Partitioning rainfall into throughfall, stemflow, and interception loss in Clove (*Syzygium aromaticum*) plantation in upstream Saba River Basin, Bali

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**Abstract**

Partitioning of gross rainfall into throughfall, stemflow, and rainfall interception were assessed in clove plantation during rainy season in Saba River Basin, Bali, Indonesia. Canopy openness did not appear to be the main factor that affected the amount of throughfall and stemflow. Rainfall partitioning showed that the throughfall took major contribution in gross rainfall, while stemflow only took small portion in gross rainfall. Managed clove plantation gave slightly larger interception rate than natural forest in Saba River Basin. Cultivation method improvement is required to improve the hydrologic services of clove plantation.

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**Keywords:** plantation; clove tree; throughfall; stemflow; rainfall partitioning

1. **Introduction**

Rainfall partitioning into throughfall (*TF*), stemflow (*SF*), and interception loss (*I*) is an important part of forest hydrology as stated by Marin *et al.* Rainfall is mainly separated into two parts. First is net rainfall under the vegetation cover which reaches the floor/ground such as throughfall and stemflow. Second is interception loss that was intercepted by vegetation cover, and then some of the fall was evaporated to the atmosphere. Crock ford and Richardson stated that rainfall partitioning in plant canopy is primary dependent on climate factor and vegetation structure. The component of rainfall partitioning can be written by following equation:

\[ P = I + TF + SF \]
where $P$ is gross rainfall, $I$ is interception loss, $TF$ is throughfall, and $SF$ is stemflow.

In the upstream Saba River Basin, plantation is the main economic income for the local farmers. Among the plantation crops, clove plantation has better economic benefit than other crops in upstream Saba River Basin. This economic benefit of clove has led the land conversion, from other land-use to clove plantation use. Originally, the plantation area in upstream river basin has been established by converting natural forest area. As the effect of economic benefit and long productive period of plantation, portion of plantation land-use in Saba River Basin relatively increases for the last ten years. Additionally, a study by Budiasa et al. stated that 35% of paddy field in upstream and middle stream area of this river basin had been converted to clove plantation area in the last two decades. Clove plantation as a major land cover in upstream Saba River Basin is expected to have a significant role in hydrologic services that could substitute natural forest role in hydrologic services. On the other hand, downstream Saba River Basin is occupied by irrigated paddy field as the main land-use. This paddy field is irrigated by relying on surface water from Saba River that is managed by traditional farmer association called Subak.

Sutawan stated that one of the threats to sustainability of irrigated paddy field in Bali is deforestation and irrigation water pollution. Other studies about deforestation effect by Asdak et al. showed that deforestation decreased interception of rainfall, and increased throughfall rate in Kalimantan lowland forest. Meanwhile, Beschta et al. and Jones suggested that deforestation also increased peak discharge in Cascades Range, Oregon. Other studies by Masese et al. showed that deforestation lowered the groundwater table, with springs and wells drying up in Sondu Miriu River Basin, Kenya.

This paper aims to fulfill the lack of documentation about rainfall partitioning in clove plantation in upstream Saba River Basin. The objective of this research is to investigate the effect of the plant canopy of clove plantation on interception loss, throughfall, and stemflow in upstream Saba River Basin. The difference between rainfall partitioning in natural forest and clove plantation would be good indicator to evaluate the land-use conversion effects to hydrologic services in reducing flood, lowering peak discharge, retaining water in the ground, and maintaining water resource sustainability in the middle and downstream parts. Results of this research are expected to be considerations for the development of land-use management in Saba River Basin area.

2. The Study Area

Experimental site is in the upstream area of the Saba River Basin, Bali, Indonesia. The river basin extend between 114°56'33"E and 115°06'30"E, 8°14'38"S and 8°20'14"S, where the altitude ranges from 200 to 2270 m. The plantation area spreads about 70% of the land use on this river basin, with clove and coffee as the two main commodities. Measurement was conducted in 20 x 35 m plot within clove plantation in Umejero village. Measurements of throughfall and stemflow were taken from October 16, 2013 to August 15, 2014. A map of the Saba River Basin is shown in Fig. 1.

3. Method

3.1. Plantation canopy characteristic

The characteristic of canopy structures was obtained by measuring canopy openness, leaf area index (LAI), tree height, stem diameter average, and plant interval. Tree heights were estimated by using clinometers. Canopy openness was measured by twelve digital hemisphere photographs taken at the height of 60 cm within the experimental plot. Photographs were taken by Nikon D5100 camera paired with Sigma 4.5 mm fisheye lens. Individual photographs were analyzed using Gap Light Analyzer software. LAI was estimated by multiplying leaves number within 50 x 50 cm space by averaged leaves area. Stem diameter was measured at the breast height.
3.2 Throughfall and stemflow

Gross rainfall was measured using a tipping-bucket automatic rain gauge (Davis Instrument) with 10 minutes record intervals. Throughfall was measured using handmade rain gauges made from 30 l water containers and 25 cm diameter plastic funnels. Ten gauges were distributed in the experimental plot from October 16, 2013. Stemflow was measured using collars made by PVC hose which was fitted to the tree stem at the breast height. The collars were sealed using silicone caulk and connected to 30 l water containers. Throughfall and stemflow containers were measured by the weight.

3.3 Statistical analysis

Linear regression of gross rainfall to throughfall and stemflow were plotted by log-transformed data to reduce the heteroscedacity. Correlation between gross rainfall and throughfall or stemflow was tested by regression analysis. The mean of throughfall and stemflow was compared to the other results in coffee plantation in Saba River Basin and in the Central Sulawesi mountainous forest by Dietz et al. Correlation between canopy openness and throughfall percentage was investigated by regression analysis and Pearson coefficient. The standard level of significance was P-value < 0.05.

4. Results

4.1 Characteristic of clove

Characteristic of clove was measured by sampling ten trees randomly within the experimental plot. Table 1 shows the result of clove characteristic. Canopy openness has 31.80% in average with relatively high standard deviation (16.42%).

Table 1. Characteristics of clove plantation in Umejero village, upstream Saba River Basin, Bali. Values in parentheses are the standard deviations.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Height (m)</th>
<th>Density (plant/ha)</th>
<th>Canopy openness (%)</th>
<th>Leaf Area Index</th>
<th>Stem diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clove</td>
<td>11.7 (0.67)</td>
<td>277</td>
<td>31.80 (16.42)</td>
<td>5.13</td>
<td>41.4 (3.6)</td>
</tr>
</tbody>
</table>
4.2 Throughfall and stemflow

The annual gross rainfall measured near the experimental plot in Umejero was 2787 mm for 2013. Throughfall and stemflow were measured under 29 rains during the experimental period. Mean throughfall contributed 62.86% of gross rainfall (Table 2). On the other hand, stemflow took slight contribution to gross rainfall because stemflow was only 0.98% of gross rainfall. Minimum rainfall amount before throughfall occurred was calculated by the back propagation of log-transformed regression. Threshold was 0.64 mm before the throughfall.

Gross rainfall versus throughfall and stemflow was plotted by log-transformed data to reduce the heterocedacity (Fig. 2). Results of regression analysis in Table 3 showed that both gross rainfall versus throughfall and gross rainfall versus stemflow were linearly correlated. P-values of both regressions were lower than significant standard level (P-value < 0.05) and $R^2$ values were 0.948 and 0.759. Pearson coefficients at 0.974 and 0.871 showed that gross rainfall versus throughfall and stemflow had strong positive correlation.

Table 2. Summary of total rainfall, throughfall, and stemflow in the clove plantation in the Saba River Basin.

<table>
<thead>
<tr>
<th>Clove plantation</th>
<th>Throughfall</th>
<th>Stemflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total rainfall (mm)</td>
<td>1669.75</td>
<td>1088.25</td>
</tr>
<tr>
<td>Total throughfall (mm)</td>
<td>1049.60</td>
<td>10.64</td>
</tr>
<tr>
<td>Percent throughfall</td>
<td>62.86</td>
<td>0.98</td>
</tr>
<tr>
<td>Percent interception</td>
<td>36.16</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Regression coefficients for log-transformed gross rainfall versus log-transformed throughfall ($TF$) and stemflow ($SF$). Values in parentheses are the standard deviations.

<table>
<thead>
<tr>
<th></th>
<th>Intercept</th>
<th>Slope</th>
<th>$R^2$</th>
<th>F</th>
<th>P-value</th>
<th>Pearson coeff</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log($TF+1$)</td>
<td>-0.1938(0.058)</td>
<td>0.9934(0.0378)</td>
<td>0.948</td>
<td>690.5</td>
<td>&lt; 0.001</td>
<td>0.974</td>
<td>40</td>
</tr>
<tr>
<td>Log($SF+1$)</td>
<td>-0.209(0.038)</td>
<td>0.232(0.025)</td>
<td>0.759</td>
<td>85.24</td>
<td>&lt; 0.001</td>
<td>0.871</td>
<td>29</td>
</tr>
</tbody>
</table>
4.3 Effects of the canopy openness on through fall

Relationship between canopy openness and throughfall \((TF)\) was investigated for total throughfall and specific rainfall interval to check the probability of correlation in lower rainfall rate. Table 4 showed that canopy openness has neither significant correlation with total \(TF\) nor any rainfall intervals. P-values were larger than standard level of significance (P-value \(\leq 0.05\)), and \(R^2\) values were very small. Pearson coefficient values showed that the canopy openness had a weak relation with the throughfall.

Table 4. Regression coefficient for canopy openness percentage versus through all \((TF)\) percentage. Values in parentheses are the standard deviations.

<table>
<thead>
<tr>
<th>Category</th>
<th>Intercept</th>
<th>Slope</th>
<th>(R^2)</th>
<th>(F)</th>
<th>P-value</th>
<th>Pearson coeff.</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (TF)</td>
<td>28.801(3.846)</td>
<td>-0.078(0.113)</td>
<td>0.05</td>
<td>0.47</td>
<td>0.508</td>
<td>-0.279</td>
<td>10</td>
</tr>
<tr>
<td>(TF &lt; 10) mm</td>
<td>28.820(25.350)</td>
<td>1.269(1.182)</td>
<td>0.13</td>
<td>1.15</td>
<td>0.315</td>
<td>0.355</td>
<td>10</td>
</tr>
<tr>
<td>(10 \leq TF &lt; 50) mm</td>
<td>85.880(19.960)</td>
<td>-1.344(0.931)</td>
<td>0.21</td>
<td>2.08</td>
<td>0.187</td>
<td>-0.454</td>
<td>10</td>
</tr>
<tr>
<td>(TF &gt; 50) mm</td>
<td>73.120(18.080)</td>
<td>-0.591(0.843)</td>
<td>0.06</td>
<td>0.49</td>
<td>0.503</td>
<td>-0.241</td>
<td>10</td>
</tr>
</tbody>
</table>

5. Discussions

Throughfall rate in Umejero clove plantation were smaller than throughfall rate in the mountainous natural forest, while the stemflow rates were not different to that in the area; throughfall rate was 62.8% and stemflow rate was 0.98% in Umejero clove plantation. According to our unpublished data in upstream Saba natural forest, the throughfall and stemflow rates measured from June 21 to August 15 were 71.2 % and 1.0 %. Dietz et al.\(^9\) showed about 70 % of throughfall rate and 1 % of stemflow rate in Central Sulawesi mountainous forest.

Investigation about the relationship between canopy openness and through all showed that the canopy openness was not significantly correlated to the throughfall. This weak correlation occurred because there should be other parameters that influence the throughfall, which would be correlated to each other. Higher through all rate also did not correspond to lower LAI values where LAI values in managed clove plantation and upstream Saba natural forest were 5.13 and 5.8. Marin et al.[1] stated that high throughfall in the forest is frequently associated with high LAI. In contrast, Dietz et al.,\(^9\) Park & Lee\(^10\), stated that LAI alone did not correlate with throughfall, but canopy crown height and stem density were highly closely correlated to throughfall. Additionally, Gash et al.\(^11\), Van Dijk, and Bruijnzeel\(^12\), suggested that throughfall should be influenced by many factors at once such as wind direction, wind speed, LAI, leave roughness, and tree height.

Comparison among results of throughfall and stemflow measurement led to a conclusion that the canopy in managed clove plantation would intercept more rainwater than the canopy in natural forest. Although clove plantation canopy would intercept more rainwater, the difference in land cultivation method would cause different value of soil infiltration and evaporation from the soil. In clove plantation, the fallen leaves of clove are collected and then utilized for essential oil extraction. The collecting of clove leaves causes thin litter layer on the topsoil. On the contrary, there is relatively thick litter layer on the topsoil of the natural forest. More litter layer on the topsoil would increase the rain amount that can be retained in the soil. The litter layer also limits the evaporation from the soil as stated by Wallace et al.\(^13\). Another difference is in plant spacing between managed clove plantation and natural forest. Managed clove plantation was cultivated in monoculture way with relatively low density of tree with the same plant spacing. On the other hand, natural forest is established naturally with varied tree species, random tree spacing, and relatively dense spacing. This condition resulted in relatively dense rooting zone within the natural forest. The dense rooting zone in natural forest would lead more porous soil structure that can infiltrate and hold more water in soil layer.

Consideration about canopy interception capacity, litter containment, and soil water retention would be able to answer the question about hydrologic role of managed plantation and natural forest in this river basin. Cultivation method in clove plantation, which also considers the capacity of litter containment and soil water retention, will be required to give hydrologic services in maintaining water resource as the natural forest does.
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