EFFECTS OF DIFFERENT IRRIGATION METHODS ON THE EVAPOTRANSPIRATION OF DATE PALM TREES UNDER ARID ENVIRONMENT

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ABSTRACT

A field experiment was conducted through the period from 11/2001 to 4/2003 to study the effects of different irrigation methods (Drip and Surface) on evapotranspiration (water consumption) (ET_C) of two date palm tree cultivars (Sukkariah and Rabiah). The irrigation methods were assigned randomly for the trees with two replicates of each cultivar. Other agriculture treatments were the same (fixed) over all the trees during this study except the irrigation methods.

Soil water balance method was used to determine the actual water consumption "evapotranspiration" of date palm trees. Soil water content was observed daily for each tree using Neutron Probe device at depths of 20, 30, 40, 50, 70, 90, and 110 cm. The change in soil water content at depths of 90 and 110 cm was used to approximate deep percolation using one dimension unsaturated flow model. The results showed no significant difference between the two cultivars in the ET_C of date palm trees. However, there were significant differences between the irrigation methods in the ET_C of the trees. The annual water consumptions of date palms were 20190 and 18500 (m^3/ha/year) for drip and surface irrigations, respectively. Although, trees irrigated with drip irrigation consumed about 10% more water than those irrigated with surface irrigation, the annual water requirement for trees irrigated with drip irrigation were about 33% less than those irrigated with surface irrigation based on irrigation efficiency of 0.9 and 0.55 for drip and surface irrigations, respectively. In addition, the results showed that values of 0.9 and 0.8 can be used as an average seasonal date palm crop coefficient for drip and surface irrigation, respectively, to approximate ET_C for date palm trees in Makkah region.

Keywords. *Evapotranspiration, date palm trees, irrigation system, drip irrigation, surface irrigation.*

INTRODUCTION

According to the limited water resources in Saudi Arabia, a good water management is essential especially in the agriculture sector which consumes more than 80% of water use in Saudi Arabia (Al-zibari, 2000). Date palm tree is one of the main fruit tree in Saudi Arabia. The total cultivated area with date palm trees represents 77% of the total cultivated area with fruits trees. The total number of date palm trees is increasing rapidly. Eighty seven percent of these trees are irrigated in a traditional way using surface irrigation method (MAW, 2001). Therefore, the irrigation requirements of date palm farms are increasing. On the other hand, most of these trees are grown in sandy soil. Accordingly, the volume of lost water due to deep percolation is increasing. The estimation of water requirements by crops is considered the main step to establish a good management plan for water resources use in the agriculture sector. In addition, adapting efficient irrigation systems such as drip and bubbler irrigation will increase water use efficiency.

Some studies were done to determine date palm trees water requirement in different parts of the world. Abou-Khaled *et al.* (1981) approximated date palms water consumption in Iraq to be 18000 (m^3/ha/year). Zaid and Arias-Jimenez (2002) reported that the water requirements of date palms in several places around the world are between 13000 (m^3/ha/year) in Morocco to 36000 (m^3/ha/year) in California, USA. They also found that the summer water requirements of date palms in Tunisia were as twice as much the winter water requirements. In Saudi Arabia, the annual date palms irrigation requirement using surface irrigation were 29788, 32736, 37910, 41273 and 42573 (m^3/ha/year) for Aseer, Riyadh, Qussim, Al-Hassa and Al-Maddinah regions, respectively as reported by Abderrahman and Al-Nabulsi 1993. They also found 38% decrease in the annual date palms irrigation requirement using drip irrigation for the five regions due to the increase in irrigation efficiency from 55% for surface irrigation to 90% for drip irrigation. Furthermore, Alzaid *et al.* (1988) calculated the water requirements of date palms irrigated with drip, sprinkler and surface irrigation for different regions in Saudi Arabia among them Makkah region. Their approximations were based on irrigation efficiency of 85%, 70% and 55% for drip, sprinkler and surface irrigation, respectively. Their results showed that the water requirements in Makkah region were 20245, 24584 and 31393 (m^3/ha/year) for drip, sprinkler and surface irrigations, respectively. A decrease of about 37% in water requirements were showed between date palm trees irrigated with drip irrigation and those irrigated with surface irrigation. In Najran region, the annual water requirements of date palms were ranging between 16989 and 26705 m^3/ha/year (Al-Ghobari, 2000). However, all of these studies in Saudi Arabia were based on empirical methods and not on actual field measurements.

Evapotranspiration can be measured directly by lysimeter or indirectly by different methods such as soil water balance, energy balance, and stem flow method (Hoffman *et al.*, 1990) or it can be approximated by empirical equations such as Penman

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equation and Penman-Monteith equation. Soil water balance method was used to determine water consumption for different trees (Basahi, 2006, Testi *et al.*, 2004 and Fares and Alva, 1999).

The objectives of this study were to determine the effects of different irrigation methods on the evapotranspiration of two date palm tree cultivars in Makkah region of Saudi Arabia using soil water balance method, also to estimate crop coefficient of date palm trees for Makkah region, based on measured data of ET_C.

MATERIALS AND METHODS

This experiment was conducted at Hada Al-Sham Agriculture Research Station, King Abdulaziz University for 18 months (11/2001 – 4/2003). Two-factor experiment in randomized complete block design in two replicates was done. Three main Factors were studied, the first factor was two palm date cultivars (Sukkariah and Rabiah), the second factor was two irrigation methods (drip and surface) and the third factor was time (month). In each treatment two homogenous palm trees were used. The 14 year old palm trees were grown in sandy soil at 10 m X 10 m spacing. Monthly averages of some of the meteorological data (temperature, relative humidity and wind speed) from 1978 to 2000 were tabulated for the study area.

Table 1. Monthly averages of some meteorological parameters for Makkah region (1978-2000).

Months	Max. temperature C°	Min. temperature C°	Mean temperature C°	Max. relative humidity %	Min. relative humidity %	Mean relative humidity %	Wind speed (m/s)
Jan.	30.1	18.4	24.3	77	38.9	58.0	1.6
Feb.	31	18.1	24.6	73.1	33.8	53.5	1.9
Mar.	34.2	20.4	27.3	68.2	28.7	48.5	2.0
Apr.	38.2	23.9	31.1	62	25	43.5	1.9
May	41.7	27.3	34.5	53.9	22.6	38.3	1.8
June	43.5	27.9	35.7	50.7	19.2	35.0	1.7
July	42.6	28.5	35.6	50.2	21.5	35.9	1.6
Aug.	42.4	28.8	35.6	55.2	24.2	39.7	1.7
Sep.	42.4	28.4	35.4	64.2	25.5	44.9	1.6
Oct.	39.7	25.4	32.6	71.7	25.8	48.8	1.5
Nov.	34.7	22.5	28.6	78.8	34.9	56.9	1.4
Dec.	31.3	19.8	25.6	79.2	40	59.6	1.4

Soil samples were taking for the soil horizons at 0 to 20, 20 to 40, 40 to 60, 60 to 80, 80 to 100, and 100 to 120 cm for each tree root zone. Soil samples were used to determine some of the chemical and physical soil properties. The results of soil samples analyses showed that the soil is sandy with average values for EC, pH, saturated hydraulic conductivity, bulk density and holding capacity of 1.24 dS/m, 7.89, 7.29 cm/min, 1.75 gm/cm^3 and 0.7 cm^3/ cm^3, respectively. Also, soil samples were used to develop soil water retention curves. The average retention curves for the soil horizons in the area are presented in Figure 1. The EC and pH of irrigation water were 1.8 dS/m and 7.7, respectively.

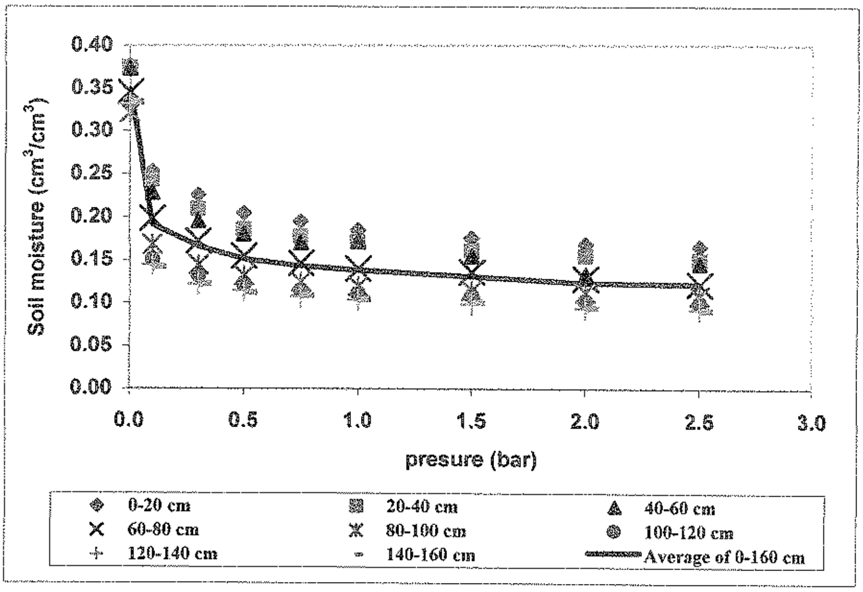

Fig. 1. Soil water retention curve for the study area.

Irrigation network contains storage tank (6 cubic meters), main line (38 mm diameter), a pump (3 hp), a controller, and 2 submain lines one for the drip irrigation the other for the surface irrigation. At the upstream of each submain a solenoid valve and screen filters were installed. In order to minimize emitters plugging, an extra disk filter was used in the drip submain. To insure uniform distribution of water for all palm trees, a diameter of 25 mm were used for the submain lines to minimize the friction losses. Rain Bird pressure compensating drippers (7.0 gph) were used to insure further water distribution uniformity. Six drippers were distributed 500 mm from the stem of each palm tree at equal distance of each other with total flow rate equal to 2.65 lit/ min/ tree. In surface irrigation method, a 5 m diameter basin surrounding each tree was receiving water from 2 outlets to insure water distribution around the tree. The average application rate of surface irrigation was 15 lit/ min/ tree.

Initial estimation for date palm trees evapotranspiration (ET_C) was calculated based on maximum reference evapotranspiration (ET_R) of 8 mm/day for the study area (Al-Amoudi *et. al.*, 2000) and value of crop coefficient equal to 1 (Abderrahman and Al-Nabulsi, 1993). The estimated value of ET_C was 8 mm/day. The total volume of water for each tree was calculated to be 300 lit/day based on canopy cover of 38 m^2. Due to the small holding capacity of the soil, the irrigation interval was 2 days. Thus, the total volume of water applied to each tree was 600 lit/irrigation. Accordingly, the time of irrigation for each system was 40 and 230 minutes for surface and drip irrigation methods, respectively.

Soil Moisture Monitoring

At each tree an access tube were installed at a distance of 500 mm from the stem of the tree. Neutron probe was used for daily monitor of soil moisture in the root zone at depths of 20, 30, 40, 50, 70, 90, and 110 cm. The Neutron probe device was calibrated using the gravimetric method. Figure 2 shows the relationship between the count ratio of the Neutron probe device and the corresponding volumetric water content of the soil. Linear regression was used to analyze the data and results showed that the following model can be used to approximate soil moisture from the neutron probe reading with R^2 value equal to 0.82.

$$Y = 1.34X - 0.028 \qquad 1$$

where: Y = volumetric soil moisture (cm^3/cm^3)

X = Neutron probe count ratio (count reading/standard count)

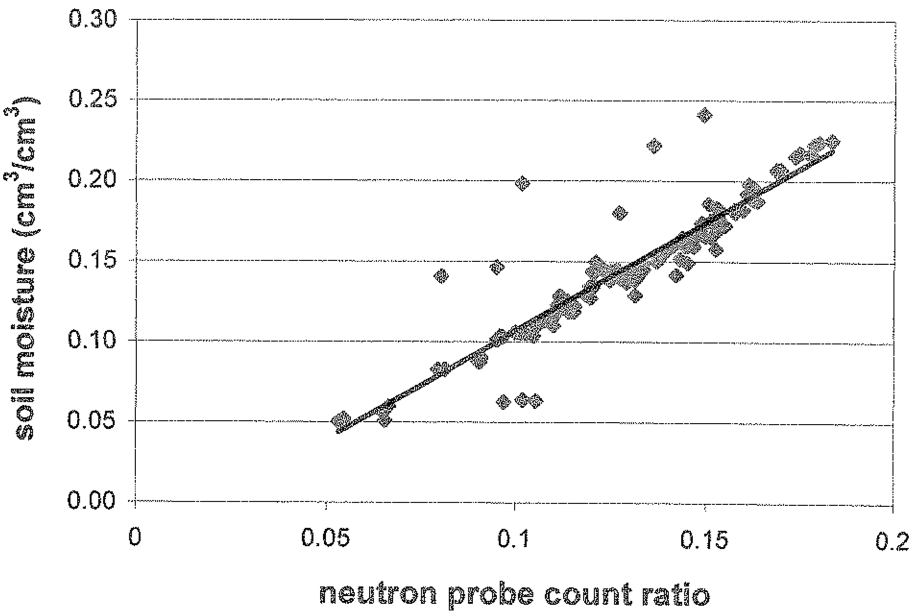

Fig. 2. The relationship between Neutron probe count ratio and soil moisture.

Evapotranspiration Determination

Soil water balance method was used to determinate the Evapotranspiration (ET_C) of date palm trees. Soil water balance model can be defined as follows:

$$ET = I + P - R - D \pm St \qquad 2$$

where, I is the irrigation depth, P is rainfall (precipitation), R is the runoff, D is the drainage at the bottom of the root zone, and St is the change in water storage in the root zone. All of these variables are expressed in the same unit (mm). Due to the dike which surrounds each tree, runoff was neglected. Also, rainfall was neglected due to small amount of rain average which is less than (100 mm/year). Irrigation depth was calculated from the calibrated application rate and time of irrigation which is controlled automatically. Water storage at the root zone was calculated using soil moisture readings. Soil moisture readings at depths of 90 and 110 cm were used to approximate drainage depth (D) under the root zone area using the following equation:

$$D = K(\theta)\left(\frac{\Delta H}{\Delta Z}\right)\Delta t \qquad 3$$

where, $K(\theta)$ is the unsaturated hydraulic conductivity, ΔH is head difference between the bottom of the root zone and net depth of the profile, ΔZ is the distance between the bottom of the root zone and the net depth (20 cm) and Δt is the time step (day). ΔH and $K(\theta)$ were calculated with equations 4, 5, 6 and 7 as described by Van Genuchten (1980).

$$H = h - z \qquad 4$$

$$|h| = \left(\frac{1}{\alpha}\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{m} - 1\right)^{-n} \qquad 5$$

$$K(\theta) = K_S S^{a}(1-(1-S^{\frac{1}{m}})^{m})^2 \qquad 6$$

$$S = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad 7$$

Where, h is the pressure head, z is the depth (cm) below the soil surface, θ (cm3/cm3) is the water content at which h is being calculated, θ_r (cm^3/cm^3) is the residual water content, θ_s (cm^3/cm^3) is the water content at saturation, K_s is the saturated hydraulic conductivity, S is the degree of saturation and α, a, m, and n are fitting parameters. The estimated fitting parameters values for the study area were 0.03, 0.5, 0.41 and 1.6 for α, a, m, and n, respectively.

The measured values of date palms evapotranspiration (ET_C) were divided by the reference evapotranzpiration (ET_R) calculated using Penman Monteith equation for the study Area (Basahi, 2002) in order to approximate coefficient for date palms trees.

The obtained data of water consumption (ET_C) of date palms were statistically analyzed using SAS (2000) according to the used experimental design.

RESULTS AND DISCUSSIONS

Weekly average evapotranspiration for each date palm tree (mm/day) was calculated for the period of the experiment (79 weeks) which started in the first week of November. Statistical analyses were preformed and the results were presented in Table 2. Analysis of variance results for ET_C under the effect of two palm tree varieties, twelve months and two irrigation methods. The results show no significant differences between replicates (R) and varieties (V) in ET_C. However, there were significant differences between months (M) and irrigation methods (S) in ET_C. In addition, the results in Table 2 show that the interaction between the V x M, V x S, and V x M x S had no significant effects on ET_C of date palm trees. However, there were significant effects for the interaction between M x S on the ET_C of date palm trees. Table 3 shows the means of ET_C under the effect of two palm trees cultivars, twelve months and two irrigation methods. The ET_C value for Sukkariah cultivar (5.4 mm/day) was insignificantly differed from the Rabiah cultivar (5.2 mm/day). Also, data of table (3) shows the superiority of summer months (May, June, July and August) over the other months with no significant differences between these summer months, while the lowest ET_C are showed from the months December, January and February. On the other hand, the results show annual average value of ET_C for date palms irrigated with drip irrigation system (5.6 mm/day) was significantly higher than those for surface irrigation system (5.0 mm/day).

Table 2. Mean squares of ET_C under the effects of two palm tree cultivars, twelve months and two irrigation systems

Source of Variation	Degrees of freedom	Mean Squares
Replicates (R)	1	0.005 NS
Varieties (V)	1	0.007 NS
Months (M)	11	0.44 **
Irrigation Method (S)	1	0.096 **
V x M	11	0.010 NS
V x S	1	0.026 NS
M x S	11	0.064 **
V x M x S	11	0.006 NS
Error	47	0.011

NS : not significant at 0.05
** : Significant at 0.01 level of probability.

Table 3. Means of ET_C under the effects of two palm tree cultivars, twelve months and two irrigation systems

Variables		ET_c (mm/day)
cultivars	Sukkariah	5.4 A *
	Rabiah	5.2 A
Month	January	2.2 D
	February	2.5 D
	March	4.2 C
	April	5.5 B
	May	7.9 A
	June	8.4 A
	July	7.9 A
	August	7.7 A
	September	6.6 B
	October	4.3 C
	November	3.9 C
	December	2.6 D
Irrigation Method	Drip	5.6 A
	Surface	5.0 B

*: Means followed by the same letter within each main factor are not significantly different.

Due to the insignificant differences between the replicates and cultivars in ET_C, The overall weekly ET_C values for both date palm cultivars were averaged for each irrigation method and plotted in Figure3. As shown in Figure 3, ET_C values had normal trend. The ET_C values were highest for the summer season, while, they were lowest for the winter season due to high temperatures and low relative humidity during summer season (Table 1).

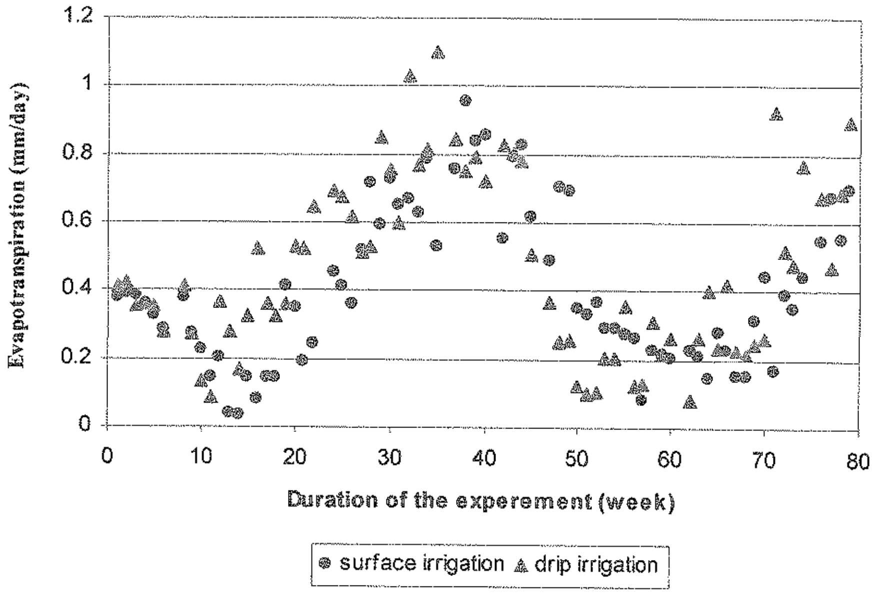

Fig. 3. Weekly average of evapotranspiration of date palm trees for drip and surface irrigation.

The weekly ET_C values were averaged over month as shown in Table 4. The results in Table 4 show that the highest value of monthly average of ET_C for drip irrigation was (9.8 mm/day) in June, while the lowest value was (2.3 mm/day) in January. On the other hand, for the surface irrigation method, the highest ETc value was (8.5 mm/day) in July and the lowest value was (1.3 mm/day) in January. Also, Table 4 shows the yearly average values of ETc were 5.5 and 5.0 (mm/day) for drip and surface irrigation, respectively. The results in Table 4 indicate that date palm trees irrigated with drip irrigation consume about 10% higher water than those irrigated with surface irrigation, which is quite unexpected.

Table. 4. Monthly averages of measured evapotranspiration.

Month		Measured monthly evapotranspiration (mm/day)	
		Drip irrigation	Surface irrigation
Jan.		2.3	1.3
Feb.		3.3	1.7
March		5.7	3.2
April		6.5	5.3
May		8.5	7.4
June		9.8	7.0
July		7.8	8.5
Aug.		8.2	6.7
Sep.		6.4	7.2
Oct.		2.5	5.6
Nov.		2.9	3.5
Dec.		2.4	2.3
Average	(mm/day)	5.53	4.98
Total	(mm/year)	2019	1850
	(m^3/ha/year)	20190	18500

The reason for this unexpected result of high evapotranspiration for drip irrigation over surface irrigation especially during the summer season may be is due to the length of irrigation period which causes more evaporation during the irrigation event. Also, drip irrigation keeps high moisture in the root zone which results more evaporation from the soil surface and transpiration from the tree (Burt and Styles, 1999). The results of this study show an increase equal to 10% in evapotranspiration of drip irrigation comparing to surface irrigation (Table 4). Due to the small size of the experiment site and the setting of the irrigation systems in this study, irrigation efficiencies of irrigation systems were not included. However, irrigation efficiency for drip irrigation is about 40% higher than those for surface irrigation (Al-Amoud, 1998 and Khalil, 1998). Thus, total water requirement for drip irrigation is less than surface irrigation. Based on irrigation efficiency values of 90% and 55% for drip and surface irrigation methods, respectively, reported by Abderrahman and Al-Nabulsi (1993) and the results of this study (20190 m^3/ha/year for drip and 18500 m^3/ha/year for surface irrigation), the annual irrigation requirements were calculated for date palms irrigated with drip and surface irrigation methods. The irrigation requirements were 22433 and 33636 (m^3/ha/year) for date palms irrigated with drip and surface irrigation, respectively. Therefore, there is a decrease of about 33% in the average of annual water requirements for trees irrigated with drip irrigation comparing to those irrigated with surface irrigation in the study area. These results are close to the results of Abderrahman and Al-Nabulsi (1993) and Alzaid *et al.* (1988).

The measured evapotranspiration were used in conjunction with the reference evapotranspiration for the study area approximated by Basahi (2002) to calculate crop coefficients (K_C) for trees irrigated with drip and surface irrigations. Table 5 shows K_C values for date palm trees for the two irrigation methods for the full year. As shown in table 5 the highest values of K_C were 1.2 and 1.1 for the drip and surface irrigation, respectively. In addition, the annual average values of K_C were 0.9 and 0.8 for drip and surface irrigation, respectively. The average value of K_C for each irrigation method was used in conjunction with Penmen-Monteith equation to estimate date palm tree evapotranspiration as shown in Table 5. The results in Table 5 show that the approximated values of annual water consumptions for date palms were 20294 and 18031 (m^3/ha/year) for drip and surface irrigation respectively. A regression analysis was performed to find out the relationship between the approximated and measured monthly averages of ET_C for date palm trees as shown in Figure 4 and 5. The results showed that the approximated ET_C values for date palms were highly correlated with the measured ET_C values for both irrigation methods with correlation factors (r) equal to 0.9 and 0.96 for drip and surface irrigations, respectively. Thus, K_C values of 0.9 and 0.8 can be used to approximate water consumption for date palms in Makkah region. These values are close to K_C values (0.95) reported by Allen *et al.* (1998), also to those K_C values (0.8) used by Al-Ghobari, (2000).

Table 5. Crop Coefficients and approximated evapotranspiration of date palms for both irrigation methods.

Month	Reference evapotranspiration (mm/day)	Crop coefficient		Approximated evapotranspiration (mm/day)	
	Penman-Monteith	Drip irrigation	Surface irrigation	Drip irrigation	Surface irrigation
Jan.	3.8	0.6	0.3	3.42	3.04
Feb.	4.5	0.7	0.4	4.05	3.6
March	5.5	1.0	0.6	4.95	4.4
April	6.6	1.0	0.8	5.94	5.28
May	7.7	1.1	1.0	6.93	6.16
June	8.1	1.2	0.9	7.29	6.48
July	7.8	1.0	1.1	7.02	6.24
Aug.	7.8	1.0	0.9	7.02	6.24
Sep.	7.5	0.9	1.0	6.75	6.00
Oct.	6.3	0.4	0.9	5.67	5.04
Nov.	4.7	0.6	0.7	4.23	3.76
Dec.	3.8	0.6	0.6	3.42	3.04
Average	6.2	0.9	0.8	5.56	4.94
	(m^3/ha/year)			20294	18031

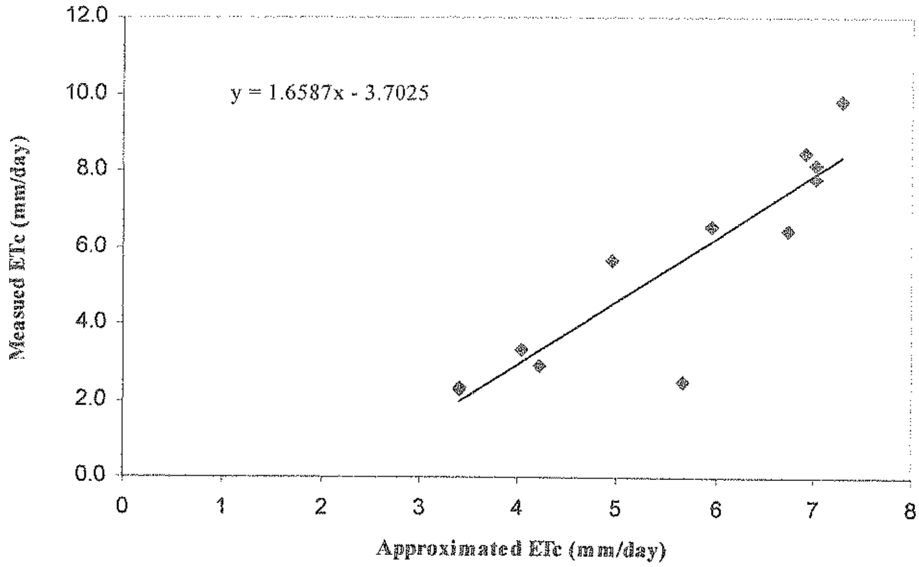

Fig 4. The relationship between measured and approximated Etc for drip irrigation

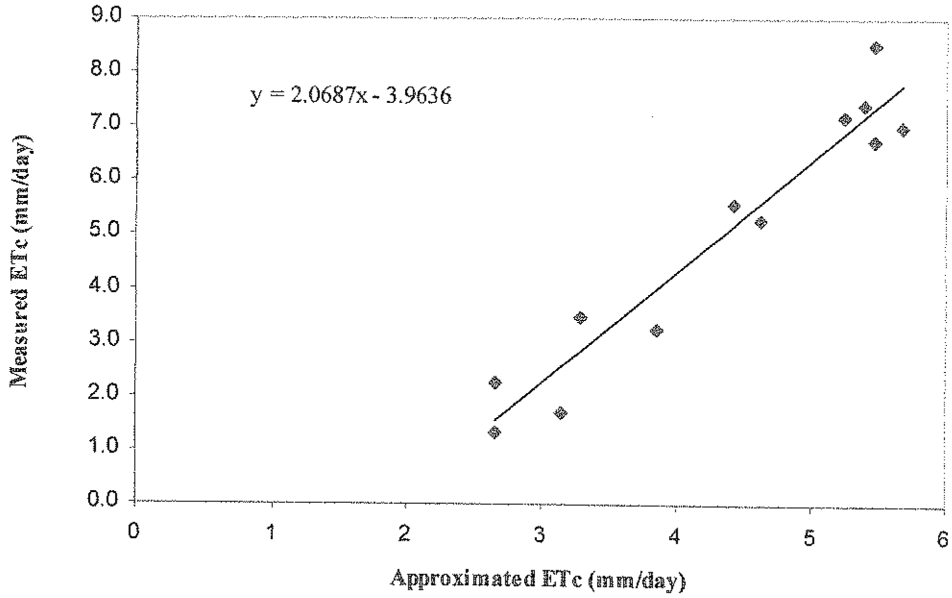

Fig. 5. The relationship between measured and approximated Etc for surface irrigation

Conclusion

In conclusion, this study showed that date palm tress irrigated with drip irrigation consumed about 10% more water than those irrigated with surface irrigation. However, due to higher efficiency of drip irrigation compared to surface irrigation, the annual water requirements for date palm trees irrigated with drip irrigation were about 33% less than those irrigated with surface irrigation. Also, the results showed that values of 0.9 and 0.8 can be used as an average seasonal date palm crop coefficient for drip and surface irrigation, respectively, to approximate the evapotranspiration for date palm trees in Makkah region.

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الملخص العربي

تأثير إختلاف طريقة الري على الإستهلاك المائي لأشجار النخيل تحت الظروف البيئية للمناطق الجافة

جلال بن محمد باصهي

قسم علوم وإدارة موارد المياه – كلية الأرصاد والبيئة وزراعة المناطق الجافة – جامعة الملك عبدالعزيز

ص.ب. ٨٠٢٠٨ جدة ٢١٥٨٩ المملكة العربية السعودية

اجريت تجربة حقلية في الفترة من ٢٠٠١/٩ الى ٢٠٠٣/٤ لدراسة تأثير إختلاف طريقة الري (تنقيط و سطحي) علـى الإستهلاك المائي لصنفين من اشجار نخيل البلح (سكرية و ربيعة).

واستخدمت طريقة الميزان المائي لإيجاد الإستهلاك المائي "بخر-نتح" لأشجار النخيل وتم قياس المحتوى الرطـوبي للتربـة يوميـاً بواسطة جهاز التشتت النيتروني عند الأعماق ٢٠، ٣٠، ٤٠، ٥٠، ٧٠، ٩٠ و ١١٠ سم. كما استخدمت قياسـات المحتـوى الرطـوبي عنـد الأعماق ٩٠ و ١١٠ سم لتقدير التسرب العميق. و قد بينت النتائج عدم وجود تأثير معنوي لإختلاف الصنف على الإستهلاك المـائي لأشـجار نخيل البلح بينما كان لتصرف المنقط تأثيراً معنوياً على الإستهلاك المائي. حيث كان الأستهلاك المـائي الـسنوي لأشـجار النخيـل ٢٠١٩٠ و ١٨٥٠٠ م^3/هكتار/سنة للري بالتنقيط و الري السطحي، على التوالي. وبالرغم من ان الأشجار التي رويت بنظام الري بالتنقيط استهلكت ميـاه تزيد بـ ١٠% تقريباً عن تلك التي رويت بالري السطحي إلاّ أن الإحتياجات المائية الكلية للإشجار التي رويت بنظام الري بالتنقيط كانت أقـل بـ ٣٣% تقريباً من الإحتياجات المائية للأشجار التي رويت بالري السطحي عند استخدام كفاءة ري تـساوي ٩٠% و ٥٥% للـري بـالتنقيط والري السطحي، على التوالي. كما بينت النتائج ايضاً انه يمكن استخدام قيمتي معامل المحصول ٠,٩ و ٠,٨ لنظامي الري بـالتنقيط والـري السطحي، على التوالي، لتقدير الإستهلاك المائي لأشجار نخيل البلح في منطقة مكة المكرمة.