

## SELECTED PROPERTIES OF PEAT DEGRADATION ON DIFFERENT LAND USES AND THE SUSTAINABLE MANAGEMENT

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### ABSTRACT

The research aimed to analyse selected properties of peat degradation on different land uses and the sustainable management. The research area is located in the lowland dome peats in the catchment area of Sibumbang River and Sibotak River in Sub District of Pedamaran, OKI South Sumatra. The research method used an experimental design of Randomized Completely Block Design with two blocks and five treatments (Site A: intercropping between oil palm and pineapples; Site B: oil palm plantations, Site C: peat forest; Site D: swamp bush; Site E: swamp grass). The research resulted that drainage and land uses decreased some properties of peats, namely total pore space, fiber and ash content as well as organic C on cultivated peats and are significantly different at level of 5% compared with uncultivated peats. Bulk density increased due to peat compaction and groundwater table on cultivated peats, which was getting deeper, and significantly different compared with uncultivated peats. All soil series did not show any changes because of drainage and different land uses. Sustainable peat management can be implemented through three approaches, i.e. managements of water, soil and crops.

Key words: Properties, peat degradation, land uses, sustainable management.

### INTRODUCTION

Peats are originated from anaerobically decomposed organic matters, where the addition rate of organic matters is higher than the decomposition rate. In the lowlands, firstly topogen peat was formed for permanent anaerobic conditions under the influence of high water levels in rivers, after that litter accumulation of plants is growing and will result in the peat formation overlay dome-shaped ombrogen peats. Ombrogen peats were formed of forest vegetation residues that are deposited thousands of years, thus the low nutrient status of peats is low and contain high wood (Armanto et al., 2016a; 2016b).

More than 80% of peats is located in lowlands (both tidal swamp and *lebak* swamp). Coastal peats are generally found in tidal swamp, while *lebak* swamp peats are

located in inland or backswamp area (*lebak*). Swamp peats are almost in whole year saturated with water (water saturated) or flooded (waterlogged) with shallow water. The water dynamics of peats is strongly influenced by the topography shape, namely generally flat to slightly flat (Hooijer et al., 2012).

In line with rapid population growth, peats reclamation by the various parties have been accused of many problems. Failure of reclaimed peats are mostly due to the attention lack to the technical aspects, namely environmental, social, economic, and cultural, from planning through implementation (Couwenberg and Hooijer, 2013; Lampela et al., 2014; Armanto et al., 2013).

This implies that the peats ecosystem is mostly damaged, network of micro and macro water systems do not work perfectly, thus the planting time become ineffective and inefficient, water availability fluctuates depending on the season, although at the

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macro level, the water availability is plentiful (Page et al., 2011; Wildayana et al., 2016a).

Based on the water dynamics and the influence of the tides, especially during high tide in the rainy season in the down-stream area, peats are divided into three zones: Zone I is an area of tidal saltwater or brackish water and are located on the land contiguous to the sea, at the mouth of the great river, and the islands of the delta near the mouth of large rivers. In this region, the influence of the tides is very strong, so often called tidal wetlands. The wetlands are directly influenced by the tide of sea water or saline water. Zone I has usually mineral soil and its main problem is high soil salinity due to the intrusion of sea water to the mainland.

Zone II is a freshwater tidal area and is located in an up-stream swamp area, but it still belongs to the down-stream area of watershed, and its position is more inward toward the mainland. In this Zone II, the movement of the river flow toward the ocean meets with tidal energy, which generally occurs two times a day (semidiurnal). Because this area is outside the influence of sea (salted) water, then the effect of fresh water from the river is very dominant, but tidal energy is still dominant too.

Zone III is located in *lebak* area, does not belong to tidal area and tidal influence is not observed again. The dominant influence of large river is heavy seasonal flooding that inundated the left and right plains of the rivers. The research site in Pedamaran is classified as Zone III.

Regarding the above problems, the study aims to analyze the selected properties of peats under permanent land uses and the Sustainable Management. In connection with conditions and the above problems, the research aimed to analyze selected properties of peat degradation on different land uses and the sustainable management.

## MATERIALS AND METHODS

The research area is sited in the lowland dome peats in the catchment area of Sibumbang River and Sibotak River in Sub District of Pedamaran, OKI South Sumatra. The research method used an experimental design of Randomized Completely Block Design with two blocks and five natural treatments. All peats showed ombrotrophic peat thickness of  $> 2.5$  m. The natural treatments were five types of different land uses, namely for cultivated peats (**Site A**: intercropping between oil palm and pineapples; **Site B**: oil palm plantations) and for uncultivated peats (**Site C**: peat forest; **Site D**: swamp bush; **Site E**: swamp grass) with the coordinates of the peat sampling presented in Figure 1. Peat maturity level in the field was determined for each of the soil profile and peats were further classified into soil family according to the Key of Soil Taxonomy (Soil Survey Staff, 2014).

**Site A** is peats that have been cultivated by local communities to plant oil palm and pineapple intercropping, which has been cultivated around 5-6 years. **Site B** is peats cultivated with oil palm monoculture with ages of 6-9 years by large private company. **Site C** is swamp forest in the location of the river valley. The type of dominant vegetation consists of ferns and some sporadic trees (especially acacia) with a height of about 3.0-4.5 m. **Site D** is swamp bush located near the former logging and illegal selective logging and *sonor* system. **Site E** is degraded peats occupied by swamp grass and the surface was affected by the repeated fires. It was estimated that more than 10-30 cm from the surface of Site E has been lost in recent times of fires. This Site E was often used for the *sonor* system and has often seasonally cultivated for food crops (e.g. rice, pineapple, maize, cassava, beans and others).

At each research Site, peat sampling was conducted at the depths of 0-15 cm and samples were analyzed in the laboratory to determine the selected properties of peats.

Calculation of water balance was based on data of climate and evapotranspiration. The collected data was processed with SPSS version 21 and using ANOVA analysis.

The means of treatments and blocks were tested with the Tukey HSD post hoc test at significance level of 5%.

### **Five Natural Treatments**

A (oil palm/pineapple, cultivated)  
(104°55'27.95" E & 3°27'45.33" S)

B (oil palm, cultivated)  
(104°57'52.37" E & 3°25'22.83" S)

C (peat forest, uncultivated)  
(104°57'54.64" E  
3°25'20.42" S)

D (swamp bush, uncultivated)  
(104°57'18.58" E & 3°26'37.31" S)

E (swamp grass, uncultivated)  
(104°53'35.12" E & 3°25'53.37" S)

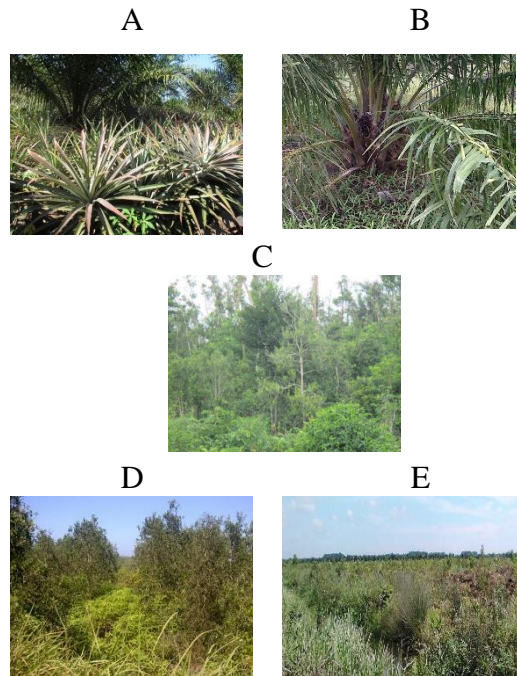


Figure 1. Research sites for soil sampling

## **RESULTS AND DISCUSSION**

Among the important inherent properties of peats are the constituent components derived from timber and residues of vegetation in permanently waterlogged conditions. Human intervention by making drainage system on peats caused the peats to experience the process of shrinking and expanding (peat subsidence). Excessive drying process caused colloidal peats becoming damaged because the shrinking and expanding properties of peats are irreversible (irreversible drying). Irreversible drying of peats changes form of peats becoming other unwanted forms, such as charcoal, it is no longer able to absorb nutrients and hold water and the process is very dangerous for the whole region and resulting combustible peats. In addition, the very low pH and low soil fertility status of peats contribute to accelerate the decline in the productivity of peats.

### **General Condition of Research Area**

The research sites are peat area planted with oil palm located within the concession area measuring 10,000 ha in the sub district of Pedamaran, OKI South Sumatra. Until August 2016, approximately 7,000 ha of research area have been cleared and around 100 ha of the surrounding of research area (especially in bordering area) is often burnt by local farmers. The surrounding area belongs to the Limited Production Forest (HPT).

Approximately 96% of the oil palm plantation is peats with thickness of on average of 1.0-5.5 m (shallow to very deep) and the maturity level of peats is classified as sapric and hemic. The depth of the groundwater table on the 5<sup>th</sup> of August ranged of 50-60 cm from the surface.

Thick layers of peats are recommended and directed as a protected area and need to be conserved, but it is also found acid sulfate soil. The dynamics of the movement of water

and peats in general are very relevant with the peat properties itself, such as the physical, chemical, and biological properties. The most responsible selected properties of peats are among other peat subsidence, irreversible drying, and low buffering due to weight loss of peats and any others.

The research results will discuss the selected properties of peats under permanent land uses. The main differences in the selected properties of peats among the five sites is summarized in Table 1 and continued to Table 2.

Table 1. Average moisture, C, N and C/N ratio of peats and Tukey HSD Test\*\*/

Type of land uses	WM (%) */	DM (%)	C (%)	N (%)	C/N ratio
<i>Cultivated peats</i>					
A (oil palm/pineapple)	444 <sup>a</sup>	80 <sup>a</sup>	41.95 <sup>a</sup>	1.78 <sup>a</sup>	23.57 <sup>a</sup>
B (oil palm)	468 <sup>b</sup>	84 <sup>a</sup>	43.51 <sup>ab</sup>	1.77 <sup>a</sup>	24.62 <sup>a</sup>
<i>Uncultivated peats</i>					
C (peat forest)	461 <sup>b</sup>	79 <sup>a</sup>	49.10 <sup>c</sup>	1.99 <sup>a</sup>	24.67 <sup>a</sup>
D (swamp bush)	471 <sup>b</sup>	83 <sup>a</sup>	48.74 <sup>c</sup>	1.95 <sup>a</sup>	25.01 <sup>a</sup>
E (swamp grass)	474 <sup>b</sup>	80 <sup>a</sup>	45.95 <sup>b</sup>	1.79 <sup>a</sup>	25.72 <sup>a</sup>

Note: \*/ WM (wet moisture); DM (dry moisture); C (organic carbon); N (nitrogen)

\*\*/ Individual numbers (means) with the same superscript within the each column are not significantly different at significance level of 5% according to Tukey HSD Test.

### Bulk Density and Total Pore Space

In general, the lowest bulk density (BD) found in surface (topsoil) and increases based on the depth and reach the highest value of BD in subsoils at a depth of 30-50 cm for the entire research sites. Deeper peat layers in all research sites showed similarities to one another with BD in the range of 0.15-0.20 g/cm<sup>3</sup>. Uncultivated peats had lower BD (0.15-0.17 g/cm<sup>3</sup>) compared with the

cultivated peats (0.23-0.24 g/cm<sup>3</sup>) and showed statistically significant differences in significance level of 5% (Table 2). This difference is due to that all cultivated peats got the human intervention and it is more dominant than in the uncultivated peats, such as illegal logging, plantations, smallholder agriculture, sonor system, fisheries and any others. This finding was relevant with works of Ismawi et al. (2012) and Wildayana (2014).

Table 2. Average means of selected properties of peats and Tukey HSD Test\*\*/

Type of land uses	WT (cm) */	BD (g/cm <sup>3</sup> )	TPS (%)	Fiber (%)	Ash (%)
<i>Cultivated Peats</i>					
A (oil palm/pineapple)	40 <sup>a</sup>	0.24 <sup>a</sup>	83 <sup>a</sup>	23.35 <sup>a</sup>	5.37 <sup>a</sup>
B (oil palm)	39 <sup>a</sup>	0.23 <sup>a</sup>	84 <sup>a</sup>	24.41 <sup>a</sup>	5.42 <sup>a</sup>
<i>Uncultivated Peats</i>					
C (peat forest)	20 <sup>b</sup>	0.15 <sup>b</sup>	88 <sup>b</sup>	37.01 <sup>c</sup>	5.93 <sup>a</sup>
D (swamp bush)	21 <sup>b</sup>	0.16 <sup>b</sup>	88 <sup>b</sup>	30.51 <sup>b</sup>	10.10 <sup>c</sup>
E (swamp grass)	23 <sup>c</sup>	0.17 <sup>b</sup>	93 <sup>c</sup>	23.52 <sup>a</sup>	12.37 <sup>b</sup>

Note: \*/ WT (water table); BD (bulk density); TPS (total pore space)

\*\*/ Individual numbers (means) with the same superscript within the each column are not significantly different at significance level of 5% according to Tukey HSD Test.

Peat loss due to fires and other disturbances occur mostly in the peat surface. Smoldering was found at high temperatures during burning. It looks like to the process of pyrolysis for producing charcoal. Changes in peat generally occur on cultivated peats, especially for selected parameters (BD increased; content of ash and fiber as well as organic C decreased). Fine-particle-sized peats and most of the swamp grass in Site E is more susceptible to burning and high temperature (due to climate condition) and water movement. Water movement can transport fine particles of peats to other places, thus these fine particles can fill some empty spaces, namely larger pores, cracks and cavities in the peat surface. This process will influence some selected properties of peats in Site E. Könönen et al. (2015) and Moore et al. (2013) found also the same results.

Total pore space (TPS) conditions exhibit a phenomenon opposite to BD, where the higher TPS is then followed by a decrease in BD. Lowest TPS values are in cultivated peats (83-84%) and the highest TPS is found in uncultivated peats ranging from 88-93%. The statistic test to describe TPS that TPS mean values of uncultivated peats are significantly different from the cultivated peats and highly significantly different compared to Site E (swamp grass). The BD showed regression of close relationship with TPS value ( $R^2 = 0.78$ ), meaning that approximately 78% of the BD values is determined by the TPS values. This means that with the declining value of the TPS, then an increase in the value of BD and this means there is a compaction of peats.

### ***Organic C, N and C/N Ratios***

Organic C in cultivated peats (41.95-43.51%) was lower and significantly different than uncultivated peats (45.95-49.10%). This difference is due to more intensive decomposition in cultivated peats, while the value of N did not show significant differences. The more degraded peats can be reflected by a decrease in C/N ratio, although C/N ratios for the entire research sites showed

no significant difference. Improved C/N ratio with depth was also reported in several researches of ombrotrophic peats. Repeated fires caused a decline in ground biomass, in addition the N volatilization happen during the peat combustion, thus the soil N concentration decreased total N and C/N ratio detected higher in uncultivated peats. N concentration is reduced in cultivated peats during land clearing; it means that land clearing is its main cause. Recover the harvest remains will be able to maintain the C/N ratio remaining still high.

The selected peat properties are generally different from each other and are influenced by the types of land uses. This may mean that this difference is as a reflection of changes in the uses of peats. The most obvious difference between cultivated and uncultivated peats are especially at a depth of 5-15 cm.

At the uncultivated peats (especially Site E, swamp grass), the difference of the selected peat properties is especially prominent when compared with the cultivated peats (Site A, Site B) and uncultivated peats (Site C and Site D). Almost all measured parameters showed a significant difference, this is due to that Site E is most often experienced fires, so many parameters measured have been modified by multiple fires every year either intentionally (*sonor* system) or unintentionally due to spreading fires coming from the surrounding of site. It is summarized that effect of drainage and land uses is able to be observed clearly in Site E.

Significant parameter differences in Site E can be defined as serious damage process of peats. Peat damage can be divided into two components, firstly the biological peat decomposition causing the release of emission gas (CO, NO and others), and secondly physical processes such as over drainage leading to peat shrinkage (peat subsidence), compaction and increased BD of peats.

### ***Soil Classification***

Based on field descriptions and laboratory data, then all soil profile have a high organic C content > 12% and classified as sapric and

hemic, so that all profiles meet the criteria as Histosols order. The main class differentiation is the decomposition degree and the thickness of peats. Site A and B are classified as *Hemic Haplosaprists* (for cultivated peats, Site A and B) and for uncultivated peats are classified as *Typic Haplosaprists* (Site C and D) and *Typic Haplohemists* (Site E). The main differentiator is based maturity of organic matter where cultivated peats are relatively more mature than uncultivated peats.

### ***Sustainable Peat Management***

Peat reclamation cannot avoid changes in the selected peat properties, but a good and equitable peat management will be able to minimize the negative impact on the high-speed peat damage. It can be reduced in the sense of extending the 'life span' by minimizing the subsidence rate by adopting several management strategies of peats, water and right selected crops. Wildayana et al. (2016b) and Armanto et al. (2016c) suggested also the similar recommendation. Therefore, we required to understand more about decomposition process of peats and peat management, water and sustainable crop. Approaches of sustainable peat management are summarized in Table 3.

### ***Water Management***

Water management mainly consists of three important components, such as drainage, irrigation and inundation.

**The best drainage system** is to maintain critical water limit of peats, but it does not result in water loss for plant growth. The drainage intensity varies depending on the condition of peat drainage and rainfall. For plantation crops, drainage system can be done by making the primary channels, secondary channels and tertiary canals. One tertiary canal has an area of about 25 ha.

This effort is made to control groundwater level and to maintain at a certain groundwater level to prevent peat subsidence. At the research site, water regulation is controlled by using the drainage pipe system-rise on the main channel (secondary channel). It is made by doing a skating canal every distance of 250 m. This skating channel is connected with the pipe-rise. Pipe serves to drain water and maintain the groundwater level between channels. To remove the excess water in the tertiary canal, it is made tertiary channel for each 50 m with the depth of 1.0 m and the width of 1.0 m.

After drainage and land clearing of peats, then the peat subsidence is relatively quickly occurred, this will decrease peat surface. Peat subsidence and decomposition of organic materials can be problematic if the mineralized materials are found below layers of peats because it consists of pyrite and quartz sand.

Table 3. Approaches of sustainable peat management

Type of Management	On farm activities
Water Management	Drainage (to remove excess water) Irrigation (to provide water to farming plots) Inundation (to maintain water depth)
Soil Management	No burning & to recover the harvest remains to the field Application of soil ameliorant
Crop Management	Food crops, industrial crops (oil palm, rubber and coconuts), cereals ( <i>palawija</i> ) and horticulture

**Irrigation** means to provide water to farming plots. When the critical limit of water can be controlled at optimum levels for plant growth, water management is not an issue except in the early stages of plant growth. If the critical limit of water cannot be controlled and lower than water needs which it should be, irrigation needs to be done, especially for food crops and vegetable crops. It is important to supply the water needs of the plant and to avoid irreversible drying. This condition may be the effect of shallow soil profile which cannot be penetrated by crop roots and water loss due to transpiration faster in the mineral soils. The ranges of drainage and irrigation needs of some selected commodities are summarized in Table 4.

**Inundation** is intended to minimize the occurrence of peat subsidence. Efforts done are to retain flooded condition by adopting the hydrophilic crops or tolerant crops to excess water (providing high economic value), such as rice, Chinese spinach, water spinach and watercress.

### Soil Management

Important soil management should be attended, namely no burning and application of soil ameliorant. **A peat burning** is generally done for land clearing on *sonor* system applied in the surrounding of research sites by the local community. Land clearing by burning must be completely stopped because it could damage the peat ecosystem for the long term.

**Soil ameliorant** is very important to improve peat productivity. Some ameliorant materials are required, among other organic

and inorganic fertilizer, limestone/dolomite, ash, and volcanic ash and any other. The ameliorant materials are aimed to improve the peat productivity and also to stimulate improvement of the physical, chemical and biological properties of peats.

### Crops Management

The most important crop management is how we choose the types of the most adaptive commodities to the environmental conditions of peat ecosystems. Utilization of peats for agriculture and plantations has grown rapidly in the research sites. Various food crops and perennial crops are cultivated on peats, but the most successfully cultivated agricultural commodities are food crops (such as rice, corn, sweet potatoes etc.), vegetable crops (chili, long bean etc.), fruit crops (such as pineapple, papaya and *rambutan*) and plantation crops (oil palm, rubber, coconut and others).

Water balance summary for fishery and some food crops in peats is given in Table 4. Most of food crops (except rice) need not only drainage to remove excess groundwater, but also irrigation to provide water to farming plot. It depends on months during the year.

**Rice** has always been cultivated by local farmers as subsistence farming. If the peat thickness is more than > 100 cm, farmers are not planting rice because production failure of rice is so very high due to deficiency of soil nutrients, organic acids inhibit growth of rooting system and resulting in low productivity even rice failure. Shallow peats are suitable for rice if peat thickness is around 10-80 cm.

Table 4. Water balance summary for fishery and some food crops in peats

Commodity	Months	Water supply (mm)	Water needs
<i>Cereals</i>			
Corn	May-June-July	< 70	Irrigation
Soybean	May-June-July	< 90	Irrigation
Peanuts	May to September	< 95	Irrigation
	November to March	> 830	Drainage

Commodity	Months	Water supply (mm)	Water needs
<i>Vegetable</i>			
Chili	May to September	< 100	Irrigation
	November to March	> 850	Drainage
<i>Fruits</i>			
Watermelon	May to August	< 80	Irrigation
	November to March	> 700	Drainage
Banana	January to December	> 1,300	Drainage
Orange	January to December	> 1,020	Drainage
Pineapple	May to August	< 100	Irrigation
	November to March	> 800	Drainage
Fish	November to March	> 700	Drainage
	May to August	< 110	Irrigation

Source: Calculated from climatic data (2016).

**Oil palm** is cultivated on peats in forms of large-scale plantations mainly by private companies, and small-scale (mostly in intercropping pattern) is done by local farmers. Oil palm is one of the quite appropriate perennial plant on thin-moderate thickness peats with the yield of Fresh Fruit Bunches (FFB) about 15 tons/ha in the third year after planting. Rubber is mostly cultivated by local farmers in small scale and mostly not well maintained. Thus the yield is also mostly very low.

**Pineapple** is cultivated among oil palm trees as intercropping pattern. Pineapple shows the high adaptability on peats and adapts well to condition of the high acidity and low fertility levels. Pineapple in intercropping pattern is already begun to fruit 14 months after planting with pineapple density of 20,000 pineapple/ha.

**Food crops** (cereals) and **vegetable crops** require good drainage to prevent rotting diseases. Some food crops planted in research site are namely corn, cassava, sweet potatoes and others and vegetable crops cultivated include chili, cucumbers, eggplant, tomatoes, cabbage, celery, beans, corn, sweet corn, vegetables and any others.

**Fruit crops** are cultivated by local farmers among others: water guava, banana, mango, *rambutan*, watermelon, pineapple, betel nut, breadfruit, jackfruit, papaya and others. Other commodities have the potential economies to

be developed, namely coconut, coffee, pepper, medicinal plants, and any others.

## ACKNOWLEDGEMENTS

The author would like to thank Sriwijaya University that has provided research funding through the “Penelitian Unggulan Profesi” by research contract No. 1023/UN9.3.1/LPPM/2016 dated 18 July 2016.

## CONCLUSIONS

- 1) Drainage and land uses decreased some properties of peats, namely total pore space, fiber and ash content as well as organic C on cultivated peats and are significantly different at level of 5% compared with uncultivated peats.
- 2) Bulk density increased due to peat compaction and groundwater table on cultivated peats, which was getting deeper, and significantly different compared with uncultivated peats.
- 3) All soil series did not show any changes because of drainage and different land uses.
- 4) Sustainable peat management can be implemented through three approaches, i.e. managements of water, soil and crops.



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