Simple method to determine irrigation water requirement for coffee (*Coffea arabica* (Linn)) nursery

E Sulistyono¹*, A Wachjar¹ and H F Rochmah¹

¹Department of Agronomy dan Horticulture, Faculty of Agriculture, Bogor Agricultural University.Jl. Meranti. Kampus IPB Darmaga. Bogor 16680. Indonesia.

*Email: pengelolaanair@yahoo.com. ekosulistyono@ipb.ac.id

Abstract. Easy method that used simple instrument was needed to calculate irrigation water requirement rapidly. The research was conducted to get coefficient for determining crop water requirement. Data was generated with single factor experiment arranged in Randomized Block Design with three replications at Bogor Agricultural University Research Station during March to October 2013. The treatment was five levels of shading that were 0, 25, 50, 75 and 100 % of shading. Coefficient of evapotranspiration was calculated by dividing evapotranpiration value with pan evaporation value. Result of the research showed that shading affected evapotranspiration or crop water requirement. So that, the coefficient of evapotranspiration under different level of shading was also different. Trend line between coefficient of evapotranspiration and leaf number was 0.002 $X^2$ + 0.032 $X$ + 1.305 for 0 % of shading. 0.002 $X^2$ + 0.009 $X$ + 1.430 for 25 % of shading. 0.007 $X^2$ - 0.086 $X$ + 1.676 for 50 % of shading. and 0.002 $X^2$ – 0.018 $X$ + 1.311 for 75 % of shading. In conclusion the coefficient of evapotranspiration under 50% of shading are 1.52, 1.36, 1.20, 1.04 at growth phase of 2, 4, 6 and 8 leaves respectively.

Key words:Coefficient of evapotranspiration, evapotranpiration, pan evaporation, leaf number, crop water requirement.

1. Introduction
Fact of irrigation system at farmer land showed that simple drip and conventional irrigation did not use instrument to determine real time irrigation water requirement. So that, farmer usually give excessive water. In order to save water. simple method was needed to calculate irrigation water requirement rapidly.

Formula that was usually used are as follows [1]:

\[ \text{CWR} = ET = Kc \cdot ET_0 \]

\[ ET_0 = Kp \cdot E_0 \]

Where:
CWR: crop water requirement
ET: evapotranspiration
Kc: crop coefficient
ET<sub>r</sub>: reference evapotranspiration  
K<sub>p</sub>: pan coefficient  
E<sub>p</sub>: pan evaporation  
The model requires a complex device.  
Several methods used to determine water requirements of coffee after transplanting phase have developed. For example, Marin <i>et al.</i> [2] developed a stem heat balance method to determine crop transpiration. Ratio of crop evapotranspiration with reference evapotranspiration based on Penman-Montheith formula. Also ratio of transpiration with reference evapotranspiration was two coefficient for calculating water requirement. Assis <i>et al.</i> [3] tried to increase coffee production by providing sufficient irrigation, so that the plant population could be added. In this way, the plant population increased from 10,000 to 20,000 plants ha<sup>-1</sup> and could increase yield. Several studies to regulate water requirements at various growth phases of adult coffee have been carried out by Silveira <i>et al.</i> [4]. Chemura [5]. Mike and Carr [6].  
However, method to determine water requirement of coffee nursery have not been developed. Formula developed in the research was builded by combining eq (1) with eq (2) as follows:

\[
ET = K_c K_p E_0 \\
ET = K_e t E_0 \\
\text{(3)}
\]

Irrigation Water Requirement (IWR) of nursery in the pot system:

\[
IWR = ET - P \\
\text{(4)}
\]

Where:

K<sub>c</sub>: coefficient of evapotranspiration  
P: precipitation  
The developed formula requires a simple device.  
Evapotranspiration as in equation (1) occurs at the surface conditions of open and wet surfaces evenly. Meanwhile, in different conditions such as in nurseries, under shading, uneven wetting gives different coefficients of plants. The research was conducted to obtain coefficient of evapotranspiration that was able to be used for determining crop water requirement.

2. Material and Method  
The plant material used was the Catimor variety Arabica coffee seedlings which was the result of a cross between the first generation Caturra variety and Hibrido de Timor (HdT). First generation (F1) Catimor has high production potential, rust resistant, dwarved and compact.

Data was generated by experiments arranged in a randomized block design with treatment of shade levels with 3 replications at the IPB Experimental Station, Darmaga, Bogor, West Java Province at altitude of 250 m above sea level in March 2013 to October 2013. The shade treatment consisted of 5 level that were without shade, shade of 25%, 50%, 75% and 100%. Irrigation was given until percolation every 2 days. Observation of evapotranspiration and evaporation of free water surface was carried out by the method as follow. Evapotranspiration was measured based on water balance in system of pot lisimeter (Fig 1) that was:

\[
P + I = ET + P k + (M_1 - M_0) \\
\text{(5)}
\]

Where:

P: precipitation (mm)  
I: Irrigation (mm)  
ET: evapotranspiration  
P: percolation (mm)  
M: soil moisture (M<sub>1</sub>-M<sub>0</sub> = 0)
Irrigation in mm units is obtained by dividing irrigation in cm³ units with the pot surface area in cm² units then multiplying by 10. Percolation in mm units is obtained by dividing the volume of percolation in cm³ units by the pot surface area in cm² units then multiplying by 10. The value of \((M_i-M_0) = 0\) is caused by soil moisture retained at the field capacity.

Evaporation (E₀) was observed according to water balance in pan system that was:

\[
P = E_0 + (H_1 - H_0)
\]  

(6)

Where:
- \(P\): precipitation
- \(E_0\): evaporation
- \(H_1\): water level at time of measurement
- \(H_0\): water level maintained as high as 500 mm

The pan size was 1.83 m in diameter and 61 cm in height.

Coefficient of evapotranspiration (\(K_{et}\)) was calculated using the following formula:

\[
K_{et} = \frac{E_t}{E_0}
\]  

(7)

Seeds used were 3 months old. The plant material used was chosen uniformly based on plant height, number of leaf pairs and seed health. Planting media used was a top soil and manure with a ratio of 4:1. Fertilizers used were urea, SP36, KCl with each dose of 3 grams per plant.

The soil for the nursery was processed and elevated ± 15 cm and cleaned from grasses. Number of sample plants in one experimental unit was 3 plant. Between beds was made trenches for draenage. Shade of paranet was put as roof of paranet house. The height of paranet house was 1.5 m.

The composition of soil and manure as planting media was 4:1. The land used was top soil. The planting media was stirred and put in a polybag. The size of polybag used was 20 cm x 50 cm. Polybags that had been planted with coffee seed were arranged according to the treatment.

Maintenance of seeds includes weeding, watering, and controlling pests and diseases. To avoid seeds from pest and disease disorders, spraying was carried out using Thiodan 35 WP and Dithane M-45 80 WP with a concentration of 2 g l⁻¹ respectively. Watering was carried out according to the treatment. Giving water to the field capacity was done by irrigating until percolation. Then water percolated was
colected and measured it's volume. The rate of Urea, SP-36 and KCl every year was 3 grams each seed respectively. The fertilizer was given every 1.5 months. Field observations was carried out for 8 months.

Phylotaxis of coffee seeds is opposite leaves. One pair of leaves appears simultaneously. Thus, the number of leaves of coffee seeds is always even. The number of leaves is calculated every 2 weeks because of the slow growth in the number of leaves.

Leaf number data and evapotranspiration data were tested by regression tests for each shade level. Leaf number data and evapotranspiration coefficient data were also tested with regression tests for each shade level.

3. Results and Discussion

Evapotranspiration is influenced by the difference between the potential of water in the soil and the potential of water in the atmosphere, also affected by resistance. The greater the difference from the water potential, the greater the evapotranspiration. Conversely, the greater resistance, the smaller evapotranspiration. The value of resistance in leaves varies from very small to very large. The resistance in the leaves is very small when the stomata close. Conversely, the resistance in a leaf is very large when the stomata open. Therefore, there is a relationship between evapotranspiration and number of leaves as presented in table 1.

Table 1 presented $R^2$(n=18) value of possible relationship between evapotranspiration and leaf number under various shading levels. The most value of $R^2$ indicated that the trend line was most suitable for predicting evapotranspiration based on the number of leaves. For example, the most suitable trend line at the 50% shade level was polynomial. Furthermore, the most suitable trend line obtained from Table 1 was presented in table 2.

Table 1. $R^2$(n=18) value of the relationship between evapotranspiration and leaf number under various shading levels

| Trend line | 0 % | 25 % | 50 % | 75 % | 100 % |
|------------|-----|------|------|------|-------|
| Exponential | 0.40 | 0.20 | 0.51 | 0.24 | 0.62 |
| Linear     | 0.39 | 0.18 | 0.52 | 0.24 | 0.63 |
| Logarithmic| 0.57 | 0.42 | 0.66 | 0.29 | 0.80 |
| Polynomial | 0.66 | 0.56 | 0.63 | 0.25 | 0.85 |
| Power      | 0.58 | 0.45 | 0.67 | 0.30 | 0.80 |

Based on the relationship between evapotranspiration and leaf number (Table 2) the turning point of the line equation can be calculated. For example in the treatment without shade it was known that increasing of leaves number to 10 leaves was followed by an increasing of evapotranspiration. In the same way, the increasing of evapotranspiration followed an increasing of the number of leaves to 11 leaves in the 25% shade. Similarly, an increasing of evapotranspiration followed an increasing of the number of leaves to 14 leaves in 100% shade. Conversely, an increasing of evapotranspiration followed an increasing of the number of leaves in the shade of 50% and 75% respectively. The increase of evapotranspiration due to the increment of the number of leaves in the 50% shade was greater than the increase of evapotranspiration due to the increase of the number of leaves in the 75% shade. Increased evapotranspiration has a good influence on physiological processes, such as nutrient absorptions, photosynthesis, water absorption, so that it can increase plant growth. Thus, a 50% shade rate provided a good growing environment for coffee nurseries.

The relationship between evapotranspiration and adult coffee growth has been investigated by many researchers. Zayas et al. [7] reported that water requirement during the flowering – fructification was 4.44 mm per day that was the most water requirement. Average evapotranspiration was 3.24 mm/day. and total evapotranspiration was ranged from 1112 to 1197 mm per year. Furthermore, Fernandes et al. [8] reported that evapotranspiration of 3.22 mm per day occurred in sprinkler irrigation systems.
Furthermore, the unit of milliliters (ml) or cubic centimeters (cc). Water that must be given to the nursery polybag is $K_{et} \times E_0$ in units of mm. Plant water requirements are calculated by the formula $K_{et} \times E_0$ based on free water surface evaporation measurements when irrigation will be carried out. Plant water requirements are calculated by the formula $K_{et} \times E_0$ in units of mm water. Furthermore, the volume of water that must be given to the nursery polybag is $K_{et} \times E_0 \times 10^3 \times$ surface area of polybag (cm²) in unit of milliliters (ml) or cubic centimeters (cc).

**Table 2.** The Fittest trend line between evapotranspiration (ETc. mm per day) and leaf number (X) under various shading levels

| Shading level | ETc = f(X)         | $R^2$  |
|---------------|--------------------|--------|
| 0 %           | -0.026 $X^2 + 0.556X + 4.953$ | 0.658  |
| 25 %          | -0.017 $X^2 + 0.377X + 5.637$ | 0.561  |
| 50 %          | 5.434 $X^{0.125}$   | 0.667  |
| 75 %          | 5.243 $X^{0.084}$   | 0.303  |
| 100 %         | -0.013 $X^2 + 0.372X + 4.298$ | 0.852  |

The coefficient of evapotranspiration is the ratio between evapotranspiration and pan evaporation. This coefficient can be used to calculate the water requirements of coffee seedlings by measuring the evaporation of the pan. Similarly, known coefficients are plant coefficients which are the ratio between plant evapotranspiration and referent evapotranspiration, pan coefficient which is the ratio between referenced evapotranspiration and pan evaporation. The evapotranspiration coefficient as well as the evapotranspiration are influenced by the number of leaves, so the relationship between the evapotranspiration coefficient and the number of leaves is known as in table 3.

Various possible relationship between evapotranspiration coefficients and number of leaves were presented in Table 3. The trend line that had the highest $R^2$ value could be used to predict the evapotranspiration coefficient. For example, the polynomial at the 50% shade level had the highest $R^2$, so the polynomial equation could be used to predict the value of the evapotranspiration coefficient better than the other trend lines. Furthermore, table 4 showed the most suitable equation to predict the evapotranspiration coefficient.

**Table 3.** $R^2$ value of the relationship between evapotranspiration coefficient and leaf number under various shading levels

| Trend line      | Shading 0 % | 25 % | 50 % | 75 % | 100 % |
|-----------------|------------|------|------|------|-------|
| Exponential     | 0.34       | 0.27 | 0.46 | 0.49 | 0.73  |
| Linear          | 0.34       | 0.29 | 0.46 | 0.55 | 0.77  |
| logarithmic     | 0.25       | 0.19 | 0.31 | 0.32 | 0.51  |
| polynomial      | 0.35       | 0.31 | 0.61 | 0.64 | 0.96  |
| Power           | 0.25       | 0.18 | 0.31 | 0.28 | 0.52  |

The relationship between the evapotranspiration coefficient and the number of leaves in the treatment without shade was $0.002 \times X^3 + 0.032 \times X + 1.035$ (Table 4). This means that $K_c$ increased if the number of leaves increased. Similarly, $K_c$ also increased if the number of leaves increased at a shade of 25%. Conversely, an increase in $K_c$ occurred in the number of leaves greater than 6, 4 and 6 leaves at 50%, 75% and 100% respectively. Evapotranspiration coefficient ($K_{et}$) was Evapotranspiration of plants (ETc) divided by evaporation of free water surface (Eo).

Based on the relationship between the number of leaves and the evapotranspiration coefficient ($K_{et}$) (Table 4) the value of $K_{et}$ of coffee seedlings can be calculated on various number of leaves and shading levels (Table 5). The table of $K_{et}$ value can be used to determine the value of $K_{et}$ in the various leaves number of coffee seedling. so that the water requirement of plants can be calculated prior to irrigation based on free water surface evaporation measurements when irrigation will be carried out. Plant water requirements are calculated by the formula $K_{et} \times E_0$ in units of mm water. Furthermore, the volume of water that must be given to the nursery polybag is $K_{et} \times E_0 \times 10^3 \times$ surface area of polybag (cm²) in unit of milliliters (ml) or cubic centimeters (cc).
eedlings. This study obtained water

Zayas

IOP Conf. Series: Earth and Environmental Science 418 (2020) 012010       doi:10.1088/1755-1315/418/1/012010

The coefficient of evapotranspiration for adult coffee plants has been studied by many researchers. Flumignan et al. [9] reported that the recommended values of Ke (E/Eto) were 0.46 and 0.26 for sprinkler and drip irrigation, respectively. The recommended values of Kcb (T/Eto) were 0.52 and 0.82 for sprinkler-irrigated and 0.5 and 0.65 for drip-irrigated treatments, varying as a function of daily ETo (ETo ≥ or <3 mm day⁻¹, respectively). Furthermore, Pereira et al. [10] explained that crop coefficient (Kc) was correlated with the number of leaves positively. Zayas et al. [7] also reported that a global crop coefficient of adult coffee was 0.86.

Water requirement from coffee seedlings is the volume of water needed to restore optimum soil water content or field capacity. It is filled with rain and irrigation. So, irrigation water demand is the difference between the water needs of coffee seeds and rain. The volume of irrigation water that must be taken from a water source depends on the efficiency of the irrigation system. The drip irrigation system has a higher irrigation efficiency compared to the sprinkler irrigation system because drip irrigation provides water to the soil in the coffee seed pot directly. Meanwhile, irrigation water from the sprinkler irrigation system evaporates and also falls outside the pot of the coffee seedlings. This study obtained water requirement from coffee seedlings at various amounts of coffee seedling leaves and at various levels of shade (Table 5).

For example in the implementation of irrigation for coffee nurseries that have 4 leaves are as follows. The first step is to measure the pan evaporation. For example the pan evaporation value is 4 mm. The second step is to calculate the water requirement of coffee seeds with 4 leaves is 1.36 x 4 mm = 5.44 mm. Crop water requirement in cubic centimeters can be calculated by multiplying crop water requirements in centimeters by the surface area of a polybag. The third stage is to do irrigation. If irrigation is done by using sprinkler irrigation, it is necessary to know the efficiency of irrigation and discharge of sprinklers. If the irrigation efficiency is 80% and the discharge of sprinkler is 25 cc / sec, then the irrigation time must be given is [(100/80) x number of coffee seeds x water requirements for one coffee seed] / (25x60) in minutes.

4. Conclusion
The coefficient of evapotranspiration under 50% of shading are 1.52, 1.36, 1.20, 1.04 at growth phase of 2, 4, 6 and 8 leaves respectively. The water requirement for coffee nursery are 1.52 multiplied by the

| Leaf number | Kc value at shading levels |
|-------------|---------------------------|
|             | 0 % | 25 % | 50 % | 75 % | 100 % |
| 2           | 1.377 | 1.456 | 1.518 | 1.283 | 1.275 |
| 4           | 1.465 | 1.498 | 1.360 | 1.271 | 1.187 |
| 6           | 1.569 | 1.556 | 1.202 | 1.275 | 1.155 |
| 8           | 1.689 | 1.630 | 1.044 | 1.295 | 1.179 |
| 10          | 1.825 | 1.720 | 0.886 | 1.331 | 1.259 |
| 12          | 1.977 | 1.826 | 0.728 | 1.383 | 1.395 |
| 14          | 2.145 | 1.948 | 0.570 | 1.451 | 1.587 |

Table 4. The Fittest trend line between Evapotranspiration coefficient (Ke(t)) and leaf number (X) under shading levels

| The level of shading | Ke(t) = f(X) | R2 |
|----------------------|-------------|----|
| 0 %                  | 0.002 X² + 0.032 X + 1.305 | 0.350 |
| 25 %                 | 0.002 X² + 0.009 X + 1.430 | 0.307 |
| 50 %                 | 0.007 X² -0.086 X + 1.676 | 0.609 |
| 75 %                 | 0.002 X² -0.018 X + 1.311 | 0.640 |
| 100 %                | 0.007 X² -0.086 X + 1.419 | 0.966 |

Table 5. Evapotranspiration coefficient of coffee nursery for various leaf number under shading levels
pan evaporation if the number of leaves is two, 1.36 multiplied by the pan evaporation if the number of leaves is four, 1.20 multiplied by the pan evaporation if the number of leaves is six, 1.04 multiplied by the pan evaporation if the number of leaves is eight. The simple stage in determining irrigation water requirements is measuring the pan evaporation, calculating the water requirement for coffee nursery and carrying out irrigation.

References
[1] Allen R G, Pereira L S, Raes D and Smith M 1998 Crop Evapotranspiration Guidelines for computing crop water requirement FAO Irrigation and Drainage Paper 56 299
[2] Marin F R, Angelocci L R, Righi E Z and Cesar Sentelhas P C 2005 Evapotranspiration and irrigation requirements of a coffee plantation in Southern Brazil Expl. Agric. 41 187–97
[3] Assis G A, Guimarães R J, Colombo A and Dominghetti A W 2014 Drip Irrigation in coffee crop under different planting densities: growth and yield in Southeastern Brazil Revista Brasileira de Engenharia Agrícola e Ambiental 18 1116-23
[4] Silveira H R O, Santos M O, Alves J D, Souza K R D, Andrade C A and Alves R G M 2014 Growth effects of water excess on coffee seedlings (Coffea arabica L.) Acta Sci. Agron. 36 44 -51.
[5] Chemura A 2014 The growth response of coffee (Coffea arabica L) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply levels International Journal of Recycling of Organic Waste in Agriculture 3 59
[6] Mike K and Carr V 2001 The water relations and irrigation requirements of coffee Experimental Agriculture Expl. Agric. 37 1 - 36
[7] Zayas C E, García R R, Varona R M, Seijas T L and Robaina F G 2015 Evapotranspiration and crop coefficients for coffee trees Ciencias Técnicas Agropecuarias 24 23-30.
[8] Fernandes A L T, Mengua R E C G, Melo G L D and Assis L C 2018 Estimation of reference evapotranspiration for coffee irrigation management: the case of Brazilian Cerrado Coffee Science 13 426
[9] Flumignan D L, Faria R T and Prete C E C 2011 Evapotranspiration components and dual crop coefficients of coffee trees during crop production Agricultural Water Management 98 791-800
[10] PereiraA R, Camargo M B P and Nova N A V 2011 Coffee crop coefficient for precision irrigation based on leaf area index Bragantia 70 1-8