The effects of rainfall intensity to floor interception of Axonopus Compressus (Dwaft) under controlled condition

A B Azinoor Azida¹, A M Nur Syahidah² and W K Lee³

¹Faculty of Civil Engineering, Universiti Teknologi MARA Cawangan Johor, Kampus Pasir Gudang, Bandar Seri Alam, 81750 Masai, Johor, MALAYSIA.
²Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA.
Email: azinoor@uitm.edu.my

Abstract. This study aims to quantify the amount of canopy storage capacity, to determine the canopy interception values and to investigate the effects of rainfall intensities to interception loss for Axonopus compressus (Dwaft) as floor vegetation under laboratory conditions. A rainfall simulator, Kohler GHE20 Hydrology apparatus, has been applied to produce an artificial rainfall with three different intensities. General water balance equation was applied where the changes in water storage between barren land and land with canopy cover was recorded to obtain the interception loss amount. Canopy storage capacity determined from this study was 1.35 to 0.48 mm for 90 to 180 mm/hr rainfall intensity, respectively. Meanwhile, the canopy interception obtained is 3 to 18% from the rainfall depth.

1. Introduction
Interception is the process by which water is captured on vegetation (leaves, bark, grasses, crops, etc.) during a precipitation event. Intercepted precipitation is returned to the atmosphere through evaporation and not available for runoff or infiltration but instead. The forest floor can consist of bare soil, short vegetation (like grasses, mosses, creeping vegetation, etc.) or litter (i.e., leaves, twigs, small branches). In the literature, little can be found on forest floor interception, although some researchers have tried to quantify the interception amounts [1].

Interception is influenced by vegetation characteristics and climatic conditions [1]. A study by Viessman et al. found that grasses also can intercept a substantial percentage of gross precipitation, up to 60% of annual rainfall. Horton discovered that interception storage capacity is the maximum amount of water that can be stored by the canopy or forest floor in conditions of zero evaporation [3]. Gerrits et al. describe interception as a threshold process because a certain amount of water is essential before consecutive processes such as infiltration or runoff can take place [4]. The storage capacity of the forest floor depends on vegetation type, the species from which it came and its decomposition rate. Various techniques have been applied to measure interception storage capacity [5], including artificial rain experiments and weighing of whole trees or single branches after precipitation [6,7]. For instance, Putuhena and Cordery measured the forest floor interception capacity of a 15-year-old Pinus radiata plantation and a native dry sclerophyll eucalypt forest at Lidsdale State Forest, Australia, in the laboratory using a technique of applying artificial rain to undisturbed samples of the forest floor [8].

Calder et al. found that interception capacity depends on rainfall intensity [9]. This affiliated with an earlier study by Best who state that higher rainfall intensities have larger drop sizes that convey a...
greater force to the surface of a leaf [10]. Therefore, it has been hypothesised that at higher rainfall intensities the water stored on a branch will decrease because the bigger raindrops will splash higher quantities of water off of the surface [11, 9]. Meanwhile, a study by Horton discovered a high rainfall intensity event would have lower interception loss than a low rainfall intensity [3]. The percentage of total interception ranges from nearly 100% where the total rainfall does not exceed the interception storage capacity to about 25% as an average constant rate for most trees in heavy rains of long duration. When the intensity is too high water can be delivered too quickly for the plants to accommodate; thus, high intensity is associated with a low interception.

These show that the role of rainfall intensity informing of plants’ interception size is significant, but this issue should be considered as inadequately studied. That is why studies by Asdak et al. and Toba and Ohta postulated the need for developing study and laboratory experiments in this area [12, 13]. There were research studies known for utilizing the sprinkler in the laboratory [14, 15]. Crown ability for retaining water increases when the size of raindrops decreases and rain intensity decreases [9, 16]. Comparable research of interception in laboratory conditions was conducted among others [17, 18]. In this study, a series of laboratory experiments were conducted under different simulated rainfall intensities to determine the effects of Axonopus compressus (Dwaft) coverage on interception loss. This paper reports on the following: (1) quantify the amount of canopy storage capacity of Axonopus compressus (Dwaft); (2) determine the canopy interception values of Axonopus compressus (Dwaft), and 3) investigate the effects of rainfall intensities to the interception loss for Axonopus compressus (Dwaft).

2. Methodology

2.1 Rainfall simulator

In this study, the experiments were conducted in the laboratory. A hydrology apparatus called rainfall simulator has been applied to collect the data. The dimensions of the rainfall simulator are 2.4 m long x 1.0 m wide x 1.8 m high. The catchment area within the apparatus is 2 m long x 1 m wide. The catchment contained graded granular material, and the thickness of the soil sample was 180 mm. The apparatus was operated using the main electricity to drive the water pump. The water pump was installed at the bottom of the apparatus next to the water storage tank to move the water from the tank to overhead sprinklers. Eight numbers of sprinklers were installed to produce artificial rainfall. The quantity of rainfall was controlled by the valves installed at the apparatus. Different rainfall intensities were customary by adjusting the valves. In order to limit the water spray as well as to prevent wind effect, a protective screen was installed around the apparatus. There were two weirs at both ends of the catchment with two portholes to allow the discharge. The apparatus also came with 20 piezometers to record the pressure of the groundwater [19]. Figure 1 shows the Kohler GHE20 Hydrology apparatus.
2.2 Rainfall intensity
Rainfall is among the crucial parameters where it influenced by the canopy structure [20]. To study the effect of rainfall intensity on interception loss, three different rainfall intensities were used in this experiment. The different intensities were produced by adjusting the valves (A and B) that have been attached to the apparatus. When Valve A is open, the pump will generate water from the storage tank, and the water will be directed back to the storage tank. However, when Valve B is open, the water was able to pass through rotameter to the overhead sprinklers, and artificial rainfall was produced. The sprinklers were then uniformly distributed the water all over the catchment. When Valve E is close, the rainfall event will occur at the upper part of the catchment. The lowest intensity that was generated by the apparatus was 90 mm/hr, followed by 140 mm/hr intensity and the highest intensity, 180 mm/hr by slightly control the opening of the valve.

2.3 Vegetation
To obtain the canopy storage capacity and interception loss, Pearl Grass or also scientifically known as *Axonopus compressus* (Dwaft) was chosen in this study. The characteristic of its blade is different from cow grass where it has a shorter and rounded blade. This type of grass can grow in semi-shade area, and it needs deficient maintenance. It does not need regular pruning or cutting to maintain the grass. Pearl grass also only needs moderate water to grow [21].

2.4 Water discharge
To allow the water to discharge in the catchment, two portholes were provided through them. The portholes produced the water discharge after the water reached a certain level. To measure water discharge and the time for the water to fill the beakers, two small beakers were placed under the portholes. The time to fill up the beakers and the volume of water discharge was recorded.

2.5 Canopy storage capacity
General water balance equation, as shown in Equation 1 was applied in this study. The interception loss values were obtained by using this impression. The changes in water storage between barren land and land with canopy cover was recorded to measure the effects of interception loss.

\[ I - O = \frac{\Delta S}{\Delta t} \]  

(1)

where; \( I \) is inflow; \( O \) is outflow; \( \Delta S \) is water storage; and \( \Delta t \) is the duration.

Inflow consists of precipitation process while outflow is a process interflow or water discharge. On the barren land, the rainfall will either infiltrate into the soil or become runoff. By adding the canopy cover at the soil surface, the interception process was added to the outflow of the hydrology cycle.

2.6 Canopy interception
Canopy interception was calculated as the percentage of canopy storage capacity to gross precipitation, as shown in Equation 2. The amount of rainwater was determined by measuring the amount of water supplied by the water tank to the overhead sprinklers.

\[ \text{Canopy interception (\%)} = \left( \frac{\text{Canopy Storage Capacity (mm)}}{\text{Gross Precipitation (mm)}} \right) \times 100 \]  

(2)

3. Results and discussions

3.1 Water discharge
The consequence of rainfall intensity on water discharge was observed in this study. Figure 2 shows the result of the water discharge which was affected by the different intensity and the presence of canopy cover at the land surface. The slowest intensity, which was 90 mm/hr discharged the water at 1 \( \times 10^{-5} \) m\(^3\)/s that is on the barren land. The water discharge for 140 mm/hr intensity was 1.4 \( \times 10^{-5} \) m\(^3\)/s, slightly higher than 90 mm/hr meanwhile 180 mm/hr rainfall intensity discharged water at rate 2 \( \times 10^{-5} \) m\(^3\)/s and this is the highest discharge at the barren land. By adding vegetation cover that is Axonopus compressus (Dwqft) at the land surface, this change the condition of the catchment and the result indicated that water discharge was slower than the water discharge at the barren land. Rainfall intensity of 90 mm/hr produced water discharge at the rate of 0.3 \( \times 10^{-5} \) m\(^3\)/s meanwhile rainfall with intensity of 140 mm/hr and 180 mm/hr recorded water discharge of 0.5 \( \times 10^{-5} \) m\(^3\)/s and 1.2 \( \times 10^{-5} \) m\(^3\)/s, respectively. High rainfall intensity will produce high water discharge as this indicated that rainfall intensity is directly proportional to water discharge for both catchment conditions. Though, at all three levels of intensities, the water discharge decreases because of the existence of the canopy cover.
In addition, the water discharge was influenced by the amount of water loss to canopy interception. The effect of land-use change on water discharge was also studied elsewhere in Srepok Watershed by using The Soil and Water Assessment Tool (SWAT) model and Geography Information System (GIS) [22]. The result shows that with the increase of land cover, the surface flow decreases while the infiltration rate increases. This is due to the afforestation activity in Srepok Watershed. Moreover, [23] found that streamflow decreases as the forest establishes while clearing the forest results in increases of streamflow.

3.2 Canopy storage capacity
The difference of water discharge at barren land and land with canopy cover was measured to determine the canopy storage capacity for _Axonopus compressus_ (Dwaft). The philosophy behind this experiment is the different values among these two covers show the water lose to canopy interception. In the case of barren soil, the rainwater falls straight to the ground because there is no impediment from the canopy cover. The volume of rainfall that reached the soil is the same as the total volume of produced rainfall. However, with canopy cover at the soil surface, some part of the rainwater is intercepted on the canopy surface before it started to drip down or evaporate. This portion of rainwater is measured as interception loss.

On the other hand, the storage capacity at 90 mm/hr was 1.35 mm for _Axonopus compressus_ (Dwaft), which was the highest capacity between these three different intensities. The interception loss recorded was 1.1 mm for rainfall with 140 mm/hr intensity, while 180 mm/hr can only store the water for 0.48 mm. It is discovered that the canopy storage capacity decreases as rainfall intensities increases, as shown in Figure 3.

**Figure 2.** Relationship between rainfall intensity and water discharge

![Figure 2](image-url)
This may be because of the high influence of the water droplet on canopy surface causes the greeneries to agitation and shed the rainwater on the canopy surface [11]. This is comparable to other study [24]. In this study, canopy storage capacity for Thatching grass (*Hyparrhenia filipendula*) was measured using the sprinkler test. The experiment shows that the maximum storage capacity of *Hyparrhenia filipendula* is 1.5 mm. This study also concluded that canopy storage capacity depends on the rainfall intensity with low intensity has higher capacity while high intensity produces low capacity. Many studies have been done by other researchers to endeavour the depression storage for different land covers. The depression storage values for different forest floor types is presented in Table 1.

![Figure 3. Rainfall intensity and canopy storage capacity for *Axonopus compressus* (Dwaft)](image)

Table 1. Forest floor water storage capacity values from other studies.

| Forest floor type                     | Water Storage Capacity (mm) | Reference |
|---------------------------------------|----------------------------|-----------|
| Peble mulch (5-9cm)                   | 0.281                      | [25]      |
| Peble mulch (2-6cm)                   | 0.526                      |           |
| *Cryptomeria japonica*                | 0.27 – 1.72                | [26]      |
| *Lithocarpus edulis*                  | 0.67 – 3.05                |           |
| Grass (*Aristida divaricata*)         | 2.5                        | [27]      |
| Woodchips (*Pinus*)                   | 8                          |           |
| Poplar leaves (*Populus nigra*)       | 2.3                        |           |

3.3 Canopy interception

*Axonopus compressus* (Dwaft) was able to intercept rainwater the most at lowest rainfall intensity which was 90 mm/hr. It can intercept almost 18% of the total rainfall. However, for 140 mm/hr rainfall intensity, 9% of the total rainfall was intercepted. This study recorded the highest rainfall intensity used is only 3% of total rainfall which was the lowest amount of intercepted water. Figure 4 shows that as the rainfall intensity increases, the canopy interception decreases. Study by Tsiko et al. shows that *Hyparrhenia filipendula* can intercept 26% of gross rainfall [24]. Canopy interception for *Hyparrhenia filipendula* is higher than *Axonopus compressus* (Dwaft) may be due to the location of the experiment. The experiment was done outdoor under the open sky and exposed to the wind compare to experiment done in the laboratory where there is a limited amount of sunlight and no wind effect.
4. Conclusion
A laboratory experimental with rainfall simulator was used to determine the effect of rainfall intensities to canopy interception. Three different rainfall intensities that has been applied were 90 mm/hr, 140 mm/hr, 180 mm/hr were the vegetation used as canopy interception is *Axonopus compressus* (*Dwarf*). The canopy storage capacity produced from three different rainfall intensities were 1.35 mm, 1.1 mm and 0.48 mm for 90 mm/hr, 140 mm/hr and 180 mm/hr rainfall intensity, respectively. Meanwhile, for the case of canopy interception, 90 mm/hr rainfall intensity intercepted 18% of total rainfall followed by 9% for 140 mm/hr and 3% for 180 mm/hr. The results show that the canopy interception varies with rainfall intensity. As a conclusion, the findings from this study show that canopy interception decreases as rainfall intensity increases.

References

[1] Dabral B G, Premnath P and Ramswarup R 1963 Some preliminary investigations on the rainfall interception by leaf litter *Indian Forester* **89** 112–116
[2] Viessman W and Lewis G L 1996 Introduction to Hydrology Chapter 3 *Interception and Depression Storage* New York Pages 40 – 51
[3] Horton R E 1919 Rainfall interception *Mon. Weather Rev.* **47** 9
[4] Gerrits A M J, Pfister and Savenije H H G 2008 Uncertainties in canopy and forest floor interception *Geogr. Res. Abstracts* **10**
[5] Dunkerley D 2000 Measuring interception loss and canopy storage in dry land vegetation. A brief review and evaluation of available research strategies *Hydrol. Proc.* **14** 669-678.
[6] Aston A R 1979 Rainfall interception by eight small trees *J. Hydrol.* **383** 396-396.
[7] Telkehaimonot Z, Jarvis P G 1991 Direct measurement of evaporation of intercepted water from forest canopies *J. App. Ecology* **28** 603-618
[8] Putuhena W M and Cordery I 1996 Estimation of interception capacity of the forest floor *J. Hydrol.* **180** 283–299
[9] Calder I R, Hall R L, Rosier P T W, Bastable H G and Prasanna K T 1996 Dependence of rainfall interception on drop size: 2. Experimental determination of the wetting functions and two-layer stochastic model parameters for five tropical tree species *J. Hydrol.* **185** 379-388
[10] Best A C 1950 The size and distribution of raindrops *Q J R Meteorol. Soc.* **76** 16–36
[11] Rutter A J, Kershaw K A, Robinson P C and Morton A J 1971 A Predictive Model of Rainfall Interception in Forests. I. Derivation of The Model from Observations in a Plantation of Corsican Pine *Agri Meteorology* **9** 367–384

**Figure 4.** Relationship between rainfall intensity and canopy interception for *Axonopus compressus* (*Dwarf*)
[12] Asdak C, Jarvis P G and Gardingen P V 1998 Evaporation of intercepted precipitation based on an energy balance in unlogged and logged forest areas of central Kalimantan, Indonesia Agri and For Meteorology 92 173–180
[13] Toba T and Ohta T 2008 Factors affecting rainfall interception determined by a forest simulator and numerical model Hydrol. Proc. 22(14) 2634–2643
[14] Hall R L and Calder I R 1993 Drop size modification by forest canopies-measurements using a disdrometer J. Geophysical Res. 90 465–470
[15] Garcia-Estringana P, Alonso-Blazquez N and Alegre J 2010 Water storage capacity, stemflow and water funneling in Mediterranean shrubs J. Hydrol. 389 363–372
[16] Calder I R 1999 Dependence of rainfall interception on drop size - a reply to the comment by Uijlenhoet and Stricker J. Hydrol. 217 164–165
[17] Pei T F, Fan S X, Han S W 1993 Simulation experiment analysis on rainfall distribution process in forest canopy Chinese J. Appl. Ecol. 4 250–255
[18] Keim R F, Skaugset A E and Weiler M 2006 Storage of water on vegetation under simulated rainfall of varying intensity Adv. Water Resour. 29 974–986
[19] Nur Syahida A M and Azinoor Azida A B 2018 The effect of vegetation canopy on canopy storage capacity with different rainfall intensity MATEC Web Conf 250 04001
[20] Azinoor Azida Abu Bakar and Muhammad Khairudin Khalil 2017 Preliminary Study on Tropical Forest Canopy Interception J. Eng. Appl. Sci. 12 5572-5577
[21] Flora and Fauna Web, National Park. Retrieved from florafaunaweb.nparks.gov.sg
[22] Quyen N T N, Liem N D and Loi N K 2014 Effect of Land Use Change on Water Discharge in Srepok Watershed, Central Highland, Viet Nam Int. Soil Wat. Conserv. Res. 2 74-86
[23] Zhao F F, Zhang L and Xu Z X 2009 Effects of Vegetation Cover Change on Streamflow at a Range of Spatial Scales 18th World IMACS/MODSIM Congress. 3591-3597
[24] Tsiko C T, Makurira H, Gerrits A M J and Savenije H H G 2012 Measuring Forest Floor and Canopy Interception in Savannah Ecosystem Phys. Chem. Earth 47-48 122-127
[25] Li X Y, Gong J D, Gao Q Z and Wei X H 2000 Rainfall interception loss by pebble mulch in the semiarid region of China J. Hydrol. 228 165–173
[26] Sato Y, Kumagai T, Kume A, Otsuki K and Ogawa S 2004 Experimental analysis of moisture dynamics of litter layers - the effect of rainfall conditions and leaf shapes Hydrol. Proc. 18 3007–3018
[27] Guevara-Escobar A, Gonzalez-Sosa E, Ramos-Salinas M and Hernandez-Delgado G D 2007 Experimental analysis of drainage and water storage of litter layers Hydrol. Earth Syst. Sci. 11(5) 1703–1716