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Estimating Palm Water Requirements Using Penman-Monteith Mathematical Model

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Abstract. The date palm water requirements have theoretically been estimated using the Penman-Monteith model. The grass was considered as the reference crop type with a height of 0.12 m. The historically agro-metrological data from seven regions popular with date palms were collected. The annual ET_c varies from location to another and approximately falls between 1,500 and 2,000 mm. The annual irrigation water requirements range from 5500 mm, with an irrigation efficiency equal to 40 % and 10 % leaching requirement, to 1,500 mm for an irrigation efficiency of 90 % and zero leaching requirement. In other words, the annual volumetric palm water requirements per hectare fall between 15,000 m^3 and 55,000 m^3 depending mostly on location, level of the irrigation management, and quality of the irrigation water. For comparison, actual field data were collected from four palm fields in the central region. Two fields deliver water to the palms using flood irrigation systems and the other two fields apply water through drip irrigation systems. The results showed that the field observations and theoretical estimates of palm water requirements have generally good agreements, particularly during the periods of mid and end seasons. During the early season, the agreement of observations and estimates of the palm water requirements are quietly fair.

Introduction

It is undoubted that the world is facing a water crisis. The cause of this crisis might be attributed to the scarcity of precipitation and limited water resources, in addition to the water demand augmentation, which is inherent to globally continuous population increase. The demand of water, which includes agriculture, municipal use, and industry, is anticipated to increase rapidly. Saudi Arabia, among other countries of the Arabian Peninsula, is one of the countries suffering most from rapid water demand and acute water shortage. For agricultural purposes alone, the abstraction of ground water is expected to reach 20.31 billion m^3 and 22.2 billion m^3 in the years 2000 and 2010, respectively [1].

Saudi Arabia continuously suffers from shortage in water quantity and quality due to increase in water demand and limitation of water resources. The poor management of the irrigation water, along with the absent rules, aggravates the problem. Since most water consumption goes to irrigation, approximately accounting for 90 % of the total water use, it becomes extremely essential to use the irrigation water more efficiently. The conservation of the irrigation water relies on several parameters involved in the on-farm and off-farm irrigation systems. One of the most, if not the most, important components, is the determination of crop water requirements within the on-farm systems. Due to difficulties in direct computation of crop water requirements, initial estimate of reference crop water requirements has been used instead. In turns, the reference evapotranspiration (ET_{ref}) must be determined a priori for ultimate determination of actual crop evapotranspiration (ET_c).

Date palm tree grows in various environmental climates. Therefore, palm trees are found grown in many countries worldwide. The world total number of date palms is around 100 million distributed in 30 countries and producing between 2.5 and 4 million tons of fruit per year [2]. Saudi Arabia, one of the most countries that grow date palms, produces more than 0.7 million tons of dates per year [3]. Zaid and Jimenez [2] indicated that the cultivated area of palm dates in Saudi Arabia is about 95,000 hectares.

In general, the date palm tree is classified as a salt-tolerate and drought-resistant crop. Palm tree can tolerate soil salinity up to 4 dS/m without causing a significant yield reduction [4]. Continuous water stress and accumulation of soil salinity may, however, lead to yielding fruits low in quantity and quality. The yield reduction of date palms is getting worse with the absence of the irrigation water management. It is unfortunate that there are no certain figures specifying the quantities of water needed for a date palm. In literature, a wide range for the palm water requirements is cited. Al-Baker [5] anticipated that the annual water requirements for a mature date palm can range from 115 to 306 m^3. The palm water requirements differ from country to another and from region to region in the same country. For instance, the quantities of water made available for date palms range from 15 000 to 35 000 m^3/ha in Algeria and from 27 000 to 36 000 m^3/ha in California, USA [2]. These ambiguous figures, in addition to limited studies on data palm water requirements, necessitate the estimate of the annual irrigation water requirements for date palms. Therefore, the main objective was to theoretically estimate the palm water requirements using the Penman-Monteith mathematical model in seven regions of Saudi Arabia. The model results will also be verified by using some field observations only in the central part of the Kingdom.

Methodology

The irrigation water requirements (IR) include the crop water use (CU), which is approximately equal to the crop evapotranspiration (ET_c), and soil leaching requirements (LR), in addition to the water losses (WL) represented by the irrigation efficiency (E_i). Mathematically, The IR of a crop may be expressed as follows:

$$IR = \frac{CU/E_i}{1-LR} \approx \frac{ET_c/E_i}{1-LR} \tag{1}$$

Determination of Crop Water USe (CU)

Different techniques are used to determine the crop water use. The crop coefficient approach is usually used for theoretical determination of CU ($\approx ET_c$). The approach combines the reference crop evapotranspiration (ET_{ref}) and the crop coefficient (K_c) as follows:

$$ET = K_c \times ET_{ref} \tag{2}$$

in which K_c = a crop coefficient dependent on the crop variety and growth stage, ET_{ref} = a theoretical reference evapotranspiration.

Determination of Reference Evapotranspiration ET_{ref}

Numerous mathematical models have been developed to determine ET_{ref}. The Penman-Monteith model is widely used in agricultural and environmental research and resulted in good agreement with field observations. Howell et al. [6] compared several ET_{ref} equations for well water, full cover winter wheat and sorghum and found that the Penman-Monteith model performed best. It has been presented by ASCE-70 [7] and by FAO-56 [8] as a method of computing estimates of reference crop water use (ET_{ref}). It turns out that the Penman-Monteith model is likely to be the most promising and standardized method to estimate ET_{ref}. Therefore it is intended to use the Penman-Monteith equation in this study.

Different forms of the Penman-Monteith equation are available in literature [7-9]. A generalized form of the Penman-Monteith model may be proposed as follows:

$$ET_{ref} = \lambda^{-1}\left[\frac{\Delta}{\Delta+\gamma^*}\left(R_n - G\right) + \frac{\gamma}{\Delta+\gamma^*} K\left(e_s - e_a\right)\right] \tag{3}$$

in which:

- ET_{ref} reference evapotranspiration [mm/day],
- λ latent heat of vapourization, [MJ/kg],
- Δ slope of the saturation vapour pressure-temperature curve at mean air temperature [kPa/^{o}C];
- γ psychometric constant [kPa/^{o}C]
- R_n net radiation, [$MJm^{-2}day^{-1}$],
- G soil heat flux, [$MJm^{-2}day^{-1}$],
- γ^* modified psychometric constant [kPa/^{o}C],
- K parameter equal to $1.854\times10^5 \frac{\lambda / r_a}{T+273}$ [MJ/m^2 day kPa].
- r_a aerodynamic resistance [s/m],
- T air temperature [^{o}C],
- e_s saturation vapour pressure at air temperature [kPa],
- e_a actual vapour pressure [kPa].

Parameters computations

The computations of the aforementioned parameters may differ in forms but have almost identical results. The equations used and presented here closely follow that of FAO-56 [7] and ASCE-70 [8].

Latent heat of vaporization (λ):

$$\lambda = 2.501 - \frac{T}{423.5}, \lambda \text{ in MJ/kg and T in } ^oC \quad (4)$$

Slope (Δ):

$$\Delta = \frac{4098\ e^o}{(T + 237.3)^2}, \Delta \text{ in KPa/}^oC \text{ and T in } ^oC \quad (5)$$

Vapor pressure (e^o):

$$e^o = 0.6108\, EXP\left[\frac{17.27\,T}{T + 237.3}\right] \quad , e^o \text{ in KPa and T in } ^oC \quad (6)$$

Psychometric constant (γ):

$$\gamma = \frac{0.001013\,P}{0.622\,\lambda}, \gamma \text{ in KPa/}^oC\text{, P in KPa, } \lambda \text{ in MJ/Kg} \quad (7)$$

Pressure (P):

$$P = 101.3\left[\frac{293 - 0.0065\,E}{293}\right]^{5.26}, \text{ E is elevation in m and P in KPa} \quad (8)$$

Modified psychometric constant (γ^*):

$$\gamma^* = \gamma\left(1 + \frac{r_s}{r_a}\right), r_s \text{ is surface resistance in s/m, } \gamma \text{ in KPa/}^oC, r_a \text{ in s/m} \quad (9)$$

Soil Heat Flux (G):

The soil heat flux is estimated for monthly periods as follows:

$$G_{month,i} = 0.07\left(T_{month,i+1} - T_{month,i-1}\right) \quad (10)$$

where

$G_{month,i}$ soil heat flux of month i [$MJm^{-2}day^{-1}$]

$T_{month,i-1}$ mean air temperature of previous month [^oC]

$T_{month,i+1}$ mean air temperature of next month [^oC]

Net radiation (R_n):

Since R_n is not measured at the selected stations, it is calculated as follows:

$$R_n = R_{ns} - R_{nl} \quad (11)$$

in which,

R_{ns} net short wave radiation, equal to $(1-\alpha)R_s$ [$MJm^{-2}day^{-1}$],

$(1-\alpha)R_s$ net radiation received by a soil or vegetative cover, in which

R_s measured solar radiation [$MJm^{-2}day^{-1}$] and

α shortwave reflectance or albedo, equal to 0.23,

R_{nl} net outgoing longwave radiation [$MJm^{-2}day^{-1}$] determined from:

$$R_{nl} = \sigma\left[\frac{(T_{max} + 273)^4 + (T_{min} + 273)^4}{2}\right](0.34 - 0.14\sqrt{e_a})(1.35\frac{R_s}{R_{so}} - 0.35) \quad (12)$$

in which

σ Stafen-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}],

T_{max} maximum air temperature [^oC]

T_{min} minimum air temperature [^oC]

R_{so} clear –sky solar radiation or cloudless solar radiation, computed from:

$$R_{so} = (0.75 + 0.00002\ E)R_a \quad (13)$$

where

E station elevation above see level [m],

R_a extraterrestrial radiation [$MJm^{-2}day^{-1}$].

Extraterrestrial radiation (Ra):

The extraterrestrial radiation is computed as follows:

$$R_a = \frac{24(60)}{\pi} G_{sc}\ d_r\ \left[\omega_s\ sin(\varphi)\ sin(\delta) + cos(\varphi)\ cos(\delta)\ sin(\omega_s)\right] \quad (14)$$

G_{sc} solar constant [0.0820 $MJm^{-2}min^{-1}$]

d_r inverse relative distance Earth-Sun,

ω_s sunset hour angle [radians]

φ latitude [radians],

δ solar declination [radians]

Where the d_r, ω_s, and δ parameters are obtained according to the following equations:

$$d_r = \frac{cos\left(2\pi \quad \frac{J}{365}\right)}{30} + 1 \quad (15)$$

$$\delta = 0.409\ sin\left(2\pi \quad \frac{J}{365} - 1.39\right) \quad (16)$$

$$\omega_s = arccos\left(-tan(\varphi)\ tan(\delta)\right) \quad (17)$$

in which,

J Julian day, i.e., a number of the day in a year determined as follows:

For the months of March to December,

J = Integer (275 Month/9 –30 +Day) – 2

For the months of January and February,
J = Integer (275 Month/9 –30 +Day)
For leap year and the months of March-December,
J = Integer (275 Month/9 –30 +Day) –1

Aerodynamic resistance (r_a):

The aerodynamic resistance r_a is estimated for neural atmospheric conditions from the following equation:

$$r_a = \frac{1n\left[(z_w - d)/z_{om}\right]\,1n\left[(z_p - d)/z_{ov}\right]}{k^2\,u_z} \tag{18}$$

where

z_w height of wind speed measurement, m.
d zero-plane displacement of wind profile [$d = 2/3h_c$, m],
h_c reference crop height [m],
z_{om} roughness length for momentum transfer [$z_{om} = 0.123h_c$ s/m].
z_p height of humidity and temperature measurements [m],
z_{ov} roughness length for transfer of heat and vapour, [$z_{ov} = 0.0123h_c$, s/m],
k von Karman's constant, [= 0.41],
u_z wind speed measured at height z_w [m/s],

For standardized measurements of wind and humidity in addition to that d, z_{om}, and z_{ov} are functions only of h_c, r_a can simply be approximated by the following developed equation:

$$r_a = \frac{1 - ln(h_c)}{(k_2)^2\,u_2} \tag{19}$$

where

k_2 constant parameter equal to 0.123.
u_2 wind speed measured at 2 m height [m/s],

The use of equation (19) has been found to cause insignificant errors in computing r_a as shown in Figure 1.

Surface resistance (r_s):

The surface resistance of soil and crop r_s is calculated using the following equation:

$$r_s = \frac{r_l}{0.5LAI} \tag{20}$$

r_l bulk stomatal resistance of well-illuminated leaf [taken as 100 s/m]
LAI leaf area index [m^2 (leaf area)/m^2 (soil surface)], and is estimated from:

$$LAI = 5.5 + 1.5\ ln(h_c) \tag{21}$$

for alfalfa and non-clipped grass, and

$$LAI = 24\, h_c \tag{22}$$

for clipped grass that is used in the present study.

Vapor pressure deficit (VPD):

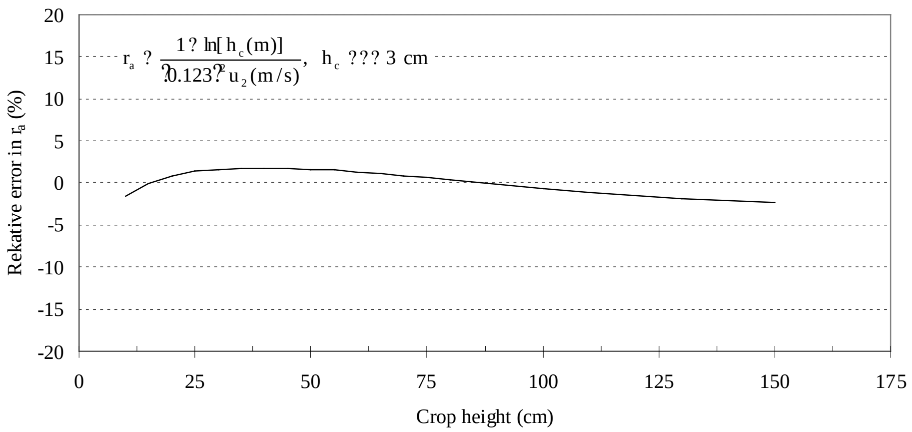

Fig. 1. Relative error in aerodynamic resistance (r_a) versus reference crop height (h_c).

In Eq. (3), the term [e_s-e_a] is known as the vapour pressure deficit (*VPD*). The *VPD* can differently be estimated depending on the availability of certain agro-climatic parameters. According to the data collected from the selected regions, the *VPD* is to be computed using the parameters of maximum temperature (T_{max}), minimum temperature (T_{min}), maximum humidity (RH_{max}), and minimum humidity (RH_{min}) as follows:

$$e_a = \left[\frac{e^o(T_{min}) \dfrac{RH_{max}}{100} + e^o(T_{max}) \dfrac{RH_{min}}{100}}{2} \right] \tag{23}$$

and

$$e_s = \left[\frac{e^o(T_{max}) + e^o(T_{min})}{2} \right] \tag{24}$$

therefore,

$$VPD = [e_s] - [e_a] = \left[\frac{e^o(T_{max}) + e^o(T_{min})}{2} \right] - \left[\frac{e^o(T_{min}) \dfrac{RH_{max}}{100} + e^o(T_{max}) \dfrac{RH_{min}}{100}}{2} \right] \tag{25}$$

Eq. (25) can also be written as:

$$VPD = [e_s] - [e_a] = \frac{1}{2}\left[e^o(T_{max}) - e^o(T_{max})\frac{RH_{min}}{100} + e^o(T_{min}) - e^o(T_{min})\frac{RH_{max}}{100} \right] \quad (26)$$

or simply,

$$VPD = \frac{1}{2}\left[e^o(T_{max})\left(1 - \frac{RH_{min}}{100}\right) + e^o(T_{min})\left(1 - \frac{RH_{max}}{100}\right) \right] \quad (27)$$

For relative humidity (RH) expressed in ratio,

$$VPD = 0.5\, e^o(T_{max})\left(1 - RH_{min}\right) + 0.5\, e^o(T_{min})\left(1 - RH_{max}\right) \quad (28)$$

A FORTRAN program was developed and used to facilitate all the previous calculations. It should be mentioned that the height of the reference crop h_c was set to 12 cm, which is the typical crop grass height. Thus the ET_{ref} was replaced by ET_o, which denotes for grass reference evapotranspiration.

Crop coefficient (K_c):

With regards to the crop coefficient, the growing period of a palm tree, like other crops, consists of four stages namely: initial, development, mid season, and late season. While K_c values for initial and mid season stages are considered constant, K_c values for development and late season stages are assumed to be linearly increasing and decreasing with time, respectively. Three values of K_c for initial stage, mid season stage and end season stage, are only needed to construct the K_c curve. The K_c values for date palms range from 0.9 to 0.95 [8]. They suggested that these values are adjusted for local conditions using the following equation, particularly for mid and end Kc values:

$$\left(K_{cadj}\right)_i = \left(K_c\right)_i + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h_{crop}}{3}\right)^{0.3} \quad (29)$$

where,

K_{cadj} adjusted K_c for the ith period (considered monthly) [dimensionless],
K_c K_c for the ith period (considered monthly) [dimensionless],
u_2 mean wind speed at 2 m height for the ith period [m/s],
RH_{min} mean minimum relative humidity for the ith period [%],
h_{crop} mean plant height during the ith month [m].

Equation (29) is valid for certain ranges of u_2, RH_{min} and h_{crop}. From the analysis of the weather data, more than 97 % of RH_{min} data for the seven regions were found to be below 20 %. Therefore, Eq. (29) cannot be used to compute K_c. An alternative average value of K_c was used for all stages and regions instead. This average K_c value for date palm tree was 0.853, which resulted from a field study conducted by Abou-Khaled et al. [10] in the central of Iraq. Thus a basic assumption of the current study is that the growth conditions for date palm trees in the Arabian Peninsula countries are similar.

Locations and weather data

Seven regions that popularly grow date palms have been selected. The necessarily weather data from nearly 1985-2000 were collected. All regions are interior locations except Qateaf that is a costal location. Of course, the results of this study depend solely on the accuracy of the collected weather data and the used K_c value, which is about 0.853. Table 1 summarizes the averages of the climatic parameters collected from the weather stations of the seven regions.

Results and Disccusion

Table 2 shows a summary of ET_o and palm ET_c and *IR* calculated for different ranges of E_i and *LR* in accordance with Eq. (2). As can be seen from the table, ET_o ranges from about 1,600 to almost 2,300 mm/year. The highest values were 2,294; 2,275; and 2,245 mm/year for Kharj, Riyadh, and Najaran, respectively. Qateaf has the lowest ET_o value that is equal to 1,609 mm/year. The average ET_o is equal to 2,038 mm/year. With regard to the *IR*, the values vary according to the magnitudes of E_i and *LR*. For zero leaching requirement and 90 % E_i, the yearly palm IR were 1851, 1524, 2128, 2002, 2156, 2173, and 1682 mm for Beasha, Qateaf, Madeana, Riyadh, Kharj, and Qaseam, respectively. For 10 % *LR* and 40 % E_i, the *IR* values (mm/year) for the seven regions ranged from 3811, recorded for Qateaf, to 5433, recorded for Kharj. Assuming 65 % average E_i and 100 trees/hectare, the average *IR* is in the vicinity of 300 m^3/tree. For drip irrigation where E_i is generally equal to 90 %, the average *IR* is equal to 120 m^3/tree, assuming that the percentage of wetted area of the field is equal to 40 %. For 60 % field witness, the palm *IR* equals 180 m^3/tree.

For 65 % average irrigation efficiency (E_i) and $0 \leq LR \geq 10$ %, the palm *IR* ranges approximately from 23,000 m^3/ha (1000 mm /1000 mm * 10 000 m^2 = 10 m^3/ha) to 36 000 m^3/ha. It can be seen from Table 2 that *IR* may exceed 50,000 m^3/ha as a result of low E_i and high *LR*. On the other hand, *IR* might be in the vicinity of 15,000 m^3/ha as for high E_i and nil *LR*. This magnitude ironically indicates the importance of irrigation water management that leads to high water use efficiency. The expansion of the irrigated area grown with Palms, along with the absence of the irrigation water management, will undoubtedly lead to considerable amount of water needed for irrigation. From the present study, it might be stated that the annual reference crop water requirements (ET_o) may approximately be in the range of 1,500 mm and 2500 mm for the seven regions.

If the figures of the annual crop water requirements (ET_c) that are found in the literature are presumably and reasonably accurate, the crop coefficients for Najran, Riyadh, and Qateaf would be 0.851, 0.949, and 0.832 respectively. Ultimately, the average K_c for date palms is about 0.88. These K_c values are likely to be closed to 0.853 that was used in this study. As the nature of this study is theoretical and preliminary, further justification and verification are needed for ultimate judgment of K_c.

Table 1. Historically averaged climatic data collected from agro-meteorological stations

Region	Month	Maximum Tempera-ture Tmax °C	Minimum Tempera-ture Tmin °C	Maximum relative humidity RH max %	minimum relative humidity RH min %	Wind Speed U_2 m/sec	Actual Sunshine duration hrs	Solar radiation RS $MJm^{-2}day^{-1}$
Beasha	1	31.70	3.82	90.87	12.49	2.0	5.91	11.8
	2	33.47	6.17	89.80	14.54	2.3	7.18	12.8
	3	36.83	9.40	91.40	10.33	2.1	6.49	12.1
	4	38.07	13.93	89.13	9.05	2.3	7.32	13.7
	5	40.81	17.29	87.92	11.06	1.5	7.48	15.0
	6	41.92	17.80	65.45	10.61	1.2	8.39	17.2
	7	42.25	19.55	62.06	14.94	1.3	7.95	15.9
	8	41.91	20.31	65.81	16.18	1.3	7.87	15.5
	9	39.86	14.97	62.18	16.52	1.4	8.21	15.0
	10	36.53	11.04	77.13	16.75	1.7	7.61	14.4
	11	32.93	8.22	83.80	15.28	2.3	7.36	12.9
	12	31.97	5.83	88.91	13.78	1.7	6.45	10.5
Qateaf	1	25.90	3.37	97.61	22.99	1.9	8.53	9.0
	2	29.70	3.02	97.34	16.29	1.1	7.02	9.7
	3	35.88	5.41	97.95	13.58	1.1	6.79	11.6
	4	40.44	10.05	94.45	15.89	1.1	6.01	14.3
	5	44.22	11.24	91.70	13.84	1.1	6.58	14.9
	6	46.08	18.00	91.49	10.89	1.2	6.91	15.6
	7	47.18	12.87	95.21	9.64	1.0	7.24	14.9
	8	45.94	13.81	97.08	11.15	1.0	7.55	14.6
	9	45.47	16.25	95.55	13.73	0.9	8.64	14.5
	10	40.41	13.90	96.52	11.89	1.3	8.57	13.1
	11	36.55	8.11	96.74	10.99	1.0	8.88	9.6
	12	32.01	6.02	98.14	23.24	1.1	9.04	7.8
Madeana	1	29.40	6.63	87.14	9.02	2.3	6.99	12.1
	2	31.38	7.66	82.30	8.70	1.7	6.59	14.1
	3	35.17	10.51	83.01	7.48	2.0	5.80	15.3
	4	39.47	13.48	84.00	7.89	1.5	7.22	17.7
	5	43.27	19.78	58.44	5.72	1.6	6.68	18.3
	6	44.65	22.98	36.37	5.18	2.3	6.31	21.9
	7	45.60	23.98	39.90	7.41	1.9	7.23	21.5
	8	45.37	23.76	51.39	5.78	2.3	7.32	19.1
	9	43.87	23.31	50.28	5.27	1.5	9.78	18.0
	10	40.00	17.82	67.55	8.56	1.7	9.93	15.7
	11	34.53	12.23	85.60	12.60	1.9	8.71	11.7
	12	30.46	9.41	83.60	12.40	1.7	7.32	10.8
Najran	1	33.66	-0.54	95.00	10.36	2.3	7.67	12.5
	2	34.08	3.00	72.71	11.41	2.4	7.43	13.0
	3	36.65	7.19	89.23	11.14	2.0	6.67	12.7
	4	36.73	11.68	98.34	9.00	1.5	6.66	15.7
	5	38.27	13.16	72.88	8.20	1.6	6.43	18.0
	6	39.47	14.66	47.52	6.31	2.3	5.90	18.1
	7	40.09	16.69	50.05	9.21	1.9	6.60	15.4
	8	39.76	16.33	55.63	10.56	2.3	7.52	15.5
	9	37.95	11.97	62.11	9.52	1.6	7.89	15.9
	10	33.85	5.52	74.17	14.38	1.7	7.40	15.1
	11	30.80	3.41	79.30	17.48	1.8	7.36	13.8
	12	30.95	1.13	98.67	10.78	1.7	7.63	10.1

Table 1 (continued). Historically averaged climatic data collected from agro-meteorological stations

Region	Month	Maximum temperature Tmax °C	Minimum temperature Tmin °C	Maximum relative humidity RH max %	minimum relative humidity RH min %	Wind Speed U_2 m/sec	Actual Sunshine duration hrs	Solar radiation RS $MJm^{-2}day^{-1}$
Riyadh	1	30.05	0.51	95.82	10.18	2.3	7.63	8.7
	2	32.55	1.78	93.58	9.70	2.4	6.23	12.1
	3	35.92	5.28	92.39	8.53	2.0	4.77	12.5
	4	40.14	11.61	90.17	8.22	1.5	5.78	14.8
	5	44.51	17.24	83.42	9.69	1.6	5.99	17.6
	6	45.29	20.22	61.00	8.64	2.3	5.92	19.6
	7	46.60	22.34	53.92	10.14	1.9	6.23	18.5
	8	46.30	20.88	56.75	8.96	2.3	6.87	17.4
	9	44.58	16.03	69.21	11.72	1.8	8.19	16.5
	10	41.25	11.04	86.43	12.85	1.7	7.80	14.4
	11	35.47	6.70	93.30	12.32	1.8	8.58	11.3
	12	30.59	2.18	94.91	8.19	1.7	8.31	8.6
Kharj	1	30.07	0.55	85.73	15.18	1.4	9.26	10.3
	2	33.47	1.40	80.55	7.82	1.9	8.02	12.7
	3	38.62	6.20	77.00	9.33	2.1	6.32	13.9
	4	41.88	10.60	75.75	7.25	1.7	7.04	14.7
	5	46.26	13.57	57.20	6.40	1.8	6.35	17.2
	6	46.93	17.61	40.70	8.30	2.1	6.84	18.5
	7	46.92	15.74	33.83	5.28	1.9	7.16	17.8
	8	46.97	17.29	42.36	7.27	1.7	7.73	18.2
	9	44.36	14.35	54.91	8.73	1.7	9.26	17.2
	10	41.47	10.46	65.92	11.08	1.6	8.51	14.9
	11	34.57	5.68	79.83	11.33	1.7	9.49	13.0
	12	31.43	1.48	86.08	14.92	1.6	9.36	9.7
Qaseam	1	26.34	1.54	84.59	18.65	1.4	7.44	10.5
	2	30.28	2.63	82.12	15.88	1.5	6.69	13.2
	3	34.62	5.63	83.59	14.35	1.5	6.15	14.7
	4	38.95	11.70	83.47	11.59	1.3	5.69	16.3
	5	43.02	14.89	61.75	12.00	1.4	6.47	18.3
	6	44.59	19.86	28.44	10.31	1.0	6.83	22.3
	7	45.63	19.68	29.00	9.56	1.4	7.33	21.8
	8	45.84	20.84	31.00	12.38	1.1	7.31	19.9
	9	43.21	15.85	37.06	13.00	1.0	10.31	17.7
	10	39.26	12.23	54.88	13.38	1.1	9.96	14.6
	11	32.48	6.29	79.31	15.69	1.1	9.76	11.0
	12	28.18	2.12	84.06	17.06	1.3	8.85	8.6

Table 2. Annual ET_o and date palm ET_c and IR (mm) considering K_c = 0.853 for seven regions in Saudi Arabia (flood irrigation)

		Beasha	Qateaf	Madeana	Najran	Riyadh	Kharj	Qaseam	AVG
Annual	ET_o	*1953*	*1609*	*2245*	*2114*	*2275*	*2294*	*1774*	*2038*
Annual	ET_c	*1666*	*1372*	*1915*	*1802*	*1940*	*1956*	*1514*	*1738*
					***LR* = 0 %**				
E_i (%)	40	4165	3430	4788	4505	4850	4890	3785	4345
	50	3332	2744	3830	3604	3880	3912	3028	3476
	60	2777	2287	3192	3003	3233	3260	2523	2897
	70	2380	1960	2736	2574	2771	2794	2163	2483
	80	2083	1715	2394	2253	2425	2445	1893	2173
	90	1851#	1524#	2128#	2002#	2156#	2173#	1682#	1931#
AVG	**65**	**2765**	**2277**	**3178**	**2990**	**3219**	**3246**	**2512**	**2884**
					***LR* = 5%**				
E_i (%)	40	4384	3611	5039	4742	5105	5147	3984	4574
	50	3507	2888	4032	3794	4084	4118	3187	3659
	60	2923	2407	3360	3161	3404	3432	2656	3049
	70	2505	2063	2880	2710	2917	2941	2277	2614
	80	2192	1805	2520	2371	2553	2574	1992	2287
	90	1949#	1605#	2240#	2108#	2269#	2288#	1771#	2033#
AVG	**65**	**2910**	**2397**	**3345**	**3148**	**3389**	**3417**	**2645**	**3036**
					***LR* = 10%**				
E_i (%)	40	4628	3811	5319	5006	5389	5433	4206	4828
	50	3702	3049	4256	4004	4311	4347	3364	3862
	60	3085	2541	3546	3337	3593	3622	2804	3219
	70	2644	2178	3040	2860	3079	3105	2403	2759
	80	2314	1906	2660	2503	2694	2717	2103	2414
	90	2057#	1694#	2364#	2225#	2395#	2415#	1869#	2146#
AVG	**65**	**3072**	**2530**	**3531**	**3322**	**3577**	**3606**	**2791**	**3204**

An attempt was made to compare the theoretically estimated palm IR with some field observations in the central part of the Kingdom (Riyadh and Alkharj regions). The data were collected from two farms delivered water to the palm with drip irrigation system and denoted by DF. The other two fields irrigated palm with flood irrigation system (basin) and denoted by BF. The collected data of the monthly applied water were not measured by any means. They, in fact, were provided by the irrigators of the farms.

Figures 2 and 3 depict the relationship between daily water requirements (mm/day) versus time (day). Figure 2 compares the average daily water requirements obtained form DF farms to that calculated. As can be seen from the figure, there is a good agreement between estimates and observations of the daily irrigation water requirements for palm tree. For the months from January to April, fair agreement is likely to exist between observed and calculated daily palm water requirements. The same conclusion can be drawn from figure 3 that shows good agreement between field observations and theoretical estimates of the daily palm water requirements during the mid and end of the year. For the months from January to April, the agreements between observed and estimated daily palm water requirements are fairly acceptable. It should be noted that the field data obtained in the study were only accomplished for the central part of the Kingdom (Riyadh and Kharj regions). The ultimate judgment of the applicability of the Penman-Monteith model over the entire Kingdom requires field studies to obtain the actually applied water for palm trees.

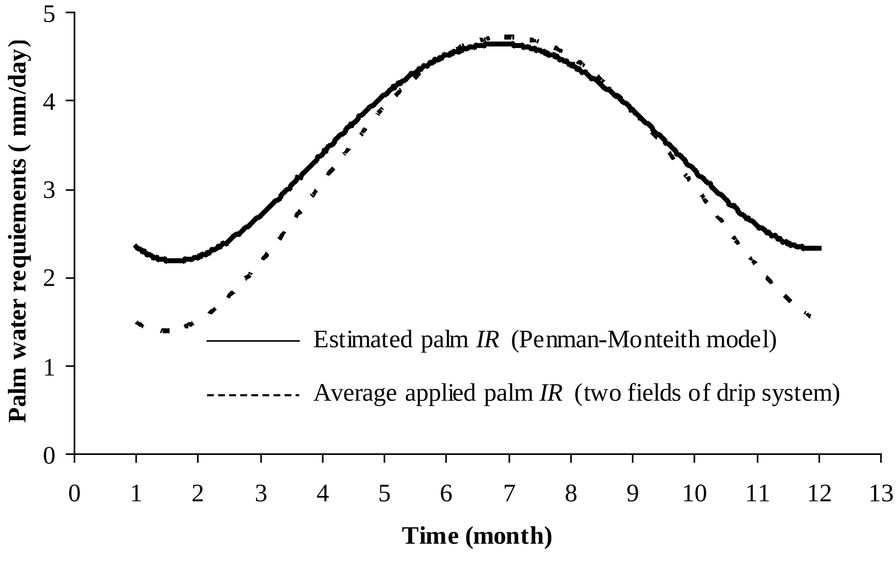

Fig. 2. Comparison of estimated and applied daily palm water requireemnts (drip system).

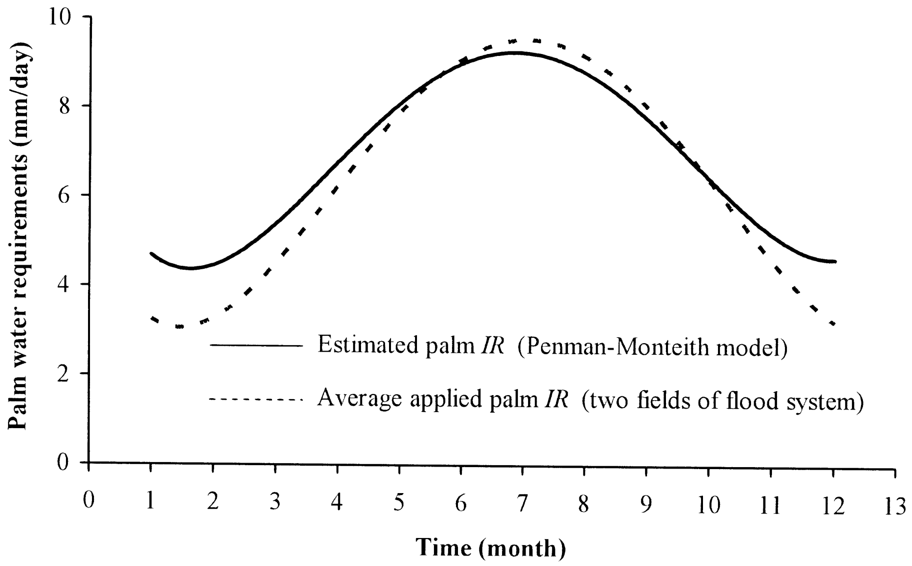

Fig. 3. Comparison of estimated and applied daily palm water requirements (flood system).

It should also be noted that the results of the present study are preliminarily theoretical and further field researches should be conducted. Needless to say that the outputs of the current study depend on the accuracy of the collected weather data and the proper choice of the K_c value as early mentioned.

Conclusion

The palm water requirements for seven Saudi regions have been estimated using the Penman-Monteith model. An averagely constant K_c value of about 0.853 was considered for the seven regions and during the crop four stages. The reference crop type chosen for this study was dense grass with 0.12 m height.

Although the results are useful in planning and designing an irrigation project for cultivated date palms and for appropriate scheduling of the irrigation water, one should consider further field studies. This is particularly important when knowing that the current study is subject to some limitations. For example, the palm crop height is less than or equal to 8 m. Also, the single crop coefficient was considered, but not the dual crop coefficient.

The results of Penman-Monteith model have tentatively shown good agreements with the field data. The collected data were for field of the central part (Riyadh and Kharj regions). Thus, one should realize that the eventual suitability of the Penman-Monteith model for estimating palm water requirements in other regions of the Kingdom requires further field data collections.

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تقدير الاحتياجات المائية للنخيل باستخدام نموذج بنمان–مونتيث الرياضي

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ص.ب. ٢٤٦٠ ،الرياض ١١٤٥١ المملكة العربية السعودية
(قدم للنشر في ١٤٢٣/٨/١٣هـ ؛ وقبل للنشر في ١٤٢٤/١/٢٢هـ)

ملخص البحث. تم تقدير الاحتياجات المائية للنخيل باستخدام نموج بنمان-موتتيث الرياضي على أساس العشب كمحصول مرجعي. كما تم جمع البيانات المناخية من محطات الارصاد الجوية لسبع مناطق مشتهرة بزراعة النخيل. وتبين من النتائج أن البخر-نتح المحصولي السنوي يختلف من موقع لاخر، ويتراوح من ١٥٠٠ الى ٢٠٠٠ مم. أما بالنسبة للاحتياجات المائية الكلية للنخيل فهي تتراوح من ٥٥٠٠ مم، وذلك لكفاءة ري تساوي ٤٠ % ونسبة احتياجات غسيلية تعادل ١٠%، إلى ١٥٠٠ مم، وذلك لكفاءة ري تساوي ٩٠ % وبدون احتياجات غسيلية. وعلى أساس حجمي للهكتار، فإن هذا يماثل ٥٥٠٠٠ و ١٥٠٠٠ م^{٣}، على التوالي، وذلك اعتمادا على الموقع الجغرافي، ومستوى ادارة مياه الري، بالإضافة إلى جودة المياه المستخدمة في ري النخيل. وللتحقق من مدى ملائمة نموذج بنمان-مونتيث الرياضي المستخدم في تقدير الأحتياجات المائية للنخيل، تم مقارنة نتائج النموذج مع بيانات حقلية تم جمعها من اربعة حقول في المنطقة الوسطى، اثنان منها تستخدمان نظام الري بالتنقيط، والآخران تستخدمان نظام الري بالغمر. وقد لوحظ وجود توافقا جيدا بين التقدير النظري والحقلي للاحتياجات المائية للنخيل خلال الفترة من مايو إلى ديسمبر، وتوافقا مقبولا خلال الفترة من يناير إلى إبريل.