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Influence of Irrigation Systems on the Plant Growth and Leaf Ratio Analyses of Rubber (*Hevea brasiliensis*) Seedlings

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ABSTRACT

The sprinkler irrigation system is the most widely used system for rubber irrigation in a nursery. However, the method is associated with high water loss during irrigation. In view of this, an experiment was conducted to assess the effect of different irrigation systems on the growth dynamics, leaf ratio analyses, water productivity, and water use efficiency of rubber seedlings. The treatments were the irrigation systems; soil + overhead sprinkler (CON), growing media (GM) + drip irrigation (DRP), GM + capillary wick system (WCK), and GM + overhead sprinkler (SPR). Each treatment was replicated three times, and the experiment was laid out in a randomized complete block design. The results showed that the DRP and WCK had significantly ($p<0.05$) higher seedlings' growth parameters by 15–39% than obtained in the SPR and CON. However, the DRP, WCK, and SPR had statistically comparable seedlings' root length and volume by 14–43% higher relative to the CON. Similar trends of plant growth dynamics, such as crop growth rate (CGR), leaf area index (LAI), and leaf ratio analyses, were observed for all treatments. However, the CON had lower CGR and LAI, which could be attributed to the lower water retention of the soil used in the treatment. The DRP and WCK had comparable water productivity with 56–60% higher than the SPR and CON treatments. The sprinkler irrigation treatments (SPR and CON) had 84% lower water use efficiency than the DRP and WCK. The DRP and WCK are the best treatments in this study because their higher water application uniformity led to higher seedlings' growth dynamics

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and water productivity. The sprinkler system had higher water loss due to the lack of application uniformity, leading to lower plant growth than other irrigations. However, the SPR shows the potential to be more cost-effective due to its lower recurrent cost of labor than drip and wick irrigation.

Keywords: Drip irrigation, growing media, sprinkler irrigation, water productivity, wick irrigation

INTRODUCTION

Rubber is produced in over 10.3 million hectares globally, and 93% of its extent comes from the Asian region (Nair, 2021). The increase in rubber production is necessary to face high latex demand worldwide (Nair, 2021). Latex production lies in developing and distributing early maturing seedlings, disease free and vigorous, which could guarantee a high field survival rate (Nabayi, 2016). Rubber seedlings are typically raised in nurseries, where they go through desired manipulations for a high field survival rate which is the basis for high latex yield (Waizah et al., 2011). Therefore, choosing an efficient and uniform water distribution irrigation method that ensures constant moisture in the root zones of rubber seedlings would lead to higher latex yield after field transplanting.

In Malaysia, there are no options for raising rubber seedlings in the nursery other than the conventional soil-polybag system (Nabayi, 2016). In the conventional soil polybag method, labor accounts for more than 80% of the total cost associated with rubber production in the nursery (Nabayi et al., 2020). The use of compost as a soil substitute to raise rubber seedlings has recently been practiced (Salisu et al., 2013). Many potting mixes and root trainers are being introduced to replace the soil-polybag system of seedlings' growth (Nabayi et al., 2018). The introduction of the growing media should result in several advantages, including lighter weight and compact structure that makes it eco-friendly as the container used with the growing media can be recycled, improved root growth, and reduced labor because of its design that makes it relatively easier to handle than polybag. In contrast, using a soil polybag system requires much space because the polybag cannot be recycled (Bunt, 1988).

Water shortages affect cell differentiation and enlargement, which determines plant growth (Cabuslay et al., 2002; Correia et al., 2001). Furthermore, a lack of uniform water distribution around the roots of plants restricts plant growth by inhibiting biochemical and physiological processes, which include photosynthesis, respiration, translocation, nutrients uptake, and carbohydrate metabolism (Bhatt & Rao, 2005; Chaitanya et al., 2003). Therefore, water shortage is the most critical environmental factor affecting crop productivity (Raj et al., 2005). It reduces the amount of water available to plants in the soil, which leads to lower plant growth and yield (da Silva et al., 2013). Several studies (Dey & Vijayakumar, 2005; Sumesh et al., 2011; Thomas et al., 2015) reported that subjecting young rubber seedlings to a prolonged water shortage decrease growth and physiological attributes, chlorophyll instability, and suppresses photosynthesis.

Water is the most dynamic and limiting environmental factor impacting plant productivity. Warm temperatures, sunlight, nutrients, and water are all required for crops to thrive. Temperature and sunlight are available in various parts of the planet; however, water is deficient (Nabayi, 2016). All plants require an optimum amount of water to grow and a maximum amount for maximum yield (Field & Long, 2018). Sprinkler irrigation, drip irrigation, and capillary wick irrigation are alternative water application technologies that can help optimize water use in agriculture and increase irrigation efficiency (Heydari, 2014). Sprinkler irrigation systems are popular because they are inexpensive to install, but they waste much water from the usual over- and under-watering plants due to their lack of water application uniformity (Nabayi, 2016). Drip irrigation saves water since less water is lost in the application process, and water is delivered directly to the plant (Maya et al., 2014). Another water-saving technique is the capillary wick irrigation system, which uses the capillary action of the wick to slowly deliver water to the plant roots (Bainbridge, 2002). The problem of low crop productivity can be overcome with the aid of a proper irrigation system. Climate change, water scarcity, and population growth have all increased efforts to find new techniques to save water for irrigating crops, the world's largest water user (Field & Long, 2018). Therefore, the objectives of this study were to ascertain (1) the effect of different irrigation systems on the growth dynamics and leaf ratio analyses of rubber seedlings and (2) the effect of different irrigation systems on water productivity and water use efficiency of the rubber seedlings.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in a rain shelter facility (2°59'05.0"N 101°44'00.9"E), Agrobio Complex, Faculty of Agriculture, Universiti Putra Malaysia (UPM), from December 2014 to July 2015. A mini weather station (WatchDog 2000 series, Spectrum Technology Inc., USA) was installed to monitor the environmental conditions in the rain shelter. BX-1 growing media (GM) (Humibox Sdn. Berhad, Malaysia) was used as the potting mix, and Rb900 (Figure 1) root trainer was used as the growing container for overhead sprinkler (SPR), drip (DRP), and capillary wick

Figure 1. Rb900 Root trainer

(WCK) treatments based on its design and suitability as previously reported by Nabayi et al. (2016), which allows plant roots to grow downward and prevent spiral growth. An amount of 230 g of the fresh GM was used per root trainer in SPR, WCK, and DRP treatments, while 8 kg of Munchong soil series (Tropeptic Haplorthox) per polybag was used for CON treatment. The soil used in the CON treatment was initially treated with 25 g of powdered Christmas Island Rock Phosphate (Cilibangi, Malaysia) as a starter during transplanting into the polybag system, which was followed by a regular NPK fertilizer (N-P-K- 15-15-15 mixture) (Cilibangi, Malaysia) application as stated in Noordin (2013).

Treatments and Experimental Design

The treatments were soil + overhead sprinkler (CON), growing media (GM) + drip irrigation (DRP), GM + capillary wick system (WCK), and GM + overhead sprinkler (SPR), which were replicated three times each and laid out in a randomized complete block design. For the GM treatments (DRP, WCK, and SPR), their seedlings were transplanted in the Rb900 tube, while for the CON, the seedlings were transplanted into a polybag. The rubber seedlings were transplanted at one-month-old. One hundred and twenty (120) rubber seedlings were used in the experiment, with 10 seedlings per replication. In addition, the clone RRIM 2000 secured from MARDI (Malaysian Agricultural Research Development Institute) was used in the experiment. A daily supply of 11 mm of water was provided in the DRP, SPR, and CON irrigation systems. Before starting the experiment, the irrigation systems were calibrated to supply 11 mm water equivalent by setting the drip and sprinkler irrigation timers for 3 min 20 secs and 2 mins, respectively, in 24 hours. The basis for choosing 11 mm for the sprinkler and drip irrigation was because the wick system is self-watering irrigation, which was applied 11 mm into the seedlings container in 24 hours.

Physical and Chemical Analyses of Soil and Growing Media

CNS analyzer (LECO Corp., USA) was used to analyze the total carbon (C), nitrogen (N), and sulphur (S) of the soil and GM. Next, the leaching method was used to determine the cation exchange capacity (CEC) and exchangeable bases (Chapman, 1965), after which the exchangeable bases were assessed using atomic absorption spectrophotometer (AAS) (PerkinElmer, 5100PC, USA). Next, phosphorus (P) was determined using an auto-analyzer (AA) (Quikchem FIA 8000 series, LACHAT Instruments, Canada). Finally, the physical properties of the GM and soil were conducted as outlined in Jones (2001) (Table 1).

Plant Growth Measurements

A graduated ruler was used to measure the plant height. The girth size of the seedlings was assessed using a vernier caliper. The total leaf area was measured with a leaf area meter equipment (LI-3100C Area meter, Lincoln, USA). Destructive sampling was used to measure plant growth characteristics

Table 1
Average (±SE) physical and chemical properties of the soil and growing media

Physical properties	Soil	Growing media (BX-1)
BD (g cm^{-3})	1.43±0.02	0.14±0.01
MC (g g^{-1})	0.21±0.06	0.71±0.01
Total Porosity (%)	46.0±3.10	91.0±2.01
SHC (cm hr^{-1})	8.2±0.20	32.0±0.04
Saturation (m^3 m^{-3})	0.56±0.05	0.95±0.04
Field capacity (m^3 m^{-3})	0.29±0.02	0.31±0.02
Permanent wilting point (m^3 m^{-3})	0.21±0.07	0.20±0.01
Particle size analysis		
Sand (%)	34.54±0.02	-
Silt (%)	15.23±0.01	-
Clay (%)	50.21±0.02	-
Chemical properties	**Soil**	**Growing media (BX-1)**
pH	4.67±0.30	6.40±0.90
EC (dS m^{-1})	0.04±0.002	1.22±0.03
CEC ($cmol_+kg^{-1}$)	8.32±0.10	63.21±0.40
C (%)	1.38±0.10	34.25±0.20
N (%)	0.13±0.02	1.09±0.20
C: N	10.6±0.02	27.0±0.10
S (%)	0.03±0.001	0.75±0.001
P (ppm)	8.34±1.02	680.57±8.30
K (ppm)	41.27±3.10	1779±13.21
Ca (ppm)	459.33±4.70	6223.67±17.60
Mg (ppm)	85.47±3.90	1709.33±23.70
Na (ppm)	5.43±0.30	17.93±0.92

Note. BD = Bulk density; CEC = Cation exchange capacity; MC = Moisture content; SHC = Saturated hydraulic conductivity

such as fresh and dry weight and root parameters at harvest (8th month). The plant samples were separated into different parts, i.e., roots, leaves, and shoots, and measured for both fresh and dry weight using a weighing machine (Multitech, GF-3000, Japan). The different parts of the seedlings were placed in a forced draft oven at 72 °C for 48 hours to obtain the dry weights and then measured using a weighing balance. The root analyses were done using EPSON WhinRhizo root scanner (Epson Perfection V700 Photo, Reagent Instrument Inc., Canada).

Plant Growth and Leaf Ratio Analyses

Hunt (1990) defined the plant growth analysis and leaf ratio parameters. Relative growth rate (RGR) is the efficiency index that explains an increase in plant size per unit area. It is relatively an increase in the plant's total dry weight. Crop growth rate (CGR) is an index of the productive efficiency of ground area in producing plant dry weight. Net assimilation rate (NAR) is also an index of productive plant efficiency in relation to the total leaf area. The leaf area index (LAI) is the ratio between the total leaf area and the ground area it covers. Leaf weight ratio (LWR) helps explain a plant's productive investment as it deals with relative expenditure on potentially photosynthesizing plant parts. Leaf area ratio (LAR) is the relationship between potentially respiring and potentially synthesizing organs.

Therefore, for the computation of the mean growth analyses of the rubber seedlings grown under different irrigation systems over eight months, the formula by Hunt (1990) was adopted as follows:

Mean RGR (g g^{-1} day^{-1} month^{-1}) =

$$= \left(\frac{\log_e W2 - \log_e W1}{t2 - t1}\right) \quad [1]$$

Mean CGR (g m^{-2} day^{-1}) =

$$= \left(\frac{1}{P}\right) \times \left(\frac{W2 - W1}{t2 - t1}\right) \quad [2]$$

Mean LAR (m^2 cm^{-2} g^{-1}) =

$$= \left(\frac{\frac{LA1}{W1} + \frac{LA2}{W2}}{2}\right) \quad [3]$$

Mean LWR=

$$= \left(\frac{\frac{Lw1}{W1} + \frac{Lw2}{W2}}{2}\right) \quad [4]$$

Mean LAI=

$$= \left(\frac{\frac{LA1}{P1} + \frac{LA2}{P2}}{2}\right) \quad [5]$$

Mean NAR (g m^{-2} day^{-1} month^{-1}) =

$$\left(\frac{(W2 - W1)}{(t2 - t1)} \times \frac{(\log_e LA2 - \log_e LA1)}{(LA2 - LA1)}\right) \quad [6]$$

where W is the total dry plant weight, L_A is the total leaf area, L_W is the whole leaf dry weight, log_e is the natural logarithm, P is the total ground area upon which the crop stands, and t is the time at which the samples were taken.

Water Productivity and Water Use Efficiency

Water productivity (WP) and water use efficiency (WUE) were determined based on Heydari's (2014) concept of WP (Equation 7) and WUE (Equation 8).

$$\text{WP } (\text{gL}^{-1}) = \frac{\textit{Total plant dry weight } (g)}{\textit{Cumulative transpiration } (L)} \quad [7]$$

$$\text{WUE} = \frac{\textit{Quantity of water used by the plant } (L)}{\textit{Output of the irrigation system } (L)} \quad [8]$$

The cumulative transpiration of the rubber seedlings was determined using equation 9 (water-balance equation).

$$T = I - (L + E + \Delta\theta) \quad [9]$$

where T is transpiration (mm), I is irrigation (mm), L is leaching (mm), E is evaporation (mm), and $\Delta\theta$ is the change in moisture storage (mm).

Data Analysis

All the data collected were analyzed using Minitab (version 20) for Windows

(Pennsylvania State University, USA). Analysis of variance (ANOVA) was used to determine the significant treatment effects of the measured parameters ($p<0.05$). Significant means were separated using Tukey's honestly significant difference (HSD) test at a 5% significance level.

RESULTS AND DISCUSSION

Plant Growth of Rubber Seedlings

The treatments did not differ significantly ($p>0.05$) in terms of specific leaf area, plant height, and number of leaves. However, the plant height and the number of leaves increased significantly ($p<0.01$) with time for all treatments. The rubber seedlings under WCK and DRP had significantly ($p<0.01$) higher total fresh weight, total dry weight, and shoot and root dry weights (Figure 2), which differed from the SPR and CON, that had the lowest. The WCK and DRP had a range increase in total fresh and dry weights by 14–26% and 26–36%, respectively, relative to the SPR and CON treatments. Similarly, the WCK and DRP had a range increase in seedlings' shoot and root dry weights by 15–36% and 17–36%, respectively, relative to the SPR and CON treatments. However, despite the growth of

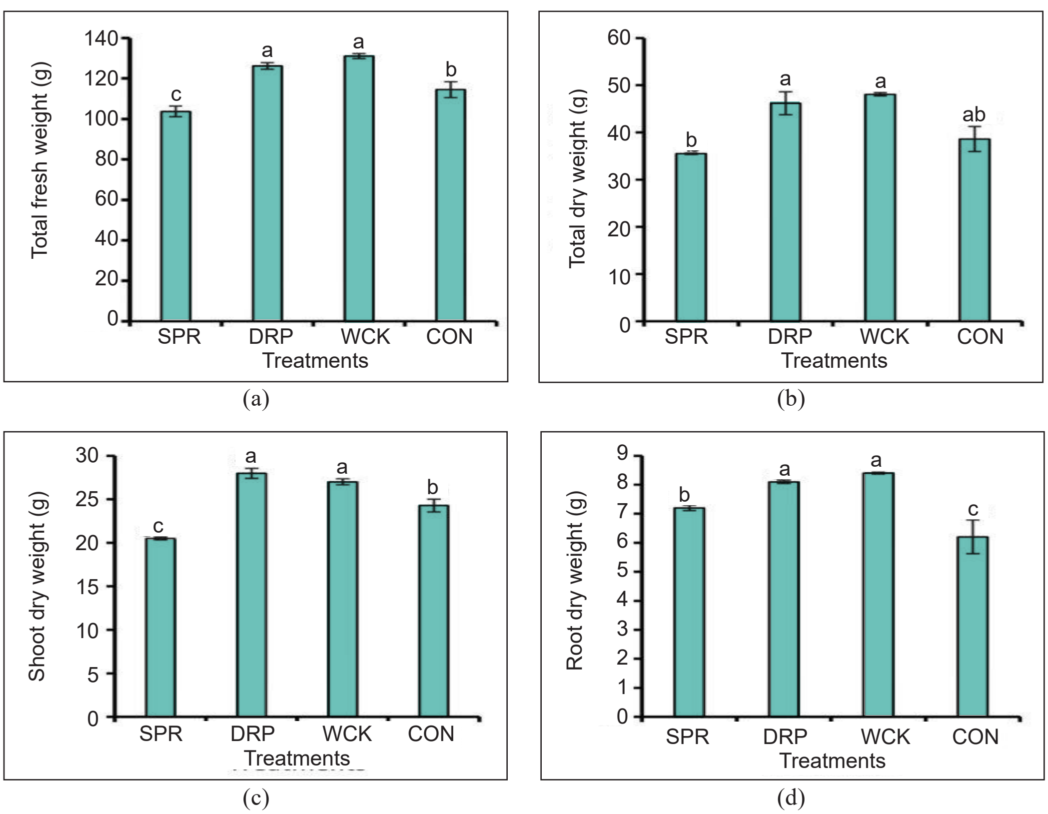

Figure 2. Means (± SE) of (a) total fresh weight, (b) total dry weight, (c) shoot dry weight, and (d) root dry weight of rubber seedlings as influenced by different irrigation systems. Means followed by different letter(s) differ significantly ($p<0.05$) from one another using Tukey's test

the statistically comparable seedlings in the SPR and CON treatments, the CON had a 20% higher shoot dry weight than the SPR treatment. In contrast, the SPR had a 13% increase in root dry weight than the CON.

The highest seedlings' total fresh and dry weights, shoot and root dry weights recorded in WCK and DRP systems could be attributed to the efficiency of the irrigation systems to supply the water uniformly in the root zone of the seedlings, as opposed to the SPR and CON that were both irrigated using a sprinkler. Nabayi et al. (2018) reported higher seedlings' growth parameters in drip and wick irrigation systems, which they attributed to the systems' moisture availability, as water is applied slowly into the root zones of the seedlings. Parameters, such as plant water-absorption patterns, are influenced by irrigation systems, which ultimately affect plant growth (Argo & Biernbaum, 1994). Drip irrigation is critical in sustaining crop productivity and minimizing water use in agriculture (El-Hendawy et al., 2008). The lower seedlings' growth parameters obtained in the SPR system and CON could be due to the lack of sufficient moisture because of the non-uniform water distribution of the overhead sprinkler which applies more water outside than inside the growing containers. Westervelt (2003) stated that lack of irrigation uniformity causes water loss, which means more water is needed to supply the required amount.

The WCK had a range increase in leaves dry weight by 20–39% higher than the other treatments (Figure 3). The WCK and DRP had 21–26% higher total leaf area than the SPR and CON. Water and sunlight determine dry matter accumulation, which could be the reason for the higher leaves and root dry weight in the WCK and DRP treatments. Aydinsakir et al. (2013) reported higher total plant dry weight in 100% soil water application than in the 75%, 50%, and 25% applications. Heydari (2014) claimed that drip irrigation is the most effective system than sprinkler because of its excellent water use efficiency. Water application efficiency in drip systems approaches 100%, with 30–50% water savings compared to other irrigation methods (Ozsan et al., 1983). Rivera et al. (2009) reported a decrease in yield and biomass components of corn due to the lack of sufficient moisture in the crop root zone. Many studies have found irrigation types, regardless of source and nutrient solution, to impact nursery seedlings' growth (Argo & Biernbaum, 1994). The lower seedlings' girth size obtained in the SPR and CON could be attributed to the lack of sufficient moisture distribution into the seedlings growing container, which agrees with Çakir (2004), who reported a decrease in corn plant girth size due to a lack of moisture uniformity around the root zone of the plant.

At harvest, the seedlings in CON had the highest shoot-to-root ratio of 5.26, which did not differ significantly ($p>0.05$) from those raised in WCK (4.73) and DRP (4.7) systems (Figure 3d). However, the three systems differed significantly ($p<0.05$) from the SPR system, which had the lowest seedlings' shoot-to-root ratio with 3.92. An increase in the shoot-

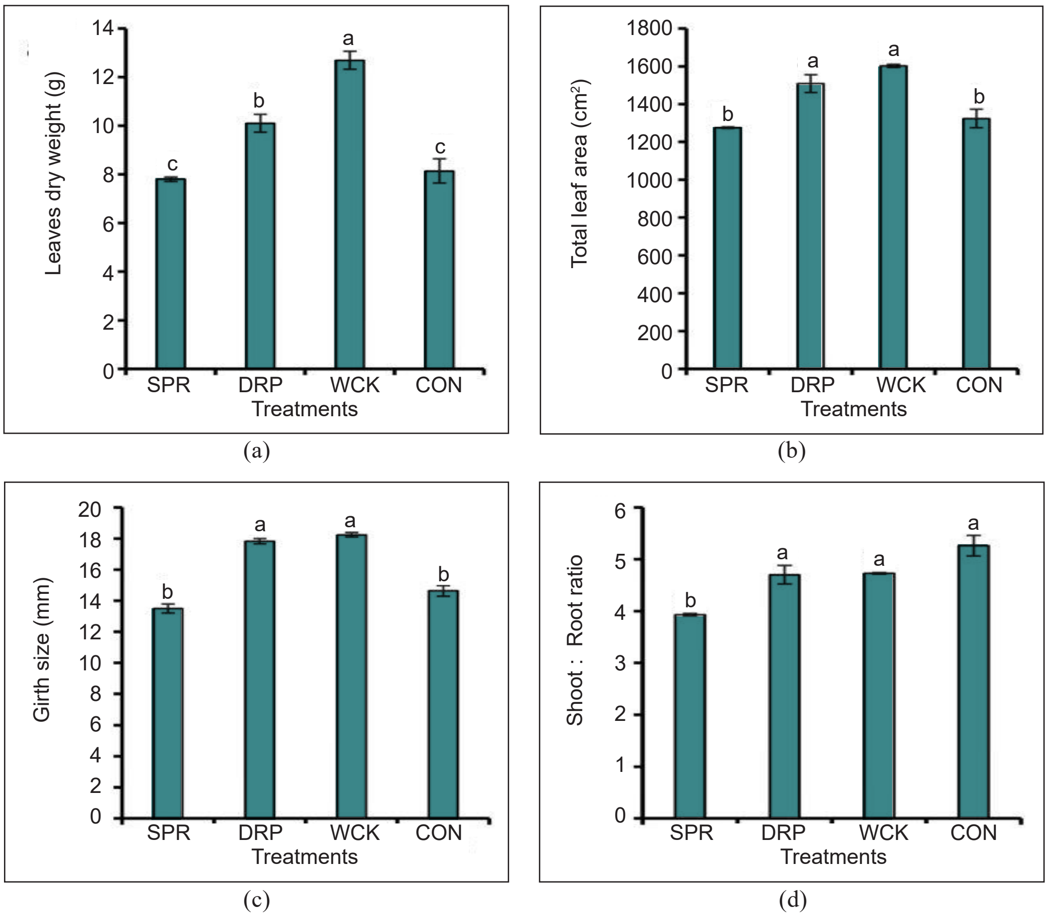

Figure 3. Means (± SE) of (a) leaves dry weight, (b) total leaf area, (c) shoot to root ratio, and (d) girth size of rubber seedlings as influenced by different irrigation systems. Means followed by a different letter(s) differ significantly (p<0.05) from one another using Tukey's test

to-root ratio signifies a higher priority for photosynthate accumulation in shoots than roots. Conversely, if shoot-to-root ratios decrease with time, roots have preferential utilization of photosynthate under the present plant growing conditions (dos Santos et al., 2007; Franco et al., 2006). The lower shoot-to-root ratios in the SPR was because of the moisture shortages between irrigation intervals in the system as the system applied more water outside the opening area of the seedlings' container (Abba et al., 2015; Nabayi et al., 2018). Dos Santos et al. (2007) explained that a higher shoot-to-root ratio indicates a lack of moisture deficit. Furthermore, Mackay and Barber (1985) stated that water and N deficiencies are the most limiting factors for shoot growth.

Root Growth Parameters of Rubber Seedlings

The DRP, WCK, and SPR had a range increase in seedlings' root length and root volume by 32–43% and 14–34%, respectively, which differed significantly ($p<0.05$) from those raised in CON treatment (Figure 4). However, the highest root surface area was observed in DRP and WCK treatments with 12–22% higher than the SPR. The result showed that GM treatments (SPR, DRP, and WCK) had better root lengths than the CON, which could be attributed to the influence of the Rb900 root trainer because of its design. The Rb900 encourages the roots to grow vertically without restricting the roots (Nabayi et al., 2020), unlike in the CON, where the vertical growth is restricted by the polybag, which in turn could affect the water and nutrients uptake. Vertical root growth leads to a better root system with intact root tips and fewer or no circling roots (Salisu et al., 2018). Higher root growth parameters in the SPR, DRP, and WCK could also be due to the light weight of the media, which encouraged the continuous growth of the root as compared to the soil. In addition, containers with internal ridges

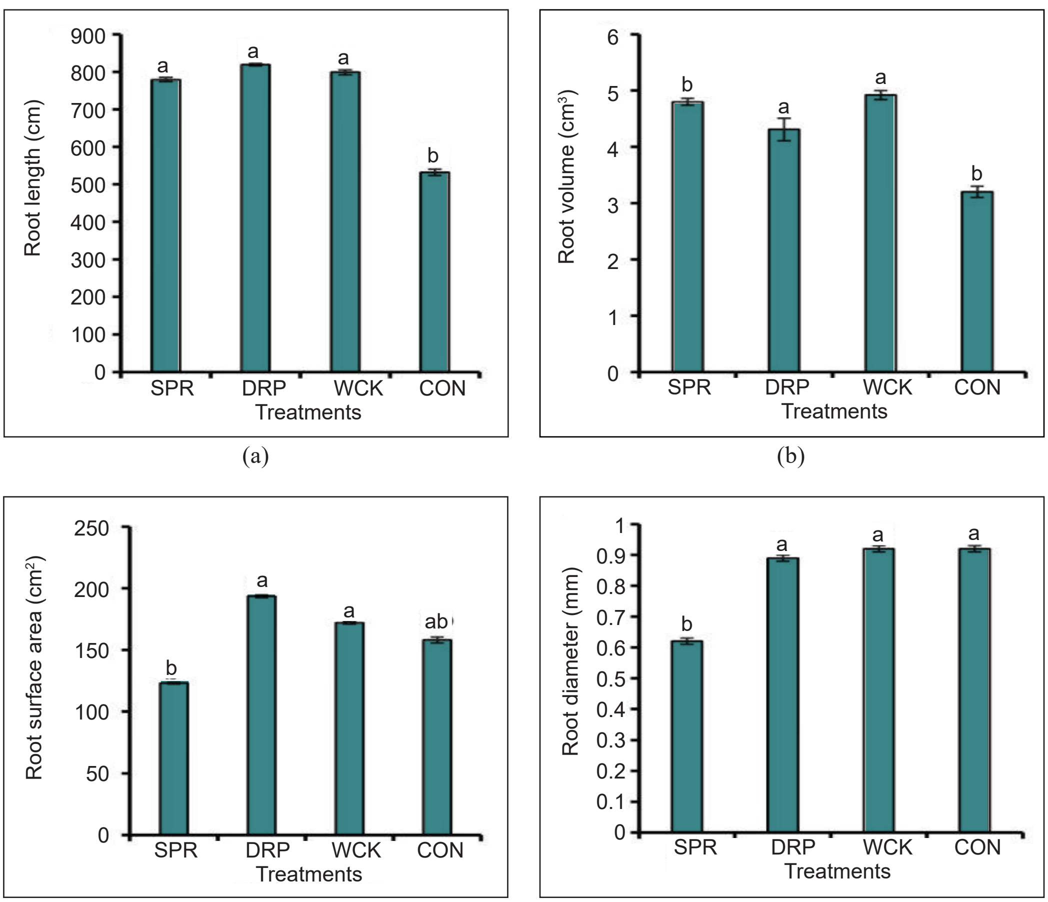

Figure 4. Means (± SE) of (a) root length, (b) root volume, (c) root surface area, and (d) root diameter of rubber seedlings as influenced by different irrigation systems. Means followed by a different letter(s) differ significantly ($p<0.05$) from one another using Tukey's test

were designed to limit root circling in container-grown seedlings (Stromberger, 2002), as root cycling could lead to stunted plant growth. Root length and surface area are important indicators for a potential uptake of water and nutrients.

The growing media have greater nutrient availability and can store more water than the soil under the CON treatment. Choosing a proper growing medium is one of the vital considerations in nursery plant production (Bunt, 1988). Generally, the root morphology of the seedlings raised in root trainers differs from those grown in the polybags (Salisu et al., 2018). The vertical root growth restriction of seedings in CON led to the production of thicker roots in the system (0.92 mm) compared with other treatments. Root restrictions can lead to a reduction in primary roots and an increase in lateral roots, which could all result from the type of container used (Salisu et al., 2018). When moisture is available, root restriction can mimic soil moisture stress (Krizek et al., 1985).

Growth Dynamics and Leaf Ratios Analyses of Rubber Seedlings

The RGR decreased with time, irrespective of the treatments, as the highest and lowest were recorded in the experiment's first and eighth months (Figure 5). However, the NAR increased in all treatments until the third month and remained constant until the eighth month. On the other hand, the LAR and LWR exhibited a similar pattern which increased initially and then declined as time progressed, irrespective of the treatments. Leaf area index (LAI) and CGR trends increased from month 1 to month 8, with higher LAI and CGR in the SPR, DRP, and WCK while the lowest in the CON throughout the months.

Higher RGR in the first month could indicate an efficient utilization of the dry matter by the photosynthetic organs (leaf and stem). The decrease in RGR with time could be associated with the higher leaf defoliation because of the temperature rise (Table 2). Higher NAR was mostly observed in DRP, which indicated its effectiveness toward higher leaves dry weight production, which agrees with our earlier findings (Nabayi et al., 2018). The mean RGR and NAR trends agree with Vijayakumar et al. (1998), who stated that enhanced plant growth dynamics parameters are linked to plant water availability. The WCK had the highest LWR in the eighth month due to the treatment's significantly higher leaves dry weight in the month (Figure 3a). The highest LAI and CGR in the DRP, SPR, and WCK were because of their significantly ($p<0.05$) higher total leaf area (Figure 3b), and it could also be due to the smaller opening area of the growing containers used being the two factors that determine LAI. The increase in LAI with time agrees with Wolf and Carson (1973), who reported that higher LAI in plants indicates plant capability in dry matter accumulation in the non-photosynthetic plant parts (i.e., roots). Similarly, the CGR, LAI, and NAR results observed in this study agree with the trends reported by Hunt (1990), who stated that a decrease in NAR leads to an increase in CGR and LAI of a crop.

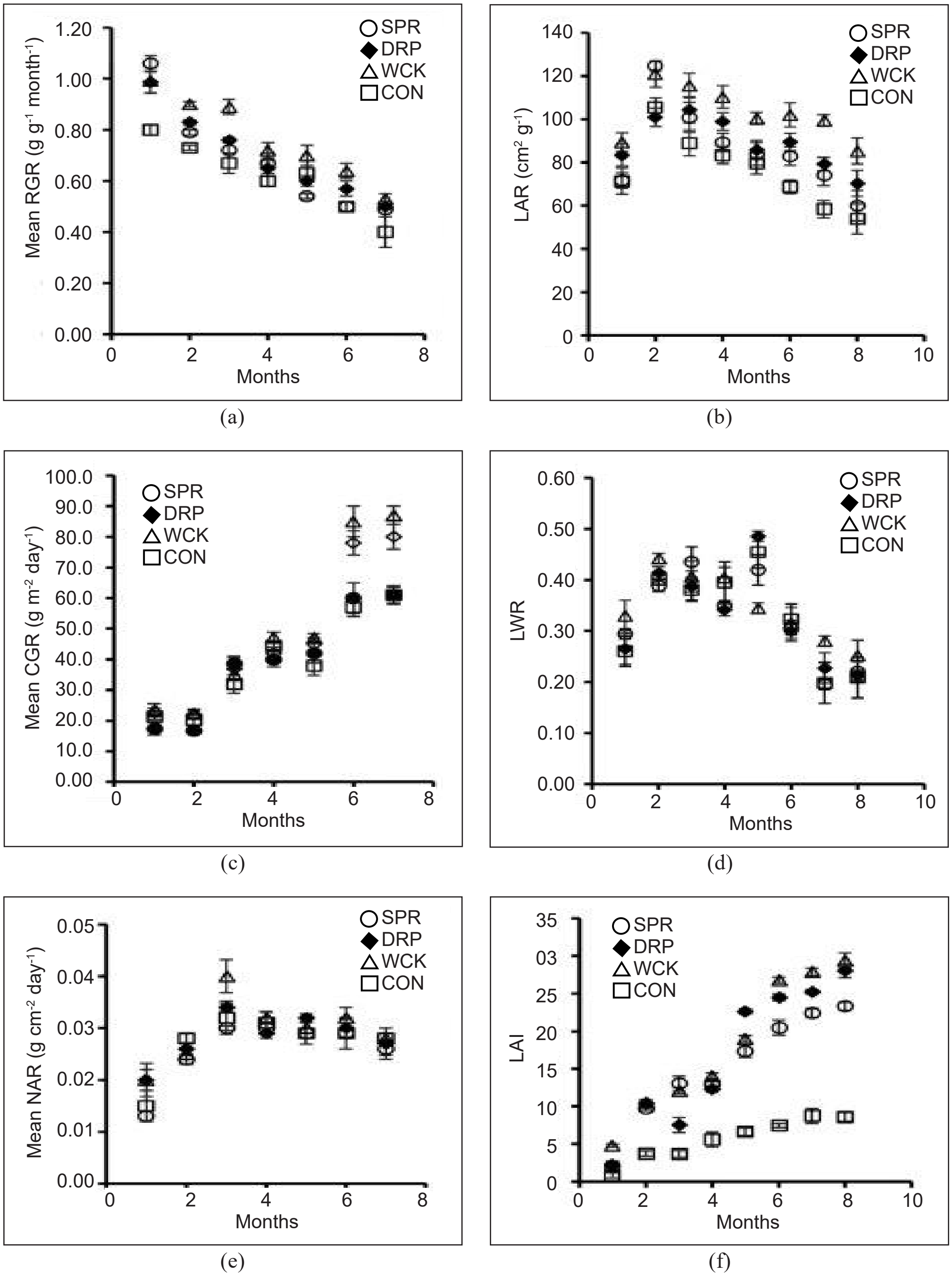

Figure 5. Means of (a) RGR, (b) LAR, (c) CGR, (d) LWR, (e) NAR, and (f) LAI of rubber seedlings as influenced by different irrigation systems in 8 months period

Note. RGR = Relative growth rate; CGR = Crop growth rate; NAR = Net assimilation rate; LAR = Leaf area ratio; LWR = Leaf weight ratio; LAI = Leaf area index

Table 2
Means of environmental factors in the rain shelter under which the seedlings grew. Values in brackets are the minimum to maximum recorded range

Month	Temperature (^{o}C)	Relative humidity (%)	Solar radiation (MJ m^{-2} day^{-1})
Dec	26.5 (22–35)	82.5 (36–100)	2.2
Jan	26.9 (21–33)	71.6 (25–98)	2.9
Feb	27.8 (20–36)	64.5 (24–95)	3.2
Mar	27.7 (22–37)	71.8 (29–97)	3.3
Apr	27.9 (23–37)	74.3 (30–99)	3.4
May	28.0 (23–36)	73.8 (38–97)	2.9
Jun	27.9 (23–35)	73.4 (27–95)	2.6
Jul	29.8 (23–37)	83.4 (28–95)	2.7

Water Productivity and Water Use Efficiency

The seedlings raised in DRP and WCK had statistically comparable (p>0.05) WP, but they differed significantly (p<0.05) in terms of WUE (Table 3). The seedlings raised in WCK and DRP had a range increase in WP by 56-60% higher than the SPR and CON. However, higher plant WUE was observed in WCK, which differed significantly (p<0.05) from other treatments. The seedlings grown in WCK recorded 19% higher WUE than those grown in DRP. On the other hand, both the WCK and DRP treatments had more than 100% higher WUE than the SPR and CON. The significantly lower WP and WUE in SPR and CON seedlings could be attributed to overhead sprinkler irrigation in both treatments. Water productivity is the amount of biomass produced per unit amount consumed. Higher WP of seedlings in DRP and WCK could also be due to lower leaching of N and K in the treatments: the higher the number of nutrients removed, the lower the available nutrients for plant use. The N and K are the two most important elements required by a rubber plant for proper growth and development (Noordin, 2013). The result agrees with Teh et al. (2015), who reported higher WP in water spinach using a wick irrigation system. Higher water use efficiency indicates higher water utilization in relation to the quantity of water supplied. The WUE is one of the most important parameters for determining optimal water management practices (Kharrou et al., 2011). The lowest WUE of seedlings in SPR treatment was due to the overhead sprinkler's lack of uniformity and

Table 3
Means (±SE) of water productivity and water use efficiency of different irrigation systems at month 8

Treatments	WP (g L^{-1})	WUE (L L^{-1})
DRP	26.0 ± 1.21a	0.64 ± 0.03b
WCK	27.1 ± 0.97a	0.76 ± 0.05a
SPR	17.3 ± 0.27b	0.11 ± 0.01b
CON	16.9 ± 0.82b	0.10 ± 0.01b

Note. WP = Water productivity; WUE = Water use efficiency; DRP = Drip irrigation; WCK = Wick irrigation; SPR = Sprinkler irrigation; CON = Control. Means with the same letter within the same column did not differ significantly from one another using Tukey at a 5% level efficiency, which ended up applying more water outside the plant containers.

To supply 11 mm into the seedlings' containers in SPR and CON treatments using a sprinkler, the system lost about 100 L in the process due to the container size, leaf interception, and lack of uniformity of the overhead sprinkler. Therefore, the sprinkler system lost up to 91%, unlike in the DRP and WCK, where water is only lost through leaching and evaporation from the seedlings' container. Bryant and Yeager (2002) reported that wick irrigation compared with overhead irrigation reduces cumulative irrigation volume by 86% without sacrificing plant growth. In addition, the drip and wick saved more than 90% of water during application relative to the overhead sprinkler irrigation. Therefore, the higher application uniformity, efficiency, and minimal water loss during application in the DRP and WCK led to the higher WP and WUE in their seedlings relative to the seedlings raised using overhead sprinklers as in SPR and CON treatments.

In this study, the sprinkler had a higher initial cost than the drip and wick irrigation systems by 25% and 92%, respectively (Table 4). Furthermore, including the cost of water would make the sprinkler irrigation system more expensive, particularly in water scarcity areas where water is costly. However, sprinklers are preferable for industries, where rubber seedlings are produced in bulk. It would be more cost-efficient because the uniformity of the irrigation system would increase with a higher number of seedlings to irrigate. In addition, the cost of using sprinklers would reduce significantly with time as opposed

Table 4
Cost of components used for the irrigation systems installation as of 6 Jan 2016

Components	Quantity	Unit price (RM)	Total price (RM)[1]
Overhead sprinkler			
Irrigation kits	1	86.8	86.8
Timer	1	45.9	45.9
Cost of installation		60	60
Total cost			192.7
Drip			
Irrigation kits	1	47.9	47.9
Timer	1	45.9	45.9
Cost of installation		60	60
Total cost			153.8
Wick			
Wick	1 roll	27.6	27.6
PVC tube	6 feet	5.5	33
Cost of preparation		40	40
Total cost			100.6

Note. [1]RM1 is approximate USD0.24

to drip and wick irrigation, which have a recurrent labor cost. Although the overhead sprinkler had a higher initial cost in this study, which could be compounded in areas with a higher cost of water, for an extended study period, i.e., more than a year, the use of the sprinkler shows the potential to be more cost-effective due to its lower recurrent labor cost.

CONCLUSION

Sprinkler irrigation system as the conventional system of rubber irrigation in the nursery, is associated with non-uniform water distribution, which impacts the growth dynamics, leaf ratio analyses, water productivity, and use efficiency of the rubber seedlings. Higher fresh and dry weight, total leaf area, girth size, and the shoot-to-root ratio of the seedlings at the end of the experiment were recorded in the DRP and WCK irrigation by 20–30% higher relative to the SPR and CON. It was mainly because of the treatments' uniform moisture distribution and availability compared to the overhead sprinkler. The DRP and WCK had 56–60% higher seedlings' water productivity than those grown in SPR and CON treatments. On the other hand, the use of overhead sprinkler irrigation in SPR and CON had 90% higher water lost during application due to the leaf interception and lack of uniformity that led to high water application outside the seedlings' containers as compared to DRP and WCK that apply water slowly into the vicinity of the seedlings' root. All the treatments followed similar trends for the leaf ratio analyses; however, the CON had significantly lower leaf ratio analyses than the other treatments. Therefore, the study recommends using water-saving irrigation systems (DRP and WCK) for raising rubber seedlings in the nursery in small-scale production. However, for large-scale production, the use of overhead sprinkler irrigation shows the potential to be more cost-effective because of the lower recurrent labor cost involved in the system compared to drip and wick irrigation systems.

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DECLARATION OF CONFLICT OF INTERESTS

The authors have no conflict of interest.

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