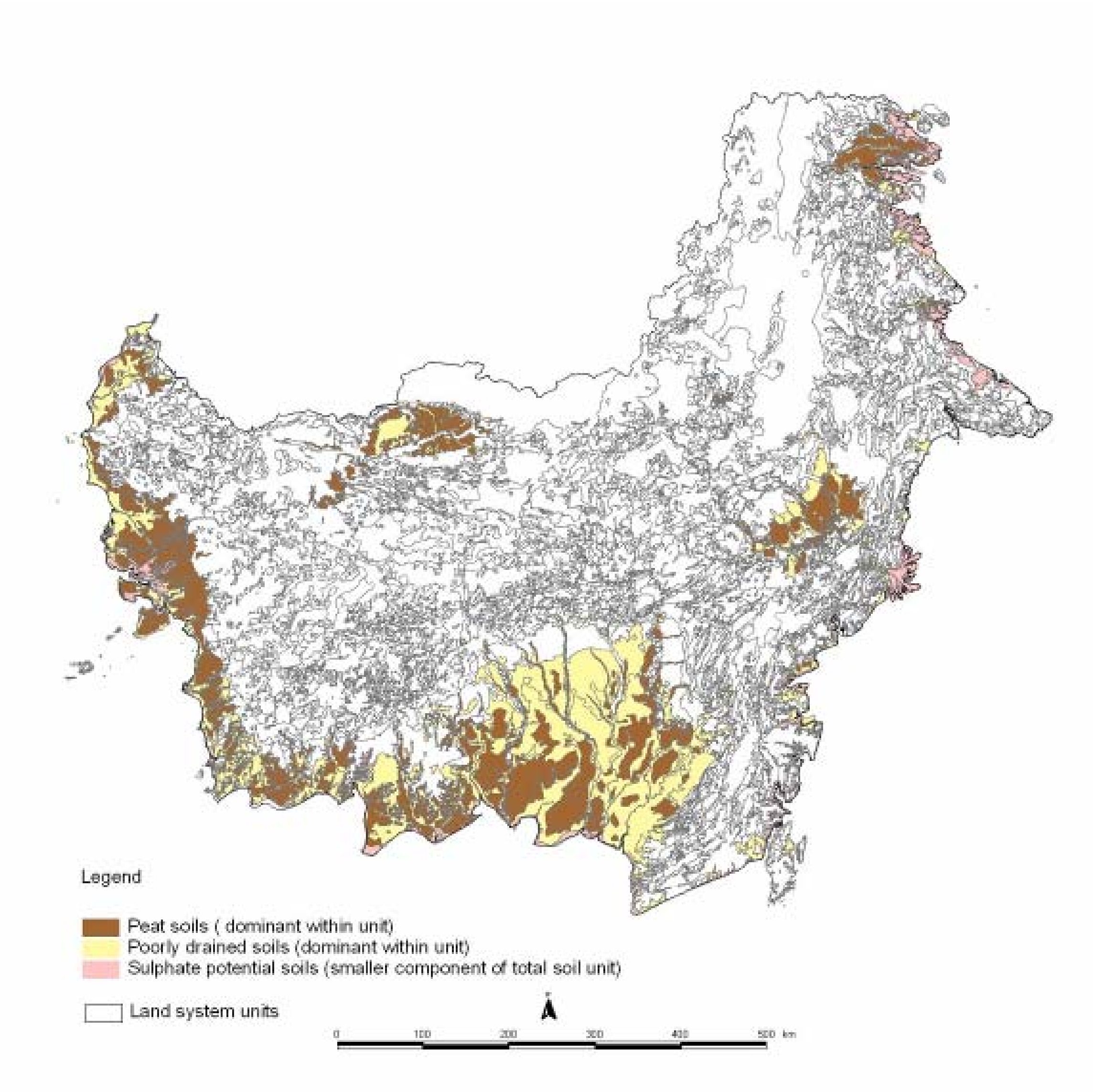


Figure 6. Peat, poorly drained and potential sulphate acid soils in Kalimantan

Adverse chemical conditions

The success of oil palm depends to a large extent on sufficient fertiliser inputs. In particular, dressings of potassium are required, and micro-nutrients such as copper, zinc and boron are fundamental to healthy palm growth on peat soils. Potential acid sulphate soils are characterized by the presence of pyrite (FeS_2). When such soils are drained, the pyrite oxidizes to sulphuric acid, leading to extreme acidification of the soil rendering them unsuitable for oil palm. Such soils are found along the coast of South- and East-Kalimantan. These soils are always a minor component within the soil mapping unit (see Figure 6).

Low water holding capacity and poor anchorage

Low water holding capacity as well as poor anchorage are related to the soil depth. Shallow soils occur mainly in the steep land systems and in land systems with sandstone and limestone plateaus (Figure 7). The major areas of shallow soils are in the central Kalimantan mountain range with the Schwaner and Mueller mountain range in the North of Central Kalimantan extending to the Western part of East-Kalimantan (Iran mountains). Shallows soils are also found in South Kalimantan (Meratus mountains) and the karst mountains and plains on the Sangkulirang Mangkalihat peninsula in East-Kalimantan.

Due to poor anchorage, oil palm on peat soils tends to lodge. Practices such as compacting the planting row prior to planting and using the 'hole-in-a-hole' method of planting help to minimize this problem. Only the top layer above the water table can be compacted. Compaction does not cause a loss in material, but it does contribute substantially to the initial peat subsidence.

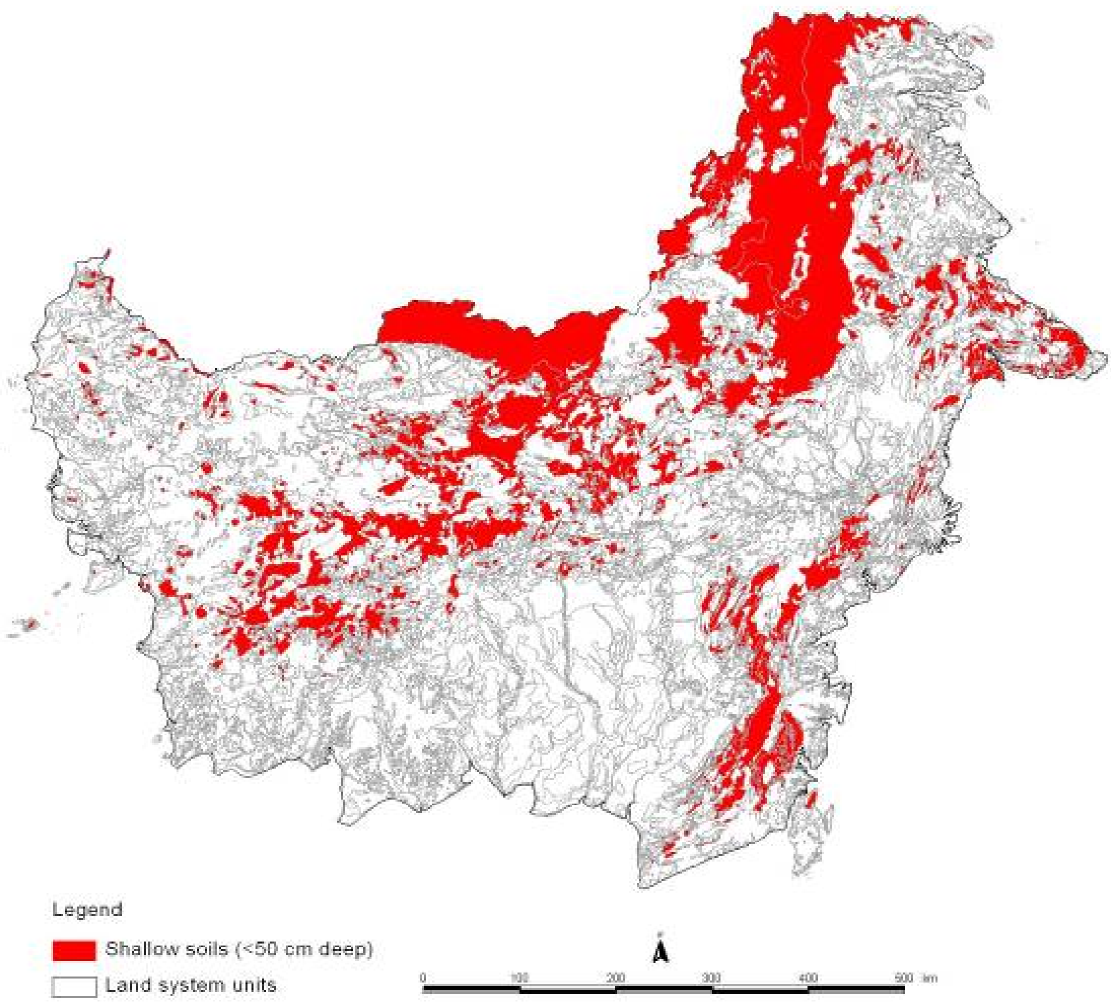


Figure 7. Shallow soils and soils with poor anchorage (dominant soils shown only) in Kalimantan

3.2 Land suitability mapping

Based on the available information the oil palm suitability map (Figure 8) was created. Table 3 shows the total area of land in Kalimantan with constraints for oil palm cultivation. Peat soils, steep lands, poorly drained conditions, shallow soils, and presence of acid-sulphate soils are the dominant limitations. Table 5 summarizes the land systems that have been classified as unsuitable for oil palm cultivation.

Table 3. Area of problems soils and steep lands

Constraint	ha	km^2	% of total area
Potential acid-sulphate soils	1104873	11049	2.1
Poorly drained mineral soils	4741327	47413	8.9
Peat soils	5899259	58993	11.0
Steeplands (slope >30%)	5623260	56233	10.5
Shallow soils	3269829	32698	6.1

About half the area of Kalimantan is considered highly to moderately suitable for oil palm (Table 4, Figure 8). About 11% of the total area is considered marginally suitable, implying that oil palm can be produced but severe constraints exist and these may partly be overcome by management. In about a third of Kalimantan the growth of oil palm is not economic under any likely circumstances.

Dominant constraints are slope steepness and soil drainage (Figure 4 and Figure 6). The latter can partly be overcome by management interventions.

Table 4. Extent of suitability classes for oil palm

Suitability class	km^2	% total area
Optimal	8752	2
Possible	264027	49
Constrained	56781	11
Not suitable	198405	37
No data	6876	1

Table 5. Unsuitable land systems for oil palm

Land system description	Main limitation	LS code
Extremely steep sided volcanic plugs, hills	Slope steepness	TBA
Sub-parallel ridges over basic rocks	Slope steepness	JLH
Mountain ridges over basic rocks	Slope steepness	BPD
Rugged karst ridges and mountains	Slope steepness	OKI
Granite mountain ridge systems	Slope steepness/soil depth	TWI
Steep hills over basic & metamorphic rock	Slope steepness/soil depth	PLN
Flat sandy terraces, covered by peat	Wetness/soil depth	BRH
Backswamps of inland floodplains	Wetness	PMG
Shallow peat swamps (base management)	Wetness	MDW
Swampy floodplain of narrow valleys	Wetness	BLI
Intertidal mudflats	Wetness/salinity	KJP
Coalescent, estuarine/riverine plains	Wetness/salinity	KHY
Deep (>2 m) peat swamps	Foothold for roots	GBT

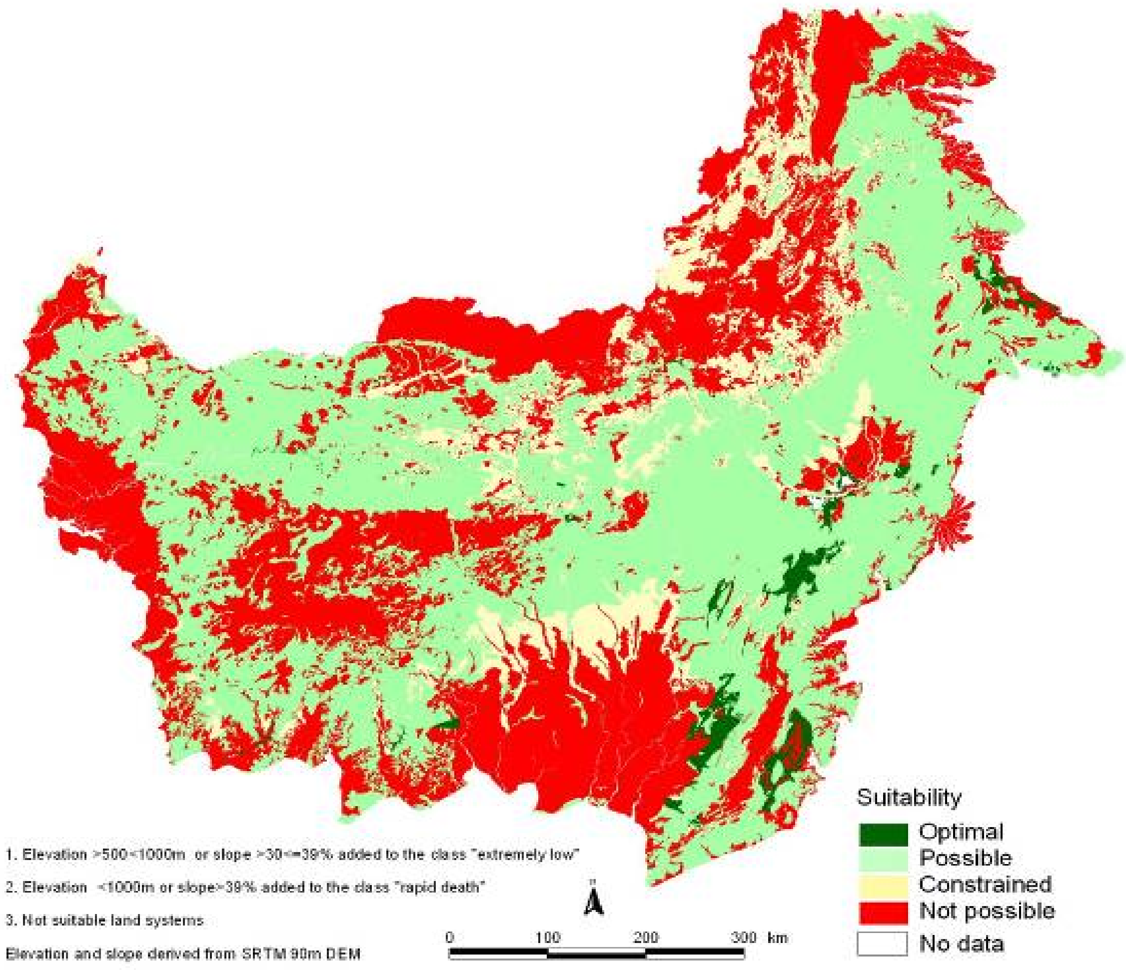


Figure 8. Physical suitability for oil palm under low input and technology (base management), (map representation for dominant soils only)

3.3 Management levels and land suitability

Management levels greatly influence crop yields. Smallholders who provide few external inputs will achieve lower yields than large-scale developers that provide all required inputs in a timely manner. Taking these factors into account, management shifts have been created, which are related to the levels of input defined under the different management systems and indicate how well a particular management type could overcome a given constraint. Two levels of management have been applied:

High, which was defined as:

- supply of fertilizers in a timely manner
- minor soil drainage works as required
- timely weeding/spraying
- high level road maintenance
- 25 ha lower limit block size
- proper labour supervision to ensure regular fruit bunch collection
- steeper slopes to be planted with care to avoid soil erosion

The following amelioration activities are assumed to be beyond the capability of 'high levels' of management:

- major flood control
- major soil drainage works
- water control to prevent acid-sulphate soil development
- terracing of steep land

Base, where management refers to the cultivation of a site in its natural state with no management inputs other than clearing. Basic land qualities such as the natural soil fertility and drainage status of the soil will thus be very important in ensuring reasonable yields. Similarly, block size will be much less relevant to a traditional farmer than a large-scale developer.

Slope conditions are relevant in the planting phase mainly. After planting no further land preparation is required and harvesting can be carried out by hand. Slope criteria are less stringent under base management. However, sloping land is more limiting for high-level management because of machinery accessibility. Similarly, strongly dissected land (small blocks) is a limitation for a high management level since it implies high costs for road and bridge construction.

For maintenance (e.g. weeding, fertilization, pest and disease control) and harvesting, one 4- or 5-tonne farm tractor is usually required for every 250 ha. In-field collection means transporting the FFB (Fresh Fruit Bunches) from field roads to the ramp alongside the main road, from where a 10-tonne lorry will transport them to the mill. The transportation needs have significant implications for the infrastructure.

Figure 8 and Figure 9 show the physical suitability of oil palm assuming different management levels: base (Figure 8), and high (Figure 9). With sloping land being more limiting for high-level management, more land in the central mountains is considered suitable under base management than under high-level management. The figures show that some of the poorly drained lands -otherwise unsuitable- are potentially suitable under high management with the application of drainage works (although increasing input costs). Draining peat soils for oil palm production is not sustainable because peat decomposes when drained, resulting in CO_2 greenhouse gas emission to the atmosphere and irreversible soil loss. Also with drainage, there is a possibility that all peat is lost before the minimum of production years required for an oil palm plantation to be economic. Peat fires have contributed to the Southeast Asian haze pollution. Biodiversity values and rare flora and fauna on peat swamps are additional arguments for conservation of peat forests and peat swamps.

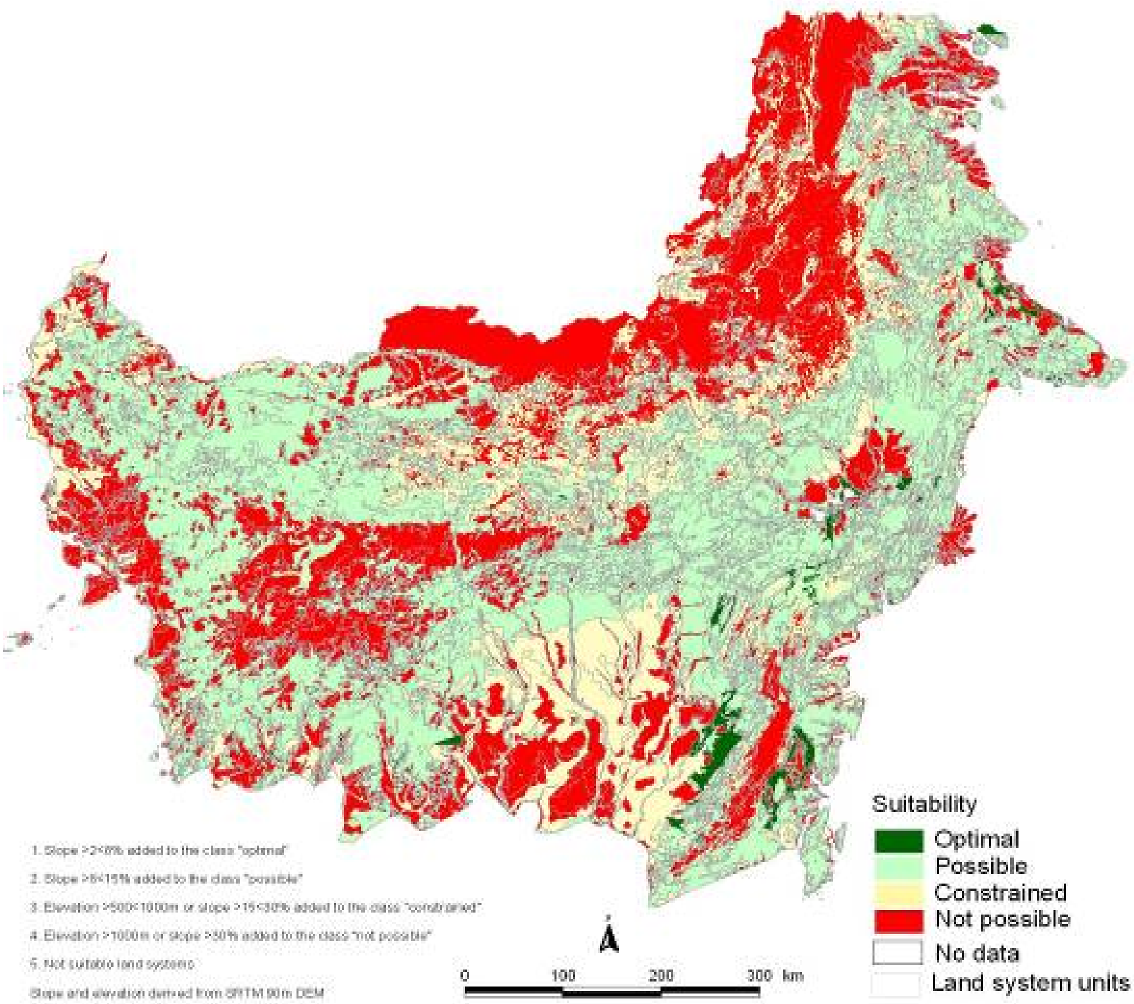


Figure 9. Physical land suitability for oil palm under high levels of input and technology

3.4 Spatial planning and forest management zonation

To estimate the potential area of expansion for oil palm that is both physically suitable and has no other restriction, an analysis was made that included a range of additional criteria. A zonation was made for forest and land management planning. The zonation is the result of a multi-layered analysis of the constraints on forest land management. It considers legal and policy constraints, environmental constraints concerning soil erosion and land degradation, social constraints through land use and tenure issues, and recent proposals contained in the spatial plan (RUTR or RTRWP) for biogenetic diversity conservation and protection. Each of the mapped classes represents a unique combination of these factors, which provide a basis for a sustainable management strategy and spatial planning. The land cover was obtained from RePPProT (1990). Figure 10 is based on Tyrie and Gunawan (1999) and RePPProT (1990) and presents the zonation for forest and land management planning.

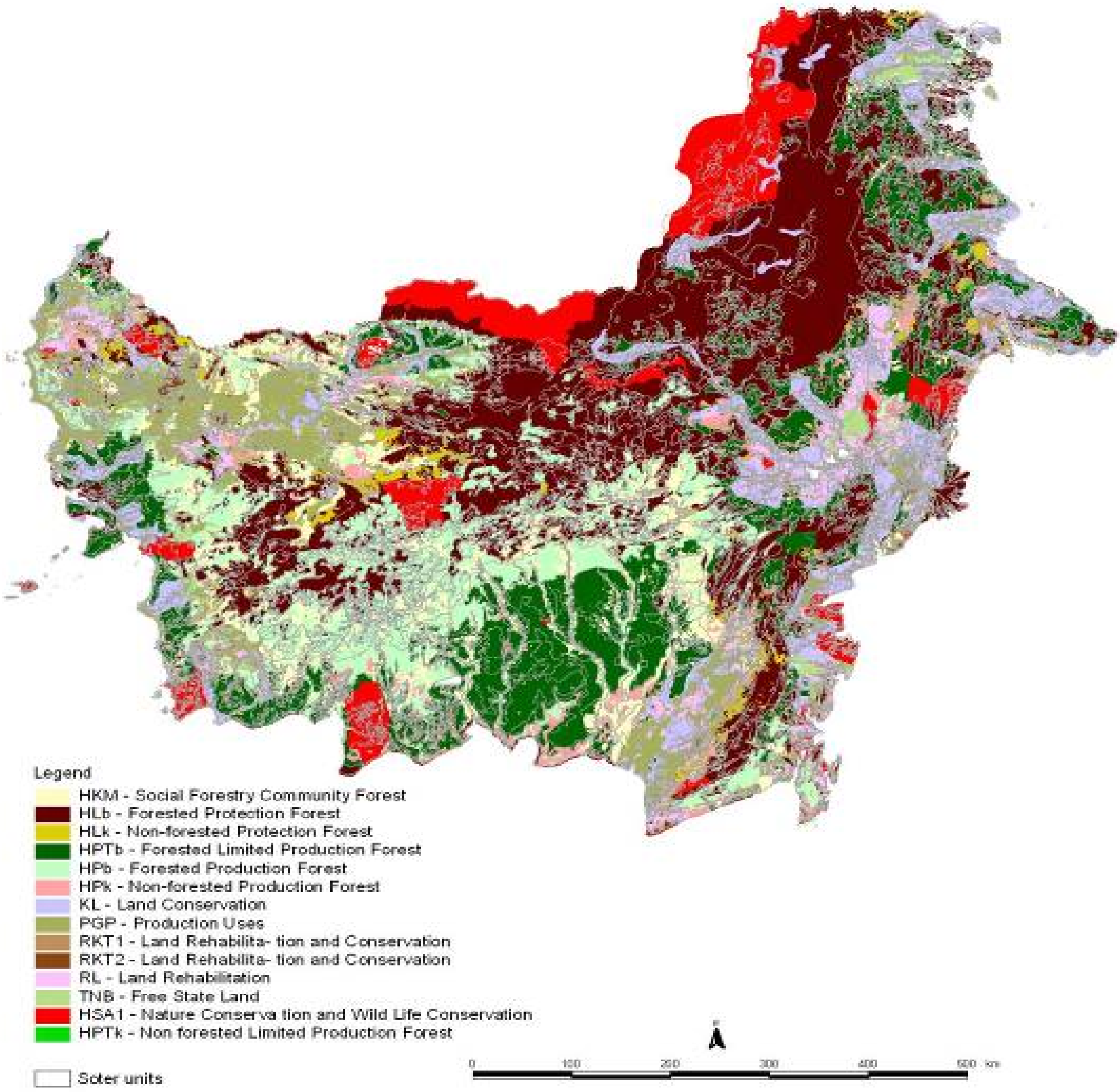


Figure 10. Zonation for forest management planning and their legal land status

The legend of the map of the land status and forest management zonation was simplified to highlight the protected forest areas, the forest reserves, and the fragile lands, to reveal areas with legal and environmental restrictions for use (see Figure 11). The remaining land area (visualized in orange), when overlaid with the land suitability map for oil palm, then indicates the area with potential for expansion for other uses, such as estate crops (oil palm). Yet, even within these areas there will be limitations not taken into account in this analysis.

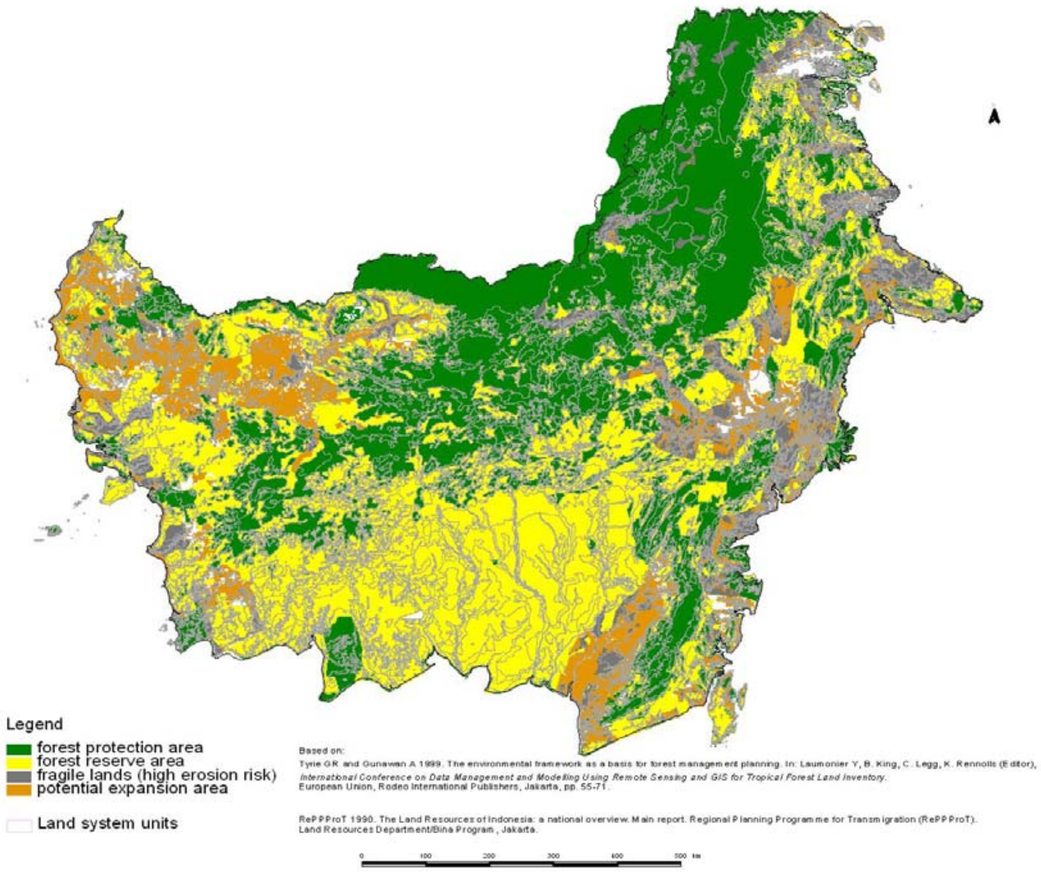


Figure 11. Forest protection status

Figure 10 and Figure 11 illustrate the complexity and multi-dimensionality of policy formulation and planning for sustainable forest management and plantation development. The responsibility for detailed spatial planning and granting concessions has shifted largely to district governments after decentralization of power from the national ministries to the districts in the late nineties. In granting concessions, the spatial dimension of estate crop planning must take the competing claims on land into account and, therefore, should consider environmental, economic, legal and social factors. It is often also a matter of spatial optimization: Where can a certain activity be done in a sustainable and productive way without harming other interests?

DISCUSSION

Possibilities for and the desirability of oil palm expansion and intensification depend on many factors, including biophysical conditions. Other key factors relate to the socio- economic and legal contexts. The biophysical land suitability study for oil palm was restricted to soil, terrain, and climate. About half the area of Kalimantan was classified as highly to moderately suitable for oil palm (base management level).

Recently, there has been considerable discussion about the plans for large-scale expansion of oil palm plantings in Kalimantan, along the Kalimantan-Sarawak-Sabah border. Definitions vary between Ministries, of the width of what is called the ‘Border oil palm mega-project’; between 5 kilometres up to 100 kilometres. Judging from the land suitability maps, the land in Kalimantan adjacent to the border with Sarawak and Sabah is dominantly unsuited for oil palm cultivation. Minor areas are considered suitable, but severely constrained, with the exception of an area in Bulungan (N-NE of East Kalimantan) and part of the West-Kalimantan border area in which oil palm establishment is biophysically possible.

Other land suitability studies done for the border area, although based on different assumptions and different methodologies, also found the major part of the border area to be unsuitable for oil palm cultivation (Bappenas 2006; IOPRI 2006; Wakker 2006).

The heart of Borneo, which is largely the Iran Mountains and the Schwaner and Mueller mountains in South and central Kalimantan, is largely overlapping with the ‘mega-border area’.

For planning and land negotiation, biophysical suitability is but one aspect of potential quality of land use. Foremost, other factors are to be considered such as the legal status of land, actual land use, biodiversity conservation, and social and tenural aspects. Indonesia has clear rules and regulations related to the use of forestland and which areas are eligible for exploitation, but these are not always enforced.

Access to land for plantation development is granted by the regional government. The Governors’ office draws up a provincial land use plan every 5 years. For changing conversion of forest land for agricultural purposes, permission is needed from the Ministry of Forestry (MoF) (Potter and Lee 1998). Due to its limited presence in the region, there are numerous discrepancies in the process of granting concessions; the compilation and approval of the provincial land use plans (RTRWP) need to be re-examined (Potter and Lee 1998). After decentralization, spatial plans are being developed at district level and therefore deviate from the earlier centrally-developed spatial plans.

Redirecting plantation development to degraded lands would facilitate the desired development of the oil palm sector while minimizing the impact of further development on Indonesia’s existing forest cover (Casson 2000). In principle, oil palm cultivation is well possible on the dominant upland soils of Kalimantan that have severe restrictions for other agricultural purposes. However, these soils are easily erodible, acid and relatively infertile and, if they are to be developed at all, then they are best managed with controlled estate crops (acid and aluminium tolerant species/varieties), properly managed, with adequate soil cover, lime and fertilizer application.

Peat soils should receive a priority in conservation. Draining peat soils for oil palm production is not sustainable because peat decomposes when drained, resulting in CO_2 greenhouse gas emission to the atmosphere –often aggravated by peat fires- and irreversible soil loss. However, in deforested and already drained and degraded peatlands, agricultural cropping has the potential to reduce fire risks and annual greenhouse gas emissions.

The methodology presented in this study can be applied using recent land cover information, more detailed soil maps, and district spatial plans.

Affiliation

On request of the Department of International Affairs of the Ministry of Agriculture, Nature and Food Quality (LNV), a study was conducted on Land Suitability for Oil Palm in Kalimantan, Indonesia. The study was carried out by Ir. Stephan Mantel, Mr. Jan Huting (ISRIC – World Soil Information), Mr. A. Gunawan (short term consultant), Dr Henk Wösten (Alterra, Wageningen UR, project leader) and Dr Jan Verhagen (Plant Research International, Wageningen UR). Contact persons at LNV were Ir. Karin Olsthoorn, Drs. Marcel Vernooij, Drs. Petra van den Hende and Dr. Leo Hagedoorn.

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APPENDIX - PLANTGRO land suitability model

PLANTGRO (Hackett 1991) is a simple model that matches crop requirements with environmental (climate and soil) conditions (see Table 6). The relationship between the environment and crop are depicted using simple graphs, are empirical and can easily be adjusted. Crop requirements are matched against the environmental conditions to establish the land suitability for a specific crop. The model determines yield reduction based on the most limiting factor. Limitations are rated on a scale of 0 to 9, 0 being optimum and 9 lethal for the crop. In general scores of 0 to 5 are considered optimal to moderately suitable, for 6 and 7 production is possible, for score 8 production is strongly limited and 9 indicates that the crop can not grow given the environmental conditions.

Table 6. Soil and climate factors used by PLANTGRO for site assessment

Cation exchange capacity	Solar radiation
Base saturation	Tolerance to brief cold
Soil reaction (pH)	Tolerance to extended cold
Nitrogen (N) Phosphorus (P) Potassium (K)	Tolerance to heat damage
Salinity	Thermal units
Effective soil depth	Water availability
Soil texture	Seasonal water logging
Slope	Flooding
	Susceptibility to wind damage

Some constraints can be remedied by management. Drainage and irrigation control excess and shortage of water. Applying fertilizers, lime etc. aim to improve the chemical condition of the soil. Crop management like the timing of planting or timing of preventive treatments against pest and disease outbreaks can be assessed for a given set of soil and climate conditions.

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