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Influence of Tree Canopy Characteristics on Rainfall Interception, Throughfall and Stemflow in a Tropical Forest

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ABSTRACT

The trees in tropical forests play a crucial role in the ecosystem. Understanding the characteristics of tree canopies and the impact of rainfall interception is vital for the hydrological cycle. Canopy characteristics have been measured at Bukit Lagong Reserved Forest, Kepong, Selangor. To determine interception loss values, daily gross precipitation (PG), throughfall (TF), and stemflow (SF) were measured over 12 months. The tree characteristics determined are tree height (TH), canopy crown diameter (CD), diameter at breast height (DBH), and canopy cover (CC). The results of this study identify the relationships between canopy characteristics and interception loss (IL) in tropical forests. Understanding how tree canopy characteristics influence canopy interception, storage, and throughfall redistribution dynamics is fundamental to advancing the use of trees in water-budget calculations for water management.

Keywords: Canopy characteristics, interception loss, stemflow, throughfall

INTRODUCTION

Tree canopies alter the paths of raindrops by dividing the incoming rainfall into throughfall and stemflow. A portion of the incoming rainfall is captured and temporarily retained on the surfaces of leaves, branches, and stems. Rainfall interception is typically influenced by various factors, including rainfall characteristics (such as amount, intensity, duration, drop size, and raindrop count), micrometeorological conditions, and forest attributes like species of the tree, structure of the canopy (including leaf area index (LAI), crown gap fraction, and stem

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surface area), along with antecedent weather conditions (Livesley et al., 2014). Both rainfall characteristics and the architecture of the forest canopy are recognised as the primary factors influencing rainfall interception by the forest canopy (Crockford & Richardson, 2000; Xiao et al., 2000; Yan et al., 2015).

Numerous studies have investigated the relationship between various forest elements and interception. The influence of forest type on interception loss values has been demonstrated by Abu Bakar and Khalil (2017) and Crockford and Richardson (2000). Abu Bakar et al. (2023) established the connection between canopy cover (CC) and the throughfall (TF) process, while Manfroi et al. (2004) examined the effects of diameter at breast height (DBH) on stemflow (SF). Dietz et al. (2006) studied the impact of tree height (TH) and leaf area index (LAI) on throughfall (TF). Crockford and Richardson (2000) also noted that canopy gaps and larger crown size significantly increase interception loss (IL). Clearly, crown size and canopy gaps are critical factors in determining interception in a forest.

Additional research highlights the significance of canopy cover as a pivotal metric for assessing forest conditions, utilised in investigations related to climate change mitigation, disease monitoring, and forest management (Chappell et al., 2001). Although canopy cover plays a role in rainfall interception, it is also subject to the temporal resolution of rainfall (Yamakura et al., 1986). Regrettably, there remains a dearth of studies focusing on the implications of forest canopy cover for interception, particularly in humid forests. Consequently, this paper seeks to elucidate the relationship between canopy characteristics, such as diameter at breast height (DBH), crown diameter (CD), canopy cover (CC), and tree height (TH), and interception loss in tropical forest ecosystems.

EXPERIMENTAL PROGRAM

Study Area

This study has been carried out in the lowland tropical rainforest situated in the Bukit Lagong Reserved Forest, Selangor, positioned in the peninsula of Malaysia, spanning between 3º 15’ N and 101º 37’ E. The local climate is characterised as tropical and equatorial. For the specific investigation on rainfall interception, a square plot of 20 × 20 m was established. The plot was outlined using PVC pickets and covered an area of 400 m^2. Then it was further subdivided into sub-grids with a 5 m × 5 m interval. Within the plot, trees of the species Mempisang, Kledan, Simpoh, and Keruing, each with a diameter at breast height (DBH) exceeding 10 cm, were recognised, labelled with distinctive markers, and assigned individual numbers, for a total of 20 trees.

Site Measurements

The measurement of TF utilised 25 standard bucket collectors, each equipped with a 225 mm-diameter orifice and a depth of 200 mm. These bucket collectors were strategically positioned at the intersection of the plot beneath the canopy cover, with 5-meter intervals. Daily averages of the data were computed. Due to the dense canopy cover in the forest, the throughfall volume was divided by the collector's receiving area to determine the TF value in depth (mm) (Yusop et al., 2003).

The process of collecting SF involved employing a halved rubber collar spirally wrapped around each carefully selected tree stem. The selection criteria were based on DBH within the plot area, and 15 trees were selected per plot to facilitate installation of the stemflow collar. These accessible trees, with a DBH exceeding 10 cm, were outfitted with a spiral rubber collar designed to channel runoff from the stem into a collecting tank at the collar's end. In this study, the rubber collar was made from PVC hose and firmly attached to the tree stem with nails. Silicone glue was used to fill any gaps between the stem and the collar, ensuring a tight fit. The amount of stemflow (SF) collected was then translated into depth measurements in mm (Bo et al., 1989).

RESULTS AND DISCUSSIONS

Measurement of Gross Rainfall (PG), Throughfall (TF) and Stemflow (SF)

Manual measurements of PG, TF, and SF were conducted over a twelve-month period, spanning from 11 April 2012 to 24 April 2013. Throughout this duration, a total of 94 rainfall events were recorded. In Figure 1, monthly patterns of PG and TF during the study period are illustrated. The wettest season with a cumulative rainfall of 2095.84 mm occurred from October to December 2012. The peak rainfall was observed in November 2012 at 405 mm, while the lowest was recorded in February 2013 with 21 mm.

Regarding TF data, the percentage over PG obtained is 80.96%. TF volume constitutes a significant portion of PG, as it represents rainfall that drips from the CC and is stored in canopy storage. It is important to note that the throughfall (TF) collection bucket positioned at the node of the grid points in the plot may capture rainfall that has not fallen within the canopy. Figure 2 shows the monthly patterns of PG and SF. SF values represent 0.034% of gross rainfall for the 12-month data as shown in Fig. 2. Interception loss (IL) is calculated as the difference between gross precipitation (PG) and net rainfall, which is the sum of throughfall (TF) and stemflow (SF) (Crockford & Richardson, 2000).

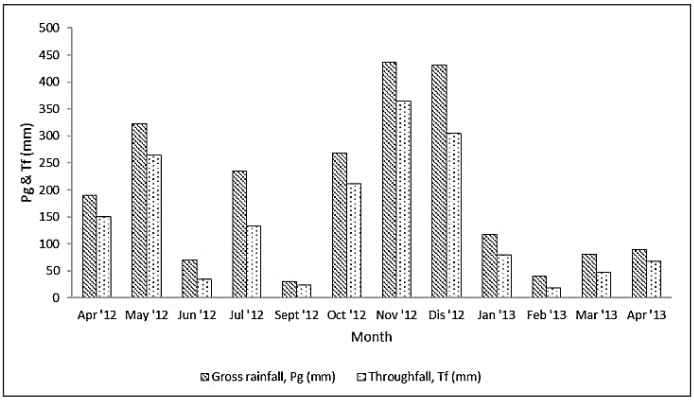

Figure 1. Monthly PG (mm) and TF (mm)

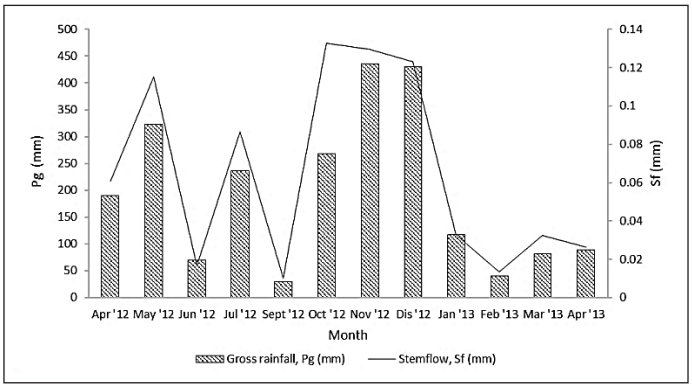

Figure 2. Monthly PG (mm) and SF (mm)

Tree Characteristics

Table 1 presents the descriptive statistics for the three characteristics, including the maximum, minimum, mean, and standard deviation: CD, DBH, TH and CC and consisting of a mix of *Mempisang, Kledan, Simpoh,* and *Keruing* species, were identified within the plot, amounting to a total of 20 trees.

Table 1
Descriptive statistics (mean, min, max and standard deviation) of CD, DBH, TH and CC

	CD (m)	DBH (cm)	TH (m)	CC (%)
Average	5.984	25.98	19.72	95.21
Min	2.11	10.6	10.8	89.53
Max	12.86	44.1	29.8	97.65
Std dev	2.62	11.75	6.54	1.57

The data on canopy CD provide insights into the dimensions of tree canopies in the study area. With an average canopy CD of 5.984 m, it delineates the typical size of tree canopies in the sample. The minimum recorded canopy CD is 2.11 m, representing the smallest observed canopy size in the dataset. Conversely, the maximum observed canopy CD is 12.86 m, indicating the largest tree canopy size recorded in the study area. The standard deviation of 2.62 m indicates the variability of canopy CD around the average. A higher standard deviation points to greater variability among the observed canopy sizes.

The DBH data offers valuable insights into the distribution of tree sizes within the researched area. With an average DBH of 25.98 cm, it represents the typical size of trees in the sample. The minimum recorded DBH of 10.6 cm indicates the smallest diameter observed among the trees in the dataset, showcasing the range of tree sizes. Conversely, the maximum observed DBH of 44.1 cm is the largest recorded for trees in the study area, providing perspective on the upper limit of tree size. The standard deviation of 11.75 cm measures the variability or spread of DBH values around the average. In this context, a higher standard deviation of 11.75 cm suggests greater variability in tree diameters within the dataset. This variability underscores the diversity of tree sizes, contributing to a comprehensive understanding of the size distribution in the studied area.

The dataset on TH offers crucial insights into the vertical dimensions of trees within the study area. With an average TH of 19.72 m, it serves as a representative measure of tree height in the sample. The minimum recorded TH, at 10.8 meters, indicates the shortest height among the trees in the dataset, highlighting the range of vertical dimensions within the studied population. Conversely, the maximum observed tree height of 29.8 m is the tallest recorded in the study area, providing perspective on the upper limit of TH. The standard deviation of 6.54 m quantifies the variability of TH around the average. In this context, a higher standard deviation of 6.54 m indicates greater variability in TH within the dataset. This variability highlights the range of tree heights (TH), aiding a thorough understanding of vertical dimensions in the studied area. The canopy cover (CC) data provide important insights into the extent of vegetation cover in the study area. An average CC of 95.21% indicates the typical percentage of ground area covered by tree canopies in the sample. The minimum recorded CC, at 89.53%, is the lowest observed percentage of ground coverage among areas with trees, underscoring the variability in vegetation density across the study site. On the contrary, the maximum observed CC of 97.65% indicates the highest ground-cover percentage in tree-covered areas, representing the upper limit of vegetation density in the study. The standard deviation of 1.57% quantifies the degree of variability or spread of CC percentages around the average. In this context, a higher standard deviation of 1.57% suggests greater variability in CC within the dataset. This variability underscores the range of vegetation cover percentages, contributing to a comprehensive understanding of canopy spatial distribution across the study area.

Correlation of PG to TF, SF and IL

The impacts of PG, TF, and SF on IL in the study area have been obtained through point correlation analysis. The correlation has been done using linear regression of the data. The correlation analysis indicates that the strongest relationship between TF and PG is given by TF = 0.8352PG – 2.2163, with an R2 of 0.9318. For this equation, TF and PG are in units of depth (mm).

The findings indicate a positive correlation between throughfall (TF) and gross precipitation (PG), with TF increasing as PG increases, as shown in Figure 3. The increase in TF with higher overall rainfall can be attributed to various factors associated with the structure and dynamics of the forest canopy. As rainfall intensity increases, the canopy may become saturated, leading to water overflow. When the canopy reaches its capacity to hold water, excess rainfall drips through the vegetation and reaches the ground as TF.

The CC within the canopy can influence the TF value. Under certain circumstances, leaves might redirect water towards the ground, amplifying TF particularly during intense rainfall events. High CC may limit the direct passage of rainfall to the ground. During low-intensity rainfall, the high CC might reduce water bypassing the leaves and branches, thereby affecting the amount of TF reaching the ground. Studies by Aussenac (1970), Ford and Deans (1978), Herwitz (1986), Johnson (1990), Ovington (1954), and Prebble and Stirk (1980) mentioned that the spatial variability of throughfall (TF) has been found to be associated with the distance from the tree trunk and different canopy characteristics.

The CD of a tree can influence the spatial distribution of TF beneath the canopy. Broader crowns can create a larger coverage area for TF, thereby affecting the distribution pattern on the forest floor. Larger CDs can generate larger canopy gaps, facilitating more direct passage of rainfall to the ground. This, in turn, can affect the ratio of TF to total rainfall in the forest ecosystem.

The results of the correlation analysis reveal the most robust relationship between SF and PG, expressed by the equation SF = 0.0003PG – 0.0005, with an R^2 value of 0.6464, as shown in Figure 4. In this equation, SF and PG are measured in depth units (mm). The findings demonstrate a correlation between SF and PG, with SF tending to increase as PG values rise. The volume of SF is

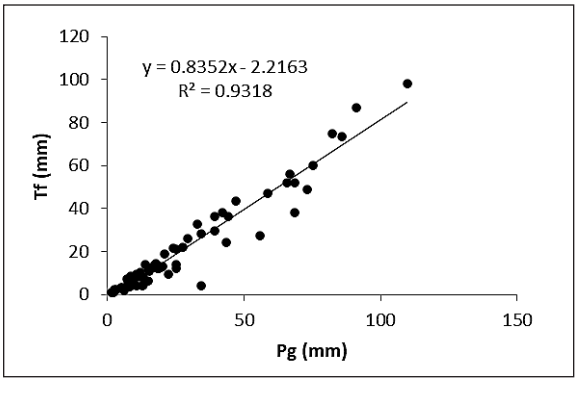

Figure 3. Correlation of TF (mm) with PG (mm)

typically dependent on various factors, including the total amount of rainfall, rainfall intensity, plant growth stages, plant density (Bäse et al., 2012; Lin et al, 2011), branch morphology, and branching architecture (Naharuddin et al., 2017), as well as canopy volume and area (Martinez-Meza & Whitford, 1996). Additionally, meteorological conditions influence SF volume (Levia & Herwitz, 2005).

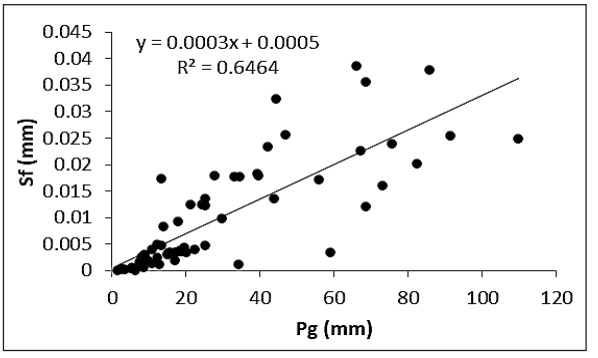

Figure 4. Correlation of SF (mm) with PG (mm)

DBH of a tree can also influence the amount of SF, which is the flow of water down the trunk or stems of a tree during rainfall. Llorens and Domingo (2007) stated that smaller or shorter trees, which are represented by the TH, have also been reported to have lower relative SF. Typically, larger trees with greater DBH exhibit a larger surface area. This expanded surface area provides more space for rainwater interception and directed flow down the trunk, potentially increasing SF. The density of the tree canopy, which is influenced by tree DBH, plays a significant role in determining how much rainwater is captured by the leaves. A denser canopy, often associated with trees of larger DBH, implies a greater number of leaves per unit area. In such cases, a larger leaf surface area is available for intercepting rainfall.

Increased leaf density in a denser canopy increases the likelihood that raindrops are intercepted by the leaves as they fall through the canopy. As a result, more water is collected and funnelled down the stem, thereby increasing the volume of SF. This relationship underscores the importance of considering not only individual tree size but also the overall canopy structure when understanding and predicting the dynamics of SF in a forested environment. Abu Bakar et al. (2021) have investigated the contribution of stemflow to rainfall interception in lowland tropical forest.

The correlation analysis results indicate the strongest connection between IL and PG, as represented by the equation IL = 0.1603PG – 2.2499, with an R^2 value of 0.3142. Both IL and PG are measured in depth units (mm). These findings indicate a correlation between IL and PG, with IL tending to rise as PG increases, as shown in Figure 5.

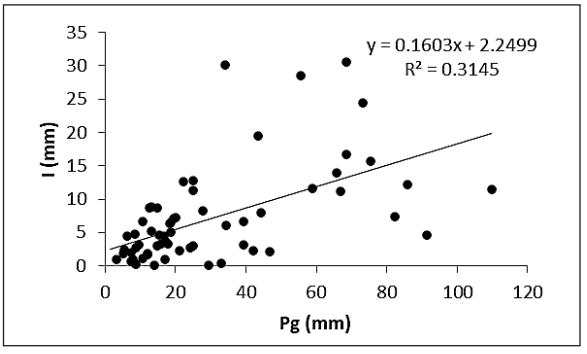

Figure 5. Correlation of IL (mm) with PG (mm)

Larger CDs often correspond to a greater surface area of leaves and branches. This increased surface area provides more space for raindrops to be captured and held by the canopy, leading to higher IL capacity. CD, often associated with a denser canopy, can lead to more effective interception of rainfall. The dense arrangement of leaves and branches provides abundant opportunities for the raindrops to be intercepted.

CC exhibits a close correlation with the Leaf Area Index (LAI), which represents the proportion of total leaf area to ground area. Higher LAI values, indicative of denser canopy cover, indicate a larger leaf surface area for capturing rainfall. This connection implies that a denser canopy, characterised by a higher CC, influences interception loss. Another researcher, Livesley et al. (2014), corroborated that more extensive canopy cover can intercept a significant portion of high-intensity rainfall, whereas thinner or less dense canopy cover is more effective at intercepting smaller showers.

CONCLUSION

This study emphasises the significance of canopy characteristics (CD, DBH, TH, and CC) in governing the extent of interception loss. The findings revealed a range of canopy interception influenced by forest structure and precipitation. The study proposes potential enhancements, including other canopy attributes like leaf area index, canopy storage, and gap fractions in the analysis, as these variables may play pivotal roles in shaping the trajectory of rainfall distribution. In summary, the positive and statistically significant correlation observed between canopy characteristics and interception loss underscores their substantial influence on the hydrological processes studied.

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REFERENCES

Abu Bakar, A. A., & Khalil, M. K. (2017). Preliminary study on tropical forest canopy interception. *Journal of Engineering and Applied Sciences, 12*(21), 5572-5577. https://doi.org/10.36478/jeasci.2017.5572.5577

Abu Bakar, A. A., Abd Latif, Z., & Lee, W. K. (2023). Comparison of canopy cover effects on rainfall interception loss in tropical forest with homogenous and mixed tree species. *Jurnal Teknologi, 85*(2), 1-9. https://doi.org/10.11113/jurnalteknologi.v85.17661

Abu Bakar, A. A., Lee, W. K., & Abd Latif, Z. (2021). Investigating the role of stemflow in rainfall partitioning in lowland tropical forest. *Journal of Mechanical Engineering, 10*(Special Issue 1), 213-225.

Aussenac, G. (1970). Action du couvert forestier sur la distribution au sol des précipitations. *Annales des Sciences Forestières, 27*(4), 383-399. https://doi.org/10.1051/forest/19700403

Bäse, F., Elsenbeer, H., Neill, C., & Krusche, A. V. (2012). Differences in throughfall and net precipitation between soybean and transitional tropical forest in the southern Amazon, Brazil. *Agriculture, Ecosystems & Environment, 159*, 19-28. https://doi.org/10.1016/j.agee.2012.06.013

Bo, M. W., Tae, H. K., & Kyong, H. K. (1989). Rainfall interception loss from canopy in forest catchment [Conference paper]. *IHP-UNESCO-FRIM Regional Seminar on Tropical Forest Hydrology*, Kuala Lumpur, Malaysia.

Chappell, N. A., Bidin, K., & Tych, W. (2001). Modelling rainfall and canopy controls on net-precipitation beneath selectively-logged tropical forest. *Plant Ecology, 153*(1-2), 215-229. https://doi.org/10.1023/A:1017532411978

Crockford, R. H., & Richardson, D. P. (2000). Partitioning of rainfall into throughfall, stemflow and interception: Effect of forest type, ground cover and climate. *Hydrological Processes, 14*(16-17), 2903–2920. https://doi.org/10.1002/1099-1085(200011/12)14:16/17%3C2903::AID-HYP126%3E3.0.CO;2-6

Dietz, J., Hölscher, D., Leuschner, C., & Hendrayanto. (2006). Rainfall partitioning in relation to forest structure in differently managed montane forest stands in Central Sulawesi, Indonesia. *Forest Ecology and Management, 237*(1-3), 170-178. https://doi.org/10.1016/j.foreco.2006.09.044

Ford, E. D., & Deans, J. D. (1978). The effects of canopy structure on stemflow, throughfall and interception loss in a young Sitka spruce plantation. *Journal of Applied Ecology, 15*(3), 905-917. https://doi.org/10.2307/2402786

Herwitz, S. R. (1986). Infiltration-excess caused by stemflow in a cyclone-prone tropical rainforest. *Earth Surface Processes and Landforms, 11*(4), 401-412. https://doi.org/10.1002/esp.3290110406

Johnson, R. C. (1990). The interception, throughfall and stemflow in a forest in Highland Scotland and the comparison with other upland forests in the U.K. *Journal of Hydrology, 118*(1-4), 281-287. https://doi.org/10.1016/0022-1694(90)90263-W

Levia, D. F., & Herwitz, S. R. (2005). Interspecific variation of bark water storage capacity of three deciduous tree species in relation to stemflow yield and solute flux to forest soils. *Catena, 64*(1), 117-137. https://doi.org/10.1016/j.catena.2005.08.001

Lin, D. J., Zheng, Z. C., Zhang, X. Z., Li, T. X., & Wang, Y. D. (2011). Study on the effect of maize plants on rainfall redistribution processes. *Scientia Agricultura Sinica, 44*(12), 2608-2615. https://doi.org/10.3864/j.issn.0578-1752.2011.12.025

Livesley, S. J., Baudinette, B., & Glover, D. (2014). Rainfall interception and stem flow by eucalypt street trees–The impacts of canopy density and bark type. *Urban Forestry & Urban Greening, 13*(1), 192-197. https://doi.org/10.1016/j.ufug.2013.09.001

Llorens, P., & Domingo, F. (2007). Rainfall partitioning by vegetation under Mediterranean conditions: A review of studies in Europe. *Journal of Hydrology, 335*(1-2), 37-54. https://doi.org/10.1016/j.jhydrol.2006.10.032

Manfroi, O. J., Kuraji, K., Tanaka, N., Suzuki, M., Nakagawa, M., Nakashizuka, T., & Chong, L. (2004). The stemflow of trees in a Bornean lowland tropical forest. *Hydrological Processes, 18*(13), 2455-2474. https://doi.org/10.1002/hyp.1474

Martinez-Meza, E., & Whitford, W. G. (1996). Stemflow, throughfall and channelization of stemflow by roots in three Chihuahuan desert shrubs. *Journal of Arid Environments, 32*(3), 271-287. https://doi.org/10.1006/jare.1996.0023

Naharuddin, Bratawinata, A., Hardwinarto, S., & Pitopang, R. (2017). Canopy interception on tree architecture models of Aubreville, Stone and Leeuwenberg in Lore Lindu National Park Area, Indonesia. *Journal of Biodiversity and Environmental Sciences, 10*(2), 75-88.

Ovington, J. D. (1954). A comparison of rainfall in different woodlands. *Forestry: An International Journal of Forest Research, 27*(1), 41-53. https://doi.org/10.1093/forestry/27.1.41

Prebble, R. E., & Stirk, G. B. (1980). Throughfall and stemflow on silverleaf ironbark (*Eucalyptus melanophloia*) trees. *Australian Journal of Ecology, 5*(4), 419-427. https://doi.org/10.1111/j.1442-9993.1980.tb01266.x

Xiao, Q., McPherson, E. G., Ustin, S. L., Grismer, M. E., & Simpson, J. R. (2000). Winter rainfall interception by two mature open-grown trees in Davis, California. *Hydrological Processes, 14*(4), 763–784. https://doi.org/10.1002/(SICI)1099-1085(200003)14:4%3C763::AID-HYP971%3E3.0.CO;2-7

Yamakura, T., Hagihara, A., Sukardjo, S., & Ogawa, H. (1986). Aboveground biomass of tropical rain forest stands in Indonesian Borneo. *Vegetatio, 68*(2), 71-82. https://doi.org/10.1007/BF00045057

Yan, W., Deng, X., Chen, X., Tian, D., Xiang, W., & Peng, Y. (2015). Long-term variations of rainfall interception in different growth stages of Chinese fir plantations. *Hydrological Sciences Journal, 60*(12), 2178-2188. https://doi.org/10.1080/02626667.2014.964243

Yusop, Z., Cham, S. Y., & Chong, J. H. (2003). Throughfall, stemflow and interception loss of old rubber trees. *Jurnal Kejuruteraan Awam, 15*(1), 24-33. https://doi.org/10.11113/mjce.v15.15656