Substantial Changes in Physical and Chemical Properties of Spodosols Soil by Hardpan Breaking and Mounding in Oil Palm Plantation

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ABSTRACT
Spodosols soil are categorized as a marginal or sub-optimum soil which has several limiting factors and potential for oil palm plantations. The main limiting factors for spodosols are the presence of a spodic layer, poor nutrients, acidic pH, low water retention capacity, and low cation exchange capacity (CEC). This study aimed to determine changes in physical and chemical soil in each layer of spodosols control and treatment hardpan breaking and mounding treatment. This study was conducted on oil palm age 13 -1 5 years on spodosols in Central Kalimantan. Each sample was taken from control block (20 ha) and treatment block (20 ha) with 5 sampling points which were composited into one. Sampling was based on depth of spodosols layers which are AP (AP0, AP+), E (E1, E2), and B (B1, B2). Observed parameter were physical (texture) and chemical soil that was to evaluate soil fertility control and treatment hardpan breaking and mounding. It used to evaluate soil fertility oil palm plantation control (T0) and treatments (T1). The results showed hardpan breaking and mounding exercise in oil palm could enhance the physical soil properties of spodosols, by improving the soil texture from sand to loamy sand (especially in layer Ap). The soil texture changing from sand to loamy sand had improved the Soil Available Water Capacity (SAWC) on spodosols from 58.3 mm to 91.7 mm. This SAWC improvement could minimize the potential of water deficit in oil palm which planted in Spodosols soil. The hardpan breaking and mounding also enhanced the chemical soil properties of spodosols, by improving pH level, C-organic, N-total, P-total, P-Bray, Exc-K, Exc-Mg, Exc-Na, and CEC.

Keywords: *spodosols, changes, physical properties, chemical properties, soil*

I. INTRODUCTION

Extensification of oil palm plantations has reached to spodosol soil spodosols land because the need and availability of productive land has decreased due to land conversion [50]. Spodosols soil is categorized as a marginal or sub-optimum soil which has several limiting factors but potential for oil palm plantations. The physical and chemical soil of spodosol cause it to be categorized as marginal soil that has several limiting factors such as coarse texture, poor drainage, poor nutrients, acidic pH, fragipan, duripan, and plaque horizon [25,46,47,55].

Area of spodosols in the world is 3.25 miliion km^2 or 4% of the land area [12], and 2.16 million ha (1.1%) are in Indonesia spread over the island of Kalimantan (2.08 million ha), Sumatera (0.02 million ha), and Sulawesi (0.06 million ha), as well as Maluku and Papua whose extent is not known yet [3,44,46]. Spodosol is formed of the major of quartz sand which is characterized by the presence of gray white acid sand layer (albic horizon) and spodic layer from accumulation of iron (Fe), aluminum (Al), and organic matter [14,51]. Spodosol is categorized as nutrient-poor soil, acidic pH, and low CEC [46,51,54].

Currently, productivity still shows a fluctuating value from Smallholder, State and Private Plantation. Spodosol with good management has a potential productivity of 18 – 22 tons ha^{-1} $year^{-1}$ [36]. Koedadiri et al. [26] reported oil palm planted on spodosol at age 9 years had low productivity ranged 5.4 tons FFB ha^{-1} $year^{-1}$, whereas on mineral soil generally ranged 24 – 28 tons FFB ha^{-1} $year^{-1}$. However, Suwardi [50] stated that oil palm productivity on spodosol is able to reach more than 20 tons ha^{-1} $year^{-1}$ through good management and media modification by hardpan breaking and mounding. Application of EFB 200 kg/palm or compost EFB 100 kg/palm with BMP utilization can increase oil palm productivity on spodosols [41].

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Figure 1. Application of hardpan breaking and mounding on spodosols in oil palm plantation

At the present time, technology for managing oil palm on spodosol is still in aspects of improving microclimate, proper fertilization, advancing growth media like hardpan breaking and mounding treatment [50,51]. Hardpan breaking and mounding are two activities that carried out simultaneously to break the hardpan layer that water above the spodic layer can infiltrate downwards and mounding (pile up) on the oil palm circle to increase root media volume in order to increase development of plant roots. Nonetheless, it is important to know analysis of chemical and physical changes in the soil after being treated by hardpan breaking and mounding treatment. Result of physical soil changes can be used as information in determining correction value of SAWC (Soil Available Water Capacity) changes for calculating water deficit and water surplus on spodosols along with recommendations for annual fertilization.

II. METHOD

This research was conducted on oil palm aged 13 -15 years on spodosol in Central Kalimantan. Soil samples were taken from block control (T0) and treatment (T1) hardpan breaking and mounding treatment were applied. Each sample was taken from control block (20 ha) and treatment block (20 Ha) with 5 sampling points which were composited into one. Sampling was based on depth of spodosols layer which are AP (AP0, AP+), E (E1, E2), and B (B1, B2). Categories of sampling in spodosol layer are presented in Table 1.

Table 1. Spodosols horizon (layers)

Code	Description
AP	Horizon A
AP+	Additional horizon A after mounding
AP0	Original Horizon A (before treatment)
E	Mineral soil horizon (silicate clay, iron, aluminum, or some compounds combination leaving a concentration of sand and dust particle)
E1	E horizon transition 1 (white)
E2	E horizon transition 2 (grey)
B	Horizon formed under A, E, or O horizon
B1	B horizon transition 1
B2	B horizon transition 2

Parameter analysis include of physical soil (soil texture) and chemical soil such as pH, C-Organic, N-total, P-total, P-Bray, Exc-K, Exc-Mg, Exc-Ca, Exc-Na, CEC, and base saturation. Physical and chemical soil analyzed and evaluation standard for soil fertility of oil palm is presented in Table 2.

Table 2. Soil fertility classification for oil palm

No	Properties	Reference	Very Low	Low	Moderate	High	Very High
1	pH	1	< 3.5	4	4.2	5.5	> 5.5
2	C Organic (%)	1	< 0.8	1.2	1.5	2.5	> 2.5
3	N Total (%)	1	< 0.08	0.12	0.15	0.25	> 0.25
4	P Total (ppm)	1	< 120	200	250	400	> 400
5	P Bray (ppm)	1	< 8	15	20	25	> 25
6	Exc-K (meq/100g)	1	< 0.08	0.2	0.25	0.3	> 0.30
7	Exc-Mg (meq/100g)	1	< 0.08	0.2	0.25	0.3	> 0.30
8	Exc-Ca (meq/100g)	2	< 2	2-5	6-10	11-20	> 20
9	Exc-Na (meq/100g)	2	< 0.1	0.1-0.3	0.04-0.7	0.8-1.0	> 1.0
10	CEC (meq/100g)	1	< 6	12	15	18	> 18
11	Base Saturation (%)	2	< 20	20-40	41-60	61-80	81-100

Reference: 1. Goh Kah Joo, 1997
2. Balittanah, 2011

III. RESULT AND DISCUSSION

3.1 The Changing of Soil Physical Properties

There is a physical change in spodosols (soil texture) in each layer with average percentage of sand decreasing, silt increasing (except AP and B2 decreasing), and clay increasing. Changes in soil texture in AP layer of sand content decreased by 9.4%, silt decreased by 4%, and clay increased by 13.5% treatment hardpan breaking and mounding (Table 3). AP value is average of AP0 and AP+ layers.

Table 3. Analysis result of changes in physical soil of spodosols on soil texture control and treatment applying hardpan breaking and mounding

No	Spodosols Layers	T0 (Control)			T1 (Treatment)		
		Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
1	AP	89.1	10.5	0.4	79.7	6.5	13.9
	a. AP+	-	-	-	68.1	6.4	25.6
	b. AP0	89.1	10.5	0.4	91.3	6.6	2.2
2	E1	96.0	3.8	0.2	94.0	5.0	1.0
3	E2	98.0	1.8	0.2	91.8	6.1	2.0
4	B1	95.8	4.0	0.2	82.7	10.8	6.5
5	B2	87.3	4.2	8.5	76.9	2.1	21.0

AP+ (Figure 2) is a new layer on oil palm circle formed from mounding activity. Result of physical soil analysis shows that AP+ layer has a good soil texture (sand 68.1%, silt 6.4%, clay 25.6%) and is equivalent to B2 layer (clay mineral). AP+ layer has a better soil texture than AP0, E1, and B1. One of the most prominent physical soil of Spodosols is its coarse texture with a single grained soil structure and a very little dust and clay fractions [12,22].

Layers E1, E2, and B1 showed improvement in soil texture, but not as significant as in AP layer. Layers E1 and E2 still have a high sand content (>90%), so they are less supportive for oil palm growth. Layer B1 has a high sand content and hard spodic layer, making it difficult for roots to penetrate [11,50].

Spodosols has hardpan depth of <100 cm and hardpan thickness that varies [35]. Layer B2 has a better soil texture than AP0, E1, and B1 because it has a higher clay content, although it still has dominant sand content. In fact, the deeper layer B2 has higher clay content than sand. However, results of this study indicate that sand content is higher than clay, this is due to consideration of effective root depth of oil palm (1 meter) so point sampling is taken close to layer B1.

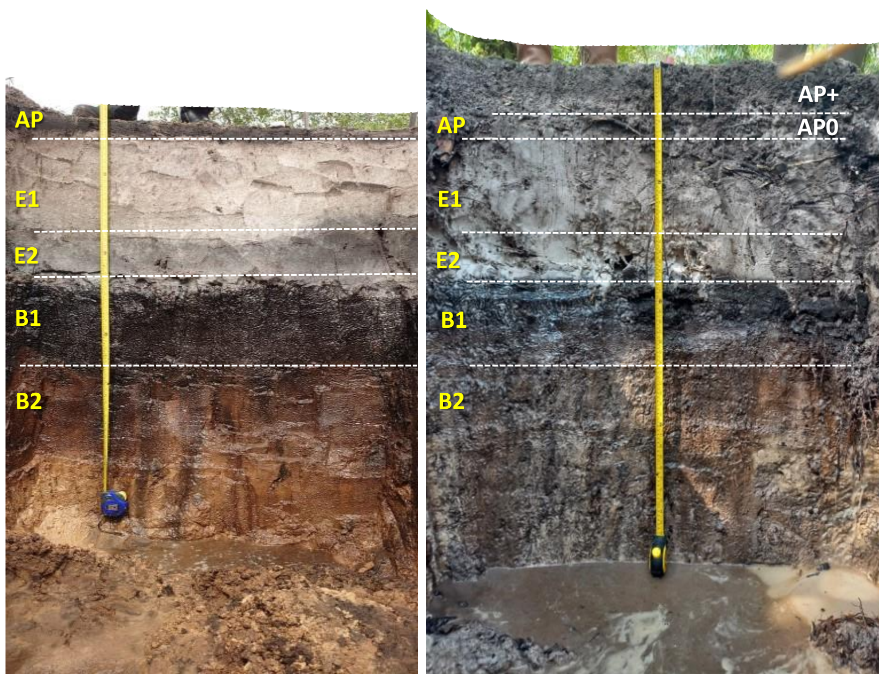

Figure 2. Spodosols profile control (left) and treatment hardpan breaking and mounding (right)

The above explains that hardpan breaking and mounding are proven to increase clay fraction in soil so the soil texture is improved where previously was dominant by sand fraction. Improvement of clay fraction caused formation of loamy texture (clay) and in relation with its colloid which able to control its physical and chemical soil. Soil texture is one of the most frequently defined soil in determining land class [29,15]. This is because soil texture is closely related to movement of water and solutes, movement of heat, air, specific surface area, easiness of soil compaction (compressibility) and weight of soil volume [16,23].

Soil dominated by sand fraction generally have loose structures and have good infiltration and permeability capacities [5,19,27]. However, in contrast to that, spodosols have poor infiltration due to presence of hardpan layer [33]. In general, sand fraction has low water and nutrient holding capacity so it is nutrient-poor and tends to lack water [17,40]. Soil with dominant sand texture has a small water holding capacity and other organic matter [20,30,8].

Table 4. Changes in SAWC value treatment of hardpan breaking and mounding

Treatment	Sand (%)	Silt (%)	Clay (%)	Texture Class	Availaber Water Content (mm)	Critical Deficit (mm)
T0	93.2	4.9	1.9	Sand	58.3	41
T1	84.1	6.2	9.7	Loamy sand	91.7	64

Changes in soil texture make changes in soil texture class from sand to loamy sand, causing the improvement value of SAWC on spodosols after treatment to increase from 58.3 mm to 91.7 mm. As previously shown by Corley and Tinker (2016) states that soil texture can affect SAWC or ability of soil to hold water. This adds to benefit value of mounding which previously only had a function as an addition in the volume root media (layer AP+), but also can increase efficiency of fertilizer absorption and value of SAWC because of having a better soil texture.

3.2 The Changing of Soil Chemical Properties

Hardpan breaking and mounding activities cause changes in chemical soil of spodosols, such as value of pH, C-organic, N-total, P-Bray, and P-total which varied among soil layers (Table 5). The treatment increase pH value in all soil layers, increasing levels occurred in layers AP (low - high) and B1 (moderate - high), while E1, E2, and B2 remined at moderate levels. The increase in pH value reached 0.4 (AP) and 0.4 (B1). This varying change in soil pH is in accordance with Ahmad's statement [2] and Hasibuan and Afrianti [18] that pH value varies according to mineral composition and nitric acid which naturally affects soil pH in addition to organic matter and texture. Soil pH values not only indicate an acid or alkaline soil, but also provide information about other soil, phosphorus availability, alkaline cation status, or toxic elements and so on. This is agreed with research by Atmojo [6] which states that low pH reduces availability of nutrients in soil, phosphate and decreases soil biological activity that plays an important role in increasing soil fertility.

Table 5. Changes in value of pH, C-organic, N total, P-Bray, and P-total control and treatment hardpan breaking and mounding

No	Spodosols Layers	T0 (Control)					T1 (Treatment)				
		pH	C Organik (%)	N Total (%)	P Bray (ppm)	P Total (ppm)	pH	C Organik (%)	N Total (%)	P Bray (ppm)	P Total (ppm)
1	AP	3.9	4.3	0.140	9	171	4.3	4.2	0.144	33	283
2	E1	5.1	0.2	0.170	3	105	4.3	0.1	0.057	7	151
3	E2	4.9	0.5	0.140	3	94	4.7	1.2	0.114	1	260
4	B1	4.1	2.7	0.090	10	84	4.5	4.0	0.259	11	169
5	B2	4.4	2.3	0.120	25	120	4.7	2.3	0.173	22	172

Note : : Very Low : Moderate : Very High
: Low : High

There is no change in C-Organic levels in layers AP, E1, B1, and B2. C-Organic in E2 has increased from very low to low. Compared to other soil layers, the highest percentage of C-organic increase (1.3%) was in B1. Based on these nutritional changes, C-organic content decreased from AP and E1, this was due to an eluviation or washing process (very intensive) with the result that levels of soil organic matter, silicate clay, Fe and Al were low but the content of quartz dust (sesquioxide's) was low, and other resistant minerals are high, so the color is rather light [7]. Meanwhile, C-organic content increased starting at E2 and continued in B2, until the content remained in B2. This can be seen in soil profile of spodosols in study area.

In layer AP, there was a 0.1% decrease in C-organic, which means that a decomposition process has taken place into elements that can be absorbed by plants, therefore plants obtain sufficient nutrients to support growth. The higher rate of decomposition of organic matter or the faster turnover of organic matter, then the faster nutrients become available (Cambardella and Elliot, 1992; Obi, 1999). According to Suharta and Yatno [46], the deeper spodosols layer, the lower C-organic matter.

There was no change level of N total at layers AP. Changes in N total level occurred in layers E1 and E2 (decreasing), as well as B1 and B2 (increasing). This happens because in part of layers AP and E there is an eluviation process or a washing process that it loses clay elements, Fe, Al, organic matter and other nutrients. Then nutrients level increases again in layer B1 (illuviation) or process of accumulating clay elements, Fe, Al, humus, and other nutrients [7], until the value remains in layer B2. Previous studies reported that nitrogen content was in range of 0.10 – 0.11% in top layer of spodosols, and high in spodic layer of 46.2% [46,51].

P-Bray value increased from low (9 ppm) to very high (33 ppm) in layer AP. There was an increase on P-Bray content treatment hardpan and mounding applied that is in layer AP which is an accumulation of fine organic matter (humus) and soil mineral matter. Ability of spodosols to bind phosphorus (P) and other nutrients is highly dependent on organic matter content in soil

[4]. There is no change in P-Bray level in layers E1, E2, B1, and B2. The deeper the layer, the lower P-Bray content, this is in accordance with viewpoint of Suharta and Yatno [46] which state that P-Bray nutrient content is generally very low (<15 ppm). While in layer B2, P-Bray value tends to be high because there is a process of illuviation or accumulation of clay, Fe, Al, humus, and other nutrients [7].

Content of P-total increased in all layers (AP, E1, E2, B1, and B2. The application of hardpan breaking and mounding can increase P-Bray and P-total content throughout spodosols layers, so that P test result is higher than P characteristic in spodosols (1 – 8 ppm) [26,51]. Ability of spodosols to bind phosphorus (P) and other nutrients is highly dependent on organic matter content in soil [4]. P is absorbed by plants mostly in the form of primary and secondary orthophosphate ions ($H_2PO_{4^-}$ and HPO_4^{2-}) which are found in soil solution and are highly dependent on pH of soil solution (Hanafiah, 2005).

There was an increase in Exc-K in all spodosols layers. Exc-K in layer AP increased from low (0.13 meq/100g) to very high (0.33 meq/100 g). In layers E1 and B2 increased from very low to moderate, while layers E2 and B1 increased from very low to high. The increase in availability of K in soil is influenced by content of organic acids and cations ($NH4^+$, Na^+, etc) from the previous layer [31,32]. Based on Wakel and Ishfaq (2022), exchangeable K is related to CEC, pH, calcium, carbonate, and organic carbon with amount of Exc-K that can be exchanged is influenced by kinetic and thermodynamic related to other exchangeable cations and soil surface soil.

Tabel 6. Changes in value of Exc-K, Exc-Mg, Exc-Ca, Exc-Na, CEC and base saturation control and treatment application of hardpan breaking and mounding

No	Spodosols Layers	T0 (Control)						T1 (Treatment)					
		Exc-K (meq/100g)	Exc-Mg (meq/100g)	Exc-Ca (meq/100g)	Exc-Na (meq/100g)	CEC (meq/100g)	KB (%)	Exc-K (meq/100g)	Exc-Mg (meq/100g)	Exc-Ca (meq/100g)	Exc-Na (meq/100g)	CEC (meq/100g)	KB (%)
1	AP	0.13	0.30	1.10	0.17	8.5	20.0	0.33	0.36	0.16	0.11	9.4	12.2
2	E1	0.07	0.04	ttd	0.02	1.4	8.9	0.22	0.07	0.08	0.04	3.1	13.0
3	E2	0.07	0.06	0.06	0.04	1.2	18.6	0.29	0.12	0.08	0.12	3.9	15.5
4	B1	0.07	0.05	ttd	0.03	7.0	2.2	0.27	0.09	0.12	0.07	9.1	6.0
5	B2	0.05	0.03	1.10	0.04	6.9	1.6	0.22	0.06	0.09	0.08	8.5	5.5

Note : : Very Low : Moderate : Very High
: Low : High

Exc-Mg in layers E1 (very low) and B2 (very low) did not change. There was an increase in Exc-Mg in layers E2 and B1 from very low to low, as well as layer AP from high to very high. Availability of magnesium for plants will be reduced in soil that have high acidity. This is due to presence of type 2:1 clay mineral in very large quantities. In the presence of this clay mineral, magnesium will be entangled between mineral lattices, when it becomes expansion and contraction of the lattice [13]. Source of magnesium availability occurs due to weathering process of minerals containing magnesium such as; dolomite limestone ($CaCO_3MgCO_3$), magnesium potassium sulfate, Epsom salt ($MgSO_4.7H_2O$), kieserite, magnesia (MgO), serpentine ($Mg_3SiO_2(OH)_4$), and magnesite ($MgCO_3$) [28,1].

Exc-Ca in all layers were at low levels, but there was an increase in layers E1 and B1 which were previously undetectable to low level. Low content of cations base such as Ca, Mg, K, and Na, correlates with level of soil acidity [42]. Ca-dd is usually associated with low soil pH, low organic matter and sandy soil texture. Ca-dd is influenced by soil reaction (pH < 6), low organic matter content, and dominant coarse texture (Supriyadi, 2007). Concentration of Ca in root area of oil palm is influenced by abundance of arthropods [9].

Exc-Na in layer E2 increased from very low (0.04) to low (0.12). In layers AP, E1, B1, and B2 there was no change in level, but on average there was an increase of Exc-Na. Jasmi [21] stated that Na can replace K function to increase turgor pressure in cells. Exc-Na is influenced by level of solubility and ability to release cations accumulated by groundwater, dispersion effect, total porosity and effect of porosity due to cation valance [37,34,43].

In all CEC values, there was an increase in values in all layers (AP low, E1 very low, E2 very low, B1 low, and B2 low), although at all layers there was no change in level. Low CEC values on spodosols are closely related to C-organic, nitrogen in soil, and low pH values, that low CEC values are unable to withstand added nutrients and nutrient leaching occurs due to lateral flow [24,39]. Soil with a high CEC is able to absorb and provide nutrients better than soil with a low CEC because nutrients are present in colloid adsorption complex, so these nutrients are not easily washed off by water [45]. Soils with organic matter content or with high clay content have a higher CEC than soils with low organic matter or sandy content [38]. By applying mounding, it is proven to be able improving soil texture which is directly correlated to improvement of CEC.

There was no change in level of base saturation in layers E1 (very low), E2 (very low), B1 (very low), and B2 (very low), but average increased. Only layer AP has decreased in level from low to very low. Content of exchangeable bases in low category causes soil reaction to become very acidic, due to leaching of bases to lower layers and horizons (Nursyamsi et al., 2008). According to Atriana et al. (2014), base saturation is positively correlated with low CEC. In areas with high rainfall, soil colloids will be dominated by H^+ ions, while alkaline cations are weakly absorbed and are in free solution [13]. Syofiani et al. [52] added, high rainfall resulted in lower content of exchangeable bases because washing process was intensive, so it was a trigger for leaching. This will cause a decrease in alkaline cation content in soil.

IV. CONCLUSION

The hardpan breaking and mounding exercise in oil palm can enhance the physical soil properties of spodosols, by improving the soil texture from sand to loamy sand (especially in layer Ap). The soil texture changing from sand to loamy sand has improve the Soil Available Water Capacity (SAWC) on spodosols from 58.3 mm to 91.7 mm. This SAWC improvement can minimize the potential of water deficit in oil palm which planted in Spodosols soil. The hardpan breaking and mounding also enhance the chemical soil properties of spodosols, by improving pH level, C-organic, N-total, P-total, P-Bray, Exc-K, Exc-Mg, Exc-Na, and CEC.

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