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Water Requirement Estimation of One-Whorl Rubber (*Hevea brasiliensis* Müll. Arg.) Planting Materials

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Abstract

Fulfilling water requirement is one of the important factors for a successful production of rubber tree planting materials. Research on the irrigation requirement for young rubber trees is crucial to determine the amount of water required for an optimum plant growth. The aim of this study was to determine the amount of water needed by one whorl rubber planting material to compensate the amount of evapotranspiration, as well as to estimate the crop coefficient value (kc). The research was conducted at the Indonesian Rubber Research Institute on July 2021. Daily evapotranspiration (ETc) of rubber planting materials of clone “PB 260”, “RRIC 100”, and “IRR 112” planted in polybag size 13 cm x 35 cm were measured by weighing the planting materials daily. Evapotranspiration for the reference crop was collected from the Indonesian Rubber Research Institute climatological station. Our study showed that the amount of water required by each rubber planting material was 92.21 mL per day per polybag when the mean of daily reference evapotranspiration (ETo) was 3.67 mm per day. Therefore, the crop coefficient (kc) of one whorl rubber planting material arranged sparsely was ± 0.32. This kc value can be used as a base to calculate water requirement of one whorl rubber planting material based on the daily reference evapotranspiration (ETo).

Keywords: crop coefficient, evapotranspiration, plant water requirement, rubber planting material, water balance

Introduction

The largest area of rubber plantation in Indonesia is located in South Sumatera. Most of the rubber farmer in South Sumatera also produce rubber planting materials for their own plantation or to sell to others farmer. To produce rubber planting materials, sufficient amount of water should be available every day for several months to fulfill their water requirement for producing young plants with vigorous growth. This condition requires the rubber planting material producer to prepare adequate irrigation system especially during dry season. In South Sumatera (located at 1^o - 4^o S and 102^o - 106^o E), rainfall is not evenly distributed throughout the year (Cahyo et al., 2011; Cahyo et al., 2016). In this area, three to four months with rainfall less than 100 mm per month usually occur during a normal year. Moreover, during El-Nino event, dry months could occur for more than four months (Saputra et al., 2016). Fluctuation of monthly rainfall of the last 20 years collected from the Indonesian Rubber Research Institute climatological station is presented in Figure 1.

Occurrence of three to four dry months during a year in South Sumatera Is a constraint for rubber tree growth. Without irrigation, three to four dry months causes moderate drought stress because the amount of water from rainfall is not enough to fulfill rubber water requirement. Therefore, irrigation during dry months is critical for the optimal plant growth, especially for the production of rubber planting materials. Rubber planting materials that are grown without irrigation during dry season show stagnant growth in stem girth. Water is an essential component for photosynthesis (Cahyo et al., 2020; Carr, 2012; Taiz and Zeiger, 2002), therefore insufficient water supply results in low growth rate and low quality rubber planting materials.

Due to the occurrence of long dry months in South Sumatera, the determination of nursery location, particularly with regard to the availability of water supply for the rubber planting materials is critical (Wijaya et al., 2011; Wijaya, 2008). Ideally, water source for irrigation is from a river or channel that never dries during dry season and therefore irrigation is still efficient during dry season. If ponds or reservoirs are used as source of water for irrigation, accurate calculation of irrigation requirement is needed. This is to assure that water from the reservoir is channeled to the rubber planting materials efficiently and sufficiently in order to fulfill plant water requirement during dry season.

Available water is determined as the level of soil water content in between field capacity and permanent wilting point (Allen et al., 1998; Doorenbos and Pruitt, 1977; Savva and Frenken, 2002; Waller and Yitayew, 2016). At the above field capacity, water will be moved to other places by percolation or seepage processes. On the contrary, if the soil water content decreases below the permanent wilting point, plant will be unable to absorb water from the soil (Kirkham, 2014). Therefore, the amount of irrigation should be provided to the plants accurately to achieve effective and efficient usage of water.

The optimum amount of water needed by plants can be estimated by measurement of plant (crop) evapotranspiration. In the absence of rainfall, in order to maintain soil water content at optimum amount for plant to grow, the amount of water that should be added to the soil (plant water requirement) should be equal to the amount of water lost by evapotranspiration (ETc). In the presence of rainfall, the plant water requirement should be calculated by using water balance method. In addition, the value of crop evapotranspiration (ETc) is depended on the value of reference evapotranspiration (ETo) and crop coefficient (kc) (Allen et al., 1998; Mangmeechai, 2020; Savva and Frenken, 2002). By determining ETc and ETo, the kc for one whorl rubber planting material planted in a polybag can also be determined. Hence, in the future plant water requirement can be easily calculated using determined kc and ETo data collected from climatological station. The aim of this research was to determine the amount of water required by rubber planting material with one whorl of leaves to compensate the amount of evapotranspiration as well as to estimate the rubber planting material coefficient value (kc). By determining kc value, the plant water requirement can be calculated accurately, hence water use efficiency can be optimized.

Material and Methods

Experimental Site and Plant Materials

The experiment was conducted on July 2021 at the Indonesian Rubber Research Institute nursery located at Sembawa, South Sumatera, Indonesia. A total of 15 plant materials representing three rubber clones (“PB 260”, “RRIC 100”, and “IRR 112”) with five replicates per clone were used for the study. The plant materials were 3-month-old with one whorl of fully expanded leaves.

The one-whorl rubber plant materials were planted in the 13 cm × 35 cm size polybags filled with Ultisol soil as the planting medium. The moisture content of the planting medium in each pot was maintained at 18.5 and 33.7% by adding 450 mL of water into the polybags once every two days, except when there was rainfall.

Climate Data

The climate data around the nursery were collected from the climatological station located at 02°55’40” S and 104°32’16” E with the altitude of 10 m above sea level. The climate data used for this research included rainfall (collected from Ombrometer Observatorium) and the reference crop evapotranspiration generated from class A evaporation pan.

Calculation of Plant Water Requirement (Evapotranspiration, ETc)

To calculate evapotranspiration (ETc), the water balance method was used due to the occurrence of rainfall during measurement of ETc. In the water balance calculation, the change of storage (dS/dt) was equal to input minus output of water. The input parameter for this calculation was rainfall (P) and the output parameters were run off (R), evapotranspiration (ETc), and percolation (Pe). The calculation of water balance is illustrated in Equation 1 (Sutanto, 2011).

$$I - O = \frac{dS}{dt}$$

$$\Leftrightarrow \quad P - R - ETc - Pe = \frac{dS}{dt} \qquad (1)$$

In this research, the rainfall recorded was very low (≤ 1 $mm.day^{-1}$), hence the run off (R) and percolation (Pe) was neglected. Therefore, the water balance calculation was simplified into Equation 2.

$$P - ETc = \frac{dS}{dt}$$

$$\Leftrightarrow \quad ETc = \frac{dS}{dt} + P \qquad (2)$$

Where:
I = Input
O = Output
= Change of the storage (soil water content)
P = Rainfall
R = Run off
ETc = Crop evapotranspiration
Pe = Percolation

The change of water storage was measured daily at 07.30 am by weighing the polybags containing rubber plants. The daily change of the weight of the polybags indicated the daily change of soil water content due to the daily evapotranspiration. The daily evapotranspiration in kg was converted to mm by dividing the volume of water loss due to transpiration by the evapotranspiration area of both plant (leaves) and the planting medium (soil top surface).

Calculation of Crop Coefficient (kc)

To calculate crop coefficient, evaporation data from Class A Evaporation Pan (EPan) of the Indonesian Rubber Research Institute Climatological Station was used to determine the reference crop evapotranspiration (ETo). The ETo was calculated using the formula presented in Equation 3 (Allen et al., 1998; Ayutthaya, 2010; Doorenbos and Pruitt, 1977; Mesike and Esekhade, 2014; Savva and Frenken, 2002).

$$ETo = kp \times EPan \quad (3)$$

Where:
ETo = Reference crop evapotranspiration
kp = Pan coefficient with the value as 0.85 for Class A Evaporation Pan
Epan = Class A Evaporation Pan
The crop coefficient (kc) of one-whorl rubber plants in polybag was calculated using Equation 4 (Allen et al., 1998; Doorenbos and Pruitt, 1977; Fisher, 2012; Mangmeechai, 2020; Savva and Frenken, 2002).

$$Kc = \frac{ETc}{ETo} \quad (4)$$

Where:
ETc = Crop evapotranspiration
ETo = Reference crop evapotranspiration
Kc = Crop coefficient

Statistical Analysis

A completely randomized design was used to analyze the effect of the clone types on the water requirement and crop coefficient of one whorl rubber plant materials. If the rubber clone types significantly affected the observed variables, the Duncan Multiple Range Test (DMRT) was employed with significance level of 95% to differentiate the means of each variable. Statistical analysis was conducted using SAS version 9 program software (SAS Institute Inc., 2002).

Results and Discussion

During the study period, the observed reference evapotranspiration (ETo) fluctuated between 1.46 to 5.08 mm per day. Within the same time frame, rainfall only occurred on 13 July 2021 as high as 1 mm per day. The fluctuation of ETo and rainfall is presented in Figure 2.

Figure 2 shows that rainfall only occurred in the evening of the first day of observation with as high as 1 mm. This amount of rainfall was lower than the ETo, hence we assumed that run off and percolation did not occur during the research duration. Therefore, in the water balance calculation we only used the rainfall (P), evapotranspiration (ETc), and change of storage ($\frac{dS}{dt}$).

In addition, based on initial soil water content data at the first day of the research and daily weight of the polybags, the weight soil and water inside the polybags was calculated to determine daily soil water content. Daily soil water content data was required to maintain soil water content at available level between permanent wilting point and field capacity, hence the amount of daily ETc was not reduced by the low water content of the soil medium. For clay loam soil used in this research, the permanent wilting point was about

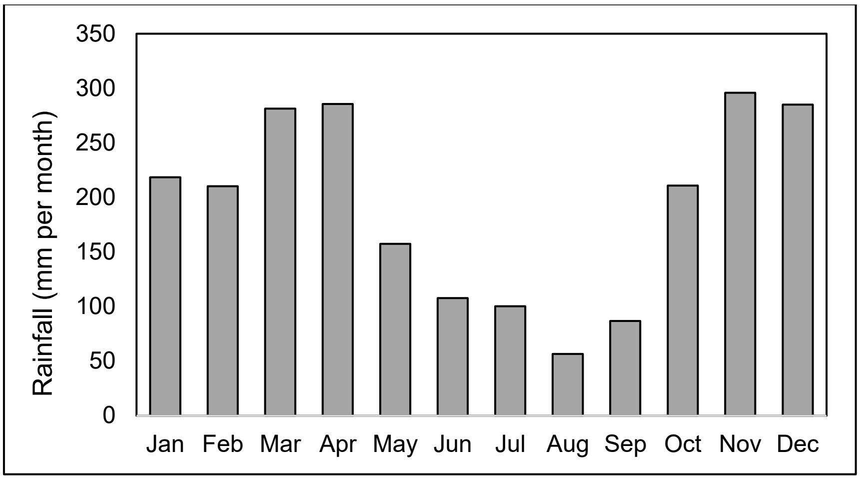

Figure 1. Fluctuation of monthly rainfall in Indonesian Rubber Research Institute, Sembawa, South Sumatera.

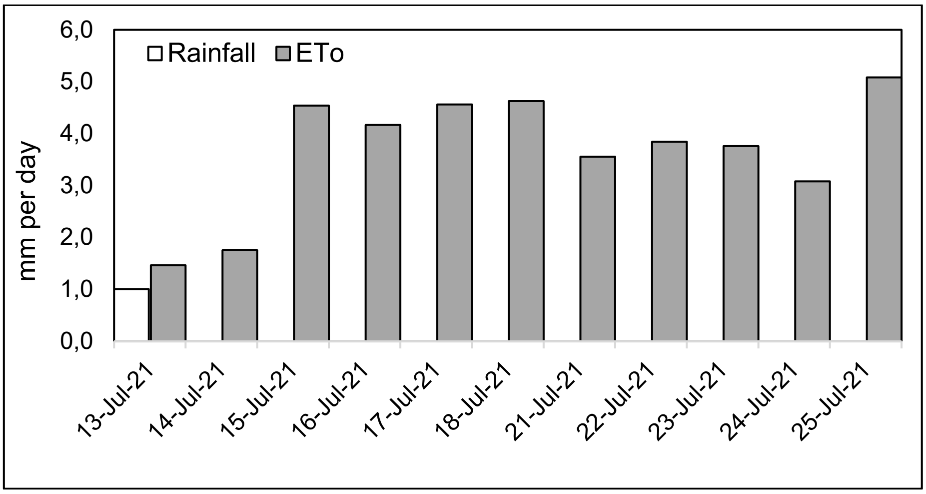

Figure 2. Reference of evapotranspiration (ETo) and rainfall (mm per day) in July 2021

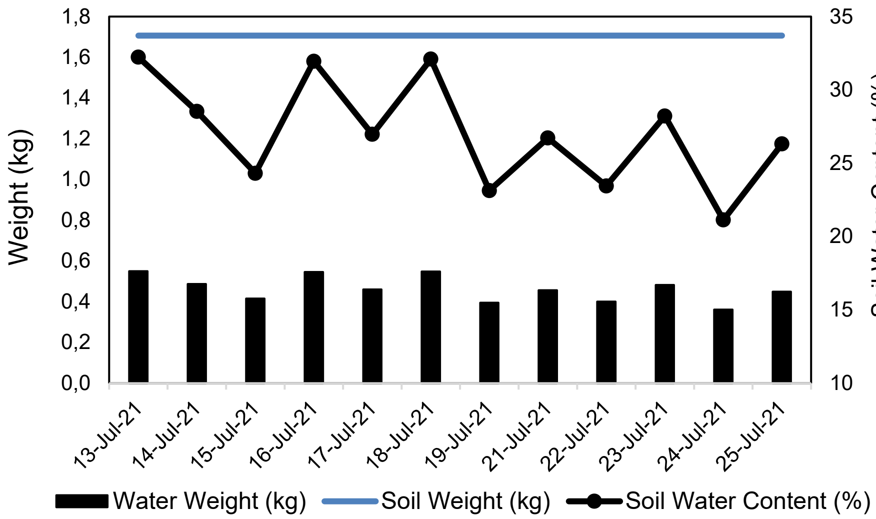

Figure 3. Fluctuation of soil water content of soil planting medium in the polybags

18.5% and the field capacity was about 33.7% (Ardika and Cahyo, 2020; Cahyo et al., 2020; Stevanus et al., 2017). Hence, the soil moisture content in this research was maintained in between 18.5 and 33.7%. The fluctuation of daily soil water content of the soil inside the polybags is presented in Figure 3.

Figure 3 shows that soil water content was maintained above permanent wilting point (18.5%), hence the ETc was maintained at normal rate. If the soil was too dry, the ETc would have dropped due to the decrease in evaporation rate. Evaporation reduces as the soil dries out (Weiss et al., 2021).

In this study, the plant water requirement was equal to the amount of ETc added by the rainfall. Daily ETc was equal to the difference of the polybag plant material weight at day n and day n+1. The weight of the polybag was observed when soil water content was in available level for the plant. The weight loss was the amount of water loss due to ETc or equal to plant water requirement. The results of the plant water requirement calculation are presented in Table 1.

Table 1 shows that the average of plant water requirement for a one-whorl rubber polybag planting material was 92.21 mL per day per polybag. The plant water requirements for all three clones were not significantly different. It indicates that in the nursery, the irrigation can be adjusted at uniform rate for all three rubber clones. The amount of plant water requirement (92.21 mL per day per polybag) was only applied to a one-whorl rubber plant. In this research the average leaf area for a one-whorl rubber planting material was 834.16 cm^2. For 6-month-old rubber planting materials with two-leaf whorls, the leaf area is estimated to be twice than the above value. Therefore, the plant water requirement for two-whorl rubber plant is also estimated to be double (around

Table 1. Plant water requirement (ETc) of three different rubber clones (mL per day per polybag)

Clone	ETc (mL per day per polybag)					Average
	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	
"PB 260"	80.81	89.94	108.17	93.31	88.44	92.13^{ns}
"IRR 112"	90.03	99.99	92.71	97.58	87.12	93.49^{ns}
"RRIC 100"	87.62	107.35	83.12	96.44	80.58	91.02^{ns}
Average	86.15	99.09	94.67	95.78	85.38	92.21

Note: Values followed by ns were not significantly different according to DMRT at α = 0.05. Rep. = replicate

Table 2. Plant water requirement (ETc) of three different rubber clones (mm per day)

Clone	ETc (mm per day)					Average
	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	
"PB 260"	0.89	0.57	0.97	1.07	0.82	0.86^{b}
"IRR 112"	0.97	1.28	1.14	1.02	1.17	1.12^{a}
"RRIC 100"	1.04	1.40	1.03	1.06	1.15	1.14^{a}
Average	0.97	1.08	1.05	1.05	1.05	1.04

Note: Values followed by different letter were significantly different according to DMRT at α = 0.05. Rep. = replicate

180 mL per day per polybag) compared to that of one-whorl rubber plant.

The results of the calculation for one-whorl rubber plant material water requirement in this study can also be used to determine crop coefficient of the 3-month-old one whorl rubber young tree by dividing ETc by ETo. ETo data was generated from Class A Evaporation Pan data (EPan) available at the Indonesian Rubber Research Institute. Considering the position of the evaporation pan and the average wind speed, as well as the relative humidity, the pan coefficient (kp) used in this study was 0.85 (Savva and Frenken, 2002). The unit of ETo generated from EPan data was mm per day, hence the ETc data in this research should be converted from mL per day per polybag to mm per day.

ETc is the water loss by soil surface (evaporation) and by plants (transpiration) (Allen et al., 1998; Weiss et al., 2021), hence to convert ETc unit from mL per day per polybag to mm per day, the volume of water loss should be divided by the surface area of soil and plants leaves. The average of total evapotranspiration area (surface area of soil and plants leaves) obtained in this study was 892.73 cm^2. The results of calculation of ETc in mm per day are presented in Table 2.

Table 2 shows that although the volume of plant water requirements of all clones was not significantly different, the ETc in mm per day of clone "PB 260" was significantly lower than clone "IRR 112" and "RRIC 100". The differences in the volume of water requirement can be attributed to the leaf area of "PB 260" which was relatively wider than "IRR 112" and "RRIC 100". The relatively similar ETc (expressed in mL per day per polybag) resulted in lower ETc in mm per day for clone "PB 260".

Based on daily ETc and ETo data, kc can be determined. The results of kc calculation are presented in Table 3.

Table 3 shows that the average kc of the three rubber clones were 0.32. Furthermore, the kc values among three rubber clones were not significantly different. This value was far lower than the kc values stated by Savva and Frenken (2002), namely 0.95 for initial stage and 1.00 for middle and end stage of rubber tree lifespan. The low kc value in this study could be attributed to the sparsely arrangement of 3-month-old rubber plants in the nursery. On the contrary, the high kc stated by (Savva and Frenken, 2002) were generated from rubber tree planted on the ground.

We planted one-whorl rubber planting materials in polybags to give reference to the producers of rubber plant materials on how much they should provide water for their nursery based on ETc calculation using determined kc for rubber planting materials and ETo data from climatological station. The unit of the result of this calculation is mm per day, hence to give sufficient water into the polybag, the ETc should be converted from mm per day to mL per day per polybag by multiplying the ETc to the sum of evaporation and transpiration area (approximation of leaves and soil surface area). For larger plants with denser canopy, the ETc and kc would need to be increased; mature

Table 3. Crop coefficient (kc) of three different rubber clones

Clone	Kc					Average
	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	
“PB 260”	0.29	0.18	0.30	0.35	0.27	0.28^{ns}
“IRR 112”	0.29	0.39	0.34	0.31	0.35	0.34^{ns}
“RRIC 100”	0.33	0.43	0.30	0.33	0.35	0.35^{ns}
Average	0.31	0.33	0.31	0.33	0.32	0.32

Note: Values followed by ns were not significantly different according to DMRT at α = 0.05. Rep. = replicate

rubber trees usually have a kc of 1.00.

Conclusion

Water requirement should be determined accurately to avoid drought stress, as well as to avoid excess water given to the plant to achieve optimum water use efficiency. To determine plant water requirement, ETc can be estimated using ETo from climatological station and determined kc for rubber planting material. Our study has determined that the plant water requirement for 3-month-old one whorl young rubber tree is 92.21 mL per day per polybag This amount of water requirement can be changed based on the change of ETo value and the size of the plant. In addition, our study has determined that the kc value for one whorl young rubber tree in polybag size of 13 cm x 35 cm was 0.32.

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