JEE Journal of Ecological Engineering
Volume 20, Issue 5, May 2019, pages 184–192
https://doi.org/10.12911/22998993/105440

Received: 2019.01.25
Revised: 2019.02.21
Accepted: 2019.03.16
Available online: 2019.04.01

Comparison of Chemical Properties of Peats under Different Land Uses in South Sumatra, Indonesia

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ABSTRACT

The research aimed at comparing the chemical properties of peats under different land uses in peats dome of the catchment area of the Sibumbung River and the Komering River in Pedamaran Sub-Districts, OKI South Sumatra, Indonesia. The research was conducted in January 2019 and used a Randomized Complete Block Design with two blocks and five natural treatments namely swamp grass, bush swamp, peat forest, oil palm, and intercropping between oil palm and pineapple. Most of the chemical properties of peats at the depth of 30–50 cm showed no changes due to the effects of land uses and drainage; however, there were significant differences with the peat depth of 5–15 cm. Decreasing organic C, exchangeable Al, Al saturation and soluble Fe on the cultivated peats were significantly different compared with the uncultivated peats. An increase in the available P, K, pH, CEC and base saturation on the cultivated peats were found and differed significantly on test level 5% compared with the uncultivated peats due to the application of ameliorant materials. The total N and C/N values were not significantly different. Most of the chemical properties of peats were decreased by the depth of peats. Soil ameliorant materials would change the buffering system of the peats to neutralize soil acidity and the pH increase.

Keywords: chemical properties, peats, different, land uses

INTRODUCTION

Most areas of eastern coast of Sumatra island belong to wetlands with the total area of around 3.10 million ha. On the basis of the hydrological processes, wetlands can be divided into tidal wetlands and *lebak* swamp. Approximately 60% of the tidal wetlands have been converted into farmland (reached 370,000 ha), which are able to produce around 50–60% of rice production in the South Sumatra province. The remaining area of more than 2.73 million ha are remain for natural conservation and will be used for plantations, among others oil palm and rubber (Armanto and Wildayana, 2016).

Approximately 75–80% of the South Sumatra wetlands are peats and peaty soils. Peat conversion and reclamation had a positive impact on agricultural production (Operacz *et al.,* 2019; Hamuna *et al.,* 2019), especially oil palm and rubber), agriculture (rice and cereals), fisheries, livestock and forestry (Wildayana *et al.,* 2016a; 2016b). However, at the same time, its negative impacts on land resources and the environment should be fully considered, such as carbon emissions, greenhouse gases (Baranowska *et al.,* 2019; Kišš *et al.,* 2019), peat subsidence, soil fertility depletion and decrease of peat productivity (Könönen *et al.,* 2015; Lampela *et al.,* 2014; Armanto *et al.,* 2016).

The formation of the South Sumatra peats can be generally explained in three ways of formation, namely the coastal peats, basin or catchment peats (*lebak* peats) and high region peats. Peats occur near the coastal area with the altitude level of 0.5–1.0 m above sea level. The coastal peats are usually shallow (thickness of less than < 3 m) and are closely associated with salt water, mangroves, brackish water, and are intensively affected by the tides (Sarno *et al.,* 2017). In turn, *lebak* peats are mostly located in inland catchment along the river valleys with peat thickness ranging from 4–15 m and shape peat domes (Armanto *et al.,* 2017). Tides affect the bordering of peat domes. The center of the peat domes is generally flat, which causes water logging in the rainy season. This research was conducted in the *lebak* peats, where the small hills and rivers can cut peat domes in the catchment. *Lebak* peats are predominantly influenced by overflowing rivers. High region peats are found in depression areas of higher altitudes (more than 15 m above sea level) and few of them are found in South Sumatra.

The decomposition rate of peats is only about 5–10% of the total biomass of peats. Accumulating peats occur if the decomposition rate is lower than the rate of organic matter accumulation (Kaleta *et al.,* 2019; Mulyono *et al.,* 2019). Consistent accumulation of organic matter (partially decomposed) continues to support the formation of peats. Water logging, poor nutrition and low pH inhibit the growth of decomposition bacteria of peats. High lignin content in plant species forming peats slows down the biological and chemical decomposition process of peats. Thus, the peat formation process belongs to complex process of organic matter under the anaerobic environment conditions. If the decomposition rate of peats becomes faster, they do not develop and their decomposition process will convert them (organic materials) into gas emissions, dissolved organic acids and various simple substances, which are dissolved in water.

As far as the conversion impact of peats to the chemical properties of peats is concerned, in the first year after land clearing, the peat conversion has caused a productivity decrease, peat subsidence, soil nutrient depletion and other environmental impacts (Hadden *et al.,* 2013). In subsequent years, the positive changes occurred in line with environmentally sustainable management of peats; however, the fluctuation changes of the chemical peat properties were not consistent and not fully understood because they depend on the environment, ecosystem, land uses, the type and management of peats, and physiographic conditions (Armanto *et al.,* 2013). The change of chemical characteristics of peats during reclamation cannot be avoided, but good and equitable management of peats will be able to minimize the negative impact on the high-speed peat degradation. Therefore, the decomposition process of peats and sustainable peat management needs to be understood.

The types of land uses, leading to a decline in peat productivity and the reason for these changes, are still not widely understood (Wildayana *et al.,* 2017). If there is the same available information, then it is always contradictory, especially on *lebak* swamp peats, which are highly dynamic. In connection with the above-mentioned problems, our research aimed at comparing the chemical properties of peats under different land uses. This research attempts to find out some explanation of the research approach in solving the bio sequence equation of soil development.

MATERIALS AND METHODS

The research was conducted in peats dome of the catchment area of the Sibumbung River and the Komering River in Pedamaran Sub-Districts, OKI South Sumatra (Figure 1). The research method used a randomized complete block design with two blocks and five natural treatments namely swamp grass, bush swamp, peat forest, oil palm, and oil palm and pineapple intercropping.

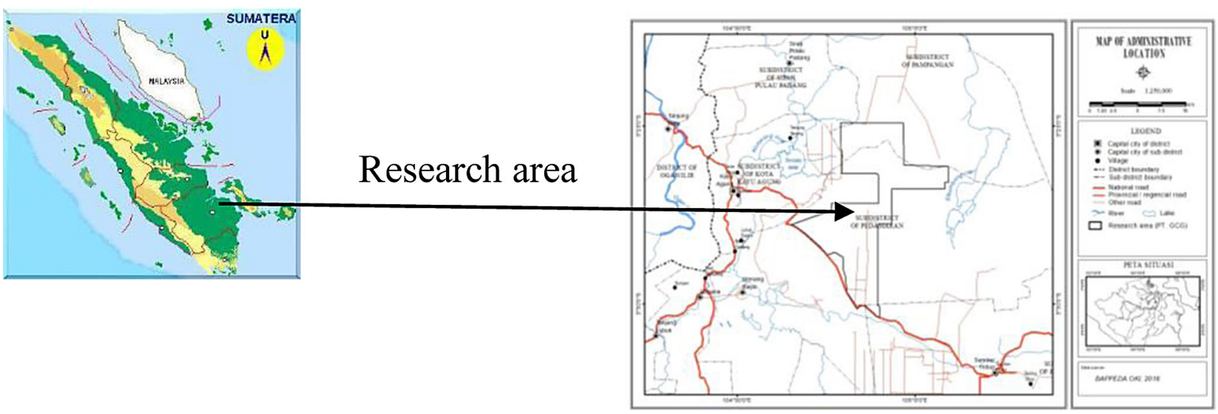

Figure 1. Research location in Sub-District of Pedamaran OKI South Sumatra

All research locations were found in an area adjacent to one another with distance < 2000 m. All locations were categorized as slightly flat to flat with slope ranging from 0–2%.

The vegetation data were recorded by using the squares method, which was located on each vegetation type with the plot sizes, i.e. 10×10 m for peat forests (dominated by trees) and 5×5 m for peat grasses and shrubs. At each study site, peat composite samples were collected at the depths of 5–15 cm and 30–50 cm; they were subsequently fully analyzed in the laboratory. The data were interpreted by using One-way ANOVA with SPSS program version 21 and Tukey HSD Test on significance level of 5%. The Tukey's test results will be able to analyze the differences in the chemical properties of peats in accordance with the land use and the impact of drainage.

RESULTS AND DISCUSSIONS

The results and discussion are limited only on four main components, namely general description of the research locations, the characteristics of the chemical properties of peats, and the relationship between morphology, properties and land management.

General Description of the Research Locations

The peats of the research locations are classified as the wet-climate peats because they are formed in the areas with type B rainfall (7–9 wet months). Average rainfall was more than > 2,200 mm/year with uneven distribution of rainfall throughout the year. All research locations include the category plains physiographic group; altitude ranges from 0–2 m above sea level and peat thickness is in the range 1.0–5.5 m. Three types of natural vegetation, namely swamp grass, swamp bush and peat forest usually prevail in peat swamp canopy.

Location A (Swamp Grass)

Swamp grass was a mixture of natural vegetation and grasses, such as *alang-alang* (*Imperata cylindrica* L.), *Pandanus* spp, *Crunis* spp, a kind of *Annonaceae*, *Zalaca* spp, creepers and vines among *Uncaria* spp, including *seduduk* (*Melastoma* Sp.) and others with an age of around 5 years. The swamp grasses were harvested annually in the amount of around 5–10 tons of dry biomass/ha (in the form of making grass to feed the cattle pens and pads). The fertility rate of swamp grass was classified as very low to low. Swamp grass showed intensive leaching process, it was evident from the content of almost all nutrients in the surface layers (5–15 cm) equal to the lower layers (30–50 cm), as well as peat subsidence and compaction occur (the density of the content in the top layer 0.22 g/cm^3 same as the lower layer). It is interesting to note that Al saturation and soluble Fe were higher in the surface layers than in the lower layer. This means the surface layer received the Al and Fe input from other places through drainage and pyrite oxidation occurs on the surface layer. Al and Fe elements could be as an inhibiting factor for plant growth. Thus, it can be concluded that an intensive decline of soil fertility in the swamp grass was due to the peat degradation, which is not able to withstand the peat degradation process, particularly of rain energy and drainage water. In addition, the composition of the alang-alang was dominated by Si (2.66%) and micro nutrients Mn (98.72 ppm), Zn (8.99 ppm) and Cu (6.29 ppm), while the content of N, P and K was very low. Therefore, swamp grass was not able to increase the peat productivity; especially *alang-alang* was very wasteful in the absorption of nutrients and water.

Location B (Swamp Bush)

The canopy layer of swamp bush in general was formed by mixture types of shrubs, *gelam (Melaleuca leucadendron*), ferns, *medang (Litsea spp), kemuning (Xantophyllum spp), pelawan (Tristania sp), kayu malam (Diospyroy spp), jambu-jambuan (Eugenia sp), mendarahan (Myristica spp)* and any others aged > 10 years, and small trees with a height of less < 2 m. The harvest of swamp bush was around 5–10 ton of dry biomass/ha in a year (such as grazing, grass for feed and livestock barns, *gelam* and small pieces of wood and scrub for firewood and hedges). Swamp bush is generally located in peat domes and was formerly utilized by local farmers for the *sonor* system. Farmers usually plant rice, cereals and various kinds of vegetables on the swamp bush. The use of fertilizers and pesticides was limited. Peats (not used for the *sonor* system) were left fallow and abandoned for about 5–10 years, and then the abandoned and fallow peats were overgrown by swamp bush.

Location C (Peat Forest)

Peat forest was classified as slightly disturbed and undrained. Peat forest was undergoing a process of selective logging in the past. Currently, logging still occurs and some illegal logging was currently underway, but in limited quantities because the amount of wood (that can be cut) was limited as well. Most peat forests belong to the layer of upper canopy formed by the types of species, such as acacia *(Acacia spp.), jelutung (Dyera lowii L.),* forest *durian (Durio sp), ramin (Gonystylus bancanus L.), pisang-pisang (Mezzetia parviflora L.)*, *nyatoh (Palaqium spp), kempas (Koompassia malaccensis), mentibu (Dactylocladus stenostachys L.)* and some natural vegetation types that are generally less known. Sporadically there was local rubber (*Hevea brassiliensis* L.). The mixture trees were about 10–25 years old. The amount of harvested biomass (wood, firewood, shrubs and grasses) was annually around 20–30 tons of dry biomass/ha.

Location D (Oil Palm Plantations)

Location D was planted with the oil palm monoculture and cultivated by large private plantation. The depth of the ground water level declines through drainage. Oil palm plantations are situated in peat dome with age of 5–10 years. The first fertilization treatment involved fertilizers of SP36 (200 kg/ha), while annual routine fertilizing was Urea (around 320 kg/ha); SP36 (about 180 kg/ha); and KCl (around 175 kg/ha) and dolomite 300 kg/ha. The harvest of dry biomass per year was about 50–60 tons/ha, which consists in harvesting FFB (fresh fruit bunches) of 15–20 tons/ha in a year, transported out of the field and harvesting the shoots along with litter (in the form of dried leaves or fallen old leaves, 20–25 tons/ha). Shoots and litter were returned into the ground. All oil palm plantations have regularly received fertilizer, especially NPK. An increase in the content of the element of P, K, CEC and base saturation of the surface layers (5–15 cm) was found because it received greater fertilization, organic matter and dolomite compared to the lower layer. The pH value of peats was higher than the lower layers. The relatively high pH conditions were capable of dissolving a wide range of micro nutrients into the forms available. The overall properties of the soil were still categorized as low to moderate with low pH value.

Location E (Intercropping between oil palm and pineapple)

Location E was cultivated as intercropping between oil palm (*Elaeis guineensis Jacq)* and pineapple (*Ananas comosus*) and managed generally by private smallholders. The depth of the ground water level declines through drainage. In general, this intercropping was aged around 5–10 years. Location E did not regularly receive fertilization, especially NPK. However, in general, the condition of soil fertility showed no significant differences compared to the oil palm monoculture. Intercropping was also located in the peat dome. The harvest of dry biomass per year was slightly lower than oil palm monoculture, which was about 45–50 tons/ha in a year; it consisted of harvesting FFB (10–17 tons/ha) and removing it from the plantations. The harvest of the shoots along with litter (in the form of dried leaves or fallen leaves, 20–22 tons/ha) was returned into the ground. The pH value of the soil was higher than the lower layers. The relatively high pH condition was capable of dissolving a wide range of micro nutrients into forms available. The overall properties of the soil were still categorized as low to moderate with acidic pH.

Characteristics of Chemical Properties of Peats

This compares the chemical properties of peats among five research locations, namely swamp grass, bush swamp, peat forest, oil palm, and intercropping between oil palm and pineapple. Thus, it will provide an overview and analysis of the impact of land uses and drainage on the chemical properties of peats. The research discussion is limited on the surface layer (5–15 cm) and the lower layer (30–50 cm) because both layers are crucial for plant growth and land uses which heavily influence the changes in peat properties.

Repeated fires on peats has led a decline in the amount of biomass and affected the chemical properties of peats in three ways: 1) peats at the surface provides various substrates as biofuels, so that decomposition peats occur quicker than the lower layer of peats, 2) the nature of surface peats change fast during the combustion and peat management (drainage, fertilizer); and 3) soluble elements in peats can be quickly decomposed and disappeared quickly through the leaching process. Further discussion emphasizes the statistical difference between cultivated peats (Location D and E) and uncultivated peats (Location A, B, and C).

Organic C, total N, C/N and Maturity of Peats

Organic matter is reflected by the content of organic C, total N and C/N. The organic matter content clearly illustrates the direct impact of the leaching process and repeated fire s. The erosion processes were relatively gentle compared to the leaching process because the research location is relatively flat (slope 0–2%). Organic C and total N in the cultivated peat (40.11–41.24% for organic C and 1.67–1.72% for total N) was lower and significantly different than the uncultivated peat (in the range of 43.76–48.13% for organic C and 1.78–1.98% for total N). This difference was due to more intensive decomposition in the cultivated peats. Increasingly degraded peats can be reflected by a decrease in C/N, no significant difference was observed for the entire research location. The C/N increased with the depth because the lower layers were not touched by the repeated fires. The repeated fires caused a decline in ground biomass, thus the total N was converted to gas form and volatilized to the atmosphere, so the total N content decreased. Recovering the remains of the harvest to the fields would enable to maintain the high C/N (Table 1 and Table 2).

Peat maturity shows the pattern followed by peat depth: the deeper peat was, the more matured peat became because the deeper layers of peats had enough time for weathering. Likewise, if the peats were intensively cultivated by human activity, then the peat maturity increased to become more mature because cultivation of peats would provide opportunities for peats to keep direct contact with oxygen and weathering of peats would occur intensively and peats were becoming increasingly matured (Table 2).

Macro Nutrients (P and K)

The highest P and K concentrations were detected in the surface peats, where rhizosphere is found because of the deposition of organic materials and fertilizing in the cultivated peats. The content of P (total P and available P) tended to follow the pH values and available P increases along with the pH values. The content of P and K in the cultivated peats was significantly different compared with the uncultivated peats (16.54–16.72 ppm for P and 25.42–25.65 ppm for K) clearly due to the influence of fertilization, followed by forests (11.36 ppm). The lowest P and K were found in the swamp grass and swamp bush (6.21–9.72 ppm P). There was only one type of P depth function in all profiles, i.e., the P contents showed the maximum value in the surface layer and decreased drastically

Table 1. Average organic C and total N contents at different depths of peats

Type of land uses	Organic C (%) */		Total N (%)	
	5–15 cm	30–50 cm	5–15 cm	30–50 cm
A (swamp grass)	43.76±0.26^{a}	40.32±0.51^{a}	1.78±0.02^{a}	0.88±0.04^{a}
B (swamp bush)	48.13±0.31^{b}	42.54±0.56^{b}	1.91±0.02^{b}	0.89±0.04^{a}
C (peat forest)	47.34±0.29^{b}	43.23±0.50^{b}	1.98±0.03^{b}	1.11±0.04^{b}
D (oil palm)	40.11±0.33^{a}	44.71±0.62^{b}	1.67±0.04^{a}	1.02±0.06^{a}
E (oil palm/pineapple)	41.24±0.34^{a}	45.56±0.66^{b}	1.72±0.05^{a}	1.08±0.06^{a}

Note: * Values (in the each column and the similar superscript) indicate an insignificant difference at $p \leq 0.05$ according to Tukey HSD Test.

Table 2. Average C/N and maturity at different depths of peats

Type of land uses	C/N*/		Peat maturity	
	5–15 cm	30–50 cm	5–15 cm	30–50 cm
A (swamp grass)	24.58±1.62^{a}	45.82±1.93^{a}	hemic	sapric
B (swamp bush)	25.20±1.53^{a}	47.80±1.93^{a}	sapric	sapric
C (peat forest)	23.91±1.64^{a}	38.95±1.95^{a}	sapric	hemic
D (oil palm)	24.02±1.77^{a}	43.83±1.97^{a}	hemic	hemic
E (oil palm/pineapple)	23.43±1.79^{a}	42.19±1.98^{a}	hemic	hemic

Note: * Values (in the each column and the similar superscript) indicate an insignificant difference at $p \leq 0.05$ according to Tukey HSD Test.

with increasing depth. There was no real influence of leaching that could be observed as the accumulation of P in the lower layers in all profiles (Table 3).

Cation Exchange Capacity (CEC) and Base Saturation (BS)

CEC and BS were predominantly found in the cultivated peats and peat forest (103.01–114.39 $cmol_c$/kg for CEC and 10.71–11.89% for BS) and were significantly different from swamp grass and swamp bush (61.32–65.33 $cmol_c$/kg for CEC and 5.21–8.63% for BS). The difference was due to the increase in pH and the application of rock phosphate fertilization, rich lime content (Ca) and application of dolomite-rich Ca and Mg in the surface layer of the cultivated peats. Besides, the pH correlated positively with CEC. If pH values are closer to neutral, then CEC and BS will increase automatically. The CEC and BS values were significantly different with depth at all research locations. This was caused by the influence of organic matter and pH values. It is estimated that the high buffering power of peats cause the stability of the CEC value (Table 4).

These bases are very easily leached indicated by the absence of differences in BS in the surface layer with the lower layer on the uncultivated peats, especially on peats swamp and swamp grass. This means that the swamp bush and swamp grass were very intensively leached compared with other profiles because swamp grass had a low canopy level, which was not able to protect it against the threat of peat degradation.

Al Saturation and Exchangeable Al

The exchangeable Al and Al saturation in the cultivated peats decreased (1.03–1.06 $cmol_c$/kg for exchangeable Al and 15.12–16.23% for Al saturation) and were significantly different from those in the uncultivated peats due to liming and fertilization. In all locations, the content of exchangeable Al followed the pattern of Al saturation; the higher the saturation of Al, the higher the exchangeable Al content (Table 5).

Iron Content and Peat Acidity

It is interesting to note that the Fe content in the cultivated peats was only a quarter compared to the value for uncultivated peats. The addition of ameliorant to the surface peats has caused enrichment with cations of soil and an increase in the pH values. The condition causing the Fe solubility was limited. The Fe content was very dominant following the pattern of pH increase, where the surface layer of the cultivated peats pH was higher; it was obtained that the Fe content has also decreased.

Table 3. Average available P_2O_5, and K_2O contents at different depths of peats

Type of land uses	P_2O_5 (mg/kg) */		K_2O (mg/kg)	
	5–15 cm	30–50 cm	5–15 cm	30–50 cm
A (swamp grass)	6.21±0.74^a	6.10±0.69^a	9.52±0.54^a	10.11±0.45^a
B (swamp bush)	9.72±0.73^b	8.70±0.68^a	12.83±0.45^b	10.16±0.44^a
C (peat forest)	11.36±0.75^b	9.44±0.70^b	13.89±0.65^b	9.99±0.46^a
D (oil palm)	16.54±0.76^c	6.81±0.73^a	25.42±0.67^c	11.02±0.48^a
E (oil palm/pineapple)	16.72±0.77^c	7.34±0.74^a	25.65±0.71^c	10.45±0.50^a

Note: * Values (in the each column and the similar superscript) indicate an insignificant difference at $p \leq 0.05$ according to Tukey HSD Test.

Table 4. Cation exchange capacity (CEC) and base saturation at different depths of peats

Type of land uses	CEC ($cmol_c$/kg)		Base Saturation (%)	
	5–15 cm	30–50 cm	5–15 cm	30–50 cm
A (swamp grass)	61.32±1.22^a	38.01±1.19^a	5.21±0.66^a	4.11±0.56^a
B (swamp bush)	65.33±1.21^a	49.14±1.17^b	8.63±0.70^{ab}	5.78±0.63^a
C (peat forest)	103.01±1.25^b	45.42±1.20^b	10.71±0.73^{bc}	5.88±0.62^a
D (oil palm)	114.39±1.28^b	63.79±1.26^c	11.89±0.74^c	7.17±0.65^b
E (oil palm/pineapple)	109.21±1.27^b	67.88±1.24^c	11.03±0.71^c	6.99±0.60^b

Note: * Values (in the each column and the similar superscript) indicate an insignificant difference at $p \leq 0.05$ according to Tukey HSD Test.

Table 5. Average exchangeable Al and Al saturation at different depths of peats

Type of land uses	Exchangeable Al ($cmol_c/kg$)		Al saturation (%)	
	5–15 cm	30–50 cm	5–15 cm	30–50 cm
A (swamp grass)	3.98±0.91[c]	1.12±0.72[c]	27.54±1.72[c]	24.97±1.49[b]
B (swamp bush)	1.67±0.85[b]	0.58±0.69[a]	19.45±1.80[b]	23.49±1.52[b]
C (peat forest)	0.98±0.85[a]	0.62±0.68[ab]	19.76±1.81[b]	22.02±1.57[b]
D (oil palm)	1.03±0.86[a]	0.67±0.67[ab]	15.12±1.84[a]	17.04±1.61[a]
E (oil palm/pineapple)	1.06±0.88[a]	0.78±0.62[b]	16.23±1.97[a]	18.78±1.56[a]

Note: * Values (in the each column and the similar superscript) indicate an insignificant difference at $p \leq 0.05$ according to Tukey HSD Test.

In all research locations, the pH values were relatively homogenous and classified as acidic (pH 4.76–4.88), but there was a slight increase in the cultivated peats and significantly different compared with the uncultivated peats. The pH values differed because the cultivated peats have been limed and fertilized. On the surface layer, the pH value was higher than the lower layer, where there was plenty of decomposed humus in the cultivated peats, which was able to influence and to improve the exchange complex, so that the pH value could be increased by one to two units higher than the lower layer (Table 6).

Relationship between Morphology, Peat Properties and Management

The chemical properties of peat were measured indicating that the lower layer (30–50 cm) showed no statistically significant difference. On the basis of these statistical results, it can be concluded that the peat deposits at the beginning were homogenous because the diversity value of chemical properties at 30–50 layers ranged about 15–30%, while the surface layers (5–15 cm) showed that the diversity value for the entire measured chemical properties was amounting to 70–85%. It means that the surface layers were classified as heterogeneous. The main causes of the high diversity were the impact of land uses, fertilization, and drainage. Thus, it can be concluded that the peat landscape in the lower layers (30–50 cm) is a "closed system" because very little elements or peats leave the system, while the peat landscape of surface peats (5–15 cm) was called as "open system" because the chemical properties are predominantly determined by the impact of various external factors, namely land uses, fertilization, and drainage.

All elements covered in this system circulate in a closed cycle and a little out of the forest cycle system. Therefore, although the forest was not fertilized, but contributed to organic C, N, CEC, the base saturation was higher and dominant on the top layer (5–15 cm) than in the lower layers (30–50 cm); however, this did not apply to P and K. The other parameters (pH and micronutrients) did not show many changes between the lower layers and the upper layers. The overall soil fertility was classified as low to moderately acidic.

The formation of this open system was described as follows: peat accumulation was uniform (value diversity 15–30%), porous and poorly drained especially in the 30–50 cm layer. The infiltration rate in this layer was very low, which caused water logging; therefore, ground water table moves laterally inter or under flow until impermeable mineral soil layer (hard rock) is encountered. Most soil nutrients are not leached in this layer.

Table 6. Average exchangeable Fe content and pH H_2O at different depths of peats

Type of land uses	Fe (mg/kg)		pH-H_2O	
	5–15 cm	30–50 cm	5–15 cm	30–50 cm
A (swamp grass)	24.31±1.77[d]	23.51±1.59[d]	3.86±0.08[a]	3.87±0.07[a]
B (swamp bush)	20.34±1.69[c]	19.87±1.62[c]	3.88±0.09[a]	3.79±0.07[a]
C (peat forest)	12.78±1.78[b]	11.98±1.71[b]	3.78±0.09[a]	3.85±0.08[a]
D (oil palm)	5.01±1.78[a]	3.54±1.76[a]	4.76±1.01[b]	3.82±0.09[a]
E (oil palm/pineapple)	4.89±1.76[a]	3.41±1.80[a]	4.88±0.99[b]	3.93±0.09[a]

Note: * Values (in the each column and the similar superscript) indicate an insignificant difference at $p \leq 0.05$ according to Tukey HSD Test.

In another case occurring in the surface layer (5–15 cm), external processes intensively affects peats, namely repeated fires causing most peats to quickly break down into simpler forms as well as excessive drainage. As results, excess water flows along the drainage channel laterally and enters the nearest river, so most of the nutrients are laterally leached or volatized to the atmosphere. The morphology of peat profiles and analysis of chemical properties reflects the laterally intensive leaching process of nutrients and other elements of peats. It is evident that almost all profiles of 5–15 cm layer have hemic maturity; various nutrients were laterally leached compared to the lower layers. The most intensive leaching was found in swamp peats and swamp grass.

In the leaching process, different types of soil nutrients, various forms of Fe and Al join leached and laterally accumulated, so that high exchangeable Fe and Al saturation are found at the layers of 5–15 cm. These elements are capable of disturbing the balance of nutrients, such as P due to high solubility of Fe and Al. In this layer, most of nutrients are immobilized (such as P) and mobile nutrients (e.g. N) continue to follow the flow of interflow or lateral flow on the surface peats.

The high leaching process has been transporting all nutrients from the surface to the nearest rivers, indicated by the color of river water was turbid and brown-black. Fractions of peats (diameter> 2 mm) dominate the leached layers due to their resistance to the leaching process. Higher leaching process in the profiles can be observed and reflected by the following characteristics: (1) the surface peats contain a lot of debris materials that are highly acid and have low CEC, adsorbing the soil nutrients, (2) peat profiles develop from the organic materials which have low nutrient content and poor fertility, and (3) mineralization and rapid destruction of organic material occur.

CONCLUSIONS

On the basis of the results and discussions of the research, The following conclusions can be drawn:

1. Most of the chemical properties of peats at the depth of 30–50 cm showed no changes due to the effects of land uses and drainage and were significantly different from the peat at the depth of 5–15 cm
2. After decreasing organic C, exchangeable Al, Al saturation and soluble Fe, the cultivated peats were significantly different from the uncultivated peats.
3. An increase in the available P, K, pH, CEC and base saturation on the cultivated peats were found and differ significantly on test level 5%, compared with the uncultivated peats due to the application of ameliorant materials.
4. Total N and C/N did not differ significantly. Most of the chemical properties of peats decreased by the depth of peats.
5. Soil ameliorant materials will move or change the buffering system of the peats to neutralize soil acidity and the pH values will increase.

Acknowledgements

We express our gratitude to our friends, university colleagues and staffs, and students for help in the implementation of this research in the fields. The field work could not have been realized without the help of Dr. M.S. Imanudin, Mr H. Junedi, Mr Moch Zuhdi and the local people. The research was funded by Sriwijaya University through research contract "Penelitian Unggulan Profesi Unsri" Nr. 0006/UN9/SK.LP2M.PT/2018 dated on 05 June 2018. We also thank to the Faculty of Agriculture, which has facilitated the implementation of this research not only in the fields, but also in the laboratory.

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