Canopy precipitation interception in a lowland tropical forest in relation to stand structure

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Abstract. It is generally accepted that vegetation provides important ecosystem services especially in term of rainfall partitioning. This study aims to evaluate the influence of canopy structure namely crown area (CA), diameter at breast height (DBH), tree height (TH) and crown spread (CS) and stand density on the partitioning of rainfall. Twelve throughfall plots of 20 x 20 m with 64 gauges randomly placed within each plot were established. For stemflow measurements, all trees within a 100 m
2 plot within the study area were collared. Interception loss was computed as the difference between precipitation and throughfall plus stemflow. Throughfall ranged from 73.47 – 82.32 % of the gross rainfall. Stemflow was found to be roughly around 2.01% of the gross rainfall. Highest interception was 24.52 % attributed to the plot having the highest above ground biomass (AGB) density. The relation between canopy interception and forest structure were analyzed by regression method. Multiple regression analysis on the potential influence of stand structure to the throughfall percentage shows that all the forest structures variables measured in this study are negatively correlated to the amount of throughfall generated. This study suggests that forests with higher value of DBH, CA, CS and TH had higher interception rate.

Keywords: Canopy interception; above ground biomass; diameter at breast height; tree height; crown size.

1. Introduction
In forest ecosystems, rainfall is partitioned by forest canopies into throughfall (TF), stemflow (SF) and interception loss (I) [1] and this separation is a very important part of forest hydrology. The ability of canopy cover to collect and store precipitation is particularly important in watershed hydrology [2]. In terms of hydrological benefits, forest interception can prevent 95 percent of soil detachment by raindrops [3] by modifying drop size distribution, retaining direct raindrop impact, and changing the spatial distribution of throughfall amount at the ground surface [4]. The process of rainfall interception is normally dependent on the type and structure of forest [5,6] and type of rainfall event (intensity, duration, frequency, and form of precipitation) [7]. In tropical forest, rainfall interception was reported to be around 6% [8] to 29% [9]. Most study agreed that high rainfall interception by forest canopies is frequently associated with leaf area index (LAI), because vegetation with a higher LAI has higher storage capacity than that with a lower LAI [10]. However, there are other forest structure variables that can be used to explain throughfall such as, forest cover, basal area [11], crown length [2] and tree height [12]. Stemflow volume usually depends on factors such as total rainfall amount, rainfall intensity, plant growing stages and plant density [13,14] branch morphology and branching architecture [15], canopy volume and area [16] meteorological conditions and [17]. Smaller or shorter trees have also been reported to have lower relative stemflow [18]. The manipulation of forest cover including changes in land cover can substantially alter the amounts and evapotranspiration of the forest by 76% and 12% respectively [19]. The studies carried out by [20] resulted in a significant decrease in throughfall below canopy densities of more than 70%, a 56 -65% decrease in throughfall from the range of mean throughfall is 81 to 89% for canopy coverage of 10 – 60%. Another researcher [21] confirmed that a deeper canopy cover can intercept most of the higher-intensity rain, whereas a thinner or less dense canopy cover can intercept smaller showers. Canopy gaps caused by alteration in forest structure can
increase stemflow yield by increasing the exposure of woody surfaces [22]. A better understanding of the role of forest structure in precipitation interception is needed to assist forest managing and planning, aiming at maximizing canopy interception for the mitigation of stormwater runoff and erosion in watershed. The aim of this study was to evaluate the influence of canopy structure regarding crown area (CA), diameter at breast height (DBH), tree height (TH) and crown spread (CS) and stand density on the canopy interception.

2. Study area and methodology
The study was conducted in the lowland tropical rainforest of the Danum Valley Conservation Area (Figure 1) that lies in the southeastern part of the state of Sabah, Malaysia (located between 4° 50’ N – 5° 00’ N and 117° 35’ E – 117° 45’ E). The local climate is tropical (equatorial climate) with mean rainfall around 2873 mm per year [22]. In this study, twelve square plots of length 20 m were constructed for rainfall interception study. Above ground biomass (AGB) of each plot was estimated by nondestructive sampling method using Yakamura and Chave model [23,24]. Tree structure data collected from the field includes diameter at breast height (DBH), tree height (TH), crown area (CA) and crown spread (CS). The throughfall collectors (n = 64) consisted of 2 L polyethylene bottle and a funnel were placed randomly under the canopies. Throughfall samples were collected on an event basis or cumulative of few short durations of rainfall event for 18 months. Throughfall collected were measured manually and estimated as the average of the throughfall collected from all gauges in each plot. Rainfall was measured manually by rain gauges placed in a clearing 200 m from the throughfall sampling site. A short period of stemflow studies was conducted by collaring all stems in a 100 m² of forest plot to estimate stemflow contribution in interception loss. The stemflow collector was constructed using half-open rubber hose and was fitted around the tree stem and mounted at the breast height. Stemflow volume was divided by total canopy area to convert the data obtained to a depth equivalent at the tree scale [25]. Interception loss was then calculated as the difference between gross rainfall and throughfall plus stemflow [7].

3. Results and discussion
Throughout the monitoring period, 73.47%–82.32% of the rain was measured as TF. Figure 2 shows the relationship between TF and GR in the studied plots. A positive linear relationship was observed between TF and GR depths at event scale (R²= 0.38) high TF production was measured during large rainfall events and low TF production was measured during low rainfall events. Since the distance between the measured plot and the GR reference site in the forest is quite at distance (approximately 200 m), therefore the spread of relative TF values could be wider. Besides, the variation in TF among
gauges reflects a heterogeneous canopy cover which is found to be mainly associated with differences in plant structure and stem density [12,26,27].

![Figure 2. Throughfall versus gross rainfall.](image)

Figures 3 show that TF is negatively correlated with the size or area of the tree structure variables (CA, DBH, TH and CS). This means that TF amount is decreased with an increase of the variable’s size. Forests with higher value of CA, DBH, CS and TH had less amount of throughfall. In this study, CA affects the amount of TF by 52% ($R^2 = 0.52$), and the value is slightly higher than other tree variables.

![Figure 3. (a)TF (%) versus CA (m$^2$); (b) TF (%) versus DBH; (c)TF (%) versus TH (m); (d) TF (%) versus CS (m).](image)

The result is followed by DBH ($R^2 = 0.51$). CS and TH affect the amount of TF by 48 % and 35 %, respectively. This study suggests that CA is the most obvious factor that influences TF volume. The presence of projecting crown may increase the variability of TF volume because evaporation of intercepted water is more rapid than from the lower crown [7]. Yet the influence of crown traits in rainfall partitioning are subjected to meteorological variables, particularly rainfall intensities, where the effect is more significant in smaller rainfall event [28]. Similar trends and relationships between forest structures and rainfall partitioning have been reported elsewhere [2,12]. Meanwhile, previous TF study, which have been carried out in Danum by [29], reported a non-significant variation of TF pattern, which means no direct relation exist between measured TF and canopy structure (gaps). Similarly,[30] reported that canopy openness did not appear to be the main factor that affects the amount of TF, instead other
parameters should be studied to find a connection with TF. The potential influence of crown traits on TF percentage was tested using multiple linear regressions for the entire plot. Canopy traits that were used to predict TF were crown spread (CS), crown area (CA), tree height (TH) and basal area (DBH). Pearson correlation analysis of the four predictors of TF generation resulted in significant correlation (P < 0.05) in three out of the four attributed pairs. One attribute pair (TF and CA) was significantly correlated at p < 0.01. Based on the correlation analysis, all forest structure variables are negatively correlated to the TF amount generated. The SPSS output for the regression analysis on the effect of forest structure variable using hierarchical multiple regression method given the following equation (1):

\[
TF = -0.037 \times AGB - 0.303 \times CA + 0.388 \times DBH + 0.240 \times TH + 5.317 \times CS
\]

\[R^2: 0.645; \text{Standard error: } 5.67 \text{mm}\]

Where TF is the response variable; AGB, CA, DBH, TH and CS are the predictor variables. It is important to note that, this value is also subjected to meteorological parameters such as rainfall intensity and drop size that control the amount of TF that can pass through the canopy crown. It is also need to consider other canopy traits such as LAI and S to be included as predictor as these variables can modify the trajectory of the rainfall partition.

The analysis on rainfall and SF shows a general trend of increasing SF with the amount of precipitation (Figure 4), although the limited data availability means that this result is very tentative.

\[y = 0.02x + 0.50 \quad R^2 = 0.52\]

\[0 \quad 0.4 \quad 0.8 \quad 1.2 \quad 1.6 \quad 2.0 \]

\[0 \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \quad 60 \]

**Figure 4.** The relationship between GR (mm) and SF (mm).

This result suggests that SF is affected by storm size. Although many studies indicate the clear influences of GR to SF generation [31,32] the results presented here were not conclusive as they were based upon small sample number of events, and as such are not statistically viable. The reliability of this regression therefore can be improved by increasing the sample size of GR and SF.

\[SF = 0.04 \times DBH + 1.04 \quad R^2 = 0.57 \quad P<0.01\]

\[SF = 0.16 \times TH + 1.29 \quad R^2 = 0.59 \quad P<0.01\]

**Figure 5.** (a) SF volume (L) versus DBH (cm); (b) SF volume (L) versus TH (m).

In general, SF volumes showed a positive relationship with both variables related to tree size (DBH and height) (Figure 5). Also, the Pearson correlation coefficient of less than 0.01, indicating that there is a significant correlation exists between DBH, TH and SF.

Highest interception was 24.52%, found in plot having the densest AGB amongst the study plots. A positive correlation (R²=0.54) was observed between rainfall interception and AGB density (Figure 6).
This indicates that interception rate tends to increase as the biomass density increases. The variation of net rainfall is also attributed to the other forest structure variability.

Figure 6. AGB versus interception.

4. Conclusion
This study emphasizes the importance of vegetation in controlling the amount of interception loss. The results showed that canopy interception ranged from 17.21% to 24.52%, affected by forest structure, above ground biomass density and precipitation, with interception rate increasing as the forest structure size increased. It is suggested that this study may be updated with longer research duration and larger experimental plots, as well as for climate variable. It is also needed to consider other canopy traits such as leaf area index, canopy storage and gap fractions to be included in the analysis, as these variables may be the factors that modify the trajectory of the rainfall partition.

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