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Impact of Land Cover Changes in Tropical Lowland Rainforest Transformation System to Soil Properties

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Abstract

The purpose of this study was to examine the impact of land cover changes from forest to jungle rubber, rubber plantations and oil palm plantations in the tropical lowland rainforest transformation landscape to several soil chemical and physical properties. Land cover changes in the lowland forests landscape transformation system do not provide significant influence on the soil properties such as soil organic carbon, Mg, K, Na and CEC, and there are significant differences among the four types of land cover for the soil properties in the form of Ca, P and base saturation. Nutrients content status of the four land cover types of organic carbon, Na, Ca, Mg, K, CEC and base saturation ranged from very low to low and P ranged from high to very high. Soil texture on the four land cover types dominated by silt and clay fraction. Silt and clay have a low correlation with soil organic carbon (r = -0.275), CEC (r = 0.459) and base saturation (r = -0.146).

Keywords: land cover change; lowland rain forest; soil properties

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1. Introduction

Land cover changes have been occurred with severe in tropical countries because of increasing population and their need for food resources [1]. Forests are rapidly converted to agricultural land use and other uses, especially to oil palm plantations [2] and rubber plantations [3]. Conversion of forest to oil palm and rubber plantations can affect the decrease in canopy cover, stand density, understorey, litter inputs, and changes in soil properties.

Impacts of land cover and land use changes on soil properties have been quite widely studied in different times and different spatial scales. Hartemink and his colleagues [4] conducted a study of land cover changes impact on the soil and the results showed that conversion of climax vegetation into an intensive land use system resulted in poor soil structure stability, decrease in nutrient reserves, loss of soil organic matter and a decrease in carbon organic. Land cover conversion can alter the chemical properties and some important of soil biology [5], changing the soil physical properties, reducing the infiltration capacity, thereby increasing runoff that triggers soil erosion and eventually the soil becomes degraded [6, 7]. Instead Geissen and his colleagues [8] reported research in Mexico where land use changes do not trigger a change in the soil chemical properties, but changes some of soil physical properties.

From the previous research results, it can be understood if it is very difficult to make a similar conclusions related to changes in land cover and land use on soil properties. This conclusion is encouraging and shows that implementing this research on local spatial level would required. The purpose of this study was to examine the impact of land cover changes from forest cover to jungle rubber, rubber plantations and oil palm plantations in the tropical lowland rainforest transformation landscape for some soil chemical and physical properties.

2. Methods

2.1. Study site

This study was located in Bungku village, Bajubang district of Batanghari regency, Jambi Province. Soil analysis carried out in the Laboratory of Physics and Soil Conservation, Bogor Agricultural University. The field inventory data was collected from October 2012 to March 2013.

2.2. Tools and materials

The tools used are a sample ring, plastic bags, hoes, crowbar and chisel, machetes and drill ground. Materials used include disturb soil samples, undisturbed soil samples, and chemicals for soil analysis in the laboratory.

2.3. Soil sampling techniques

This study used purposive sampling method with eight replications on the four types of land cover (logged forest, jungle rubber, oil palm and rubber plantations). Undisturbed soil samples taken using set of soil core samples for bulk density, porosity and water available determination were taken from the three depths, 5–10 cm, 15–20cm and 25–30cm, with a sharp-edged steel cylinder of height 5 cm and diameter 5cm forced manually into the soil. Disturbed soil samples were taken in five replicates from four corners and centre of a square plot of size 20m × 20m located near the centre of the surface run off plot of the four land covers type. Samples were taken from three depths, 5–10 cm, 15–20cm and 25–30cm with a hand trowel uniformly along each depth. Collected soil samples were labelled.

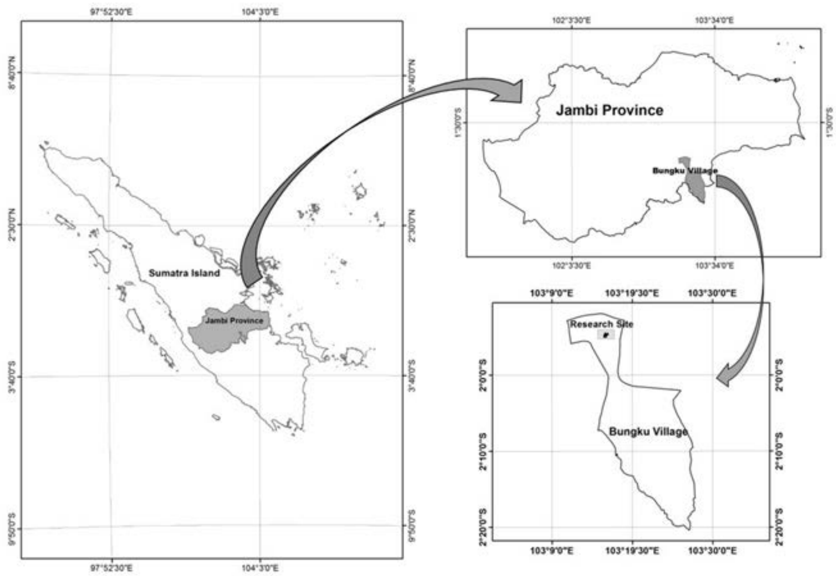

Figure 1: Location of Study Site

2.4. Analysis of soil samples

Undisturbed soil samples used for the analysis of bulk density and soil porosity (Gravimetric methods), soil water potential (pF 2; 2.54 pF; pF 4.2), water available and pore water drainage by using a pressure plate and pressure membrane apparatus. Disturbed soil samples were used for analysis of soil organic carbon content (Walkey and Black method), P (HCl 25%), content of Ca, Mg, K, Na, and CEC (N NH4Oac pH 7.0 method), base saturation and particle size distribution (pipette method) [9].

2.5. Data analysis

Descriptive statistical analysis of the data was done to see the average and standard deviation of the soil properties. Mean difference test was conducted to analyse the differences of each soil properties among land cover type.

3. Results and Discussion

Soil type at the study area are ultisols. Ultisols are soils with a clay increase in subsoil horizons and low base saturation[10]. Ultisols are soil types with a very broad distribution, which reached 25% of the land area in Indonesia. Ultisols distribution in Sumatra Island is the second largest after Kalimantan where the area reached

9.469.000 hectares which can be found from the plains to the mountainous relief. Ultisols generally not managed properly, which to a large-scale enterprises has been exploited for oil palm plantations, rubber plantations and timber industries, but on a small scale due to economic constraints causing the soil is not managed properly by the farmer so that less productivity[11].

3.1. Soil physical properties

The soil physical properties analysed are bulk density, porosity, water available, and soil moisture content. Result of the soil physical properties are presented in Table 1.

Table 1: Analysis results of physical soil properties of each land cover

Land cover	Soil depth	Bulk density (gr/cm^3)	Porosity (%)	Water available (%)	Moisture content (%)
Forest	5-10 cm	1.22 ± 0.07	54.13 ± 2.49	9.27 ± 1.66	25.24 ± 3.99
	15-20 cm	1.32 ± 0.04	50.32 ± 1.61	8.74 ± 0.98	26.41 ± 2.36
	25-30 cm	1.33 ± 0.06	49.76 ± 2.39	8.94 ± 1.93	26.31 ± 2.40
	Overall	1.29 ± 0.08	51.40 ± 2.89	8.98 ± 1.52	25.98 ± 2.93
Jungle Rubber	5-10 cm	1.21 ± 0.10	54.22 ± 3.85	10.66 ± 2.02	29.94 ± 2.15
	15-20 cm	1.30 ± 0.08	51.08 ± 2.88	8.30 ± 1.66	29.60 ± 2.38
	25-30 cm	1.37 ± 0.05	48.24 ± 1.84	6.86 ± 0.89	29.97 ± 1.93
	Overall	1.29 ± 0.10	51.18 ± 3.78	8.61 ± 2.21	29.84 ± 2.07
Rubber plantations	5-10 cm	1.30 ± 0.05	50.46 ± 1.76	8.39 ± 1.68	32.43 ± 2.61
	15-20 cm	1.27 ± 0.10	52.02 ± 3.94	9.42 ± 3.94	35.66 ± 5.70
	25-30 cm	1.28 ± 0.06	51.82 ± 2.26	10.01 ± 2.59	34.33 ± 3.10
	Overall	1.28 ± 0.07	51.60 ± 2.73	9.27 ± 2.16	34.14 ± 4.09
Oil palm plantations	5-10 cm	1.24 ± 0.05	53.32 ± 1.84	9.85 ± 2.08	30.74 ± 1.39
	15-20 cm	1.30 ± 0.09	50.91 ± 3.57	8.92 ± 2.20	30.56 ± 5.80
	25-30 cm	1.38 ± 0.07	47.88 ± 2.69	7.95 ± 1.44	28.90 ± 1.38
	Overall	1.31 ± 0.09	50.70 ± 3.50	8.82 ± 1.97	30.07 ± 3.48

3.1.1. Bulk density

Results of soil bulk density analysis showed that the four types of land cover are not significantly different (Figure 2). The mean value of bulk density from the largest to the smallest are oil palm plantations (1.31 ± 0.09), jungle rubber (1.29 ± 0.10), forests (1.29 ± 0.08) and rubber plantations (1.28 ± 0.07). Bulk density tends to increase with the depth of the soil (Table 1), except in the rubber plantations where bulk density tendency decreased with the depth of the soil. Increasing of bulk density in lower soil horizons caused by increase in clay fraction of the ultisols. Increasing the number of clay fractions will form the argillic horizon which impede the vertical water flow, on the contrary the horizontal water flow will increases and would increase the soil erosivity [11]. The mean bulk density at a depth of 5-10 cm in rubber plantations and oil palm plantations were higher than forests and rubber, its indicates that soil compaction due to human activities [12].

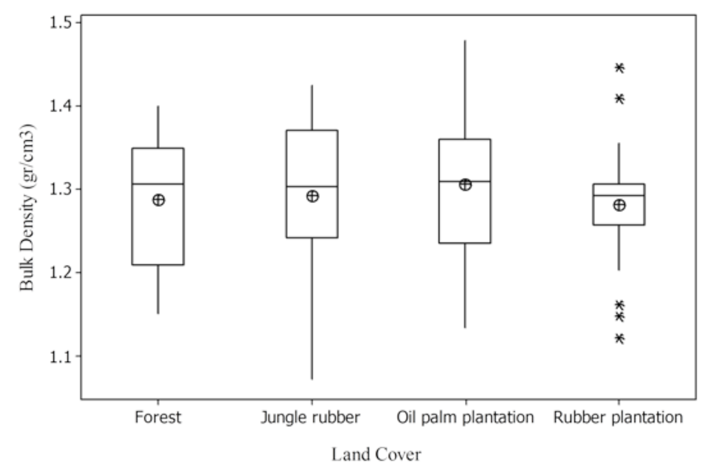

Figure 2: Bulk density of each land cover type

3.1.2. Soil porosity

Results of soil porosity analysis showed that the four types of land cover are not significantly different (Figure 3). The mean value of soil porosity from the largest to the smallest are rubber plantations (51.60 ± 2.73), forest (51.40 ± 2.89), jungle rubber (51.18 ± 3.78) and oil palm plantations (50.70 ± 3.50) respectively. Soil porosity tends to be lower with the depth of soil except in rubber plantations (Table 1).

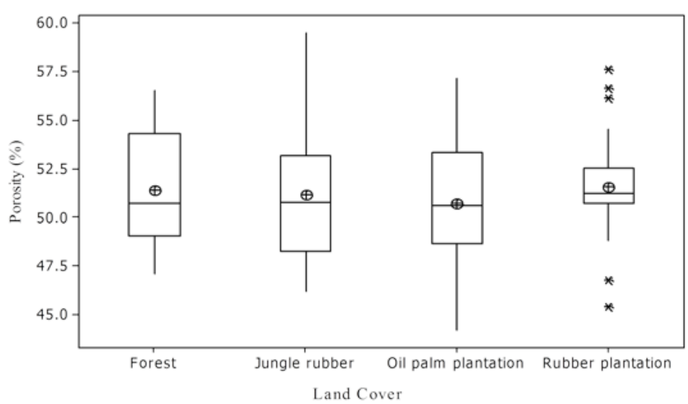

Figure 3: Soil porosity of each land cover type

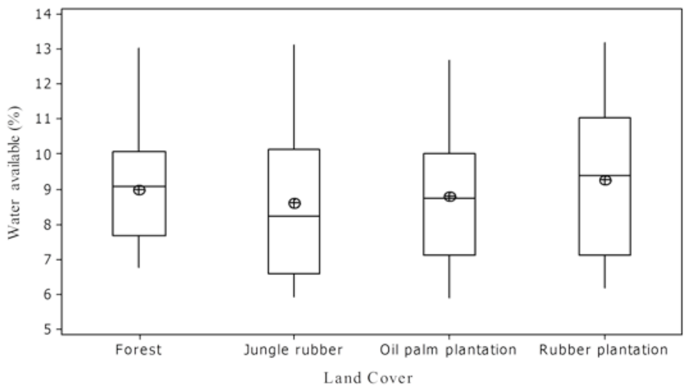

Figure 4: Soil water available of each land cover type

3.1.3. Soil water available

Results of water available analysis showed that the four types of land cover are not significantly different (Figure 4). The mean value of water available from the largest to the smallest are rubber plantations, forest, oil palm plantations and jungle rubber respectively. Water available tends to be lower with the depth of soil except in rubber plantations (Table 1).

3.1.4. Soil texture

Results of soil texture analysis (Table 2) showed that soil texture varied among the land cover type. Soil texture on forest cover was clay loam, on the jungle rubber dominated by silty clay loam texture, on the rubber plantations varied that consists of silty clay loam, silty clay, clay and silt loam, while on the oil palm plantations dominated by silty clay loam texture. Lithological origins of soils determines that the soil properties associated with soil geochemical environment of the landscape such as texture, pH, complex exchange and free oxides, but does not much affect the organic properties [13]. The soil chemistry properties is related to the historical patterns of land use changes, and not to lithological related variations [14].

3.2. Soil Chemical Properties

Results of soil chemical properties analysis of each land cover type and the status of soil nutrient content were classified based on the criteria of Indonesia Soil Research Center [15] showed that the mean value of soil nutrients were varied.

3.2.1. Organic carbon and P

Conversion of forest would decrease of soil organic carbon content from 1.34% (forest land) to 1.09% (jungle rubber), 0.95% (rubber plantations), and 1.05% (oil palm plantations). The highest soil organic carbon content found in forest caused by the diverse type of vegetation that produces much litter through the fallen leaves, stems, and twigs. The plant roots will die decomposed thereby increasing soil organic matter. However, the results of the mean difference test showed that organic carbon were not significantly different at the 0.05 significance level. This suggests that forest cover changes into jungle rubber, rubber plantations and oil palm plantations does not alter the content of soil organic carbon. Previous study also reported that forest conversion indicates only very small changes of the soil organic carbon content and no significant changes [16].

Table 2: Soil texture from each land cover soil samples

Land cover	**Soil fraction (%)**			**Soil texture**	**Land cover**	**Soil fraction (%)**			**Soil texture**
	Sand	**Clay**	**Silt**			**Sand**	**Clay**	**Silt**	
Forest	24.19	31.01	44.8	clay loam	Rubber plantations	16.27	55.96	27.77	clay
	20.27	28.46	51.27	clay loam		15.29	53.46	31.25	clay
	26.58	35.74	37.68	clay loam		15.4	26.86	57.74	Silt loam
	25.61	38.86	35.53	clay loam		15.53	41.81	42.66	Silty clay
	27.73	29.09	43.18	clay loam		15.32	40.65	44.03	Silty clay
	27.91	28.55	43.54	clay loam		15.47	36.2	48.33	Silty clay loam
	23.59	30.63	45.78	clay loam		16.09	38.3	45.61	Silty clay loam
	25.19	16.49	58.32	Silt loam		18.38	31.86	49.76	Silty clay loam
Jungle rubber	11.17	43.27	45.56	Silty clay	Oil palm plantations	31.91	28.61	39.48	Clay loam
	10.22	41.01	48.77	Silty clay		23.1	25.4	51.5	Silt loam
	12.07	37.39	50.54	Silty clay loam		17.71	37.3	44.99	Silty clay loam
	12.23	39.85	47.92	Silty clay loam		18.43	30.09	51.48	Silty clay loam
	12.46	28.8	58.74	Silty clay loam		18.73	33.59	47.68	Silty clay loam
	12.32	34.67	53.01	Silty clay loam		19	34.87	46.13	Silty clay loam
	12.91	39.05	48.04	Silty clay loam		16.94	32.38	50.68	Silty clay loam
	11.8	33.46	54.74	Silty clay loam		17.64	31.77	50.59	Silty clay loam

Table 3: Nutrients content status of each land cover

Soil nutrients	Soil nutrients content				Nutrient status			
	F	JR	R	OP	F	JR	R	OP
Organic carbon (%)	1.34 ± 0.52	1.09 ± 0.42	0.95 ± 0.39	1.05 ± 0.37	L	L	VL	L
P (ppm)	55.39 ± 7.03	53.23 ± 4.42	67.78 ± 8.99	60.15 ± 11.39	H	H	VH	VH
Na (me/100g)	0.15 ± 0.02	0.17 ± 0.11	0.14 ± 0.10	0.15 ± 0.03	L	L	L	L
Ca (me/100g)	0.55 ± 0.14	0.91 ± 0.41	0.49 ± 0.08	1.26 ± 0.70	VL	VL	VL	VL
Mg (me/100g)	0.35 ± 0.11	0.39 ± 0.19	0.38 ± 0.06	0.34 ± 0.10	VL	VL	VL	VL
K (me/100g)	0.16 ± 0.04	0.13 ± 0.05	0.13 ± 0.02	0.12 ± 0.04	L	L	L	L
CEC (me/100g)	13.24 ± 1.39	14.89 ± 1.00	14.39 ± 2.07	13.94 ± 0.77	L	L	L	L
Saturation base (%)	9.25 ± 2.37	10.90 ± 5.33	8.07 ± 1.71	13.42 ± 4.76	VL	VL	VL	VL

Remarks: F = forest, JR = jungle rubber, R = rubber plantations, OP = oil palm plantations, VL = very low, L = low, H = high, VH = very high

The result of this research contrary to previous studies that reported the soil organic matter is sensitive to land use and the characteristics of site such as soil texture [17]. Land clearing of the forests causes a decrease in soil organic carbon by 27% [18], and the conversion of forests into rubber plantations has reduced soil organic matter by 48.2% during the period of 40 years in Hainan China [19]. In general, the results of this study indicate that the content of soil organic carbon are very low in the rubber plantations and lower in the forest, jungle rubber and oil palm plantations based on the criteria of Indonesia Soil Research Center[15].

Changes in land cover gives varied response to soil P content. The mean value of soil P content from the highest to the smallest are jungle rubber, forest, oil palm plantations and rubber plantations respectively. The results of mean difference test showed that P content of rubber plantations was not significantly different with oil palm plantations, but significantly different with the jungle rubber and forest. Soil P content of the forest was not significantly different with the jungle rubber and oil palm plantations. Nutrient status of soil P at forest and jungle rubber were high and status of soil P at rubber plantations and oil palm plantations were very high based on the criteria of Indonesia Soil Research Center[15]. Soil P content were very high at rubber plantations and oil palm plantations possibility caused by fertilization activities that allow the addition of P to the soil [12].

In general, the conversion of forests into jungle rubber, rubber plantations and oil palm plantations do not alter the content of soil organic carbon and soil P. These results are consistent with the previous research that forest conversion to various land cover showed no significant differences for the content of available P, organic carbon, total nitrogen and C/N ratio [8]. The influence of oil palm plantations management practices on soil properties such as soil organic matter and nutrient availability has been known varied according to the type of soil and topography position [20], the age of oil palm stands [21] and possibly also because the effect of rain [22]. So it can be understood if the content of organic carbon and soil P on oil palm plantations was higher than on rubber plantations.

3.2.2. Content of Ca, Mg, K and Na

The highest content of Na found in the jungle rubber and the lowest in rubber plantations. The results of mean difference test analysis showed that Na content was not significantly different, or in other words that the land cover changes not affect the content of Na in the soil. Nutrient status of Na on the four land cover types were low based on the criteria of Indonesia Soil Research Centre [15].

The highest Ca content found in the oil palm plantations and the lowest on rubber plantations. The results of mean difference test analysis showed that Ca content of forest cover was not significantly different with the rubber plantations and jungle rubber, but significantly different with oil palm plantations. Nutrient status of Ca on the four land cover types were low based on the criteria of Indonesia Soil Research Centre [15].

The highest Mg content found in the jungle rubber and the lowest found in oil palm plantations. But the results of mean difference test analysis showed that Mg was not significantly different at the 0.05 significance level. It means that forest conversion does not affect the content of Mg in the soil. Nutrient status of Mg on the four land cover types was very low based on the criteria of Indonesia Soil Research Centre [15].

The highest K was found in the forest cover and the lowest in the rubber plantations. The results of mean difference test showed that K was not significantly different at the 0.05 significance level. It means that forest land cover conversion to jungle rubber, rubber plantations and oil palm plantations was not change the content of K in the soil. Nutrient status of K on the four land cover types were low based on the criteria of Indonesia Soil Research Center[15]. In general this research showed that land cover changes in the tropical lowland forests landscape transformation system was not provide significant influence on the soil chemical properties such as soil organic carbon, Mg, K, and Na.

3.2.3. Cation exchange capacity (CEC) and base saturation

The highest cation exchange capacity (CEC) was found in the jungle rubber and the lowest in the forest cover (Table 3), but the results of mean difference test showed that the CEC of the four land cover types were not significantly different. This means that land cover changes has no effect on soil CEC. CEC of the four land cover types were categorized as low nutrient status. These results are in contrast with studies in south-eastern highlands of Ethiopia in which the conversion of forests into agricultural land resulted in CEC decreased of 2.6% which may be caused by decreasing in the concentration of organic matter [23].

The highest base saturation was found in the oil palm plantations and the lowest in rubber plantations (Table 3). The results of mean difference test showed that the base saturation of oil palm plantations, jungle rubber and forests were not significantly different. Base saturation in the jungle rubber was significantly different with oil palm plantations, but not significantly different with forests and rubber plantations. Base saturation on the four land cover types was very low based on the criteria of Indonesia Soil Research Centre [15]. Results of previous studies showed that conversion of natural forests into agricultural land was significantly increase the percentage of base saturation [23]. Ultisols generally have a value of base saturation <35%, and some types of ultisols having cation exchange capacity < 16 cmol/kg clay [11].

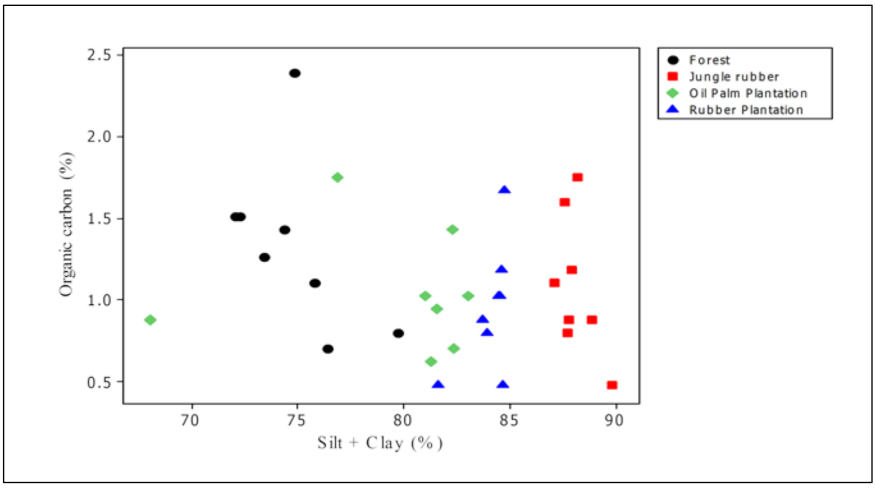

Figure 5: Organic carbon based on silt and clay content

3.3. Relationship between soil texture with organic carbon, CEC and Base Saturation

Distribution of soil fraction in this study area was dominated by silt and clay. The content of silt and clay have low correlation with soil organic carbon (r = -0.275) so relationship pattern between silt and clay with soil organic carbon were not insufficient to provide information (Figure 5). The results of this research was contrary with the authors in [24] which suggests that the fraction of finely soil texture will bind the soil organic matter and reduce the rate of decomposition, so the higher of the percentage fraction of silt and clay will increase the soil organic carbon. The content of soil organic carbon on forest land cover was high in spite of having lower silt and clay fraction.

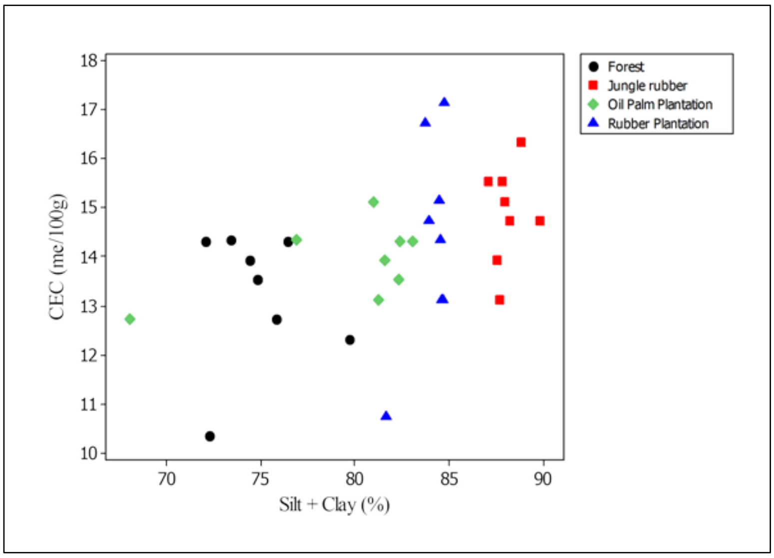

Figure 6: CEC based on silt and clay content

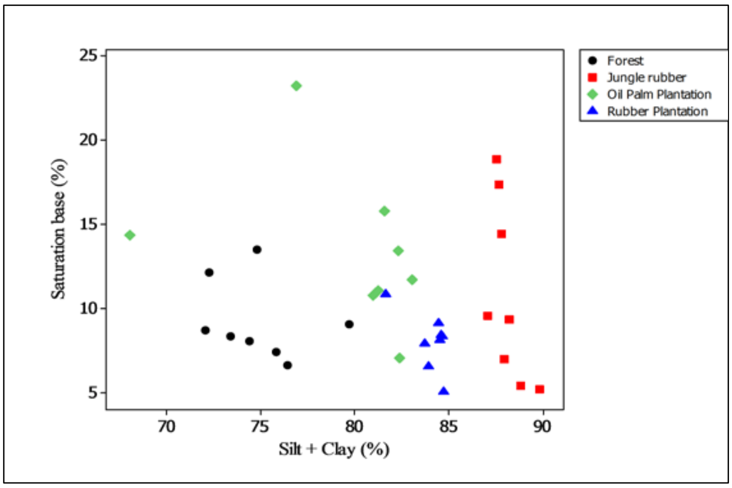

Figure 7: Base saturation based on silt and clay content

CEC tends to increase along with the increasing of percentage of silt and clay fraction (Figure 6), although the silt and clay fraction of each land cover has a fairly low correlation with CEC (r = 0.459). The authors in [25] noted that the increasing of sand fraction was significantly affect soil nutrients. Low percentage of sand fraction and increasing of silt and clay fraction will improve soil nutrients significantly, especially CEC. The content of silt and clay also has a low correlation with base saturation (r = -0.146) so the relationship pattern between silt and clay with base saturation were not insufficient to provide information (Figure 7).

4. Conclusion

Land cover changes in the tropical lowland forests landscape transformation system was not provide significant influence on the soil properties such as organic carbon, Mg, K, Na and CEC, and there were significant differences among the four types of land cover for the soil properties such as Ca, P and base saturation. Nutrient status of the organic carbon, Na, Ca, Mg, K, CEC and base saturation on the four land cover types ranged from very low to low, however nutrient status of P ranged from high to very high. Soil texture on the four land cover types dominated by silt and clay fraction. Silt and clay have a low correlation with soil organic carbon (r = -0.275), CEC (r = 0.459) and base saturation (r = -0.146).

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