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Evaluation of post-mining land for rubber and oil palm plantations in Kutai Kartanegara, Indonesia

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Abstract: This study aimed to understand the limiting factors of rubber plant and oil palm growth and to find out the appropriate technology, soil, and land management for rubber and oil palm plantations. This study was conducted in post-mining land known as "Limited Company Mahakam Sumber Jaya" in Kutai Kartanegara (East Kalimantan, Indonesia), over an area of 121 hectares, between November 2015 and April 2016. The primary data collected by soil and land surveys consist of physical characteristics and vegetation biodiversity. Some other physical and chemical characteristics data resulted from laboratory of soil analysis. In this study, land suitability classification for rubber and oil palm plantations were evaluated using parametric methods by rating the climate components, soil, and land characteristics. According to the analysis of climate components, climate suitability for rubber and oil palm plantations belongs to class S1 (very suitable). On the other side, in terms of land evaluation for rubber plantation based on soil analysis data and land characteristics, the area was classified into class S3 (marginally suitable, 25 hectares with slope and soil fertility as limiting factors) and class N1 (currently not suitable, 96 hectares with soil depth, soil fertility, texture, and drainage as limiting factors). The same classes were observed for oil palm plantation, land area was classified into class S3 (marginally suitable, 75 hectares with soil depth, texture, and fertility as limiting factors) and class N1 (currently not suitable, 46 hectares with slope, soil depth, fertility, texture, and drainage as limiting factors).

Keywords: land evaluation, post-mining, rubber, oil palm.

Introduction

Rubber tree (*Hevea brasiliensis* Müll. Arg.) and oil palm (*Elaeis guineensis* Jacq.) are important and strategic plantations in East Kalimantan, Indonesia because their productions are one of large export commodity and foreign exchange earner for Indonesia. Rubber tree produces latex that is used for the manufacture of lump, crumb rubber, and sheet rubber. Indonesia is the largest producer and exporter of oil palm worldwide. Oil palm is exported in the form of crude palm oil (CPO) and palm kernel oil (PKO). East Kalimantan with an area of 211,440 km^2, in 2016 had a planted area of 1,090,106 hectares of oil palm with a production of 10,812,893 tons of crude palm oil (CPO),and a rubber plantation area of 49,311 hectares with a production of 62,106 tons of latex (Estate Service of East Kalimantan Province, 2016).

Currently, plantation development is faced with limited land due to land conversion activity such as from productive land to settlement land and infrastructure development (Suhendry *et al.*, 1996; Hardjowigeno and Widiatmaka, 2001). The existence of competition in the use of land with other sectors such as food crop agriculture and mining encourages to use marginal lands and/or sloping land for the development of these commodities (Beek, 1974; Sitorus *et al.*, 2008). Among marginal lands, widely available one in East Kalimantan is coal post-mining land.

The area of coal mining area in East Kalimantan Province in 2015 reached 5,908,000 hectares (Jatam, 2015) and it is expected to increase further. After the coal mining activities are complete, it will cause land damage and leave a land which is different from its original properties before being mined (Kustiawan, 2001; Sitorus *et al.*, 2008). Besides, coal mining also causes a disturbance of the land ecosystem, i.e. changes in the horizon sequence along the soil profile, with rocks and ground material originally located in the lower layers moved to cover the ground (Dallaire *et al.*, 2015; Legwaila *et al.*, 2015). In other terms, the post-mining land is highly degraded. Physical degradation is characterized by chunks of underlying rock with massive structure, sandy texture, and low water holding capacity. Chemical degradation is characterized by the lack of nutrients availability, high acidity, the emergence of heavy metals contamination, and the emergence of toxic elements when mining wastes are exposed to air and water. Furthermore, the biological degradation is indicated by a low soil organic matter content (Mummey *et al.*, 2002; Sitorus *et al.*, 2008).

The level of post-mining hardness is high, as the epipedon consists of sandstone, clay and gravel fragments, and sand fractions. As a result, the land is either easily eroded or affected by landslides (Devictor *et al.*, 2008). This is not very suitable for plant growth. Due to the more active mining business, post-mining land management needs to get more serious attention so that negative impacts can be minimized (Mactarlane *et al.*, 2006; Angel *et al.*, 2008).

Commonly, after the end of coal mining activities, other potential and alternative land uses are considered to be applied. As previously explained above, rubber and oil palm are important crops in East Kalimantan. Therefore those crops have a chance to be cultivated in this area. Due to the many negative effects found in the area of post-mining land use, hence, land evaluation must be carried out before using the land for cultivating rubber tree and oil palm.

Thus, in this study, several properties of post-mining land were evaluated to assess whether this land is suitable for the cultivation of rubber tree and oil palm. Those land properties include climate, topography and derived indezes, and soil properties such as texture, structure, occurrence of sandstone as soil parent material, $CaCO_3$, $Ca(SO_4)_2$, cation exchange capacity (CEC), base saturation (n), pH, organic carbon (C-org), salinity and alkalinity.

Materials and Methods

Field Survey and Data Collection

The study was undertaken in an area of 121 ha on post-mining land owned by the mining company “Limited Company Mahakam Sumber Jaya”, in the District of Kutai Kartanegara. Field survey was conducted between November 2015 and April 2016. Soil samples were analyzed in the Soil Laboratory, Faculty of Agriculture, Mulawarman University between May and June 2016.

Twelve soil samples have been collected from 6 soil profiles as described in Table 1.

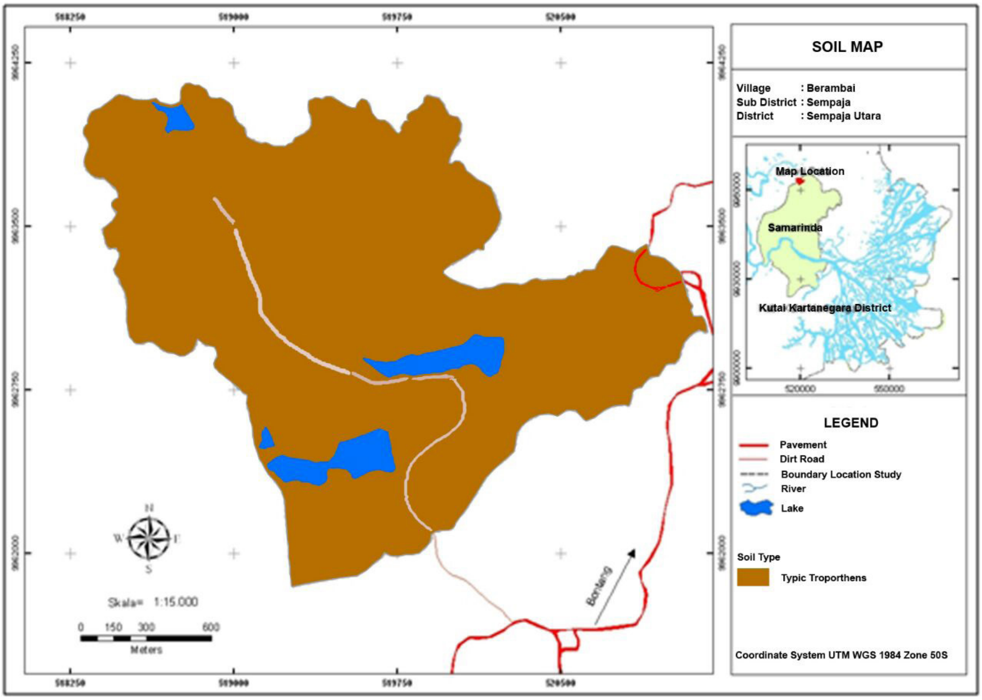

Figure 1 - Soil map of the study area.

Table 1 - Soil profiles in the area of "Limited Company Mahakam Sumber Jaya" post-mining land.

Soil Profiles	Soil Mapping Unit (SMU)	Soil Samples	Soil Depth (cm)	Descriptions
Profile 1	SMU 1	Horizon A	0-30	Dark grayish brown (5 YR 4/2), sandy loam texture, friable consistency, many pores, many roots, sharp horizon boundary.
		Horizon AC	30-55	Grayish (5 YR 4/1), sandy loam texture, friable consistency, many pores, gravel, abrupt horizon boundary.
Profile 2	SMU 2	Horizon A	0-30	Dark gray (5 YR 4/1), sandy loam texture, friable consistency, many pores, many roots, diffuse horizon boundary.
		Horizon AC	30-55	Grayish (5 YR 3/2), clay loam texture, sticky consistency, few pores, few fine trained siliciclastic sedimentary rocks,claystone, abrupt horizon boundary.
Profile 3	SMU 3	Horizon A	0-30	Yellowish brown (7.5 YR 5/6), clay loam texture, firm consistency, few pores, many roots, diffuse horizon boundary
		Horizon AC	30-55	Dark brown (7.5 YR 5/8), clay loam texture, firm consistency, few pores, claystone, abrupt horizon boundary

Table 1 - continued

Soil Profiles	Soil Mapping Unit (SMU)	Soil Samples	Soil Depth (cm)	Descriptions
Profile 4	SMU 4	Horizon A	0-32	Yellowish brown (10 YR 4/5), clay loam texture, firm consistency, few pores, many roots, undulating horizon boundary
		Horizon AC	32-60	Brown (7.5 YR 5/4), clay loam texture, firm consistency, few pores, claystone, abrupt horizon boundary
Profile 5	SMU 5	Horizon A	0-30	Yellowish brown (10 YR 4/5), clay loam texture, firm consistency, few pores, many roots, sharp horizon boundary
		Horizon AC	30-55	Brown (7.5 YR 5/4), clay loam texture, firm consistency, few pores, few roots, many claystone, abrupt horizon boundary
Profile 6	SMU 6	Horizon A	0-25	Dark grayish brown (5 YR 4/2), clay loam texture, firm consistency, few pores, many roots, abrupt horizon boundary
		Horizon AC	25-50	Brown (7.5 YR 5/6), clay loam texture, very firm consistency, few pores, few claystone, abrupt horizon boundary

At this stage, we collected other information about the study area, i.e. climate data, vegetation, geology, and other data that support the research.

Soil mapping units (SMUs) were identified based on differences in slope, drainage, soil physics (color, texture, consistency). The results of these observations were displayed in the form of Land Unit Map with a scale of 1:2,500 as described in Figures 2 and 3. Slope at each data point was measured using a clinometer.

Soil sampling was performed by adopting a regular grid with a spacing of 50 meters. At each node of the grid, soil was sampled with a hand borer. If there is no the differences of physical properties between one node of the grid and others, drilling was continued. If there is a difference, the limit of soil mapping unit was created. In this research, 12 soil samples have been collected from 6 soil profiles. Then, soil samples were analyzed in soil laboratory. Analysis results were evaluated to determine the physical and chemical soil properties. From this analysis, it is known that the sub-group of soil belongs to Typic Troporthens. Within each soil mapping unit, a soil profile was excavated and described in terms of morphological characteristics (color, structure) and surrounding environment. Next to the horizon in the soil profile, 1 kg of soil sample was collected and analyzed in the laboratory for physical and chemical properties including soil texture, consistency of soil aggregates, pH, CEC, base saturation, C-org., NPK, and exchangeable aluminium (Dent and Young, 1981).

Data Analysis and Land Evaluation

Parametric method to calculate the climate index (CI)

To determine the land suitability class based on Climate Index, a weighting score is given to the climatic characteristics with a value between 0–100. Climate characteristics having a maximum value of 100 correspond to the optimal plant growth, while a minimum rating will have a very negative effect on plant growth. Climatic characteristics for rubber tree and oil palm plantations are presented in Table 1 of Appendix 1, while monthly rainfall amounts (2001-2010) for the study area are shown in Table 2 of Appendix 2.

The value of Climate Index (CI) is calculated using the following equation:

$$CI = R\min x \sqrt{\frac{A}{100} x \frac{B}{100} x \ldots} \qquad (1)$$

where:

CI = climate Index

R min = minimum rating

A, B,... = another rating except the minimum rating

The climate index values obtained were then converted to determine the climatic suitability class according to Table 2.

Table 2 - Value of climate index and class of climate suitability.

Climate Index	Climate Suitability	Limitation
75–100	S1 = Very suitable	No
50–75	S2 = Moderately suitable	Light
25–50	S3 = Marginally suitable	Moderate
12.5–25	N1 = Currently not suitable	Heavy
0–12.5	N2 = Permanent not suitable	Very Heavy

Source: Beek (1974)

Parametric method to calculate land index (LI)

This method begins by weighting any land or land characteristics including climate, topography, wetness index, soil physical property, fertility, salinity, and alkalinity (Sys *et al.*,1991). Ratings range between 0–100. Land characteristics with a maximum value of 100 will result in optimal plant growth, while the land characteristics with a minimum rating will negatively affect plant growth.

The ratings used to calculate the land index are calculated using the following equation:

$$\boldsymbol{L} = R\min x\sqrt{\frac{A}{100}x\frac{B}{100}x...} \qquad (2)$$

where:

LI = Land Index

R min = Minimum rating of land characteristic

A, B,... = Other land characteristics rating except the minimum rating

The land index value obtained is used to determine land suitability class. The list of land indexes is shown in Table 3.

Table 3 - Value of land index and land suitability class.

Land Index	Land Suitability Class	Limitation
75–100	S1 = Very suitable	No
50–75	S2 = Moderately suitable	Light
25–50	S3 = Marginally suitable	Moderate
12.5–25	N1 = Currently not suitable	Heavy
0–12.5	N2 = Permanent not suitable	Very Heavy

Source: Sys et al. *(1991)*

For some soil properties, the calculation has been weighted according to soil depth. A divisor and the corresponding weighting factors has been derived according to Table 4 (Sys *et al.*, 1991). Likewise, the cation exchange capacity (CEC) of clay has been derived from a total depth of 50 cm or horizon B, while for cation bases (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), pH, and C-org. content the values have been calculated for a reference depth of 25 cm.

Table 4 - Splitter and weighting factors for different soil depth.

Soil Depth (cm)	Divisor	Weighting Factors
125–150	6	2.00–1.50–1.00–0.75–0.50–0.25
100–125	5	1.75–1.50–1.00–0.50–0.25
75–100	4	1.75–1.25–0.75–0.25
50–75	3	1.50–1.00–0.50
25–50	2	1.25–0.75
25	1	1.00

Source: Sys et al. *(1991)*

Determination of subclass of land

Subclasses of land are expressed with a letter and indicate the type of land characteristics that is the most limiting factor. Characteristics of land used as a limiting factor as described by Sys et al. (1991) are the following: climate (c), topography (t), wetness index (w), physical properties of soil (s), soil fertility (f), and salinity or alkalinity (n).

Results

Climate Suitability Class

Evaluation of climatic suitability of rubber tree and oil palm plantations is presented in Table 5.

Table 5 - Climate suitability evaluation for rubber and oil palm.

Climate Characteristics	Value	Rating	
		Rubber Tree	Oil Palm
Annual rainfall (mm)	2 282	100	100
Month of excess rain	0	100	*
Long dry season (month) <1/2 PET	0	100	100
Average annual temperature (˚C)	27.7	100	100
Average annual maximum temperature (˚C)	31.9	100	100
Average minimum temperature in the lowest month (˚C)	23.5	100	100
n/N	0.45	95	95

**: not used PET = Potential Evapour Transpiration n/N = sunshine hours / maximum sunshine (hours per day)*

Land Suitability Class

Evaluation of land suitability for rubber tree and oil palm in soil mapping unit (SMU 1 to SMU 6) are presented in Tables 6 and 7, respectively. Land suitability class for rubber tree and oil palm plantations are presented in the following Figure 2 and Figure 3, respectively.

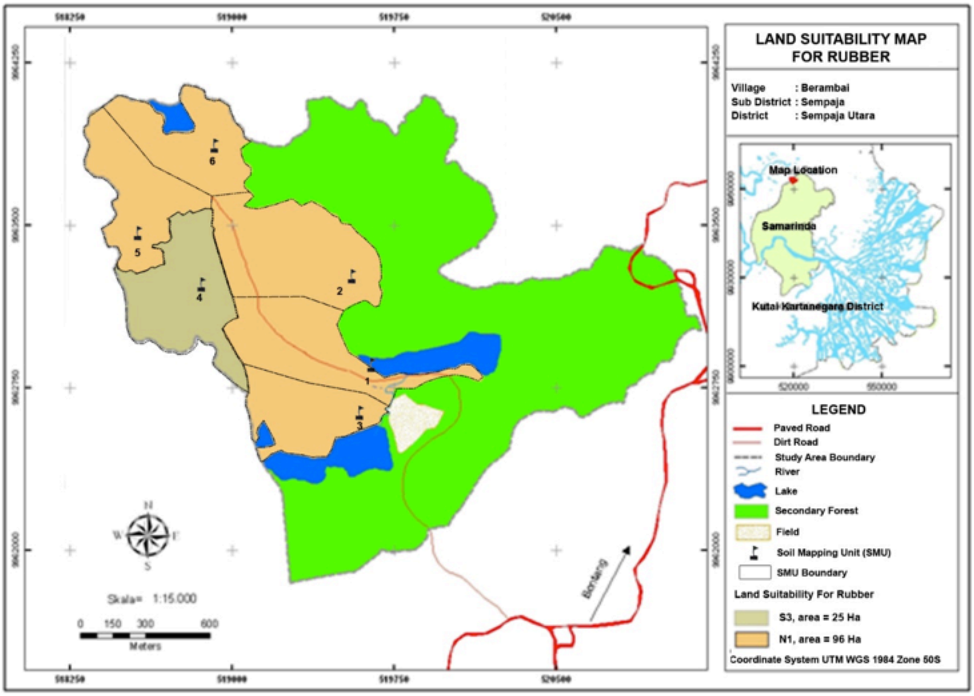

Figure 2 - Land suitability map for rubber tree.

Discussion

Climate Suitability Map

The analysis and calculation of the climate components (Table 5) included rainfall, length of the dry season, average air temperature, and the ratio of long radiation (Q) for rubber tree and oil palm in the study area over a period of 10 years (2005–2014). The data are as follows:average annual rainfall 2,282 mm, monthly average rainfall 190.17 mm, 102 rainy days,average annual temperature 27.7°C, ratio of dry to wet

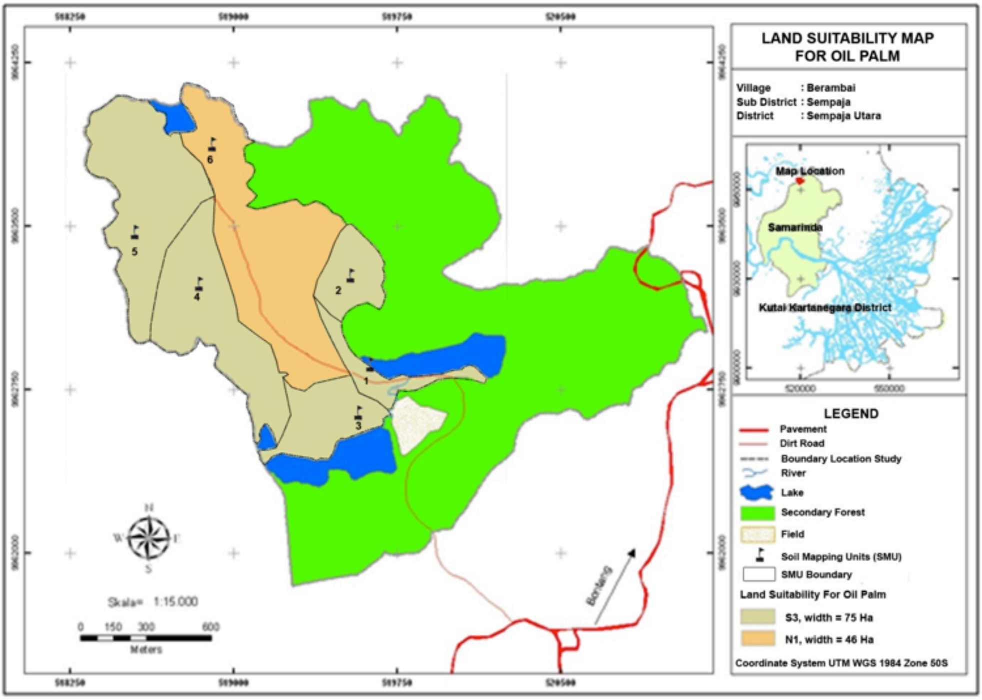

Figure 3 - Land suitability map for oil palm.

Land suitability for rubber tree is presented in Figure 2. Soil mapping unit 1, area is 20.39 hectares (21.24%), belongs to S3tds class (marginally suitable) which has strong limiting factors for the rubber plant growth, i.e. 30% slope, effective soil depth of 40 cm, and a sandy loam texture. The best suitable areas for rubber plant growth are found on slopes between 0–4% (i.e. flat) with soil depth more than 200 cm and a clay loam soil texture (See Table 3 at Appendix 3).

Land in soil mapping unit 4, area is 25 hectares (100%), was classified into N1dsf class (currently not suitable) and has as limiting factors a 40 cm soil depth, a sandy loam soil texture, and a very low Cation Exchange Capacity (CEC) of 15 meq/100 g.

Soil mapping unit 3 belongs to S3dwf, area is 15.01 hectares (15.63%) class (marginally suitable), its soil pH is 4.4, while rubber plant requires perfect drainage, soil pH >5.0, and soil depth > 200 cm.

Land in soil mapping unit 2, area is 26.90 hectares (28.02%), belongs to S3df class (marginally suitable), with the limiting factors being the soil depth (80 cm) and a pH of 4.2.

Soil mapping unit 5, area is 17.56 hectares (18.30%), belong to S3dfs class (marginally suitable), with the limiting factors being soil depth (90 cm), CEC (14

Table 6 - Evaluation of land suitability for rubber tree crop in Soil Mapping Unit (SMU) 1-6.

Land Characteristics	SMU 1		SMU 2		SMU 3		SMU 4		SMU 5		SMU 6	
	Data	Rating	Data	Rating	Data	Rating	Data	Rating	Data	Rating	Data	Rating
Climate	95	100	95	100	95	100	95	100	95	100	95	100
Topography (t)												
Slope (%)	30	40	0-2	100	0-2	100	15	85	15	85	8	95
Wetness (w)												
Flooding	F0	100	F0	100	F0	100	F0	100	F0	100	F0	100
Drainage	moderate	100	perfect	100	imperfect	60	Moderate	100	perfect	100	perfect	100
Physical Soil Properties (s)												
Texture	SL	60	SL	60	SL	60	SCL	85	SL	75	SL	75
Coarse fragments (% volume)	0	100	30	80	30	80	0	100	0	100	0	100
Soil Depth (cm)	>40	55	40	55	50	55	>80	60	90	60	70	60
$CaCO_3$ (%)	0	100	0	100	0	100	0	100	0	100	0	100
Gypsum (%)	0	100	0	100	0	100	0	100	0	100	0	100
Fertility (f)												
Apparent CEC (cmol(+)kg^{-1} clay)	14	70	15	70	22	85	13	70	14	60	12	60
Base saturation (%)	40	90	32	85	25	100	20	85	24	85	12	70
Sum exchangeable basic cations (cmol(+)kg^{-1} soil)	6.72	100	6.74	75	6.0	75	2.6	95	5.0	60	2.7	90
pH in water (H_2O)	4.6	65	4.7	85	4.4	60	4.2	60	4.3	60	3.5	60
Organic Carbon (%)	4.1	100	2.7	100	1.0	85	2.4	100	1.0	90	2.0	100
Salinity and Alkalinity (n)												
ECe (dS/m)	0	100	0	100	0	100	0	100	0	100	0	100
ESP (%)	0	100	0	100	0	100	0	100	0	100	0	100
Land Index	15.26		23.46		21.72		29.70		19.47		24.12	

F0=no flooding, SL= Sandy Loam, SCL=Sandy Clay Loam, CEC = Cation Exchange Capacity, ECe = Electric Conductivity of the saturated paste extract, ESP =Exchangeable Sodium Percentage meq/100 g), and pH (4.3).

Soil mapping unit 6, area is 16.05 hectares (16.72%), was classified into S3dfs class (marginally suitable), with the limiting factors soil depth (70 cm), soil pH (3.5), low CEC, and sandy loam soil texture.

Oil palm suitability map is presented in Figure 3. Land on soil mapping unit 1, area is 5.46 hectares (7.28%), belongs to the S3tds class (marginally suitable) which has strong limiting factors for oil palm growth, i.e. 30% slope, effective soil depth of 40 cm, and a sandy loam texture. The suitable areas for oil palm growth should have a slope between 0–4% (flat), soil depth more than 150 cm, and a clay or silty clay soil texture (See Table 3atAppendix 3).

Land in soil mapping unit 2, area is 7.72 hectares (10.29%), was classified as S3dws (marginally suitable), as its limiting factors are soil depth (40 cm), imperfect drainage, and a sandy loam soiltexture. Oil palm plant requires perfect drainage, groundwater depths > 150 cm, and clay or clay loam soil texture.

Land in soil map unit 3, area is 10.50 hectares (14.01%), belong to S3dwf class (marginally suitable), with the limiting factors being soil depth (50 cm), imperfect drainage, and soil pH (4.4).

Land in soil mapping unit 4, area is 23.81 hectares (31.75%), was classified as S3fsd (marginally suitable), with the limiting factors CEC (13.0 meq/100g), soil pH(4.2), and soil depth (80 cm), while oil palm plantations require a soil depth above 150 cm and pH more than 5.5.

Soil mapping unit 5, area is 27.48 hectares (36.35%), was classified into S3sf class (marginally suitable), with the limiting factors being the sandy loam soil texture and pH (4.3).

Land in the soil mapping unit 6, area is 46.00 hectares (100%), belongs to N1dfs class (currently not suitable), with the limiting factors being soil depth (only 70 cm), pH (3.5), CEC, and sandy loam soil texture. The topography of the land is more than 30% steep, which means that it is sensitive to water erosion, especially where land that has not been covered by continuous vegetation yet, because of high rainfall, namely 2,282 mm peryear (Sys *et al.*, 1991; Sindu, 1999).

Conclusions

Based on the observations it can be concluded that in terms of the climate components of suitability for rubber and oil palm plantations to the study area is very suitable (S1 class). Nevertheless, land suitability is only marginal or not suitable. According to soil survey data and soil laboratory analysis, it can, in fact, be concluded that land suitability at post-mining land for rubber tree was classified into S3 class (marginally suitable) with an area of 25 hectares, and N1 class (currently not suitable) with an area of 96 hectares. While for oil palm was classified into S3 class (marginally

Table 7 - Evaluation of land suitability for palm oil in Soil Mapping Unit (SMU) 1-6.

LAND CHARACTERISTICS	SMU 1		SMU 2		SMU 3		SMU 4		SMU 5		SMU 6	
	Data	Rating	Data	Rating	Data	Rating	Data	Rating	Data	Rating	Data	Rating
Climate	95	100	95	100	95	100	95	100	95	100	95	100
Topography (t)												
Slope (%)	30	40	0-2	100	0-2	100	15	85	15	85	8	95
Wetness (w)												
Flooding	F0	100	F0	100	F0	100	F0	100	F0	100	F0	100
Drainage	moderate	100	perfect	100	imperfect	60	perfect	100	perfect	100	perfect	100
Physical Soil Properties (s)												
Texture	SL	70	SL	75	SL	75	SCL	85	SL	60	SL	60
Coarse fragments (% volume)	0	100	30	80	0	100	0	100	0	100	0	100
Soil Depth (cm)	>40	60	40	60	50	60	>80	85	90	85	70	75
CaCO3 (%)	0	100	0	100	0	100	0	100	0	100	0	100
Gypsum (%)	0	100	0	100	0	100	0	100	0	100	0	100
Fertility (f)												
Apparent CEC (cmol(+)kg^{-1} clay)	14	85	15	85	22	100	13	85	14	80	12	80
Base saturation (%)	40	90	32	85	25	90	20	100	24	100	12	70
Sum exchangeable basic cations (cmol(+)kg^{-1} soil)	6.72	100	6.74	100	6.0	100	2.6	85	5.0	95	2.7	80
pH in water (H_2O)												
Organic Carbon (%)	4.6	83	4.7	85	4.4	80	4.2	85	4.3	65	3.5	50
	4.1	100	2.7	100	1.0	100	2.4	100	1.0	85	2.0	100
Salinity and Alkalinity (n)												
ECe (dS/m)	0	100	0	100	0	100	0	100	0	100	0	100
ESP (%)	0	100	0	100	0	100	0	100	0	100	0	100
LAND INDEX	24.44		33.57		34.15		37.03		33.05		21.88	

F0=no flooding, SL= Sandy Loam, SCL=Sandy Clay Loam, CEC = Cation Exchange Capacity, ECe = Electric Conductivity of the saturated paste extract, ESP =Exchangeable Sodium Percentage suitable) with area of 75 hectares and N1 class (currently not suitable) with area of 46 hectares.

Moreover, it can be suggested that several management of post-mining area for rubber and oil palm cultivations are needed to be considered such as making adequate planting holes (1 m^3) to increase the soil depth so the volume growth of plant roots can be optimal. The topsoil needs an application of organic fertilizer, inorganic fertilizer, and lime into each planting hole to improve soil fertility which means can increase the values of CEC and soil pH. In addition, to minimize water erosion, it is necessary to make terraces to shorten the length of the slope in order to increase the infiltration and reduce the rate of runoff. For imperfect drained land, small ditches should be created in the surface flow channels. Even though those managements planning are less economic, the extensification are needed after rehabilitation of post-mining land due to the increasing demand in management of oil palm and rubber tree in East Kalimantan. Others extenfication that can be implemented such as peat land clearing, swampy land development by ditch construction, and post mining rehabilitation. For the land having slope undulating until dissected, it is necessary to make terraces. Another effort that can be developed is to utilize sub-optimal land to be more effective and efficient by planting rubber and oil palm on that land.

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APPENDICES

Appendix 1

Table 1 - Climate characteristics for rubber crop and oil palm

Climate Characteristics	Climate classes, limitation level and ratings for rubber						Climate classes, limitation level and ratings for oil palm					
	S1	S2	S3	N1	N2		S1	S2	S3	N1	N2	
	0	1	2	3	4		0	1	2	3	4	
	100 95	85	60	40	25	0	100 95	85	60	40	25	0
Annual Rainfall (mm)	>2000	2000-1700	1700-1450	1450-250	-	<1250	>2000	2000-1700	1700-1450	1450-250	-	<1250
Months of excess rain (x)	0-1	1-2	2-4	>1	-	-	0-1	1-2	2-4	>1	-	-
Dry Season Duration (Month:P<1/2/PET)	0-1	1-2	2-3	3-1	-	>4	0-1	1-2	2-3	3-1	-	>4
Annual Average Temperature (°C)	>25	25-22	22-20	20-18	-	<18	>25	25-22	22-20	20-18	-	<18
Annual Maximum Average Temperature (°C)	>29	29-27	27-24	24-22	-	<22	>29	29-27	27-24	24-22	-	<22
Minimum Daily Average of The Coldest Month (°C)	>20	20-18	18-16	16-14	-	<14	>20	20-18	18-16	16-14	-	<14
n/N	>0.5	0.5-0.4	0.4-0.26	0.25-0.15	-	<0.15	>0.5	0.5-0.4	0.4-0.26	0.25-0.15	-	<0.15

(x) = total of month with rainfall >500 mm, plus ½ of the month with rainfall of 300-500 mm

Appendix 2

Table 2 - Climate database (rainfall) location study 2001-2010

Years	Monthly Rainfall (mm)												Total (mm)	Average (mm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2001	375.5	200.5	282.5	195.0	135.0	223.0	-	-	-	-	-	-	1411.5	235.3
	WM	WM	WM	WM	WM	WM								
2002	243.0	73.0	216.2	93.2	381.0	73.0	157.0	24.7	184.0	182.0	228.0	290.0	2145.0	
	WM	DM	WM	IM	WM	DM	WM	DM	WM	WM	WM	WM		
2003	10.5	68.5	145.1	208.8	130.0	208.8	34.5	71.5	43.9	139.6	270.0	246.9	1578.1	131.5
	DM	DM	WM	WM	WM	WM	DM	DM	DM	WM	WM	WM		
2004	218.6	67.0	67.6	256.4	159.7	214.5	132.7	79.9	194.7	151.2	206.1	275.5	2023.9	168.7
	WM	DM	DM	WM	WM	WM	WM	IM	WM	WM	WM	WM		
2005	141.0	164.4	326.0	138.0	374.0	66.8	14.2	78.6	0.0	29.7	443.5	245.1	2021.3	168.4
	WM	WM	WM	WM	WM	DM	DM	IM	DM	DM	WM	WM		
2006	207.3	317.4	128.0	164.3	359.4	123.1	102.3	70.2	107.5	47.7	219.5	204.3	2051.1	170.9
	WM	WM	WM	WM	WM	WM	WM	DM	WM	DM	WM	WM		
2007	392.2	137.8	103.0	151.0	289.0	249.0	343.0	122.1	183.3	164.5	296.6	358.0	2762.5	230.2
	WM	WM	WM	WM	WM	WM	WM	WM	WM	WM	WM	WM		
2008	191.0	277.0	414.0	390.0	132.0	217.0	211.0	228.0	72.0	274.0	504.0	323.0	3253.0	271.1
	WM	WM	WM	WM	WM	WM	WM	WM	DM	WM	WM	WM		
2009	164.0	196.2	298.2	309.5	186.4	41.2	157.3	122.7	98.5	232.3	165.3	221.3	2192.9	187.7
	WM	WM	WM	WM	WM	DM	WM	WM	IM	WM	WM	WM		
2010	148.2	161.5	157.2	163.7	222.6	320.1	258.7	144.1	202	235.1	207.1	216.9	2437.2	203.1
	WM	WM	WM	WM	WM	WM	WM	WM	WM	WM	WM	WM		
Total	2091.2	1663.3	2137.8	2069.7	2369.1	1736.5	1410.7	941.8	1085.9	1456.1	2513.1	2381	21588.97	1952.7
Average	209.1	166.3	213.7	206.9	236.9	173.6	156.7	125.23	120.6	161.7	279.2	264.5	2621.9	234.3

Appendix 3

Table 3 - Land characteristic and ratings for rubbertreeand oil palm

Land Characteristics	Land classes, limitation level and ratings for rubber						Land classes, limitation level and ratings for oil palm					
	S1	S2	S3	N1	N2		S1	S2	S3	N1	N2	
	0	1	2	3	4		0	1	2	3	4	
	100 95	85	60	40	25	0	100 95	85	60	40	25	0
Topography (t)												
Slope (%)	0-4	4-8	8-16	16-30	30-45	>45	0-4	4-8	8-16	16-30	30-45	>50
Wetness (w)												
Flooding	F0	-	-	F1	-	F2+	F0	F0	F1	F2	-	-
Drainage	perfect, groundwater level >150 cm	perfect, groundwater level >100-150 cm	moderate	imperfect	bad drainage	bad drainage	moderate	perfect	imperfect	bad	bad drainage	bad drainage
Physical Soil properties												
(s)Texture/structure	C<60s, Co, CL, SiCs	C>60s, L, SCL	SL, LfS	LS, LcS, fS	-	Cm, SiCm, S, C>60v, CS, C<60v	C>60s C<60s, SiCs	SiCl,Co, Cl, SC, L	SCL	SL, LS	-	Cm, SiCm, L, S, LcS, fS, S, cS
Coarse Fragments (Vol%)	0-3	3-15	15-35	35-55	-	>55	0-3	3-15	15-35	35-55	-	>55
Soil Depth (cm)	>200	200-150	150-100	100-50	-	>50	>150	150-100	100-50	50-25	-	<25
$CaCO_3$ (%)	0	-	-	0-1	-	>1	0	0-1	1-5	5-10	-	>10
Gypsum (%)	0	-	-	0-0.2	-	>0.2	0	0-0.5	0.5-2	2-3	-	>3
Fertility (F)												
CEC (cmol(+)kg^{-1} clay)	High (-)	High (+)	-	-	-	-	>16	<16	<16	-	-	-
Base Saturation (%)	25-30	30-35	35-50	50-80	>80	-	>35	35-20	<20	-	-	-
	25-20	<20	-	-	-	-						
Sum Exchangeable Basic cations (cmol(+)kg^{-1} soil)	1.6-2.8	2.8-3.2	3.2-4.0	4.0-6.5	-	-	>5	5-3.5	3.5-2	<2	-	-
pH in water	5.3-5.2	5.2-5.0	5.0-4.5	4.5-4.0	<4.0	-	5.8-5.5	5.5-5.0	5.0-4.2	4.2-3.5	<3.5	-
	5.3-5.5	5.5-6.0	6.0-6.5	6.5-7.0	-	>7.0	5.8-6.0	6.0-6.5	6.5-7.0	7.0-7.5	-	-
Organic Carbon (%)	>1.2	<1.2	-	-	-	-						
Salinity and Alkalinity (n)												
ECe (dS/m)	0	0-0.5	0.5-1	1-2	2-6	>6	0	0-0.05	0.5-1	1-2	2-6	>6
ESP (%)							0	0	0	0	0	0

F0=no flooding, F1= flooding level 1, F2=*flooding level 2 or higher than level 1,* F2+ *=flooding higher than level 2,SL= Sandy Loam, SC=Sandy Clay, SCL=Sandy Clay Loam,CEC = Cation Exchange Capacity, ECe = Electric Conductivity of the saturated paste extract, ESP =Exchangeable Sodium Percentage*