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Changes in Water Table Depth in an Oil Palm Plantation and its Surrounding Regions in Sumatra, Indonesia

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Abstract: This study was carried out to determine changes in depths of water table in an oil palm plantation and its surrounding region. Daily water table depths and daily climatic elements were considered in this study. Eight well point locations were chosen randomly throughout the oil palm plantation. To test relationships among the different variables, correlation coefficients were statistically tested using t-test at 95 and 99% confidence levels. The results showed that fluctuation depth of the water table at the oil palm area depended on climatic elements. In general, water table depth decreases during dry season and increases during wet season. However, water table depths reduction does not happen permanently. Similarly, water table depths were not changed by oil palm plantation at the oil palm area. Strong correlations were observed between oil palm area and oil palm areas with water table at river side plain. Meanwhile, some other locations were shown to have weak correlation for water table at oil palm and those locations. At oil palm area, water table depth was found to be correlated with some water balance elements such as effective precipitation, soil surface evaporation, run-off and water infiltration rate.

Key words: Water table depth, watershed, climate element, oil palm, surrounding region

INTRODUCTION

Oil palm has been estimated to use water between 1.83-4.13 mm palm^{-1} day^{-1} for its growth and productivity (Harahap and Darmosarkoro, 1999) as compared to forest trees and annual crops which need around 5.02-6.32 mm and 1.83-4.13 mm day^{-1} (Schilling, 2007), respectively. Soil water table is the upper boundary of saturated sub-surface water or aquifer zone, whereby the pressure in this boundary equals to that of the atmosphere (He *et al*., 2002).

A huge loss of water from land will cause a decrease in water table depth. The main factors which determine the water table depth are infiltration, precipitation and percolation mechanisms as sources of recharge in a system and evapotranspiration by upflux as discharge that causes the loss of water from the system.

A profound influence of proper water management on the productivity of oil palms may be associated with improvements in conditions that are suitable for root development. With raising the watertable, secondary and tertiary roots are generally concentrated close to the water table and primary roots penetrate to the greater depths during drier periods to produce upward-growing secondaries and tertiaries. When water table recedes during dry weather, roots are apparently able to proliferate through less toxic areas in the moist acid horizon to reach below the water table.

This study was carried out to observe the impacts of oil palm establishment on water table dynamics in an oil palm area and its surrounding region in Sumatra, Indonesia.

MATERIALS AND METHODS

The study which lasted for three years, was conducted in the Kabun region of Tandun Riau, Indonesia. The type of the soil in the landscape is that of typic hapludult paleudult with clay texture, having an elevation of 30-70 m above the sea level and forming flat-wavy region. There are 8 well-point locations consisting of the young oil palm area (P1), the adult oil palm plantation area (P2), the residential area of oil palm plantations (P3), the mature oil palm plantation area (P4), the residential district in the city (P5), the sub-district town (P6), the cocoa planting (P7) and the housing at Giti village (P8). Each point distributed in one line transect, began at the river bank and ended at the village (Table 1, 2 and Fig. 1).

The observed data were: (1) Daily water table depths and (2) Daily climatic elements. The data analysis included

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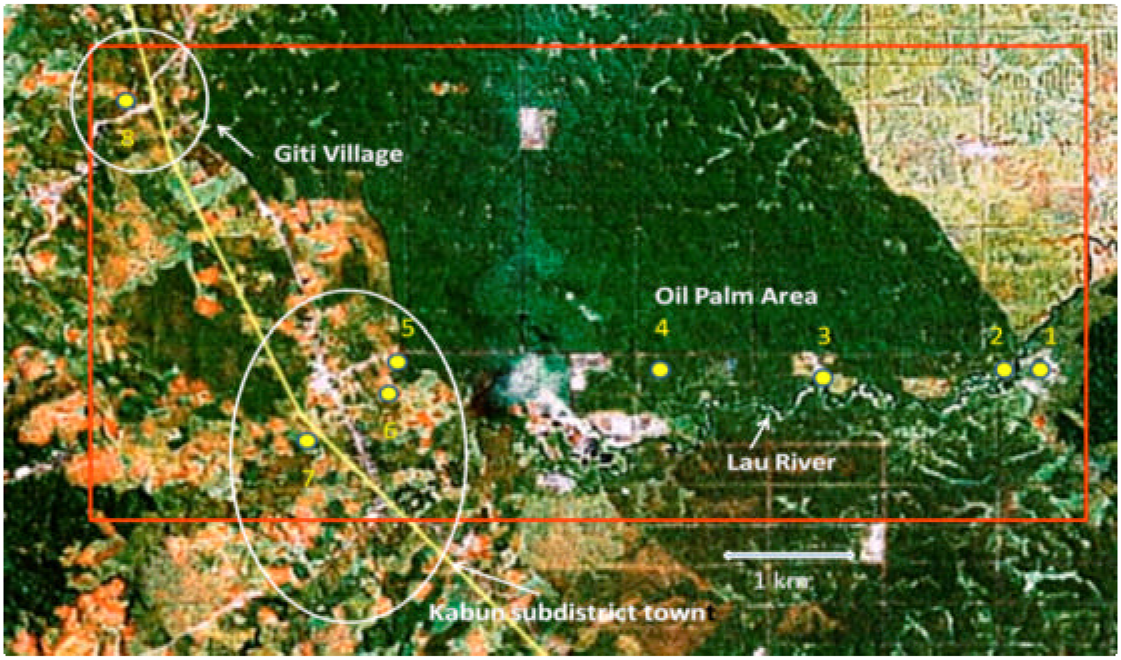

Fig. 1: Distribution of well points for water table depths monitoring in the oil palm plantation

Table 1: Distribution of the well points at Kabun-Aliantan watershed

Locations	Geographic positions	Elevation (meters above of sea level)	Codes
Young oil palm (2004 planting year)	N: 00°27,948' E: 100°50,262'	41	P1
Adult oil palm near to the Lau river (1992 planting year)	N: 00°27,925' E: 100°50,202'	38	P2
Adult oil palm at Marihat block A (1989 planting year)	N: 00°27,936' E: 100°49,977'	48	P4
Complex housing of oil palm plantation	N: 00°27,925' E: 100°49,219'	44	P3
Housing 1 at the sub-district town	N: 00°27,700' E: 100°47,060'	53	P5
Housing 2 at the sub-district town	N: 00°27,927' E: 100°47,208'	56	P6
Housing at the village	N: 00°29,121' E: 100°45,797'	63	P8
Cocoa planting area	N: 00°27,566' E: 100°46,961'	59	P7
Side of Lau river	N: 00°27,925' E: 100°50,202'	38	PS

Table 2: Some soil physic properties of the well points at Kabun-Aliantan watershed in 0-100 cm soil depth

	Fraction of texture (%)					
Codes	Sand	Silt	Clay	Texture class (USDA)	Organic matter (%)	Saturated hydraulic conductivity (K_s, m h^{-1})
P1	86	6	8	Sand	0.25	8.17
P2	58	20	22	Sandy clay loam	0.18	1.90
P3	46	18	36	Sandy clay	0.35	0.77
P4	32	18	50	Clay	1.42	0.49
P5	32	32	36	Clay loam	1.61	0.84
P6	18	16	66	Clay	0.27	0.36
P7	20	14	66	Clay	1.88	0.38
P8	50	22	28	Sandy clay loam	0.26	1.21

(1) Correlation analysis of water table depths at each well-point location with several climatic elements in the same period of time and (2) Correlation analysis of water table depth between the oil palm area and the other locations in the same period of time. The parameter correlation was then statistically tested using t-test (Steel and Torrie, 1981) with 95 and 99% confidence levels. Other variables measured in the oil palm area were (1) Effective precipitation, (2) Soil surface evaporation under canopy covering and (3) Run-off.

RESULTS AND DISCUSSION

Water table fluctuation: Water table depths were found to have fluctuated during the observation time, especially in the oil palm areas that showed similar water table

Table 3: Values of daily water table depths at the location observed during August 2008-April 2010 period

Location (code)	Average (cm)	SD cm	SD %	Maximum values (cm)	Time periods	Minimum values (cm)	Time periods	Average(cm)
P1	-186.4	69.2	37	16.8	Oct-2009	-305.4	July-2009	322.2
P2	-251.0	83.1	33	-28.0	Nov-Dec-2009	-390.2	June-July-2009	362.2
P3	-67.3	49.4	73	52.8	Nov-Dec-2009	-177.5	Jan-Feb-2009	230.3
P4	-186.3	109.2	58	36.1	Nov-Dec-2009	347.5	Jan-Feb-2009	383.6
P5	-64.5	11.5	17	-37.2	Sep-Oct-2009	-93.9	August-2009	56.7
P6	-16.3	17.9	101	33.2	August-2009	-85.2	May-June-2009	118.4
P7	-117.9	61.2	52	43.4	Sep-Oct-2009	-248.9	May-June-2009	292.3
P8	-67.3	30.0	44	-3.0	Sep-Oct-2009	-161.4	May-June-2009	158.4
Ps	-39.3	62.4	158	85.0	March-2009	-148.0	October-2008	233.0

fluctuation patterns. On the other hand, the water table did not fluctuate as much as in the cocoa planting areas, plantation housing complex and Giti village. At each location, it was observed that the daily water table fluctuated with different values and at different times (Table 3).

At the young oil palm area (P1) and the adult oil palm plantation area (P2), the depths of water table were observed to reduce during April-September 2009. After October, the water table rose back to the original level. This finding indicated that there is no permanent decline in the depths of water table. The standard deviations of daily water table depths at the young oil palm area (P1) and the adult oil palm plantation area (P2) were 37 and 33%, respectively. The value of the standard deviation indicated that the water table depth at P1 and P2 is not significantly different at both areas.

Even though the water table fluctuations in the residential area of oil palm plantations (P3) were similar with that of the oil palm area, the fall in the water depths during April-September 2009 was not significant because there was no discharge of water by transpiration at this area. The transpiration by oil palm is approximately around 4-5 mm day^{-1} (Harahap and Darmosarkoro, 1999). The water table level came back to its normal depth after October 2009 with a standard deviation of 73%. This is a big variance in the depth of water table. If the depth of water table is positive, it means that water surface is higher than the ground surface which basically occurs when the water surface is very high.

At the mature oil palm plantation area (P4), the fluctuations in depths of water table during April-September 2009 were similar to those observed at the young oil palm area (P1) and the adult oil palm plantation area (P2). After October, the water table came back to its normal level. Amplitude at this area showed a high variance, indicating that in adult oil palm, there are high responses to recharge and discharge of water. Discharging of water usually comes from evapotranspiration and drainage (Berendrecht *et al*., 2004). Water table depth is very responsive to recharge and discharge caused by precipitation and evapotranspiration, respectively, therefore in a short time, these factors can change water table depth (Tanco and Kruse, 2001).

At the residential district in the city (P5), the pattern of water table fluctuation is different from those observed in the oil palm area. There was no decline of water table but there was small amplitude with low variation of water table (i.e., 17% only). This could be due to the fact that no crop was present in this area. Meanwhile, at the sub-district town (P6), as well as the residential district in the city (P5), decline period in the depths of water table was not observed. However, a high variation of water table (about 101%) was observed due to the shallower confining layer.

The daily water table depth at the cocoa planting (P7) did not have a very similar fluctuation pattern to that of the oil palm area. In particular, the decline in the pattern was observed during May-June 2009. However, this decline was not too much in the oil palm area. The reason for that lies in the lower water requirement of cocoa plant (2-3 mm day^{-1}) as compared to oil palm (4-5 mm day^{-1}). The standard deviation of the average daily water table is 52%. The cocoa area has enough response to water recharge and discharge.

Decline period of water table was not observed in the housing at Giti village (P8). From May to June 2009, however, the lowest water table was observed. The fluctuation pattern at this area is similar to that of the sub-district town. Water table at this area is shallower (158 cm with 44% standard deviation). The area is not covered by plants making it not too responsive to discharge and recharge. The fluctuation in water table at Lau River Side showed the highest deviation (158%). The depths reached 233 cm. Variation and amplitude was relatively at the highest amount because the river is placed for collecting water flow from both ground water flow and run-off from ground surface. The pattern in oil palm and the river side also had a falling period as well. This occurred in May-September 2009 period.

Correlation of water table depth and climate and soil physic properties: The fluctuation in water table depths is related to the weather climate condition. In the dry periods with low precipitation, water table depths were low but became higher in the wet seasons. According to Haridjaja and Herudjito (1979), precipitation is fallen from the air in solid or liquid form such as rain, snow, ice, mist or vapour to the earth surface (He *et al*., 2002). The rate of evapotranspiration in adult oil palm area was 93% of potential evaporation rate. The weak correlation between water table depth and evaporation was due to the assumption of no significant dry season (Harahap and Darmosarkoro, 1999). The flow of water movement occurring from water table surface to unsaturated zone (subsoil zone) was significant during the dry season which caused the decrease in the water table depths in the forest area upto 100% (from 4-8 m) (Talsma and Gardner, 1986).

All the locations in oil palm area and its surrounding region showed higher water table depths in the January-March 2010 period as compared to the earlier observation period (October-December 2008), except for the adult oil palm plantation area (P2). Precipitation and rainy days are climatic variables which can affect water table depths. They showed a high positive correlation with water table depths as compared to evaporation which showed a weak negative correlation with water table depths (Table 4). In the dry period, however, cumulative evaporation showed a high negative correlation while in the wet period, this relationship was not clearly observed (Table 5).

Water table dynamics is determined by the balance of recharge and discharge of water. The main sources of water recharge are precipitation and soil water ground flow, whereas the main sources of water discharge are evapotranspiration and drainage. Water table changes are very responsive to recharge (mainly precipitation) and discharge (mainly evapotranspiration). Therefore, changes in water table can occur quickly. There was no significant decrease in water table depths at all of the observation locations. Nevertheless, water table depth in oil palm area showed significant differences between the highest and the lowest depths recorded (P1, P2 and P4), whereas small fluctuations in the depths of water table were observed at the housing area in the sub-district town (P5 and P6) (Table 6). The oil palm showed similar fluctuation pattern of water table depths to that of the cocoa planting area (P7). The upward movement which caused evapotranspiration from leaf and soil surface was the main factor causing significant decrease in the water table depths. In the oil palm area which has relatively large canopies, a sharp decrease in the water table depths was found as compared to the other locations.

The role of evapotranspiration in the depths of water table in wood plant area such as oil palm plantations was reported by Bliss and Comerford (2002) and Jutras *et al.* (2006). They stated that the reduction of wood plant population would cause a decrease in transpiration rate which could, then, increase water

Table 4: Correlation (r) between the 10 day-period average of water table depth changes at each location with climate variable in August 2008-April 2010

	Locations								
Climate variable	P1	P2	P3	P4	P5	P6	P7	P8	Ps
Precipitation	0.48**	0.54**	0.19 ns	0.48**	0.13 ns	0.47**	0.41**	0.42**	0.60**
Rainy days	0.48**	0.51**	0.20 ns	0.44**	0.26*	0.55**	0.42**	0.44**	0.56**
Evaporation	-0.05 ns	-0.01 ns	-0.21 ns	-0.13 ns	-0.10 ns	-0.11 ns	-0.15 ns	-0.08 ns	-0.05 ns

ns: Non-significant, *,**Significant at 5 and 1% level, respectively

Table 5: Correlation (r) between the cumulative of evaporation in the dry period (July-2009) and the wet period (December-2009) and water table depths

	Locations								
Climate variable	P1	P2	P3	P4	P5	P6	P7	P8	Ps
Dry period	-0.96**	-0.82**	-0.32 ns	-0.72**	0.26 ns	-0.24 ns	-0.68**	0.52**	-0.59**
Wet period	0.37*	0.54**	0.42*	0.22 ns	-0.26 ns	-0.23 ns	-0.11 ns	0.17 ns	0.46*

ns: Non-significant, *,**Significant at 5 and 1% level, respectively

Table 6: Average and amplitude of water table fluctuation during October 2008-March 2010 period

	Locations								
Water table depth (cm)	P1	P2	P3	P4	P5	P6	P7	P8	Ps
Average	-186.4	-251.0	-67.3	-186.3	-64.5	-16.3	-117.9	-67.3	-39.3
Maximum	16.8	-28.0	52.8	36.1	-37.2	33.2	43.4	-3.0	85.0
Minimum	-305.4	-390.2	-177.5	-347.5	-93.9	-85.2	-248.9	-161.4	-148.0
Max-min	322.2	362.2	230.3	383.6	56.7	118.4	292.3	158.4	233.0

Table 7: Correlation (r) between water table fluctuations with saturated hydraulic conductivity values

	Water table fluctuation values		
Soil physic properties	Maximum-minimum	Maximum-average	Minimum-average
Saturated hydraulic conductivity	0.31 ns	0.39 ns	0.14 ns
Clay content	-0.20 ns	-0.27 ns	-0.06 ns
Silt content	-0.58 ns	-0.57 ns	-0.57 ns
Sand content	0.37 ns	0.43 ns	0.24 ns

ns: Non-significant at 5%

Table 8: Correlation (r) of water table depths between oil palm areas (P1, P2, P4) and other areas during August 2008-April 2010

Correlation	P1	P2	P3	P4	P5	P6	P7	P8	Ps
P1	1	0.91**	0.54**	0.81**	0.25 ns	0.55**	0.59**	0.50**	0.80**
P2	0.91**	1	0.34**	0.71**	0.05 ns	0.41**	0.44**	0.36**	0.78**
P3	0.54**	0.34**	1						
P4	0.81**	0.71**	0.69**	1	0.57**	0.76**	0.84**	0.60**	0.75**
P5	0.25 ns	0.05 ns			1				
P6	0.55**	0.41**				1			
P7	0.59**	0.44**					1		
P8	0.50**	0.36**						1	
Ps	0.80**	0.78**							1

ns: Non-significant at 5%, **Significant at 1%

Table 9: Water balance at adult oil palm (P4) during January-December 2009

Periods	Precipitation (mm)	Thrufall precipitation (mm)	Sf (mm)	Tf (%)	Sf (%)	Effective precipitation (mm)	Soil surface evapitation (mm)	Run-off (mm)	Infiltration (mm)	Water table depth (cm)
Jan.	161.5	157.8	1.5	97.7	0.93	159.2	52.2	20.7	86.4	-223.3
Feb.	275.2	268.9	2.5	97.7	0.91	271.3	59.8	35.2	176.3	-182.7
March	291.9	285.2	2.6	97.7	0.89	287.8	67.3	37.4	183.2	-171.1
Apr.	147.9	144.5	1.3	97.7	0.88	145.8	44.2	18.9	82.7	-158.0
May	87.9	85.9	0.8	97.7	0.91	86.7	50.1	11.3	25.3	-137.0
June	111.8	109.2	1.0	97.7	0.89	110.2	51.8	14.3	44.1	-207.2
July	183.9	179.7	1.7	97.7	0.92	181.3	57.6	23.5	100.2	-287.9
August	145.0	141.7	1.3	97.7	0.90	143.0	49.6	18.6	74.8	-316.5
Sept.	124.3	121.4	1.1	97.7	0.88	122.6	48.4	15.9	58.2	-326.3
October	200.6	196.0	1.8	97.7	0.90	197.8	54.0	25.7	118.1	-335.8
Nov.	364.2	355.8	3.3	97.7	0.91	359.1	48.9	46.6	263.6	-268.8
Dec.	550.8	538.1	5.0	97.7	0.91	543.1	41.5	70.5	431.1	-169.2

table depths in that area. Hydraulic conductivity and other soil physic properties did not seem to influence the fluctuation of water table depths. It could be seen from the relation of its value at each well location with the difference of maximum-minimum, maximum-average and average-minimum values (Table 7).

Correlation of water table depth in oil palm areas with the other locations: The water table depth in oil palm areas (P1, P2 and P3) showed higher correlation with each other as compared to the other locations (P4, P5, P6, P7 and P8), except for the side plain of the river (PS) (Table 8). The level of canopy plant covering influences the pattern of water table fluctuation. The areas with similar canopy covering level, among oil palm areas, have similar fluctuation patterns. Meanwhile, other places (P3, P5, P6, P7 and P8) with no full plant covering have different water table fluctuation patterns as compared to oil palm areas (P1, P2 and P4). Pothier *et al*. (2003) and McJannet (2008) reported that in conifer and wood plant areas, the level of canopy covering determines water table depth. The plant area with low canopy covering has shallower water table depth, whereas deeper water table depth is found in the area with full canopy covering (Pothier *et al*., 2003; McJannet, 2008).

Water balance and water table in oil palm area: The effective precipitation at certain time periods determines water table depths through infiltration parameters. Some measured water balance elements in oil palm area are shown in Table 9.

The months with high effective precipitation and high amount of soil water infiltration caused high water table depths, whereas the periods with low effective precipitation and soil water infiltration caused lower water table depths. In the adult oil palm area (P4), it could be seen that water table depth was related to the amount of effective precipitation and soil water infiltration (Fig. 2 and 3).

Effective precipitation and water infiltration are the sources of soil water recharge. Increasing effective precipitation and water infiltration will increase water table

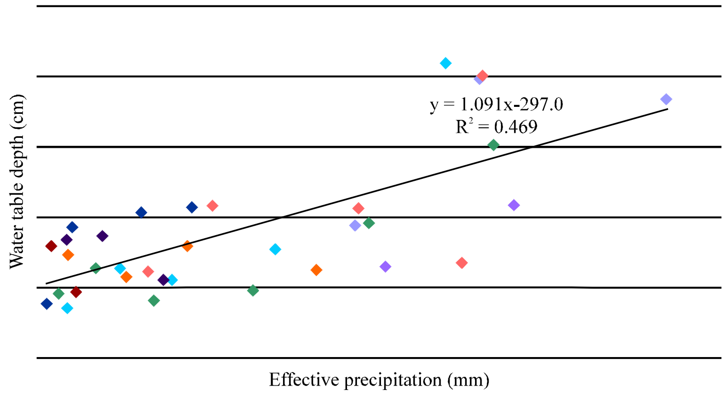

Fig. 2: Relationship between 10 day period of effective precipitation and average water table depth at adult oil palm area (P4)

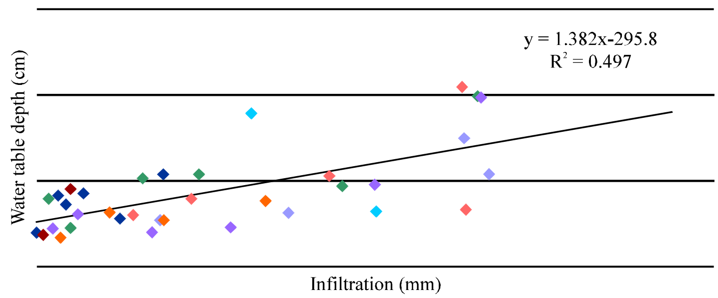

Fig. 3: Relationship between 10 days period of infiltration and average water table depths at adult oil palm area (P4)

depths. Soil surface conservation can reduce water lost by run-off and soil surface evaporation. Soil surface evaporation constituted about 30% of the effective precipitation while water run-off constituted about 13% of the effective precipitation.

CONCLUSION

Fluctuations in the water table depths in the oil palm area were dependent on climatic elements, mainly precipitation. Soil physical properties did not significantly influence the fluctuation of water table depths. Water table depth decreased during the dry season and increased during the wet season.

There was no permanent decrease in water table depth. In more specific, water table depth in areas surrounding the oil palm area fluctuated following precipitation condition but the difference between the highest and the lowest conditions was not greater than that of the oil palm area. Similarly, water table depth in the area located in the oil palm area regions did not show any decrease as a result of oil palm plantation establishment.

There was a strong correlation between oil palm area and water table depth in the river plain, whereas weak correlation was found between water table in oil palm area and that location in other areas. In the oil palm area, water table depth was shown to be related to some water balance elements including effective precipitation, soil surface evaporation, run-off and water infiltration rate. Reduction of soil surface evaporation and run-off water by the use of soil water conservation systems is needed to keep the water table depth in optimal condition.

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