EFFECT OF DEFICIT IRRIGATION MANAGEMENT ON QUALITATIVE AND QUANTITATIVE YIELD OF SUGAR BEET (*BETA VULGARIS* L.) IN KARAJ, IRAN

MANSURI, M.[1] – BABAZADEH, H.[1*] – EMDAD, M. R.[2] – TALEGHANI, D.[3]

[1]*Department of Water Science and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[2]*Department of Irrigation and Soil Physics, Soil and Water Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran*

[3]*Sugar Beet Seed Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran*

**Corresponding author*
e-mail: h_babazadeh@hotmail.com; phone: +98-912-699-0105

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Abstract. Environmental pollution and food security resulting from agricultural input surpluses are of great concern to the world in recent year. Improving use efficiency of agricultural inputs becomes an important way to relieve above issues. Due to the long growing season of sugar beet, its response to deficit irrigation is very important. According to the objective, a field study was conducted to investigate the effects of conventional (control), fixed and alternate furrow irrigation on qualitative and quantitative yields of sugar beet was carried out in Karaj, Iran. The treatments were applied in two consecutive years (2013 and 2014) as randomized complete block design with three replications. The irrigation water applied in the control treatment was 1127 mm, while the fixed and alternate furrow irrigation reduced drainage by 44% and 50%, respectively. The root yield was obtained 79 t/ha under alternate furrow irrigation, and 16% higher compared to fixed furrow irrigation. Average water use efficiency (WUE) for sugar beet root production in conventional, fixed, and alternate furrow irrigation were achieved 7, 11, and 12 kg/m^3, respectively. Moreover, the maximum water use efficiency for of pure sugar production (1.5 kg/m^3 of water used) was obtained in the alternate furrow irrigation treatment. So, it was 23 and 117% higher than fixed and conventional furrow irrigation treatments, respectively. α-amino nitrogen absorption in the alternate furrow irrigation treatment increased by 29% compared to other treatments, which suggest balanced fertilization management is needed in alternate furrow irrigation. Consequently, alternate furrow irrigation management with reduced drainage achieved maximum WUE.
Keywords: *alternate furrow irrigation, fix furrow irrigation, water use efficiency, root yield, drainage*

Introduction

Agricultural input surpluses cause severe environmental pollution and natural resource depletion; thus, the need to improve the utilization efficiency of agricultural inputs has become urgent. However, the high crop production in this region mainly depends on the surplus of agricultural inputs, which has caused serious resource shortage, environmental pollution and soil erosion in recent years (Liang et al., 2010).

Water resource is an important factor influencing crop productivity (Hardin, 2008). Crop production in semi-arid area mainly relies on irrigation. This is true for Iran where annual rainfall is less than 400 mm with negligible amount of rain during the growing season of summer crops (Sepaskhah and Parand, 2006). Drought stress is one of the main problems in the crop production in arid and semi arid area, and it is a serious threat to successful crop production all over the world (Ober, 2001). Akhavan et al.

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(2007), demonstrated that, deficit irrigation, if correctly managed, can be one of the known strategies for making optimal use of water. Increased water use efficiency (WUE) in agriculture plays an important role for maintaining food security and, it is one of the important goals in water use management (Deng et al., 2006). Therefore, to maintain grain supplement stably and safely, it is critical to improve the utilization efficiency of agricultural inputs, save resource consumption and ensure food security (Wang et al., 2016).

Thus, new irrigation strategies must be established to use the limited water resource more efficiently. One of the new irrigation strategies is the deficit irrigation scheduling, which is a valuable and sustainable production strategy for dry region (Greets and Raes, 2009). Under good management practices, deficit irrigation can result in substantial water saving with little impact on the quality and quantity of the harvested yield (Topak et al., 2011). In general, it has been proved that under stress conditions concentrations of dissolved substances increase to correct the conditions, and that this is directly related to the physiological system of the plants and osmotic absorption by the roots (Morillo-Velarde and Ober, 2006). Some field crops including sugar beet can adapt well to deficit irrigation practices (Kirda et al., 2002). Sugar beet is reputed to be a deep rooting crop and relatively insensitive to water stress because of the morphological and physiological characteristics of its root system (Doorenbosand and Kasam, 1979). Sugar beet has the ability to grow in a wide range of salinities and climatic conditions (Tognetti et al., 2003), and Sugar beet is resistant to drought and needs strategies to reduce the effects of drought stress so that it can achieve high yields (Hsiao, 2000). Sepaskhah (1996) reported that, for plants like sugar beet (grown for their leaves or roots) shallow groundwater and alternate furrow irrigation led to high WUE, but deep groundwater might cause substantial reduction in root yield if deficit irrigation was applied. One of the internal responses of sugar beet to water shortage, in addition to reduced growth, is increased sugar concentration in roots. On other hand Uçan and Gençoğlan (2004), reported that the root yield increased as the applied irrigation water increased, and a linear relationship was found between these two parameters. However, drought stress is an important factor in reducing yield which, depending on the climate under which it is grown, varies from 5 to 15 t/ha (Pidgeon et al., 2001).

In the several growth stages of sugar beet, many researchers have investigated deficit irrigation management. Firoozabadi et al. (2003) reported that they applied mild, moderate, and severe stress continuously on sugar beet under normal conditions during the growing season, and achieved 58, 45, and 34 t/ha root yields, respectively. Bazza and Tayaa (1999) have reported that deficit irrigation by 25% in furrow irrigation led to 21% reduction in root yield, but that water use efficiency would increase by 5% compared to the control that received full irrigation. In the study carried out by Rytter (2005), it has been reported that deficit irrigation by 40% reduced sugar beet dry matter by 50% compared to the treatment that received full irrigation. Applying drought stress in the last growing season increased root impurities, especially nitrogen, sodium, potassium, and hence, increased molasses production. Therefore, water stress in the end period of sugar beet season has an effect on sugar concentration of the harvested crop (Clover et al., 2001). Topak et al. (2011) studied the effect of deficit irrigation on sugar beet in semi-arid zone by drip irrigation system, and concluded that 25% and 50% saving in irrigation water caused 6.1 and 45.7% reduction, respectively, in the net income. Albayrak et al. (2010) reported that total sugar yield in alternate furrow irrigation increased compared to conventional furrow irrigation and water use efficiency

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was 29% higher. Mohamoodi et al. (2008) studied the relation to different irrigation regimes in 30, 50, 70 and 90% FC. Irrigation treatment showed that the optimum soil water content for root yield is at 70% field capacity with 78.5 t/ha and maximum quality observed. In a research carried out by Hassanli et al. (2010) it was shown that drip irrigation water management could lead to production of up to 79 t/ha of sugar beet roots, with water use efficiency in root and sugar production being 9 and 1.26 kg/m^3, respectively.

Because of water scarcity in the study area sugar beet cultivation relies extensively on irrigation and is mainly irrigated using conventional furrow systems without soil moisture monitoring or climate based scheduling. Consequently water stress is a common cause of yield loss. Therefore alternative irrigation technologies and more efficient irrigation management should be developed to overcome the problems associated with water stress or over irrigation (Hassanli et al., 2010).

Under these conditions, there is one way for farmers to maximize their profit on sugar beet production. Research results show that the best management of deficit irrigation on sugar beet crop and to choose the most appropriate irrigation scheduling for saving irrigation water is AFI (Topak et al., 2011), therefore deficit irrigation management, the optimum irrigation scheduling for the sugar beet in the arid and semi-arid region.

The objectives of this study were to evaluate the effect of deficit irrigation management on quality and quantity yield of sugar beet. The study examined reduce drainage, yields and IWUE for different irrigation management.

Material and methods

Field experiments of furrow irrigated sugar beet were conducted at the research field of the Kamalabad station of the Sugar Beet Research Institute in Karaj, Iran, at 50°55’E, longitude, 35°55’N latitude and 1313 m altitude during 2013 and 2014 growing season of sugar beet. Climate in this region is semi-arid with total annual precipitation of 265 mm. In the growing season of sugar beet we have no significant rainfall in both years. The soil in this area have no salinity and drainage problems such as water table, some physical properties of the experimental field soil are presents in *Table 1*, and some chemical irrigated water quality properties are shown in *Table 2*.

The experiments were conducted in the same field for the 2-year period. The cultivar, fertilizing, and insect control in all plots were the same for the 2 years. The Pars sugar beet variety was planted on 27 April 2013 and on 2 May 2014, and harvest day were 15 November and 27 October, respectively, for 2013 and 2014. The experimental design was a randomized block with three replications. Each plot consists of 12 row of sugar beet that was 90 m long and 0.5 m wide, the slope of furrow was about 0.00019 m m^{-1}. Sowing density was 3-6 plants per meter.

The design consisted of three irrigation methods. The irrigation methods were alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI). AFI is a deficit irrigation management which one of the two neighboring furrows is alternately irrigated during consecutive watering. The second deficit irrigation is FFI that irrigation is fixed to one of the two neighboring furrows and at last CFI is the conventional method where all furrows irrigated per irrigation, contrast to above mentioned managements.

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Table 1. *Some Physical properties of experimental field soil*

Depth cm	Clay %	Silt %	Sand %	Texture	Bulk density gr/cm^3	Field capacity %	Permanent wilting point %
0-30	31.4	42	26.6	Clay loam	1.47	27.4	14
30-60	34.6	27.4	38	Clay loam	1.42	26.6	14.9

Table 2. *Chemical properties of irrigation water at the study area*

HCO_3 (mg/l)	CO_3 (mg/l)	Cl (mg/l)	K (mg/l)	Na (mg/l)	Mg (mg/l)	Ca (mg/l)	EC (dS/m)	SAR	pH
146	0	0.8	0.8	62	16	23	0.5	2.2	8

Soil water content was measured by gravimetric method in all plots. Irrigation was applied at different intervals according to the soil water content measurement in the root zone. All plot irrigated when the soil water content in the root zone reached 50% of available soil moisture. Doorenbos and Kassam (1979) indicated that the maximum sugar beet yield was usually obtained when the sugar beet plants were irrigated at 50% of available water holding capacity.

The required volume of water was calculated using *Equation 1:*

$$d_n = \Sigma \left(\theta fc_i - \theta_i\right)\Delta z \qquad \text{(Eq. 1)}$$

where D_n is the net volume of irrigation water in mm, θ_{fci} plant moisture content at field capacity (in volumetric percentage), and θ_i soil moisture prior to each irrigation (in volumetric percentage), and Δz soil depth in mm. Therefore, the volume of irrigation water was determined beforehand based on soil moisture.

Siphon tubes (25 mm, ID) from an equalizing ditch supplied the water for irrigation treatment. The amount of irrigated water was measured by volumetric methods, and that runoff discharge of the furrows measured by WSC flume (Type II).

The crop evapotranspiration during each irrigation interval (ET, mm) was estimated from *Equation 2* (Heerman, 1985):

$$ET = I + R - D \pm \Delta W \qquad \text{(Eq. 2)}$$

where ET is the evapotranspiration (mm), I is the depth of irrigation (mm), R is the rainfall (mm), D is the depth of drainage (mm), and ΔW is the change of soil water storage in the measured soil depth. In this study, R was observed at the climatology station in Karaj. The amount of irrigation water applied was checked by inflow and outflow from furrow. ΔW was obtained from the difference between soil water content values to a depth of 0.6 m. The value of D was assumed to be negligible because the amount of irrigation water not increased above field capacity as result of deficit irrigation.

Sugar beet root yield was determined by machine harvesting the five center rows in each plot (each 8 m long). The quality parameters in roots were analyzed in the laboratory of Sugar Beet Research Institute in Karaj, Iran.

Considering the volume of water used and crop yield, water efficiency index was calculated using *Equation 3:*

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$$IWUE = \frac{Y}{W} \quad \text{(Eq. 3)}$$

where IWUE is irrigation water use efficiency (kg produced root/m^3 irrigation water used), Y root or sugar yield (kg/ha), and W the volume of water used (m^3/ha).

Analysis of variance was conducted to evaluate the effects of the treatments on sugar beet root yield (t/ha), white sugar yield (t/ha) and quality parameters, Duncan's multiple range tests was used to compare and rank the treatment means. Differences were declared significant at $P < 0.05$ or $P < 0.01$.

Results

ANOVA of applied water, root yield and sugar yield showed in *Table 3*. ANOVA of the combined 2-year sugar beet root data and Year indicated significant effects for irrigation management. Irrigation management interaction was significant in sugar beet root yield but not significant in white sugar yield (*Table 3*).

Table 3. *ANOVA of irrigation and yield of sugar beet*

		df	Sum of squares	MS	F-value	Sig.
Root yield	Year (Y)	1	98.07	98.07	19.68	0.0022
	Treatment (T)	2	771.59	385.79	77.41	<0.0001
	Y*T	2	138.07	69.03	13.85	0.0025
Sugar yield	Year (Y)	1	54.60	54.60	155.65	<0.0001
	Treatment (T)	2	22.19	11.09	31.63	0.0002
	Y*T	2	0.55	0.27	0.78	0.4901
WUE_r	Year (Y)	1	0.0008	0.0008	0.01	0.9401
	Treatment (T)	2	87.96	43.98	330.59	<0.0001
	Y*T	2	11.29	5.66	42.43	<0.0001
WUE_s	Year (Y)	1	0.69	0.69	94.12	<0.0001
	Treatment (T)	2	2.19	1.09	149.09	<0.0001
	Y*T	2	0.07	0.04	4.76	0.0435

The effect of year on white sugar yield were significant, and the result of Duncan´s multiple range test showed significant differences ($p < 0.01$) among some treatments in white sugar yield for the combined 2 year (*Table 3*). White sugar yield with AFI was always higher than at other full and deficit irrigation management.

The number of irrigation events and amount of applied water, fresh root and white sugar yield values of sugar beet for each irrigation management are shown in *Table 4*. The seasonal amount of applied water was the mean of the two seasonal and amounted to 1127 mm, 599 mm and 625 mm for CFI, FFI and AFI, respectively.

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***Table 4**. Total number of irrigation, amounts of irrigation and yield of sugar beet*

Year	Treatment	Number of irrigation	Irrigation water applied (mm)	Water saving (%)	Sugar beet root yield (t/ha)	Relative root yield (%)	White sugar yield (t/ha)	Relative white sugar (%)
	CFI	13	1197±6.81^{a}	0^{a}	83.6±1.42^{a}	100^{a}	10.1±0.76^{b}	100^{b}
2013	FFI	13	597±8.74^{e}	44^{b}	74.5±1.58^{c}	89^{c}	8.8±0.69^{c}	87^{b}
	AFI	13	667±6.03^{c}	56^{b}	80.6±0.78^{ab}	96^{b}	12±0.89^{a}	118^{a}
	CFI	11	1058±4.51^{b}	0^{b}	84.7±3.82^{a}	100^{a}	6.6±0.41^{d}	100^{b}
2014	FFI	11	602±2.00^{d}	43^{b}	62.4±1.00^{d}	73^{b}	5.8±0.18^{d}	88^{b}
	AFI	11	584±2.00^{e}	45^{b}	77.8±4.77^{bc}	92^{c}	8.1±0.68^{c}	124^{a}
Year (Y)			**		**		**	
Tretment (T)			**		**		**	
Y*T			**		**		Ns	

*significant in 5% level, ** significant in 1% level, ns non-significant

Table 5 shows the WUEr and WUEs for two years and average of the both years. WUE was significant ($p < 0.01$). The WUEr for CFI, FFI and AFI was 7.49, 11.42 and 12.70 kg/m^3 respectively and WUEs for CFI, FFI and AFI was 0.73, 1.21 and 1.59 kg/m^3 respectively.

***Table 5**. Water use efficiency values of root and sugar yield in combined year*

Treatment	WUE$_r$ (Kg/m$^{3)}$			WUE$_s$ (Kg/m$^{3)}$		
	2013	2014	Average of year	2013	2014	Average of year
CFI	6.98±0.08^{b}	8.01±0.35^{a}	7.49±0.59^{a}	0.84±0.06^{b}	0.62±0.04^{b}	73±0.13^{b}
FFI	12.48±0.44^{b}	10.36±0.19^{b}	11.42±1.27^{b}	1.47±0.10^{a}	0.96±0.03^{a}	1.21±0.30^{a}
AFI	12.08±0.19^{b}	13.32±0.80^{b}	12.70±0.84^{b}	1.79±0.14^{a}	1.38±0.11^{a}	1.59±0.25^{a}

WUEr: Water use efficiency of root yield
WUEs: Water use efficiency of sugar yield

ANOVA of the combined 2-year show that, irrigation management were not significant in polarization, white sugar content and molasses. Alkalinity, Sodium, Potassium and amino nitrogen was affected by irrigation management and year. Organic material such as amino nitrogen, potassium and sodium was affected by irrigation management. Molasses was not significant in irrigation management (*Table 6*).

Sugar beet root quality data in relation to different irrigation managements are presented in *Table 7*.

Figure 1 shows the relationships between root yield and applied water under different irrigation managements. Regression analysis showed that there was a polynomial relationship between seasonal water consumption and sugar beet yield, which is a good function and significant (*Figure 2*).

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Table 6. *ANOVA of sugar beet root quality parameters under different irrigation management*

		df	*Sum of squares*	*MS*	*F-value*	*Sig.*
Polarization	Year (Y)	1	31.90	31.90	30.12	0.0006
	Treatment (T)	2	26.74	13.37	12.64	0.0033
	Y*T	2	2.25	1.13	1.07	0.39
Sodium	Year (Y)	1	33.4	33.4	191.80	<0.0001
	Treatment (T)	2	1.87	0.93	5.36	0.03
	Y*T	2	4.43	2.21	12.71	0.003
Potassium	Year (Y)	1	1.12	1.12	10.68	0.0114
	Treatment (T)	2	1.039	0.52	5.02	0.0387
	Y*T	2	1.10	0.55	5.32	0.0340
Amino Nitrogen	Year (Y)	1	2.20	2.019	134.52	<0.0001
	Treatment (T)	2	0.44	0.219	14.63	0.0021
	Y*T	2	0.36	0.181	12.09	0.0038
Alkalinity	Year (Y)	1	234.07	234.07	392.98	<0.0001
	Treatment (T)	2	14.91	7.46	12.52	0.0034
	Y*T	2	5.90	2.95	4.95	0.0398
Molasses	Year (Y)	1	5.42	5.42	77.11	<0.0001
	Treatment (T)	2	0.30	0.15	2.14	0.1800
	Y*T	2	0.19	0.09	1.32	0.3204

Table 7. *Sugar beet root quality parameters under different irrigation management*

Year	**Treatment**	**Polarization %**	**White sugar concentration %**	**Sodium Meq/1000 g**	**Potassium Meq/1000 g**	**Amino Nitrogen Meq/1000 g**	**Alkalinity %**	**Molasses %**
2013	CFI	14.6±0.87[b]	11.8±0.87[bc]	1.7±0.34[d]	4.4±0.12[bc]	1.3±0.03[b]	4.8±0.18[c]	1.9±0.11[b]
	FFI	14.4±1.11[b]	12.1±1.04[b]	2.2±0.39[d]	4.0±0.51[c]	1.3±0.12[b]	4.9±0.56[c]	1.9±0.32[b]
	AFI	17.6±0.95[a]	14.8±0.97[a]	1.7±0.35[d]	5.0±0.17[b]	1.9±0.09[a]	3.5±0.20[c]	2.2±0.14[b]
2014	CFI	11.7±0.63[c]	7.8±0.84[e]	5.6±0.54[a]	4.6±0.19[bc]	0.8±0.05[c]	13.6±1.52[a]	3.3±0.20[a]
	FFI	12.7±0.13[bc]	9.3±0.20[de]	3.7±0.39[c]	5.2±0.26[a]	0.8±0.12[c]	10.9±1.37[b]	2.8±0.09[a]
	AFI	14.2±1.50[b]	10.4±1.01[cd]	4.5±0.35[b]	5.1±0.60[a]	0.8±0.21[c]	10.5±1.69[b]	3.2±0.58[a]
Year (Y)		**	**	**	*	**	**	**
Treatment (T)		**	**	*	*	**	**	Ns
Y*T		Ns	Ns	**	*	**	Ns	Ns

*significant in 5% level, ** significant in 1% level, ns non-significant

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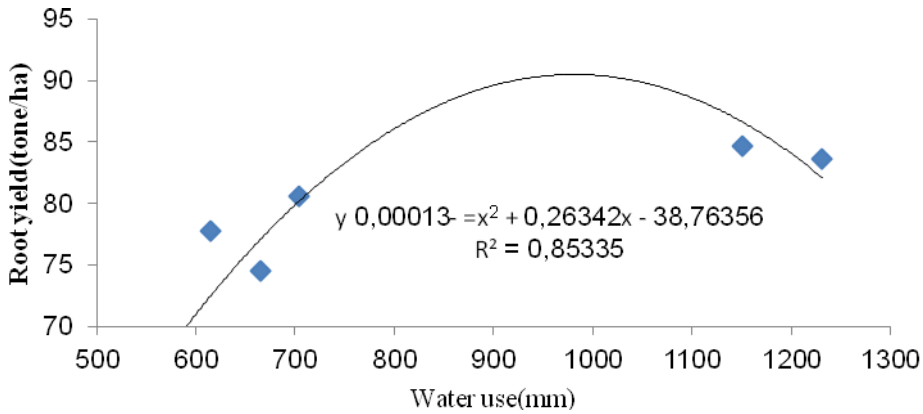

Figure 1. *Total root yield of sugar beet as a function of water management*

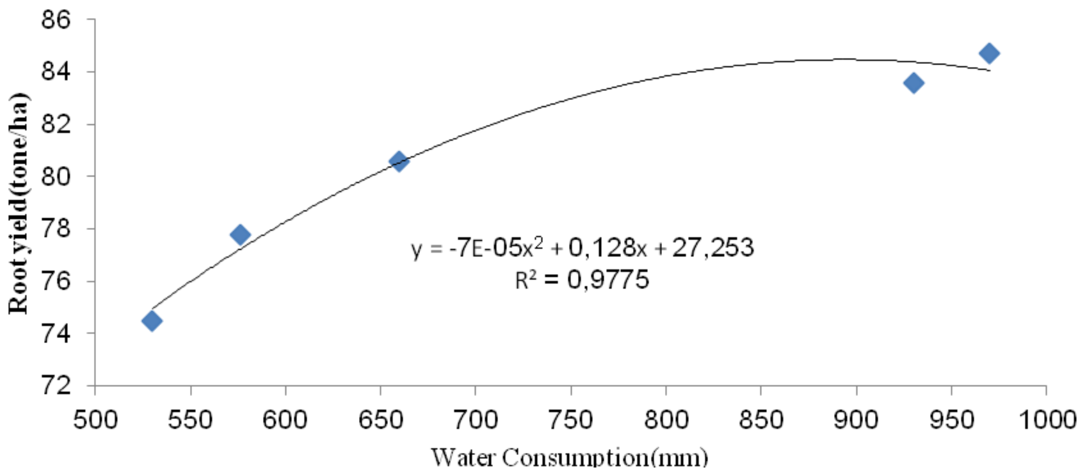

Figure 2. *Total root yield of sugar beet as a function of water management*

Discussion

In this research, results show that AFI and FFI saved water by approximately 50.5% and 43.5%, respectively, as compared to CFI. The lowest amount of applied water under AFI treatments as compared with CFI might be due to the great reduction of wetted surface in AFI; almost half of the soil surface is wetted in AFI as compared with CFI. The highest Eta occurred in the CFI obviously owing to an adequate soil water supply during the growing season (970 mm). This result supports the outcome obtained by Geraterol et al. (1993), who found that AFI methods can supply water in a way that greatly reduces the amount of wetted surface, with leads to less evapotranspiration and less deep precipitation. Reduced irrigation water due to the alternate furrow management reported by El-Sharkawy et al. (2006), Sepaskhah and Ghasemi (2008), Shayannejad and Moharreri (2009), Ibrahim and Emara (2010) for sugar beet; Nelson and Kaisi (2011).

AFI management, by reducing outlet drainage, can avoid the reduction of groundwater level and deep earth subsidence. AFI management, because of lateral infiltration water in furrow among watering, can cause decreased vertical infiltration. For this reason, nitrate and phosphate that is concentrated in land surface do not move

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into ground water therefore environmental pollution is avoided. AFI management is a good way to reach sustainable agriculture.

Large yield, averaging 84.2 t/ha, was obtained from CFI management plots. Minimum yield was obtained from FFI management plot which averaged 68.5 t/ha. As mentioned by Uçan and Gençoğlan (2004), sugar beet is a crop, which is affected by water deficit. Fluctuation in the yield showed itself to be related to the amount of water given. While the water saving in our study was 44 % (AFI) and 50 % (FFI), the decreases in average beer root yield for 2 years were found to be 6 and 21%, respectively. Therefore, it was observed that the ratio of decreases in beet root yield for each percent deficit rate was not constant. Vamerali et al. (2009) indicated that sugar beet root yields for full and deficit irrigation plots were significantly different. While the rates of decreases in evapotranspiration by Uçan and Gençoğlan (2004), were found as 46.5 and 34%, respectively, the rate of decrease in yield were found as 31.5 and 44%, respectively.

According to these values, it is obvious that there is a parallel relation between the WUEr and WUEs values. Although CFI management that gave the highest root yield and water applied also gave the lowest value of WUEr and WUEs, and the highest value of WUEr and WUEs was obtained in AFI management. This trend supports Febrio et al. (2003), who pointed out that maximum WUE tends to not occur at maximum water applied for sugar beet and usually occurs at an evapotranspiration less than the maximum.

Generally, WUE are influenced by crop yield potential, method of irrigation, method used to estimate or measure water apply and climate characteristics of region.

Root sugar content was generally increased in response to deficit irrigation treatment. Sugar beet roots accumulated more sugar (33%) under AFI management than under CFI management. Sucrose production from sugar beet depends on maximizing storage root growth over along growing season (Topak et al., 2011). It is necessary to apply a suitable irrigation program together with appropriate agricultural measures for taking a high sugar rate in the sugar beet production (Uçan and Gençoğlan, 2004). Dunham (1993) reported that the increase in the sucrose rate to fresh weight root is due to a slower accumulation of water.

The amount of K in sugar beet root generally did not change with the water deficit management during both growing seasons in this study.

The effect of deficit irrigation on Na content of root was significant ($p < 0.05$) in year 2013 and not significant in year 2014. Ober et al. (2005) reported that the effected of water deficit on Na content is less clear and varies from year to year. Na value range from 1.7 Meq/1000 g for CFI to 2.7 Meq/1000 g in year 2013 and 3.6 Meq/1000 g to 4.5 Meq/1000 g in year 2014. Maralian et al. (2008) demonstrated that, deficit irrigation increased Na content of root.

The effect of deficit irrigation management on amino N was not consistent throughout the years. Average amino N value varied from 1.05 Meq/1000 g to 1.35 Meq/1000 g. The most severe effect of water deficit on amino N content was observed in AFI management. However, CFI and FFI management had same effect on amino N content of root in both years. It must be noted that these substances reduce sugar beet quality because they are considered non-compatible dissolved materials contrary to non-toxic or compatible dissolved substances such as some amino acids and non-reducing that can accumulate in large amounts without causing any disturbances in the biological functions of cells (Rontein et al., 2002).

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Finally, the result shows that AFI management with reduced water use and environmental pollution can help achieve sustainable agriculture.

Conclusions

Results showed that deficit irrigation management at sugar beet led to decrease in root and sugar yields. Water use efficiency values increased slightly with increase in water deficit. Water was used more efficiently at the AFI management. Irrigation management AFI could be used for sugar beet grown in arid and semi-arid regions where irrigation water supplies are limited. Under this condition, 44% of water saving was obtained even though there was a 6% yield loss for sugar beet, based on the average of 2 years. The alternate furrow irrigation management had the maximum water use efficiency of root and sugar, 12.70 kg/m^3 and 1.59 kg/m^3, respectively.

In conclusion, this study revealed that if water is limited and deficit irrigation is spread over growth season of the sugar beet, WUE_r and WUE_s may be improved under 44 and 50% deficit irrigation schedule. Alternate furrow irrigation management in sugar beet may be feasible for water saving and reducing drainage. It can be concluded that using deficit irrigation is a good water management technique to protect the environment without reducing the water use efficiency.

The current study has been done in loamy texture soil and it might be different in other soil mixtures. Therefore, it is recommended that further experiments can be implemented in various soil textures and furrow lengths to evaluate deficit irrigation management on qualitative and quantitative yield of sugar beet.

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