Performance of closed-type irrigation system at a greenhouse

Vita Ayu Kusuma Dewi[1*], Budi Indra Setiawan[2], Budiman Minasny[3], Roh Santoso Budi Waspodo[2], Liyantono[1]

(1. Department of Mechanical and Biosystem Engineering, IPB University, Jalan Raya Dramaga, Bogor, Indonesia 16680
2. Department of Civil and Environmental Engineering, IPB University, Jalan Raya Dramaga, Bogor, Indonesia 16680
3. School of Life and Environmental Sciences, The University of Sydney, Central Ave St. no 3 Eveleigh, New South Wales, Australia 2015)

Abstract: Water application in the plant house is usually done by surface irrigation and manual micro-irrigation. Because of the conventional irrigation system's inefficiency, water-saving irrigation has been developed. Smart or automated irrigation usually uses a micro-controller to maintain irrigation timing and soil moisture conditions. This automation is highly efficient in water application and can increase plant productivity. However, this system is costly, and the irrigation components are not always available for smallholder farmers. Here we develop a controlled irrigation technology based on the capillarity principle that dramatically reduces the cost. This irrigation technology does not use any micro-controller device and the components can be easily acquired. This irrigation was driving by evapotranspiration and matric suction. This system was tested in an organic vegetable plant house from February to March 2018. This technology can maintain soil, water content between field capacity and wilting point. In addition, all plants perform well during the cultivation period. This technology only requires 0.038 m^3 water during the whole period of cultivation (40 days). Compare with the sprinkler irrigation, it is 40% more efficient. Through this technology, all smallholder farmers can easily apply and reduce water loss in irrigation

Keywords: high productivity, horticulture, irrigation, plant house, water use efficiency

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1 Introduction

The use of micro-irrigation in the plant house has been widely, adopted including drip irrigation (Candra et al., 2015; Kuslu et al., 2016; Moller and Weatherhead, 2007), and sprinkler irrigation (Bria et al., 2017; Christen et al., 2006). The micro-irrigation system was developed into a smart or automated irrigation system using micro-controller components (Laumal, 2017). The micro-controller can be activated using a wireless network (Af'idah et al., 2014; Putranto, 2018; Syamsiar et al., 2016; Wiranto et al., 2014), the solar-based controller (Ascione, 2017; Sirait et al., 2015; Yu et al., 2018). The application of water is determined by a programmable logic controller (Setiawan et al., 2013) and can be based on soil moisture content (Chaer et al., 2016; Rahmawati and Aji, 2015).

However, smart-irrigation technology that use micro-controller has not been fully adopted especially by smallholder farmers because of its high operational cost. Rejekiningrum and Saptomo (2015) mentioned that the application of automatic irrigation must consider financial feasibility and assisted by continuous financial support. The

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***Corresponding author: Vita Ayu Kusuma Dewi,** IPB University, Jalan Raya Dramaga, Bogor, Indonesia 16680, Indonesia. Email: dr.vita15@gmail.com. Tel: +6285736741066, Fax: +62518425583.

design of an irrigation technology should not just consider water efficiency and productivity, but it should also consider its practical application to smallholder farmers.

Therefore, this study aims to develop a simple controlled irrigation technology based on the capillarity principle that can be easily used for horticulture plants. This research, introduce definition of "smart irrigation," which in this case, smart is represented by a simple, cost-effective concept and able to apply by all stakeholders. This technology is inexpensive, easy to build, and should be able to maintain soil moisture required for plants. This system will increase water use efficiency and crop productivity.

2 Material and Methods

2.1 Irrigation system concept

The basic concept of this irrigation system builds from simple principles of communicating vessels and capillarity. This irrigation design can be classified as a sub-surface irrigation that has a high efficiency because water is applied in the root zone (Devasirvatham, 2009; Haryati et al., 2010; Lakova, 2016). Water is supplied to the pot via the communicating vessels principle. The theory said that containers or vessels that are interconnected, if filled with a similar liquid, then the surface of this liquid will be of the same height at all vessels. As water is supplied to the pot, water is supplied to the soil via the capillarity principle. Capillary irrigation distributes water through a fabric filter. This irrigation system is driving by evapotranspiration and matric suction, so it can flow naturally without microcontroller. This is the novelty of this research.

2.2 Irrigation system design

The irrigation system consists of several parts as shown as Figure 1, including (1) a reservoir, (2) a connecting valve, (3) distribution pipes, (4) pots for growing media, and (5) a water level controlling pot. This design considers an ergonomic principle, where the system can be placed on a table. The materials used for this system were described in Table 1.

Table 1 Materials used in the automated irrigation system

Function	Material
Reservoir	Bucket (375 × 295 × 260 mm) Floating valve 2”
Distribution pipes	PVC pipe 2” Pipe Tee 2” Pipe Elbow 2” Pipe Knee 2”
Filter	Fabric (Legacy)
Planting media	Pipe Increaser 4” × 2” PVC pipe 4”
Discharge gauge	Water meters (m^3 scale)

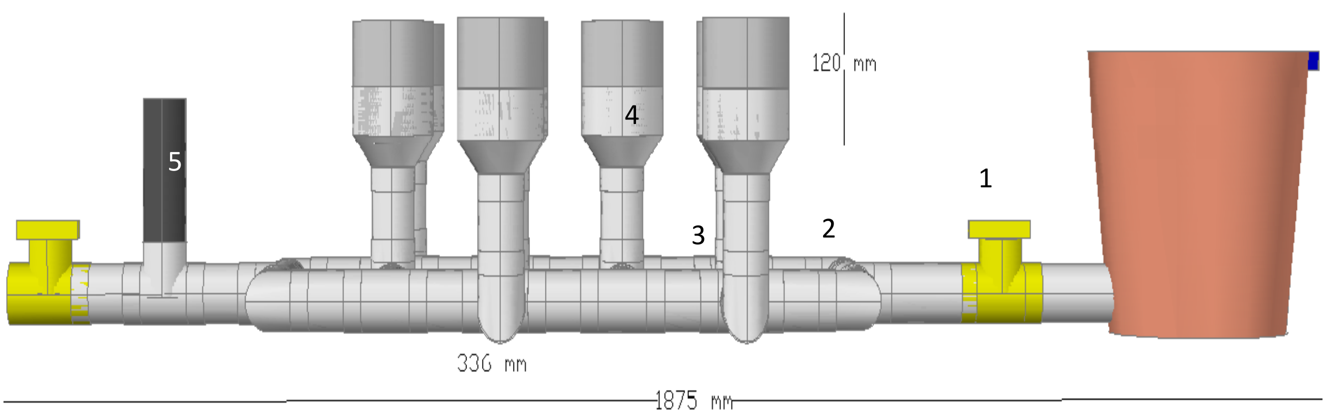

Figure 1 Irrigation system component

The reservoir made from a bucket that is connected to a floating valve and distribution pipes. The floating valve will release water while the water level in the reservoir is based on a required height. The pots were connected via pipes as shown in Figure 2. The height of the pot is determined based on the roots of vegetables. The growing media (soils) are filled in the pots, and the bottom of the pot is a filter made of fabric with a hydraulic conductivity that is higher than soil’s hydraulic conductivity. The filter delivers irrigation water from the distribution pipe to the root area of the plant based on the capillarity principle. The type of fabric can be adjusted to the type of soil with the material's hydraulic conductivity as a parameter. The hydraulic conductivity of the fabric used in this study is 158.4 cm/hour measured by the falling head method.

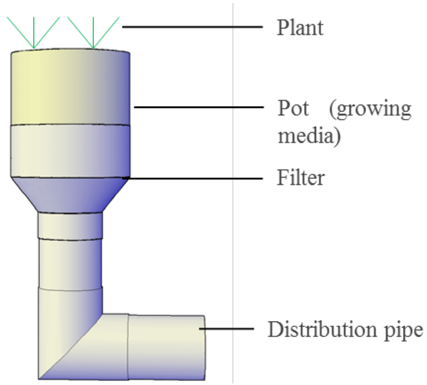

Figure 2 Design of pot

2.3 Workflow of irrigation system

Water from the main water source will flow into the reservoir according to the requirements, which is based on a defined water level. The water level in the pot will follow the reservoir's level. The initial set up the water level in this study was 16.8 cm, equivalent to the surface of the filter on the planting media.

While evapotranspiration process occurs, the water content in the growing media will be reduced. Growing media in the form of soil will suck water through the filter with the effect of matric suction. Then the water level in the reservoir will decrease. A floating valve that is connected to the water source will automatically release water if the water level in the reservoir falls below the required height. This added water will automatically flow to each pot through the distribution pipe. The water level in the reservoir is at the filter surface, so water will be distributed to the root zone based on the capillarity principle of the soil. During cultivation, the water level will be maintained at the reservoir's water level. The amount of water used is calculated through a water meter installed in the inlet pipe. The remaining water was calculated at the end of the cultivation period using a water meter in the drainage pipe

2.4 Irrigation system test

The irrigation system was tested on an organic vegetable system that is grown in a plant house located in the Department of Civil and Environmental Engineering, Bogor Agricultural University from February 2018 to March 2018. This is a naturally ventilated plant house as shown in Figure 3. The crop being cultivated was Kailan (*Brassica oleracea* var. *alboglabra*). Vegetable seedlings were grown for about 14 days before transplanting in the plant house in a soil media (for 40 days).

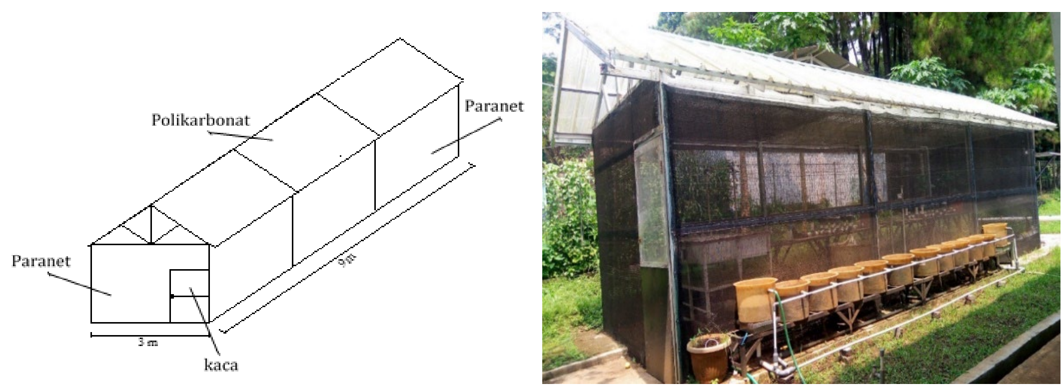

Figure 3 Plant house as a research location

Daily climate parameters, soil and plant parameters were collected during the study period (40 days). Climate parameters include solar radiation (Decagon PYR Pyranometer), air temperature, humidity and air pressure using the Decagon VP-4 system. Soil water content was observed using Decagon EC-5. Soil samples were analyzed in the Soil Physics Laboratory of Indonesian Soil Research Institute (ISRI). Plant parameters that were measured include plant height, number of leaves and plant mass (wet and dry).

Irrigation performance was evaluated by its functional aspect (Candra et al., 2015) and plant growth (Sahira, 2017).

Functional aspect means that the system can maintain soil, water content between field capacity and wilting point. The analytical methods used in this study include Van Genuchten model (Genuchten, 1980).

Figure 4 Prototype of the Irrigation system

3 Results

3.1 Irrigation system leakage and maintenance test

The proposed irrigation system is shown in Figure 4 using a bucket as a reservoir, floating valve, pipes as planting media and distribution pipes, fabric as a filter and the water meter. The system was first tested for leakage and the maintenance of water level. The leakage test showed that the system has no leakage and the water table is maintained at the desired level. Water can distribute continuously, and the soil surface looks wet in around the plant roots represent subsurface irrigation purpose.

3.2 Soil physical properties

The soil used to test the system is a silt loam based on the USDA soil texture triangle. Silt loam has a large soil water holding capacity that is available to plant, compared to sand and clay. The soil physical properties are shown in Table 2. The water retention data of the soil is fitted to the Van Genuchten model (Genuchten, 1980):

$$\theta(h) = \theta r + \frac{\theta s - \theta r}{\left[1+|\alpha h|^{n}\right]^{m}} \tag{1}$$

where, θ is volumetric water content (cm^3 cm^{-3}), θr is residual water content (cm^3 cm^{-3}), θs is saturated water content (cm^3 cm^{-3}), h is soil water potential (cm), α is a scale parameter inversely proportional to mean pore diameter (cm^{-1}), n and m are the shape parameter of shape parameters of soil water characteristic. The parameters of the Van Genuchten model were estimated using the Neuropack package (Minasny and McBratney, 2002). The parameters are residual water content (θ_r) = 0%; saturated water content (θ_s) = 60%; a = 0.0261 cm^{-1}; m = 0.18 and n= 1.23. Field capacity condition (FC) occurs while soil water content at 35.6% and 14.9% for permanent wilting point (PWP). Based on the Van Genuchten model, the relationship between *pF* and soil water content presented in the water retention curve as shown in Figure 5.

Table 2 Soil physical properties

Parameter	Unit	Value
Texture		
Sand	%	15.00
Silt	%	66.00
Clay	%	19.00
Bulk density	g cm^{-3}	0.72
Particle density	g cm^{-3}	1.88
Porosity	% volume	62.00
Permeability	cm hour^{-1}	38.56

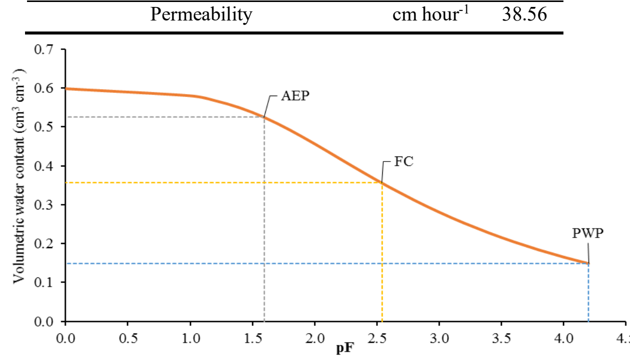

Figure 5 Water retention curve

3.3 Performance of irrigation system

3.3.1 Soil water content condition

Soil water content is a parameter to evaluate the functional aspect of the irrigation system. Soil water content during the study period is fluctuated, however the condition still on the available water, which is between field capacity and permanent wilting point (Figure 6). In this condition, the plant roots can easily absorb the water. Soil, water content was an increase in the initial stage and decrease while late season. Allen et al. (1998) mention, the crop coefficients for lettuce were 0.7 (initial stage), 1.0 (mid-season) and 0.95 (late season). It means the biggest evapotranspiration was happening in the mid-season. The readily available water (RAW) value in this study is 62.2 mm which means irrigation water should apply approximately 62.2 mm to refill water in the root zone.

Based on the soil, water content condition, the irrigation system able to maintain soil, water content between field capacity and wilting point, even though evaluation is needed to reach an optimum condition. In this study, the soil, water content in the mid-season is between field capacity (FC) and readily available water (RAW) condition which is best plant growth is in between these conditions.

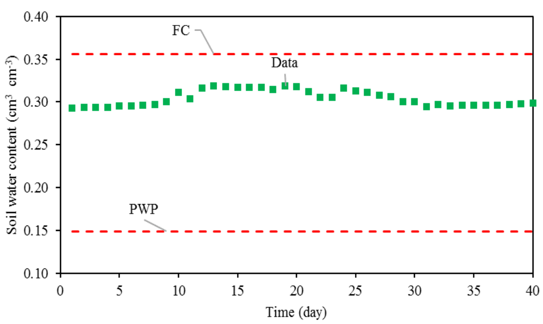

Figure 6 Soil water content condition during the study period

3.3.2 Plant growth performance

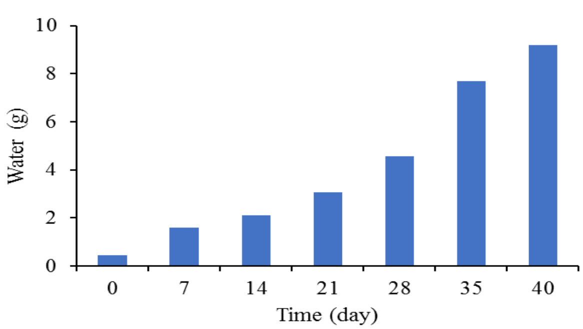

Figure 7 The water in a plant increases continuously until harvest day

Table 3 shown a plant growth parameter during the study period. Plant growth performs well and no dead plant until the harvest period. In this study, the water content in the plant was obtained from weight data. The water content in the plant shown in the Figure 7. The amount of water in the plant is between 81%-91% of the plant's wet weight.

The yield was 85.6 g from the system, with the water consumption 38 L. In this stage, the water productivity was 2.2 g L^{-1}, and land productivity was 1038 g m^{-2}. This yields still below the commercial Greenhouse that produce 2000 g m^{-2}. The soil condition in the pot causes it was organic soil. This condition cannot be ascertained the available nutrients.

Table 3 Plant biomass based on the measurement

Time	Weight		Height	Number of
(day)	Wet (g)	Dry (g)	(cm)	leaves
0	0.55	0.10	5.00	3
7	1.85	0.26	8.80	4
14	2.30	0.21	14.80	5
21	3.45	0.40	16.20	8
28	5.30	0.75	18.90	8
35	8.80	1.10	20.80	9
40	10.70	1.50	23.90	9

3.3.3 Water consumption

In the reservoir was applied 0.020 m^3 irrigation water (initial conditions) and automatically filling when the water level decreasing. Based on observation, the floating valve refills water once per five to six days. Total water use during the study period is 0.053 m^3 and the remaining water at the end of cultivation is 0.015 m^3. Therefore, the water consumption in the system during cultivation is 0.038 m^3 or 38 mm, it means the water consumption is 0.0045 m^3/pot or 4.5 mm/pot. Dewi et al. (2017) calculate the water use during Kailan cultivation with sprinkler irrigation in the plant house is 55 mm. So, this irrigation system can save 40% of water use than sprinkler irrigation.

3.4 General Discussion

Over the last decade, many researches develop a controlled irrigation system with various control strategies such as on-off threshold, Fuzzy logic, ANN, Proportional Integral Differential (PID), etc. that connect to the sensor or expert system (Jha et al., 2019; Romeroa et al., 2012). This research introduces the new method and cost-effective irrigation system without a micro-controller. The irrigation system was driving by evapotranspiration with modest principles such as capillarity and connecting vessels. The irrigation system directly watering the root zone; it means there is no percolation, erosion, or leaching the nutrient in the media. This condition was different from the surface irrigation maybe cause erosion. Besides that, the advantages of this irrigation system solved the cultivation problem such as limitation of land and water, labor or human, operation and maintenance, water efficiency, and climate changes. This irrigation system able to use in urban farming

The results of this study indicate that land and water productivity less than in commercial plantation. The limitation of this research is organic cultivation. It could be affected by the soil nutrient (Nurlaeny, 2015) or agronomy factor of the plant (from seedling and cultivation). Although this irrigation system is able to maintain available water, improvisation is still needed to increase productivity. Land productivity in the design that has been designed could be maximized again by adjusting the distance between the planting media pots by considering the type and area of the plant canopy to be planted.

4 Conclusion

Irrigation system performs well during the study period. Beside can maintain soil, water content condition between field capacity and permanent wilting point, this irrigation system has higher water use efficiency than sprinkler irrigation. In addition, the plant grows well until the cultivation period with water content in the plant around 81%-91% of the plant's wet weight. Water consumption during the cultivation period is 0.038 m^3 or 38 mm (for 40 days). Based on the result, this irrigation system needs further evaluation to reach an optimum condition both of water use efficiency and yield.

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