The effect of vegetation canopy on canopy storage capacity with different rainfall intensity

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Abstract. Canopy Interception is one of the vital component in hydrological cycle and underestimating the interception process can significantly affect the water balance. A study of rainfall interception was conducted using rainfall simulator called hydrology apparatus. Three different rainfall intensities were used in this study; 90 mm/hr, 140 mm/hr and 180 mm/hr. These intensities were produced by 8 nozzles. The test were first carried out on the barren land without the existence of canopy cover. To study the effect of canopy cover on canopy storage capacity, broadleaf plant (*Scindapsus Aureus*) was used to cover the barren land. The differences between the amount of water discharge between these two different land covers were observed to determine the quantity of water stored in the canopy. Results indicated that *Scindapsus Aureus* intercepted more water at lower intensity than at higher intensity. The lowest intensity was 90 mm/hr stored 1.6mm of rainwater while 140 mm/hr retained 0.8 mm. 180 mm/hr was the highest rainfall intensity used in this study intercepted 0.3mm of total precipitation. Therefore, this study proved that rainfall intensity is one of the main factors that influence the rainfall interception process.

1 Introduction

Canopy interception can be described as an act of blocking the rainwater or snowflakes from direct fall to the ground by using tree, grass or shrub. Interception process is considered as a very significant process in hydrological balance because it is the second process after precipitation process. It influences all the other processes in water cycle for example, infiltration, runoff, flood generation and moisture recycling [1].

Canopy storage capacity (S) is the amount of water that can be stored in the canopy [2]. It is one of the vital parameter to the canopy interception process along with canopy cover and wet canopy evaporation [3]. Generally, canopy storage capacity is expressed in mm. [1] state that storm intensity plays a vital role to canopy storage capacity where high intensity results to having low storage capacity. Meanwhile, small intensity results to higher storage capacity. After the canopy storage capacity has reached its limit, the water

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retained on the leaf will start to drip down [3]. **Table 1** shows the canopy storage capacity by other researchers.

Direct method and indirect method is used to determine storage canopy capacity. While indirect method cost less [4] and easy to apply [5], it takes longer time to measure the capacity of storage [4]. Direct method need less period but it also needs special instrumentation, hence it costs more [4]. Rainfall intensity, duration of the storm and temporal and spatial variability of trees are few factors that influence canopy storage capacity [6]

The objective of this paper was to study the canopy storage capacity for *Scindapsus Aureus*. Other objective was to investigate the effect of different rainfall intensity on canopy storage capacity.

Table 1 Canopy Storage Capacity from previous researches

Tree Species	Type of leaf	Canopy Storage Capacity, S (mm)	Location	References
Quercus Petraea	Broadleaf	0.22 - 0.8	Belgium	[4]
Fagus Sylvatica	Broadleaf	0.24 - 1.12		
Mixed oak-beech	Broadleaf	0.53 - 1.17		
Branchystegia Spiciformis	Broadleaf	1.8	Zimbabwe	[1]
Hyparrhenia Filipendula	Needle Leaf	1.5		
Quercus Brantii	Broadleaf	1.56 (Leaf Period) 0.56(Leafless Period)	Iran	[7]
Hevea Brasiliensis	Broadleaf	0.11	Malaysia	[9]
Juniperus Virginia	Needle Leaf	2.14 - 3.44	USA	[2]
Tallgrass Prairie	Needle Leaf	0.27 - 3.86		
Pinus Eldarica	Needle Leaf	1.31	Iran	[8]
Cupressus Arizonica	Needle Leaf	1.00		

2 Methodology

2.1 Vegetation Sample

Scindapsus Aureus Plant was chosen to obtain the canopy storage capacity using laboratory work as shown in **Fig. 1**. *Scindapsus Aureus* is a broadleaved plant where it has round, flat, heart-shaped, dark green, and plump leaves. The size of the leaves is about 3 to 4 inches for young plant. *Scindapsus Aureus* is also a perennial plant. It requires 15°c to 30°c to grow and a little or too much sunlight will change the color of the leaves. This plant was used for this study because it can grow outdoor as well as indoor [10]. Therefore, it is suitable to be used in laboratory.

2.2 Soil Properties

The type of soil used for this experiment was tested using particle size distribution test. Soil sample was weighted and dried for 24 hours. After that, it was placed on mechanical shakers for about 10 minutes to allow the soil to go through different size of sieve stack. The sieves were weighted to measure the soil retained on each pans. The initial moisture content was obtained by drying the soil for 24 hours in drying oven at 105°c to 110°c [11].
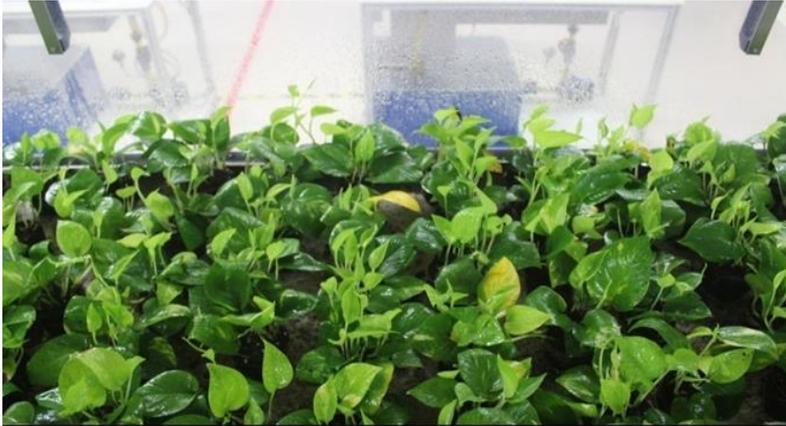
Fig. 1. Vegetation Cover (*Scindapsus Aureus*)

2.3 Hydrology Apparatus

In this study, the tests were performed using laboratory measurement. Hydrology apparatus called rainfall simulator was the main apparatus for data collection. The overall dimensions were approximately 2.4m long x 1.0m wide x 1.8m high. It was operated using main electricity to drive water pump. 8 nozzles were installed to produce artificial rainfall. Adjustment of valves provided controlled the quantity of rainfall. By controlling valves, different rainfall intensities were established. The catchment area was 2 m long x 1 m wide. The catchment contained graded granular material and the thickness of soil sample was 180mm. A protective screen was installed around the apparatus to limit the water spray as well as to prevent wind effect. The constraining weirs at both end of tank catchment were used to measure the amount of water discharge. The apparatus also came with 20 piezometers to record the pressure of groundwater [12]. **Fig. 2** shows the Kholler GHE20 Hydrology apparatus.

Fig. 2. Kholler GHE20 hydrology apparatus

2.3.1 Rainfall Intensity

Three different rainfall intensities were used in this experiment to study the effect of rainfall intensity to canopy storage capacity. The different intensities were produced by

adjusting the valves (A and B) that had been attached to the apparatus. Valve B was opened to allow the water passed through rotameter to overhead sprinklers to produce artificial rainfall. The sprinklers were then distributed the water uniformly all over the catchment. The rainfall intensities that were generated using rainfall simulator were 90 mm/hr, 140 mm/hr and 180 mm/hr.

2.3.2 Time for water discharge

After the pump circulated the water from the tank to sprinklers and produced rainfall, the rainfall felt into the catchment. The water then infiltrated into the soils. After several minutes, the catchment started to fill with water and once it reached the drainage provided in the soil, the water started to discharge through portholes at the end of catchment. The time taken for water to discharge after rainfall started was recorded using stopwatch.

2.3.3 Water discharge

Two portholes provided in the catchment allowed the groundwater to discharge through them. After the groundwater reached a certain level, the portholes produced the water discharge. Two small beakers were placed under the portholes to measure water discharge and the time was recorded for the water to fill the beakers. The volume of water discharge was then recorded.

2.3.4 Canopy Storage Capacity

General water balance equation as shown in Equation 1 was used in this study. By using this concept, the interception loss was obtained. The changes in water storage between barren land and land with canopy cover was recorded to measure the interception loss.

$$I - O = \frac{\Delta S}{\Delta t} \qquad (1)$$

where ;
I = Inflow
O = Outflow
ΔS = Water Storage
Δt = Time

Inflow consists of precipitation process while outflow is a process interflow or water discharge. On barren land, the rainfall will either infiltrate into the soil or become runoff. By adding canopy cover, the interception process was added to the hydrology cycle. An amount of water that was intercepted by leaves was considered as interception loss. Hence, it affected the volume of interflow. **Fig. 3** shows the component of hydrological balance with interception process.

3 Result and Discussion

3.1 Soil properties

The soil used in this study was granular sand and the initial moisture content is constant throughout the test period which range between 4% to 6% because the tests were performed indoors in controlled process of precipitation and absence of wind and direct sunlight.
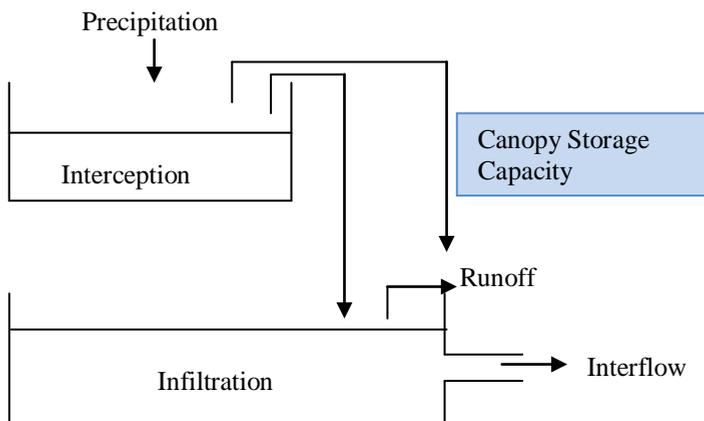

Fig. 3. Diagrammatic representation of hydrological balance

3.2 Rainfall intensity

Three different rainfall intensities were used in this experiment; 90 mm/hr, 140 mm/hr and 180 mm/hr. Rainfall by natural precipitation process has lower intensity compare to artificial rainfall. Most of the intensities produce by rainfall simulator are higher for example, [13] used rainfall simulator to study the canopy water storage under four intensities; 20, 60, 250 and 420 mm/hr. [14] studied the effect of vegetation and soil stability on surface runoff and soil erosion under 60 mm/hr rainfall intensity. In addition, [15] chose 100 mm/hr to investigate the impact of land use and cover on surface runoff.

3.3 Time for water discharge

This section discussed the influence of canopy interception process towards time of water discharge. The result showed that the presence of vegetation cover altered the time taken for water to start discharging. For barren land, 90 mm/hr rainfall intensity took about 9 minutes for water to discharge after precipitation process while time for water discharge for 140 mm/hr rainfall intensity was 7 minutes. The fastest for water to discharge was 5 minutes for 180 mm/hr.

By changing the condition of the catchment by adding *Scindapsuss Aureus* Plant, the results indicated that the time for water discharge was slower than the barren land. The longest time the rain water took to discharge was 18 minutes for 90 mm/hr. Rainfall intensity of 140 mm/hr and 180 mm/hr discharged the water at 10 minutes and 9 minutes respectively.

It can be concluded that the rainfall intensity affects the time of water discharge for both catchment conditions. Canopy cover slowed down the impact of rainfall on the soil surface causing the water to infiltrate into the soil at a slower pace [16]. The time taken for water discharge decreased when the rainfall intensity increased for both catchment cover.

Therefore, the rainfall intensity is inversely proportional to the time of water discharge as shown in **Fig. 4**. There is a lack of information regarding time of water discharge. However, [17] found the delay in net precipitation peak rate about 10 minutes compared to gross precipitation peak rate. It indicates the delay of peak runoff from a storm due to interception process.
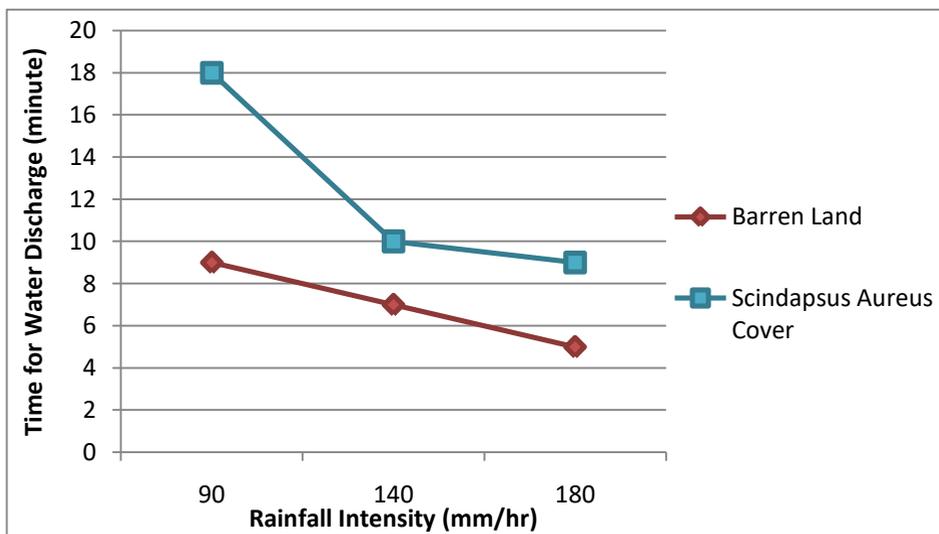

Fig. 4. Relationship between rainfall intensity and time for water discharge

3.4 Water discharge

The effect of rainfall intensity on water discharge also was observed. The results show in **Fig. 5** indicated that water discharge is effected by different intensity and also the presence of canopy cover. For barren land, the slowest intensity which is 90 mm/hr discharged the water at 1×10^{-5} m^3/s. The water discharge for 140 mm/hr intensity was 1.4×10^{-5} m^3/s, slightly higher than 90 mm/hr. 180 mm/hr rainfall intensity discharged water at rate 2×10^{-5} m^3/s. This is the highest rate at barren land.

   The result demonstrates that canopy cover reduces the rate of water discharge. Intensity of 90 mm/hr produced water discharge at rate 0.2×10^{-5} m^3/s while 140 mm/hr and 180 mm/hr rainfall intensity recorded 0.7×10^{-5} m^3/s and 1.1×10^{-5} m^3/s of water discharge respectively. Rainfall intensity is directly proportional towards water discharge for both catchment condition. The higher the intensity, the higher the water discharge. However, canopy cover caused the water discharge decreases at all three level of intensities.

   In addition, the amount of water loss to canopy interception also influenced the water discharge. [18] stated that the average daily runoff increases as the area of forest decreases. The growth of forest decreases the surface flow and increases the infiltration rate. Thus, land cover does affect the water discharge [19] . Furthermore, streamflow increases after clearing forest area but decreases as the forest is established [20]. [21] declared vegetation decreases runoff energy and improve soil texture.

3.5 Canopy storage capacity

Canopy storage capacity for *Scindapsus Aureus* was determined by measuring the difference between water discharge at barren land and land with canopy cover. The theory

behind this is the different values between these two covers indicate the water lose to canopy interception. For barren soil, rain water fall straight to the ground because there is no obstacle from canopy cover. The amount of rainfall that reached the soil is the same with the total amount of rainfall produced. However, with canopy cover, some part rain water is stored on canopy surface before it started to drip down or evaporate. This part of rain water is considered as interception loss.
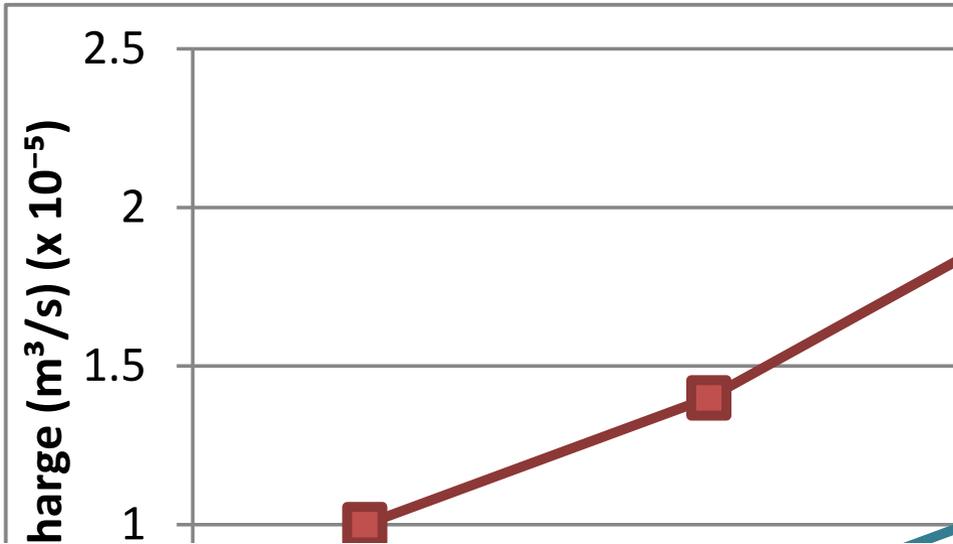

Fig. 5. Relationship between rainfall intensity and water discharge

For *Scindapsus Aureus*, the storage capacity at 90 mm/hr was 1.6 mm which was the highest capacity between these three different intensities. For rainfall with 140 mm/hr intensity, the interception loss recorded was 0.8 mm while 180 mm/hr can only stored the water for 0.3 mm. It is discovered that the canopy storage capacity decreased as rainfall intensities increased as shown in **Fig. 6**. This may be because of the high intensity impact on canopy surface causes the leaves to shake and shed the water on surface without storing it. [13] found as rainfall intensity increases, incremental storage gains decreases. However, they also stated that canopy cover generally intercepts more water at higher rainfall intensity. Canopy storage capacity in their study range between 0.05 mm to 1.1 mm. The finding is contrary to this study where it is recorded that interception loss decreases as rainfall intensity decreases. However, [22] support this finding. They found that the higher the intensity, the lower the canopy storage capacity due to high impact and leaves shacking. [1] also agreed that less intensive intensity intercept more water compare to high intensity. They found that Msasa Leaf has capacity to store water about 1.8 mm and Thatching grass is 1.5mm.
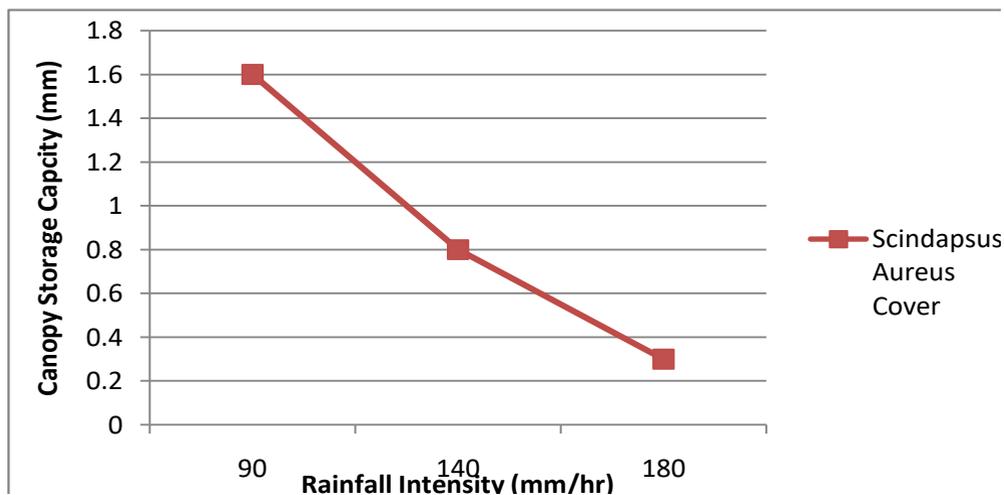
Fig. 6. Relationship between rainfall intensity and canopy storage capacity.

4. Conclusion

A rainfall simulator was used for measurement of canopy interception for *Scindapsus Aureus.* Three different intensities; 90 mm/hr, 140 mm/hr, 180 mm/hr were used to investigated the effect of different rainfall intensity on canopy storage capacity. By studying the differences in water storage in barren land and land with canopy cover, the canopy storage capacity was determined. It was found that the canopy storage capacity for *Scindapsus Aureus* varies with rainfall intensity. Canopy storage capacity was 1.6 mm, 0.8 mm and 0.3 mm for 90 mm/hr, 140 mm/hr and 180 mm/hr rainfall intensity respectively. From the result, it can be concluded that the canopy storage capacity decreases as the rainfall intensity increases.

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