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Article

# A Model and Its Performance of Evapotranspirative Irrigation Tested to Grow Water Lettuces

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Efficient use of irrigation water is crucial to face the uncertain trend of a declining water resource. Ensuring a supply of water that matches crop evapotranspiration (*ETc*) while optimizing soil moisture is challenging. This study aimed to come up with a model of an irrigation system that can supply water immediately to meet *ETc* without using electricity. To test the proposed water balance model a trial was established in water lettuces. The system consisted of 15 pots connected in serial using water pipes and hoses through the bottoms of the pots. The first pot was used as a water level controller and the last pot used as a drain water collector. Irrigation water would flow immediately to the pots that had water levels lower than the setting level. Testing carried out on rainy days resulted in considerably higher rainwater (99.8%) being utilized compared to the irrigation water (0.2%). For water lettuces, the yield was 258.9 g/m$^2$, water use efficiency reached 95% while the economical and physical water productivity were 2.17 g/L and 2.28 g/L, respectively. The water level in the pots could be maintained within the expected range while the soil moisture maintained an unsaturated condition. Further tests however are still needed, which currently is underway.

**KEYWORDS:** Evapotranspirative irrigation, Water balance model, Water lettuce, Water productivity

## Introduction

Climate change has caused water resource becomes more uncertain whether in space and time which in turn affects the availability of irrigation water. Since then, increasing the efficiency of irrigation water has drawn more attention. Precision farming with smart irrigation is an important endeavor to meet the actual water need by the crop.

There are techniques (drip, sprinkler, etc.) available to supply the irrigation water efficiently though most of them rely on sensors to detect soil moisture or water potential, which is not representing the rate of water consumed by the crop, or crop evapotranspiration (*ETc*). *ETc* known as the most determining component of water balance in the soil-plant-atmosphere system (Consoli and Vanella, 2014) which is highly dependent on weather, plant variety and maturity. It is not easy for these techniques to meet *ETc* neither in time nor quantity.

Literally, crops absorb the water effortlessly when the soil moisture in the root zone is at the readily available water (*RAW*) which is somewhere between the field capacity (*FC*) and permanent wilting point (*PWP*) (Dewi *et al*., 2020). Practically, it is not a simple task to maintain *RAW* since the water from the soil surface takes time to reach the root zone while *ETc* fluctuates uncertainly with time.

Water productivity (*WP*) is important indicator to judge how the water supplied contribute to the crop production (Hinai and Jayasuriya, 2021). There are 2 types of *WP* resumed here as follows (Muharomah *et al.*, 2020):

$$WP_p = \frac{W_d}{ET_c} \quad (1)$$

$$WP_e = \frac{W_d}{R+Q} \quad (2)$$

$$WUE = \frac{ET_c}{R+Q} \quad (3)$$

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In which, subscripts $p$ for physical and $e$ for economical. Herewith, R is rainfall, $WP_p$ denotes the contribution of $ET_c$ to the weight of the dried biomass ($W_d$), $WP_e$ denotes the contribution of irrigation water ($Q$) to $W_d$, and $WUE$ is the water use efficiency (%) (Sun *et al*., 2006). The unit of R and Q is liter (L), the unit of $W_d$ is gram (g), and the unit of $WP_p$ and $WP_e$ is g/L.

While $WP_e$ may highly fluctuate with season, $WP_p$ is more stable and thus becoming a valuable indicator for comparison among different irrigation techniques. The highest $WP$ is reached when $Q$ meets with $ET_c$, or $Q = ET_c$ which should be the set target of any irrigation practice. Thus, any deviation of $Q$ toward $ET_c$ will reduce $WP$. Higher $WUE$ can be attained when the incoming water timely distributed uniformly over the fields (Hassan-Esfahani *et al*., 2015), and contribute directly to $WP_e$ and $WP_p$ (Fuadi *et al*., 2016; Sirait *et al*., 2015). Rationalizing the water supply at a certain level can increase $WP$ (Hasanah *et al*., 2017).

Smart irrigation system can indeed improve $WP$ but is highly relies on electricity and instrumentations which are rarely available in the real fields (González Perea *et al*., 2016). Instead, a simpler cost-effective irrigation manageable by farmers is essential (Wang *et al.*, 2021) which can support the farmer-lead irrigation development (FLiD). Under FLiD, a preferable irrigation technique should be less burden on public finances, faster process to implement and spreading more benefit (P)[1].

There are various types categorized as unpowered irrigation driven by the natural *ETc* process. To date, pitcher irrigations can meet *ETc* precisely and are advantageous for small-scale farming though the pitcher making is time consuming (Setiawan, 2000; Saleh, 2010; Abu-Zreig *et al*., 2006; Paredes and San Jose, 2019; Siyal *et al*., 2009). Ring emitter made of a perforated hose covered with a specific garment can release the water sucked by plant's roots (Saefuddin and Saito, 2019; Saefuddin *et al*., 2019; Sumarsono *et al*., 2018).

Evapotranspirative irrigation (ETI) is another new type of irrigation technique that has been developed (Ardiansyah *et al*., 2019; Agustina, 2021; Arif *et al*., 2022). In principle, ETI uses *ET* energy to maintain the water level below, that through capillarity supplies the water to the rootzone. Herewith, any decrease in the water level will be balanced immediately with the same volume of incoming water controlled by a mechanical bulb-valve. The mechanism is self-regulated and use no electricity. Some results, in small plots, show ETI can increase water productivity over 14.5% without reducing rice yield (Agustina, 2021; Arif *et al.*, 2022) and was proven water-efficient and inexpensive to cultivated water lettuces (Muharomah *et al*., 2021).

This study aimed to come up with a model of irrigation sys-

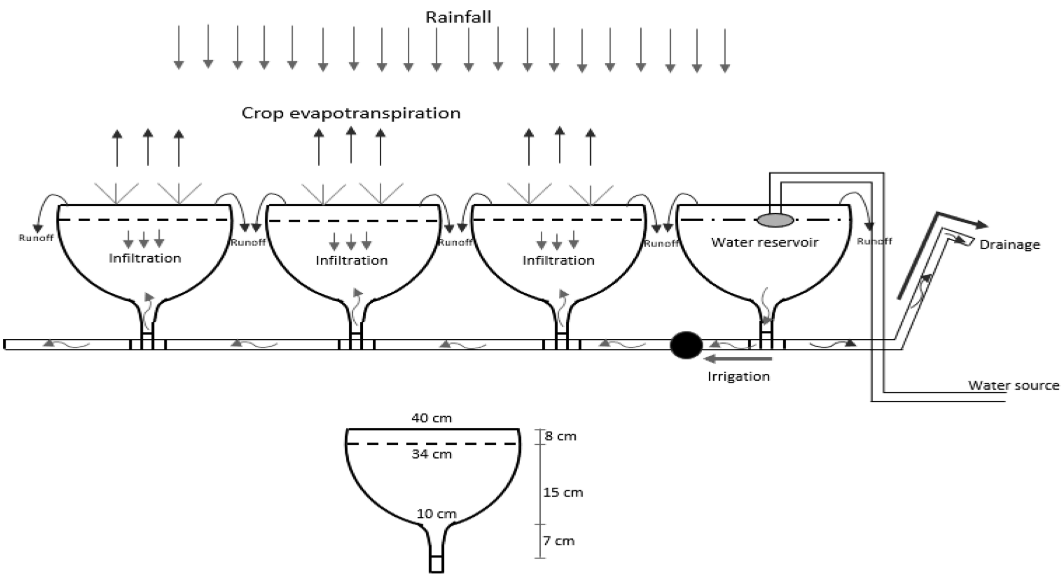


**Figure 1.** A schematic figure of the irrigation system.

[1]Farmer-led irrigation: the what, why, and how-to guide (worldbank.org)

 

tem that can supply the water immediately to meet *ETc* without utilizing electrical energy. Then the objective of this study is to derive the water balance model and obtain its performance tested to grow water lettuces.

## Methodology

The study was conducted in the Department of Civil and Environmental Engineering, IPB University, Bogor, Indonesia on the latitude of 6°33'24.23"S, longitude of 106°43'33.4"E and altitude of 250 m above sea level. The field site has been equipped with an Automatic Weather Station (AWS). The average annual rainfall is over 3000 mm with the wet season commonly starts from September to February though some time longer until end of April. An outside experiment was done from November and December 2020 which was in the coincident with the rain season.

The subsurface ETI designed here (Figure 1) comprises a series of pots connecting each other with water hoses (1/2 inch diameter) through their bottoms (Muharomah *et al.*, 2021). There are 15 pots formed like funnel with its upper and lower diameters are 40 cm and 10 cm, and height of 23 cm. The first pot was set as a reservoir that receives water from a tapped water through a mechanical water bulb-valve functioned to maintain its water level. While the last pot was equipped with an outlet to drain the excess of rainwater.

The other 13 pots were filled with planting media made of alluvial soil plus organic material and planted with water lettuces (*Ipomoea aquatic*) following the standard cultivation practice. The cultivation lasted 45 days in which every 15 days, parts of the plant, about 5 cm above the soil surface, were cut/harvested and the remains were left to regrow. The wet biomass was weighted and then oven-dried at 80°C for 3 days to get the dry biomass ($W_d$).

The water from the reservoir will immediately flow when the water level in the planted pots drop due to roots' abstraction. Analog flowmeter was used to measure the waterflow and record every day around 06:00 GMT+7. Intermittent soil sampling in the surface soil using 100 mL ring sample was conducted to check the water content above the water level following the gravimetric method.

Referred to Figure 1, the water balance equation in volumetric unit can be written as follows:

$$\frac{\Delta V_i}{\Delta t} = (R_i - Etc_i)A_p + Q_i - D_i \quad (4)$$

$$\Delta V_i = V_i^{t+\Delta t} - V_i^t \quad (5)$$

$$R_i = P - RO_i \quad (6)$$

$$RO_i = \begin{Bmatrix} P & H_i \geq H_p \\ 0 & H_i < H_p \end{Bmatrix} \quad (7)$$

$$ETc_i = Kc_i ETp \quad (8)$$

Where $V$ is water volume in the pots (cm$^3$), $R$ is the entering rainwater/infiltration (cm day$^{-1}$), $ETc$ is crop evapotranspiration (cm d$^{-1}$), $A_p$ is the area of soil surface (cm$^2$), $Q$ is irrigation (cm$^3$ d$^{-1}$), $D$ is drainage (cm$^3$ d$^{-1}$), $P$ is precipitation (cm d$^{-1}$), $Kc$ is the crop coefficient, $ETp$ is the potential evapotranspiration (cm d$^{-1}$), $RO$ is runoff (cm d$^{-1}$), $H$ is the water level in the pot (cm), $H_p$ is the highest water level ($H_p$ = 30 cm), $i$ is pot number ($i$ = 1, 2, ... $n$, $n$ = 14), and $t$ is time (d) with $\Delta t$ is the time interval (d).

Considering the pot is in the form of a funnel, the volume of water is calculated as follows.

$$V_i = \frac{\pi}{3}(r_i^2 H_i - R_0^2 h_0) \quad (9)$$

$$H_i = h_i + \theta_i Z_i \quad (10)$$

Where $r$ is the radius of the cone at $H$ (cm), $R_0$ and $h_0$ are constants each 34 cm and 22 cm, $h$ is the water level in the saturated soil layer (cm), $\theta$ is the volumetric water content in the unsaturated soil layer (cm$^3$ cm$^{-3}$), and $Z$ is the depth of the unsaturated soil layer (mm).

As $Q$ and $D$ were measured in the first and the last pot and with the inclusion of water status in the plant, Eq. (5) can be expanded as follows:

$$\Sigma_i^n \frac{\Delta V_{T,i}}{\Delta t} - [A_p \Sigma_i^n (R_i - Kc_i ETp) + Q - D] = 0 \quad (11)$$

$$V_{T,i} = V_i^t + V_{b,i}^t \quad (12)$$

Where $V_T$ and $V_b$ are the volumes of total water (cm$^3$) and water in the biomass (cm$^3$). The potential ET ($ET_p$) was calculated using Hargreaves model as follows.

$$ETp = C\, R_s(T_a + 17.8) \quad (13)$$

In which, $T_a$ is the average temperature (°C), and $R_s$ is the solar radiation (MJ $m^{-2}$ $d^{-1}$), and $C$ = 0.0135 (Muharomah *et al.*, 2020). The crop coefficient ($K_c$) was calculated by mean of optimization process using the Solver in MS Excel to minimize the absolute error ($\varepsilon$) of Eq. (5) in the following form (Arif *et al.*, 2019):

$$\varepsilon=\left|\frac{\Delta V_i}{\Delta t}-(R_i-Kc_iETp)A_p+Q_i-D_i\right| \quad (14)$$

# Results and Discussions

## 1. Microclimate Condition

Figure 2 shows the microclimate consists of the average temperature ($T$), the average relative humidity ($RH$), the daily solar radiation ($Rs$) and the daily potential evapotranspiration ($ETp$) calculated using Eq. (13). The daily temperature ($T$) varied from 23.9°C and 28.5°C with the average value of 26.6°C in 45 days. This range was fairly within the favorable temperature for water lettuce, which is between 20-28°C. However, the maximum daily temperature varied from 26.6°C to 35.9°C. These high temperatures (>35°C) will cause momentarily wilts (Chowdhury *et al*., 2016; Haditiya and Prijono, 2018). While the average humidity varied between 74.9% and 92.6% with the overall average was 83.2%. This range of $RH$ is also above 80% which is favorable for the plant growth. Solar radiation ($Rs$) varied between 3.7-27.4 MJ $m^{-2}$ $d^{-1}$ with the average was 13.0 MJ $m^{-2}$ $d^{-1}$.

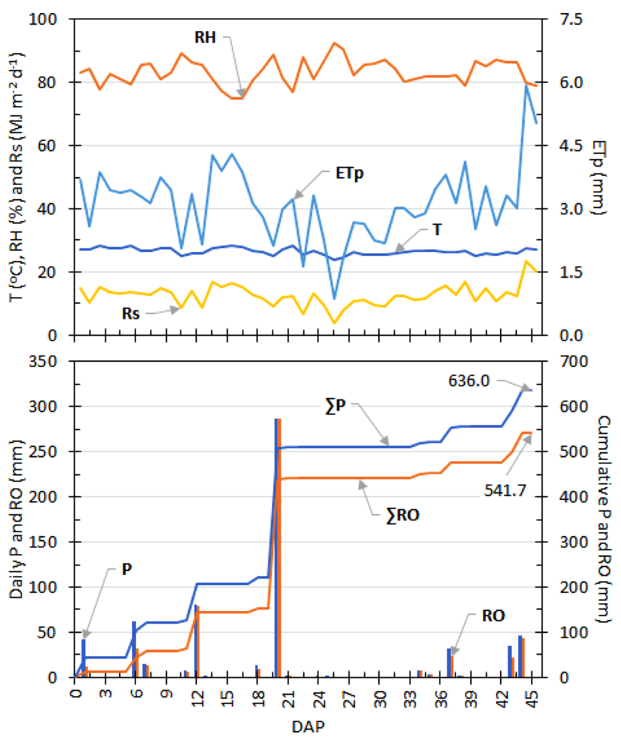


Figure 2. Microclimate from November 11th to December 27th, 2020.

Potential evapotranspiration ($ETp$) fluctuated abruptly in the range of 0.9-6.9 mm with the average value of 3.2 mm. This range is not far from the data reported earlier between 3-5 mm/d by Muharomah *et al.* (2020), Hasanah *et al.* (2015), Hasanah *et al.* (2017), Diansari *et al.* (2019), Amalia *et al.* (2020), Dewi *et al.* (2020b), Dewi *et al.* (2020a).

Precipitation ($P$) frequently occurred with the highest value reached 287 mm in 20-DAP (Dec 1st, 2022) and its cumulative ($\sum P$) amounted to 636 mm. Most of the precipitation overflowed as run-off ($RO$) accumulated to 541.7 mm (85%). Thus, it was only a small fraction (15%) of the precipitation infiltrating into the soil layers.

## 2. Water Balance Components

Figure 3 shows the daily and cumulative rainwater plus irrigation, drainage and potential evapotranspiration. These water components fluctuated with time and were highly influenced by the rainwater ($R$). The water that entered the soil ($R$+$Q$) was 859 L dominated by rainwater ($R$) amounted to 857 L (99.8%). While irrigation water ($Q$) contributed only 1.9 L (0.2%). Most of the rainwater instantly drained ($D$) accumulated to 663.8 L (77.3%).

Rainwater ($R$) was defined here as precipitation ($P$) minus run-off ($RO$). Run-off occurred when the precipitation exceeded 82.8 L with its intensity 0.051 m/d. The soil percolation rate might be less than this intensity. This value was sufficiently higher capable to drain the rainwater by gravity as the drainage ($D$) appeared almost instantly following the rainfall events. Herewith, the drainage coefficient or ratio [$D$/($R$+$W$)] fluctuated once to reach 96% with the average was 29%. This high response of the drainage is deemed beneficial to demonstrate the leaching capability of the soil. For subsurface irrigation, leaching capability is important to prevent salt accumulation on the soil surface because of salinity process. Salt accumulation would increase the soil electrical conductivity ($EC$) and deter plant growth.

The other parts of the water were stored in the soil layers 9.8 L (1.1%) and consumed by the plant as the crop evapotranspirations ($ETc$) 185.3 L (21.6%). This value was lower than that of Diansari *et al.* (2019), where they used floating

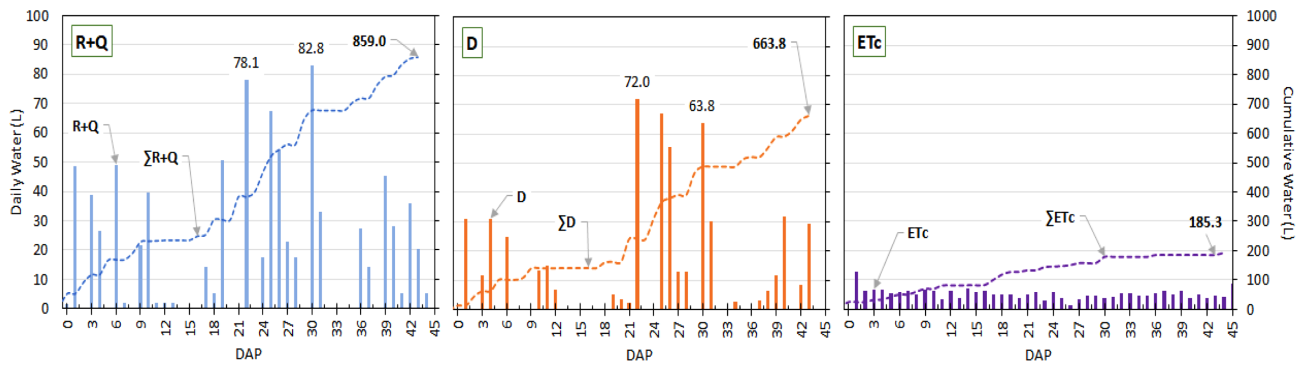


**Figure 3.** Rainwater (*R*), irrigation (*Q*), drainage (*D*) and crop evapotranspiration (*ETc*).

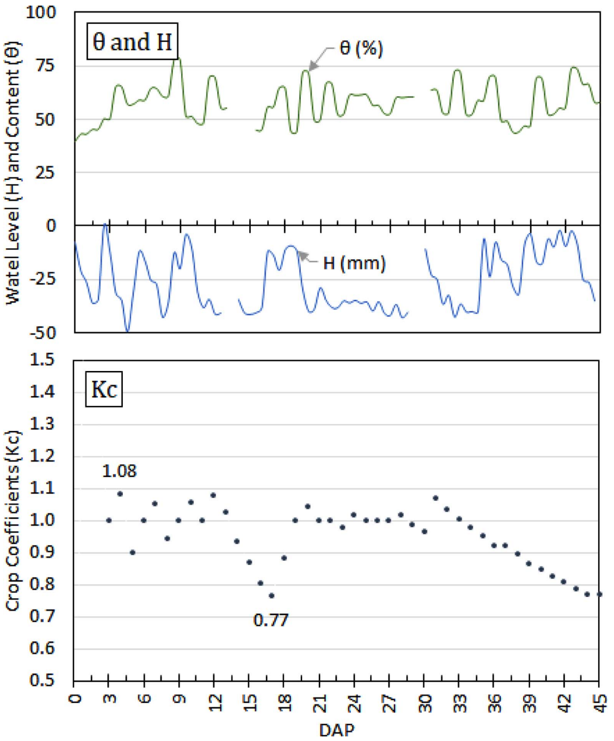


**Figure 4.** Water level (*H*) and content (*θ*) and crop coefficients (*Kc*).

pots and resulted in 243 L for 3 harvestings. Reduced water use was also reported by Arif *et al.* (2021) which could enhance land and water productivities.

Irrigation water (*Q*) functioned mainly to return the water level to the set position when it decreased due to the water consumption by the plants or crop evapotranspiration (*ETc*). With no rainwater (*R*=0), this apparatus can be used to estimate the crop evapotranspiration (*ETc*) or functionalized as a lysimeter (Casanova *et al.*, 2009; Domínguez-Niño *et al.*, 2020) and furthermore to determine the crop coefficients. Herewith, given *R*=0 then simply *ETc*=Q.

Figure 4 shows the water level (*H*) in the soil layer and saturation degree (*S*) of the soil above *H*. In this experiment, the water level was set 25 mm below the soil surface. Here, *H* varied with time in the range of 0.36-49.5 mm with the average value 26.6 mm. This considerably slight deviation indicating that this irrigation system was capable to keep the water levels within the tolerable range. Furthermore, the soil saturation degree was between 39-78% with the average value 58%. Thus, the surface soil remained unsaturated with water unsimilar to hydroponic (Dewi *et al.*, 2020) and floating techniques (Diansari *et al.*, 2019).

As shown also in Figure 4, crop coefficient (*Kc*) resulted from the optimization process (Eq. 14) varied with time. Here, *Kc* varied between 0.77-1.08 and decreased steadily from 1.1 to 0.77 after 30 days after planting (DAP). It is noticeable *Kc* was lower when there was no rainfall in the period of 12-21 DAP. These values of *Kc* for water lettuce are not far from those reported elsewhere (Allen, 2003; Allen and Pereira, 2009).

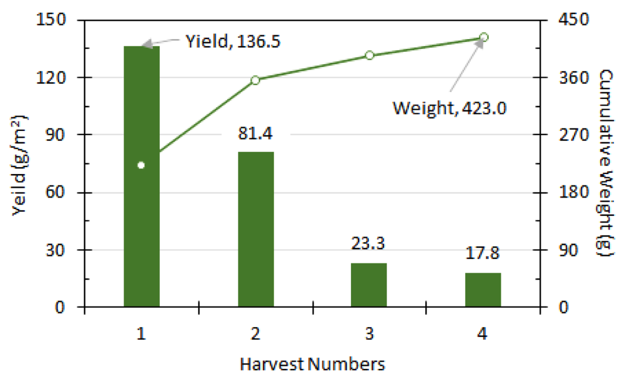


**Figure 5.** Biomass production.

3. Yield, Water Productivity and Water Use Efficiency

Figure 5 shows the yield and cumulative weight of the cut biomass from 4-time harvestings. Yield measured as the total oven-dried biomass divided by the whole surface area. The dried biomass ($W$) accumulated to 423 g while the yield decreased with the subsequent harvesting from 136.5 g/m$^2$, 81.4 g/m$^2$, 23.3 g/m$^2$ and 17.8 g/m$^2$. The overall yield was 258.9 g/m$^2$. Furthermore, economical water productivity ($WP_E$) was 2.17 g/L, physical water productivity ($WP_P$) was 2.28 g/L, and water use efficiency ($WUE$) was 95%. The $WP_E$ is not far from the results reported earlier 2.4 g/L by Muharomah *et al.* (2020) and 2.2 g/L by Dewi *et al.* (2020) in greenhouses with different techniques.

## Conclusions

A new non-conventional irrigation technology named Evapotranspirative Irrigation (ETI) model has been developed and tested, and it can work well for crop cultivation. The system consisted of 15 pots connected in serial using water pipes and hoses through the bottoms of the pots. The first pot was used as water level controller and the last pot used as drain water collectors. Irrigation water could flow immediately to the pots when the water level there lower than the setting level. The water level in the pots could be maintained within the expected range while the soil moisture above was kept in unsaturated conditions. The yield, water productivity, and water use efficiency in this technology can reach higher values compared to conventional methods. Further tests however are still needed which currently underway toward the dry season.

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