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Net Rainfall Components under Various Ages of the Oil Palm

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ABSTRACT

This study analysed the net rainfall components under different ages and leaf area index (LAI) of the oil palm to determine the contribution of net rainfall towards water requirements of the palm. We hypothesised that older palms, with their higher LAI, would have lower net rainfall due to higher interception of rain. The study was conducted in oil palm plantations in Mendis village, Bayung Lincir District, Sumatra. Tipping-bucket rain gauges connected to data loggers were used to measure the rainfall components (throughfall, stemflow, interception and gross rainfall) at ten-minute intervals for four months. The proportions of throughfall, stemflow, and interception for the oil palm aged between 5 to 20 years were 92.2% - 58%, 2.4 – 0.7%, and 5.4% - 41%, respectively. The equations relating throughfall (Tf), stemflow (Sf), and net rainfall (Pn) to LAI were Tf = -8.5032 LAI + 116.74, Sf = -0.469 LAI + 3.8808, and Pn = -8.9722 LAI + 120.62, respectively. Under various oil palm ages, net rainfall (Pn) had an inverse linear relationship with an increase in LAI by 3.5 and 7.2 with a decrease in net rainfall from 94.6% to 58.8%. The results from this study should serve as a guide to the water management of oil palm plantations.

Keyword: oil palm, interception, throughfall, stemflow, leaf area index.

INTRODUCTION

Oil palm requires about 2000 - 2500 mm year^{-1} of water a year and this amount of large water is required uniformly throughout the year without a prolonged dry season. The annual total water deficit ideally should not exceed 250 mm (Fauzi *et al*. 2002). For almost all oil palm plantations, the only input of water is from precipitation (Kerkides *et al.* 1996), as irrigation is rarely used in oil palm plantations.

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Water management in oil palm plantations is very important. Corley and Tinker (2016) estimated that with every 100 mm water deficit, oil palm yield would decline by 10%. Rain interception, stemflow and throughfall are rainfall components in the hydrologic process that are important in the management of water resources (Arnell 2002). The part of the rain retained on the surface of leaves and branches is called interception, while stemflow is the portion of gross rainfall that flows down along the surface of the tree trunk to reach the ground. And the rainfall reaching the ground, having fallen through the gaps between canopies, unintercepted, or as leaf drips is known as throughfall (Figure 1).

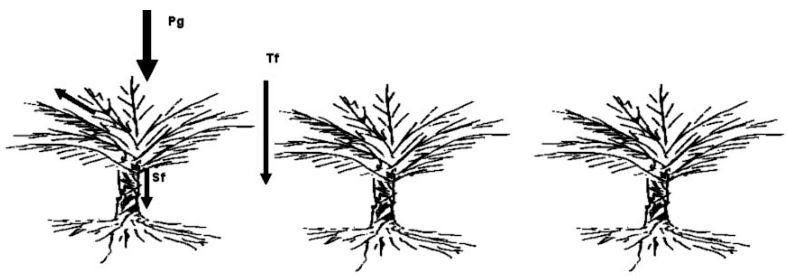

Figure 1. Net rainfall components in oil palm plantations (Pg – precepitation gross, Ic – interception, Sf – stemflow, Tf – throughfall)

Redistribution of throughfall and stemflow by canopies modifies evaporation, which plays an important role in water balance on local and catchment scales (Herbst *et al.* 2006; 2007). The relationships between rainfall and tree morphologies were also studied by Van Stan *et al*. (2011) who reported that *F. grandifolia* trees with broader vertical canopy depth enhanced stemflow production for inclined rainfall, whereas *L. tulipifera* with its broader horizontal canopy enabled stemflow production for non-inclined rainfall.

Rainfall interception is of paramount importance as far as hydrological cycle is concerned, in that as rain falls onto the oil palm canopy, it is retained for some time, afterwhich a part of it is lost to the atmophere through evaporation. (Gomez *et al.* 2000). Canopy interception loss is influenced by canopy architecture and meteorological properties (Crockford and Richardson 1990). Canopy interception loss ranges from 10 to 40% of gross rainfall in natural forests and may even exceed 50% (Calder 1990). Leaf area index (LAI) also plays a role in the process of rainfall interception (Pérez *et al*. 2017). LAI for oil palm depends on the number of fronds, leaflet area and planting density (Noor and Harun 2004).

Chong *et al.* (2018), Ahmadi *et al*. (2009), Bentley (2007), Murtilaksono *et al.* (2007), and Marin *et al*. (2000) have measured the net rainfall components for oil palm, but all these studies were done for mature oil palm with full canopies. There have been no studies on net rainfall under various ages of oil palm, for instance, young or maturing oil palms. Consequently, there is a knowledge gap on how the relative proportions of the net rainfall components would change according to the age of the palm age or degree of canopy cover.

This research is important in estimating the potential net rainfall required by the oil palm in deciding the need for irrigation. Older, more mature oil palm with higher LAI, for instance, would intercept more rainfall than younger trees. The amount of irrigation would therefore have to be adjusted for these differences in net rainfall components under various oil palm ages. Thus, the objective of this study was to measure and analyse the net rainfall components under different ages of the oil palm,

MATERIALS AND METHODS

This studywas conducted in oil palm plantations located in the Mendis village, Bayung Lincir District, Musi Banyuasin, South Sumatra Province, Indonesia at coordinates of 2°15’00” to 2°30’00” N and 103°45’ 00” to 104°00’00”E.

Custom-built tipping-bucket rain gauges with a minimum resolution of 0.5 mm of rain were used for rainfall measurement. The rain collector had an opening diameter of 400mm, with the rain gauge being connected to a data logger for recording rainfall parameters (throughfall, stemflow, and gross rainfall) at ten-minute intervals. For throughfall measurement, three rain gauges were arranged along a straight line in a North-South direction at a 9-m distance between every two gauges, while for the stemflow measurements, three sampled trees were selected randomly.

The old pruned fronds on the selected tree trunks were removed to fix a alumunium collar and sealed with nails and bitumen to direct stemflow into the rain gauge. Finally, for collecting gross precipitation above the canopies, another rain gauge was installed in a nearby open area that was not hindered by tall plants and buildings. It was regarded as representative of the gross precipitation (above canopies) at the experiment site.

LAI measurements were carried out in the field using three palms replicating per tree age class. The palm age classes were 5, 10, 15, and 20 years old. LAI was estimated using the equation of Hardon *et al*. (1969) namely,

$$\text{LAI} = a \times N \times D \times 0.55 \tag{1}$$

where a is the total area of frond 17 (both sides of the frond in m^2), N is the number of fronds per palm, D is the planting density (148 palms/ha), and 0.55 is a correction factor (relative leaf area conversion). LAI was determined based on frond 17 from each palm tree. Frond 17 was selected as representative of the whole of the crown (Tailliez and Koffi 1992). A total of three fronds were cut and the leaflet area was measured manually. This manual method is known as the direct LAI method, and is widely used for crops and adapted for vegetation in small-scale studies (Bréda 2003; Pérez *et al*. 2017). This method is useful in agriculture and ecological studies where the plant is harvested to measure the leaf area (Klingberg *et al.* 2017).

In order to measure the gross precipitation, a tipping bucket was erected from the ground at 90°, while stemflow water was collected via rubber collars fastened in a downward spiral manner around the oil palm trunk into the tipping bucket. As for throughfall, six plastic hoses were connected and channelled into the tipping bucket, slanted at a 10% slope from the tipping bucket. Each tipping bucket was equipped with a sensor connected to a data logger (Figure 2).

Similarly, the measurements using the tipping bucket method were automatically recorded by the data logger during the rainfall period event at intervals of 10 min. Interception was calculated as follows:

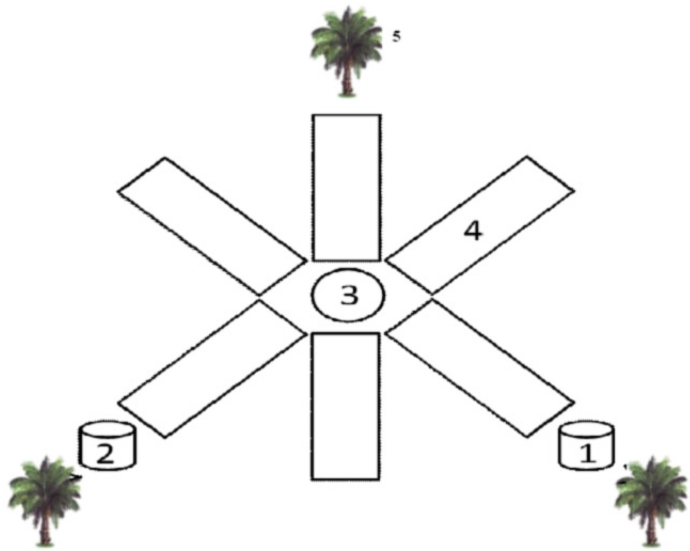

Figure 2. Aerial view of interception scheme for measurement

Notes : 1 - tipping bucket to measure gross rainfall (put on top of trees); 2: tipping bucket to measure stemflow in the bottom of tree; 3: - tipping bucket to measure throughfall (among trees, selected randomly); 4: plastic hose; 5: oil palm trees.)

$$Ic = Pg - Sf - Tf \quad (2)$$

where Ic is interception, Pg is gross precipitation, Tf is throughfall, and Sf is stemflow (all in %).

RESULTS AND DISCUSSION

Table 1 shows that with increasing LAI, interception increased by 5.4 to 41%. This study showed that the proportion of canopy interception to rainfall is very small (Ic = 0) for LAI <2.3, as determined from the equation in Figure 3.

Interception loss was between 32.3 to 41 % of total gross precipitation for mature oil palm (>10 years). This result was very similar to a Malaysian study that determined interception loss as being between 32 to 41% (Chong *et al.* 2018). Throughfall accounted for about 64.9% of gross rainfall for 15-year-old trees which was also similar to that reported by Chong *et al*. (2018) and Kee *et al.*

TABLE 1
Precipitation proportion, LAI, throughfall (Tf), stemflow (Sf) and interception (Ic) of rainfall in the upper oil palm canopy (Pg) at different ages.

Age (years)	Gross precipitation Max (mm d^{-1})	Gross precipitation Min (mm d^{-1})	LAI	Tf/Pg (%)	Sf/Pg (%)	Ic/Pg (%)
5	0.7	42.1	3.5	92.2	2.4	5.4
10	0.5	56.3	4.9	66.3	1.4	32.3
15	0.2	85.1	6.2	64.9	0.8	34.4
20	0.7	67.7	7.2	58.2	0.7	41
Std error	0.1	9.1	0.80	7.48	0.39	7.85

(2000) who found 70-78% of gross rainfall being accounted for by throughfall. The proportion of stemflow in this study was 2.0-2.7% similar to that reported by Chong *et al*. (2018) and Bentley (2007).

Figure 3 shows a strong linear relationship between tree age and LAI (R^2 = 0.99). Awal *et al.* (2008) also reported a similar strong correlation between tree age and LAI at 2 years for the oil with the range of LAI being between 0.57 to 0.79 which increased to 3.5 to 5.02 for tree aged 16 years.

A similar trend was observed between throughfall and stemflow with LAI as shown in Figures 4 and 5. As LAI increased, its effect was a consequent reduction in throughfall and stemflow with increasing rainfall interception by the leaves.

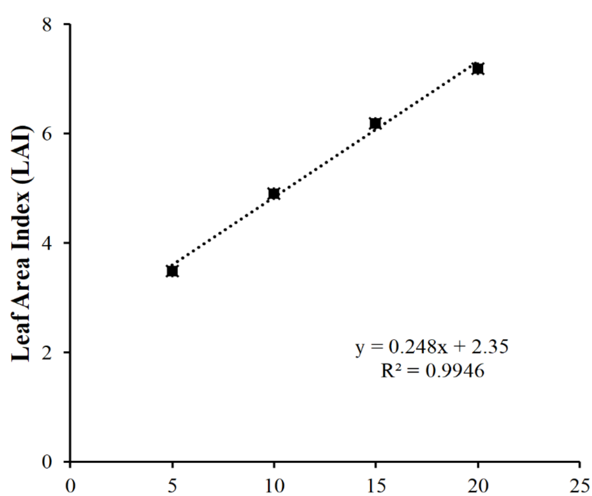

Figure 3. The relationship between tree age and Leaf Area Index (LAI)

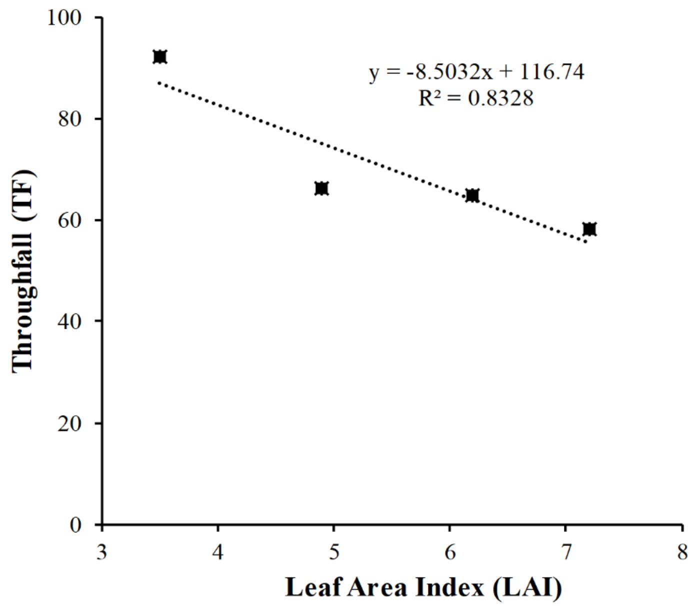

Figure 4. Relationship between LAI and throughfall

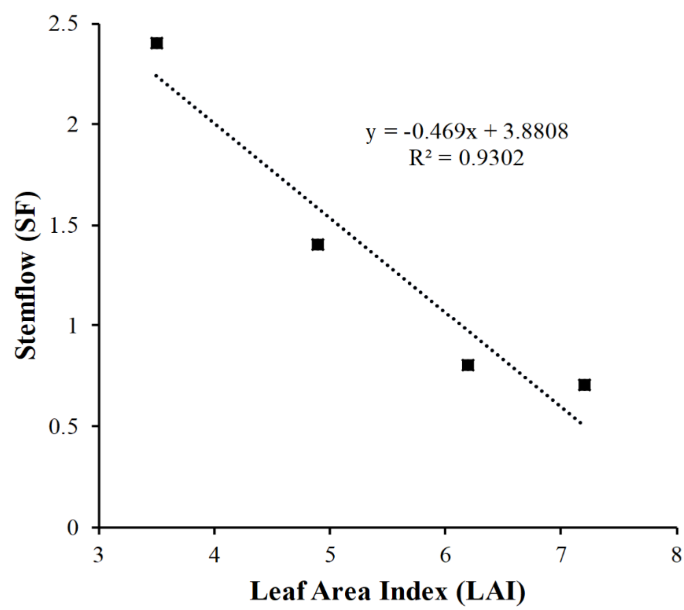

Figure 5. Relationship between LAI and stemflow

Figure 6 shows a positive linear trend between LAI and interception as an increasing LAI led to a greater likelihood of the gross rainfall being intercepted by the canopy of the palm. In his study, Farmanta (2012) noted that interception increased with an increase in LAI which was also similar to the results of the present study. Likewise, Pramono and Ginting (1997) found that a high density of canopies have a higher intercepted amount of rain, while rain intensity showed an inverse relation to interception capacity (Siregar *et al*. 2006).

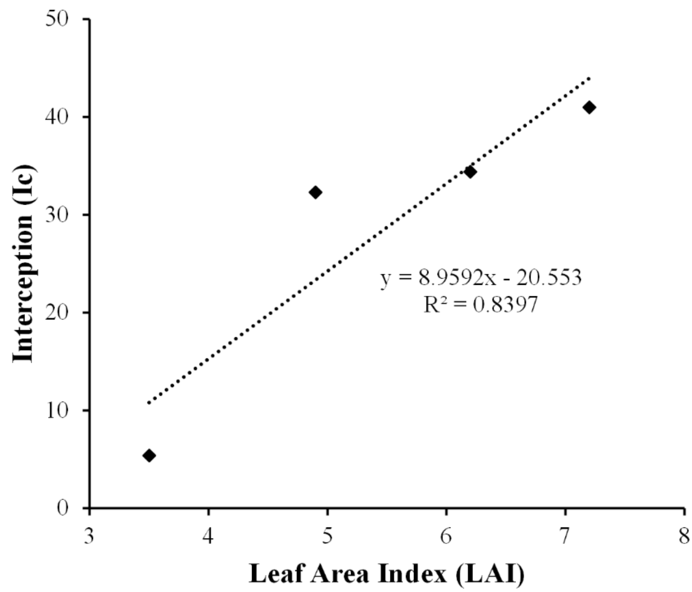

Figure 6. Relationship between LAI and interception

Figure 7 presents the inverse linear relationship between LAI and net rainfall, that is, as LAI decreases net rainfall increases. Net rainfall is expressed as the amount of stemflow and throughfall. Therefore, the decreasing trend of net rainfall follows an increasing trend of higher rain water interception with increasing LAI (Banabas 2007). Dinata (2007) found a negative relationship between throughfall and age of tree.

Net rainfall declines with increasing tree age and LAI due to increasing canopy density. Net rainfall is relatively higher for young oil palm because the canopies that are formed are relatively sparse, as indicated by their smaller LAI. Consequently, more rain water falls to the ground via throughfall and stemflow. Branch angle, LAI and canopy gap fractions play important roles in rainfall partitioning (Crockford and Richardson 2000; Johnson and Lehmann 2006).

The texture of the oil palm trunk is fibrous and its unique frond arrangement and structure allows for the intercepted rainfall to be collected and channeled down into the tree trunk. Andre *et al*. (2008) and Ahmadi *et al*. (2009) documented

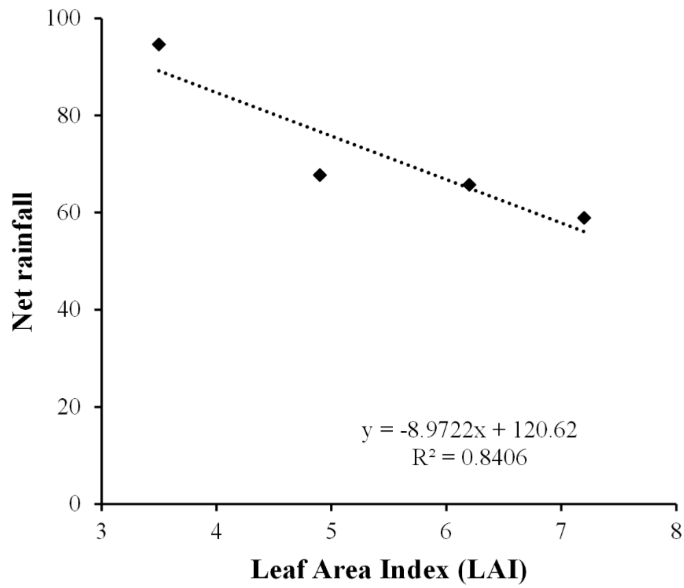

Figure 7. Relationship between LAI and net rainfall

that stemflow is generally higher for trees with funnel-like canopy shapes, larger crown projection area, smoother bark, and a lower growth of canopy lichens and mosses.

Interception is also a factor affecting net rainfall. Interception strongly correlates with rainfall above the canopy because interception increases with increasing LAI. According to Ward and Robinson (2000), rainfall duration is the important factor in interception loss after canopy storage capacity. It influences interception by reducing the amount of water stored on the vegetation and increases evaporative losses. Farmanta (2012) documented that because the mature oil palm have higher LAI than younger ones, intercepted rain is retained longer in the canopies of older trees and more of the retained water in older trees will be lost as evaporation compared to younger trees. The larger surface area of the tree trunk for older palms also means that the oil palm trunk would have a larger capacity to absorb the stemflow than the trunks of younger trees.

CONCLUSIONS

The proportions of throughfall, stemflow, and interception of rainfall for oil palm trees between ages 5 to 20 years were 92.2% to 58%, 2.4 to 0.7%, and 5.4% to 41%, respectively. The linear equations between throughfall stemflow, and net rainfall with LAI were Tf = -8.5032 LAI + 116.74, Sf = -0.469 LAI + 3.8808, and Pn = -8.9722 LAI + 120.62, respectively. Our study results should serves as a guide in in water management of the oil palm of various ages.

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