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Determination of water requirement and effect of its variations on some quantitative and qualitative traits of sugar beet product

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ABSTRACT

To determine sugar beet water requirement and the effect of changing the quantity of applied water on some production components, a study was carried out in Ekbatan Agricultural Research Station of Hamedān, Iran in four years (1994-1997) during which optimum water requirement, root and sugar yield, water use efficiency on the basis of root yield, sugar percentage and water use efficiency on the basis of sugar yield under no water and nutrients limitation conditions were measured and compared by water balance method for four growth periods of 130, 134, 152 and 162 days. At the same time, the water requirement of reference crop - poa - was measured by lysimeter in order to study the pattern of the variations of sugar beet crop coefficient. It was found that the amount of applied water for sugar beet was 8427, 7328, 10256 and 9026 $m^3.ha^{-1}$ in the four studied years, respectively with the average amount of 8759 $m^3.ha^{-1}$. Average four-year maximum crop coefficient was 1.04 at mid-growing season and the minimum one was 0.42 at early-growing season. The highest root yield, sugar yield and sugar percentage was obtained from 162-day growth period (116.8 $t.ha^{-1}$, 20.36 $t.ha^{-1}$ and 17.43%, respectively). The lowest ones were obtained from 130-day growth period (52.21 $t.ha^{-1}$, 8.5 $t.ha^{-1}$ and 16.26%, respectively). Results revealed that in 130-day growth period, root yield decreased and meanwhile, water use efficiency on the basis root yield and sugar yield was decreased to 7.1 and 1.2 $kg.m^{-3}$ applied water, respectively. In the longer growth period, water use efficiency on the basis of root yield and sugar yield was 11.4 and 2 $kg.m^{-3}$ applied water, respectively.

Keywords: Crop coefficient, Lysimeter, Sugar beet, Water use efficiency, Water requirement, Yield

INTRODUCTION

Sugar beet is a biennial crop that is cultivated for sugar extraction in the first year. Mean global cultivation area of sugar beet was 5.37 million hectares in 2005-2007 with the yield of 250.93 million tons (FAO, 2009).

Sugar beet can be cultivated in most parts of Iran and is known as the main source for sugar production. Given the spatial and geographical diversity of its cultivation, sugar beet water requirement varies which can be related to excessive water application on one hand (Faberio *et al*., 2003) and its resistance to water stress particularly during late growth period on the other hand (Karimi and Naderi, 2008). Owing to geographical and spatial diversity of sugar beet cultivation and the possibility of applying different water managements, extensive research has been carried out on its water requirement and its effects on its yield which is summarized as follow:

Research shows that sugar beet evapotranspiration (ET) varies from 250 mm in humid regions to 2700 mm in hot and arid regions (Gifford and Evans, 1981; Stanhill, 1986). Benz *et al*. (1985) reported sugar beet water demand as 591 mm in North Dakota, the U.S., and Utset *et al*. (2007) reported its mean daily ET as 5-12 mm. Panahi *et al*. (2006) estimated mean ratio of sugar beet lysimetric ET to evaporation from Class A pan as to be 0.79 during its growing season. They estimated water use efficiency (WUE) of sugar beet as to be

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5.01 and 0.49 kg.m^{-3} applied water in terms of root yield and white sugar yield, respectively. Shahabi and Rahimian (2008) reported three-year average (lysimetric) water requirement, root yield and WUE of sugar beet as 1221 mm, 56.5 t.h^{-1} and 4.6 kg.m^{-3} in Mashhad, Iran, respectively. Using water balance method in a semi-arid cold region in Turkey, Sahin *et al*. (2007) reported that sugar beet actual ET was 492.9 mm and its mean seasonal crop coefficient (K_c) was 0.65. In their studies on sugar beet water use under climatic conditions of Karaj, Iran, Ghalebi (2000) and Taleghani *et al*. (2008) found that the application of 883 mm water in sprinkler irrigation and 1350 mm water in surface irrigation resulted in the production of maximum root yield, pure sugar and WUE.

Richter *et al*. (2006) reported late-summer hot and dry weather as the cause of sugar yield loss in sugar beet cultivation in the U.K. and proposed earlier sowing and later harvest for preventing yield loss. This strategy resulted in 0.5-1.5 t.ha^{-1} increase in sugar yield on sandy soil and 2 t.ha^{-1} increase on loam soils. On the other hand, assimilates partitioning is correlated with sowing date so that, in later sowing, leaves are lost more rapidly and assimilation capacity decreases. Soltani *et al*. (1999, 2005) believed that gradual growth of the leaves greatly affected the yield under earlier sowing conditions. Kirda (2002) suggested low irrigation as the cause of higher sucrose concentration in sugar beet. Karimi and Naderi (2008) stated the positive role of late-season water and water deficit stresses in sugar yield rise, while Mirzaee and Rezvani (2007) found that drought stress adversely affected qualitative traits of sugar beet in Hamedān, Iran and revealed that irrigation withdrawal during late growing season resulted in the loss of qualitative characteristics of sugar beet including gross sugar percentage and extraction efficiency. Late-growing season moisture stress increases the impurities of sugar beet roots such as K and Na and consequently, significantly decreases sugar extraction efficiency and increases molasses percentage. Some likely reasons for the differences in results are different responses of sugar beet cultivars (Amjadi, 2003), sowing date, number of irrigations (Hosein Pour *et al*., 2006) and irrigation method (Taleghani *et al*., 2008). In a study on the effect of sowing date and plant density on quantitative characteristics and yield of sugar beet, Vafadar *et al*. (2008) found that the best combination was sowing date of April 13 and the density of 100000 plants.ha^{-1}. By applying different irrigation regimes on sugar beets, Groves and Bailey (1994) found that sugar yield and percentage were closely related to applied water and ET. In their studies in southern America in 1996 and 1997, Cassel *et al*. (2001) confirmed the application of drip irrigation system for controlling the leaching of soil NO_3 and optimum water use. In their study, 3-28% more sugar was produced than that in flood irrigation practice. Tognetti *et al*. (2003) reported that the yield and physiological responses of sugar beets drip irrigated with 75% of ET was similar to those of sugar beets sprinkler irrigated with 100% of ET. Mirzaee and Rezvani (2006) examined the effects of low-irrigation at four different growth stages of sugar beets by furrow-irrigating with 55, 70 and 85% of ET. They found that the differences between treatments in terms of mean sugar percentage, extractable sugar percentage and sugar extraction efficiency were not significant except in the treatment of irrigation with 55% of ET at third growth stage.

The economy of Hamedān, Iran mainly relies upon farming due to the lack of huge industries and its 800000 hectares of cultivation area. Water is an economical commodity, its application is invaluable. As an industrial crop, sugar beet is crucially important in local economy because of its role in supplying sugar factory of Hamedān. On the other hand, irrigation without predetermined plans and on the basis of personal experiences decreases irrigation efficiency and increases its losses. Therefore, given the importance of sugar beet in terms of production, water application and the limitations of water resources, the current study was carried out to determine optimum water demand of sugar beet by water balance method in draining lysimeter in Hamedān, Iran. Furthermore, the effect of the amount of irrigation water on root yield, sugar yield and WUE on the basis of root yield and sugar yield was examined and compared.

MATERIALS AND METHODS

The study was carried out in four years, 1994-1997 at Ekbatan Agriculture Research Station which is located 10 km away from Hamedān, Iran (Lat. 48°26´-48°32´ N., Long. 34°33´-34°52´ E., Alt. 1730 m). The regional climate is cold semi-arid with 312 mm mean annual precipitation (Zare Abyaneh *et al*., 2010). Evapotranspiration (ET) was measured by a draining lysimeter with an area of 1×2.25 m^3. It was located in the middle of a field with an area of 1500 m^2 with uniform conditions in terms of cultivation and irrigation. The edge of lysimeter was 10 cm higher than the soil surface and its internal walls were insulated to prevent the entrance of irrigation water of surrounding fields. The study field had a deep soil with a weak alkalinity. Its texture was moderate to heavy which was the result of alluvial sediments. The soil texture was loam and loam-clay at 0-26 and 26-94 cm depth, respectively. In addition, the material and the depth of soil layers inside the lysimeter were similar to general conditions of the region with no limitation of salinity and alkalinity. Soil moisture percentage was 32-38% at different layers at saturation. Field capacity point was 21.3-22.9%, permanent wilting point was 10.3-10.4% of volumetric moisture and its apparent density was 1.74-1.90 $g.cm^{-3}$.

A layer of sand with 20 cm thickness was situated on the floor of the lysimeter to facilitate the outflow of drain water. The lysimeter without plant cover and soil subsidence was irrigated once in order to have soil physical attributes similar to those of surrounding field.

Daily soil ET was measured by manual sowing of polygerm cv. TR41 on 60-cm-long rows with inter-plant spacing of 20 cm at 5 cm depth using soil water balance equation (Eq. 1) (Doorenbos and Pruitt, 1977):

$$ET_c = I + P - D \pm \Delta W \quad (1)$$

where, ET_c was potential evapotranspiration of sugar beets (mm), I was the quantity of irrigation water (mm), P was precipitation (mm), D was the quantity of drain water outflow (mm) and ΔW was the variations of soil moisture percentage at root depth (mm).

Irrigation date was determined by mounting a tensiometer at root development depth and measuring daily tension after the soil capillary moisture discharge at the tension of 30-40 cbar (Hanks and Ashcroft, 1980). The amount of water delivered to lysimeter at each irrigation and the amount of outflow drainage between irrigations were measured. The amount of precipitation, if happened, was measured by cylindrical rain gauge and water requirement was calculated by Eq. 1 after applying all measured parameters.

Nutrients were supplied from urea and ammonium phosphate sources as 110 kg $N.ha^{-1}$ and 90 kg $P.ha^{-1}$. One-third of urea and all ammonium phosphate fertilizers were applied at sowing time, and the remaining urea fertilizer was applied at two stages as dressing. The weeds were manually controlled during growing season and the pests were controlled by pesticides.

The water requirement of the reference crop (poa) was measured by lysimeter similar to that of sugar beet. Finally, crop coefficient (K_c) of sugar beet for each growth stage was obtained by dividing its evapotranspiration (ET_c) by evapotranspiration of the reference crop (ET_0) (Eq. 2) (Zare Abyaneh *et al*., 2009):

$$K_c = \frac{ET_c}{ET_0} \quad (2)$$

Emergence percentage, the separation of quadruple growth stages and the amount of applied water were regularly recorded during growing season. At the end of growing season, the crop was harvested from lysimeter and its yield was weighed.

At harvest, four roots were randomly selected in lysimeter as sample and were topped. Then, they were washed and weighed, root pulp was prepared in the laboratory of Agriculture and Natural Resources Research Station of Hamedān, Iran, and sugar percentage was measured by polarimetric method. Since the amount of sugar is economically the most important factor in sugar industry, sugar yield of sugar beet is regarded as the product of root yield multiplied by sugar percentage. At the end, water use efficiency (WUE) was calculated by the amount of applied water (including irrigation water + precipitation) in each year and the yield (root yield and sugar yield) according to the following equation (Zare Abyaneh *et al*., 2009):

$$WUE = \frac{Y}{W} \quad (3)$$

where, WUE is water use efficiency (kg yield per m^3 applied water), Y is root or sugar yield ($kg.ha^{-1}$) and W is the amount of applied water ($m^3.h^{-1}$).

Results and Discussion

Multi-year experimental researches are highly reliable because the effects of uncontrollable climatic parameters are removed (Aghaee *et al*., 1993). Therefore, the results of the current study can be reliably exploited since it was replicated in four consecutive years. In this study, sugar beet and poa water requirements were measured by calculating total applied irrigation water and precipitation between two irrigations and the drainage outflow from lysimeter and the application of Eq. 1. These results are presented in Table 1 for all four years. In addition, crop coefficient (K_c) of sug-

Table 1. Evapotranspiration (ET) of reference crop (poa) and sugar beet at different growth stages (Hamedān, 1994-1997)

Year	Growing season		ET ($mm.d^{-1}$)		K_c	Total applied water ($m^3.ha^{-1}$)
	Stage	Duration (d)	Poa	Sugar beet		
First year (1994)	Initiation	14	6.3	2.7	0.42	8427
	Development	28	7.12	5.3	-	
	Mid-season	70	8.1	8.74	1.08	
	Termination	22	3.5	2.0	0.57	
Average		33.5	6.95	6.28	0.89	
Second year (1995)	Initiation	23	6.8	2.6	0.38	7328
	Development	26	7.47	6.7	-	
	Mid-season	57	8.1	7.53	0.93	
	Termination	24	3.7	2.9	0.78	
Average		32.5	6.93	5.64	0.77	
Third year (1996)	Initiation	39	5.9	3.0	0.51	10256
	Development	20	8.4	6.2	-	
	Mid-season	69	9.9	10.1	1.02	
	Termination	34	4.1	2.58	0.63	
Average		40.5	7.53	6.33	0.79	
Fourth year (1997)	Initiation	20	6.3	2.4	0.38	9026
	Development	31	6.88	6.4	-	
	Mid-season	65	7.7	8.6	1.12	
	Termination	36	4.5	2.7	0.6	
Average		38	6.59	5.94	0.84	
Average	Initiation	24	6.33	2.68	0.42	8759
	Development	26	7.45	6.15	-	
	Mid-season	65	8.45	8.75	1.04	
	Termination	29	3.95	2.55	0.65	
Average		36	7.00	6.02	0.82	

ar beet was separately calculated for its quadruple growth stages and applied water per unit area by lysimetric data (Table 1). The measurements were done daily. Therefore, the results are reliable at daily level or above.

The maximum water requirement of sugar beet and reference crop (i.e. poa) occurred at mid-season stage. Its mean amount was 8.75 $mm.d^{-1}$ for sugar beet and 8.45 $mm.d^{-1}$ for poa. This can be explained by the fact that both crops reached to their maximum ground cover at mid-season stage and so, their transpiration increased due to shoot expansion. At this stage, water is important to maintain leaf turgid in order to maximize photosynthesis and potential yield (Ghaemi *et al*., 2008). Ground cover by sugar beet canopy about two months after its sowing and the increase in its LAI at mid-growing season which can play a role in maximizing ET is reported by Orazizadeh *et al*. (2008) and Fortune *et al*. (1999), too. Poa required more water than sugar beet at the other growth stages because it was sown before sugar beet and its growth period continued even after the harvest of sugar beets. In other words, the growth period of poa was longer and its canopy was greater than that of sugar beet at early and late growth periods.

Table 1 shows that the longest growth period of sugar beet was 162 days in the third year and the shortest one was 130 days in the second year. According to this Table, the amount of applied water was directly proportional to the length of growth period, so that 10256 $m^3.ha^{-1}$ water was applied in the third year and 7328 $m^3.ha^{-1}$ water was applied in the second year. Also, sugar beet K_c varied as a function of growth stages as Utset *et al*. (2007) stated. Sugar beet K_c was calculated by Eq. 2 for different growth stages as presented in Table 1. The highest K_c was at the mid-season stage which was 1.04 on average, and the lowest one was at early-season stage (0.42, on average). Fotoohi *et al*. (2006) reported maximum K_c as to be 1.14 in Miāndowāb, Iran which is in agreement with the amount obtained in the current study. Mean K_c of sugar beet during its growth period was found to be 0.7 in the current study which is close to 0.65 reported by Sahin (2007). Finally, the general diagram of K_c trend on the basis of the calculated mean (Table 1) was drawn as shown in Fig. 1.

Fig. 1 reveals that the water requirement of the crops fluctuates between the maximal at early-season stage and the minimal at mid-season stage. Furthermore, the amount of applied water is the sum of daily applied water and/or the pro-

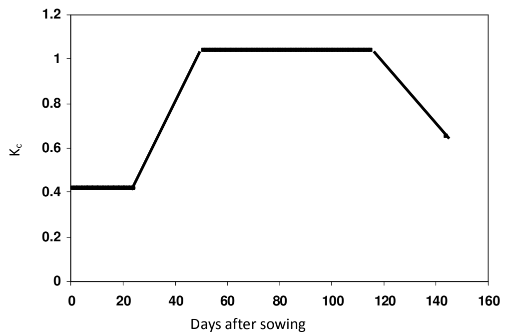

Fig. 1. Variations of crop coefficient (K_c) of sugar beet in four growing seasons (average)

duction of $ET_0 \times K_c$. The fluctuation of the amount of applied water changes the yield of crop due to the fluctuation of growth period length in addition to the changes during four growth stages. Therefore, the yield and sugar percentage of sugar beets are given separately for the study years in Table 2. As can be seen, the yield was different in different years, whereas such a difference was not observed in sugar content. Hence, the fluctuations of the amount of the applied water were caused by the fluctuations of the duration of the crop growth period. It can be accepted that sugar percentage under lower level of applied water was equivalent to that under higher level of applied water. This finding was consistent with the findings of Dunham (1993) who reported that a wide range of irrigation treatment just slightly impacted sugar percentage at final harvest. Thus, when no water stress is applied, it should not be expected that higher applied water level results in a higher sugar content. Table 2 indicates that the highest root yield and sugar percentage were obtained in the third year owing to longer growth period and the lowest ones were obtained in the second year due to shorter growth period. The root yield and sugar percentage in the current study were in the range reported by Ucan and Gencoglan (2004). They reported that the application of 1232 mm water resulted in the production of 57.36 $t.h^{-1}$ root yield and 17.2% sugar percentage and the application of 1331 mm water resulted in the production 62.35 $t.ha^{-1}$ root yield and 15.1% sugar percentage. The comparison of the figures of Table 2 reveals that the crop yield was higher in the third and fourth years than in the first and second years. Mean root yield was 108.63 $t.ha^{-1}$ in the second two years and 57.24 $t.ha^{-1}$ in the first two years. The increase in yield in the second two years vs. the first two years could be related to the earlier sowing in the former which was in agreement with the reports of Richter *et al*. (2006) and Fotoohi *et al*. (2008). Richter *et al*. (2006) mentioned early sowing and late harvest as the reasons for higher root yield.

In a more precise study, a question should be tried to be answered: can the increaseed growth period duration affect sugar yield as an important economical criterion? To answer the question, sugar yield which well describes the effect of early or late sowing was calculated (Karimi and Naderi, 2008). The results are presented in Table 2, according which the highest sugar yield (20.36 $t.ha^{-1}$) was obtained in the third year in which the growth period was 162 days, and the lowest one (8.5 $t.ha^{-1}$) was obtained in the second year in which the growth period was 130 days, whereas average sugar percentage during these four years was 16.73% and the comparison of the years with each other showed that it was around this figure in all four years. Since the cultivation in lysimeter is based on the provision of growth conditions in terms of water and nutrients availability, it can be accepted that no water stress or nutrient deficiency occurred (FAO, 2009). The increased ET in the third year compared to the other years is a proof of this claim which shows that the moisture conditions were more appropriate and the plants were able to fix more CO_2. Furthermore, results showed that ET was 12% higher in the second two years (1996 and 1997) than in the first two years (1994 and 1995) implying that plants enjoyed better moisture conditions in the second two years and fixed more CO_2. This factor combined with the availability of adequate nutrients due to the cultivation in controlled environment of lysimeter played role in increasing the yield. So, the differ-

Table 2. Evapotranspiration (ET), yield and sugar percentage of sugar beets in the studied years (Hamedān, 1994-1997)

Sowing date	Growth period (day)	Irrigation water (mm)	Precipitation (mm)	Drained water (mm)	ET (mm)	Soil moisture variations (mm)	Sugar percentage (%)	Yield ($t.ha^{-1}$)		WUE ($kg.m^{-3}$)	
								Root	Sugar	Root	Sugar
29 May – 18 Oct., 1994	134	1384.3	13	451.6	842.7	103.00	16.32	62.27	10.16	7.4	1.2
13 Jun. – 26 Oct., 1995	130	1587.1	18.4	759.5	732.81	113.19	16.26	52.21	8.50	7.1	1.2
10 May – 27 Oct., 1996	162	2382.7	18.7	1027.1	1025.62	348.68	17.43	116.8	20.36	11.4	2.0
20 May – 25 Oct., 1997	152	2126.9	24	932.3	902.6	316.00	16.9	100.46	16.98	11.1	1.9
Average	145	1870.25	18.53	792.63	875.94	220.21	16.73	82.94	13.88	9.5	1.6

ence in sugar yield cannot be related to the moisture stress and the lack of organic and inorganic matters. On the other hand, growth period was longer in the second two years and therefore, higher sugar yield should have been expected. Detailed separate examination of the years revealed that sugar yield was 9.33 $t.ha^{-1}$ in the first two years and 18.67 $t.ha^{-1}$ in the second two years. In other words, it was twice as much in the second two years as in the first two years. Thus, sowing date and optimum moisture conditions had an increasing effect on yield and seemingly, earlier sowing and later harvest in the third and fourth years as well as the different mechanisms involved in each growth stage were able to result in higher yield (Fotoohi *et al*., 2006). Fotoohi *et al*. (2006) suggested that one of these mechanisms could have been higher ground cover percentage which in turn, increased LAI and paved the way for realizing maximum photosynthesis through fixing more CO_2 and more assimilation by leaves towards realizing potential yield. In addition to the role of sowing date in yield, the roles of some other factors can be mentioned such as physical improvement of soil structure inside lysimeters by the activities of soil-borne animals and roots, the remaining of root residues from the previous years, the increase in soil organic matter content, and better management of lysimeters over the time. Additionally, the lack of high temperature stress in the second two years owing to the increased precipitation (Table 2) and decreased average temperature provided better climatic conditions for yield escalation. However, since these parameters were not measured, their roles cannot be quantitatively examined.

By separating WUEs on the basis of root and sugar yield in each cultivation year, it can be concluded that there were no marked differences between the first and second years and between the third and fourth years. Nonetheless, this difference exists between the first and second years with a shorter growth period and between the third and fourth years with a longer growth period. Therefore, mean WUEs on the basis of root and sugar yield were 7.25 and 1.2 $kg.m^{-3}$ applied water in the first two years and 11.25 and 1.95 $kg.m^{-3}$ applied water in the second two years. In other words, earlier sowing and later harvest of sugar beet under lysimetric conditions aiming at the complete supply of water and relative supply of nutrients played role in increasing WUE under no moisture stress conditions.

Conclusion

Water is essential for germination, emergence and maintenance of the turgidity of sugar beets. In addition, water is an invaluable economical commodity and its optimum use is necessary. Therefore, sugar beet water requirement and K_c were measured by cultivation with poa in lysimeter during four years. Results showed that mean four-year evapotranspiration of sugar beet (ET_c) was 876 mm in Hamedān which varied in the ranged of 733-1026 mm during growing season. Similarly, the water requirement of reference crop (poa) was measured under the same temporal and spatial conditions. On this basis, mean four-year evapotranspiration of reference crop (ET_0) was 6.5 $mm.d^{-1}$ varying in the range of 6.3-7.1 $mm.d^{-1}$. Sugar beet K_c was calculated by the equation $K_c = ET_c/ET_0$ separately for each growth stage. Maximum K_c was 1.04 at mid-growing season owing to full vegetative growth and ground cover and the minimum one was 0.42 at early-growing season due to the onset of vegetative growth. It was found that WUE and yield were associated with sugar beet root and that the amount of sugar was a function of the variations of water requirement and the duration of the growth period in the studied years. Minimum root yield was 52 $t.ha^{-1}$ for a 130-day growth period and 117 $t.ha^{-1}$ for a 162-day growth period. The highest WUE on the basis root was 11.8 $kg.m^{-3}$ obtained after 162 days and the lowest one was 7.1 $kg.m^{-3}$ obtained for a 130-day growth period. Since all the measurements of the water requirement of sugar beet and reference crop and other yield components were based on lysimetric cultivation and were done in four years, the results are reliable and recommendable. Hence, it is recommended to use the information of the current study in the sugar beet fields of Hamedān, Iran to improve the efficiency of water utilization and suitable planning.

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