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Determination of evapotranspiration and crop coefficient of sugar beet using lysimeter and its comparison with experimental methods in Shahrekord, Iran

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ABSTRACT

This study aimed to determine the evapotranspiration and crop coefficient (kc) of sugar beet during the plant growth using drainage lysimeter based on water balance and experimental methods for three years in Shahrekord, Iran. After planting sugar beet seed inside and outside lysimeter, evapotranspiration was measured on weekly and monthly basis by measuring the equation of water- balance. Results showed that the total evapotranspiration of sugar beet was 1016.6 mm during the growing season and the rate of water drainage and the soil moisture content were 73.9 and 66.1 mm, respectively. The amount of evaporation from the class A evaporation pan was 1364.5 mm. Evapotranspiration of the reference crop was measured by drainage lysimeter and calculated using the experimental methods. Results showed that evapotranspiration rate of the reference crop was 1123.03 mm and among the experimental methods, the Blaney- Criddle, Food and Agriculture Organisation's (FAO)-24 and Penman-Monteith (FAO)-56 methods had more accuracy. Crop coefficient at early, development, middle, and final stages was 0.72, 0.81, 1.04, and 0.7, respectively, with an average of 0.89 for the whole growing period. The average pan evaporation coefficient (Kp) was 0.83, and the average water requirement coefficient (Kc.p) was 0.73. In other words, sugar beet water requirement was 0.73 of the evaporation from the evaporation pan which can be used in estimation of accurate water requirement. Water use efficiency for root and white sugar yield was 5.14 and 0.753 kg m^{-3}, respectively.

Keywords: Evaporation, class A pan, pan coefficient, reference crop, water requirement coefficient

INTRODUCTION

Because of the need for sugar consumption, sugar beet is grown in vast areas of the world which makes its irrigation water requirement (IWR) estimation so important. Sugar beet water requirement varies from 250 mm (wet weather condition) to 2700 mm (dry weather condition) based on variety and climate difference (Koocheki 1997). Methods used to estimate sugar beet water requirement include direct and experimental methods. Lysimeter is a direct method for water requirement estimation. Studies performed in Iran showed that the amount of sugar beet evapotranspiration estimated by drainage lysimeter was 1221 mm in Toroq Mashhad (Rahimian et al. 2008), 516 and 1296 mm in Karaj for sugar beet seed (Chegin et al. 2010), and root (Khajehnouri 1993) production, respectively, 1066 mm in Kabotarabad, Isfahan (Panahi et al. 2007), 1635 mm in Mahidasht, Kermanshah (Taheri 1983), 1885 mm in Kermanshah (Vaziri 1992), 1096 mm in Hamedan (Rahimi 1998), 1705 mm in Urmia (Razavi 1996), and 1130 mm in Isfahan (Aghdaie et al. 2000). Sugar beet water requirement is influenced by different factors such as climate, soil, planting date, plant characteristics, and irrigation methods. Climate, especially humidity influences evapotranspiration. In a wet zone in Germany, using drain-

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age lysimeter, sugar beet evapotranspiration was 286 mm during a growth period (Roth 1992), while in south western of Italy, in a semi-wet area, using lysimeter , the evapotranspiration was 670 mm (Caliandro et al. 1980). Planting and harvest dates have a direct effect on sugar beet IWR. In a study by Barbier (1982), late and early harvest of sugar beet crop resulted in 650 and 350 mm evapotranspiration, respectively. In Davis, California, the actual sugar beet evapotranspiration was 975.4 and 726.4 mm for early and late planting, respectively (Pruitt et al. 1978). Soil type also influences evapotranspiration so that 372.9-420 mm evapotranspiration was reported for sugar beet in heavy soil. In Hokkaido, USA, the evapotranspiration was 5.38 mm per day in an average soil (Trzeciecki 1994). In California, using drainage lysimeter, sugar beet evapotranspiration was 1045 mm in a clay-loam soil with 67% evaporation from the class A pan (Ehlig et al. 1979). In Albecete, Spain, Urrea et al. (2006) estimated reference crop evapotranspiration using Penman-Monteith 56, Penman, Penman (FAO)-24 I and II, Blaney Criddle (FAO)-24, FAO radiation 24, and Hargreaves-Samani methods and compared results with lysimeter data. They ranked the equations based on their accuracy as follows:

Penman-Monteith 56 > Hargreaves-Samani > FAO radiation 24 > Penman (FAO)-24 I and II > Penman > Blaney Criddle (FAO)-24.

The amount of evapotranspiration estimated by Penman (FAO)-24 I and II and Blaney Criddle (FAO)-24 equations was greater and that of Penman equation lower than the value estimated by lysimeter. In Chelif zone, Legoupil et al. (1972) reported 1611 and 1165-1375 mm sugar beet evapotranspiration using lysimeter and experimental methods, respectively. Hargreaves et al. (2003) compared evapotranspiration results estimated by Hargreaves and Samani equation (Hargreaves and Samani 1985) with lysimeter in Chamberlain, Idaho, and reported that Hargreaves and Samani equation results were 97% greater than lysimeter results. Dehghanisanij et al. (2004) compared barley evapotranspiration results estimated by drainage lysimeter in Karaj with Penman-Monteith 56, Hargreaves and Samani, Penman-Wright, Macking, and Blaney Criddle (FAO)-24. Results showed that in April and August, monthly ET values estimated by all aforesaid equations (except Penman-Monteith 56 and Hargreaves and Samani) were greater than those estimated by lysimeter which might be due to the rapid temperature increase. However, in October and November, the ET values were underestimated which might be due to rapid temperature decrease. The crop coefficient (Kc) incorporates crop characteristics and average effects of evaporation from the soil. Crop coefficients are properties of plants used in predicting evapotranspiration. It is the ratio of ET observed for the studied crop (ET_c) over that observed for the reference crop (ET_0) (Allen et al. 1998). Crop coefficients were first introduced by Doorenbos and Kassam (1979). Jensen et al. (1990) reported that crop coefficients are influenced by climate, soil, plant properties and irrigation methods. Crop coefficients vary according to plant type, growth stage, climate, and irrigation conditions (Godratnema 2003). Kassam and Smith (2001) reported sugar beet crop coefficient for different morphological stages including early, development, intermediate, and final stages as 0.40, 0.85, 1.20, and 0.90, respectively. In a study by Synder (2002), sugar beet crop coefficient was 0.20, 1.05, and 0.95 for early, intermediate, and final development stages, respectively. In Toroq, Mashahd, Sugar beet crop coefficient was 0.50, 0.60, 0.90, 1.0, 0.90, and 0.80 in June, July, August, September, and October, respectively (Rahimian et al. 2008). Chegini et al. (2010) reported 0.29, 0.89, 1.12, and 0.66 crop coefficients for sugar beet. Zare Abyaneh et al. (2012) reported that average sugar beet IWR for four years was 8759 m^3 ha^{-1} with 4.42 (early stage), 1.0 (mid-season), and 0.65 (final stage) crop coefficients. They have also reported 24, 26, 65, and 29 days plant development duration for early, development, mid-season, and final stages, respectively. Mirzaei and Rezvani (2012) evaluated sugar beet crop coefficient based on water balance by measuring soil moisture changes and daily evapotranspiration of the reference crop in Qazvin. Using Penman-Monteith equation, they showed that the crop coefficient proposed by FAO based on four developmental stages was influenced by soil moisture, growing degree days, and leaf area index. Therefore, the above factors should be considered in crop coefficient evaluation. They have also developed the crop coefficient curve and mathematical equations for crop coefficient estimation. The crop coefficient for early, mid-season, and final growth stages was 0.59, 1.19, and 0.85, respectively. Crop coefficient values for early and final growth stages, using field water balance approach, was greater and lower than FAO method, respectively. A 5th degree regression relationship was found between growing degree days (GDD) and crop

Table 1. Soil physical properties of the experimental field

Sampling depth (cm)	0-25	25-50	50-75	75-120	120-140	140-185	Average
Field capacity (weight percentage)	22.5	23	24	17.2	19.2	20.6	21.08
Permanent wilting point (weight percentage)	12.7	12.9	13.5	9.5	9.7	10.1	11.4
Soil bulk density (g cm^{-3})	1.34	1.57	1.78	1.67	1.69	1.67	1.62
Soil texture	Silt-clay	Silt-loam	Loam-sand	Sand-loam	Silt-loam	Silt-loam	

coefficient. Nielsen and Hinkle (1996) estimated maize crop coefficient based on GDD, growth stage, and growth duration and showed that crop coefficient results based on GDD and growth stage, contributed in the prediction of evapotranspiration for irrigation programming. In a sugar beet study, Mirzaei and Abdollahian-Noghabi (2012) used the following equation for GDD evaluation:

$$GDD = \Sigma(Tmax+Tmin) / 2 - TB$$

$$\text{If } Tmin < 3°c \Rightarrow Tmin = 3°C \quad (1)$$

$$\text{If } Tmax > 30°c \Rightarrow Tmax = 30°C$$

in which,

Tmax = the maximum daily temperature recorded by the closest weather station

Tmin = the minimum daily temperature recorded by the closest weather station

TB = base temperature for sugar beet development which was considered to be 3 ^{o}C

This study aimed to estimate the sugar beet evapotranspiration based on water balance using lysimeter method under standard conditions to compare it with experimental methods. Crop coefficient and evaporation from class A pan were also estimated to determine sugar beet IWR for irrigation programming.

MATERIALS AND METHODS

This study was conducted in three years (1997-99) at Agricultural Research Center, Shahrekord (Latitude 32°18′N and Longitude 50°56′E at 2066 m above sea level). The soil texture was clay-loam. The average temperature and humidity were 19.18 ^{o}C and 36.5%, respectively. In order to measure sugar beet evapotranspiration, a drainage lysimeter (circular) with 3 m diameter, 2.2 m depth, and 7.06 m^2 area was placed in the middle of a field with an area of 2400 m^2 evenly cultivated by sugar beet crop. In the spring of each year and before planting, lysimeter soil was saturated and water moved from lysimeter into drainage tube. When the soil reached field capacity, monogerm seed was planted with a density of 80000 plants per hectare. Row to row and plant to plant distances within area covered by the lysimeter were 60 and 20 cm, respectively. In each year, plants were thinned and weeds were removed. Because of boron deficiency in the soil, boron-foliar spray applied two times and necessary fertilizers were applied based on Soil and Water Institute recommendation. Before and after planting, and also before any irrigation, the moisture content of lysimeter soil was monitored and measured up to 185 cm depth uing neutron moisture meter. Finally, based on physical properties of lysimeter soil (Table 1) and by using equation (2), sugar beet evapotranspiration was estimated (Allen 1998).

$$ETc = I + P - D \pm \sum_{i=1}^{n} (Pw_1 - Pw_2) \quad (2)$$

in which, *Etc* is plant's evapotranspiration (mm), *I* is the amount of irrigation water (mm), *P* is the amount of rainfall (mm), *D* is drained water (mm), *Pw1* is soil moisture before irrigation (mm), and *Pw2* is soil moisture after irrigation (mm).

First and second irrigations were normally performed but following irrigations were performed based on 45% moisture drainage from the soil at root development depth and to compensate the soil moisture deficiency, the IWR was calculated based on field capacity. A drainage lysimeter value was used for determination of reference crop evapotranspiration (lawn). The daily lysimeter data of the reference crop had been measured daily for several years, which was used in the current study for the sugar beet growing period. Crop coefficient (Kc) for growing period was measured based on equation (3):

$$Kc = \frac{ETc}{ETo} \quad (3)$$

in which, *Etc* is sugar beet evapotranspiration and *ETo* is reference crop (lawn) evapotranspiration.

While measuring the evapotranspiration of the reference crop by drainage lysimeter, the evapotranspiration ofsugar beet was measured simultaneously using 58 experimental methods. Based on minimum standard error of estimate (SEE) and coefficient of determination (R^2), 13

Table 2. Sugar beet evapotranspiration based on lysimeter water balance at different plant growth stages and GDD (average of three years).

Date	Growth stage (based on FAO four stages)	Growing degree days (GDD)	Irrigation water (ml)	Rainfall (ml)	Drainage water (ml)	Soil moisture change (ml)	ETc (ml during growth stage)	ETc (ml per day, during growth stage)
2.5-3.8 (25 days)	Early	335.6	159.3	10.5	25.1	-21.5	123.2	4.93
3.8-4.9 (32 days)	Development	888.5	160	5.6	17.5	39.7	187.8	5.87
4.9-6.26 (79 days)	Intermediate	2337.8	638.5	2.1	26.3	20.8	635.1	8.04
6.26-7.15 (20 days)	Final	2685.3	48.7	0	6.2	25.2	67.7	3.39
Total		2685.3	1006.5	18.2	75.1	64.2	1013.8	

experimental methods which had low SEE and high R^2 were selected (Ebrahimipak 2012). Low SEE and high R^2 values indicate higher correlation between evapotranspiration results estimated by experimental methods and and those measured by lawn lysimeter. During growing season, the daily amount of evaporation from class A pan was measured and the evaporation coefficient of the pan was measured by equation (4):

$$Kp = \frac{ETo}{Ep} \tag{4}$$

in which, *Kp* is pan coefficient and *Ep* is the amount of evaporation from class A pan.

At harvest, roots were collected from 5 m^2 plot area (by eliminating the border rows) and root yield was estimated. After weighing, roots were washed in sugar factory and root pulp was sent to Sugar Beet Technology Laboratory for sugar content determination. Harvested plants were oven-dried at 60 ^oC for 48 hours and the total dry matter yield was determined.

RESULTS AND DISCUSSION

Sugar beet evapotranspiration measured by drainage lysimeter

Table 2 shows sugar beet evapotranspiration based on water balance measured by drainage lysimeter at four different stages of FAO and GDD. Total sugar beet evapotranspiration was 1013.83 ml with a maximum of 635.1 ml GDD at mid growing season and a minimum of 67.7 ml at final growing season. Evapotranspiration results of this study had -17.04, -21.6, -5.07, -38.04, -7.6, -15.77, -40.6, and -10.4% difference with results of Rahimian and Shahabifar (2008), Khajehnouri (1993), Panahi et al. (2007), Taheri (1983), Rahimi (1998), Razavi (1996), and Aghdaie and Fyzee (2000), respectively which might be due to climate, plant density, soil type, planting and harvest dates. During growing season, the average rainfall was 18.2 ml which was insufficient and indicated that the plant growth period is located in dry season, and almost all IWR was provided by irrigation. The volume of drainage water was 75.1 ml which means that from 1006.5 ml irrigation water, 75.1 ml was out of access. Soil moisture variation was 64.2 ml from which 6.3% was related to evapotranspiration and 6.5% was related to irrigation water. According to Table 2, the morphological growth of sugar beet is divided into four stages including early, development, intermediate, and final stages (Doorenbos and Kassam 1979; Kassam and Smith 2001). Early growth stage was lasted for 25 days with 10.8-335.6 GDD and 123.2 ml (average 4.93 ml) evapotranspiration which might be due to the lack of full plant coverage. The intermediate growth stage was lasted for 32 days with 335.6-888.5 GDD which might be due to the aerial parts growth rate and increase in water requirement. As e result, the evapotranspiration was 187.8 ml (average 5.87).

The intermediate and final growth stages were lasted for 79 and 20 days with 888.5-2337.8 and 2337.8-2685.3 GDD, respectively. In terms of evapotranspiration, intermediate growth stage had higher values (635.1 ml with an average of 4.93 ml) than final growth stage (67.7 ml with an average of 4.93 ml) which might be due to high leaf area index and as a result higher photosynthesis rate. Using weekly lysimeter data, and calculation of daily evapotranspiration together with GDD (based on equation 1), correlation between average daily evapotranspiration (ETc) and GDD was fitted in the form of 3rd degree which is shown in equation 5 and Figure 1.

$$ETc= -2\times10^{-9} (GDD)^3 + 3\times10^{-6} (GDD)^2 + 0.0024 (GDD) + 3.8971 \tag{5}$$

R2=0.9599

in which,

ETc = sugar beet evapotranspiration based on ml per day

GDD = growing degree days based on

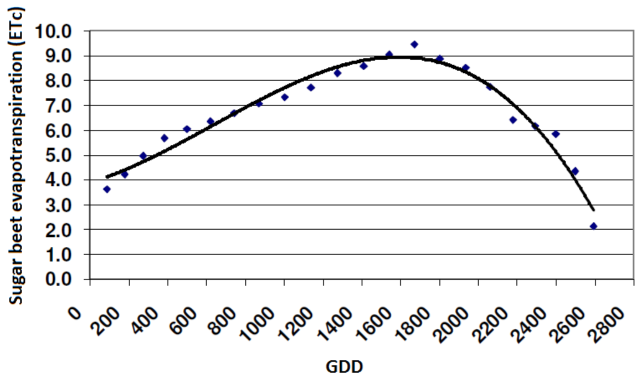

Figure 1. The correlation between sugar beet evapotranspiration (ml) and GDD

Table 3. Evaporation from class A pan, reference crop evapotranspiration, and crop coefficients.

Date	Growth stage (based on four FAO stages)	Growing degree days (GDD)	ETo (ml)	Etc (ml)	E_{PAN} (ml)	Kp	Kc	Kc from equation (average)	Kc x Kp=Kcp	Kcp from Equation (average)
2.5-3.8 (25 days)	Early	335.6	176.06	123.23	206.34	0.85	0.7	0.75	0.6	0.72
3.8-4.9 (32 days)	Development	888.5	230.41	187.8	274.4	0.84	0.82	0.76	0.69	0.62
4.9-6.26 (79 days)	Intermediate	2337.8	611.95	635.1	763.68	0.8	1.04	1.11	0.83	0.98
6.26-7.15 (20 days)	Final	2685.3	104.62	67.7	120.1	0.87	0.65	0.82	0.57	1.06
Total		2685.3	1123.04	1013.83	1364.5					

cumulative thermal units measured by special relationship according to base temperature.

The highest daily evapotranspiration was about 1600 GDD (9 ml per day) (Figure 1).

Comparison between sugar beet and reference crop evapotranspiration using direct method (lysimeter)

To determine crop coefficient, reference crop lysimeter data was also used. The reference crop lysimeter data was recorded on a daily basis for several years and was used for sugar beet growth period in this study. According to Table 3, evapotranspiration of reference crop lysimeter was 1123.04 ml. Results also showed that from planting to early July, reference crop evapotranspiration was greater than sugar beet and it continued increasing with a constant slope. However, by increasing leaf area index and root development at development stage, sugar beet evapotranspiration increased sharply and from early July to early September it became greater than reference crop and from late September the trend was vice-versa. These results are in agreement with those obtained by Dehghanisanj et al. (2004) and Urrea et al. (2006).

Comparison of the reference crop evapotranspiration measured by direct (lysimeter) and experimental methods

According to the results of this study, Torak, Penman-Monteith, Copais, Irmak, Penman-Monteith (FAO)-56, Priestley–Taylor, modified Penman-Monteith, Christiansen, Blany Criddle FAO 24, Hargreaves-Samani, relative Penman-Wright, Torrent White, and modified Penman-Monteith by (FAO)-24 had more accuracy than reference crop lysimeter results.

Estimation of ugar beet crop coefficient

Sugar beet crop coefficient results, which were calculated based on ETc/ETo ratio, using four FAO stages and GDD, is presented in Table 3. The maximum sugar beet crop coefficient (1.04) in the range of 888.5-2337.8 GDD was obtained at intermediate growth stage and the minimum (0.65) in the range of 2337.8-2685.3 GDD was obtained at final growth stage, respectively. Table 5 shows monthly sugar beet crop coefficients. The crop coefficient in May, June, July, August, and September was 0.74, 0.74, 0.91, 1.1, 1.03, and 0.7, respectively which were 12% more than those reported by Rahimian et al. (2008) for June (0.5), July (0.6), August (0.9), September (1), October (0.9), and November (0.8) in Toroq, Mashhad.

Table 4. The reference crop and sugar beet evapotranspiration measured by lysimeter and experimental methods, and crop coefficient (average of three years)

	Method	Early growth stage (25 days)	Development stage (32 days)	Mid-season (79 days)	Final stage (20 days)	Total/average
ET0*	Lawn lysimeter	179.21	227.26	593.95	122.62	1123.03
Etc**	Sugar beet lysimeter	129.81	183.1	617.11	86.1	1016.43
Kc***	Sugar beet coefficient	0.724	0.805	1.04	0.702	0.817
EP	Pan evaporation	209.48	271.25	742.76	141.01	1364.5
KP	Pan evaporation coefficient	0.855	0.837	0.799	0.869	0.84
KP×KC	Combined ratio	0.619	0.673	0.83	0.61	0.683
ET0	Penman-Monteith	138.33	187.34	552.66	205.87	1084.3
KC		0.732	1.04	1.34	0.712	0.957
ET0	Penman (1948)	124.5	148.5	506.4	190.8	970.2
KC		0.92	0.885	0.914	0.575	0.824
ET0	Penman FAO24	118.4	166.1	503.4	190.12	978.02
KC		0.83	0.917	1.028	0.685	0.866
ET0	Modified Penman	119	171.9	537	202.1	1030.8
KC		0.745	0.8	1.071	0.785	0.851
ET0	Penman-Wright	119.8	178.8	523	175.3	996.9
KC		1.15	1.073	1.06	0.64	0.981
ET0	Penman-Monteith56	133.8	182.7	541.2	200.7	1058.41
KC		0.95	0.86	0.87	0.6	0.82
ET0	Blany Criddle FAO24	176.1	230.2	539.9	160.9	1107.1
KC		1.11	1.1	1.24	0.675	1.03
ET0	Macking 1984	142.2	206.9	627.2	221.5	1197.8
KC		1.087	1.027	1.096	0.73	0.985
ET0	Hargreaves-Samani	113.9	170.9	541.7	197.8	1024.3
KC		1.1	1.067	1.07	0.63	0.968
ET0	Torrent White	176.4	175.1	429.9	182.6	964
KC		0.935	0.95	1.038	0.625	0.894
ET0	Christiansen	177.4	245.6	627.2	157.3	1207.5
KC		0.93	1.013	1.075	0.61	0.907
ET0	Priestley–Taylor	143.1	198.8	615.8	233.8	1191.5
KC		0.95	1.015	1.054	0.6	0.904
ET0	Torak	155.3	199.3	557.9	186.1	1098.6
KC		1.04	1.1	1.13	0.667	0.98

* reference plant evapotranspiration ml
** Sugar beet evapotranspiration ml
*** sugar beet crop coefficient

Sugar beet crop coefficient for early, development, intermediate and final growth stages was 0.72, 0.81, 1.04, and 0.70, respectively with an average of 0.89, which were 5% more than those reported by Kassam and Smith (2001) (0.4, 0.85, 1.2, and 0.9, respectively) and 15% more than those obtained by Chegini et al. (2010). Kassam and dorenbos (1979) reported crop coefficient values for early (0.4-0.5), development (0.75-0.85), intermediate (1.05-1.2), and final (0.9-1) growth stages which had 41% (less than this study), 0%, 0%, and 22% (more than this study) difference with this study. The difference between this study and the aforesaid studies might be due to climate change, plant density, soil type, planting and harvest date. Based on weekly crop coefficient values and GDD of the aforesaid data, a 3rd degree polynomial with regression coefficient ($R^2 = 0.8991$) and a degree of trust ($p<0.001$) can be established (equation 4). 3rd degree polynomial has high accuracy and regression coefficient, which indicates that these changes follow 3rd degree equation. When ETc cannot be measured, this equation and GDD data of the specified period can be used to estimate crop coefficient and IWR.

$$Kc = -3 \times 10^{-10}(GDD)^3 + 1 \times 10^{-6}(GDD)^2 - 0.0006(GDD) + 0.8128 \quad (4)$$

$R^2=0.8991$

in which, *GDD* is calculated by taking the average of the daily temperatures compared to base temperature.

Figure 2 shows that the highest crop coefficient (1.11) in 1650 GDD was recorded at intermediate growth stage.

Table 4 indicates sugar beet crop coefficient which was measured through the ratio of ET observed for the studied crop (ETc) to that estimated by experimental methods.

Penman-Monteith 56, Penman (1948), modified Penman-Monteith, modified Penman by (FAO)-24, Priestley–Taylor, Christiansen, Penman-Monteith, Hargreaves-Samani (1994), Torak,

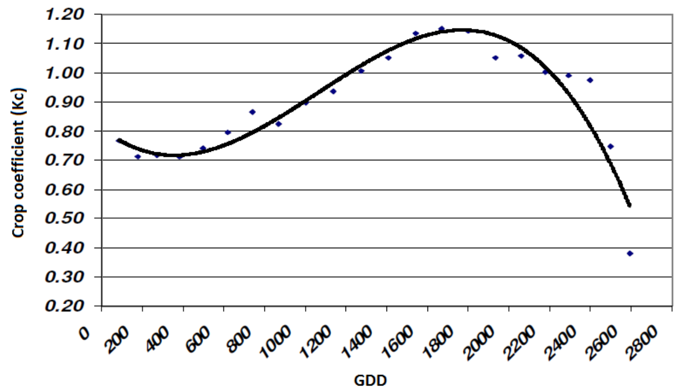

Figure 2. Relationship between sugar crop coefficient and degree of heat unit absorbed by plant

Table 5. GDD, sugar beet and reference crop evapotranspiration, Kc, Kp, and Kc.p in different months (average of three years)

Parameter	April	May	June	July	August	September	October	November
GDD	219	721	1312	1895	2412	2685		
ET0 (ml)	74.6	217.7	286.8	224.9	196.3	122.7	187.2	1123.0
ETC (ml)	55	161.4	259.7	251.8	201.9	86.4	169.4	1013
EP (ml)	87.4	254.3	361.5	289.6	230.7	141.1	227.4	1364.5
Kc from measurement	0.74	0.74	0.91	1.12	1.03	0.70	0.89	
Kc from equation	0.63	0.79	1.07	1.22	0.97	0.60	0.88	
KP	0.85	0.86	0.80	0.78	0.85	0.87	0.82	
KC×KP=KCP	0.63	0.63	0.72	0.87	0.87	0.61	0.73	
Kc from equation	0.63	63.0	0.86	1.10	1.12	1.00	0.89	

Penman-Wright, Macking, Torrent White, and Blany Criddle methods had 0.37, 0.85, 3.99, 5.65, 8.61, 9.62, 9.92, 14.63, 15.59, 16.63, 16.72, 17, and 20.68% difference with measured crop coefficient. It was concluded that Penman-Monteith 56, Penman (1948), modified Penman-Monteith methods which had less than 5% difference within a year and more accuracy than other methods are highly recommended.

Evaporation from class A pan

The evaporation from class A pan was estimated on a daily, weekly, and monthly basis (Table 3 and 4). According to Table 3, evaporation from class A pan was 1364.5 ml with maximum (763.7 ml) and minimum (120.1) values obtained at intermediate (at 888.5-2337.8 GDD) and final (at 2237.8-2685.3 GDD) stages, respectively. Based on Table 5, maximum and minimum evaporation from class A pan were recorded in July (361.5 ml) and May (87.37 ml), respectively. The relationship between reference crop evapotranspiration (with full coverage) and evaporation from evaporation pan is called pan evaporation coefficient (Kp) which was 0.82. Pan evaporation is usually calculated at lysimeter stations that measure reference crop evapotranspiration.

The pan coefficient estimated by Ebrahimipak (2011), Satar (1999), Soltani (2000), Razavi (2002), Sarami (2004), Madahyan and Farzamnia (2005), and Hang and Miller (1986) was 0.94, 0.88, 0.85, 0.79, 0.724, 0.68, and 0.95, respectively which had 6, 2.7, -4, -14.2, and 12.09% difference with this study.

As it shown in Figure 3, the highest evaporation from evaporation pan was 10.8 at 1150 GDD which corresponds to intermediate growth stage.

Since the ratio of sugar beet evapotranspiration to class A pan evaporation is one of the accurate indexes for IWR determination and irrigation programming based on pan evaporation, therefore a relationship was established between class A pan evaporation and sugar beet evaporation to estimate the IWR based on pan evaporation. To achieve this goal, first the sugar beet crop growth rate (Kc) and pan evaporation coefficient (Kp) were estimated and then Kc was multiplied by Kp to obtain Kc.p. If the result was multiplied by pan evaporation, the sugar beet evapotranspiration could be estimated. The average of this ratio, for the entire growth period, was 0.73 (Table 5), in other words the sugar beet water requirement was 0.73 of pan evaporation. The maximum value (0.83) was obtained at intermediate growth stage (888.5-23337.8 GDD) and the minimum (0.57) at

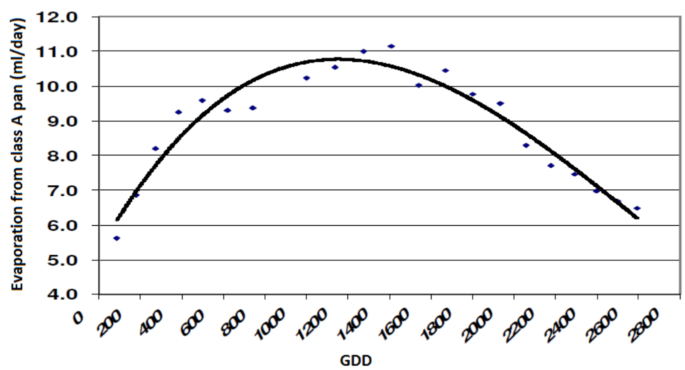

Figure 3. Relationship between evaporation from class A pan (ml per day) and GDD

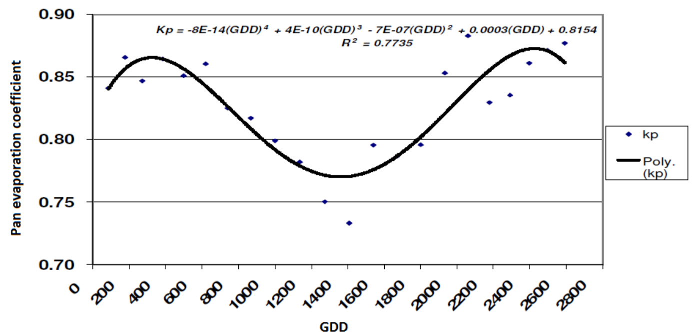

Figure 4. The 4th degree correlation between pan evaporation coefficient and GDD

Table 6. Yield and yield components of sugar beet (average of three years)

Total yield (t ha^{-1})	Sugar content	Sugar yield	Root potassium (meq 100g root^{-1})	Root sodium (meq 100g root^{-1})	Root amino nitrogen (meq 100g root^{-1})	White sugar (%)	Extraction coefficient of sugar	Molasses sugar (%)
52.2	14.6	7.65	5.55	2.59	5.15	11.71	80	2.9

final growth stage (2337.8-2685.3 GDD). In a study by Panahi et al. (2007), the ratio of sugar beet evapotranspiration to pan evaporation was 0.79 which was greater than this study. Table 5 shows Kc.p in a monthly basis with maximum (0.87) and minimum (0.61) results obtained in August and September, respectively.

Based on Kc.p, class A pan evaporation (weekly basis), and GDD results in Table 5, a 3rd degree polynomial equation with regression coefficient (R^2=0.817) was established. When ETc cannot be measured, equation 5 can be used to estimate the evaporation pan and IWR:

$$K_{C.P} = -2 \times 10^{-10}(GDD)^3 + 8\times10^{-7}(GDD)^2 - 0.0006(GDD) + 0.7214 \quad (5)$$

R^2=0.817

in which, GDD is the growing degree days based on cumulative thermal units.

As it shown in Figure 4, the highest Kc.p value (0.92) was estimated at 1800 GDD.

Yield

According to Table 6, the total sugar yield was 52.2 t ha^{-1} with 14.6% sugar content and 7.65 t ha^{-1} sugar yield. The amount of potassium, sodium and amino nitrogen was 5.55, 2.59, and 5.15 meq Kg^{-1} sugar beet. White sugar and Extraction coefficient of sugar were 11.71 and 80%, respectively.

Water use efficiency

Table 7 indicates the water use efficiency of sugar beet for 1 m^3 irrigation water. Water use efficiency based on root production and sugar yield was 5.14 and 0.753 kg m^{-3} of water. In other words, for producing 1 kg root, 1% sugar, and 1 Kg sugar, 200.3 litres, 713 m^{-3}, and 1360 litres of water was used, respectively.

Table 7. Water use efficiency in correlation with yield and yield components for three years (average of three years)

Water consumption (m^3 ha^{-1})	Total yield (Kg ha^{-1})	Water use efficiency (root) (Kg m^{-3})	Sugar content	White sugar yield (Kg ha^{-1})	Water use efficiency (sugar yield) (Kg ha^{-1})
10160	52200	5.14	14.6	7650	0.753

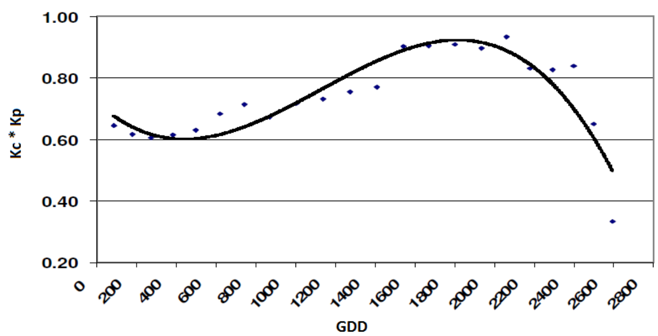

Figure 5. Correlation between Kc.p and GDD absorbed by plant

Conclusion

Results of this study showed that there was a significant linear equation between reference crop evapotranspiration measured by lysimeter and sugar beet crop, and also between reference crop evapotranspiration measured by Penman-Monteith method and lysimeter results which may be used for determination of sugar beet evapotranspiration (in the lack of lysimeter data) by using meteorological data. On the other hand, the GDD values measured by different methods indicated a linear equation between absorbed GDD and sugar beet evapotranspiration, sugar beet growth coefficient, pan evaporation coefficient, and Kc.p which facilitated the determination of crop evapotranspiration, crop coefficient and IWR in the lack of ETc data.

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