Water in the forest: rain-vegetation interaction to estimate canopy interception in a tropical borneo rainforest

H P Astuti\(^1\)* and H Suryatmojo\(^1\)

\(^1\)Faculty of Forestry, Universitas Gadjah Mada, Indonesia

*E-mail: henipuji.a@mail.ugm.ac.id

Abstract. Canopy interception has an important role in the hydrological cycle. This research was conducted in virgin forest area and Intensive Forest Management System (IFMS) with selective cutting and line planting technique in IUPHHK-HA PT. Sari Bumi Kusuma. This study aims to determine: 1) the value of canopy interception in the virgin forest area and IFMS with selective cutting and line planting technique 2) the relationship between gross rainfall and canopy interception in virgin forest area and IFMS with selective cutting and line planting technique. The value of gross rainfall, stemflow, throughfall, and vegetation canopy cover were used to determine the canopy interception. Canopy interception was calculated by volume balance approach’s method. The relationship between gross rainfall and canopy interception was analyzed using SPSS software and SigmaPlot. The results of this research show that the average value of interception in the Virgin Forest is 30.44\%, while the average value of interception in Selective Cutting and Line Planting Silvicultural System (TPTJ) is 15.68\%. This result shows that there is a strong and positive relationship between gross rainfall and canopy interception, which is expressed in the equation \(I_{c\mu} = 0.0001 (P)^{2.9972}\) dan \(I_{c\mu} = 0.0004 (P)^{2.5795}\).

1. Introduction
Tropical virgin forest management system holds an important role in the area of hydrologic systems control, maintaining the sustainability of forest ecosystems and the sustainability of timber production. Management of tropical virgin forest with intensive silviculture system (Silin) will be able to balance the hydrological processes and ecosystem sustainability as well as production. The upstream Katingan Watershed is one of the largest watersheds in Central Kalimantan which has a total area of 1,908,297 acres [16]. PT Sari Bumi Kusuma is one of the pioneer company in Indonesia which was given a business license Harvesting Forest wood (IUPHHK) in virgin forests of the manage resting on sustainable forest management based on the decision letter of the Minister of forestry 201/Kpts-II/1998 on 27th February 1998. Virgin forests of PT Sari Bumi Kusuma was located in the upstream Katingan, which is managed by using an intensive silviculture system (Silin), that’s called Selective Cutting and Plant Cutting (TPTJ) Silviculture System. The TPTJ silviculture system is very suitable to be applied to logged-over area and low-potential forests to increase their productivity [18]. This system implements a pattern of forest management that focuses on increasing the productivity of virgin forests differs in age with selective cutting. The diameter limit of 40 cm and enrichment planting with commercial tree species in strip planting (in line 3 metres), and leave an area of 17 meters as the line between to maintain biodiversity [4].
The forest area of PT Sari Bumi Kusuma in the upstream area, so that all forest management activities carried out by the company will effect on downstream areas. The hydrologic cycle in the tropical rainforest is a unique system. Disruption of one component will impact on others and cause instability in the hydrologic cycle. Forest harvesting, or other reductions to vegetative cover generally reduces evapotranspiration and interception, increases surface runoff volume and the amount of water available for infiltration [17]. Canopy interception loss is commonly derived as the residual between event gross rainfall (PG) measured above the canopy or in a nearby clearing and net rainfall, calculated as the sum of separately measured throughfall (TF) and stemflow (SF) below the canopy [7] [12]. For the interception of dry and wet deposits by vegetation, the development of the plant canopy is a key factor. For dry deposition, the particle size of the contaminant is the other key parameter. Interception is more effective for small particle, the leaf area index is more adequate basis [6].

Interception is the part of the rainfall that is intercepted by the earth’s surface and which subsequently evaporates. The earth’s surface includes everything that becomes wet after a rainfall event and that dries out soon after. It includes: vegetation, soil surface, litter, build-up surface, etc. How much of the precipitation evaporates depends on land cover characteristics, rainfall characteristics, and on the evaporative demand. Forest interception is an important event in the hydrologic cycle because of its effects on rainfall deposition, soil moisture distribution, wind movement, and impact energy of raindrops on soil erosion [3]. Interception can amount up to 15-50% of precipitation, which is a significant part of the water balance. One can distinguish many types of interception, which can also interplay with each other. For example canopy, forest floor, fog, and snow [1]. Rainfall partitioning showed that the throughfall took major contribution in gross rainfall, while stemflow only took small portion in gross rainfall. Stemflow took slight contribution to gross rainfall because stemflow was only 0,98% of gross rainfall [13]. Stemflow volume varies considerably for individual trees [14] as a function of both biotic and abiotic factor. Biotic factors affecting stemflow production range from bark microrelief [9] [11] to crown length and tree size [14] [11]. Abiotic factors, such as wind speed [5] and direction [11] rainfall characteristics, and season [7] [15] also influencing the stemflow.

The opening of the forest by TPTJ activity has been lower canopy interception. The opening of the canopy closure has been lowering the ability of forests in controlling the rain in the form of forest interception up to 50% of the maximum forest interception capabilities in virgin forest [16]. The application of TPTJ in tropical virgin forests have reduced the percentage cover of the canopy by 38.5%. Impact of canopy cover changes to rain shower Interception in The Intensive Forest Management System in a Tropical Rainforest in Indonesia. Canopy interception in virgin forests and TPTJ forest are 23.7% and 19%. Virgin forests in the 13 SS plot is one of the cutting blocks in 2011 are managed by implementing the TPTJ silviculture system. The Application of TPTJ system causes of changing vegetation structure, composition, cover of canopy and influences the hydrological process of the area. The vegetation of the forest became one of the components of a watershed can
affect the condition of a watershed. The first influence given by forest vegetation to the water system is to hold rainwater through vegetation (canopy interception) and evaporate it back into the atmosphere. Canopy interception plays an important role as a reduction in rainwater and a distributor of rainfall for other processes in the hydrological cycle. Canopy interception can reduce the speed of falling rainwater on the surface of the forest floor, thus potentially reducing surface runoff and erosion. The objectives of this study were knowing the canopy interception in virgin forest area and IFMS with selective cutting and line planting technique.

2. Methodology

2.1. Research Location

IUPHHK-HA PT Sari Bumi Kusuma (00°38' -01°07' LS and 111°54' -112°26' E) which located in Seruyan Hulu Sub-District, Seruyan District and Bukit Raya Sub-District, Katingan District. Climate classification based on Schmidt and Fergusson (1952), the climatic conditions in the area of IUPHHK-HA PT Sari Bumi Kusuma climate type in on A (very wet) with an average rainfall of 273.94 mm/month and the average monthly temperature ranges from 22°C – 28°C in the night day 30°C – 33°C. Research of canopy interception observed on the permanent plot which is used as a region to represent the 13 QQ plot area (virgin forest), and the 13 SS plot area (forest with selective cutting and line planting technique). The 13 QQ plot has 117-hectare area, more large from the 13 SS plot which has 110-hectare area. This research was conducted at two different locations i.e. virgin forest that is used as a control against the impacts of forest management activities (13 QQ) and logged-over area forest that controlled by TPTJ system (13 SS).

![Figure 2. Research map in virgin forests and TPTJ forests](image)

2.2. Rainfall Data

During the observation from 23th January – 06th March 2016, there were 27 rain days with 35 rain events. Only 18 data with rain that happened on different days can be used and each of these data is discrete. The gross rainfall data were collected using the rain gauge. Rain data was taken in two ways:

1. At 07.00 a.m - 17.00 p.m, it is measured after the rain has stopped
2. At 17.00 p.m - 07.00 a.m, the data is taken in the morning

2.3. Throughfall

Throughfall is obtained by installing a throughfall tool consisting of a 1.5 liters bottle equipped with a funnel. The tool is mounted on a wooden pole as high as 1 meter above the ground. Throughfall is measured by 15 devices that installed systematically with the distance between tools of 5 meters. The
data is obtained by measuring the volume of water divided by the area of the tool. Placement of throughfall was designed with a spacing of 5 x 5 meters tools are the result of modifications.

![Figure 3. Design of throughfall in the TPTJ forest and virgin forest](image)

**Figure 3.** Design of throughfall in the TPTJ forest and virgin forest

![Figure 4. Design of throughfall in the virgin forest dan TPTJ Forest](image)

**Figure 4.** Design of throughfall in the virgin forest dan TPTJ Forest

2.4. **Stemflow**

Stemflow (Sf, mm) was measured on 8 trees which were representative of the dominant species in the virgin forest plot and TPTJ plot. Stemflow is obtained by installing a carpet wrapped around a tree trunk and then connected to water reservoir (10 liters). The tree that is used as for stemflow must represent the area both from the type of tree and the diameter of the stem. The sampled tree species in the virgin forest plot was Dipterocarpaceae, while in the TPTJ plot were Dipterocarpaceae and Euphorbiaceae.

![Figure 5. Design of stemflow](image)

**Figure 5.** Design of stemflow

2.5. **Vegetation structure**

Vegetation in tropical forest has a very wide variety of leaves and different with TPJ forest. Monitoring vegetation structure is use by permanent plot. The permanent plots are located in virgin
forest as control (totally 1 hectare) and in Intensive Forest Management System (IFMS) with selective cutting and line planting technique (totally 1 hectare). Each type of plant was measured by 25 permanent plots (totally 1 hectare). The permanent plot classification based on the growth of plant (nested plot) that is separate in 4 classes: 20 x 20 m for trees; 10 x 10 m for poles; 5 x 5 m for sapling; and 2 x 2 m for seedling. Forest vegetation conditions were analyzed using the software sexi-fs and the Arc. GIS to know the description of the canopy cover in virgin forest and TPTJ forest.

![Vegetation structure](image)

**Figure 6.** Vegetation structure, (a) TPTJ forest (b) virgin forest

2.6. Canopy Interception

Rainfall interception loss (I, mm) was determined as the difference between gross and net precipitation (Throughfall + Stemflow). The revised version of the analytical model of rainfall interception was used to model interception losses at the SMF and YSF plots. Canopy interception measurements are carried out using the a volume balance approach [2]. The data was collected from rainfall, throughfall, & crown drip and stemflow in each canopy interception plot.

\[ Ic = P - (S_F + T_F) \]

Information: \( Ic = \) Canopy Interception, \( P = \) Precipitation, \( S_F = \) Stemflow, \( T_F = \) Throughfall

3. Result & Discussion

3.1. Throughfall

Throughfall was part of the precipitation that reaches the forest floor either directly or by dripping between the leaves, twigs and branches. Generally, throughfall is greater in more open forest types and in stands with pioneering constituent species and intolerant species. Throughfall measurement is done to find out how much rainfall percentage passes when the precipitation process takes place both in virgin forests and in TPTJ forests which are logged over areas. Some of the rain will drip into the surface of the forest floor through the sidelines of the canopy (throughfall) and drip from the canopy that has been saturated with crown drip. Crown drip occurs when rainwater that drops has been able to fill a full canopy storage capacity. The biggest contribution from the distribution of rain that reaches the ground is through throughfall. The greater the throughfall, the rainfall that reaches the surface of the land will also be even greater, resulting in smaller interception. Throughfall will affect soil moisture but only during and shortly after rain. Translucent flow also influences the process of moisturizing the soil, infiltration and percolation process.
In this study the percentage throughfall in virgin forests ranged between 36.30-99% of the total thickness of rain that fell during the study or with an average of 69.56%, while in the TPTJ forests ranged from 64.27 to 99.41% of the total the thickness of rain that fell during the study or by an average of 84.32%. The amount of throughfall variation is caused by the amount of rain. Another factor that influences the amount of throughfall is canopy density, stand age, and wind.

### 3.2. Stemflow

Stemflow is a part of precipitation that will fall to the ground flowing through the vegetation stem. The value of the stemflow value is generally smaller than the value of the translucent flow. The stemflow value is very diverse, even between each tree with the same species. Stemflow becomes part of rainwater that plants cannot hold after reaching interception capacity and eventually flows through the stem. Water that reaches the surface of the soil through the stem stream does not have enough energy to cause the destruction of soil grains. The force of water damage to the flow of the stem will occur after becoming a surface runoff.

![Figure 7](image1.png)

**Figure 7.** Comparison of throughfall in the virgin forest and TPTJ forest

![Figure 8](image2.png)

**Figure 8.** Comparison of stemflow on virgin forest and TPTJ forest

The value of the stem flow is very small and does not even reach 1% of the total rainfall that has fallen so that the amount of stem flow is often ignored in the calculation of interception. In this study, variations in virgin forest stemflow ranged from 0.0001 to 0.0055% of the total thickness of rain that fell during the study or with an average of 0.0017 and for TPTJ forests ranging from 0.0004 -
0.00768% of the total thickness of rain down during the study or average of 0.0037%. The value of stemflow in the TPTJ forest in this study is greater than virgin forests. This is influenced by the presence of pioneer plants, most of which are still at the level of saplings and poles that grow around the stemflow tree. The leaves and branches of the pioneer plants attached to the stemflow tree will provide additional rainfall flow input so that it will increase the stemflow tree stem flow value. In addition to thick rain, other factors such as the physical properties of tree trunks and canopy area will also affect the production of stemflow volume.

The higher the rainfall, the higher the flow of stems will occur. If there is light rain and in a short time there is no flow of stems, this happens because the falling rainwater has been intercepted by the tree canopy and evaporated again by the atmosphere. Water that flows through the stem is only to wet the stem, not enough to saturate the stem. In times of high rainfall, rainwater that has saturated the vegetation canopy will descend into a stream of stems. The large volume of water flowing through the stem has an impact on the potential of water that can be infiltrated into the soil. The greater the water that reaches the surface of the soil, the greater the potential for water to be infiltrated into the soil. If the volume of water that reaches the surface of the soil exceeds the soil infiltration capacity then the water that reaches the surface of the soil tends to be a surface runoff. Ecological stems are important for plants because water will be absorbed by the soil and enter the root zone which is then used by plants for root growth.

3.3. Vegetation Structure
Vegetation is one of the factors that play an important role in the hydrological process, especially in the interception process. Incident rainfall first reaches the leaf surface, then a portion of rainfall is intercepted. The leaf area is an important factor influencing the rainfall partitioning [10]. One of the characteristics of vegetation that affects the interception process is canopy cover density. The presence of a canopy on the ground is very effective in holding and reducing precipitation, thereby suppressing the kinetic energy of the fall of raindrops that will reach the ground. On the other hand, the canopy can also reduce surface runoff and reduce erosion. In virgin forests the vegetation structure is more dominated by the rate of tree growth. The little sunlight that reaches the forest floor causes the growth of sapling level and even a little. Vegetation conditions in virgin forests when viewed from the distribution of diameter and height trees, tree species, and canopy cover are in good condition because no forest harvesting is carried out. Whereas in forests with the TPTJ system, there are more open areas due to the sunlight. On the structure of the virgin forest vegetation is more dominated by the growth rate of the tree. Lack of sunlight getting to the forest floor vegetation growth causes a level stake and semaipun a bit. The condition of vegetation in virgin forest seen from the distribution of diameter and height. tree, canopy cover, and experienced good condition because it does not do the activities of forest harvesting. While in the forest with the system silvikultur TPTJ, there is more of an open area consequently sunlight getting to the forest floor would be a lot more.
The number of species found in logged-over TPTJ Plots is less than the species found in virgin forest PUP, most of which are only covered by pioneer species. The difference in the number of species is possible because of the activities of certain types of logging (commercial) in logged-over areas which cause a reduction in the number of individuals or even cause the loss of several types of individuals found in the area. Vegetation canopy closure greatly affects the hydrological cycle, especially canopy interception. In the virgin forest, canopy cover in virgin forest (95%) more than forest with selective cutting and line planting technique (59%). Canopy cover in virgin forests is still more dense than the TPTJ forest, where the plants are 4 years old, meaning that the canopy in the forest area will maximize the function of the forest in interpreting rainwater. Closer canopy cover will reduce the speed of falling rain before reaching the surface of the forest floor.

3.4. Canopy Interception
Interception is the process of falling rainfall to the surface of vegetation which will then be held back for a while, and then will be absorbed by the vegetation concerned or evaporated back into the atmosphere. The interception process occurs during the rain and after the rain stops until the surface of the canopy becomes dry again [2]. In the hydrological cycle interception is considered an important factor because rainwater that reaches the surface of the land will be reduced by a large amount by the interception process. On the other hand, measurement of interception is definitely still difficult. Interception plays a very important role in the forest hydrological cycle. Rain interception will be the initial process of starting the hydrological cycle in a forested area. Some of the rain that falls in forested areas will be intercepted by the forest canopy to wet it to saturate the canopy. In the beginning, canopy filling is increasing rapidly. And at that time, 90% of canopy storage will become features. When the canopy is saturated and cannot accommodate rain that falls, some of the rainwater will flow through stemflow until it finally reaches the surface of the forest floor. Smaller rainfall events contributed to a lower percentage of throughfall and stemflow but higher percentage of canopy interception loss [8].

Canopy interception charts show various variations in the value of canopy interception in Virgin and Forest Forests with the TPTJ silviculture system. In this study, variations in interception of virgin forest canopy ranged between 0.99 - 61.88% or with an average of 30.44% of the total thickness of rain that fell during the study while in forests with TPTJ silviculture systems ranged between 0.59 - 35.72% or with an average of 15.68%. The magnitude of the value of interception of canopy in virgin forests that are not harvested is indeed different from virgin forest forests that have been harvested and managed with the TPTJ silviculture system. The greater the value of interception of a forest, the greater the amount of rainfall that can be vaporized back into the atmosphere through the evaporation process.
In this study, canopy interception in virgin forests is always greater when compared to the forests with TPTJ systems. These results indicate that the virgin forest canopy has a greater ability to collect rainwater compared to the Forest canopy with the TPTJ silviculture system. The difference in interception in the two forests can also be caused by factors such as the amount of rain falling, the age of the stand, the width of the canopy and the wind. Species with large woody surface areas will hold more water in the canopy and need more time to saturate. This factor will affect the amount of rainwater that can be temporarily detained by the vegetation canopy which will then be evaporated back into the atmosphere. Canopy interception can also play a role in delaying the time needed to reach peak discharge at a flow of the river to become increasingly longer in time.

The opening of the forest by TPTJ activities have increased the percentage of rain under a canopy which resulted in interception of the canopy. Based on Suryatmojo's research [16], canopy interception in virgin forests and TPTJ forests was 23.76%, and 19.08%. The magnitude of canopy interception in forests with TPTJ silviculture systems ranges from less than 20%. The magnitude of the canopy interception after the implementation of the TPTJ silviculture system (four years after planting) did not experience a significant increase, it can be seen from the results of canopy interception obtained from Suryatmojo's research [16]. Based on the previous research, it can be seen that the size of canopy interception in virgin forests after being measured turns out to have increased by 6%.

The relationship between rainfall and canopy interception in virgin forest can be known by using sigma plot assistance. R² in virgin forests = 0.9506 (Figure 11), meaning that there is a significant relationship between rainfall and canopy interception. 95.06% canopy interception of virgin forest is influenced by 4.94% rainfall and influenced by other factors. In the TPTJ forest, 79.27% of canopy interception was influenced by rainfall and 20.73% was influenced by other factors. The correlation relationship resulting from the rainfall and canopy interception is a positive and significant correlation. The greater rainfall happened, the greater the interception in virgin forests, but if the canopy is saturated, the interception value will be reduced.
4. Conclusion

Overall, we can conclude that interception has different roles in the hydrological cycle. The most important role is as a rainfall reducer, causing a significant amount of rainfall to be directly fed back to the atmosphere which is not available for infiltration. Second, interception influences the spatial distribution of infiltration. This has large influences on the soil moisture pattern and on subsurface flow paths. Finally, interception redistributes the water flows in time. Due to the filling of the spatial variable storage capacity and rainfall, the delay time is not homogeneous in space. Intensive Forest Management System (IFMS) with selective cutting (four years old after planting) was good condition. With the forest management, forest interception TPTJ the next few years potentially will be able to resemble the interception in the virgin forest at this time.

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