Chapter 9
Determination of Date Palm Water Requirements in Saudi Arabia

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9.1 Introduction

Date palm, *Phoenix dactylifera* L., is one of the oldest fruit trees in the world. The number of date palms is about 120 million worldwide, of which 70 million palms can be found in the Arab world (Zaid 2002). The place of origin of the date palm is uncertain. Some researchers claim that the date palm first originated in Babel, Iraq, while others believe that it originated in Dareen or Hofuf, Saudi Arabia (Fig. 9.1). The date palm is a perennial, the females of which normally begin to bear dates within an average of five years from the time of planting of the offshoot. The date palm reaches an age of about 150 years.

In Saudi Arabia oases, date palm trees stand tall with their branches outstretched towards heaven and their roots anchored deep into the earth. These dense green groves have been a treasured part of the Saudi landscape for generations, both for their beauty and their utility. Since ancient times, the date palm has been a source of food for the inhabitants of the Arabian Peninsula, and its branches have granted shade from the strong desert sun (Figs. 9.2 and 9.3).

The Government of the Kingdom of Saudi Arabia represented by the Ministry of Water, Environment and Agriculture has exerted incessant efforts to develop the agricultural sector. Continuous support and care was allocated to the date palm production sector in particular, due to the important role of this blessed tree in the realization of food security and its historical relation to the Saudi population. Several farmers

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Fig. 9.1 Location of date palm fields in eight different regions of Saudi Arabia. (Source: Al-Shemeri 2016)

Fig. 9.2 Date palm production in Saudi Arabia

Fig. 9.3 Drip irrigation for Date palm production in Saudi Arabia

with the support of the government, have started cultivating high quality varieties of date palms. Concern regarding the problems of marketing and processing of dates has increased as investment in these fields was encouraged. The Saudi farmers' concern with agriculture has increased, and date palm orchards were established on appropriate modern scientific basis avoiding traditional methods of cultivation. Numerous modern projects for date palm plantation and production were established in many parts of the Kingdom. Table 9.1 shows the estimated number of date Palm trees of different regions in the Kingdom of Saudi Arabia for the years from 1999 up to 2015, while Figs. 9.4 and 9.5 show the estimated area and dates palm production (General Authority for Statistics 2015).

The Kingdom of Saudi Arabia is considered as one of the pioneer countries in date palm cultivation and dates production. The current date production (for the year 2015) is estimated by over than million tons with an increase of about 45% in the last twenty years. The cultivated areas of date palm have also increased and reached about 140 thousand hectares in the year 2004 with an increase of 57% during the same period. The number of date palms in the Kingdom are estimated to be 28 million and about 400 different date varieties are found in different agricultural areas of the Kingdom. Each area in the Kingdom is characterized by certain date palm varieties.

Table 9.1 Estimated number of date palm trees by region for the years 1999 to 2015

Region	1999	2002	2003	2004	2005	2015
Riyadh	4160565	4493410	4702830	4941944	4972529	7030731
Makkah	1781466	1923983	1890100	1773830	2027431	1237568
Madina	2299666	2483639	2701372	2810870	2843902	4619640
Qasseim	3120558	3370203	3188705	3790032	3922561	6979753
Eastern Province	2579856	2786244	2907115	2919608	2544652	3731759
Assir	2289709	2472886	1698691	1900168	1829933	1027431
Tabuk	627595	677803	895940	899863	870023	834358
Hail	1315040	1420243	1988091	1780201	1696804	1773442
Northan Frontier	1751	1891	1942	1826	2047	23089
Jizan	7746	8366	11172	8738	7360	8581
Najiran	437512	472513	387136	443709	608488	385623
Albaha	102956	111192	88952	124894	145177	70612
Jouf	580768	627229	862065	892174	1155076	848217
Total	19305188	20849602	21324111	22287857	22625983	28572819

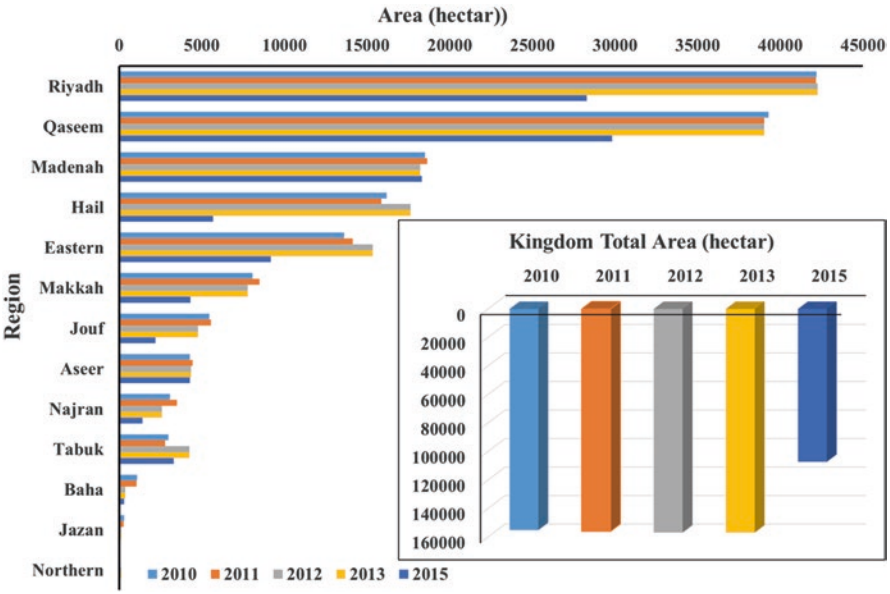

Fig. 9.4 The estimated areas of dates palm production in Saudi Arabia. (Source: General Authority for Statistics 2015)

9.2 Location and Climate

The Kingdom of Saudi Arabia is situated in southwest Asia between latitude 16–32 North and longitude 35–65 East. The total area of the Kingdom is about 2.25 million square kilometers which represents about 80% of the area of the Arabian Peninsula. The Kingdom's area extends from the Red Sea in the West to the Arabian

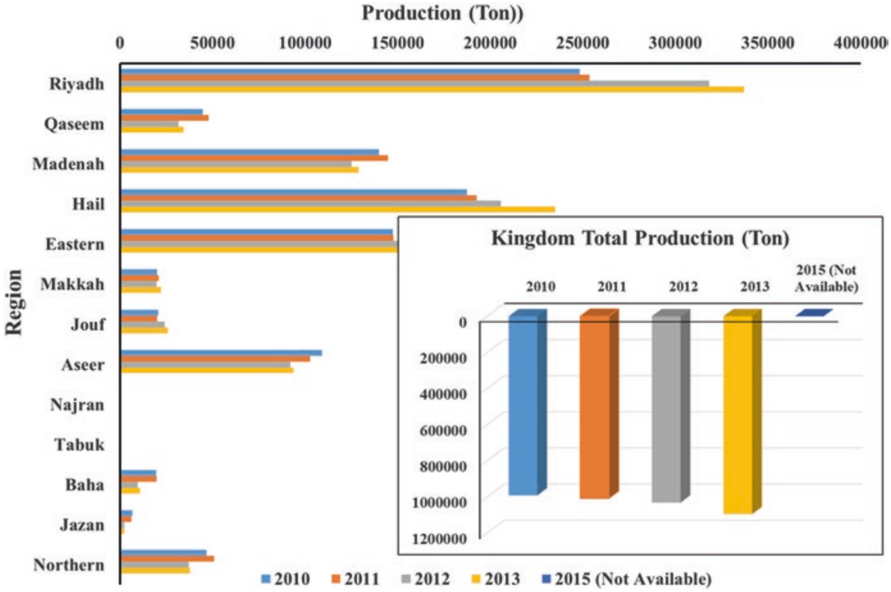

Fig. 9.5 The estimated of dates production in Saudi Arabia. (Source: General Authority for Statistics 2015)

Gulf in the East. The vast area of the Kingdom together with its geographic location led to diversity in its terrain and geological formation which had brought about relative advantages to certain parts of the Kingdom. Most of the regions in the Kingdom fall within the dry tropical zone for west continents. The climate of the Kingdom is characterized by hot, dry and long summer where temperatures in certain areas sometimes reach more than 45° C during the months of June, July and August, generally with an average temperature of around 35° C during the summer. On the other hand, the winter season falls during the months of December, January and February when temperatures in certain areas often drop to less than zero degree. Levels of humidity rise during summer season and range between 35 and 85%, whereas during the winter season, it ranges between 35 and 70%. The levels of humidity are generally considered high during the summer months in the western coastal areas compared to the eastern coast area. In the middle inland areas, levels of humidity are relatively low ranging between 15 and 35% during summer months, and rising a little during winter season, ranging between 20 and 70% (Al-Omran et al. 2002).

Despite the Kingdom, spreads over more than two million square kilometers, most its areas are considered the driest in the world. The average annual rainfall is about 100 mm, most of which occurs between December and March. Sometimes, the average annual rainfall in some areas of the southern region of the Kingdom reaches 400 mm. The Kingdom is exposed to north, northeasterly or north-westerly dry winds during most of the year, while the western winds coming from the Mediterranean during winter and the seasonal southwestern winds during summer cause the rainfall in different areas of the Kingdom. Rates of evaporation in the Kingdom are high due to high air temperatures, scarcity of rainfall and drought.

9.2.1 Water Resources

Water used for irrigation purposes is counted as one of the most important factors affecting the agricultural sector. The most important sources of water are underground water, rainwater, and treated wastewater. The Ministry of Agriculture being aware of the importance of water conservation and the rationalization of water consumption in date palm plantation.. The Ministry further encouraged the farmers and agricultural companies to adopt appropriate irrigation methods and follow the concept 'More Crop per Less Drop' which means more crop production by using less quantities of water instead of the concept of 'More Crop per Drop' which means more crop production by using the same quantity of water. In this context, the Ministry is striving hard to create awareness for the use modern irrigation systems such as Drip irrigation or the use of Pivot Sprinklers and avoidance of traditional methods such as flood irrigation. The ministry provides agricultural licenses only in the precondition of use of modern irrigation systems.

9.2.2 Soil Salinity and Date Palm

Date palm growth is influenced by soil salinity, which results in loss of productivity. The soluble salts present in soil are mainly: Na, Ca, Mg, Cl, and SO_4. Richards (1954) defines saline soils as soils that have an electrical conductivity (ECe) higher than 4 dsm^{-1} at 25°C, with a sodium absorption ratio (SAR) of less than 15 and pH generally less than 8.5. In the Saudi Arabia, most of the soils are suitable for date palm plantation since these soils have lower values of ECe, usually less than 4 and are well aerated (Heakal and AlAwajy 1989). However, Saudi Arabia's date palm can also be grown in saline soil where ECe reaches up to 16–20 dsm^{-1} (Bashour et al. 1983) in some areas of central region, and between 2–8 dsm^{-1} in Al-Hasa oasis (Al-Barrak 1990), and more than 20 dsm^{-1} in coastal soils of Al-Hasa (Al-Barrak 1997). The electrical conductivity of main aquifers in Saudi Arabia ranged between 2 and 5 dsm^{-1} (Al-Omran et al. 2005). According to Ayers and Westcot (1985), date palm can tolerate an ECe of 4.0 dsm^{-1} with an ECw of 2.7 dsm^{-1} without losing any yield (Maas and Hoffman 1977).

9.2.3 Date Palm Spacing

The spacing between date palms differs worldwide. The recommendation for date palm spacing for the farmers in Saudi Arabia is 10 m × 10 m i.e. 100 offshoot/ha (Ministry of Agriculture 2000). This spacing allows a sufficient sunlight even after the plants grow tall in 7–10 years, and allow sufficient working space within the field. In some regions, the spacing is smaller than recommended which is 7 m × 7 m, about 204 trees /ha. In some other old oasis such as Al-Hasa, it is common to grow some other crop with the date palms. Vegetables crops are grown while the date palms are still young, and after the date palms grow tall enough to allow cultivation under them, the planting of fruit trees such as citrus among them is advisable. In other areas such as on the edges of the basin, the date palm is grown with alfalfa and citrus, figs and pomegranate as associated crops. Some private farmers also use different spacing such as, 8 × 8 m. However, narrower spacing is not advisable.

9.2.4 Irrigation Methods

Irrigation is the timely application of water to a crop when it is really in need of any water applied when not necessary, is a waste of a precious commodity. Irrigation must take place where the roots of the plant can easily reach it. It is of no use to the plant if water is applied where the roots cannot reach it. For a date palm tree, if the soil is divided into four layers of equal depth from top to bottom, 40% of all roots can be found in the top layer, 30% in the second layer, 20% in the third layer and the remaining 10% in the last layer. The same percentages apply in concentric rings around the plant. The same percentage of water will also be extracted from the soil in the different layers due to the presence of the roots in these respective layers.

Different irrigation techniques are available, but not all of them are suitable for date palm irrigation. The flood irrigation method is the oldest method known, and is also the method most widely used at the old date palm farms in all regions of Saudi Arabia. Recently the new irrigation systems like drip irrigation (surface drip irrigation and subsurface drip irrigation) and bubbler have been introduced and are in use on the modern farms.

9.2.5 Irrigation Water Quality

Many researchers have reported on the evaluation of irrigation water quality in different regions of Saudi Arabia, including Riyadh region, Al-Hasa oasis, Al-Qassium, Al-Kharj, and some selected regions (Hamza et al. 1975; Mee 1983; Al-Omran et al. 2005; Al-Jaloud and Hussain 1992; MAW 1985; Jahangir et al. 1987). The water composition for 16 different aquifers is reported in Water Atlas of Saudi Arabia (MAW 1985). The details of different aquifers are given in Table 9.2. The groundwater from the aquifers were analyzed and sodium adsorption ratio (SAR), adjusted sodium adsorption ratio (adj RNa), adjusted sodium adsorption ratio (adj SAR) exchangeable sodium percentage (ESP), calcium/magnesium ratio (Ca^{++}/Mg^{++}), and chloride/sulfate ratio (Cl^-/SO_4^{--}) were calculated from analytical data.

The chemical composition of the water samples of Riyadh region is presented by plotting on a Piper trilinear diagram (Piper 1944) (Fig. 9.6). The Piper diagram provides a convenient method to classify groundwater types, based on the ionic composition of different water samples. This diagram shows the main minerals present in water, calculated on the basis of the major concentrations of ions in Riyadh region which is rich in calcium - magnesium sulphate - chloride water type.

Table 9.2 Most important features of different aquifers

Aquifers	Water Depth (m)	Discharge (Ls^{-1})	Location (Region of Saudi Arabia)
Al-Saq	150–1500	100	Central – North
Wajid	150–900	40–80	Southern
Tabuk	60–2500	15–20	Central – North
Minjur	1200–2000	60–120	Central
Dhruma	100	60–120	Central
Biyadh	30–200	25–50	Northern
Wasia	100–800	85–110	Central – East
Umm-ER-Radhuma	160–200	50–100	Eastern
Dammam	50–100	7–22	Eastern
Neogene	NA	50–100	Eastern
Jilh	NA	10–18	West – Riyadh
Khuff	NA	7–23	East – El-Qawayh
Aruma	NA	30–32	Central – East
Jubalia	NA	NA	Central
Basalt	NA	NA	Western
Aluuvial	NA	50	Western - Costal

NA data not available
Source: MAW (1985)

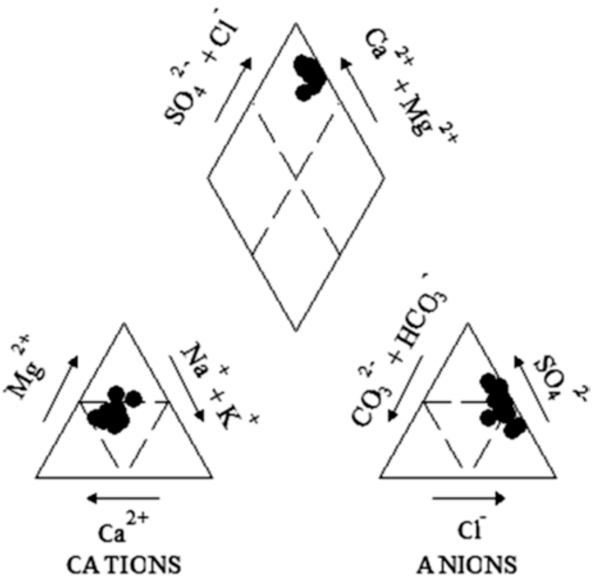

Fig. 9.6 Piper – tri-linear diagram showing the major ionic composition of Riyadh region groundwater. (Source: Al-Omran et al. 2005)

Table 9.3 Yield potential of date palm with varying soil salinity (EC_e) and irrigation water salinity (EC_w)

	Yield Potential				
	100%	90%	75%	50%	maximum EC_e
EC_e (dSm^{-1}	4	6.8	10.9	17.9	32
EC_w (dSm^{-1})	2.7	4.5	7.3	12.0	–

Source: Ayers and Westcot (1985)

9.2.6 *Salinity and Date Palm Production*

Mass and Hoffman (1977) provide an extensive list of salinity coefficients for a number of field, vegetable, forage and fruit crops. These coefficients consist of a threshold and the rate yield declines with increasing salinity (slope). The salinity threshold (a) is the maximum average soil salinity (ECe) the crop can tolerate in root zone without the decline in yield. Using these coefficients, the yield potential (% yield) can be estimated from the following equation:

$$Y = 100 - b\left(EC_e - a\right) \tag{9.1}$$

Where

Y = relative yield
b = the rate yield declines with increasing salinity.
a = threshold salinity value for date palm (4 dsm^{-1})
EC_e = electrical conductivity of root zone

Table 9.3 shows the yield reduction of date palm at different values of soil salinity (ECe) and irrigation water salinity (ECw) as reported by Mass and Hoffman (1977). Although, the date palm is a fruit plant, it is one of the most resistant (tolerant) plants to salinity where ECe can be 4 dsm^{-1} without losing any yield. The table provides irrigation water salinity (ECw) that, if used continuously to achieve LF of 15–20% (Ayers and Westcot 1985), would result in yield potential of 100, 90, 75, and 50%. The ECw values at 100% yield potential for date palm are 2.7 dsm^{-1} which represent the poorest water quality that, if used continuously, will produce and ECe level of 4.0 dsm^{-1} which is equal to salinity threshold value. If the average values of ECe at the root zone throughout the season was 10.9 dsm^{-1}, or ECw with leaching fraction of 15–20% is 7.3 dsm^{-1}, then the yield potential of date palm is 75%.

9.2.7 *Estimation Evapotranspiration*

9.2.7.1 Estimating Crop ET

Since long, different methods were employed to estimate the water requirements of different crops. As a result, numerous methods have been developed and adopted for different crops. Some of these methods are more accurate than others and some more convenient to use than others, because of the availability of information of metrological data for the date palm trees**.** Since the direct measurement of crop evapotranspiration (ET_c) is expensive, time consuming and laborious, it is usually estimated from more easily available climatic data. This approach involves the estimation of a meteorological related reference evapotranspiration (ET_r) and a set of ET crop coefficients (K_c) to determine crop water requirement.

Various procedures have been used to obtain the necessary reference ET_r data and several types of crop coefficients curves have been published (Wright and Jensen 1972). However, all the existing methods of estimating crop ET from climatic data involve some empirical relationships and assumptions, hence local or regional verification or calibration is necessary to gain higher reliability in obtaining practical utility of ET equation. The recent development of computerized weather stations provides hourly-integrated measurement of meteorological variables and a means to estimate ET on short-term basis and with more accuracy.

9.2.7.2 Estimating Reference Evapotranspiration (ET_r)

The equations for estimating ET_r may be broadly classified as those based on combination theory, humidity data, radiation data and miscellaneous methods that involve multiple correlation for ET and various climatic data. The Technical Committee on Irrigation Water Requirements presents comprehensive details of these methods, American Society of Civil Engineers (Jensen et al., 1990). The most commonly used procedures to estimate….are the Penman, Jensen- Haise, Blaney-Criddle, Thornthwaite and pan evaporation methods. These methods were calibrated under local conditions by measuring the evapotranspiration for two years from alfalfa grown in lysimeters and obtaining the climatic data from weather station in the area (Al-Omran et al. 2004).

9.2.7.3 Crop Coefficients

Many evapotranspiration estimating methods result in an ET estimate for a reference surface of water or reference crop of grass or alfalfa. Extensive research has been conducted on reference ET methods and crop coefficients because of their use in irrigation scheduling and water resources allocation, management, and planning. The available methods for estimating reference ET when properly used with reliable crop coefficients permit furnish crop ET within the accuracy of most field-irrigation systems to deliver water (Jensen and Wright 1978). Various procedures have been used during the past three decades to obtain the experimental crop and reference data needed to develop ET crop coefficient. Several sets of curves derived from these data have been published (Wright and Jensen 1978). Although crop coefficients have been suggested for the arid and semiarid climates yet haven't been tested under severe hot and arid climate of Saudi Arabia.

9.3 A Case Study of Date Palm Water Requirement

The aim of present study was to determine the date palm water requirements of eight regions of Saudi Arabia taking into consideration the shaded area of the tree and irrigation water quality and to compare it with the actual water added by farmers in each region of Saudi Arabia.

The agricultural sector consumed more than 85% of water consumption which reached to more than 23 billion m^3 in 2012 (Ministry of Electricity and Water 2014). As the demand of water increases, an effective and accurate evaluation of crop water requirement (CWR) is essential for planning, designing, operating, managing farm irrigation systems. The efficient use of water resources for irrigation can be done through estimation of CWR. Evapotranspiration (ET) plays a major role in irrigation water management. Allen et al. (1998) reported that many factors may play a role in limiting crop development, which are: water availability, soil salinity, poor land fertility, poor soil and water management, plant density and soil water contents. In Saudi Arabia, the limiting factor in agricultural development is water availability to irrigate the increasing number of date palm trees. Based on the recent statistical reports (General Authority for Statistics 2015), the total number of date palm trees are 28.5 million on 54000 ha drip irrigation and 53200 ha surface irrigation fields.

In Saudi Arabia, estimation of water requirement of date palm has been reported by many researchers. These estimates differ between 6200–55000 m^3/ha. Alazba (2001) estimates water requirement to be between 15000–55000 m^3/ha, depending upon irrigation system or leaching requirement. Al-Ghobari (2000) has estimated the total annual amount of water required by one date palm tree as 136 m^3 in Najran of south western region. Kassem (2007) monitored water requirements in Qassem region. Using soil water balance method, he determined the annual water use with drip irrigation as 16400 m^3/ha, with a density of 100 tree/ha. Al-Amoud et al. (2012) estimated the actual water use in the range between 21360–28290 m^3/ha, for density of 100 tree/ha. A study conducted by Ismail et al. (2014) in the western part of Saudi Arabia calculated water requirement based on Penman-Montieth equation for ET_o, Kc ranged from 0.8–1.0, and the evapotranspiration area (23 m^2/tree), to be 7300 m^3/ha, for density of 100 tree/ha. Recently, Dewidar et al. (2015) estimated water requirement of date palm using non-weighing lysimeter. They reported that volumetric palm water requirement per day fell between 87–297 L/day, with daily average of 182 L and crop coefficient ranged from 0.74 to 0.91. In Kuwait, the date palm water requirement using drainage type lysimeters through water balance budget was ranged between 23392–27251 m^3/ha (Bhat et al. 2012). In Algeria, Mihoub et al. (2015) reported that the annual water requirement is 17411 m^3/ha, for a density of 120 tree/ha by drip irrigation compared to 26117 m^3/ha by surface irrigation. In Jordan, Jordan valley, Mazahrih et al. (2012) reported that the amount of applied irrigation water per date palm tree were 27, 40, 53 and 67 m^3 for the irrigation treatments 50, 75, 100 and 125% ET_c respectively.

9.3.1 Experimental Sites

This study was conducted on eight different regions of Saudi Arabia to estimate monthly and annual irrigation water requirements of date palm (*Phoenix dactylifera L.*) of Klayas variety. Field measurements and determination of ET_c were taken during one year starting Oct. 2013–Sept. 2014 on complete grown tree (more than 10 years old). Fields that have been selected are located in regions of the Medina (Al Ula), Tabuk (Teimaa), Makkah (Al Jumum), Al Jouf (Sakakah), Riyadh (Sodos), Qassim (Riyad Al Khabra, Hail (AL Kaedh), East Region (Al Ahsa) (Fig. 9.1). The characterization of the soil and irrigation water are shown in Tables 9.4 and 9.5 (Al-Shemeri 2016).

9.3.2 Meteorological Data

Small weather stations were installed at each site of the study to monitor the changes in meteorological parameters during the study period. The meteorological data recorded were: net radiation (MJ/ m^2day), wind speed (m/hr), air temperature (°C), relative humidity (%) and rainfall (mm). The air water vapour pressure deficit (kPa) was calculated using daily and hourly average temperatures and relative humidity. Finally, the reference evapotranspiration (ET_r, mm/day) was calculated according to the Penman-Monteith (PM) equation as specified by the FAO protocol (Allen et al. 1998).

Table 9.4 The physical and mechanical analyses of the soil

Sites	Mechanical analysis				Soil constants			Ca CO_3 %	O.M %	Hydraulic conductivity cm/h
	Sand %	Silt %	Clay %	Soil Texture	W.P %	F.C %	SP %			
Medina	88.9	5	6.1	Sandy	5.08	10.15	20.3	3.82	0.1	6.5
Tabuk	81.4	7.5	11.1	Sandy Loam	7.5	15	30	6.34	0.72	5
Makkah	71.4	17.5	11.1	Loam Sandy	8	16	32	3.56	1.78	3.1
Al Jouf	90.7	5	4.3	Sandy	5.8	11.6	23.2	2.3	0.11	6.25
Riyadh	65.7	17.5	16.8	Loam Sandy	6.95	13.9	27.8	36.9	0.58	2.9
Qassim	47.1	30	22.9	Loam	8.9	17.8	35.6	7.93	2.88	2.2
Hail	83.9	7.5	8.6	Sandy Loam	7.7	15.4	30.8	2.7	0.15	3.55
East Region	67.5	17.5	15	Sandy Loam	8.3	16.6	33.2	14.1	1.88	4.2
Max	**90.7**	**30**	**22.9**	**–**	**8.9**	**17.8**	**35.6**	**36.9**	**2.88**	**6.25**
Min	**47.1**	**5**	**4.3**	**–**	**5.08**	**10.15**	**20.3**	**2.3**	**0.1**	**2.2**

Table 9.5 The analyses of the irrigation water

					Cation (meq/L)				Anion, meq/l		
Sites	TDS (mg/L)	SAR	pH	EC (dS/m)	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$
Medina	544	3.35	7.63	0.85	1.1	4.8	0.15	0	1.6	5.0	2.5
Tabuk	390	2.23	7.6	0.61	1.9	3.11	0.12	0	1.5	3.0	2.5
Makkah	1004	3.31	7.5	1.57	2.9	6.62	0.21	0	2.0	7.5	6.0
Al Jouf	960	4.15	7.4	1.5	2.6	7.81	0.15	0	2.0	8.1	5.2
Riyadh	646	3.42	7.61	1.01	1.98	5.4	0.18	0	2.1	5.1	4.8
Qassim	1536	8.44	7.8	2.4	3.0	16.99	0.30	0	2.76	16.88	5.12
Hail	601	3.45	7.6	0.94	1.0	5.0	0.20	0	2.1	5.1	2.6
East Region	998	3.66	7.5	1.56	3.0	7.5	0.25	0	2.6	7.0	6.5

9.3.3 Estimation Method of ET

9.3.3.1 Penman Montieth Method

Using the Penman Monteith equations (9.2, 9.3, 9.4, 9.5 and 9.6) based on climate data on the farm as part of the national project of the rationalization of the irrigating water in agriculture (RIWA), Ministry of Environment, Water, Agriculture to estimate the water needs. Then, calculate the total irrigation water requirements based on the quality of irrigation water and soil salinity, taking into account the values of crop coefficient Kc for each month, irrigation efficiency and shaded area of date palm. The combined FAO Penman-Monteith method was used to calculate ET_o through the following equation:

$$ET_O \frac{0.408\Delta(Rn - G) + \gamma\left(\frac{900}{T + 273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{9.2}$$

Where:

ET_o = Reference evapotranspiration (mm/day)
Rn = Net radiation at the crop surface (MJ/m^2 per day)
G = Soil heat flux density (MJ/m^2 per day)
T = Mean daily air temperature at 2 m height (°C)
U_2 = Wind speed at 2 m height (m/sec)
e_s = Saturation vapour pressure (kPa)
e_a = Actual vapour pressure (kPa)
$e_s - e_a$ = Saturation vapour pressure deficit (kPa)
Δ = Slope of saturation vapour pressure curve at temperature T (kPa/°C)
γ = Psychrometric constant (kPa/°C)

As crop evapotranspiration ETc can be calculated as:

$$ET_c = K_c \times ET_r \tag{9.3}$$

Where

K_c = crop coefficient ranged from 0.8 – 1.0 depend on the month of year as noted in (Allen et al. 1998)
$ET_r = ET_o$ = Reference crop evapotranspiration (mm/day)
ET_c = Crop evapotranspiration (mm/day)

The percentage of evapotranspiration area (S_e) was calculated from actual shaded are at noon in June to the actual area to each tree from the following equation as described by Hellman (2010) for grape:

$$S_e = \frac{Shaded\ area\ per\ tree}{Actual\ area} x100 = \frac{\pi R^2}{10m\, x\, 10m} \tag{9.4}$$

Where

S_e = The percentage of evapotranspiration area.
R = radius of tree (m).
Shaded area = Area of the shade of one tree measured at noon.

Leaching requirements were calculated using the following equation (Doorenbos and Pruitt 1977).

$$LR = \frac{EC_{iw}}{2MaxEC_e} \times \frac{1}{Eff} \tag{9.5}$$

Where

LR = The fraction of the water to be applied that passes through the entire root zone depth and percolates below
EC_{iw} = Electrical conductivity of irrigation water (dsm^{-1})
EC_e = Electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable degree of yield reduction (dsm^{-1}).
Max EC_e = Maximum tolerable electrical conductivity of the soil saturation extract for a given crop (dsm^{-1}).
Eff = Leaching efficiency (90% for sandy and loamy sands).

Calculating the Grass Water Requirements (*GWR*)

$$GWR = \frac{ET_c \times S_e}{(1 - LR) \times Effir} \tag{9.6}$$

Where

GWR= Gross Water Requirement (m^3/ha).
ET_c = Crop Evapotranspiration (m^3/ha).
Effir = Efficiency (%), 90%.
LR = Leaching Requirements.
S_e = The percentage of evapotranspiration area.

9.3.3.2 Water Balance Method

Water balance method by difference of soil moisture contents between two irrigations period by measuring changes in moisture contents after and before irrigation at the root zone using a device to measure moisture (Terra Sen Dacom Sensor) at depths of 10 – 120 cm all year. After verifying the accuracy of moisture sensitive, calibrated sensors with direct method (gravimetric laboratory method) with data from the sensors for a period of two months for three sites. The total amount of irrigation for one year calculated by the following equation:

$$\mathrm{ET} = \mathrm{P} + \mathrm{I} - \mathrm{Dr} \pm \Delta S \quad (9.7)$$

Where

ET = Consumptive use (in mm)
P = Precipitation (in mm)
I = Irrigation added (in mm)
Dr = Drinage (in mm) and
ΔS = change in soil water content (in mm)

9.3.3.3 The Amount of Applied Irrigation Water

a) The study site: The amount of applied irrigation water throughout the year by readings of flow meter (actually added) in the field experiment using soil moisture and data of meteorological stations.
b) Farmers fields: The amount of applied irrigation water throughout the year by flow meter added by farmers (actually added to the fields by farmers adjacent to the field of study).

9.3.4 Results and Discussions

9.3.4.1 Climatic Conditions at the Experimental Sites

The observed average values of the climatic variables at the eight sites are presented in Table 9.6. The data revealed that the highest maximum temperature during the year in the Makkah and East Region were 49.9 and 47.5 °C, while the lowest

Table 9.6 The observed average values of the climatic variables eight sites

Sites	Stat	T-Mean °C	T-max °C	T-min °	Rainfall mm	Radiation MJ/m^2	RH-min %	W.speed m/s	ET$_0$ mm	Kc	ETc mm
Medina	Min.	9.30	13.50	2.80	0.00	2.05	6.00	0.40	2.23	0.80	1.78
	Max.	34.40	40.10	30.30	0.60	11.22	44.00	5.10	12.21	1.00	12.21
	Ave.	24.34	30.51	17.81	0.00	8.19	16.51	2.53	7.11	0.91	6.63
Tabuk	Min.	5.60	9.50	-3.30	0.00	0.79	6.00	0.20	1.18	0.80	0.94
	Max.	33.20	41.80	26.30	8.00	9.76	75.00	4.20	10.57	1.00	10.57
	Ave.	21.67	28.72	14.35	0.11	7.23	18.47	1.95	5.72	0.91	5.32
Makkah	Min.	20.20	23.90	13.10	0.00	1.81	6.00	0.50	2.43	0.80	1.94
	Max.	39.50	49.90	32.00	12.80	9.15	58.00	2.80	8.40	1.00	8.40
	Ave.	30.36	37.71	23.77	0.04	6.67	23.27	1.36	5.46	0.91	5.03
Al Jouf	Min.	4.10	7.00	-1.60	0.00	0.46	4.00	0.80	0.75	0.80	0.60
	Max.	37.50	43.60	32.30	42.00	10.89	92.00	6.50	15.65	1.00	15.65
	Ave.	22.47	28.62	15.93	0.38	7.45	22.05	2.72	6.59	0.91	6.19
Riyadh	Min.	7.40	10.70	-0.70	0.00	1.17	5.00	0.50	1.22	0.80	0.98
	Max.	37.10	44.10	30.70	16.60	10.00	87.00	4.30	12.72	1.00	12.72
	Ave.	24.90	31.81	16.95	0.26	7.52	17.73	1.91	6.29	0.91	5.86
Qassim	Min.	6.00	9.90	-1.90	0.00	1.41	5.00	0.70	1.51	0.80	1.21
	Max.	38.00	45.70	30.50	13.40	9.08	76.00	5.00	13.34	1.00	12.74
	Ave.	25.12	32.80	16.82	0.08	6.90	17.58	2.23	6.50	0.91	6.05
Hail	Min.	4.80	7.30	-2.40	0.00	0.76	7.00	0.40	0.76	0.80	0.61
	Max.	37.10	43.80	31.20	30.40	10.81	95.00	4.80	10.43	1.00	10.43
	Ave.	22.31	29.50	15.08	0.54	7.51	22.32	2.14	5.90	0.91	5.50
East Region	Min.	9.10	14.40	0.50	0.00	0.88	6.00	0.60	1.16	0.80	0.90
	Max.	39.20	47.50	32.70	26.80	10.28	89.00	4.80	12.69	1.00	12.70
	Ave.	25.60	34.28	18.81	0.40	6.98	20.96	2.08	6.30	0.91	5.88

minimum temperature during the year in the Tabouk and Hail were −3.3 and −2.4 °C. The highest maximum net radiation during the year in the Madinah and Al-Jouf were 11.22 and 10.89 MJ/m^2 while the lowest minimum net radiation during the year in the Al-Jouf and Hail were 0.46 and 0.76 MJ/m^2. The highest maximum relative humidity during the year in the Hail and Al-Jouf were 95 and 92 % while the lowest minimum relative humidity during the year in the Al-Jouf wase 4 %. The highest maximum wind speed during the year in the Al-Jouf and Madinah were 6.5 and 5.1 m/s while the lowest minimum wind speed during the year in the Tabouk and Madinah were 0.2 and 0.4 m/s. The results of the study showed that the crop evapotranspiration, ETc (mm/year) of the sites in, Medina, Tabuk, Makkah, Al Jouf, Riyadh, Qassim, Hail, East Region were 2418.75, 1940.51, 1837.76, 2259.03, 2139.23, 2207.41, 2032.09, 2144.87 mm/year, respectively. These results indicate that the estimation of ETc at the different sites of Saudi Arabia is affected by weather conditions. The highest value of ETc was in Medina field site, which could be attributed to the highest net radiation and temperatures.

9.3.4.2 Date Palm Water Requirement in the Experimental Sites

a) *Using the Penman Monteith equation (56) based on climate data*

The results of the study in Table 9.8 showed that the irrigation water requirements (m^3/ha) after taking into account the proportion of cultivated area for each tree of the sites in Medina, Tabuk, Makkah, Al Jouf, Riyadh, Qassim, Hail, East Region were 9495.24, 7340.18, 7298.93, 8913.59, 8614.96, 8568.68, 7996.99, 8510.72 m^3/ha, respectively, with the 100 Palm trees/ha. The total annual irrigation water requirements (m^3/tree) in these sites were: 95, 73.4, 73, 89, 86, 85.7, 80, 85 m^3, respectively, as the radius of shaded area per tree is 3.5 m with effective diameter of 90%, and the rate of leaching were: 12, 8, 13, 12, 14, 11, 13, 13%, respectively. With an irrigation efficiency of 90%, it was found that the on an average, overall irrigation water requirements at all the sites was 8342.41 m^3/ha/year with 100 (trees/ha). These values of ETc and CRW are attributed to the metrological conditions of each site. However, the reduction in the estimated CWR to an average of 8342 m^3/ha compared to overall average of 20000 m^3/ha as reported by many researchers (Al-Amoud et al. 2012; Ismail et al. 2014; Mihoub et al. 2015; Dewidar et al. 2015) is mainly attributed to the percentage of vegetative cover or shaded area (Se) of the tree. As we calculated the Se values as (0.33) of the actual area of the tree. Therefore, the practice distance of 10 m x 10 m between trees on the farms of Saudi Arabia does not seem appropriate at all the sites. This area of 100m^2 for each tree is an overestimate of the crop water requirements and therefore, it must be change to 7 m x 7 m in order to have a higher vegetative cover on the date palm farms.

b) *Water balance method*

The results of water balance method indicate the linear relationship with $r^2 = 0.90 – 0.93$ between the data of Terra Sen Dacom sensors and direct method (Gravimetric Method) as depicted in Fig. 9.7) for a period of two months on the three sites. The

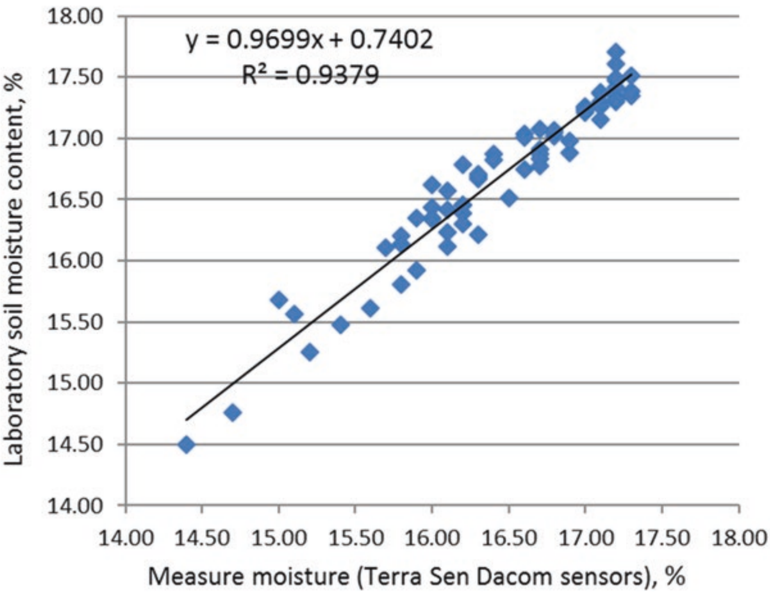

Fig. 9.7 Relationship between gravimetric soil moisture contents and the measured soil moisture contents (Terra Sen Dacom sensors)

results presented in Table 9.4 show that the volume of water consumed was 3604.31, 3515.25 m^3/ha/year for Qassim and Al Jouf, respectively. The amount of rainfall for Qassim and Al Jouf during the season were 92.85, 434.99 m^3/ha/year, respectively. The water balance methods showed that the water consumption for the two sites were very low as compared to ETc estimation by P-M or water added to field. This reduction in total amount of water consumption is mainly due to short depth of the sensor installed in the site (120 cm). It seems that about 50% of water added to date palm trees goes to waste and is being lost through percolation.

c) *The amount of applied irrigation water in study sites*

Table 9.7 shows that the amount of irrigation water actually added by a flow meter of all study sites, of the Medina, Tabuk, Makkah, Al Jouf, Riyadh, Qassim, Hail, East Region were 11305.0, 9463.9, 9692.0, 11252.75, 1007.4, 10035.0, 10272.5, 10082.8 m^3/ha/year, respectively. While these volumes added by the farmers in adjacent, farms were: 13717, 12277, 12220, 13340, 12050, 12880, 12620, 12610 m^3/ha/year, respectively. The increases of the amount of irrigation in adjacent farms by the farmers are mainly due to poor knowledge on irrigation requirements. Before installing the irrigation water monitoring system on the study sites, the farmers used to add three times higher than this volume and that could reach to 35000 m^3/ha.

Table 9.7 Compared the amount water applied in the different methods sites and increase water ratio (%) compared to Penman-Monteith Method

Sites	Water Requirements of Different Methods (m^3/ha/year)				The Increase Water Ratio, (%) Compared to Penman-Monteith Method	
	Penman-Monteith method	Water balance method	Applied Irrigation Water			
			Field Study	Farmer Adjacent	Field Study	Farmer Adjacent
Medina	9495.24	–	11305.0	13717.00	16.0	30.8
Tabuk	7340.18	–	9463.9	12277.00	22.4	40.2
Makkah	7298.93	–	9692.0	12220.00	24.7	40.3
Al Jouf	8913.59	3515.25	11252.8	13340.00	20.8	33.2
Riyadh	8614.96	–	10007.4	12050.00	13.9	28.5
Qassim	8568.68	3604.31	10035.0	12880.00	14.6	33.5
Hail	7996.99	–	10272.5	12620.00	21.2	36.6
East Region	8510.72	–	10082.8	12610.00	15.6	32.5

Table 9.8 Water use efficiency Kg/m^3, Yield Kg/ha and water saving, % in the field study as compared to the adjacent farmer's field

Sites	Field Study			Farmer Adjacent			Water Saving (%)	**EC_e**	Yield %
	Water applied, m^3/ha/year	Yield, Kg/ha	Water use, Kg/m^3	Water applied, m^3/ha/year	Yield, Kg/ha	Water use, Kg/m^3			
Medina	11305.00	7482	0.66	13717.00	7374	0.54	17.58	1.000	100.00
Tabuk	9463.90	6240	0.66	12277.00	6170	0.50	22.91	0.935	100.00
Makkah	9692.00	5406	0.56	12220.00	5324	0.44	20.69	4.600	97.84
Al Jouf	11252.75	6215	0.55	13340.00	6150	0.46	15.65	4.840	96.98
Riyadh	10007.40	7620	0.76	12050.00	7520	0.62	16.95	2.050	100.00
Qassim	10035.00	6742	0.67	12880.00	6531	0.51	22.09	10.950	74.98
Hail	10272.50	6908	0.67	12620.00	6708	0.53	18.60	2.600	100.00
East Region	10082.80	8400	0.83	12610.00	8520	0.68	20.04	6.030	92.69

9.3.5 *Water Use Efficiency Kg/m^3, Yield Kg/ha and Water Saving*

Table 9.8 shows that the productivity per hectare ranged between 5406 kg.ha^{-1} in Makkah and 8400 kg.ha^{-1} Al Ahasa. Water use efficiency (WUE) of palm in Medina, Tabuk, Makkah, Al Jouf, Riyadh, Qassim, Hail and East region in study sites were: 0.66, 0.66, 0.56, 0.55, 0.76, 0.67, 0.67, 0.83 kg.m^{-3}, respectively, while in the neighboring fields, these values were: 0.54, 0.50, 0.44, 0.46, 0.62, 0.51, 0.53, 0.68 kg/m^3, respectively. The water savings were: 17.58, 22.91, 20.69, 15.65, 16.95, 22.09, 18.60, 20.04 %, respectively.

Based on the equation given by Mass and Hoffman (1977) (Yield % = 100 – b (EC_e - a), on the reduction of yield using saline water on all sites of the study. For the date palm trees, the threshold salinity values (a) are 4.0 dsm^{-1} and (b) as 3.6%. As revealed by Table 9.8 the date palm production was affected by salinity in Al-Qassim site with a reduction 25% followed by East Region farm at 7.31%. The rest areas were not affected by salinity.

9.4 Summary and Conclusions

For the improvement of date palm cultivation in the Kingdom of Saudi Arabia, new innovative solutions are needed that in addition to the irrigation water issues could also address constraints like: pest and diseases control, draught, water shortage, soil and water salinization, water quality production, and socio economic and institutional constraints. Integrated efforts by irrigation researches, technicians, managers, and the farmers have to be put together in order to conserve water used in date palm cultivation. No single technology can solve all the water quantity and quality problems confronting irrigation of date palm and other crops. Many technologies, such as irrigation scheduling, advanced irrigation systems, limited irrigation methods, soil moisture management, wastewater irrigation, can be used to use less water for date palm irrigation. An Improved water management is required at all levels of irrigation including planning and design, project implementation, and operation and maintenance. These management improvements require comprehensive changes in institutions and organizations, water policy and law, rehabilitation or introduction of new irrigation systems, education and training of the farmers and extension workers, and researchers and development priorities.

The determination of annual evapotranspiration and water requirements of eight different regions of Saudi Arabia is an offer to improve irrigation water management of date palm. Regions that have been selected for the study include: Medina (Al Ula), Tabuk (Teimaa), Makkah (Al Jumum), Al Jouf (Sakakah), Riyadh (Sodos), Qassim (Riyad Al Khabra, Hail (Al Kaedh), East Region (Al Ahsa). The results of the study showed that the crop evapotranspiration, ETc (mm/year) without taking shaded area per tree, in the regions of Medina, Tabuk, Al Jouf, Riyadh, Qassim, Hail, Al Ahsa were 2418.75, 1940.51, 1837.76, 2259.03, 2139.23, 2207.41, 2032.09, 2144.87 mm/year, respectively. Irrigation water requirements (m^3/ha) after taking into account the proportion of cultivated area for each year are 9495.24, 7340.18, 7298.93, 8913.59, 8614.96, 8568.68, 7996.99, 8510.72 m^3/ha, respectively, for the 100 Palm/ha. The annual total irrigation water requirements in these regions were found to be 95, 73.4, 73, 89, 86, 85.7, 80, 85 $m^{3/}$tree, respectively as the radius of shaded area per tree is 3.5 m. The decrease of the CRW in all sites of study to around 8000 m^3/ha is mainly attributed to percentage of shaded area of date palm tree. The study suggests maintaining the tree-to-tree distance of 7 m x 7 m, instead of practicing 10 m x 10 m in order to reduce the estimation of CRW of date palm trees. The water balance methods showed that water consumption for the two sites were very low compare to ETc estimation by P-M or water added to field. This reduction in total amount of water consumption is mainly due to short depth of the sensor installed in the site (120 cm). It seems that 50% of water added to date palm tree goes to waste as leaching water.

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