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Plant Growth, Nutrient Content and Water Use of Rubber (*Hevea brasiliensis*) Seedlings Grown using Root Trainers and Different Irrigation Systems

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ABSTRACT

Rubber seedlings raised in the soil-polybag system experience root coiling and restriction and the overhead sprinkler results in much water wastage. The objective of the study was to determine the influence of root trainers and three irrigation systems on rubber seedlings grown in a peat-based medium. The irrigation systems were the overhead sprinkler (SPR), drip (DRP) and capillary wick (WCK). The fourth treatment was the control (CTRL), which required growing rubber seedlings in conventional soil-polybags that were then irrigated using the wick system. The treatments were compared with one another in terms of their influence on nutrient loss, crop water productivity and water use efficiency, plant growth parameters and plant nutrient content of the rubber seedlings. A field experiment was carried out in a rain shelter for eight months, and data collection was carried out once per month. The experimental layout was the completely randomised block design. The results showed that WCK had the lowest cumulative leachate volume and the least cumulative nutrients leached. Both DRP and WCK had the highest plant growth parameters such as total fresh and dry weight, total leaf area and girth size, water productivity and leaf nutrient content. WCK was the best irrigation system together with the peat-based growing medium for raising rubber nursery seedlings.

Keywords: Irrigation, capillary, wick, *Hevea brasiliensis*, rubber, water use, water productivity

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INTRODUCTION

The foundation for high latex production lies in the production of seedlings that are disease-free and quick to mature and that have a high field survival rate. This can be achieved by proper soil fertility management in the nursery where these seedlings are grown (Waizah et al., 2011). Rubber nurseries in the past were established mostly in newly cleared forests, which are quite rich in plant nutrients. Today, however, existing forests are protected and fertile land areas are converted to industrial use. Thus, new rubber plantations are now limited to marginal (less fertile) land (Waizah et al., 2011).

The conventional system of raising rubber seedlings in Malaysia uses the soil-polybag and the sprinkler irrigation system. The sprinkler irrigation system is common because it is cheap to install, but this system suffers from high water wastage, among other disadvantages. Lienth (1996) stated that it is difficult to irrigate a crop without over-watering and under-watering some plants. Some of the water will miss the crop altogether and fall to the ground, increasing nutrient runoff. Westervelt (2003) stated that the lack of irrigation uniformity means more water is needed to irrigate crops.

The drip system is a much better water-saving irrigation system with higher water use efficiency, but it is more expensive to install. In this system, less water is lost during application because the water is applied directly to the immediate vicinity of the plant, thus saving water (Maya et al., 2014). It has the highest uniformity (90%) in water applied to plants, yet the system could have problems that lead to poor uniformity such as low pressure inlet and clogging of the emitters (Hsiao et al., 2007).

Capillary wick irrigation system is another water-saving irrigation system where water is supplied slowly to the plant roots via the capillary action of the wick (Bainbridge, 2002) (Figure 1). The wick is usually made of an absorbing material such as cotton that will draw the water out of a water container and into the soil, thus watering the soil and plant. This system is also much cheaper to install. Capillary wick irrigation was first introduced in India, where it was used in conjunction with buried clay pot irrigation (Bainbridge, 2001). The wick system is used in areas of high evapotranspiration, such as tropical and sub-tropical countries (Ritchey & Fox, 1974). The use of wick irrigation has been demonstrated to work well in raising seedlings of perennial crops e.g. citrus (Bainbridge, 2002). The method is also useful because of its ability to maintain soil moisture (Marrone 1982; Stalder & Pestermer, 1980).

Water application methods influence the growth of nursery seedlings differently (Argo & Biernbaum, 1994). The idea of nursery irrigation is to maintain the pores filled with air and water to minimise moisture stress. However, water shortage during plant nursery growth in the container may negatively affect nutrient reserves in the plants (Scagel et al., 2011, 2012).

The conventional container used for seedling planting is the polythene bag (polybag) filled with soil as the medium for plant growth. However, seedlings raised in polybags suffer from many disadvantages. The seedling stock produced in polybags experienced problems of root coiling, distortion and transplanting shock (Sharma, 1987). Soil-polybags also need more space and soil volume, and this makes it difficult to handle due to its large size and weight (Josiah & Jones, 1992).

A recent alternative method to growing seedlings is the use of root trainers or tubes that incorporate structural features such as vertical internal ribs designed to minimise root disturbance, to reduce root spiralling and strangulation problems, to maximise lateral root development and to shape the roots into a form that will allow more proliferation when the plant is grown into a tree. Essentially, the tree seedlings raised in containers would have lower root exposure and disturbance during field planting, thus lowering transplanting shock and allowing for higher survival and growth rates (Kinghorn, 1974).

Other than using soil as a conventional growing medium, organic materials such as compost, peat, tree bark, coconut (*Cocos nucifera* L.) coir or inorganic material such as clay, mineral wool, perlite and vermiculite (Grunert et al., 2008; Vaughn et al., 2011) can also be used. The most important physical factors of a growing medium for influencing the growth of plants are water retention and aeration of the medium. Both these properties affect not only the availability of water and air, but also the thermal properties, mineral availability and biological activity (Klock, 1997). However, physical and chemical attributes of the growing medium play a role in determining the nutritional status of natural rubber, especially during the immature stage (Salisu et al., 2013).

Because of the coarse texture of most growing media, they cannot retain the water and nutrients needed for plant growth. Consequently, water and nutrients leach through the growing medium quickly; hence, an irrigation system is required that supplies water slowly in order to minimise the leaching problem.

The aim of this study was to compare the efficiency of three irrigation systems i.e. overhead sprinkler, drip and capillary wick irrigation systems, in growing rubber seedlings in root trainers. The above treatments were additionally compared with the control, which was the wick irrigation system, for rubber seedlings grown in the conventional soil-polybag system. These treatments were compared with one another in terms of their influence on nutrient loss, crop water productivity and water use efficiency, plant growth parameters and plant nutrient content of the rubber seedlings.

MATERIALS AND METHODS

Experimental Design and Treatment Details

This experiment was done in a rain shelter facility (2° 59’ 05.0 ” N 101° 44’ 00.9” E) at Field No. 15, Universiti Putra Malaysia, Serdang, Selangor. To avoid water supply from rain and to reduce solar radiation reaching the young rubber seedlings, the rain shelter was partially covered with black plastic netting on the sides. The rubber seedlings were grown in a root trainer called RB900 (Humibox Sdn Bhd., Selangor) and filled with BX-1 growing medium (peat material) (Figure 2).

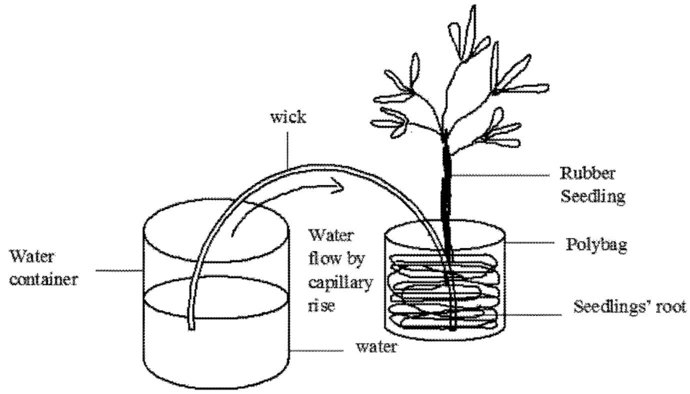

Figure 1. Capillary wick irrigation system

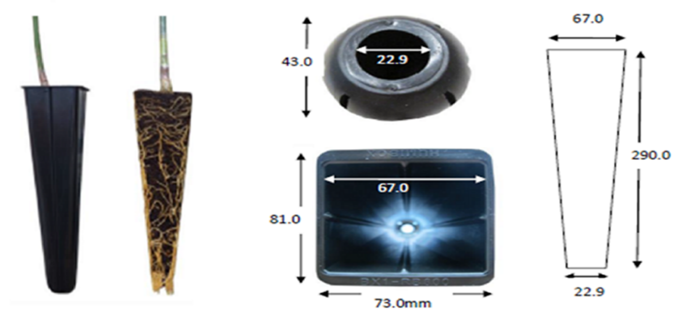

Figure 2. RB900 tube root trainer

The BX-1 medium (Peltracom, Latvia) used constituted 100% neutralised white peat treated with slow-release fertilisers. The exact formulation and ingredients of the BX-1 medium is a trade secret, so whatever information about this medium was obtained from the details given on the package. White peat is the remains of partially decomposed peat moss (*Sphagnum* sp.) of different species. BX-1 medium was used because it is enriched with nutrients and it is also lighter, so its handling is easier and therefore, the workload is reduced. RB900 root trainers were used because they can improve root growth and the containers can be reused.

This study had four treatments (with three replications each), where for the first three treatments, an amount of 230 g of BX-1 medium per RB900 tube was used in each of the three treatments. The irrigation systems used were the overhead sprinkler (SPR), drip (DRP) and wick (WCK). The fourth treatment was the control (CTRL), which consisted of the conventional soil-polybag, while irrigation was done using the wick system. Each replication had 10 rubber seedlings; therefore, a total of 120 seedlings were used for the whole experiment. The experiment was laid out in the Randomised Complete Block (RCB) design. The rubber seedling clones used for the experiment were from the RRIM 2000 at one-month-old. For the control, the 5-kg Munchong (*Tropeptic Haplorthox*) soil series in a 15 cm x 20 cm polybag was used as the growing medium (soil-polybag system or CTRL). Munchong soil is classified as kaolinitic, very fine, isohyperthermic, Tropeptic Haplorthox (Noordin, 2013). The Munchong soil series is clayey, and strong to yellowish brown in colour. Its structure is moderate to strong with fine and medium sub-angular blocks. The soil is classified as one of the most suitable soils for rubber planting (MRB, 2009).

Each experimental plot consisted of a single tray or tube stand set that accommodated 10 rubber (*Hevea brasiliensis*) seedlings, or a polybag stand that accommodated 10 polybag seedlings as control. Each tray stand measured 50 cm wide and 150 cm long. Within each experimental block, treatments were separated from one another by a space of at least three tray stands, and blocks were separated from one another by the length of at least two tray stands. The total area, inclusive of border space, was about 9 m by 14 m or 126 m^2 (Figure 3). The water flow from the overhead sprinklers was adjusted in such a way to prevent water from falling onto neighbouring plots.

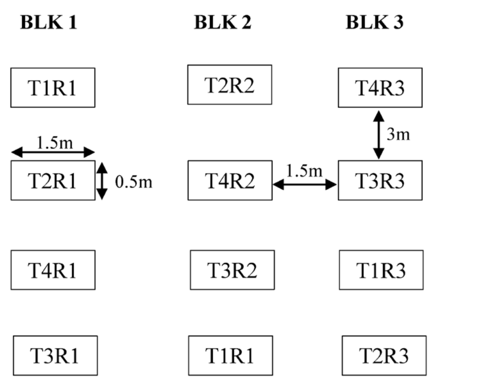

Figure 3. Experimental design [T1=SPR, T2=DRP, T3=WCK, T4=CTRL]

Watering was done once a day in the morning for the SPR and DRP treatments. The water content in the growing media was measured using a moisture meter (FieldScout TDR 100-6440FS, Spectrum Technology, Inc., USA) every day before every irrigation to monitor moisture status in the growing medium. A daily supply of 11 mm of water was provided in the DRP and SPR irrigation systems. Prior to starting the experiment, we had set up the irrigation systems so that 11 mm of water supply was equivalent to turning on the water supply from the systems for 3 min 20 s and 2 min for the DRP and SPR system, respectively. The measurement 11 mm was chosen because this was the amount of water flowing into the soil for the WCK system (11 mm was the mean daily difference in the water amount in the WCK water container).

This amount of water was supplied to maintain the media/soil moisture at about field capacity so as to avoid plant water stress. The average volumetric water content (VWC) of the BX-1 medium treatments (SPR, DRP, WCK) and soil (CTRL) were 38 m^3 m^{-3} and 27 m^3 m^{-3}, respectively, which were above field capacity (FC) for BX-1 media and slightly lower than FC for the soil (Table 1). The mean VWC values, however, showed that overall, there was no moisture stress in the treatments. A mini weather station (WatchDog 2000 series, Spectrum Technology Inc., USA) was placed inside the rain shelter to monitor the microclimate conditions under which the rubber seedlings were grown. Throughout the experiment for eight months, the average daily temperature, relative humidity and total solar irradiance under the rain shelter were kept at 27°C, 80% and 3.2 MJ m^{-2} day^{-1}, respectively. The average day length was 12 h per day. The BX-1 growing medium and the soil were analysed for physical and chemical properties.

Plant growth parameters (fresh and dry weight, leaf area, girth size, root volume, root length) were measured monthly, after which destructive samples were taken for leaf area and nutrient analysis. Fresh and dry weights were measured using a weighing scale, and root analysis was carried out using an EPSON WhinRhizo root scanner (EPSON PERFECTION V700 PHOTO, Reagent Instrument Inc., Canada). Vernier calipers were used to measure girth. Leaf area was measured using a leaf area meter machine (LI-3100C Area meter).

The concepts used by Heydari (2014) for water productivity (WP) and water use efficiency (WUE) were adopted for calculating WP and WUE based on the following formula:

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

$$\text{WUE (L L}^{-1}\text{)} = \frac{\textit{Amount of water used by the plant (L)per plant}}{\textit{Output of the irrigation system (L) per plant}} \quad (2)$$

DETERMINATION OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL AND BX-1 MEDIA

Physical Properties

The soil particle size was analysed using the pipette method and the particle size distribution of the BX-1 mediuma was determined by pore size distribution using sieves of different sizes in the shaking method (Teh & Jamal, 2006). Soil and BX-1 medium pH were determined by a suspension ratio of 1:5 for (soil to water) and 1:10 for (BX-1 medium to water) (McLean, 1982) using a pH meter (Meter-Toledo Delta 320 pH meter); the same suspensions were used for EC determination, as described by Rhoades et al. (1990).

Soil bulk density (Mg m^{-3}) was determined using the core method (Blake & Hartge, 1986). Total porosity (%) of soil was calculated from the measured soil bulk density values, assuming particle density of mineral soils (2.65 Mg m^{-3}) and using the following equation (Baver et al., 1972):

$$\text{Total porosity (\%)} = 1 - \frac{\textit{bulk density}}{\textit{particle density}} \times 100 \quad (3)$$

$$\text{Moisture content } (gg^{-1}) = \frac{weight\ of\ fresh\ soil - weight\ of\ oven\ dry\ soil}{weight\ of\ oven\ dry\ soil} \times 100 \quad (4)$$

The saturated hydraulic conductivity of both soil and BX-1 medium was determined using the constant head method (Klute & Dirksen, 1986). Water retention was determined using the pressure plate and pressure membrane described by Richards (1947). The applied pressure was 0.1, 1, 10, 33 and 1500 kPa. The samples were then oven-dried at 105 oC for 24 h, then weighed and multiplied by soil bulk density to obtain the volumetric water content (VWC).

Particle density (Pd) of the BX-1 media was obtained from an assumed formula given by Inbar et al., 1993 as follows:

$$\text{Pd } (Mg\ m^{-3}) = \frac{1}{\frac{\%\ organic\ matter}{100 \times 1.55} + \frac{\%\ ash}{100 \times 2.65}} \quad (5)$$

where 2.65 Mg m^{-3} and 1.55 Mg m^{-3} are the average particle density of the mineral and organic soil, respectively.

BX-1 medium bulk density was determined by oven drying a known quantity of the medium in relation to the total volume of the tube (RB900). The total porosity (TP) of the medium was computed from bulk density (Bd) and particle density (Pd) of the growing medium as they are inversely related (Beardsell et al., 1979; Hanan et al., 1980). Total porosity is defined as the total volume of pore space in a substrate.

Moisture content of the fresh media was determined by subtracting the oven-dry weight from the fresh weight and divided by the oven-dry weight of the medium. The bulk density, total porosity and gravimetric moisture content were calculated using the following formula:

$$\text{Bulk density } (Mg\ m^{-3}) = \frac{Weight\ of\ media,\ \ oven\ dried\ at\ 105^{o}C}{volume\ of\ fresh\ medium} \quad (6)$$

$$\text{Total porosity } (\%) = 1 - \frac{Bd}{Pd} \times 100 \quad (7)$$

$$\text{Moisture content } (g\ g^{-1}) = \frac{weight\ of\ fresh\ media - weight\ of\ oven-dried\ medium}{weight\ of\ oven-dried\ medium} \quad (8)$$

Transpiration by the rubber seedlings under different irrigation systems was calculated using the 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).

The evaporation was calculated every day by weighing plantless soil and BX-1 growing systems that were watered every day with a known amount of water. Water loss was measured as that having been lost through the opening of the container only.

Soil Chemical Properties

Total C, N and S were determined using CNS analyser (LECO TruMac® CNS, USA). The leaching method by Chapman (1965) was used to determine cation exchange capacity (CEC) and exchangeable bases. Exchangeable K, Ca and Mg were determined using the leaching method with 1 M ammonium acetate buffered at pH 7. The levels of Ca, K and Mg were determined using an atomic absorption spectrophotometer (AAS) (Perkin-Elmer, 5100PC, USA). P and CEC were determined using an auto-analyser (AA) (Quikchem FIA 8000 series, LACHAT instrument, USA).

BX-1 Media Chemical Properties

Total C, N and S was measured using a CNS analyser (Nelson & Sommers, 1982). Total P, K, Ca, Mg and other micronutrients were extracted using the dry ashing method. An auto analyser (AA) was used to determine total P while K, Ca, Mg and other micronutrients were analysed using an atomic absorption spectrophotometer (AAS). The CEC of the BX-1 medium was determined using the shaking method (Fauziah et al., 1997).

Leaf and Leachate Analysis

Leaf sampling was conducted based on the Malaysian Rubber Board (MRB) guidelines. Four basal leaves from the first sub-terminal whorl were collected as a leaf sample (Rubber Research Institute of Malaysia, 1990). The sampled leaves were cut from stems and placed in a forced draft oven at 60ºC for 48 h, after which the weight was determined using a weighing machine (Multitech, GF-3000, Tokyo, Japan). Leaf samples were used for N, P, K, Ca and Mg analyses. The amount of N was determined using a CNS analyser while P, K, Ca and Mg were prepared using the dry ash method. The filtrates were sent to an Auto Analyser (AA) and atomic absorption spectrophotometer (AAS) for determination of P and K, Ca, Mg, respectively.

Leachate samples from the experimental field were collected every week using a plastic container. Enough leachate collected for each experimental unit was mixed (pooled) and sub-sampled for laboratory analysis monthly. The sample was first filtered using filter paper (Whatman No. 2, 8µm size) before it was sent to the laboratory for analyses. N and P were analysed using AA and K, Ca and Mg using AAS.

Data Analysis

Data analysis was done using the SAS system for Windows (SAS 9.4, SAS Institute Inc., Cary, NC, USA). ANOVA (Analysis of Variance) and Proc GLM were used to determine the significant treatment effect on various measured properties with the significant difference at $p<0.05$. The SNK (Student-Newman-Keuls) test and t-test for mean separation were used to detect the significant differences between the means.

RESULTS AND DISCUSSION

Physico-Chemical Properties of BX-1 Growing Medium and Munchong Soil Series

The results of the physical and chemical properties of the two different growing media (BX-1 medium and soil) are presented in Table 1. The analyses showed that the medium had a very low bulk density that was 90% lower than that of the soil, making it much easier to handle than the mineral soil. It also had a gravimetric moisture content of 0.71 g g^{-1}. The bulk density of peat depends on the plant's residue component, ash content and the degree of decomposition. The bulk density of peat is generally low, ranging from 0.1-0.5 Mg m^{-3}, with a moisture content under natural conditions exceeding 80% (Xuehui & Jinming, 2009). The properties of the media showed that the peat sample could hold more water and air than the Munchong soil. The medium had a total porosity of

Table 1
Mean (±Standard Error) physico-chemical properties of the soil and BX-1 growing media

Physical Properties	Soil	BX-1 Media
Bulk Density (Mg m^{-3})	1.43±0.03	0.14±0.01
Moisture Content (g g^{-1})	0.21±0.08	0.71±0.01
Total Porosity (%)	46.0±3.10	91.0±2.01
Saturated Hydraulic Conductivity (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**	**BX-1 Media**
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 (ug g^{-1})	8.34±1.02	680.57±8.30
K (ug g^{-1})	41.27±3.10	1779±13.21
Ca (ug g^{-1})	459.33±4.70	6223.67±17.60
Mg (ug g^{-1})	85.47±3.90	1709.33±23.70
Na (ug g^{-1})	5.43±0.30	17.93±0.92

*C and nutrient contents are expressed per unit dry weight

91%, with 20.4% macropores (>6.3 mm), 32% mesopores (2-6.3.0 mm) and 22.5% micropores (0.5-2.0 mm), following the particle size distribution of the BX-1 medium. The medium could hold more water because of the large proportion of mesopores. The percentage of macropores should be at least 20-25% (Kuslu et al., 2005). The percentage of macropores in the medium agrees with the value reported by Kuslu et al. (2005). The medium had a higher available water content of 27.3% than the soil, which showed the ability of the medium to hold more available water for the crop. The high CEC (63.21 cmol+kg^{-1}) of the medium could be attributed to industrial treatment of the medium with lime and fertiliser, as CEC is a measure of nutrient retention capacity.

The Munchong soil series is derived from sedimentary rocks (Salisu et al., 2013). The results of the analysis showed that the main content of this soil was clay. The result also showed that the soil had plant available water, low pH (4.6), low CEC (8.35 cmol+kg^{-1}) as well as little available nutrients, which are characteristics of highly-weathered Ultisols and Oxisols (Shamshuddin & Fauziah, 2010). The predominant chemical properties of these soils include low soil acidity (pH<5) and low inherent fertility, which make the soils less productive for crops (Shamshuddin & Fauziah, 2010).

Cumulative Nutrient Leaching Losses, Water Productivity, Water Use Efficiency and Elemental Ratios

The statistically significant ($p<0.05$) results for the cumulative leachate volume and cumulative nutrient leachates are shown in Figure 4. The results showed that overall, the better treatments were the ones using WCK and CTRL because these had the lowest cumulative leachate volume as well as the lowest cumulative leachate for the individual nutrients. The SPR and DRP treatments, on the other hand, had the highest amounts of cumulative leachate volume and cumulative leachate of nutrients. In terms of cumulative leachate volume, the SPR and DRP systems had 39% and 80% higher cumulative leachate volume than the WCK and CTRL systems, respectively. The lowest cumulative leachate was recorded for CTRL.

SPR and DRP had the highest cumulative leachate volume because the required amount of water, aided by the higher hydraulic conductivity of the medium, was applied for a shorter period than for WCK and CTRL (Table 1). This means in the DRP system, the water flowed down from the point of entry and rapidly downwards to the bottom, without having to wet the entire or a large part of the medium first. On the other hand, the higher leachate volume in SPR was due to the nature of the irrigation system, which supplied water over the entire

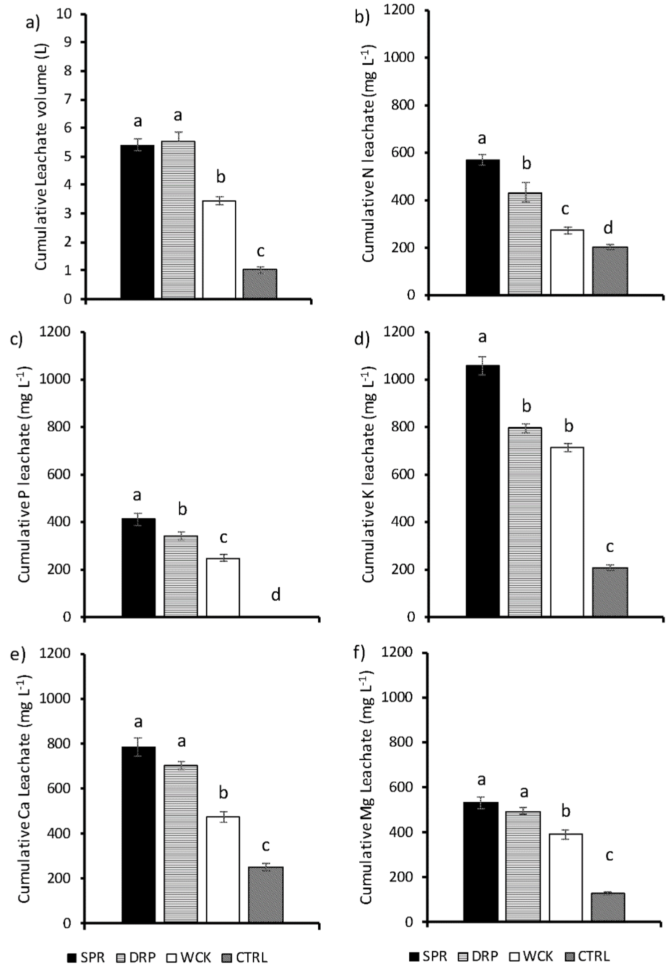

Figure 4. Means (±standard error) of different irrigation systems effect on cumulative (a) leachate volume, (b) N leachate, (c) P leachate, (d) K leachate, (e) Ca leachate, and (f) Mg leachate. (SPR=Overhead sprinkler, DPR=Drip, WCK=Capillary wick, CTRL=Soil-polybag with capillary wick irrigation). Means with same letters in the same chart are not significantly different from one another at 5% level of significance

opening area of the container. This caused more leaching in the system. DRP started to leach when wetted over a small area, so less N and K were leached than by SPR, which leached when most of the medium was wetted. WCK had low leaching of nutrients because the water flowed from wick to medium more slowly and gradually. Water was absorbed by the surrounding medium first before leaching out, and this was reflected in the high leaf nutrient content (Table 2). The lowest cumulative leachate volume in CTRL was due to higher soil compaction and volume and lower hydraulic conductivity of the soil than was the case for the medium (Table 1).

Table 2
Effect of different irrigation systems on the leaf nutrient content (per dry weight)

Treatments	N (%)	P (%)	K (%)	Ca (%)
SPR	4.01 ± 0.10b	0.25 ± 0.003b	0.63 ± 0.001b	0.47 ± 0.003b
DRP	4.27 ± 0.10a	0.28 ± 0.01b	0.87 ± 0.01a	0.53 ± 0.04a
WCK	4.22 ± 0.01a	0.32 ± 0.01a	0.90 ± 0.10a	0.50 ± 0.03a
CTRL	3.82 ± 0.20c	0.19 ± 0.003c	0.53 ± 0.03b	0.43 ± 0.03c
*Sufficiency level (%)	3.71-3.91	0.21-0.27	1.10-1.60	0.60-0.70

*According to Noordin (2013)
Means (± Standard Error) for the Same Column and Same Parameter, Followed by Same Letter, are not Significantly Different from One Another at the 5% Significant Level by SNK. (SPR=Overhead Sprinkler, DRP=Drip, WCK=Capillary Wick, CTRL= Soil-Polybag with Capillary Wick)

Nitrogen concentration leached out by the samples using the different irrigation systems was related to the volume of water leached out (Zotarelli et al., 2009). The low cumulative N leachate under CTRL was attributed to the lower soil N level (Table 1). Andrisse (1988) found a substantial amount of the total available K in soil solution in peat soil. Hence, K is strongly mobile and prone to leaching. In addition, K fixation is almost absent in peat despite its high CEC, and peat does not also readily adsorb exchangeable K. This experiment agreed with Andrisse's (1988) findings as more K was leached than other nutrients (Figure 4). The effect of the different irrigation systems on the seedlings' water use efficiency and water productivity was significant ($p<0.01$) (Figure 5). The most important month was the final month of the experiment, which was the eighth month, the month that the seedlings were due for field transplanting. The highest cumulative WP of the seedlings was recorded for the WCK and DRP systems, and it was 30% higher than for SPR and CTRL. The higher WP for DRP and WCK was due to their highest plant dry weight of the seedlings recorded for the systems (Table 3). The lowest WP, recorded for CTRL, was due to the lowest seedling plant dry weight achieved in this treatment and possibly due to the higher bulk density of the soil, which might have led to root growth restriction. CTRL had the highest transpiration value of 11.84 L of water compared to the other treatments, with their transpiration value in the range of 8-10 L of water, cumulatively over a period of eight months. In spite of the higher transpiration values, dry matter yield was low due to the polybag's root growth restriction of the seedlings. Potential root growth was restricted due to root coiling as it prevented development of lateral roots (Josiah & Jones, 1992). The highest WUE was obtained in CTRL, which allowed 25% higher WUE than did DRP and WCK and 96% higher WUE than did SPR. The poorer SPR had only 3% water utilisation in the last month. The highest WUE in CTRL was due to its lowest cumulative percolation loss (Figure 4a), which resulted in higher transpiration. The amount of water supplied was almost equal to the irrigation need of the seedlings that resulted in the least amount of leachate and it could also be a result of the higher soil quantity used.

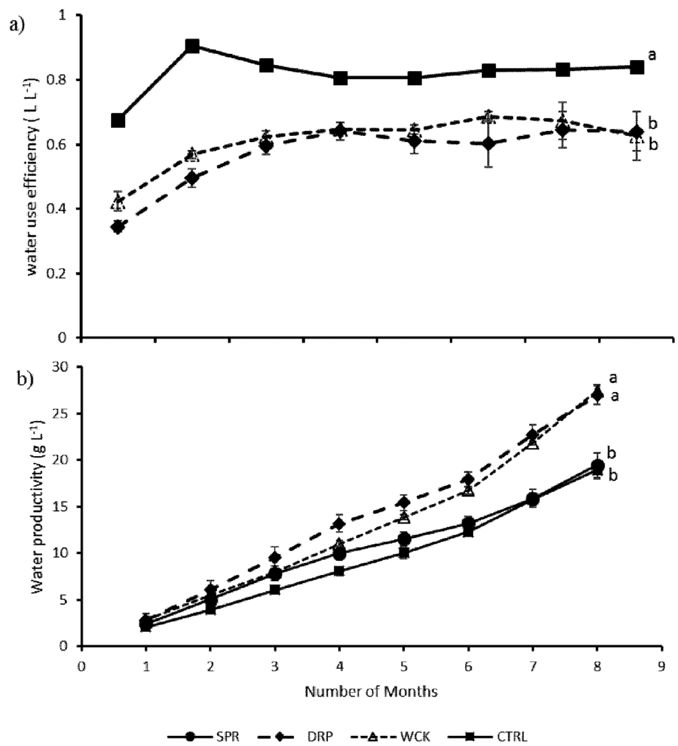

Figure 5. Means (±standard error) of (a) water use efficiency and (b) water productivity of rubber seedlings as influenced by different irrigation systems and month. (DPR=Drip, WCK=Capillary wick, CTRL=Soil-polybag with capillary wick system). At Month 8, means with same letters are not significantly different from one another at 5% level of significance. SPR (overhead sprinkler) had a WUE of less than 0.04 LL^{-1} throughout the eight months

The results of the WP and WUE were similar to those obtained by Teh et al. (2015), who reported that the wick irrigation system had the highest WP and WUE than two other irrigation systems on the growth of water spinach (Ipomoea reptans). Salemi et al. (2011) claimed that irrigating crops with less water increased water productivity in their study.

Water use efficiency (WUE) is among the most important indices for determining optimal water management practices (Kharrou et al., 2011). The lowest water use efficiency in the SPR system was due to the lack of uniformity and efficiency of the system, which resulted in much water wastage. El-Rahman (2009) reported high water use efficiency (WUE) in wheat using the drip irrigation saving system.

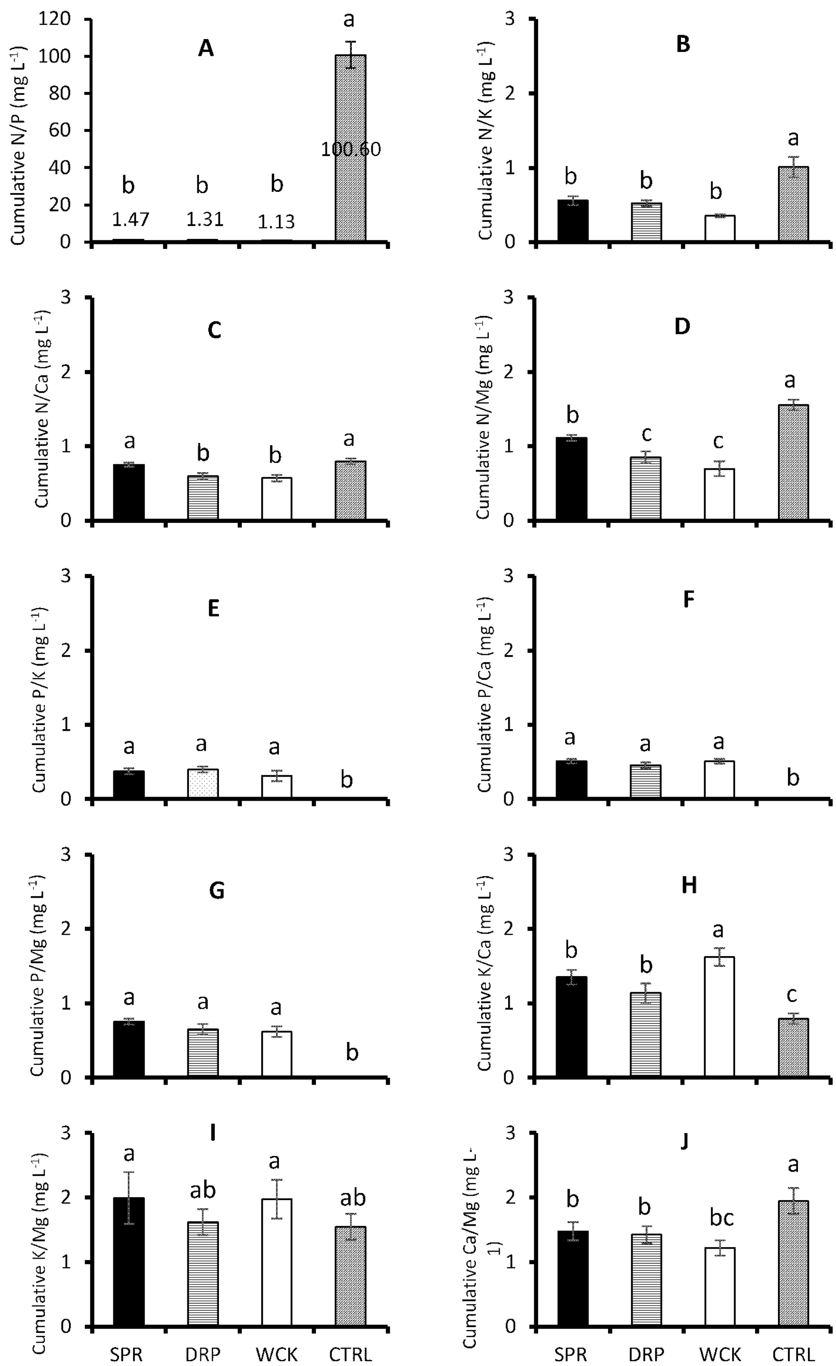

Figure 6. Means (±standard error) of different irrigation systems' effect on cumulative leachate ratios of (A) N/P (B) N/K (C) N/Ca (D) N/Mg (E) P/K (F) P/Ca (G) P/Mg (H) K/Ca (I) K/Mg (J) Ca/Mg (SPR=Overhead sprinkler, DPR=Drip, WCK=Capillary wick, CTRL=Soil-polybag with capillary wick irrigation). Means with same letters in the same chart are not significantly different from one another at 5% level of significance

Elemental Ratios

The results of the elemental ratios are shown in Figure 6. In the eight months of the research, CTRL had the highest N/P, N/K, N/Ca, N/Mg and Ca/Mg, with a range of 30-90% higher than the BX-1 treatments (SPR, DPR, WCK), despite CTRL having the lowest leachate of the elements (Figure 4). This was due to the lower cumulative leachates of P, K, Ca and Mg in relation to the N by the CTRL treatment as shown in Figure 4. The BX-1 treatments exhibited higher percentages of P/K, P/Ca, P/Mg and K/Ca ratios, which did not differ significantly ($P<0.05$) from one another except in N/Ca and N/Mg with the highest (50%) percentage recorded for SPR, which could be attributed to the higher amount of nutrients leached out by SPR (Figure 4).

The higher elemental ratios recorded in the BX-1 treatments were due to the higher nutrient content of the BX-1 media. There were no significant differences between them in terms of most of the elemental ratios because the BX-1 medium was uniform in nutrients (Table 1). Statistically similar elemental ratios among the BX-1 treatments could be the reason why they did not differ significantly in terms of growth parameters and leaf nutrient content (Table 2), but SPR had the lower of the parameters mentioned not because of the nutrient content of the growing medium as was the case for CTRL, but because of the nature of the irrigation system.

Plant and Root Growth

The interaction between the different irrigation systems and the duration (eight months) of the experiment for seedlings' water content, total fresh and dry weight, total leaf area and girth size were significant ($p<0.05$) and the results are presented in Table 3. In the last month of the experiment (Month 8), the overall better treatments in terms of highest plant growth parameters were DRP and WCK. There was no significant difference between these two treatments, but they differed from SPR and CTRL (the poorer treatment being SPR). The interaction for plant height and number of leaves was not significant ($p>0.05$), but the main effect of time (months) was significant ($p<0.05$), which

Table 3
Effect of different irrigation systems on the growth of seedlings (per plant basis).

Treatments	Water Content (g)	Total Fresh Weight (g)	Total Dry Weight (g)	Total Leaf Area (cm^2)	Girth Size (mm)
SPR	68.2 ± 0.50b	103.7 ± 2.62c	35.5 ± 0.20b	1275.0 ± 4.41b	13.9 ± 0.31b
DRP	82.0 ± 0.60a	126.2 ± 1.60a	44.2 ± 2.40a	1508.1 ± 61.12a	17.7 ± 0.21a
WCK	84.0 ± 0.51a	131.1 ± 1.21a	47.1 ± 0.41a	1602.1 ± 8.12a	18.0 ± 0.10a
CTRL	76.7 ± 3.52b	114.5 ± 3.80b	37.8 ± 2.61ab	1323.5 ± 48.91b	14.6 ± 0.30b

Means (± Standard Error) for the Same Column and Same Parameter, Followed by Same Letter, are not Significantly Different from One Another at the 5% Significant Level by SNK. (SPR=Overhead Sprinkler, DRP=Drip, WCK=Capillary Wick, CTRL= Soil-Polybag with Capillary Wick) of course showed a continuous increase of the parameters as plant growth progressed.

The DRP and WCK systems had the highest plant water content, fresh and dry plant weight, total leaf area and seedling girth size, while the lowest values of these parameters were recorded for the SPR system. The SPR parameters did not differ significantly from those of CTRL (Table 3). Increase in plant growth parameters is a function of water and sunlight, so the higher growth parameters recorded for DRP and WCK could be due to the influence of the irrigation systems, since the treatments were treated and raised in the same conditions of temperature and solar radiation. The higher values for DRP and WCK were due to the ability of the irrigation systems to dissolve the BX-1 medium nutrients into solutions for the seedlings' use, as moisture is non-limiting in the systems on the one hand and due to the availability of nutrients in the medium on the other hand. The lower values recorded for CTRL could also be attributed to the lower nutrient content of the soil compared to that of the growing medium (Table 1). Girth size was lowest for the SPR and CTRL treatments; girth size for rubber is very important because it determines the amount of latex flow and latex quality (Salisu et al., 2013).

Higher growth of the seedlings was obtained for DRP and WCK (Table 3) because of the lower leachate of nutrients in the treatments with a consequent higher WP of the systems as well as higher nutrient content in the leaves (Table 2). CTRL had the lowest water and nutrient leaching, and this was translated in the higher WUE of the treatment. However, WP and growth parameters of the seedlings were low because of the lower nutrient content of the soil.

Table 4 shows the interaction between the treatments and the months for root length, root volume, root surface area and root diameter, which were significant ($p<0.05$) for nearly all the months. The most important was the eighth month of the experiment, when there was no significant difference in the seedlings that were raised in the BX-1 growing system (SPR, DRP and WCK) in terms of the seedlings' root length and root volume.

Table 4
Root growth of seedlings (per plant basis) at month 8.

Treatments	Root Length (cm)	Root Volume (cm^2)	Root Surface Area (cm^2)	Root Diameter (mm)
SPR	779.30 ± 5.90a	4.80 ± 0.06a	123.10 ± 0.80b	0.62 ± 0.01c
DRP	819.12 ± 3.50a	4.31 ± 0.20a	193.50 ± 10.00a	0.89 ± 0.01b
WCK	798.71 ± 6.80a	4.92 ± 0.08a	172.00 ± 1.04a	0.92 ± 0.01a
CTRL	532.08 ± 17.01b	3.20 ± 0.10b	158.20 ± 2.93ab	0.92 ± 0.01a

Means (± Standard Error) for the Same Column and Same Parameter, Followed by Same Letter, are not Significantly Different from One Another at the 5% Significant Level by SNK. (SPR=Overhead Sprinkler, DRP=Drip, WCK=Capillary Wick, CTRL= Soil-Polybag with Capillary Wick)

At Month 8, the BX-1 system treatments (SPR, DRP and WCK) had an average root length and volume of 765.67 cm and 3.7 cm^3, respectively, which were significantly different from those achieved in the conventional system treatment (CTRL), which achieved 532.03 cm and 3.2 cm^3 for root length and volume, respectively. However, there was no significant difference in terms of root surface area and root diameter among the BX-1 system treatments (161.3 cm^2 and 0.82 mm) and the conventional system (158.3 cm^2 and 0.92 mm). The BX-1 system had an increase of root length and root volume of 30% and 15% respectively, more than those recorded for the CTRL system. Krizek et al. (1985) stated that when moisture is non-limiting, restricting the growth of roots can mimic the effect of soil moisture stress on plant growth.

Nutrient Content of Rubber Seedlings Leaves

The interaction between different irrigation systems and Month 8 was significant ($p<0.05$) for the N, P, K and Ca content of the seedlings' leaf tissue, as can be seen in Table 2. Only the interaction for the Mg leaf content (0.4%) was not significant ($p>0.05$). The better treatments in terms of leaf nutrient content were obtained from the seedlings that were raised in the DRP and WCK irrigation systems, while CTRL had the lowest seedling leaf nutrient content. The higher nutrient content recorded for DRP and WCK can be attributed to the lower amount of nutrients leached, especially N and K. Overall, the lowest nutrient tissue content was recorded in the CTRL despite its having the lowest nutrient leachate because of the lower nutrient content of the soil by more than 10 times (Table 1).

CONCLUSION

This study showed that water application methods influenced the growth of rubber seedlings. The conventional method for irrigating rubber seedlings in Malaysia is the sprinkler system, and this research showed that this system was a weak irrigation system as it yielded the highest amount of nutrient leachate, the lowest growth parameters and poorer water productivity and water use efficiency. The sprinkler system had another limitation i.e. higher water loss due to canopy interception of water. The study indicated that the drip and capillary wick systems had the highest plant growth parameters and leaf nutrient content than the sprinkler and control systems. This was because the drip and wick systems could supply water to the growing seedlings more slowly and steadily. The capillary wick system proved to be the best irrigation system used together with a root trainer and the BX-1 growing medium, recording the lower amount of leachate, the highest plant and root growth parameters and the highest water productivity. By using the root trainer rather than a polybag, a smaller amount of growing medium was used, but it was sufficient to sustain the growth of the seedlings for eight months with better growth than the conventional system. The research also suggested that farmers have an alternative growing system for nursery rubber seedlings. Using a root trainer and the better physical and chemical properties of the BX-1 growing medium gave better seedling growth and leaf nutrient content in this study than did the conventional system (soil-polybag).

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