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Performance Evaluation of Drip Irrigation System and Water Productivity (WP) of Rock Melon Grown inside Netted Rain House Shelter

Mohd Fauzie Jusoh^{1,2*}, Nurhayatie Adnan², Muhammad Firdaus Abdul Muttalib¹ and Ayob Katimon¹

¹ School of Bioprocess Engineering, Universiti Malaysia Perlis, Jejawi Complex of Education 3, Jejawi Industrial Zone, 02600 Arau, Perlis, Malaysia.

² Department of Agriculture Science, Faculty of Agro Based Industry, Universiti Malaysia Kelantan, Jeli Campus, 17600 Jeli, Kelantan, Malaysia.

E-mail: fauzie_jsh@yahoo.com

Abstract. The yield of the crops may be subject to the distribution of water directly to the plant root zone using drippers or emitters. To date, there has not been adequate work to evaluate irrigation system performance and water productivity (WP) specifically for rock melon inside a netted rain house shelter in tropical area. Amongst the problem of this system is the non-functional irrigation components after been used for specific of time, thus reducing the irrigation efficiencies and distribution uniformity. This study evaluates irrigation performance of drip irrigation system and estimates WP of rock melon cultivation in the netted rain house shelter. The results indicate that the operating pressure of the drip irrigation system tested varied from 0.8 to 3.0 psi with a discharge rate between 0.14 and 0.25 Lmin⁻¹. Water application uniformity between laterals varied from 66.06 to 89.72%. The WP of rock melon was around 7.93 kg/m³, which is considerably high and in similar range as demonstrated in previous literature. The field evaluation also reveals that the manipulation of valve controller at lateral based on a few selected scenarios did not provide a significant difference in pressure and discharge at the head, middle, and tail section of the drip irrigation system. Such findings would be a very useful information for a precision water management particularly for rock melon cultivation grown under rain house shelter system.

1. Introduction

Drip irrigation technology is one of the modern irrigation methods to keep the soil root zone moist. Irrigation technology has gradually improved along with the evolution in water technology, water transfer, and agriculture system [1]. Irrigation is designed to supply a sufficient amount of water promptly to crops. Therefore, the effective and sustainable use of water for agriculture has become a global priority and it contributes to the development of cultivation processes in agriculture [1,2].

A typical drip irrigation system consists of a few components for instance, pumping unit, control head, main line, submain line, lateral line, microtube and emitter or dripper. The pressure is necessary to force water flowing through the components of the system by a suitable pressure generated by the pump [3,4]. Moreover, excellent uniformity of water application can be achieved if the correct size of



the pump is used [5]. The main line, sub main line, and lateral line with a diameter of 40, 32, and 16 mm respectively have commonly been used by Malaysian farmers. Typically, these pipes made up of PVC or polyethylene hose so that it is not easily degraded when exposed to direct solar radiation. Reference [4], stated that sub main line usually not available for small scale fertigation projects. Emitters are mounted on the lateral lines through microtube (1 mm) and attached to a dripper.

Drip irrigation system directly supplies the water and fertilizer requirements by allowing water to drip slowly to the plant's roots zone with minimum losses [6]. The drip irrigation system applies a low flow rate and low pressure at the emitters. Consequently, this method can save the water because it is typically designed to permit the water drip slowly direct to the root zone [7]. However, a good filtration system is required as it is easily clogged by the suspended solids (chemical reaction of nutrients) in the irrigation water due to the small water hole [8]. Although drip irrigation system slowly and moderately wets the soil near the plant root zone, it is difficult to distribute the equal amount of water to plants within the field [9].

Drip irrigation system typically uses 30-50% less water than a sprinkler system. In this regard, the fertigation system enables to water only the specific plants and not the row crops [10]. Drip irrigation working at a low flow rate and operating pressure between 10 to 20 psi at the dripper and the pump outlet typically needs around 40 psi [11] depending on the farm size. Reference [5], has argued adequately designed and maintained drip irrigation can give high performance. The use of a drip irrigation system offers high uniformity and higher water use efficiency [6]; beside, it provides efficient use of water and fertilizer [9]. Reference [12], proved that interaction between different irrigation management and nitrogen rates resulted in higher water productivity up to 37 kgm⁻³ for greenhouse-grown tomato. Therefore, the adoption of a highly efficient irrigation system such as a drip irrigation system is one of the suitable applications of irrigation water. This system usually uses to water the orchard and greenhouse plants. Drip irrigation also adaptable for almost soil type and topography with an adequate design system [5][6]. Moreover, this system has been designed specifically for the drought areas and also for limited farming space [8]. In contrast, this irrigation system is complex, need proper maintenance, more expensive compared to other irrigation system and only a few farmers using this type of irrigation system [13].

A rain house shelter has excellent irrigation performance if the design of the drip irrigation system follows a standard specifications. However, unused agriculture structure for a long time (more than six months), due to electricity supply and water storage issues, may affect the irrigation efficiency. Poor irrigation efficiency will impact crop production since it disturbs irrigation water supply and reduces nutrients uptake by the plants. Therefore, this study attempts to evaluate the performance of a drip irrigation system and estimate water use efficiency for rock melon under newly developed, unused, and abandoned rain house shelter.

2. Materials and Methods

2.1 Study area

The field experiments were conducted under netted rain house shelter at Agro Techno Park, Universiti Malaysia Kelantan, Jeli. The study area is located at the coordinate of 5°45'09.0" N latitude and 101°52'27.6" E longitude. The temperatures of inside and outside netted rain house shelter varied from 30.1 to 41.7 °C (indoor) and 30.2 to 37.1 °C (outdoor) respectively. Meanwhile, the minimum and maximum relative humidity was 40 and 89% respectively. Both temperature and relative humidity were monitored by using a hygrometer during the growing period. Figure 1 shows the outside and inside view of the netted rain house shelter.

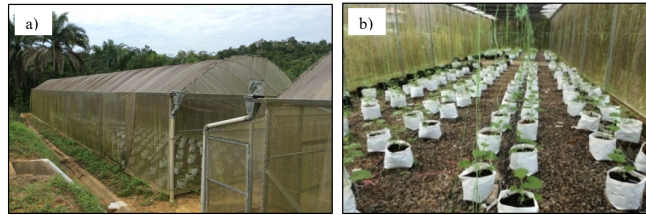


Figure 1. Outside (a) and inside (b) view of netted rain house shelter used in this study.

2.2 Drip irrigation system layout

The dimensions of the netted rain house shelter were 6×30 m (wide \times length). The drip irrigation system was equipped with a 2 horsepower (hp) centrifugal pump to supply the water from the mixing tank to the point of discharge during the tested period. Flow rate meter was installed to the fertigation system to measure the volume of water supplied and the data was recorded based on weekly inspection. The system consists of four tanks (one mixing water tank and three storage water tanks) to supply the water and fertilizer to the field. The capacity of each tank is 300 gallons (0.3 m^3). Main line (high density polyethylene, HDPE, 32 mm diameter) was connected directly to 5 lateral lines with individual control valve. The length of the main line and lateral were 5.7 and 13.4 m respectively. Each lateral has 30 drippers and located at a distance of 0.5 m apart.

The netted rain house shelter was divided into three sections, which were the head, middle, and tail sections (Figure 2). Pressure gauges were installed at the laterals to measure operating pressure during the cultivation period. The whole system was tested one week before rock melon transplanting to ensure the laterals and drippers were correctly functions and no leakage along the pipelines. The clogged or damage drippers detected were replaced with the new one.

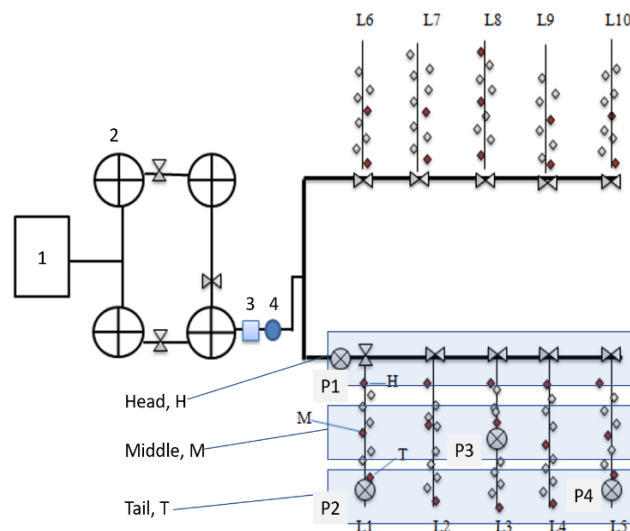


Figure 2. The layout of the drip irrigation system at netted rain house shelter (1 = tube well, 2 = water tank, 3 = water pump, 4 = flowrate meter, P1-P4 = pressure gauge, L1-L10 = lateral line) .

2.3 Site preparation and rock melon cultivation

Netted rain house shelter was cleaned and sprayed with fungicide (Previcur N) before planting. Cocopeat (100%) was filled into polybags (33 cm length, 50 cm wide) as planting media and each polybag was soaked into the water to gain the weight between 7 and 8 kg per polybag. Rock melon seeds were treated with lukewarm water before sowing inside the planting tray filled with peat moss. Hand sprayer was used to moist the media on planting tray and later, it was wrapped using black plastic and keep in the nursery to accelerate the germination rate. After 7 days, germinated seedlings were transplanted into

polybags. Each lateral line consists of 30 plants and the total number of rock melon inside the house were 300 plants. Raffia string was used as a trellis to support its stem for creeping.

Commercial fertilizer A and B for rock melon were diluted and mixed according to its desired electrical conductivity (EC) values, as suggested by the manufacturer. The values of pH also were recorded during the mixing proses. The best pH for the solution was between 5.5 and 6.5. Weeding, pruning and monitoring were executed as regular practices by the farmers. During the flowering stage, hand pollination was performed between 8.00 am until 10.00 am daily by using the male flower collected from a different plant. Developed fruit (1 fruit per plant) was wrapped using newspapers to prevent insects' attack. Rock melon was harvested after 65 days and all the fruits were weighed using the weighing scale.

2.4 Irrigation performance

Irrigation performance of drip irrigation system was evaluated with and without crop cultivation. The pressure was measured at four points (refer to Figure 2) by using pressure gauges. Discharges at emitters were measured by using collecting bottles and measuring cylinders. The coefficient of variation (CV) is used to measure the variability of flow in the drip irrigation system by using Equation 1. The obtained value was compared with Table 1 to classify the drip irrigation performance. Reference [14], expressed CV as:

$$CV = \frac{\text{Standard Deviation}}{\text{Mean for a sampled number}} \quad (1)$$

Table 1. Coefficient of variation values and its corresponding classification

CV	Classification
< 0.1	Excellent
0.2 – 0.1	Very good
0.3 – 0.2	Acceptable
0.4 – 0.3	Poor
> 0.4	Unacceptable

Source: [15]

Equation 2 was used to calculate water application uniformity (AU), where it depends on the uniformity of water discharge. This equation also gives information on how water distributed efficiently in the field. Water application uniformity obtained was compared with the general criteria for uniformity value as depicted in Table 2. WP is defined as ratio between amount of crop produced and the amount of water involved in crop production system [27]. Crop yield was estimated by weighing the weight of rock melon during harvesting day and the total amount of water consumed was evaluated by continuous monitoring of flow rate meter reading weekly.

$$AU = (1.0 - CV) \times 100 \quad (2)$$

Table 2. Percentage of application uniformity and its corresponding classification

AU (%)	Classification
100-95	Excellent
90-85	Good
80-75	Fair
70-65	Poor
< 60	Not Acceptable

Source: [5]

2.5 Effect of valve opening-closing on discharge

A separate experiment was performed to evaluate the effect of closing and opening of the valve at laterals to the discharge rate according to selected different scenarios (refer to Table 3). Discharges were measured by collecting the volume of water dripped from the emitter in one minute at the head, middle and tail sections of the fertigation system.

Table 3. Different scenarios of valve opening and closing at laterals

Scenario	Lateral				
	1	2	3	4	5
1	☒	◀▶	◀▶	◀▶	◀▶
2	◀▶	☒	◀▶	◀▶	◀▶
3	◀▶	◀▶	☒	◀▶	◀▶
4	◀▶	◀▶	◀▶	☒	◀▶
5	◀▶	◀▶	◀▶	◀▶	☒

☒ Valve fully opened, ▶◀ Valve fully closed

3. Results and Discussion

Figure 3 presents the amount of water consumed during the rock melon cultivation. Total water consumed and rock melon yield was 18.59 m³ and 147.50 kg respectively. Therefore, WP was estimated to be 7.93 kg/m³. The high value of WP means high yield can be produced with a low amount of water applied and vice versa. Reference [16], calculated WP for dripped open field cultivated muskmelon in the range of 7-13 kg/m³ at different actual evapotranspiration. However, reference [17], estimated lower WP for melon, which was 5-6 kgm⁻³ under a drip irrigation system. WP obtained in this study is in an acceptable range and this variation might be due to different field practices and irrigation frequency applied. As asserted by [18], different crop types and varieties had different WP values where these values depending on their rainfall pattern, soil type and climatic conditions. Proper and reliable water supply is the main contributing factor to high production and high value of WP [19]. The WP could be increased by mulching practice as suggested by [20] since it can improve soil water content. High WP value indicated high water use efficiency.

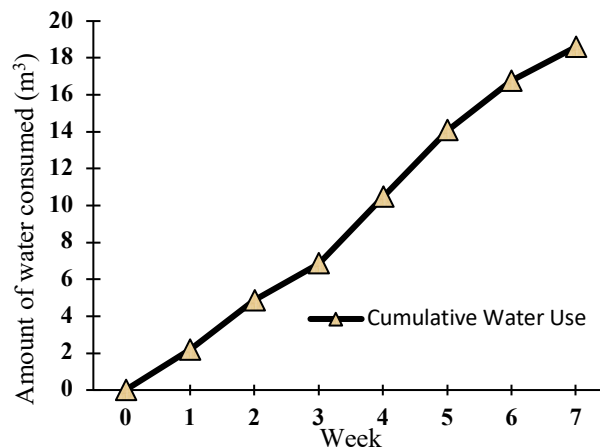


Figure 3. The amount of water consumed during rock melon cultivation

Irrigation level with higher amounts of water generally has lower WP and water use efficiency values [21]. Frequently applied of low irrigation water amount can increase fruit yield due to the consumption of water by the plant was higher when irrigation begins at low soil water content. Throughout the study, the operating pressure of the drip irrigation system tested varied from 0.8 to 3.0 psi with a discharge rate between 0.14 and 0.25 Lmin⁻¹. The working pressure was considered 1.5 times higher compared to the recommended pump power by [22] for 300 polybags. The existing system can still be operated normally

since excess pressure developed in the piping system being controlled by a valve to recirculate water to the mixing tank. However, this contributed to losses in power consumption and expenditure wastage. It is suggested to replace the 2.0 hp pump with 0.5 hp pump for better irrigation performance.

Table 4 illustrates the coefficient of variation (CV) and water application uniformity (AU) values with crop and without crop. In general, CV values were mostly classified as very good and acceptable in both conditions. CV values at laterals with crop and without crop were in the range of 0.14-0.45 and 0.10-0.34 respectively. It seems that CV estimation without crop showed lower values and duration taken to estimate it influencing these values. CV values obtained from without cropping can be classified mostly as the good and acceptable performance of irrigation system compared with without crop (mostly very good and excellent) as described by [15]. As eloquently stated by [23], different categories of CV also could be observed because of manufacturing variability, clogging due to the suspended fertilizer and damaged emitter.

Table 4. The parameter values that indicate the performance of lateral line in irrigation system with and without crop.

Condition	Lateral	Mean	SD	CV	AU	Classification of CV	Classification of AU
With Crop	1	0.29	0.06	0.22	77.69	Acceptable	Fair
	2	0.24	0.05	0.21	79.50	Very Good	Fair
	3	0.25	0.07	0.30	70.05	Acceptable	Poor
	4	0.18	0.08	0.45	54.64	Poor	Unacceptable
	5	0.18	0.04	0.25	74.96	Acceptable	Poor
	6	0.17	0.03	0.20	79.94	Very Good	Fair
	7	0.19	0.06	0.32	67.80	Poor	Fair
	8	0.19	0.05	0.27	73.16	Acceptable	Fair
	9	0.21	0.03	0.14	85.53	Very Good	Good
	10	0.16	0.04	0.26	73.82	Acceptable	Poor
	Average	0.21	0.05	0.26	73.71		
Without Crop	1	0.25	0.03	0.12	87.62	Very Good	Good
	2	0.19	0.02	0.10	89.59	Excellent	Good
	3	0.17	0.02	0.10	89.72	Excellent	Good
	4	0.16	0.02	0.13	87.39	Very Good	Good
	5	0.17	0.02	0.14	85.99	Very Good	Good
	6	0.14	0.05	0.33	67.00	Poor	Poor
	7	0.15	0.03	0.17	82.77	Very Good	Fair
	8	0.19	0.03	0.14	86.14	Very Good	Good
	9	0.15	0.05	0.34	66.06	Poor	Poor
	10	0.14	0.04	0.29	71.27	Acceptable	Fair
	Average	0.17	0.03	0.19	81.36		

It can be observed that CV without crop has a lower value than CV with crop cultivation as shown in Figure 4. Pair sample t-test showed significant different of CV between two conditions. Frequently flushing for whole cropping season guarantee each plant obtained the same amount of irrigation water every day. [25] reported that flushing was needed to remove the accumulation of sediments in the lateral before emitters become completely clogged. Therefore, it is vital to flush the laterals as frequent flushing reduce water variation along the lateral lines.

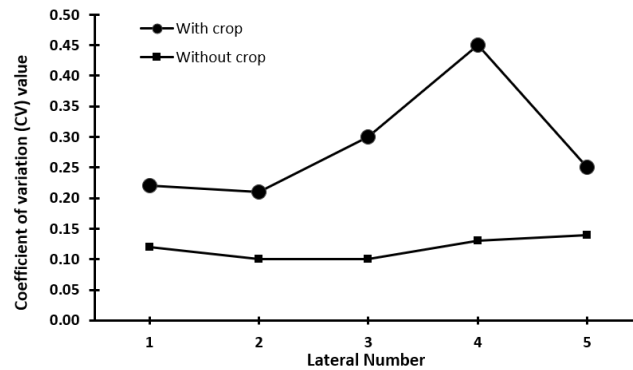


Figure 4. Comparison between the coefficient of variation values with crop cultivation and without crop cultivation. The different letters at the line represent a significantly different ($p < 0.05$).

Water application uniformity (AU) express how evenly the uniformity of water is spread over the irrigated area used. AU between lateral with crop conditions was found to be in the ranged Of 54 % and 85 % with an overall average of 74 %. These contributed to fair classification of AU between laterals for with crop conditions. On the contrary, AU between lateral without crop conditions was performed better (67% - 89%) with an average AU of 81%. Sixty percent of laterals without crop conditions were categorized as good and others as fair (2%) and poor (2%). [5] indicated that uniformity of water application decline due to defective of irrigation pump, broken or twisted distribution lines, obstruction in the dripper or filters, corrosion of parts in irrigation system, and inadequate design. [24] tested the performance of a drip irrigation system and found that average uniformity for drip irrigation system under the greenhouse was 80%. This value was almost similar to the result obtained (74%-81%). The application uniformity was depending on the manufacturing variation in emitters and pressure variation in the system due to pipe friction and elevation changes [13]. Therefore, maintenance and repair works have to be performed with great care periodically. Figure 5 compares the AU values with crop and without crop cultivation. Paired sample t-test showed significant AU on lateral 3 and 4. However, AU did not significant at lateral 1,2 and 5 for both conditions. This result might be due to same pressure magnitude at the beginning and at the last of lateral point. [26] mentions that the design and management of irrigation system not the only factor that influences water uniformity, but it could be from hydraulic gradients existing within the wetted soil which affect the water movement. Figure 6 expresses the mean of discharge was not significant among the head, middle and tail sections. The mean discharge for head (0.364 Lmin^{-1}) was reported to have the highest value compared to the middle (0.317 Lmin^{-1}) and tail (0.257 Lmin^{-1}). Droplets of water at the head section had the highest average discharge due to the nearest point from water resource and distribution of water movement did not influence by the precipitation or sediments compared to the other drippers at middle and tail sections.

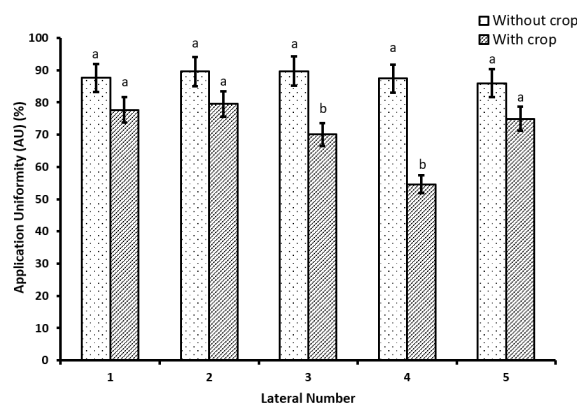


Figure 5. Comparison between AU values of with crop and without crop cultivation. The different letters at the bar chart represent significantly different ($p < 0.05$).

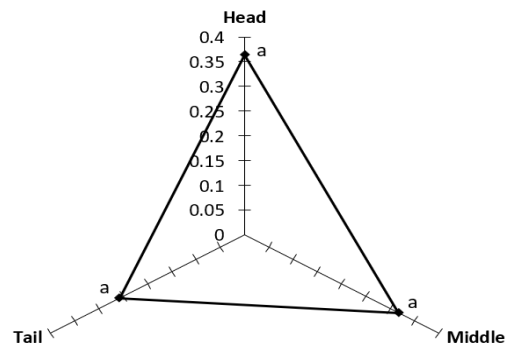


Figure 6. The mean discharge values at different sections of the drip irrigation system. Mean discharge values with different letter indicate a significant difference ($P < 0.05$).

4. Conclusion

Irrigation performance and WP for the rock melon cultivation inside the netted rain house shelter using the drip irrigation system was successfully evaluated. The WP obtained for rock melon using this system was 7.93 kgm^{-3} which is inline with the predicted WP value in the previous literature. Generally, most of the lateral lines performed well and some need to be monitored periodically, especially during the growing process to prevent clogging to the dripping system. The existing pump should be replaced with lower water pump power for the designated greenhouse to reduce energy consumption and better irrigation performance. The results also demonstrated variation of water application uniformity and water coefficient variation between laterals line, although they are located in the same fertigation system. Performance irrigation should be evaluated continuously from the beginning of greenhouse completion until current usage for detecting any abnormalities and leakage of the irrigation system.

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