Agricultural Water Management 169 (2016) 77–89

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Evaluation of reference evapotranspiration models and determination of crop coefficient for *Momordica charantia* and *Capsicum annuum*

Josilva M. Muniandy[a], Zulkifli Yusop[a,b,*], Muhamad Askari[a]

[a] Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai, 81310 Johor, Malaysia
[b] Centre for Environmental Sustainability and Water Security, Research Institute for Sustainable Environment, Universiti Teknologi Malaysia (UTM), Skudai, 81310 Johor, Malaysia

ARTICLE INFO

Article history:
Received 19 March 2015
Received in revised form 22 January 2016
Accepted 20 February 2016
Available online 27 February 2016

Keywords:
Penman
Crop evapotranspiration
Minilysimeter
Momordica charantia
Capsicum annuum

ABSTRACT

Studies on water balance and irrigation at agricultural areas require accurate values of reference evapotranspiration (ET_o). This study was conducted in the agricultural farm in the Modern Agriculture Centre in Kluang, Malaysia, to determine the crop coefficients of bittergourd (*Momordica charantia*) and chili (*Capsicum annuum*) by choosing the best ET_o model. The experiment was conducted for two different crop cycles between October 2013 and May 2014. An automatic weather station was installed to record weather parameter at 30 min interval. Twenty six ET_o models which were classified into four different groups were employed. The performance of the models was evaluated using Class A pan evaporation data from Kluang weather station. Eight statistical tests were used to assess and rank the accuracy of these 26 models. The ET values from the best ET_o model of each group were then modeled with weather variables using multiple regression technique. Crop coefficient (K_c) curves were developed as the ratio between actual crop evapotranspiration measured by minilysimeters and the ET values of the best model. The temperature based models tend to overestimate observed pan ET values, thus were not recommended at this site. Results of the mass transfer based Penman model show comparatively better ET_o estimates among others. The total water requirement for bittergourd for the whole growing period is 153 mm while chili recorded 229 mm. The K_c values for the bittergourd were 0.58, 0.88 and 0.69 while for chili were 0.58, 0.95 and 0.73 for the initial, mid and end growth stages, respectively. The present results show very similar mid and end season chili K_c values with a study from Ghana while the mid and end season K_c of bittergourd is quite similar with a study in Florida, USA using cucumber. The values obtained can help farmers to determine the water requirement of these vegetable crops so that proper irrigation can be applied according to its growth stage and weather condition.

1. Introduction

Bittergourd (*Momordica charantia*) and chili (*Capsicum annuum*) are some of the most popular vegetables that grow in tropical areas such as the Amazon, east Africa, Asia, and the Caribbean. Bittergourd also known as bitter melon or karella is a slender, climbing vine with long-stalked leaves and yellow. The fruit has a bitter taste and looks like a warty, oblong gourd that resembles a small cucumber. Chili is a spice crop that can be confused with other terminologies like pepper and capsicum. It is a small perennial shrub that can grow up to meter in height. It has a spicy hot taste unlike other vegetables and has been part of Asian and Mexican cuisine for a very long time. Besides used for cooking, both of these plants have high nutrient values and medicinal properties, where bittergourd is used to cure diabetes, ulcer, gout and rheumatism, while chili is used as analgesic for arthritis pain, mastectomy pain and to cure fungal infection on skin (Crisan et al., 2009; Wang et al., 2014). The production of both crops has increased throughout the years. These crops use a large quantity of water, in which more than 90% of the water abstracted by roots is transpired back to the atmosphere causing increase in crop water requirement (Grace and Williams, 2004). All vegetable crops require adequate water management which strongly affect the plant growth and crop yield.

Crop water use is a function of evaporation (E) and transpiration (T) that fluctuates daily. Allen et al. (1998) provides definition on evapotranspiration (ET) and reference evapotranspiration (ET_o). ET is defined as the sum of evaporation from water/soil surfaces and the amount of water transpired by plants. ET_o is defined as evap-

* Corresponding author.
E-mail address: zulyusop@utm.my (Z. Yusop).

http://dx.doi.org/10.1016/j.agwat.2016.02.019
0378-3774/

otranspiration from an extensive surface of green grass of uniform height (0.08–0.15 m), an albedo of 0.23, fixed canopy resistance (70 s m^{-1}), actively growing, completely shading the ground, and not short of water. There are many components that affect ET_o, which include weather variables like solar radiation, air temperature, relative humidity (RH), and wind speed; crop factors such as type of vegetation, crop density and the growth stage; and other conditions such as soil type, salinity, fertility, cultivation level, crop disease, and pests (Allen et al., 1998). ET is one of the most difficult components to be determined in the water balance compared to other components like precipitation or irrigation (Fisher et al., 2005; Xu and Singh, 2005).

Numerous models exist to estimate the ET_o, but these models give inconsistent values due to their differences in modeling assumptions and input data requirements, or because the models have been developed for specific areas (Lu et al., 2005; Xu and Singh, 2005). FAO56 Penman-Monteith model is considered to be the best approach for estimating ET_o and for the determination of crop coefficient because of its good approximation to lysimeter observations (Droogers and Allen, 2002; Popova et al., 2006; Xu and Singh, 2002). However, the FAO56 Penman-Monteith model requires many weather variables which can potentially introduce certain amounts of measurement and/or computational errors and cause cumulative errors in the calculated ET_o (Meyer et al., 1989; Rahimikhoob et al., 2012). Due to this, other models that require less parameter should be considered for evaluation. Even though certain models such as Blaney-Criddle, Hargreaves, Makkink, Priestley Taylor and Turc, are developed under different weather variables, the models have been proven useful when applied at different climate regions (Federer et al., 1996; Kashyap and Panda, 2001; Trajkovic, 2007; Xu and Singh, 2001). Therefore, multiple ET_o evaluation study for tropical regions is urgently required.

The crop evapotranspiration (ET_c) is defined as the ET rate of crop under standard condition where there is no stress by water quality constraints, pests, or inadequate soil fertility (Allen et al., 1998). To determine the crop water requirement accurately, correct estimation of ET_c is crucial as it provides the basis in determining water availability, crop water balance and crop water requirements (Pereira et al., 1999). Crop water requirement is defined as the depth of water required by plants to compensate the water loss via ET so plants are able to grow optimally while soil water balance shows amount of soil water added, removed or stored in volume of soil during a time period (Allen et al., 1998). Under-application of water can cause water deficit for plants and increase soil salinity, whereas over-application causes water wastage and nutrient leaching from the root zone (Merriam et al., 1999; Pereira et al., 2002). Thus, ET_c can help farmers in order to decide when to start irrigation and how much water to apply to increase crop yields and profits while reducing costs, energy, and environmental impacts.

Lysimeters are used to determine the ET_c as actual ET depends on soil moisture. A lysimeter is basically a container that isolates soil from its surroundings but still replicates the adjoining soil, crop density and crop elevation as identical as possible. It provides a controlled soil-water environment for accurate measurement of water use and nutrient movement under defined bottom boundary condition (Dugas and Bland, 1989; Liu et al., 2002). The lysimeter can be categorized to either the weighing (measures ET directly by water mass balance) and non-weighing (measures ET indirectly by volume balance) type (Rana and Katerji, 2000). The usage of microlysimeter (non-weighing) is preferable since it does not require high level of expertise and special equipment compared to the high precision weighing lysimeter with continuous electronic data reading devices (to record water loss via ET and drainage) and other methods like Bowen ratio, remote sensing, surface energy balance, scintillometers and eddy covariance method (Allen et al., 2011; Gebler et al., 2015; Rana and Katerji, 2000; Shuttleworth, 2008; Tomlinson, 1997; Wilson et al., 2001).

Crop water use or water requirements is determined by multiplying ET_o with crop coefficient, K_c. It is useful to determine the water requirement of crops according to their growth stage and environmental factors. The K_c value is sensitive and depends on several aspects such as type of crop, weather variables, canopy cover density, growth stage, soil moisture and agricultural operations (Allen et al., 1998). Previous studies have found that K_c for the same crop may vary from region to region depending on environmental factors such as climate and soil evaporation. Even though Allen et al. (1998) have compiled a list of K_c of various crops under different climates, K_c for a crop still has to be determined regionally as it may vary with factors like types of crop, growing stage, soil moisture, climate and agronomic techniques (Doorenbos and Pruitt, Doorenbos and Pruitt, 1977; Ko et al., 2009; Piccinni et al., 2009). In addition, some authors have reported differences between published and locally developed K_c (Kashyap and Panda, 2001; Tyagi et al., 2000). Due to this, more studies on determining different types of crop K_c at different climates should be conducted as it may help modelers and water resource engineers to provide more reliable water management schemes. Two approaches to determine crop coefficient are the single and dual crop coefficient approach. The dual crop coefficient approach divides the ET into E and T, whereas in the single crop coefficient approach, both E and T are combined into a single value (Allen et al., 1998). In the dual crop coefficient, the value of Kc is essentially composed of two terms: the basal coefficient (K_{cb}) defined for a non-water-deficit condition with a “dry” soil surface; and K_e is a coefficient to account for soil or soil/crop surface evaporation from wetting by irrigation or precipitation (Allen et al., 1998).

Developing K_c values involved determining the crop growing stages, lengths and K_c values for each stage. The K_c is different through the growing period due to differences in ET at various growth stages. According to the FAO methodology by Allen et al. (1998), the four growing stages of a crop are initial stage (Time from planting to approximately 10 percent of ground cover), crop development stage (from 10 percent of ground cover to effective full cover), mid-season stage (from full cover to beginning of maturity) and end-season stage (from start of maturity to end of harvest).

Three K_c values are needed to create a K_c curve, which include the K_{cini} for the initial stage, K_{cmid} for the mid-season stage and lastly the K_{cend} for the end-season stage (Er-Raki et al., 2007; Mirzaei et al., 2011). The K_c value obtained from this experiment is compared to the values from the FAO publication that is adjusted to the local conditions/climate by these equations (Allen et al., 1998):

$$K_{\text{cini}} = f_{\text{w}} K_{\text{cini}} \quad (1)$$

where f_w is the wetted perimeter. It is taken as 1.0 since the study site applies sprinkler irrigation.

$$K_{\text{c mid}} = K_{\text{c mid}} + [0.04(u_2 - 2) - 0.004(\text{RH}_{\text{min}} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (2)$$

$$K_{\text{c end}} = K_{\text{c end}} + [0.04(u_2 - 2) - 0.004(\text{RH}_{\text{min}} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (3)$$

where RH_{min} is the mean minimum RH ($20 < RH_{min} < 80\%$), h is the average crop height ($0.1 < h < 10$ m) and u_2 is the mean daily wind speed at 2 m height ($1 < u_2 < 6$m/s).

The main objectives of this study are (i) to evaluate the performance of 26 ET_o models by comparing with the pan evaporation data obtained from the nearest meteorological station and (ii) to determine the crop coefficients of bittergourd and chili crops.