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Full Length Research Paper

Lysimeter based water requirements and crop coefficient of surface drip-irrigated date palm in Saudi Arabia

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Abstract

Fifteen non-weighing reinforced concrete lysimeters were used to grow alfalfa (*Mcdicago sativa*) and grass (*Cynodondactylon*) as a reference crops, and date palm (*Phoenix dactylifera* L.) as experimental crop to obtain the daily water requirements and crop coefficient throughout productive cycle of date palm. The experimental site was located at the experimental station of the Centre for Date Palm and Dates in Al-Hassa, Saudi Arabia on a sandy loam textured soil. The results showed that estimated potential evapotranspiration of alfalfa and grass crops throughout the experimental period were approximately 2185 and 2068 mm, with a daily average of 5.98 and 5.66 mm per day, respectively. The date palm evapotranspiration increased from 3.09 mm/day in February at pollination stage to 8.25 mm/day in July at fruit maturity stage, and then dipped to 5.42 mm/day in September at the end of harvest. The volumetric palm water requirements per day fell between 87 and 297L during January and July months, respectively with a daily average of 182 L through the whole year depending mostly on climatic conditions and quality of the irrigation water. The date palm crop coefficient was not constant throughout its productive cycle and it ranged from 0.74 to 0.91 according to crop growth stages. The average crop coefficient for the date palm productive cycle through the whole year was 0.83.

Keywords: Crop coefficient, reference evapotranspiration, crop evapotranspiration, lysimeters.

INTRODUCTION

Water scarcity is a major challenge facing many nations especially the third world countries in the present time. This can be attributed to climate change, increasing demand for freshwater by the competing users in different sectors and more importantly, the environmentally induced problems such as desertification and overexploitation of the existing water resources (Pereira, 2005). The gap between irrigation supply and demand is increasing every year. Searching for new water resource is very difficult and also expensive. So the shortest way for effective planning and implementation of policies on irrigation projects is determination of the evapotranspiration (ET) that is very essential in many disciplines including the irrigation system design, irrigation scheduling and hydrologic and drainage studies (Irmak and Haman, 2003).

The study of date palm water requirements is essential, as date palm (*Phoenix dactylifera*) is one of the main fruit trees in the Kingdom of Saudi Arabia. The total number of date palms has reached 24 million, and the number is increasing every year (Alamoud et al., 2012). In perennial crops like date palm, it is necessary to know

Table1. Physicaland chemical properties of the filed at different soil layers

Soil depth (cm)	Particle size distribution (%)			BD	PWP	FC	ECe
	Sand%	Silt%	Clay%	g cm^{-3}	(%)	(%)	(dS m^{-1})
0-20	61	16	23	1.63	5.32	14.74	3.18
20-40	39	34	27	1.62	6.54	17.27	4.13
40-60	45	26	29	1.61	6.54	15.90	3.72
60-80	45	30	25	1.61	6.00	16.00	3.88
80-100	67	10	23	1.62	6.00	16.00	3.60

BD=Bulk Denisty, PWP = Permanent Welting Point, FC = Field Capacity, ECe = Electrical Conductivity Of Saturated Paste Extract.

both the total and seasonal water requirements to estimate match plant requirements with the available water supply. The crop water use during developmental stages depends on the daily evapotranspiration (ET) rates which is influenced by the atmospheric conditions (solar radiation, temperature, wind and humidity), the nature of the crop and the developmental stage (Bhat et al., 2012). The date palm water requirements differ from country to another and from region to region in the same country.

Al-Amoud et al. (2000) found that the annual amount of 108 m^{3}per tree is sufficient to obtain the highest water use efficiency in a study conducted on the date palms under three irrigation treatments (50%, 100%, and 150% of the pan evaporation A). Al-Ghobary (2000) has estimated the total annual amount of water required by one date palm as 136 m^3 in Najran of southwestern region of Saudi Arabia. Alazba (2004) found that the actual annual water use of the date palm ranged from137 and 55 m^3 in Eastern region to about 195 and 78 m^3 in the central region for flood and drip irrigation, respectively. In a study-conducted in Tunisia by Al-Buzaidi (1982), it was found that, the lowest total annual water requirements were equal to 63 m^3 per tree, while the actual water requirements, including all types of losses were 95 m^3/tree.

The date palms crop coefficient (Kc) values for mature date palm grown in hot arid environment were found to vary from 0.9 to 0.95 (Allen et al.,1998). Doorenbos and Pruitt (1977) have suggested the range between 0.8 and 1, while Saeed et al. (1990) have obtained a range between 0.85 and 1.37 using three empirical ET methods. Al-Zeid (1988) has suggested the crop coefficients for the various stages of date palm growth to vary from 0.55 to 0.75. The soil conservation service values for the date palm crop coefficient fall within 0.65 and 0.80 (SCS, 1970). The objective of this study was to determine the daily water requirements and crop coefficient of a young date palm tree, grown in the soil and climate conditions of Al-Hassaregion, Kingdom of Saudi Arabia.

MATERIAL AND METHOD

Characteristics of the experimental site

This study was conducted at the experimental station at the Centre for Date Palm and Dates, Al Hassa, Kingdom of Saudi Arabia. The geographical location coordinates of the farm are 25° 22'N latitude, 49° 34'E longitude and 179 m altitude. The soil profile of the experimental site in the upper 0–100 cm soil was, well-drained sandy loam texture composing of 51.4% sand, 23.2% silt and 25.4% clay. The average soil water content at field capacity from surface soil layer down to 100 cm depth at 20 cm intervals was 15.98 % and the permanent wilting point for the corresponding depths was 6.08 % respectively. Some other physical and chemical properties of the experimental soil are presented in table 1. A Richard’s pressure chamber was used for determining soil water retention for pressures of 101.3, 303.9, 506.6, 709.3, 1013.2, 5066.2 and 15199.7 kPa (Figure 1).

Climatic conditions

Environmental conditions were monitored by an in-situ meteorological station, retrieving data on solar radiation (Rs, MJ m^{-2}day^{-1}), wind speed (U, kmhr^{-1}), air temperature (Tair, ºC), relative humidity (RH, %) and rainfall (P, mm). The air water vapor pressure deficit (VPD, kPa) was calculated using daily and hourly average temperatures and relative humidity. Finally, the reference evapotranspiration (ETo, mm day^{-1}) was calculated according to the Penman-Montieth (PM) equation (Monteith, 1965) as specified by the FAO protocol (Allen et al., 1998):

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma[(900U_2)/(T+273)](e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where R_n and G are daily net radiation and soil heat flux

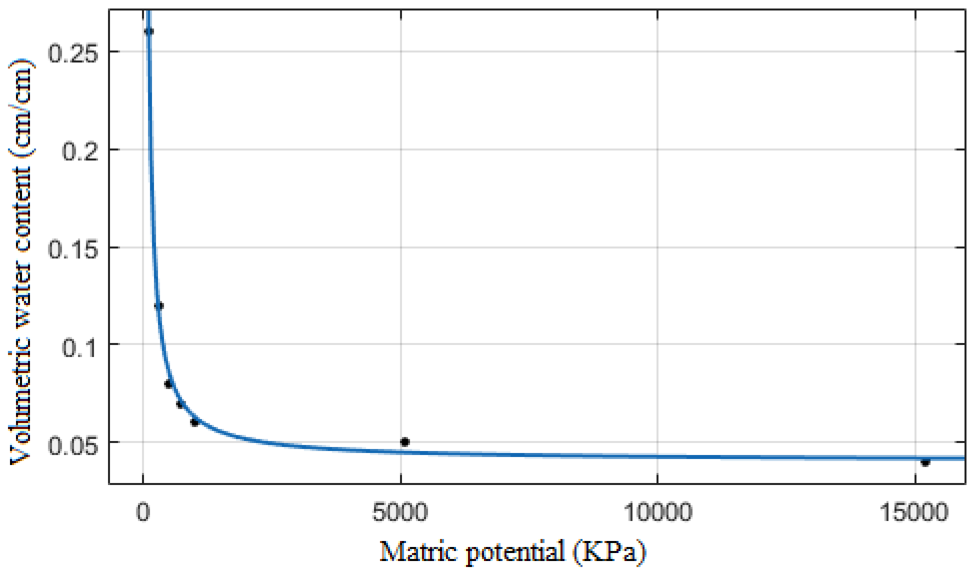

Figure 1. Water retention curve of the soil for the field site

in MJ m^{-2}, respectively, Δ is the slope of saturation vapor pressure curve (kPa/C^{o}), U_2 is the average daily wind speed at 2 m above soil surface (m s^{-1}), γ is the moisture constant (kPa/C^{o}), T is the average daily air temperature at 2 meter height (ºC) and (es - ea) is the saturated vapor pressure deficit (kPa).

Lysimeters

Nine non-weighing reinforced concrete lysimeters with surface-area dimensions of 1 m wide x 1.5 m long and inside-depth of 1.5 m were used to grow alfalfa (*Mcdicago sativa*) and grass (*Cynodon dactylon*) as a reference crops. The date palm trees (*Phoenix dactylifera* L.) were grown in a six drainage lysimeters measuring 4.0 m in diameter and 1.5 m in height as an experimental crop to obtain daily water requirements and crop coefficient of the date palm trees (Figure 2). The lysimeters were placed on a compacted bottom of 1.5m deep hole in the soil and fitted with suitable inlets for irrigation and outlets for collecting drained water. The lysimeters were filled with native soil after putting a 15-cm layer of graded gravel at the bottom to facilitate drainage process. An underground passage was provided to allow access to measure the drainage water. Since the genetic makeup of the plants influence their growth and development and in turn, their water requirements, tissue-cultured plants of “Khalas” cultivar were used to avoid any potential discrepancies in the estimation process. Plants in lysimeters were irrigated in the same way (i.e., drip irrigation) as those plants in the surrounding areas to maintain a favorable moisture regime in the root zone.

Cropping details

Field measurements were taken during the productive cycle of 8 years old date palm tree (Khalas cv) from 1 November 2014 to 31 October 2015. The experimental date palms had an average height of trunk 1.90 m; average trunk diameter of 0.66 cm; average leaf length of 320 cm and average number of 51 leaves per palm. The date palms were spaced at 8.0 m between rows by 8.0 m between palms. The date palm productive cycle had five stages, started with a pollination stage (from 1 February to 1 March); Hababouk stage (from 2 March to 15 April); Kimri stage (from 16 April to 30 June); Khalal stage (from 1 July to 25 August) and Tamer stage (from 26 August to 30 September). The chemicals and pesticides were applied identically as necessary to all blocks. Fertilizers were divided and delivered in accordance with farm management practice for palm trees.

Irrigation scheduling

The amounts of water were measured by flow meters, which were fixed to the sub main lines, and the readings were taken at each irrigation event. Flow controls were used to control the amount of water delivered to the laterals. The date palm trees were daily-irrigated using ten drippers with a water volume, Vw (liters per plant) of

$$V_w = \frac{E_{ca} \times K_t \times K_c \times A_p \times K_r}{E_i \times (1 - LR)} \quad (2)$$

where E_{ca} is the "class A" pan evaporation, K_t=0.7 is the pan coefficient, Kc=1.0 is the constant crop coefficient,

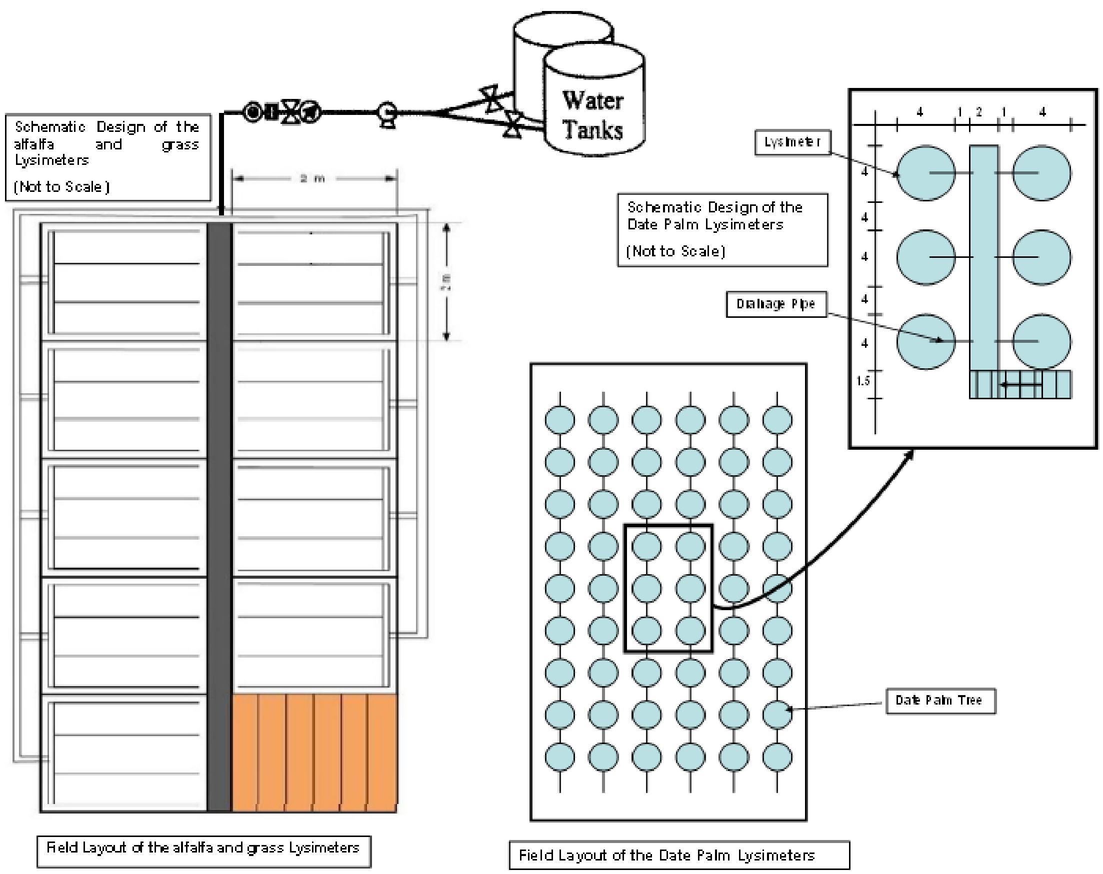

Figure 2. Date palm, alfalfa and grass evapotranspiration measurement experimental set-up

Ap=64m^2 is the soil surface area/plant, E=0.93 is the irrigation system efficiency, LR is the leaching requirements and K_r is a reduction factor.

The reduction factor (K_r) was estimated using equation (3) as suggested by Keller and Bliesner (1990) and Esmail (2002):

$$K_r = 0.1 \times GC^{0.5} \quad (3)$$

where K_r is reduction factor and GC is ground cover value.

In order to calculate GC, the diameter of shaded area in centimeters (cm) was taken after mid-day. The ground cover as percentage was calculated by the procedure described by Hellman (2004) as follows:

$$GC(\%) = \frac{Shaded\ area\ per\ tree}{Area\ per\ tree} \times 100 \quad (4)$$

where GC is the ground cover (%), Shaded area per tree = Tree spacing within row x the average width of measured shaded area between two trees, and Area per tree = Row width x tree spacing within row.

Leaching requirements (LR) were calculated by the equation suggested by Doorenbos and Pruitt (1977):

$$LR = \frac{EC_W}{2max.EC_e} \cdot \frac{1}{LE} \quad (5)$$

where ECw is the electrical conductivity of water (mmho/cm), ECe is the electrical conductivity of soil extract (mmho/cm), max ECe is the maximum electrical conductivity of soil extract tolerated by date palms (mmho/cm) and LE is the leaching efficiency (90% for sandy and loamy sands).

Soil water balance

Components of the basic water balance equation for the lysimeter are precipitation (P), irrigation (I), drainage (D_d), evapotranspiration (ET), runoff (R) and change of water in the soil (ΔSM), written as:

$$P + I - D_d \pm \Delta SM - R - ET_c = 0 \quad (6)$$

The soil moisture storage change was obtained by:

$$\Delta SM = SM_t - SM_{t-1} \quad (7)$$

Where SM_t and SM_{t-1} are the storage soil moisture at

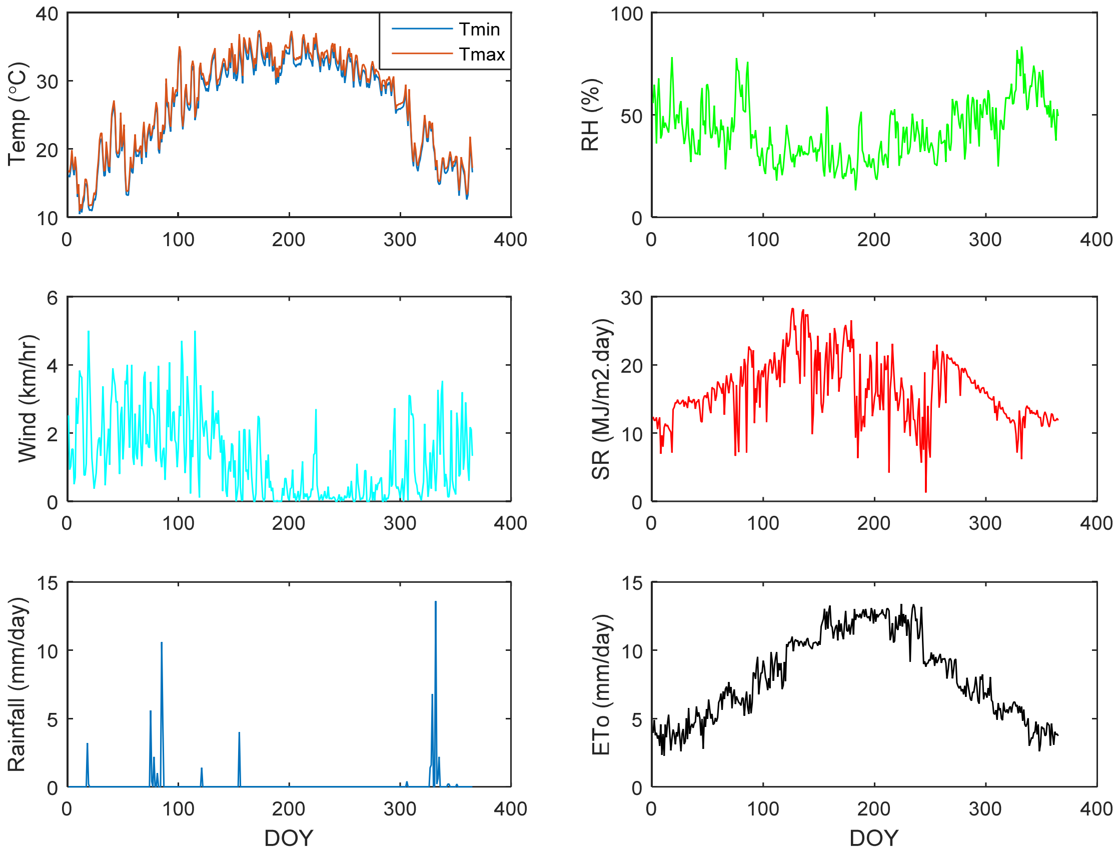

Figure 3. Average daily values of air temperature (Temp), relative humidity (RH), wind speed (Wind), solar radiation (SR), rainfall and evapotranspiration (ETo) at the experimental site.

time instants t and t-1, respectively.

Date palm crop coefficient

The crop Coefficient (Kc) was estimated as:

$$K_c = ET_c / ET_r \quad (8)$$

where ETc is crop (actual) evapotranspiration and ETr is reference evapotranspiration

RESULT AND DISCUSSION

Climatic conditions in the experimental site

The observed daily average values of the climatic variables in the experimental site are shown in figure 3. The data revealed that the maximum mean monthly temperature was 33.30 ºC during the summer months (June and September), while the lowest mean monthly temperature was 17.49 ºC during the winter months (December and February). The highest mean relative humidity was 50.72 % during December and February months; while the lowest mean relative humidity was 33.86 % during June and September months. The region also presents an irregular rainfall regime with a rainy season period, in which the maximum monthly rainfalls were 0.79 and 0.83 mm in March and November, respectively. The wind speed increased from February to September and then decreased toward the end of the observational period, with an average value of 1.27 km/hr for the whole experimental period. The maximum mean daily value of net radiation was 22.89 MJ/m^{2}day in May.

Amount of the applied water

Irrigation water needs are generally low during the initial growth stages, but increases exponentially during the vegetative phases and then again, decrease during flowering and fruiting stages. The daily values of the applied water revealed that the maximum values were 15.34 and 15.09 mm/day in June and July months, respectively (Figure 4), where the air temperature; wind speed and sun shine were high and the relative humidity

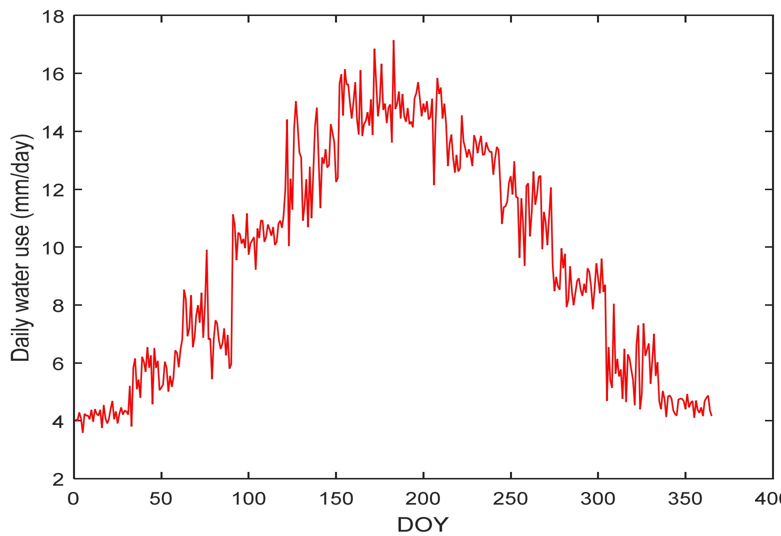

Figure 4. Amount of water applied daily to experimental palms during the study period

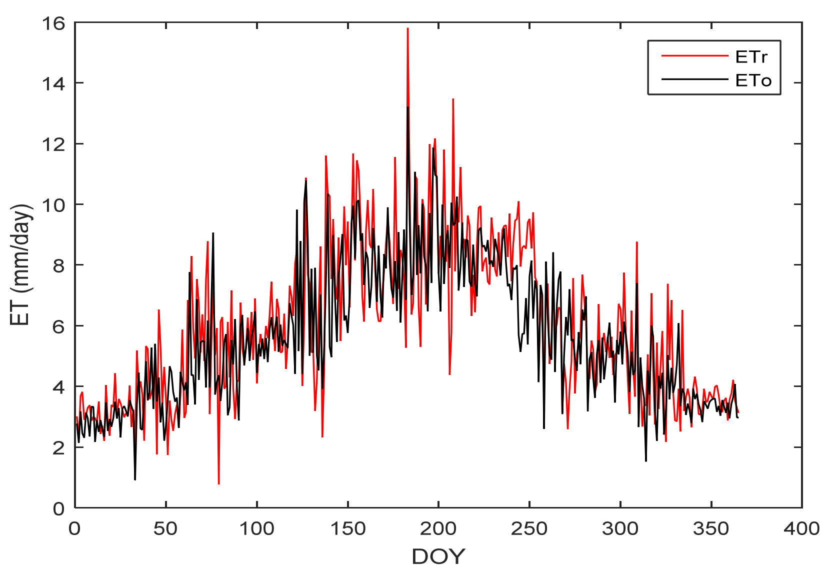

Figure 5. Potential evapotranspiration measured by alfalfa and grass crops during the study period

was low. From mid- experimental period there was a downward trend through the end of the year when the daily values of the applied water fell to the lowest points in in January and December months at 4.28 and 4.63 mm/day, respectively, where the air temperature; wind speed and sun shine were low and the relative humidity was high.

Evapotranspiration of alfalfa and grass crops

The reference evapotranspiration values varied with the time period, depending on the atmospheric temperature and other climatic parameters. Figure 5 shows how the values of evapotranspiration from alfalfa (ETr) and grass (ETo) in mm per day fluctuated between January to December (2015). It is clear that ETr values during winter months (January to March) ranged between 3.12 and 5.1mm/day, respectively. With increasing temperatures from April, plants looked more stressed requiring more frequent irrigations. During summer months (May to July),ETr values ranged between 7.25 and 9.20 mm/day, respectively. Similarly, ETo values

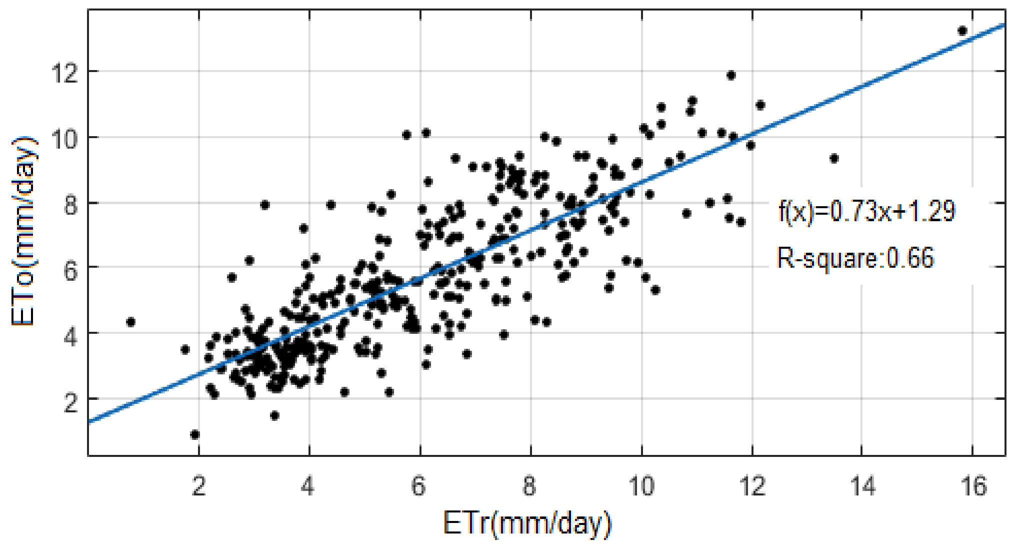

Figure 6. A scatter plot of the ETr and ETo values during the study period

Table 2. Rainfall (P), deep drainage (Dd), irrigation (I), soil water change (ΔSM) and average daily evapotranspiration obtained by the soil water balance, ETc for date palm during 2015.

Month	P (mm)	Dd (mm)	I (mm)	ΔSM (mm)	ETc (mm/day)
Jan	3.4	56.19	129.68	1.73	2.42
Feb	0	68.59	157.14	2.03	3.09
Mar	24.7	112.58	220.84	-1.71	4.34
Apr	0	153.57	313.02	3.29	5.21
May	1.4	191.42	396.42	2.32	6.58
Jun	4	222.63	450.52	1.85	7.67
Jul	0	204.9	458.92	-1.71	8.25
Aug	0	190.35	413.27	-4.27	7.33
Sep	0	183.62	343.71	-2.49	5.42
Oct	0	134.49	272.05	2.1	4.37
Nov	24.6	98.7	176.83	1.32	3.38
Dec	2.8	59.66	141.17	2.09	2.65

reflected a similar trend during winter and summer months, but they slightly underestimated ETr indicating alfalfa irrigated plots received more irrigation as compared to the grass plots. Further, during the entire study period, the mean daily evapotranspiration showed that ETr (5.98 mm/day) was not significantly different from ETo (5.66 mm/day). In addition, ETo values were compared to ETr data using linear regression, generating respective regression coefficients (Figure 6). Based on the results in figure 6, the data are much higher than the regression line and therefore the accuracy of the model obtained is poor with intercept value (1.29), slope (0.73) and coefficient of determination (R^2=0.66).

Evapotranspiration of the date palm tree

The terms of the soil water balance equation used to determine the crop evapotranspiration of the date palm tree are presented in table 2. The date palm evapotranspiration (ETc) increased from 3.09 mm per day in February month at pollination stage to 8.25 mm per day in July at the kalal stage then it decreased to 5.42 mm/day in September at the end of tamer stage. After harvesting, the crop evapotranspiration declined to reach the minimum values of evapotranspiration 2.65 and 2.42 mm/day during December and January, respectively. The maximum values of ETc were 7.67 and

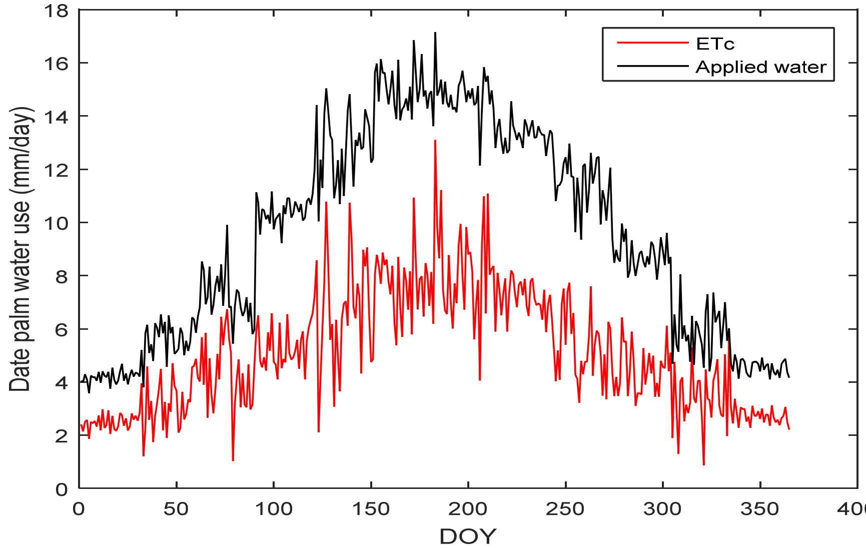

Figure 7. Comparisons of applied water and actual water requirement of date palm

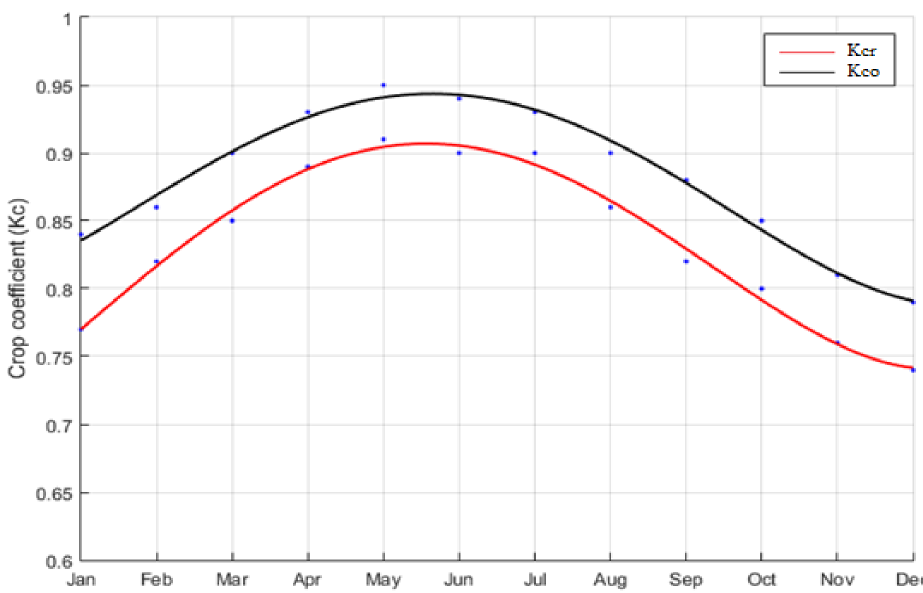

Figure 8. Temporal fluctuation in the crop coefficient (Kc) throughout the year

8.25 mm/day in June and July, respectively. This is mainly due the fact that date palm was at fruits formation stage (kimri and kalal stages), and the climatic conditions of air temperature, wind speed, net radiation and sunshine were high. The date palm evapotranspiration throughout the one year of the experimental period was approximately 1857mm, with a daily average of ETc= 5.08 mm per day. Figure 7 also shows that the total water applied to the soil throughout the productive cycle of the date palm (irrigation plus rainfall= 3605.3 mm) was much greater than the actual water requirement of the date palm (ETc=1857 mm). These results are in conformity with those obtained by (Al-Amoud et al. 2012; Kassem, 2007; Al-Ghobary, 2000).

Crop coefficient of date palm (Kc)

Date palm evapotranspiration (ETc) and alfalfa evapotranspiration (ETr) were combined to compute the date palm crop coefficient (Kcr) as shown in in figure 8, which depicts that Kcr is not constant throughout its

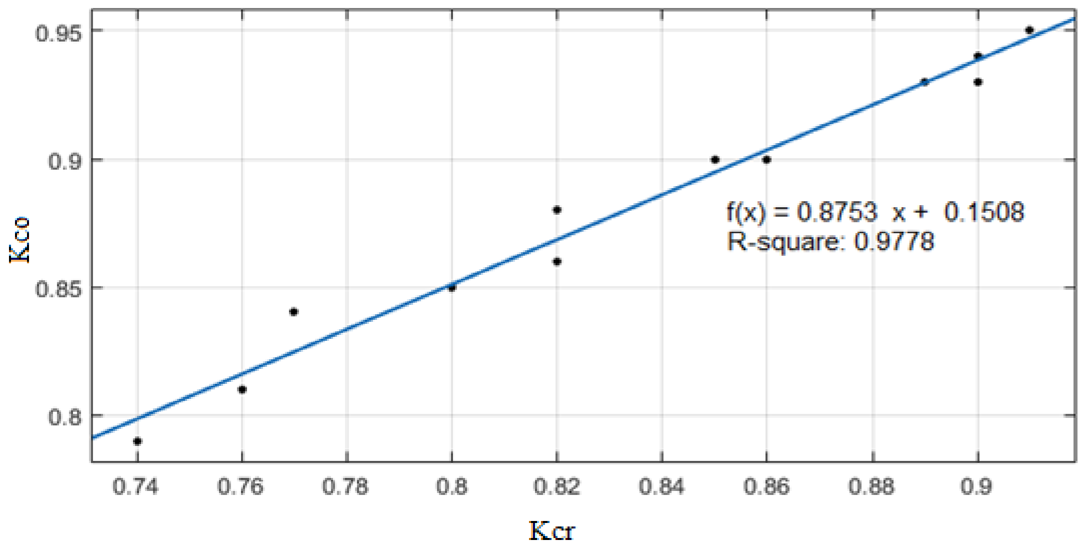

Figure 9. Scatter patterns of Kcr (Date palm evapotranspiration / alfalfa evapotranspiration) and Kco (Date palm evapotranspiration / grass evapotranspiration)

productive cycle. The crop coefficient of the date palm increased from 0.82 in February at pollination stage to 0.91 in May at kalal stage then dipped to 0.81 in September at the end of tamer stage. From harvesting onwards, Kcr declined to reach the minimum values of crop coefficient 0.74 in December due to low temperature and pruning process. The average date palm crop coefficient (Kcr) through the whole year was 0.83. Similarly, the date palm crop coefficient (Kco) calculated as a relation between ETc and grass evapotranspiration (ETo) followed similar trends as Kcr values, which seemed to be consistent throughout the year. However, Kco slightly overestimated Kcr values. The scatter plot that have been carried out between Kcr and Kco values (Figure 9) revealed that there is a reliable and close relationship between both the values (intercept=0.15, slope = 0.87 and R^2=0.97). Date palm water requirement can be estimated by the crop coefficient (Kcr) obtained as a function of the days after pollination (DAP) by the equation: $Kcr = 7.12E\text{-}05(DAP)^4 - 0.0016(DAP)^3 + 0.0073(DAP)^2 + 0.021(DAP) + 0.807$ where R^2=0.98.

CONCLUSION

This study was to determine actual evapotranspiration and crop coefficient throughout the productive cycle of the date palm (Khalas cultivar) by using lysimetery. The experimental site was located at the experimental station of the Centre for Date Palm and Dates, Al-Hassa, Kingdom of Saudi Arabia on a sandy loam textured soil. The results indicated that estimated potential evapotranspiration values of alfalfa and grass crops throughout the year were approximately 2185 and 2068 mm, with a daily average of 5.98 and 5.66 mm per day, respectively. The date palm evapotranspiration increased from 3.09 mm per day in the month of February during the pollination stage to 8.25 mm per day in July at the fruit maturity stage then decreased to 5.42 mm/day in September at the end of harvest. This study revealed that the daily minimum and maximum date palm water requirement ranged between 87 and 297L during the months of January and July, respectively with average of 182 L/day for the entire year. The date palm crop coefficient was not constant throughout its productive cycle and it ranged from 0.74 to 0.91 according to crop growth stages. The average crop coefficient for the date palm tree productive cycle throughout the year was 0.83.

ACKNOWLEDGEMENT

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REFERENCES

Al-Amoud AI, Bacha MA, Al-Darby AM (2000). Seasonal water use of date palms in the central region of Saudi Arabia. Intl. Agric. Eng. J, 9(2), 51-62.

Alamoud AI, Mohammad FS, Al-Hamed SA, Alabdulkader AM (2012). Reference evapotranspiration and date palm water use in the Kingdom of Saudi Arabia. Intl. Res. J. of Agric. Sci. and Soil Sci, 2(4), 156-169.

Alazba A (2004). Estimating palm water requirements using Penman-Monteith mathematical model. J. of King Saud University, 16, 137-152.

Al-Buzaidi AA (1982). Palm tree water requirement. Training course in the cultivation and protection of date palms and dates in Tunisia, April 10-May 4, Regional project for Palm and Dates Research Center in the Near East and North Africa, Baghdad.

Al-Ghobari HM (2000). Estimation of reference evapotranspiration for southern region of Saudi Arabia. Irrigation Sci, 19(2), 81-86.

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome, 300(9), D05109.

Al-Zeid AA (1988). Guide for crop irrigation requirements in the Kingdom of Saudi Arabia.

Bhat NR, Bhat VS, Lekha MK (2012). Estimation of water requirements for young date palms under arid climatic conditions of Kuwait.World J Agric Sci, 8(5), 448-452.

Doorenbos J (1977). Guidelines for predicting crop water requirements. FAO irrigation and drainage paper, 24, 15-29.

Esmail SM (2002). Design and Management of Field Irrigation Systems (In Arabic). First edition. Dar Al Maarif. Cairo, Egypt.

Hellman E (2004). Irrigation scheduling of grapevines with evapotranspiration data.

Irmak S, Haman DZ (2003). Evapotranspiration: potential or reference.IFAS Extension, ABE, 343.

Kassem MA (2007). Water requirement and crop coefficient of date palm trees" Sukariah CV". Misr J. of Agric. Eng, 24, 339-359.

Keller J, Bliesner RD (1990). Sprinkle and trickle irrigation. Van Nostrand Reinhold.

Monteith JL (1965). Evaporation and environment. In Symp. Soc. Exp. Biol (Vol. 19, No. 205-23, p. 4).

Pereira LS (2005). Water and agriculture: facing water scarcity and environmental challenges.

Saeed AB, Etewy HA, Hassan OA (1990). Watering requirement and scheduling of date palm. Agricultural Mechanization in Asia, Africa and Latin America (Japan). 21(4), 49-52.

Soil Conservation Service (SCS). 1970. Irrigation Water Requirements. Soil Conservation Service, Washington, DC, USA. 88pp.