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Scheduling Irrigation Water Requirements of Bermuda grass (Cynodon dactylon) at King Saud University

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Abstract: In this study, scheduling the irrigation water requirements of Bermuda grass (Cynodon dactylon) has been determined at King Saud University. Soil and water samples from the study are analyzed to explore the properties of soil and water salinity respectively. The analysis of meteorological data indicates high and low reference evapotranspiration in July and January, respectively. The irrigation frequency in the study area differs from two days in April, May, June, July, August and September to six days in January. The irrigation requirements per the one period reaches to 19.33 mm.

Keywords: irrigation scheduling, reference evapotranspiration, water salinity, King Saud University

Introduction

Based on the definition of the water scarcity by [1] shown in table 1: the ratio of the total freshwater withdrawals for some country to its total renewable water resources, Saudi Arabia is classified as a severely water scarce country where it withdraws 1,056 percent of renewable water resources available in the country.

According to Aqua stat database 2015, the withdrawal of water in Saudi Arabia increased dramatically from 1.75 km^3 in 1975 to 25 km^3 by 2006.

Table(1) Country classification based on water scarcity

Withdraws of total renewable water resources %	Classification
< 20	Water abundant
20-40	water scarce
> 40	severely water scarce

Majority of the water withdrawn is from deep and fossil aquifers[2] . Eighty seven percent of the extracted water is used to meet the agricultural sector (Figure 1) requirements[3] .

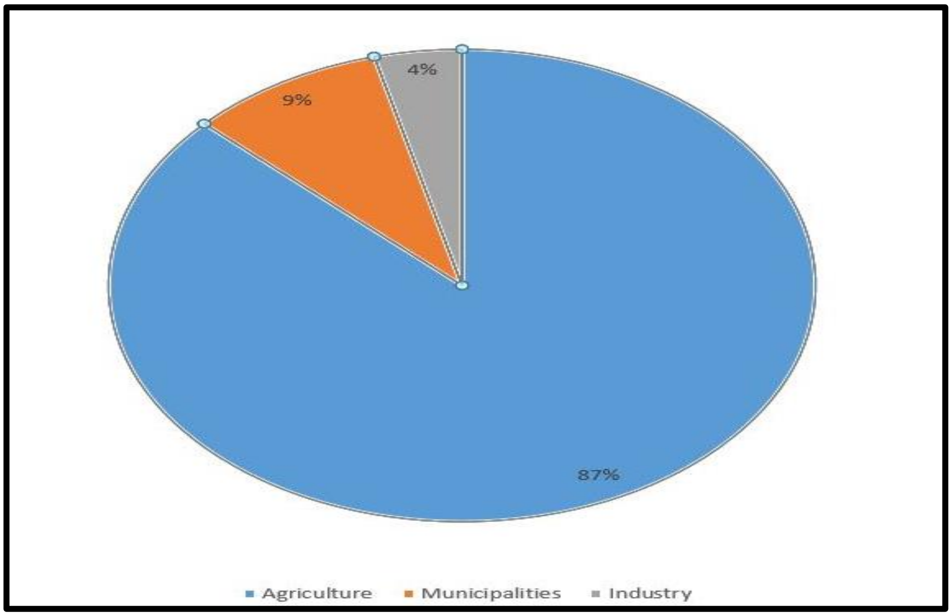


Figure (1) statistics of extracted water use in Saudia Arabia to 2006 by sector[3]

Sustainable soil and ground water resources management in arid and hyper arid regions like Saudia Arabia is of highly importance because of the limited water resources[4, 5].

Overestimating of irrigation requirements has many drawbacks like ground water wasting, increasing production cost and ground water pollution[6, 7]. On the other hand, underestimating of irrigation requirements leads to accumulating salts in the crop root zone decreasing yield, **and leading to soil erosion**[8, 9].

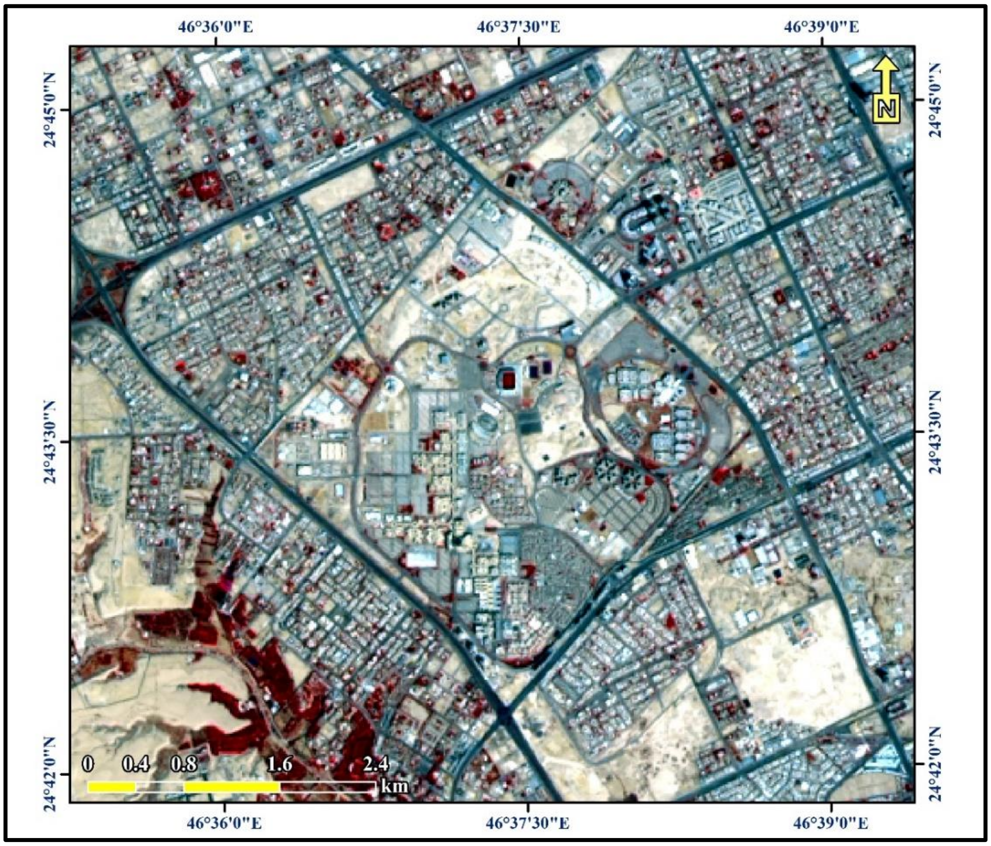
The adequate determination of the irrigation water requirements depends on the precise choice of the models used for estimating the crop water and leaching requirements. In this context, a study by [4] reveals that the empirical and semi-empirical methods overestimate the crop water requirements in comparison with Penman-Monteith method recommended by Food and Agriculture Organization. Another study results by [5] referred that the traditional model overestimates leaching requirements for salt-tolerant crops and underestimates leaching requirements for low and moderate salt-tolerant crops in comparison with the geochemical simulation model used for the same purpose.

Bermuda grass(Cynodon dactylon), classified under Warm season varieties [10] , is one of the most common lawn grass used in Arriyadh and Saudi Arabia[11]. It is one of the most drought tolerant turfgrasses[12].

According to the workers who are responsible for the irrigation in the study area when asked about the quantity of water used for irrigation, their answers indicate that the irrigation process is applied in a random way. This study aims to scheduling irrigation water requirements for Bermuda grass at King Saud University, Riyadh area.

Study area and data source

This study was conducted at King Saud University, Riyadh area figure (2). The hyper-arid climate dominates the study area. The monthly climatic averages data shown in table (4) for King Khaled international airport station located at 24.71 °N and 46.71 °E with elevation (612) m was used for computation the monthly reference evapotranspiration. This data is taken from the Presidency of Meteorology and Environment (PME), Saudi Arabia for the period from 1985-2010.



Figure(2) RGB Landsat image for the study area

Methodology

To scheduling irrigation water requirements for Bermuda grass (warm season), the following steps have been followed.

1- **Field and lab work**

Twenty samples of soil in addition to a sample of water used for irrigation in the study area were taken to determine the soil texture and water salinity respectively. The adequate method to determine the soil texture is by using hydrometer and Stock's law which has been used in this study. The salinity of the irrigation water was measured by electrical salinity meter manufactured by Waterproof.

2- Irrigation water requirements (IWR)

Irrigation water requirements(IWR) are defined as the sum of the crop water requirements(CWR) and leaching requirements(LR) [14] as follows:

$IWR_{i,q} = CWR_i + LR_{i,q}$ (1)

Where:

$IWR_{i,q}$: Irrigation water requirements for crop i, irrigated with q type water.

CWR_i: water requirements for crop i.

$LR_{i,q}$: soil leaching requirements planed with crop i and irrigated with q type water.

If we take the leaching requirements as a fraction, the equation (1) can be re-arranged as:

$IWR_{i,q} = CWR_i \cdot \frac{1}{1-LR_{i,q}}$ (2)

A- Calculating the crop water requirements (CWR)

Monthly crop evapotranspiration or crop water requirements can be assessed by multiplying the reference evapotranspiration (ET_o) by the crop coefficient (Kc) for the plant growth stage [10] as follows:

$CWR_i = K_{c,i} \cdot ET_o$ (3)

Where *CWR*: water requirements for crop i (mm/day)

ET_o : Reference evapotranspiration (mm/day)

K_{ci} : Crop coefficient relating to the crop type i and its growth stage. For this study, the Crop coefficients are shown in table2.

Table (2) Lengths of crop development stages [11] and Single crop coefficients [10] (table11).

crop	Developments stages					
	initial	develop	mid	late	total	Plant date
Bermuda grass	150	40	130	45	365	24 March-23 March
Kc	0.80	0.80	0.85	0.85		

Estimation of reference evapotranspiration (ET_o)

Monthly reference evapotranspiration (ET_o) in this study was calculated using Penman-Monteith equation described in details in FAO-56 [10] through this equation:

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \quad \ldots\ldots\ldots\ldots (4)$$

Where:

ET_o: reference evapotranspiration [mm / day],

R_n: net radiation at the crop surface [MJ/ m^2 day]

G: soil heat flux density [MJ/ m^2 day]

T: mean daily air temperature at 2 m height [C^0] ,

u_2: wind speed at 2 m height [m / s]

Δ : slope of the saturated vapor pressure curve [kPa / C^0]

e_a: actual vapour pressure [kPa]

e_s : saturation vapour pressure [kPa]

γ: Psychrometric constant [kPa / C^0].

The CROPWAT software developed by the Land and Water Development Division of FAO[15] is used to calculate the monthly crop evapotranspiration from the available climatic data variables shown in table 4 .

B- Calculating the Leaching requirements (LR)

The estimation of leaching requirements in this study was carried out by using the equation(5)[16].

$$LR = \frac{EC_W}{5(EC_e) - EC_w} \quad (5)$$

Where:

LR : the minimum leaching requirement ; EC_w : salinity of the applied irrigation water in dS/m (measured in lab 0.85 dS/m) ;

EC_e : Average soil salinity tolerated by the crop as measured on a soil saturation extract in dS /m. The value of EC_e for the crop in this study equals to 6.9 dS/m [9] table 13-1.

3- Water-soil characteristics

The available water capacity (AWC) is defined as the difference between volumetric soil moisture content at field capacity (θ_{fc}) and volumetric soil moisture content at permanent wilting point (θ_{pwp}) [17]:

$$AWC = \theta_{fc} - \theta_{pwp} \quad (6)$$

Where:

AWC: available water capacity($cm^3 cm^{-3}$).

θ_{fc}: volumetric soil moisture content at field capacity($cm^3 cm^{-3}$).

θ_{pwp} : volumetric soil moisture content at permanent wilting point($cm^3 cm^{-3}$).

The closed form equation developed by van Genuchten (1980) [18] can estimate these two hydraulic soil properties from the soil-water retention curve.

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + (\alpha h)^n]^{1-1/n}} \quad (7)$$

Where:

θ_s and θ_r are residual and saturated water contents respectively($cm^3 cm^{-3}$).

α (cm^{-1}) is related to the inverse of the air entry suction,

n is a measure of the pore size distribution.

$\theta(h)$ is the volumetric water content (cm^3 cm^{-3}) at suction h (cm).

Rosetta MODEL[19] based on the soil texture class determined in the lab is used to estimate the equation 7 parameters as shown in table 3.

Table(3) parameters used in equation 7

Soil texture	The equation parameters			
	θ_r	θ_s	α	n
Loamy Sand	0.0485	0.3904	0.0347	1.7466

The total available soil water (TAW) is defined as the amount of water that a crop can extract from its root zone and calculated by multiplying available water capacity (AWC) by the rooting depth (D) for the crop[10]:

$$TAW = AWC.\ D = 1000(\theta_{fc} - \theta_{pwp})\ D \qquad (8)$$

Where:

TAW the total available soil water (mm)

D the rooting depth (m).

The root depth range for the crop in this study is 0.5-1.0 m[10](table 22). The averaged value 0.75 m is used for calculations in equation 8.

The readily available soil water (RAW) is defined as the fraction of the total available soil water (TAW) that a crop can extract from the root zone without suffering water stress[10]:

$$RAW = p\ TAW \qquad (9)$$

Where:

RAW the readily available soil water (mm).

P average fraction of Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress occurs (0 – 1).

In this study, the p value defined in equation 9 is taken from the literature as 0.50 [10] (table 22).

4- Irrigation Scheduling

The irrigation frequency (IF) or irrigation interval known as the time period between one irrigation period and another can be calculated as follows:

$$IF = \frac{RAW}{CWR} \quad (10)$$

Where:

IF irrigation frequency (days or period).

RAW readily available water (mm) calculated in equation 9.

CWR crop water requirements (mm/day)

To determine the amount of water per the irrigation frequency, we use this equation:

$$IWQ = RAW \cdot \frac{1}{1-LR}$$

Where:

IWQ the irrigation water quantity in irrigation frequency(mm)

RAW Ready available water (mm)

LR the leaching requirement.

Results and discussion

1- Descriptive statistics of the monthly average of measured metrological variables

Table 4 shows the monthly averages of maximum temperature, minimum temperature, relative humidity, wind speed and the actual duration of sunshine at King Khaled Airport station. The monthly average of maximum temperature ranges from 21.6 Co in January to 45 Co in July with annual average 34.7 Co. In addition, the monthly average of minimum temperature ranges between 6.8 Co in January and 27 Co in July with annual average of 17.4 Co. On the other hand, the monthly average of relative humidity ranges from 50% in January and 14% in July and August (figure3).

Regarding to the wind speed, the maximum and minimum monthly average are 305 Km/day and 173 Km/day in July and October respectively.

Table (4) the monthly averages of measured metrological variables

Month	Min temp C°	Max temp C°	humidity %	Wind velocity Km/day	Sun hours Hour/day
January	6.8	21.6	50	242	9.6
February	9	24.9	40	281	10
March	12.8	28.7	35	302	11.3
April	18	34.7	33	293	11
May	22.9	40.7	22	276	12
June	24.9	43.7	15	295	13.5
July	27	45	14	305	14

Month	Min temp C°	Max temp C°	humidity %	Wind velocity Km/day	Sun hours Hour/day
August	26.6	44.7	14	252	14
September	22.7	41.8	18	202	13
October	17.4	36.7	24	173	12
November	12.5	29.9	37	199	11.3
December	8.4	23.7	46	223	9.2
Average	17.4	34.7	29	254	11.7

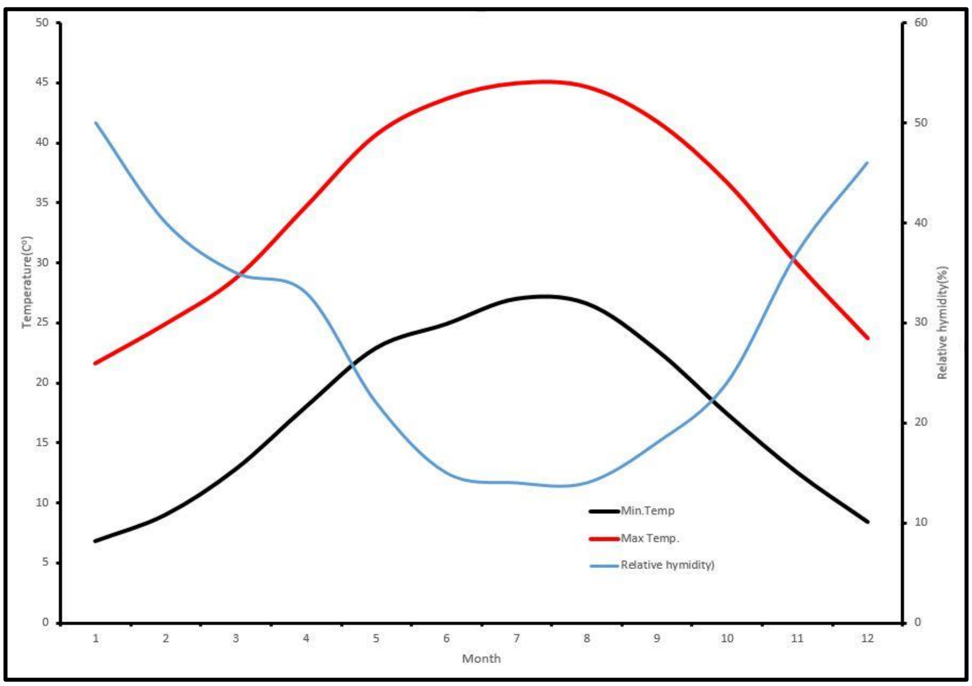


Figure (3) Monthly averages of Max,Min temperature and relative humidity in the study area

The monthly average of the actual duration of sunshine varies in value from 9.2 and 14 hour per day in December and July respectively with annual average of 11.7 hour per day (figure 4).

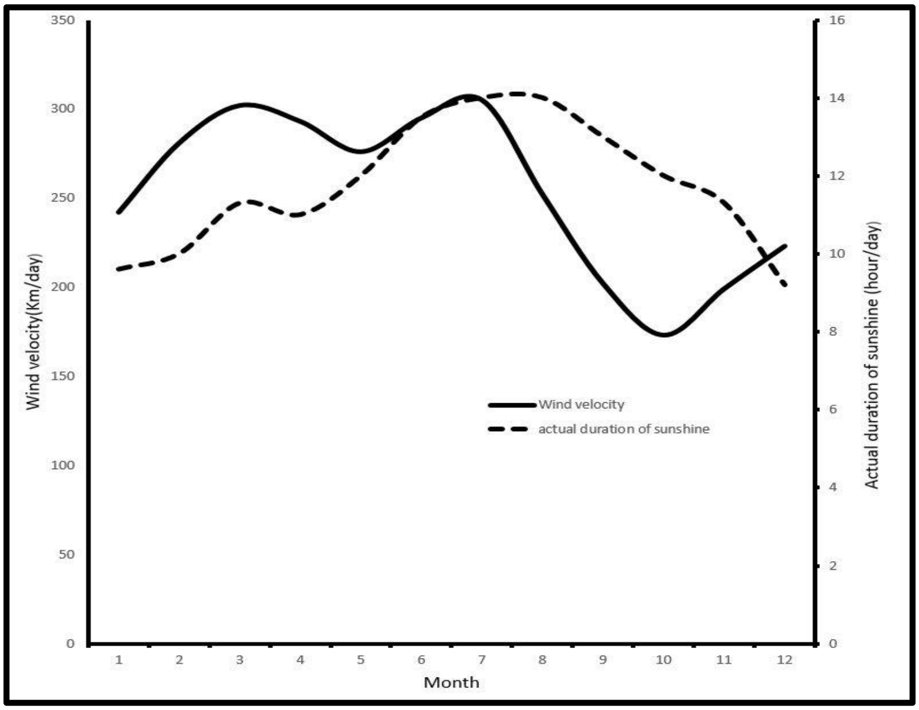


Figure (4) Monthly averages of wind velocity and actual duration of sunshine in the study area

2- The reference evapotranspiration and the Bermuda grass water requirements

Table5 shows the monthly reference evapotranspiration and Bermuda grass water requirements calculated based on equation 4 &3 respectively. The monthly reference evapotranspiration values range from 111 mm in January to 359.7 mm in July with annual sum of 2725 mm (figure5). The summer season has higher values in comparison with winter season.

The variations in the reference evapotranspiration values between summer and winter months can be interpreted by the notable differences in the temperature degrees through these two seasons. The monthly Bermuda grass water requirements range in value from 94 mm in January to 287 mm in July (table5, figure5). The annual Bermuda grass water requirements reached 2212 mm.

Table (5) the monthly reference evapotranspiration and Bermuda grass water requirements

Month	Reference evapotranspiration (ETo) using (penman-Monteith) mm/month	Kc	Monthly crop water requirements *CWR* = Kc . ETo(mm/month)
January	111.21	0.85	94.5285
February	138.42	0.85	117.657
March	202.32	0.82	165.9024

Month	Reference evapotranspiration (ETo) using (penman-Monteith) mm/month		Kc	Monthly crop water requirements *CWR* = Kc . ETo(mm/month)
April	239.28		0.80	191.424
May	300.41		0.80	240.328
June	332.98		0.80	266.384
July	359.7		0.80	287.76
August	324.62		0.79	256.4498
September	252.67		0.80	202.136
October	197.55		0.83	163.9665
November	148.91		0.85	126.5735
December	117.1		0.85	99.535
sum	2725.17			2212.6447

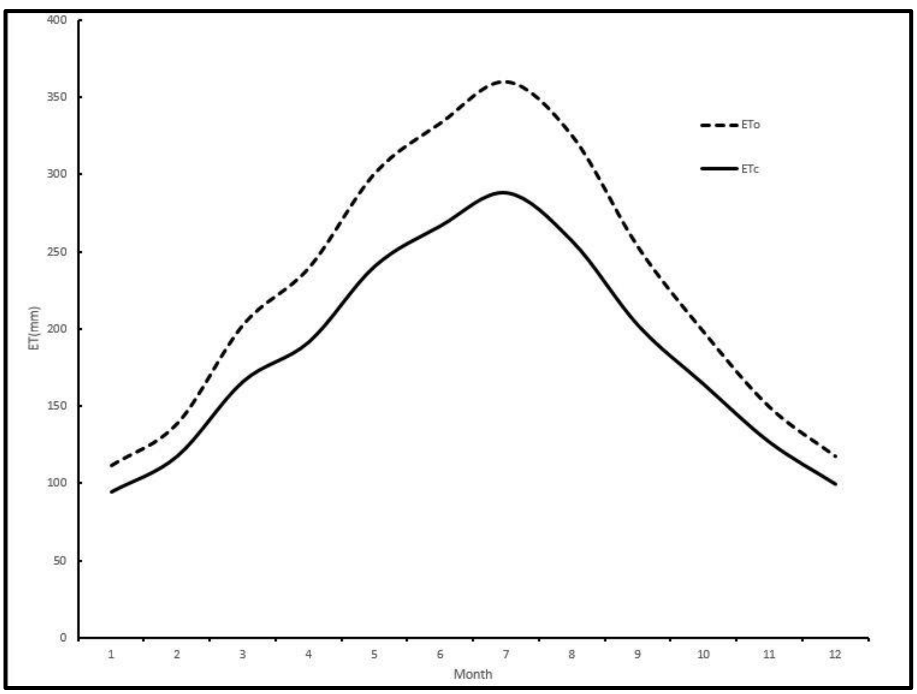


Figure (5) Monthly reference and crop evapotranspiration in the study area

3- leaching requirements and irrigation water requirements

The leaching requirements calculated in equation 5 is 0.03. This small value reflects the low salinity (measured as 0.85 dS/m) of the tertiary treated water used for irrigation in the study area from King Saud's University wastewater treatment plant.

The calculated total irrigation requirements in the study area equals to 2281 mm per year. The higher temperature in July can explain the highest value of irrigation water requirements for this month and vice versa in January where the temperature is the lowest (table 6 figure 6).

Table (6) Monthly irrigation requirements in the study area

Month	Irrigation water requirements(IWR)(mm)
1	97.45206186
2	121.2958763
3	171.0334021
4	197.3443299
5	247.7608247
6	274.6226804
7	296.6597938
8	264.3812371
9	208.3876289
10	169.0376289
11	130.4881443
12	102.6134021
sum	2281.07701

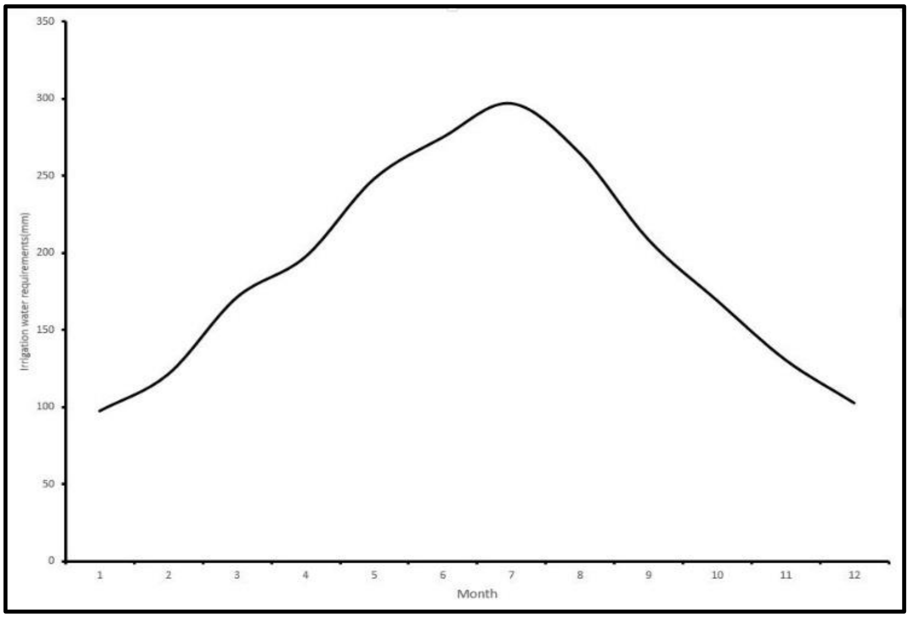


Figure (6) Monthly irrigation water requirements in the study area

4- soil-water characteristics and irrigation scheduling

The table 7 shows the soil-water characteristics, which is derived from the water retention curve (figure7), based on van Genuchten equation.

Table (7) soil-water characterstics

Soil texture	θ_{fc} (cm^3 cm^{-3})	θ_{pwp} (cm^3 cm^{-3})	AWC (cm^3 cm^{-3})	TAW (mm)	RAW (mm)
Loamy Sand	0.10	0.05	0.05	37.5	18.75

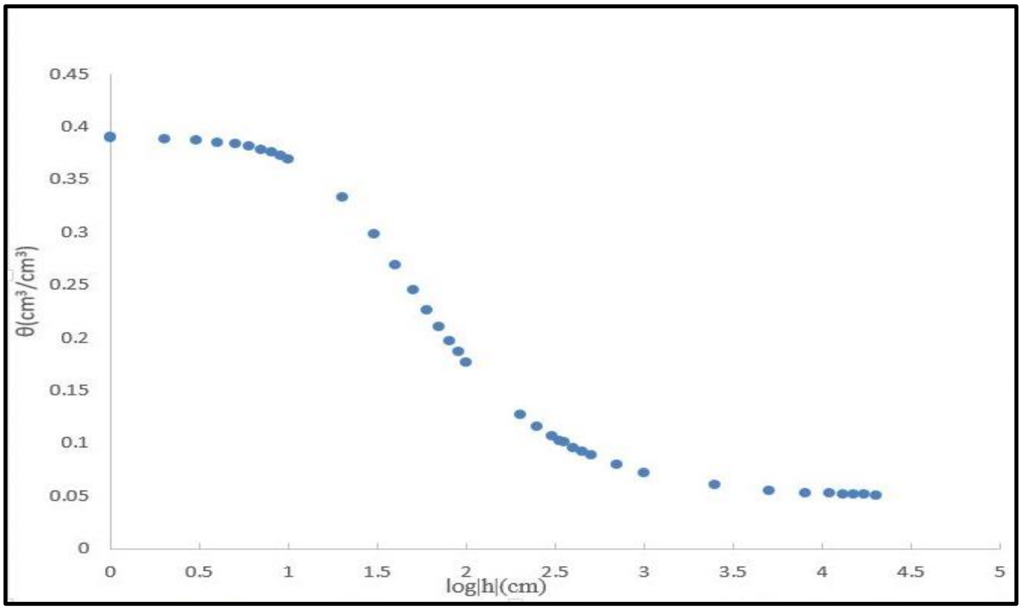


Figure (7) Soil-water retntion curve

The irrigation water scheduling is illustrated in table 8. The irrigation frequency ranges from 6 days in January to nearly two days in April, May, June, July, August and September. Short irrigation frequency period is noticed in summer season where the evapotranspiration is very high.

A quantity of 19.33 mm is needed to meet the irrigation requirements nearly every two days in April, May, June, July, August and September. The same quantity is applied every three days in March and October respectively. January and December are characterized with long irrigation frequency as low evapotranspiration is noticed in these two months.

Conclusion

This study aimed to scheduling Irrigation Water Requirements of Bermuda grass (Cynodon dactylon) at King Saud University. The annual quantity of the reference evapotranspiration equal to 2725 mm. The highest and lowest value of the reference evapotranspiration is noticed in July and January respectively.

The crop water requirements showed high values in summer season and moderate to low values in the other seasons.

Table (8) irrigation skedualing in the study area

Month	CWR	Irrigation frequency (IF)	How much to irrigate (IWQ)
	mm/month	Period(days)	mm/period
1	94.5285	6.148939209	**19.33**

Month	CWR mm/month	Irrigation frequency (IF) Period(days)	How much to irrigate (IWQ) mm/period
2	117.657	4.462122951	
3	165.9024	3.503565952	
4	191.424	2.938503009	
5	240.328	2.418569622	
6	266.384	2.11161331	
7	287.76	2.019912427	
8	256.4498	2.266525456	
9	202.136	2.782779911	
10	163.9665	3.544931434	
11	126.5735	4.444058195	
12	99.535	5.839654393	

The low value of the leaching soil requirements indicates the low salinity of the water used for irrigation in the study area.

The irrigation frequency in the study area differs from two days in April, May, June, July, August and September to six days in January. The irrigation requirements per the one period reaches to 19.33 mm in the study area.

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جدولة مياه الري لمحصول النجيل في جامعة الملك سعود

الملخص: في هذه الدراسة، تمت جدولة مياه الري اللازمة لنبات النجيل المزروع في جامعة الملك سعود. ولمعرفة خصائص التربة وملوحة المياه المستخدمة في الري فقد تم تحليل عينات من منطقة الدراسة لهذا الغرض.

تشير بيانات المناخ التي تم تحليلها إلى ارتفاع معدل التبخر نتح المرجعي في شهر يوليو وانخفاضها في شهر يناير.

وأظهرت نتائج الدراسة تفاوت دورة الري في منطقة الدراسة ما بين يومين في شهر إبريل، مايو، يونيو، يوليو، أغسطس وسبتمبر لتبلغ ستة أيام في شهر يناير. بلغت كمية المياه لكل دورة ري تسعة عشر ملم.

الكلمات المفتاحية: جدولة الري، التبخر نتح المرجعي، ملوحة التربة، جامعة الملك سعود.