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Effect of Ground Water Level and Steel Slag Application on Soil Moisture Variability and Actual Hydrophobicity of Peat Soil in Oil Palm Plantation

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ABSTRACT

The study was carried out to study the effect of ground water level and steel slag application on soil moisture variability and actual peat soil hydrophobicity in oil palm plantation agro-ecosystem. The study plot was designed using split plot design with three treatments of water level management as main plot and four dosages of steel slag (electric furnace slag) application as sub plot. During the study, actual moisture content observation was carried out in the field for six times, representing dry and wet months. Actual hydrophobicity valuation was determined by comparing actual water content with the critical water content of peat hydrophobicity. The result showed that the ground water level apparently affected actual soil moisture content at layer of 0-2.5, 2.5-5 and 5-10 cm, especially during the dry month. The highest moisture content that can be stored at upper layer (0-10 cm) was obtained at the water level management of 40-60 cm from peat soil surface. At dry month, the ground water level was too deep (>80 cm) will cause soil hydrophobicity of the layer 0-10 cm, at the circle area as well as at interrow area of oil palm tree. Steel slag application on the circle area until 9.86 kg/tree in the all water level management treatment plots did not apparently affected the soil moisture of the upper layer. Ground water level management at ranged of 40-60 cm could retain higher soil moisture and avoid the upper layer from hydrophobicity.

Key words: Hydrophobicity, ground water level, peat soil, oil palm plantation, steel slag

INTRODUCTION

Under natural conditions, the tropical peatland are invariably water-logged with high water tables at or near the surface. To use tropical peatland for oil palm cultivation, controlled drainage is required to remove excess water and lower the water table to a depth required by oil palm under best management practices Lim *et al.* (2012). However, uncontrolled drainage would reduce soil moisture and hydrophobicity will appear (Brandyk *et al.*, 2003). Lim *et al.* (2012) stated that over-drained areas caused low yielding oil palm plantations on peatland. Peat soil ground water level fluctuation strongly affected the soil moisture distribution and soil hydrophobicity (Szajdak and Szatylowicz, 2010; Sri Nuryani *et al.*, 2009).

Peat soil hydrophobicity occurred because of the decreased of hydrophobic functional groups and was dominated by hydrophobic functional groups (Valat *et al.*, 1991; Sri Nuryani *et al.*, 2009). At the hydrophobic condition, the peat soil showed negative attributes consisting the decreased ability to retain water, decreased soil moisture, decreased soil infiltration, peat subsidence (Brandyk *et al.*, 2003; Wosten *et al.*, 2006; Szajdak and Szatylowicz, 2010; Othman *et al.*, 2011), limit the growth and yield of oil palm (Lim *et al*., 2012) and pseudo sand formation at the peat soil surface (Yulianti, 2009). The formed pseudosand was easily eroded through wind and/or water flow.

Soil hydrophobicity could be directly observed in the field condition. Actual soil hydrophobicity is soil hydrophobicity assessment on the field soil moisture condition (Dekker *et al*., 2001a, 2005). Actual hydrophobicity assessment was carried out through comparing the actual soil water content to critical water content (Brandyk *et al*., 2003; Dekker *et al*., 2005). Dekker *et al*. (2001b) introduced that the critical water content is a transition zone, above the transition zone which a soil is wettable and below which a soil is hydrophobic. Soil samples can be either wettable or hydrophobic within the transition zone. Maintained soil moisture will prevent physically the soil to hydrophobicity (Muller and Deurer, 2011). Soil moisture could be carried out by maintaining the ground water level at the proper depth (Wosten *et al*., 2008; Lim *et al*., 2012), in this way the soil moisture profile would reach the upper level soil. In addition, to prevent soil hydrophobicity could use soil amandement (Muller and Deurer, 2011). Soil amandement application on peat soil has been implemented, among other is steel slag. The steel slag is by-product formed in the process of steel manufacturing. The kinds of steel slag which is the most produced in Indonesia is electric furnace slag. Chemical properties of steel slag contained more Fe, Ca, Mg and Si but less P, K and micro nutrients. Electric furnace slag application had been analyzed for peat soil stability and improving soil fertility as well as increasing yield (Suwarno, 2010).

Based on the background, the objectives of the study were to study the effect of ground water level and steel slag application dosage on soil moisture variability and actual peat soil hydrophobicity in oil palm plantation agro-ecosystem.

MATERIALS AND METHODS

Research site: The study was carried out in Panai Jaya Oil Palm Plantation at sub-district Panai Tengah, district Labuhan Batu, province North Sumatera (2°22'25"-2°22'50" N and 100°16'0"-100°17'10" E). The oil palm block being studied as research plot was 6 years old oil palm (planting year was 2008). The Panai Jaya Oil Palm Plantation is cultivated on peatland area with the thickness of peat ranged of 344-503 cm and hemic-sapric maturity degree (Yulianti, 2009; Winarna and Sutarta, 2010).

Soil analysis: The applied method analysis of peat soil were consisting of ash content (Loss of Ignition), bulk density, water retention (pF 2.54 and 4.2), fiber content, total porosity, saturated hydraulic conductivity, pH and C-organic. Peat maturity degree was determined by using von Post method. Actual soil water content analysis (gravimetric) was carried out directly in the field.

Research plot: Research plots was designed using a split plot design with three replications. Plots treated with three treatments of ground water level management as main plots and four dosages of steel slag application as a subplot. Ground water level management was carried by setting weirs (water level control structures) at the collection drains and equipped with an over-flows facility. Soil bags were used to construct weir. Ground water level management I (WLM-1) by setting the over-flow at depths of 40-60 cm, ground water level management II (WLM-2) by setting the over-flow at depths of 60-75 cm and the ground water management III (WLM-3) without water level control structures. The result of all ground water management was water level fluctuation condition that was different than the research period of November 2013-November 2014. Dosages of steel slag application consisted of 0, 3.15, 6.51 and 9.86 kg/tree. The steel slag application was spread evenly at the circle area of oil palm tree. The application was given twice a year, first application in December 2013 and the second in May 2014. The water level at each plot was observed using piezometer to measure the water level fluctuation during the research.

Soil sampling and soil moisture determination: Disturbed and undisturbed soil sample were taken from the circle and interrow area of oil palm trees at the depths of 0-2.5, 2.5-5, 5- 10, 10-20, 20-30 and 30-40 cm. Soil samples for actual soil water content determination was taken six times in period i.e., 6 February 2014, 12 March 2014, 11 June 2014, 15 July 2014, 8 October 2014 and 13 November 2014. Soil water content was determined using gravimetric method directly in the field.

Actual peat soil hydrophobicity: In this study, the actual peat soil hydrophobicity was evaluated by comparing actual soil water content with the critical water content of hydrophobicity. The critical water content is known as the transition zone or a range of water content value (Dekker *et al*., 2001a, 2005; Ritsema *et al*., 2008). The actual soil water content above the transition zone which a soil is wettable and below which a soil is hydrophobic. Critical water content was determined through observation a number of soil samples having moisture condition ranging from wet to dry, then its hydrophobicity was also observed (Dekker *et al*., 2005; Ritsema *et al*., 2008).

Water Drop Penetration Time (WDPT) method of Bisdom *et al*. (1993) was used for determination of the soil hydrophobicity, this method was based on time required for a drop of water being infiltrated into the soil (Hallett, 2008). Hydrophobicity of the peat soil was determined by observing the water droplets on the surface of peat soil samples, which had been smoothed prior to analysis. Bisdom *et al*. (1993) distinguished five classes of hydrophobicity on the basis of the time needed for the water drops to penetrate into the soil: Class 0, non water repellent (infiltration within 5 sec); class 1, slightly water repellent (5-60 sec); class 2, strongly water repellent (60-600 sec); class 3, severely water repellent

(600-3600 sec) and class 4, extremely water repellent (>1 h). When the contact angle is <90° and water penetration occurs in <5 sec (class 0), the peat soil is able to re-absorb water. However, if the contact angle is >90° and penetration time is >5 sec (class 1), the peat is considered to be hydrophobic.

Statistical analysis: Data of this research were statistically analyzed using analysis of variance (ANOVA) and a significance probability of 5%. When the treatment was significantly different, the data was further tested with Duncan Multiple Range Test (DMRT) at $\alpha = 5\%$.

RESULTS AND DISCUSSION

Soil and characteristics: Physical and chemical characteristics of peat soil of the research location is presented in Table 1. The peat soil was determined based on the sapric maturity on the upper layer (0-10 cm) and on the hemic maturity on the layer of 10-40 cm, with a fiber content of sapric at upper layer is lower than the hemic at the deeper layer. The peat soil acidity was classified very acid, while the ash content of sapric was higher then in hemic peat. Bulk density of sapric (at the upper layer) was higher then hemic. Increased bulk density occurred in the higher decomposition degree (Andriesse, 1988; Verry *et al*., 2001), besides the presence of compacted soil at the upper layer as the result of cultivation. Decomposition degree and compacted of soil also affected the water retention capability of peat soil. Based on the percentage of water content at pF 4.2 to water content at pF 2.54 (strongly retained-water), sapric showed higher than the hemic. Peat characteristics such as bulk density, hydraulic conductivity and total porosity have closely related to the water retention capability of peat. Verry *et al*. (2011) stated that the capacity of peat soil to retain water is a function of its bulk density, because the ability of soil to bind water increases with an increase in soil bulk density.

Rainfall and ground water level fluctuation: The rainfall data of the location was recorded during the period of December 2013-November 2014. At the same period, recorded the ground water level at each research plot using piezometers. Figure 1 showed the rainfall and ground water level fluctuation for the period of study. Ground water level fluctuation was categorized into three groups based on their management. First management (WLM-1) were obtained the fluctuation of ground water level ranged 20-75 cm, while second management (WLM-2) at ranged 20-80 cm and the third (WML-3) were obtained ranged 25->80 cm. In general, the ground water level fluctuation followed the rainfall pattern, where the ground water level will decrease if the rainfall is low or during the dry month. Six times observation of actual water content in the research plot was carried out with different ground water level.

Variability of soil water content: Observations of actual soil moisture content in the research plots with different ground Water Level Management (WLM) and the application of steel slag were carried out in the period of 6 February to 13 November 2014. There were fluctuations in ground water levels in all three treatments of WLM during the observation period of actual soil moisture content. Table 2 shows the depths of the ground water level during the observation time of the actual water content.

Figure 2 shows that the distribution of soil moisture in the soil profile increased in accordance with the soil depth, while the temporal variability (in the period of 6 February to 13 November 2014) of the actual soil water content among the three treatments of WLM in that period was sufficiently large on the upper layer (0-10 cm). The difference in the depth of the ground water level at the three ground water management significantly affected the reduction of soil moisture in the layers of 0-2.5, 2.5-5 and 5-10 cm ($p<0.05$), especially on 6 February and 4 June 4, 2014. Soil moisture level with the layers of 0-10 cm in the treatment of WLM-1 showed the highest value than the WLM-2 and WLM-3. However, the effect of a decrease in ground water level was no longer significantly influential on soil moisture with the condition of the layer deeper than 10 cm at all observation times.

Table 1: Peat soil characteristics of research site in Panai Jaya oil palm plantation

	Soil depths (cm)	
Soil characteristics	0-10	10-40
pH (H_2O)	3.68	3.50
C-organic (%)	55.08	55.26
Degree of decomposition (von Post)	Sapric	Hemic
Ash content (%)	5.05	4.73
Fibre content (%)	44.00	68.00
Bulk density (g cm^{-3})	0.21	0.16
Hydraulic conductivity (m jam^{-1})	0.33	0.74
Total porosity (%)	88.00	90.67
Water content at pF2.54 (%, w/w)	354.21	375.93
Water content at pF4.2 (%, w/w)	171.48 (48.41)	179.10 (47.64)

Values in percentage of water content at pF 4.2 to water content at pF 2.54

Table 2: Ground water level (cm) during the observation period of soil moisture content

Water level management	6 Feb 2014	12 Mar 2014	4 Jun 2014	15 Jul 2014	8 Oct 2014	13 Nov 2014
WLM-1	59.4	56.6	69.2	66.3	26.0	25.2
WLM-2	67.2	71.0	66.4	68.2	33.0	35.0
WLM-3	83.6	81.1	83.2	80.1	47.3	47.1

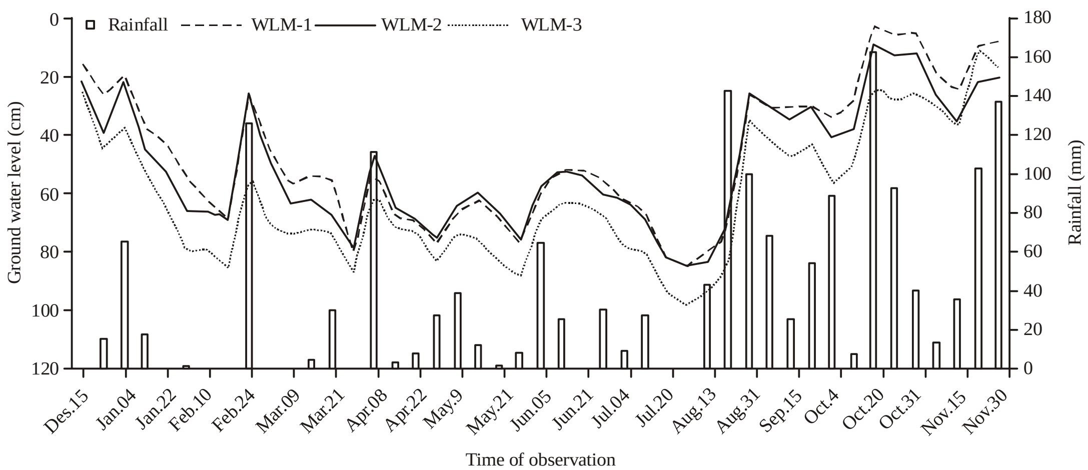

Fig. 1: Rainfall and ground water level of research location in the period of December 2013 until November 2014

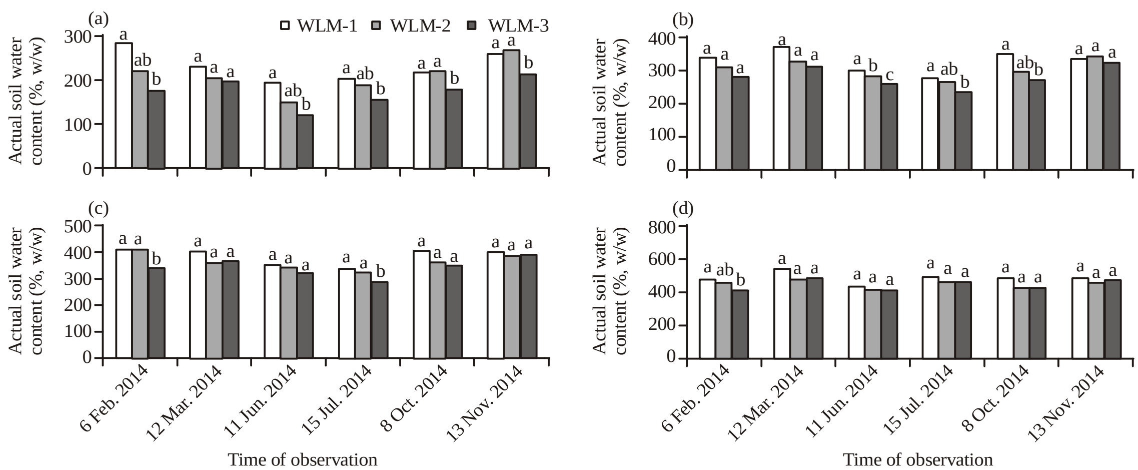

Fig. 2(a-d): Temporal variability of actual soil water content between 6 February until 13 November 2014, different letters denote the significant differences ($\alpha = 0.05$) between WLM treatments, (a) Layer 0-25 cm, (b) Layer 2.5-5 cm, (c) Layer 5-10 cm and (d) Layer 10-1 cm

In the dry months (March and July), all WLM treatments decreased the ground water level. The largest decrease occurred in the WLM-3, i.e., over 80 cm. Melling and Hatano (2010) also obtained the same result on peat soil of Malaysia. Decrease in ground water levels would affect the distribution of soil moisture to the entire peat soil profile in upper layer (Kurnain *et al*., 2006). Changes of ground water level resulted in the release of a number of volumes of soil water from the upper layer. The high of hydraulic conductivity and total porosity of peat accelerate the release of soil moisture due to the suction of the decreasing water level (Kurnain *et al*., 2006). Based on the observations of the soil water content after July 2014 during the wet seasons (rainfall >100 mm), variability of soil moisture on the all WLM was relatively small. This is because the ground water level of all WLM is relatively shallow and has quite similar fluctuations.

Another treatment on the research plots was the application of steel slag with dosages of 0, 3.15, 6. 51 and 9.86 kg/tree. However, the application of steel slag with a dosage until 9.86 kg/tree in the all WLM treatment level was not significantly influential on the peat soil moisture level at the upper layer both during the wet and dry months (Fig. 3). Time for the observation of this study was relatively short, as a result, to determine the effects of steel slag applications needs more observations which will be continued in the next year.

Critical water content of peat soil hydrophobicity: The soil water content has a considerable influence on the actual hydrophobicity of peat soil in the field. The soil hydrophobicity can occur if the soil moisture is lower than the critical water content. The critical water content is known as the transition zone or a range of soil water content

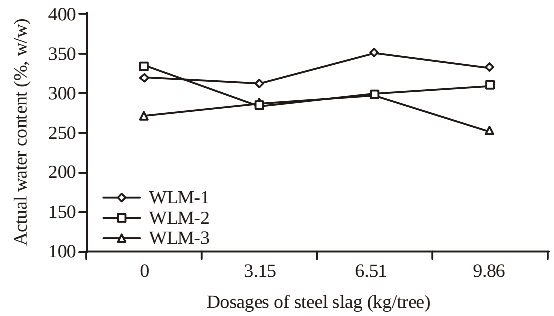

Fig. 3: Mean of actual soil water content at layer 0-40 cm in the research plots between period of 6 February and 13 November 2014

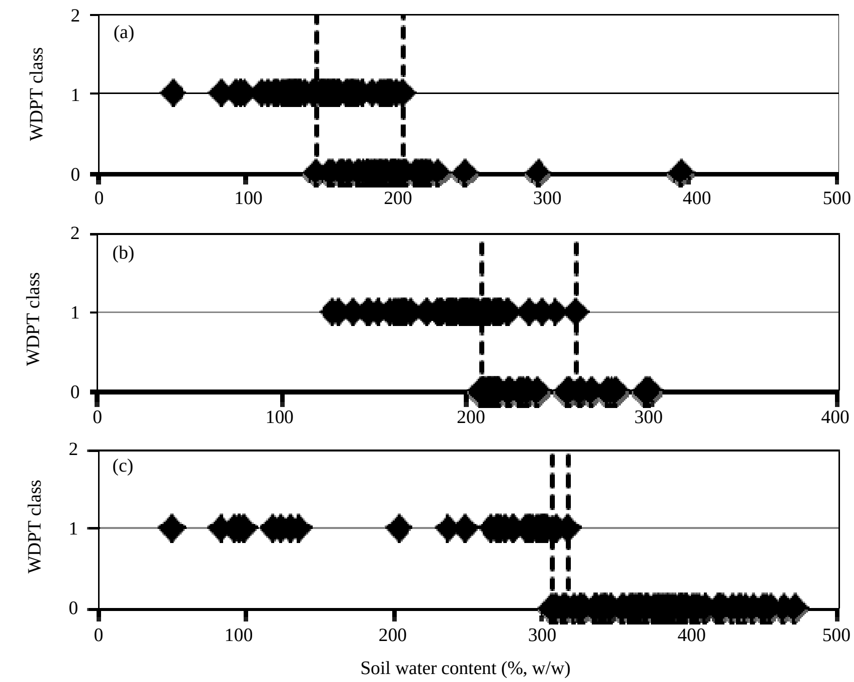

Fig. 4(a-c): Critical water content of peat soil at layers of (a) 0-2.5, (b) 2.5-5 and (c) 5-40 cm are 147.48-205.97%, 206.94-258.96% and 305.94-317.43% (w/w), respectively

(Dekker *et al*., 2001b, 2005; Ritsema *et al*., 2008). Figure 4 presents the critical water content of peat soil at the layers of 0-2.5, 2.5-5 and 5-40 cm. A critical water content value is used to determine the actual hydrophobicity of the studied peat soil, which compares between the actual water content with critical water content in the corresponding layers. The actual water content above the transition zone which a soil is wettable and below which a soil is hydrophobicity. Soilsamples can be either wettable or hydrophobic within the transition zone (Dekker *et al*., 2001a). Differences in critical soil water content at each layer of peat soil in the field is mainly influenced by the properties of peat soil.

Actual peat soil hydrophobicity: Based on six times observations of soil moisture content in the field, it shows that there is a considerably great variability, especially in the upper layer of peat soil due to ground water level fluctuations. The relatively large decrease of soil moisture occurs during the dry months and ground water level becomes deeper. In the event of a decrease in soil water content exceeds its critical water content, hydrophobicity will occur (Szajdak and Szatylowicz, 2010; Ritsema *et al*., 2008; Dekker *et al*., 2001b). Assessment on soil hydrophobicity in the field was conducted to determine the impact of fluctuations of ground water levels on the actual hydrophobicity of peat soil.

Figure 5 shows the relationship between actual soil water content (in the circle and interrow area of oil palm trees) and the critical water content of peat soil at layers of 0-2.5 cm, 2.5-5 cm, 5-10 and 10-40 cm in the three conditions of WLM. This assessments were carried out on the actual soil moisture

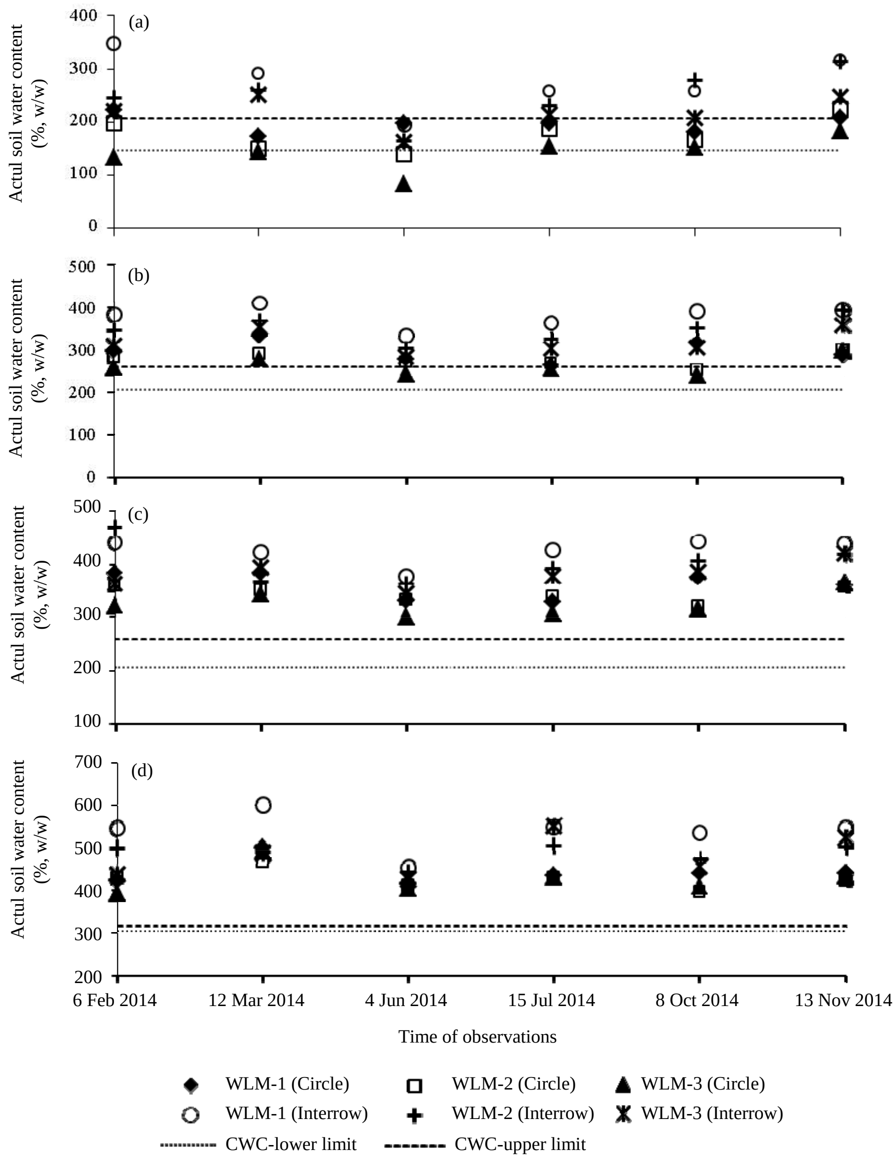

Fig. 5(a-d): Relationship between actual water content (at the circle and interrow area) and critical water content (CWC) of peat soil at the layer of (a) 0-2.5, (b) 2.5-5, (c) 5-10 and (d) 10-40 cm in the three water level management (WLM) between period of 6 February to 13 November 2014

conditions during the six times observations in the period of February 6 to November 13, 2014. When the condition of the ground water level is too deep, the soil layers of 0-2.5 cm, 2.5-5 and 5-10 cm are very vulnerable to hydrophobicity, especially in the circle areas. This condition will be more easily occur during the dry season with 8-12 dry spells or more (Salmah *et al.*, 1991). The soil layers of 0-2.5 cm in the circle areas with WLM-3 treatment always suffer from hydrophobicity, indicating that there was a formation of pseudo sand in this layer. Open the circle due to chemically intensive maintenance of weeds or cover crops caused a lower water retaining capacity, especially in the conditions of excessive drainage and during the dry season (Lim *et al.*, 2012). The condition causes the appearance of soil hydrophobicity and formation of pseudo sand materials, usually at the layer of 0-2 cm (Yulianti, 2009).

Management of ground water level in peatland for oil palm cultivation should increase water retention and keep it as long as possible until the peat surface, especially during the dry season (Melling and Hatano, 2010). During the rainy season, the ground water level should be controlled at a lower level (from soil surface) to reduce excessive water, whereas in the dry season, the ground water level is controlled at a higher level for the preservation of peat soil (Ambak and Melling, 2000; Wosten *et al.*, 2008; Othman *et al.*, 2010; Lim *et al.*, 2012). Management of ground water level in the ranges of 40-60 cm from the soil surface in the filed can retain moisture until the upper layers and prevent the occurrence of peat soil hydrophobicity. Deep ground water levels mean an increased subsidence of the peat by oxidation as well as an increase in hydrophobic susceptibility (Wosten *et al.*, 2008).

CONCLUSION

The management of ground water level of peatlands in oil palm plantations significantly affect the actual soil moisture content (field condition) at the layers of 0-10 cm, especially during the dry months. The maintenance of water levels in the range of 40-60 cm, significantly increased the ability of the peat soil retain water (above the critical water content) at the layer of 0-10 cm. Excessive soil drainage (depth of ground water level >80 cm) causes soil hydrophobicity at the upper layers (0-10 cm), especially in the dry season. Application of steel slag on the circle areas of tree with a dosage until 9.86 kg/tree in the first year of research did not significantly affect on the peat soil moisture in the upper layers.

The implication of the results of the study is that the ground water level in oil palm plantations can be maintained in the ranges of 40-60 cm from the soil surface (piezometer reading) in order to conserve the soil moisture and avoid the occurrence of peat soil hydrophobicity. Steel slag application needs to be studied further from other aspects such as the improvement of peat soil quality and green house gas mitigation.

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