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EFFECT OF DEFICIT IRRIGATION, NITROGEN AND POTASSIUM FERTILIZATION ON SUGAR BEET PRODUCTIVITY IN SANDY SOILS

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ABSTRACT: *Two field experiments were carried out in a sandy soil in El-Bostan area, Aly Mubark Experimental Farm, Southern El-Tahrir region, (latitude of 30.57^0 N and longitude of 30.71^0 E), El-Buhira Governorate, Egypt, during the two successive seasons of 2013/2014 and 2014/2015 to find out sufficient amount of irrigation water and the optimal levels of nitrogen and potassium fertilizers to get the highest yield and quality of sugar beet grown in a sandy soil under drip irrigation system conditions. A split plot design with three replications was used to lay out eighteen treatments, represented the combinations of three deficit irrigation regimes (applying irrigation water at 60%, 80% and 100% of the actual crop evapotranspiration "ET_c"), which occupied the main plots, whereas six combinations among three nitrogen fertilization levels (80, 100 and 120 kg N/fed "0.42 ha^{-1}") and two potassium levels (24 and 48 kg K_2O/fed) were distributed randomly in the sub-plots. Sugar beet Sara multi-germ variety was sown in both seasons.*

Results revealed that irrigating sugar beet at 80% ET_c significantly increased root length and diameter, sucrose%, extractable sugar% (ES) and purity% in both seasons. However, applying water at 100% ET_c significantly increased leaf area index (LAI), K and α-amino N contents in root as well as top, root and sugar yields/fed in both seasons. Increasing potassium fertilizer level to 48 kg K_2O/fed significantly increased all traits under study, except purity% significantly decreased, in both seasons, meanwhile the increment in ES% did not reach to the significant level in the 1st season. Root length and diameter, Na, K and α-amino N contents, LAI, top, root and sugar yields/fed were significantly increased by increasing nitrogen levels from 80 to 120 kg N/fed, whereas adding 100 kg N/fed gave the highest significant values of sucrose% and ES%, in both seasons. The combination between water regime at 80% ET_c and 48 kg K_2O/fed gave the highest averages of root length, sucrose% and ES%, in both seasons. The combination between water regime at 100% ET_c and 48 kg K_2O/fed significantly increased root yields/fed in both seasons, as well as sugar yield/fed in the 1st one. The addition of water at 100% ET_c with 120 kg N/fed significantly increased root diameter, LAI and yields of top, root and sugar/fed in both seasons. Sucrose%, ES% and purity% significantly increased by the application of water at 80% ET_c and 100 kg N/fed in both seasons. The combination between 48 kg K_2O/fed and 100 kg N/fed produced the highest significant values of sucrose% and ES%, in the 1st season.

Water use efficiency (WUE) calculated on root and/or suger yield basis increased with decreasing the amount of applied irrigation water indicating that deficit irrigation regime is a good tool to increase WUE for sugar beet under drip irrigation condition in sandy soil.

Based on the previous results, the application of irrigation water at 80% ET_c with the addition of 48 kg K_2O/fed and 100 kg N/fed could be recommended to get the best quality, while the combination of 100% ET_c, 48 kg K_2O/fed and 120 kg N/fed is recommended to get the highest yields of sugar beet grown in a sandy soil under drip irrigation at El-Bostan, El-Buhira Governorate.

***Keywords**: Sugar beet, dip irrigation system, water stress, water use efficiency, nitrogen and potassium*

INTRODUCTION

It is well known that Egypt suffers from a scarcity of water, in a time the Egyptians try to expand the arable area to reach self-satisfaction in some strategic crops and commodities while their population is rapidly increased. Therefore, increasing water use efficiency became a vital demand. Water use rationalization is a good tool to achieve this goal through the usage of drip irrigation, especially in the newly reclaimed soils. The potential benefits of deficit irrigation are increasing irrigation water use efficiency (WUE), reducing irrigation costs and water opportunity costs (English and Raja, 1996). In this respect, Weeden (2000) indicated that irrigation water was applied at levels of between 500 and 1000 mm for production of sugar beet in areas like the USA, Egypt and Pakistan. In addition, Hussein *et al.* (2015) revealed that the highest growth parameters were obtained by irrigation with 75 % of $ET_{c,}$ while the lowest values were gained under the highest water stress (50 % of the ET_c). There was high positive correlation between transpiration and root yield of sugar beet (Stewart and Hagan 1973, Dunham 1995 and Ucan and Gencoúglan 2004). Tognetti *et al.* (2002) evaluated some water regimes (50, 75, 100 and 120% of ET_o and unirrigated). They found that the root yield and sucrose% increased with increasing water quantity, while the unirrigated gave the lowest α-amino N. Hosseinpour *et al.* (2006) found that increasing water quantity increased root yield and leaf area, and decreased WUE for root and sugar yields. They added that the highest root yield was recorded with 100% of ET_o, while 25% ET_0 treatment resulted in the highest WUE for root and sugar yields. Mahmoodi *et al.* (2008) affirmed that the highest root and sugar yields and quality traits were obtained under 70% of field capacity (FC) compared to 90% FC. Esmaeili (2011) reported that continuous water stress achieved the highest WUE. Masri *et al.* (2015) revealed that 75% ET_c water regime under drip gave the highest values of LAI, sucrose and purity percentages. Meantime, increasing IWR led to increasing impurities%.

Under conditions of sandy soils, mostly characterized with poor nutrients and light texture, good management of applying nutrients and irrigation water are considered of paramount importance to obtain an economic yield of cultivated crops.

Nitrogen and potassium are the most promoting nutrients for sugar beet to achieve high root yield and quality traits. Supplying sugar beet with NK was responsible for root size, considered as the sugar storage (Barlog *et al.* 2013). Potassium is an important element for sugar beet yield and quality, in balance with other essential plant nutrients (Li and Liang, 1997). Kant and Kafkafi (2002) and Wang *et al.* (2013) mentioned that K plays significant roles in increasing root elongation, depth, enlarging root absorptive surface, maintaining turgor by reducing water loss and wilting and maximizing water retention in plant tissue, nutrients uptake, phloem unloading. They added that K enhances the photosynthetic products translocation from the source (leaves) to the sink organs (roots), which subsequently increases the plant dry matter and leads to an increase in the storage root growth. Mehrandish *et al.* (2012) reported that the highest root and sugar yields were observed with 100 kg K_2O/ha, which also improved quantitative and qualitative characteristics under deficit irrigation. Amin *et al.* (2013) indicated that applying 100 kg N/fed gave the highest root length and diameter, impurities and yields of top, root and sugar. Meanwhile, sucrose% decreased with increasing N rates from 50 to 100 kg N/fed. El-Sarag and Moselhy (2013) showed that the highest gross sugar, top, root yields were obtained by adding 211 kg N/ha and 140 kg K_2O/ha. The maximum sucrose% was achieved by adding 141 kg N/ha and 100 kg K_2O/ha. Mehran and Saadat (2013) cleared that adding 114 kg K_2O/ha under different rates of N significantly increased sucrose%, root and sugar yields/fed. Increasing N level up to 285 kg N/ha without K fertilization led to a significant increase in impurities%. Neseim *et al.* (2014) found that the drought stress significantly reduced root morphological, root and white sugar yields. Meanwhile, insignificant differences were found in Na, K, α-amino N, sucrose% and purity%. In addition, adding 75 K_2O kg/fed gave the highest yield, sucrose% and the lowest impurities% under drought stress. Also, adding 100 kg K_2O/fed gave the highest root and sugar yields and WUE under sufficient irrigation. El-Geddawy and Makhlouf (2015) pointed out that roots length, diameter and fresh weight, K and Na contents, top, root and sugar yields were significantly increased by increasing nitrogen up to 120 kg N/fed. The highest sucrose % was recorded with 100 kg N/fed. Masri *et al.* (2015) mentioned that increasing N rate up to 120 kg N/fed significantly increased root weight/plant, impurities%, root and white sugar yields. They added that the excessive N application lowered sucrose, purity and extractable sugar percentages. Badr (2016) indicated that applying 110 kg N/fed gave the highest fresh root and top yields. Moreover, adding 70 kg N/fed produced the maximum sucrose, extractable sugar and purity percentages. Sugar yield was significantly increased by increasing N level up to 90 kg N/fed.

This work was conducted to find out the optimal water regime, nitrogen and potassium levels to attain the maximum root and sugar yields with the best quality traits of sugar beet crop grown in a sandy soil under drip irrigation system as well as to raise water use efficiency.

MATERIALS AND METHODS

Two field experiments were carried out in a sandy soil in El-Bostan area, Aly Mubark Experimental Farm, Southern El-Tahrir region, (latitude of 30.57^0 N and longitude of 30.71^0 E), El-Buhira Governorate, Egypt, during the two successive seasons of 2013/2014 and 2014/2015 to find out the optimal levels of nitrogen and potassium fertilizers and appropriate irrigation regime to get the highest yield and quality of sugar beet grown in a sandy soil under drip irrigation system conditions. A split plot design with three replications was used to lay out eighteen treatments, represented the combinations of three deficit irrigation regimes (applying of irrigation water at 60%, 80% and 100% of the actual crop evapotranspiration "ET_c"), which occupied the main plots, whereas six combinations between three nitrogen levels (80, 100 and 120 kg N/fed) and two potassium levels (24 and 48 kg K_2O/fed) were distributed randomly in the sub plots. The sub plot area was 24 m^2 including 4 ridges of 60 cm in width and 10 m in length with 25 cm between hills. Drip irrigation system used in the present work consisted of a main delivery pipeline (PE, 32 mm) and a sub-main line (PE, 25 mm). The drip laterals were of polyethylene material (16 mm diameter), with inline emitters spaced at 25-cm apart. The discharge rate of the emitter was 4 liters/h. Overall dose of 30 kg P_2O_5/fed was added in form of super phosphate (15% P_2O_5) during seed bed preparation. Nitrogen fertilizer was added in form of ammonium nitrate (33.5% N) in 5-equal dose; the 1st one was added after thinning (4-true leaf stage) and the other four doses were applied at 2-week interval after the first application. Potassium was added in 3-equal dose in form of potassium sulfate (48% K_2O), the 1st one was applied with the 3rd dose of nitrogen and the other two ones were added at the same time of applying nitrogen doses. Sugar beet variety namely Sara was sown in the 1st week of October, while harvesting was done at age of 210 days in both seasons. The preceding crop was maize followed by fallow. Other field practices were done as recommended by Sugar Crop Research Institute, Agriculture Research Center. After sowing sugar beet seeds, a total amount of 45 mm water (189 m^3) was daily applied at four irrigations to ensure full emergence of sugar beet plants, thereafter, the studied irrigation regimes were applied. Soil samples were collected before planting to determine some soil physical and chemical characteristics of the experimental site (Table 1). Soil analyses were done according to the methods shown by Piper (1950), Chapman and Pratt (1961), Jackson (1967), Markus *et al.* (1982) and Soltanpour (1991).

Measurements and calculations:

A. Calculations related to irrigation:

1. Reference Evapotranspiration (ET_o):

The values of the reference evapotranspiration (ET_o) were calculated using average of the previous five years of weather data obtained from South El-Tahrir Metrological Station using Penman-Monteith equation, CROPWAT model (Allen *et al*. 1998). The crop evapotranspiration (ET_c) values were calculated according to the following equation:

$$ET_c = ET_o * K_c$$

Where; ET_c: crop evapotranspiration (mm/day), ET_o: reference evapotranspiration (mm/day) and K_c: crop coefficient values for sugar beet crop (Table 2).

Table 1: Soil physical and chemical characteristics of the experimental site for 2013/2014 and 2014/2015 seasons

2013/2014 season										
Soil depth (cm)	Particle size distribution %			Texture class	Available nutrients (mg/kg soil)			FC %	WP %	AW %
	Sand	Silt	Clay		N	P	K			
0-15	92.6	2.9	4.5	Sandy	12.55	8.14	80.1	12.3	5.3	7.0
15-30	91.3	4.7	4.0	Sandy	10.11	7.15	60.17	12.0	5.2	6.8
30-45	90.5	5.5	4.0	Sandy	6.45	5.75	40.70	11.1	4.3	6.8
Soil depth (cm)	D_b g/cm^3	EC ds/cm	pH	Soluble cations and anions (meq/l)						
				Ca^{+2}	Mg^{+2}	Na^+	K^+	HCO_3^-	SO_4^{-2}	Cl^-
0-15	1.43	0.37	8.6	1.20	0.65	1.6	0.20	1.17	0.58	1.9
15-30	1.60	0.39	8.8	1.31	0.61	1.7	0.25	1.21	0.55	2.1
30-45	1.71	0.41	8.8	1.40	0.62	1.8	0.30	1.25	0.64	2.2
2014/2015 season										
Soil depth (cm)	Particle size distribution %			Texture class	Available nutrients (mg/kg soil)			FC %	WP %	AW %
	Sand	Silt	Clay		N	P	K			
0-15	90.6	5.3	4.1	Sandy	14.75	8.56	80.98	12.5	5.40	7.10
15-30	91.2	4.8	4.0	Sandy	12.10	6.87	73.51	11.87	4.99	6.88
30-45	92.7	3.0	4.3	Sandy	7.35	5.75	57.16	11.12	4.48	6.64
Soil depth (cm)	D_b g/cm^{-3}	EC ds/cm	pH	Soluble cations and anions (meq/l)						
				Ca^{+2}	Mg^{+2}	Na^+	K^+	HCO_3^-	SO_4^{-2}	Cl^-
0-15	1.42	0.37	8.5	1.16	0.75	1.52	0.30	1.15	0.65	1.93
15-30	1.57	0.40	8.4	1.33	0.65	1.67	0.35	1.13	0.56	2.30
30-45	1.70	0.42	8.4	1.42	0.62	1.77	0.39	1.29	0.74	2.16

2. Applied Irrigation Water:

The amounts of the applied irrigation water (AIW) were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

$$AIW = \frac{ET_c * K_r * I}{E_a} + LR$$

Where: AIW: depth of applied irrigation water (mm), ET_c: crop evapotranspiration (mm/day), K_r: evaporation reduction coefficient, that depends on ground cover. A value of 1.0 was used "where the spacing between drip lines is less than 1.8 m, FAO,56" (Allen *et al.*, 1998), I: irrigation intervals (day), E_a: irrigation efficiency of the drip irrigation system, "an average value of 90 % was used" and LR: leaching requirements, "10% of the calculated applied irrigation water was additionally applied per-irrigation during the growing season for leaching purposes". The total amount of applied irrigation water under the studied water regimes 60%, 80% and 100% ET_c were 1642.9, 2190.5 and 2738.2 m^3/fed, respectively.

Irrigation time was determined before each irrigation event by measuring the actual emitter discharge according to the equation given by Ismail (2002) as follows:

$$t = \frac{AIW * A}{q}$$

Where: t: irrigation time (h), AIW: applied irrigation water (mm), A: wetted area (m^2) and q: emitter discharge (liter/h).

Crop coefficient values (as shown by Allen *et al.*, 1998) are presented in Table 2.

3. Water Use Efficiency (WUE):

Water Use efficiency (kg/m^3) was calculated according to **Jensen (1983)** as follows:

WUE $_{\text{root yield}}$ = root yield (kg/fed) / applied irrigation water (m^3/fed)

WUE $_{\text{sugar yield}}$ = sugar yield (kg/fed) / applied irrigation water (m^3/fed)

B. Criteria of sugar beet crop:

A representative sample of ten plants was randomly taken from the guarded rows of each sub-plot after 120 days from sowing to determine the following characteristics:

1. Leaf area index (LAI), which was determined in 10 leaf disks of 1.0 cm diameter using the “disk method” described by Watson (1958) and then the following equation was used:
   LAI = leaf area per plant (cm^2) / plant ground area (cm^2)
2. Photosynthetic pigments were determined in the fresh leaves according to the method described by Wettestien (1957).
   Chl. "a" mg/g.f.w. = 9.684 (A 662) – 0.99 (A 644).
   Chl. "b" mg/g.f.w. = 21.426 (A 644) – 4.65 (A 662).
   Carot. mg/g.f.w. = 4.695 (A 440) – 0.268 (chl. "a" + chl. "b").
   Where: chl. "a", "b" and carot.: concentrations of chlorophylls "a", "b" and carotenoids, respectively, and A: optical density at the wave length indicated.

Table 2: Sugar beet crop coefficients.

Growth stage		Crop coefficient (K_c)
Stage	Period (day)	
Initial stage	35	0.35
Development	60	1.2
Mid stage	70	0.7
Late stage	40	0.5

At harvest, a sample of ten plants was randomly taken from the middle rows of each sub-plot to determine the following traits:

1. Root length (cm).
2. Root diameter (cm).
3. Potassium and sodium concentrations (meq/100 g beet) in roots were determined using "flame photometer" according to Brown and Lilliland (1964). Alpha amino nitrogen concentration determined using Hydrogenation method according to Pergel (1945).
4. Sucrose percentage was determined as described by Le Docte (1927).
5. Extractable sugar% (ES) was calculated according to Dexter *et al.* (1967) as follows: ES % = sucrose % - sugar lost to molasses - 0.6
6. Purity % was calculated according to Deviller (1988) as follows:
   Purity % = 99.36 – [14.27 (Na + K + α-amino N) / sucrose%].
7. Top and root yields, which were determined on sub-plot weight (kg) and converted to tons/fed.
8. Sugar yield was calculated according to the following equation:
   Sugar yield (ton/fed)= extractable sugar% x root yield (ton/fed).

Statistical analysis:

The collected data were statistically analyzed as shown by Snedecor and Cochran (1981). Least significant difference (LSD) was used to compare the differences between treatment means at 5% level of probability as mentioned by Waller and Duncan (1969).

RESULTS AND DISCUSSION

A. Agronomical and physiological characteristics:

1. Root length:

Data in Table 3 showed that root length was significantly affected by the studied irrigation water regimes (IWR) in both seasons. The results cleared a statistical positive response to increasing the amount of irrigation water up to 80% ET_c, while decreasing amount of irrigation water to 60% ET_c and/or increasing it to 100% led to reductions in root length, in both seasons. Decreasing IWR from 100% to 80% ET_c led to significant increases in root length amounted to 24.24% and 13.03%, in the 1st and 2nd season, respectively. The reduction in the root elongation could be referred to the reduction in soil moisture, which could influence NK uptakes and its rate of diffusion which in turn reduced the root elongation (Grzebisz *et al.* 2013).

Raising potassium level from 24 to 48 kg K_2O/fed led to a gradual and significant increase in root length in both seasons. The effective role of potassium comes through its influence in storing materials of metabolic process, which may be used partially in plant growth in terms of root length and thickness. The effectiveness of potassium on root elongation was reported by Mehran and Samad (2013).

There was a significant positive response of this trait with increasing the applied level of nitrogen fertilizer. The positive influence of nitrogen could be due to its role in cell division and elongation as a principal component in chlorophyll component. This result is in agreement with that reported by Amin *et al.* (2013) and El-Geddawy and Makhlouf (2015).

The interaction between water regimes and nitrogen levels showed a significant influence on root length in both seasons. Applying irrigation water at 80% ET_c attained the highest values of this trait compared to the other two water regimes, when plants were fertilized with 120 kg N/fed in both seasons. Regarding to the significant N x K interaction, the highest significant value of root length were achieved by the application of 48 kg K_2O/fed combined with 120 kg N/fed in the 1st season.

2. Root diameter:

Data in Table 3 clear that the applied water regimes achieved a significant influence on root diameter in the 1st and 2nd seasons. It was found that applying water at 100% ET_c over passed the other two IWR in this trait.

The results pointed to a significant positive increase in root diameter due to the increase in K fertilization level to 48 kg K_2O/fed in both seasons. The effectiveness of potassium on root growth was reported by Neseim *et al.* (2014).

Table 3 affirmed that root diameter significantly responded to the gradual increase in the applied N-level up to 120 kg N/fed in both seasons. This result may be referred to the important role of nitrogen in enhancing plant growth and building-up its organs. This result coincides with those found by Amin *et al.* (2013).

The interaction between water regimes and nitrogen fertilization levels attained a significant effect on root diameter in both seasons. Meanwhile, the interaction between water regimes and potassium fertilization levels had a significant influence on this trait in the 1st season only.

3. Leaf area index (LAI):

Data in Table 3 cleared that the evaluated water regimes had a significant effect on LAI in both seasons. The highest LAI values were obtained from beets given 100% ET_c, while the lowest ones were recorded by beets irrigated at 60% ET_c, in the 1st and 2nd season. These results are in accordance with those obtained by Hosseinpour *et al.* (2006). Also, Waston (1952) reported that the size and longevity of sugar beet leaf canopies strongly influenced by soil moisture.

Increasing potassium fertilizer level from 24 to 48 kg K_2O/fed caused a significant increase in the values of LAI, in the two growing seasons (Table 3). This result may be attributed to the role of potassium in increasing cell volume and hence increasing leaf area/plant.

The results indicated that increasing nitrogen level from 80 up to 120 kg N/fed led to a significant increase in LAI. This finding may be due to the role of nitrogen in cell elongation and increasing the vegetative growth. These results are in agreement with those confirmed by Kandil *et al.* (2002).

Leaf area index was significantly influenced by the interaction between water regimes and nitrogen fertilizer levels in both seasons (Table 3). Applying water at 100% ET_c with 120 kg N/fed gave the highest values of LAI compared to the other two water regimes in both seasons. The interaction between water regime and potassium fertilization significantly affected on LAI in the 1st season only.

4. Photosynthetic pigments:

Leaf pigments substances refer to the contents of chlorophyll "a", "b" and carotenoids. Nitrogen is an essential element in the synthesis of chlorophyll, and in turn photosynthesis and the released energy. Also, potassium and iron elements have vital functions in the formation of chlorophyll.

Data in Table 4 cleared that the amount of irrigation water given at 80% ET_c attained significant increments in chlorophyll "a" and "b" over the other two irrigation regimes, in both seasons. The values of carotenoids significantly decreased as the amount of the applied irrigation water decreased in the 2nd season only. These results were in agreement with Chutia and Borah (2012) and Xiang *et al.* (2013), who mentioned that drought stress, caused a significant decrease and degradation in chlorophyll "a", "b" as well as total chlorophyll content.

Regarding potassium and nitrogen effects on photosynthetic pigments, results cleared a statistical positive response to the applied levels of potassium and/or nitrogen. Adding 48 kg K_2O/fed and/or nitrogen up to 120 kg N/fed significantly raised the values of photosynthetic pigments in both seasons.

Table 3: Root length (cm), root diameter (cm) and leaf area index (LAI) as affected by water regimes, nitrogen and potassium fertilizers and their interactions in 2013/2014 and 2014/2015 seasons

Treatments		Root length (cm)							
		2013/2014				2014/2015			
Water regimes	Potassium levels (kg K_2O/fed)	Nitrogen levels (kg N/fed)							
		80	100	120	Mean	80	100	120	Mean
60 % ET_c	24	19.78	22.00	24.33	22.04	18.22	20.89	22.67	20.59
	48	22.45	24.33	26.56	24.45	20.11	22.55	25.00	22.56
Mean		21.11	23.17	25.45	23.24	19.17	21.72	23.84	21.57
80 % ET_c	24	22.89	24.11	27.55	24.85	18.89	21.55	25.67	22.04
	48	24.11	26.44	30.45	27.00	20.44	23.89	27.44	23.93
Mean		23.50	25.28	29.00	25.93	19.67	22.72	26.56	22.98
100 % ET_c	24	17.78	19.89	22.11	19.93	16.78	20.56	21.55	19.63
	48	19.11	21.33	25.00	21.81	18.22	21.67	23.22	21.04
Mean		18.44	20.61	23.56	20.87	17.50	21.11	22.39	20.33
Potassium x Nitrogen	24	20.15	22.00	24.67	22.27	17.96	21.00	23.30	20.75
	48	21.89	24.04	27.33	24.42	19.59	22.70	25.22	22.51
Mean		21.02	23.02	26.00		18.78	21.85	24.26	
LSD at 0.05 level for:									
Water regimes (A)		1.70		A x C	0.64	A	1.51	A x C	0.70
Potassium levels (B)		0.30		B x C	0.52	B	0.33	B x C	NS
Nitrogen levels (C)		0.37		AxBxC	NS	C	0.40	AxBxC	NS
A x B		NS				A x B	NS		
		Root diameter (cm)							
60 % ET_c	24	8.56	9.22	10.67	9.48	7.44	8.89	9.33	8.56
	48	9.22	9.45	11.00	9.89	8.28	9.11	9.89	9.09
Mean		8.89	9.34	10.84	9.69	7.86	9.00	9.61	8.82
80 % ET_c	24	11.00	11.89	12.56	11.82	10.33	11.00	11.22	10.85
	48	11.89	12.44	12.89	12.41	10.89	11.44	11.89	11.41
Mean		11.44	12.17	12.72	12.11	10.61	11.22	11.56	11.13
100 % ET_c	24	11.11	12.08	13.45	12.21	11.22	12.11	12.78	12.04
	48	12.33	12.67	14.56	13.19	11.89	12.67	13.89	12.82
Mean		11.72	12.37	14.00	12.70	11.56	12.39	13.33	12.43
Potassium x Nitrogen	24	10.22	11.06	12.22	11.17	9.67	10.67	11.11	10.48
	48	11.15	11.52	12.82	11.83	10.35	11.07	11.89	11.11
Mean		10.68	11.29	12.52		10.01	10.87	11.50	
LSD at 0.05 level for:									
Water regimes (A)		1.84		A x C	0.39	A	1.57	A x C	0.43
Potassium levels (B)		0.18		B x C	NS	B	0.20	B x C	NS
Nitrogen levels (C)		0.23		AxBxC	NS	C	0.25	AxBxC	NS
A x B		0.32				A x B	NS		
		LAI							
60 % ET_c	24	1.73	2.06	2.31	2.03	2.06	2.16	2.41	2.21
	48	1.92	2.36	2.60	2.29	2.21	2.23	2.54	2.33
Mean		1.83	2.21	2.45	2.16	2.14	2.19	2.47	2.27
80 % ET_c	24	2.67	2.77	3.09	2.84	2.23	3.11	3.46	2.93
	48	2.76	2.80	3.25	2.94	2.39	3.33	3.53	3.08
Mean		2.71	2.78	3.17	2.89	2.31	3.22	3.49	3.01
100 % ET_c	24	3.41	3.52	3.68	3.53	3.35	3.54	3.57	3.49
	48	3.48	3.54	3.73	3.58	3.50	3.62	3.72	3.61
Mean		3.44	3.53	3.70	3.56	3.43	3.58	3.65	3.55
Potassium x Nitrogen	24	2.60	2.78	3.02	2.80	2.55	2.93	3.15	2.88
	48	2.72	2.90	3.19	2.94	2.70	3.06	3.26	3.01
Mean		2.66	2.84	3.11		2.62	3.00	3.20	
LSD at 0.05 level for:									
Water regimes (A)		0.15		A x C	0.12	A	0.11	A x C	0.18
Potassium levels (B)		0.06		B x C	NS	B	0.08	B x C	NS
Nitrogen levels (C)		0.07		AxBxC	NS	C	0.10	AxBxC	NS
A x B		0.10				A x B	NS		

NS: Insignificant difference.

Table 4: Photosynthetic pigments (mg/g.f.w) as affected by water regimes, nitrogen and potassium fertilizers and their interactions in 2013/2014 and 2014/2015 seasons

Treatments		Chlorophyll a (mg/g.f.w)							
		2013/2014				2014/2015			
Water regimes	Potassium levels (kg K_2O/fed)	Nitrogen levels (kg N/fed)							
		80	100	120	Mean	80	100	120	Mean
60 % ET_c	24	3.17	3.51	3.73	3.47	2.92	3.38	4.12	3.47
	48	3.26	3.59	3.78	3.54	3.22	3.77	4.30	3.76
Mean		3.22	3.55	3.76	3.51	3.07	3.58	4.21	3.62
80 % ET_c	24	4.85	5.13	5.63	5.20	4.69	5.60	5.54	5.28
	48	5.01	5.24	5.91	5.39	4.90	5.85	5.95	5.57
Mean		4.93	5.19	5.77	5.29	4.79	5.73	5.75	5.42
100 % ET_c	24	4.26	5.02	5.20	4.83	4.73	4.89	5.23	4.95
	48	4.67	5.14	5.32	5.04	4.85	4.96	5.39	5.07
Mean		4.46	5.08	5.26	4.93	4.79	4.93	5.31	5.01
Potassiumx Nitrogen	24	4.09	4.55	4.85	4.50	4.11	4.62	4.96	4.57
	48	4.31	4.66	5.00	4.66	4.32	4.86	5.21	4.80
Mean		4.20	4.60	4.93		4.22	4.74	5.09	
LSD at 0.05 level for:									
Irrigation regimes (A)		0.26		A x C	0.23	A	0.42	A x C	0.39
Potassium levels (B)		0.11		B x C	NS	B	0.19	B x C	NS
Nitrogen levels (C)		0.13		AxBxC	NS	C	0.23	AxBxC	NS
A x B		NS				A x B	NS		
		Chlorophyll b (mg/g.f.w)							
60 % ET_c	24	1.73	2.07	2.35	2.05	1.70	2.03	2.16	1.96
	48	2.06	2.21	2.50	2.25	2.05	2.26	2.44	2.25
Mean		1.89	2.14	2.42	2.15	1.87	2.15	2.30	2.11
80 % ET_c	24	3.13	3.13	3.47	3.24	3.04	3.35	3.37	3.25
	48	3.22	3.25	3.40	3.29	3.11	3.37	3.52	3.34
Mean		3.18	3.19	3.44	3.27	3.08	3.36	3.45	3.29
100 % ET_c	24	2.46	2.61	2.88	2.65	2.76	2.84	2.96	2.86
	48	2.75	2.85	3.06	2.89	2.93	3.11	3.24	3.09
Mean		2.61	2.73	2.97	2.77	2.85	2.97	3.10	2.97
Potassiumx Nitrogen	24	2.44	2.60	2.90	2.65	2.50	2.74	2.83	2.69
	48	2.68	2.77	2.99	2.81	2.70	2.91	3.07	2.89
Mean		2.56	2.69	2.94	2.73	2.60	2.83	2.95	
LSD at 0.05 level for:									
Water regimes (A)		0.33		A x C	NS	A	0.07	A x C	0.09
Potassium levels (B)		0.06		B x C	NS	B	0.04	B x C	NS
Nitrogen levels (C)		0.08		AxBxC	NS	C	0.05	AxBxC	NS
A x B		0.11				A x B	0.07		
		Carotenoids (mg/g.f.w)							
60 % ET_c	24	1.15	1.21	1.58	1.31	0.92	1.17	1.28	1.12
	48	1.20	1.27	1.70	1.39	1.09	1.22	1.17	1.16
Mean		1.18	1.24	1.64	1.35	1.01	1.20	1.23	1.14
80 % ET_c	24	1.11	1.21	1.67	1.33	1.38	1.47	1.71	1.52
	48	1.46	1.54	1.78	1.59	1.55	1.67	1.80	1.67
Mean		1.28	1.38	1.73	1.46	1.46	1.57	1.76	1.60
100 % ET_c	24	1.07	1.20	1.51	1.26	1.36	1.60	1.84	1.60
	48	1.21	1.34	1.73	1.43	1.54	1.73	2.01	1.76
Mean		1.14	1.27	1.62	1.34	1.45	1.66	1.93	1.68
Potassiumx Nitrogen	24	1.11	1.21	1.59	1.30	1.22	1.41	1.61	1.41
	48	1.29	1.39	1.74	1.47	1.39	1.54	1.66	1.53
Mean		1.20	1.30	1.66		1.31	1.48	1.64	
LSD at 0.05 level for:									
Water regimes (A)		NS		A x C	NS	A	0.39	A x C	NS
Potassium levels (B)		0.05		B x C	NS	B	0.06	B x C	NS
Nitrogen levels (C)		0.06		AxBxC	NS	C	0.08	AxBxC	NS
A x B		0.09				A x B	NS		

NS: Insignificant difference.

The interaction between water regimes and nitrogen levels caused significant effects on chlorophyll "a" in both seasons, and chlorophyll "b" in the 2nd one. In addition, chlorophyll "b" was significantly affected by the interaction between water regimes and potassium fertilization levels in both seasons as well as carotenoids in the 1st season.

B. Juice quality and chemical constituents:

1. Potassium, sodium and α-amino N concentrations in roots:

Increasing the impurities in sugar beet roots negatively affect the amount of the extracted sugar. Data in Table 5 pointed out that supplying beets with water at 80% ET_c led to significant decrease in α-amino N and K contents in roots in both seasons as well as Na in the 1st season.

The results cleared that the difference between potassium fertilization levels in their influence on the values of α-amino N, K and Na was significant in both seasons. Raising K-fertilizer level to 48 K_2O/fed resulted in the highest α-amino N, K and Na contents in roots. The effective role of potassium on impurities content has been reported by Neseim *et al.* (2014).

Data revealed that raising N-fertilizer doses from 80 up to 120 kg N/fed continuously and significantly increased the values of α-amino N, K and Na, in both seasons. These results may be due to nitrogen effects in increasing root length and diameter (Table 3), hence increased the absorption of N, K and Na. These results were in agreement with El-Geddawy and Makhlouf (2015).

The interaction between water regime and nitrogen fertilization led to significant effects on the values of α-amino N and K contents in roots in both seasons as well as Na in the 2nd season. The contents of sodium in root were significantly affected by the interaction between potassium and nitrogen fertilization in both seasons. In addition, α-amino N content in roots was significantly affected by the interaction between water regimes and potassium fertilizer levels in the 1st season only.

2. Sucrose and extractable sugar percentages:

Data in Table 6 pointed out that the amount of irrigation water given to sugar beet at 80% ET_c achieved the highest values of sucrose and extractable sugar percentages in the 1st and 2nd seasons compared to the other two irrigation regimes. In this respect, Dreesman *et al.* (1994) and Bloch *et al.* (2006) mentioned that drought stress decreased the photosynthetic rate, transpiration rate and stomatal conductance of sugar beet, which resulted in a reduction in sucrose%.

There was a significant and continuous response of sucrose% to increasing the applied dose of potassium fertilizer. Increasing K level to 48 kg K_2O/fed significantly increased sucrose% in both seasons and extractable sugar% in the 2nd one. Such increases in these traits may be referred to the distinguished role of potassium in biosynthesis and transfer of sucrose to storage roots. In this concern, Grzebisz *et al.* (2013) mentioned that the transportation of assimilates in the phloem is also K concentration-dependent.

The results in Table 6 cleared that adding 100 kg N/fed was enough to produce the highest and significant values of sucrose and extractable sugar in both seasons. However, it could be noticed that increasing nitrogen level up to 120 kg N/fed reduced the values of sucrose and extractable sugar percentages. These results may be due to that the extreme application of N causes an imbalanced partitioning of assimilates among leaves and storage root, and leads to decreasing sucrose concentration. This result coincides with those found by El-Geddawy and Makhlouf (2015).

Table 5: Alpha amino N, potassium and sodium concentrations as affected by water regimes, nitrogen and potassium fertilizers and their interactions in 2013/2014 and 2014/2015 seasons

Treatments		α-amino N (meq/100 g beet)							
		2013/2014				2014/2015			
Water regimes	Potassium levels (kg K_2O/fed)	Nitrogen levels (kg N/fed)							
		80	100	120	Mean	80	100	120	Mean
60 % ET_c	24	1.20	1.40	1.50	1.37	0.90	1.10	1.23	1.08
	48	1.57	1.63	2.00	1.73	1.33	1.63	1.37	1.44
Mean		1.38	1.52	1.75	1.55	1.12	1.37	1.30	1.26
80 % ET_c	24	0.80	1.20	1.57	1.19	0.83	0.87	1.33	1.01
	48	1.17	1.30	1.80	1.42	1.13	1.43	1.77	1.44
Mean		0.98	1.25	1.68	1.31	0.98	1.15	1.55	1.23
100 % ET_c	24	1.73	1.90	1.43	1.69	1.27	1.63	1.70	1.53
	48	1.87	1.97	1.53	1.79	1.30	1.73	1.73	1.59
Mean		1.80	1.93	1.48	1.74	1.28	1.68	1.72	1.56
Potassium x Nitrogen	24	1.24	1.50	1.50	1.41	1.00	1.20	1.42	1.21
	48	1.53	1.63	1.78	1.65	1.26	1.60	1.62	1.49
Mean		1.39	1.57	1.64		1.13	1.40	1.52	
LSD at 0.05 level for:									
Water regimes (A)		0.20		A x C	0.35	A	0.24	A x C	0.15
Potassium levels (B)		0.16		B x C	NS	B	0.07	B x C	NS
Nitrogen levels (C)		0.20		AxBxC	NS	C	0.09	AxBxC	NS
A x B		NS				A x B	0.13		
		Potassium (meq/100 g beet)							
60 % ET_c	24	3.73	4.07	4.31	4.04	3.33	4.02	4.28	3.88
	48	4.30	4.38	5.16	4.61	4.09	4.47	5.03	4.53
Mean		4.02	4.23	4.74	4.33	3.71	4.24	4.66	4.20
80 % ET_c	24	3.13	3.46	3.77	3.45	3.62	3.05	3.71	3.46
	48	3.58	3.72	4.52	3.94	3.80	3.83	4.02	3.88
Mean		3.36	3.59	4.15	3.70	3.71	3.44	3.86	3.67
100 % ET_c	24	4.56	4.14	4.56	4.42	3.70	4.06	4.17	3.98
	48	4.44	4.66	4.93	4.68	4.18	4.45	4.80	4.48
Mean		4.50	4.40	4.74	4.55	3.94	4.26	4.49	4.23
Potassium x Nitrogen	24	3.81	3.89	4.21	3.97	3.55	3.71	4.05	3.77
	48	4.11	4.25	4.87	4.41	4.02	4.25	4.62	4.30
Mean		3.96	4.07	4.54		3.79	3.98	4.34	
LSD at 0.05 level for:									
Water regimes (A)		0.47		A x C	0.26	A	0.33	A x C	0.37
Potassium levels (B)		0.12		B x C	NS	B	0.17	B x C	NS
Nitrogen levels (C)		0.15		AxBxC	NS	C	0.21	AxBxC	NS
A x B		NS				A x B	NS		
		Sodium (meq/100 g beet)							
60 % ET_c	24	1.37	1.98	2.46	1.94	1.31	1.46	1.69	1.49
	48	1.71	2.35	2.74	2.27	1.71	1.74	2.02	1.82
Mean		1.54	2.17	2.60	2.10	1.51	1.60	1.86	1.66
80 % ET_c	24	1.16	1.89	2.49	1.85	1.10	1.43	1.83	1.45
	48	1.79	2.25	2.66	2.23	1.60	1.69	2.14	1.81
Mean		1.48	2.07	2.57	2.04	1.35	1.56	1.98	1.63
100 % ET_c	24	1.36	2.05	2.52	1.98	1.39	1.66	1.80	1.61
	48	1.85	2.46	2.82	2.38	1.68	1.74	2.16	1.86
Mean		1.61	2.26	2.67	2.18	1.53	1.70	1.98	1.74
Potassium x Nitrogen	24	1.30	1.97	2.49	1.92	1.27	1.52	1.77	1.52
	48	1.78	2.35	2.74	2.29	1.66	1.73	2.11	1.83
Mean		1.54	2.16	2.61		1.47	1.62	1.94	
LSD at 0.05 level for:									
Water regimes (A)		0.06		A x C	NS	A	NS	A x C	0.11
Potassium levels (B)		0.06		B x C	0.10	B	0.05	B x C	0.09
Nitrogen levels (C)		0.07		AxBxC	NS	C	0.07	AxBxC	NS
A x B		NS				A x B	NS		

Table 6: Sucrose, extractable sugar and purity percentages as affected by water regimes, nitrogen and potassium fertilizers and their interactions in 2013/2014 and 2014/2015 seasons

Treatments		Sucrose percentage							
		2013/2014				2014/2015			
Water regimes	Potassium levels (kg K_2O/fed)	Nitrogen levels (kg N/fed)							
		80	100	120	Mean	80	100	120	Mean
60 % ET_c	24	16.30	17.59	17.50	17.13	16.64	18.16	17.76	17.52
	48	16.83	17.82	17.30	17.32	17.75	18.70	18.46	18.30
Mean		16.57	17.70	17.40	17.22	17.20	18.43	18.11	17.91
80 % ET_c	24	16.80	19.28	18.71	18.26	18.06	19.38	18.66	18.70
	48	17.03	19.50	18.35	18.29	18.46	21.39	19.70	19.85
Mean		16.92	19.39	18.53	18.28	18.26	20.39	19.18	19.27
100 % ET_c	24	16.82	18.12	18.17	17.70	18.48	19.71	18.93	19.04
	48	17.39	18.73	18.18	18.10	18.99	19.82	19.12	19.31
Mean		17.10	18.42	18.18	17.90	18.74	19.77	19.03	19.18
Potassium x Nitrogen	24	16.64	18.33	18.13	17.70	17.73	19.08	18.45	18.42
	48	17.08	18.68	17.94	17.90	18.40	19.97	19.09	19.15
Mean		16.86	18.51	18.04		18.06	19.53	18.77	
LSD at 0.05 level for:									
Water regimes (A)		0.72		A x C	0.43	A	0.98	A x C	0.58
Potassium levels (B)		0.20		B x C	0.35	B	0.27	B x C	NS
Nitrogen levels (C)		0.25		AxBxC	NS	C	0.33	AxBxC	NS
A x B		NS				A x B	0.47		
		Extractable sugar percentage							
60 % ET_c	24	14.19	15.29	15.08	14.85	14.67	16.01	15.52	15.40
	48	14.50	15.37	14.59	14.82	15.51	16.32	16.03	15.95
Mean		14.34	15.33	14.84	14.84	15.09	16.17	15.77	15.68
80 % ET_c	24	14.90	17.13	16.34	16.12	16.09	17.43	16.45	16.66
	48	14.89	17.24	15.79	15.97	16.32	19.16	17.29	17.59
Mean		14.89	17.19	16.07	16.05	16.20	18.30	16.87	17.12
100 % ET_c	24	14.46	15.68	15.72	15.29	16.36	17.40	16.57	16.78
	48	14.94	16.14	15.62	15.57	16.75	17.42	16.61	16.93
Mean		14.70	15.91	15.67	15.43	16.55	17.41	16.59	16.85
Potassium x Nitrogen	24	14.51	16.03	15.71	15.42	15.70	16.95	16.18	16.28
	48	14.78	16.25	15.33	15.45	16.19	17.64	16.64	16.82
Mean		14.65	16.14	15.52		15.95	17.29	16.41	
LSD at 0.05 level for:									
Water regimes (A)		0.73		A x C	0.46	A	1.01	A x C	0.58
Potassium levels (B)		NS		B x C	0.38	B	0.28	B x C	NS
Nitrogen levels (C)		0.27		AxBxC	NS	C	0.34	AxBxC	NS
A x B		NS				A x B	NS		
		Purity percentage							
60 % ET_c	24	93.83	93.32	92.62	93.26	94.57	94.19	93.57	94.11
	48	92.94	92.66	91.15	92.25	93.63	93.37	92.85	93.28
Mean		93.39	92.99	91.89	92.75	94.10	93.78	93.21	93.70
80 % ET_c	24	95.04	94.50	93.39	94.31	94.97	95.40	94.07	94.81
	48	93.88	94.04	92.37	93.43	94.29	94.70	93.61	94.20
Mean		94.46	94.27	92.88	93.87	94.63	95.05	93.84	94.51
100 % ET_c	24	92.85	92.98	92.68	92.84	94.44	94.03	93.56	94.01
	48	92.66	92.44	92.08	92.39	93.98	93.65	92.87	93.50
Mean		92.76	92.71	92.38	92.62	94.21	93.84	93.21	93.75
Potassium x Nitrogen	24	93.91	93.60	92.89	93.47	94.66	94.54	93.73	94.31
	48	93.16	93.05	91.87	92.69	93.96	93.91	93.11	93.66
Mean		93.53	93.32	92.38		94.31	94.22	93.42	
LSD at 0.05 level for:									
Water regimes (A)		0.56		A x C	0.43	A	0.43	A x C	0.38
Potassium levels (B)		0.20		B x C	NS	B	0.18	B x C	NS
Nitrogen levels (C)		0.25		AxBxC	NS	C	0.22	AxBxC	NS
A x B		NS				A x B	NS		

NS: Insignificant difference.

The interaction between water regimes and nitrogen fertilizers had significant effects in sucrose and extractable sugar percentages in both seasons. Sucrose% was significantly affected by the interaction between water regimes and potassium levels in the 2nd season. In addition, the interaction between potassium and nitrogen fertilization levels significantly affected sucrose and extractable sugar percentages in the 1st season.

3. Purity percentage:

Results in Table 6 cleared that purity% similarly responded to the evaluated water regimes as sucrose% did in the 1st season only, where the middle IWR (80% ETc) gave the highest positive and significant value of purity%. This influence might be due to the pronounced effect of this IWR on sucrose% which is considered the main component in juice, where the higher the sucrose%, the higher the purity%. This result is in agreement with that reported by Mahmoodi *et al.* (2008) and Masri *et al.* (2015) in their studies.

The results pointed to a significant increase in the values of purity% as the applied dose of potassium was raised from 24 to 48 kg K_2O/fed, in both seasons.

The highest values of purity% were attained with the middle nitrogen fertilization level, *i.e.* 100 kg N/fed. Raising the added N dose to 120 kg N/fed depressed the values of purity% in both seasons. The reduction in purity% accompanied the increase in N level beyond 100 kg N/fed could be attributed to the increase in impurities% (Table 5) and the reduction in sucrose % (Table 6). This finding was in line with those stated by El-Geddawy and Makhlouf (2015).

All studied interactions showed insignificant effects on purity percentage, except the interaction between water regime and nitrogen fertilization, which was significant in both seasons, it could be noticed that the highest values of this mentioned trait were recorded by the combination between water regime at 80% ET_c and 100 kg N/fed, in both seasons.

C. Top, root and sugar yields/fed:

1. Top yield:

Data in Table 7 show that increasing the amount of irrigation water to 80% and 100% ET_c significantly increased top yield/fed by (2.85 and 3.52 tons) and (2.73 and 4.31 tons) in the 1st and 2nd season, respectively compared to that gained by applying water at 60% ET_c.

The application of K fertilizer significantly increased the values of top fresh yield/fed in both seasons. The increment of top fresh yield/fed as a result of increasing K level to 48 kg K_2O/fed amounted to 4.37% (0.40 ton) in the 1st season, corresponding to 4.85% (0.48 tons) in the 2nd one, respectively. These results are in agreement with those of El-Sarag and Moselhy (2013).

Data in Table 7 illustrate a positive and significant response of top yield/fed to the gradual increase in the applied N fertilization level up to 120 kg N/fed. Raising N level to 100 and 120 kg N/fed improved top yield by 9.05% and 21.06% in the 1st season, corresponding to 7.69% and 16.77% in the 2nd one, respectively compared to 80 kg N/fed. These findings referred to the important role of nitrogen in enhancing plant growth and building up its organs. These findings are in line with those stated by Amin *et al.* (2013) and Badr (2016).

Top yield/fed was significantly affected by the interaction between IWR and N fertilizer in both seasons as well as the interaction between K and N fertilizers in the 2nd one.

2. Root yield:

Results in Table 7 demonstrated that the root yield was significantly and positively responded to the gradual increase in the amount of irrigation water in both seasons. Increasing the applied irrigation water to 80% and 100% ET_c given to sugar beet led to an increase in root yield/fed of (3.33 and 6.23 tons) and (2.38 and 6.48 tons) in the 1st and 2nd season, respectively compared to that irrigating beets at 60% ET_c. These results were in agreement with those reported by Hosseinpour *et al.* (2006) and Mahmoodi *et al.* (2008). In the same respect, Clover *et al.* (1999) affirmed that drought stress reduced root yield, due to root weight reduction/plant.

The results pointed out that root yield significantly increased with increasing K fertilizer level to 48 kg K_2O/fed, in both seasons. This finding may be attributed to the stimulatory effect of potassium fertilizer on the rate of photosynthesis. These results were in agreement with Neseim *et al.* (2014).

Supplying sugar beet with 100 and 120 kg N/fed significantly improved root yield/fed by 9.35 % (1.7 tons) and 23.92 % (4.35 tons) in the 1st season, corresponding to 14.59 % (2.58 tons) and 30.03 % (5.31 tons) in the 2nd one, respectively compared to that fertilized with 80 kg N/fed. The relative influence of N fertilizer on root yield is mainly due to its positive effect on root growth in terms of root length and diameter (Table 3). These results are in agreement with those confirmed by El-Geddawy and Makhlouf (2015) and Badr (2016).

The interaction between water regimes and potassium levels had significant effects on root yield/fed, in both seasons. In the 1st season, raising K fertilization level from 24 to 48 kg K_2O/fed with the application of water at 60% ET_c led to higher root yield/fed (2.36 tons) compared with that harvested at 80% ET_c (0.83 ton) or that gained at 100% ET_c (1.77 tons), indicating that applying irrigation at the lowest regimes (60% ET_c) resulted in the highest WUE. In the 2nd one, the difference between the two K levels in their effect on root yield was insignificant when sugar beet was irrigated at 80% ET_c. However, the difference between the two K levels reached the level of significance when IWR was applied at 60 and/or 100 % ET_c., it can be noticed that IWR of 60 % ET_c recorded the highest WUE.

The interaction between water regimes and nitrogen levels had a significant effect on root yield/fed, in both seasons. These results coincided with those of El-Sarag and Moselhy (2013). In the 1st season, it was found that raising N fertilization level from 80 to 100 kg N/fed increased root yield/fed by 2.45, 1.68 and 0.96 tons, respectively, corresponding to increases of 5.77, 3.97 and 3.31 tons as N level was increased from 80 to 120 kg N/fed, when sugar beet was irrigated at 60, 80 and 100% ET_c, respectively. In the 2nd season, the same trend was observed, showing that the gradual increase in the amount of water from 60 up to 100% ET_c led to more leaching of the applied N doses beyond root zone, decreasing the opportunity of its absorption by plant roots in the sandy soil. Moreover, these results manifested that irrigation deficit at 60% ET_c recorded the highest water use efficiency.

3. Sugar yield:

Data in Table 7 revealed that applying irrigation water at 100% ET_c produced the highest sugar yield in both seasons due to its distinguished influence on root yield. Increasing the amount of irrigation water to 80% and 100% ET_c significantly increased sugar yield/fed by 30.15% (0.76 ton) and 42.46% (1.07 ton) in the 1st season, corresponding to 24.17% (0.66 ton) and 47.25% (1.29 ton) in the 2nd one, respectively compared to 60% ETc. Similar results were recorded by Masri *et al.* (2015). These findings coincide with those of Selim *et al.* (2010), who reported that the highest sugar yield was recorded with amount of 2653 m^3 water/fed under drip irrigation in sandy soil.

Table 7: Top, root and sugar yields (tons/fed) as affected by water regimes, nitrogen and potassium fertilizers and their interactions in 2013/2014 and 2014/2015 seasons

Treatments		Top yield (ton/yield)							
		2013/2014				2014/2015			
Water regimes	Potassium levels (kg K_2O/fed)	Nitrogen levels (kg N/fed)							
		80	100	120	Mean	80	100	120	Mean
60 % ET_c	24	5.98	6.85	8.19	7.01	6.82	7.73	8.20	7.59
	48	6.13	7.38	8.84	7.45	7.01	7.87	9.02	7.97
Mean		6.06	7.12	8.52	7.23	6.92	7.80	8.61	7.78
80 % ET_c	24	9.19	9.72	10.56	9.82	9.61	10.41	10.92	10.31
	48	9.46	10.17	11.36	10.33	10.11	10.58	11.42	10.70
Mean		9.32	9.95	10.96	10.08	9.86	10.50	11.17	10.51
100 % ET_c	24	10.15	10.41	11.29	10.62	11.11	11.60	12.55	11.75
	48	10.06	11.08	11.47	10.87	11.50	12.26	13.50	12.42
Mean		10.11	10.75	11.38	10.75	11.31	11.93	13.02	12.09
Potassiumx Nitrogen	24	8.44	8.99	10.01	9.15	9.18	9.91	10.56	9.88
	48	8.55	9.54	10.56	9.55	9.54	10.24	11.31	10.36
Mean		8.50	9.27	10.29		9.36	10.08	10.93	
LSD at 0.05 level for:									
Water regimes (A)		0.73		A x C	0.50	A	0.28	A x C	0.23
Potassium levels (B)		0.23		B x C	NS	B	0.11	B x C	0.19
Nitrogen levels (C)		0.29		AxBxC	NS	C	0.13	AxBxC	NS
A x B		NS				A x B	NS		
		Root yield (ton/fed)							
60 % ET_c	24	12.85	15.42	19.22	15.83	13.77	16.55	19.68	16.67
	48	15.70	18.03	20.85	18.19	15.01	18.05	21.10	18.05
Mean		14.27	16.72	20.04	17.01	14.39	17.30	20.39	17.36
80 % ET_c	24	18.16	19.76	21.86	19.93	16.84	19.24	22.39	19.49
	48	18.75	20.52	23.01	20.76	17.36	19.99	22.60	19.98
Mean		18.46	20.14	22.43	20.34	17.10	19.61	22.49	19.74
100 % ET_c	24	20.78	21.97	24.32	22.36	20.66	22.89	25.26	22.94
	48	22.86	23.60	25.93	24.13	22.45	24.85	26.93	24.75
Mean		21.82	22.78	25.13	23.24	21.56	23.87	26.10	23.84
Potassiumx Nitrogen	24	17.26	19.05	21.80	19.37	17.09	19.56	22.44	19.70
	48	19.10	20.71	23.26	21.03	18.27	20.96	23.54	20.93
Mean		18.18	19.88	22.53		17.68	20.26	22.99	
LSD at 0.05 level for:									
Water regimes (A)		1.38		A x C	0.49	A	0.38	A x C	0.66
Potassium levels (B)		0.23		B x C	NS	B	0.31	B x C	NS
Nitrogen levels (C)		0.28		AxBxC	NS	C	0.38	AxBxC	NS
A x B		0.40				A x B	0.54		
		Sugar yield (ton/fed)							
60 % ET_c	24	1.80	2.35	2.89	2.35	2.03	2.65	3.05	2.58
	48	2.27	2.76	3.03	2.69	2.33	2.95	3.38	2.89
Mean		2.04	2.56	2.96	2.52	2.18	2.80	3.22	2.73
80 % ET_c	24	2.71	3.39	3.58	3.23	2.71	3.35	3.69	3.25
	48	2.80	3.55	3.62	3.32	2.84	3.83	3.91	3.52
Mean		2.76	3.47	3.60	3.28	2.77	3.59	3.80	3.39
100 % ET_c	24	3.01	3.44	3.83	3.43	3.38	3.99	4.19	3.85
	48	3.42	3.81	4.05	3.76	3.77	4.33	4.47	4.19
Mean		3.22	3.62	3.94	3.59	3.58	4.16	4.33	4.02
Potassiumx Nitrogen	24	2.51	3.06	3.43	3.00	2.71	3.33	3.65	3.23
	48	2.83	3.37	3.57	3.26	2.98	3.70	3.92	3.53
Mean		2.67	3.22	3.50		2.84	3.52	3.78	
LSD at 0.05 level for:									
Water regimes (A)		0.16		A x C	0.12	A	0.18	A x C	0.17
Potassium levels (B)		0.06		B x C	NS	B	0.08	B x C	NS
Nitrogen levels (C)		0.07		AxBxC	NS	C	0.10	AxBxC	NS
A x B		0.10				A x B	NS		

NS: Insignificant difference.

Results revealed that K fertilizer levels increased sugar yield statistically in the growing seasons. These results are in agreement with Mehrandish *et al.* (2012) and Neseim *et al.* (2014). An increment in sugar yield/fed amounted to 8.6% (0.26 ton) was recorded when beet plants were fertilized with 48 kg K_2O/fed, in the 1st season and 9.28% (0.30 ton) in the 2nd one compared to those supplied with 24 kg K_2O/fed. These results may be due to potassium's role in increasing sucrose, extractable sugar and purity percentages (Table 6) and root yield (Table 7).

Results in Table 7 pointed out that the increasing nitrogen levels to 100 and 120 kg N/fed increased sugar yield/fed by 20.59% (0.55 ton) and 31.08% (0.83 ton) in the 1st season, corresponding to 23.94% (0.68 ton) and 33.09% (0.94 ton) in the 2nd season, respectively compared to 80 kg N/fed. The same trend were found by Amin *et al.* (2013) and El-Geddawy and Makhlouf (2015). The effectiveness of raising N fertilizer levels on sugar yield could be referred to its positive influence on root yields/fed (Table 7).

Sugar yield/fed was significantly affected by the interaction between the examined IWR and K levels in the 1st season.

The interaction between water regimes and nitrogen levels showed a significant influence on sugar yield/fed, in both seasons. In the 1st season, it was noticed that raising N fertilization level from 80 to 100 kg N/fed increased sugar yield/fed by 0.52, 0.71 and 0.40 tons, corresponding to increases of 0.92, 0.84 and 0.72 tons as N level was increased from 80 to 120 kg N/fed, when sugar beet was irrigated at 60, 80 and 100% ET_c, successively. Similar trend was observed in the 2nd season. Moreover, these results showed that irrigation deficit at 60% and 80% ET_c achieved the highest water use efficiency, compared to that gained by applying water at 100% ET_c.

D. Water Use Efficiency (WUE):

Mathematical models that best fit the relation between amounts of applied irrigation water (m^3/fed) and WUE for sugar beet root and sugar yields were developed for the two growing seasons. The obtained models for WUE of root yields (Fig. 1) in the two seasons were:

$WUE_{root\ yield} = -3.6561 Ln\ (AIW) + 37.419 \quad R^2 = 0.99$

$WUE_{root\ yield} = -3.7246 Ln\ (AIW) + 37.998 \quad R^2 = 0.91$

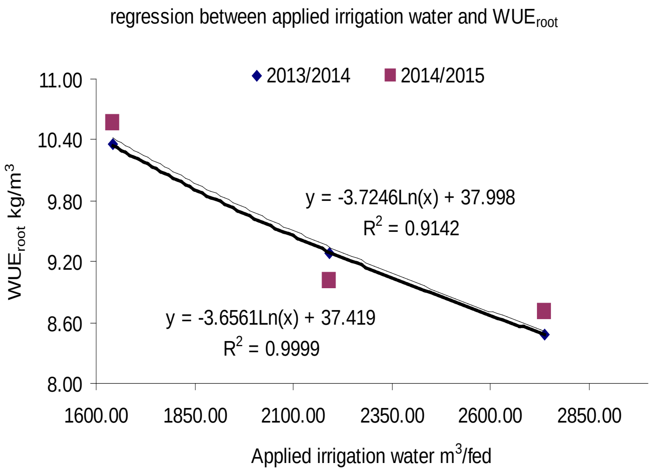

Fig. 1: Logarithmic regression between applied irrigation water and water use efficiency for root yield.

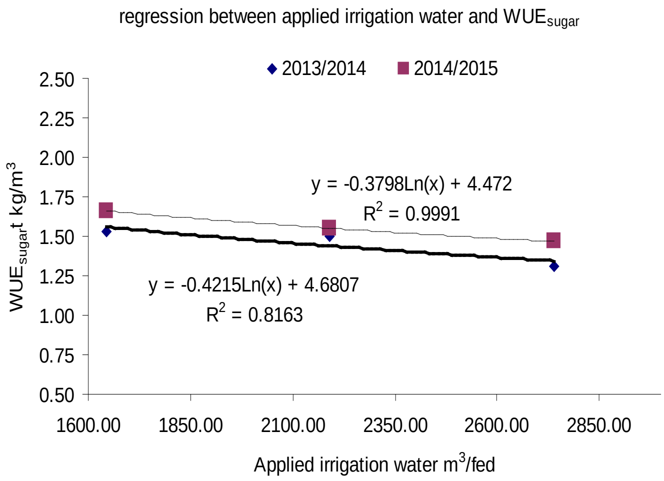

Fig. 2: Logarithmic regression between applied irrigation water and water use effeciency for sugar yield.

The obtained models for WUE based on sugar yields (Fig. 2) in the two seasons were:

$WUE_{sugar\ yield}$ = -0.4215Ln (AIW) + 4.681 R^2 = 0.82

$WUE_{sugar\ yield}$ = -0.3798Ln (AIW) + 4.472 R^2 = 0.99

The highest values of the coefficient of determination (R^2 > 0.9) indicate that the given equations can be used within the range of the examined values to describe the relation between amounts of applied irrigation water and water use efficiency for root and sugar yields.

Results illustrated in Figure 3 show the values of WUE for sugar beet root yields as affected by irrigation regime treatments in the two growing seasons. Results indicated, in general, that WUE values for root yield incresed with decreasing the amounts of applied irrigation water. The obtained WUE_{root} values increased from 8.49 kg/m^3 for the 100% ET_c treatment to 9.29 and 10.35 kg/m^3 for the 80% ET_c and 60 % ETc regimes, respectively in the 1st growing season. The same trend was found in the 2nd one, where the relative increase in WUE_{root} values due to difecit irrigation regimes were 3.5 % and 21.9% for the 80% ET_c and 60 % ET_c treatments, respectively. For the WUE values of sugar yield, results illustrated in Fig. 4 show that, there is a positive response in WUE_{sugar} values with decreasing the amounts of applied irrigation water. The WUE_{sugar} values increased from 1.31 kg sugar/m^3 for the 100% ET_c to 1.50 and 1.53 kg sugar/m^3 for the 80% and 60% ET_c treatments, respectively in the 1st growing season and from 1.47 kg sugar/m^3 for the 100% ET_c to 1.55 and 1.66 kg sugar/m^3 for the same respective treatments in the 2nd growing season. The obtained results indicated that difecit irrigation is a good tool to increase water use effeciency for suger beet crop grown under sandy soil conditions.

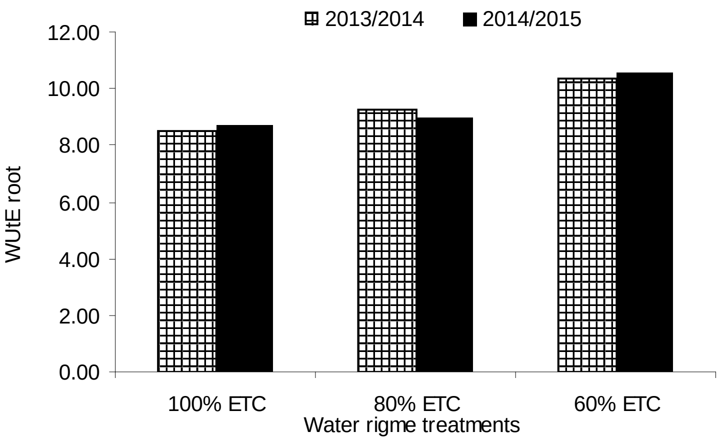

Fig. 3: Water use efficiency for sugar beet root yield as affected by irrigation regimes.

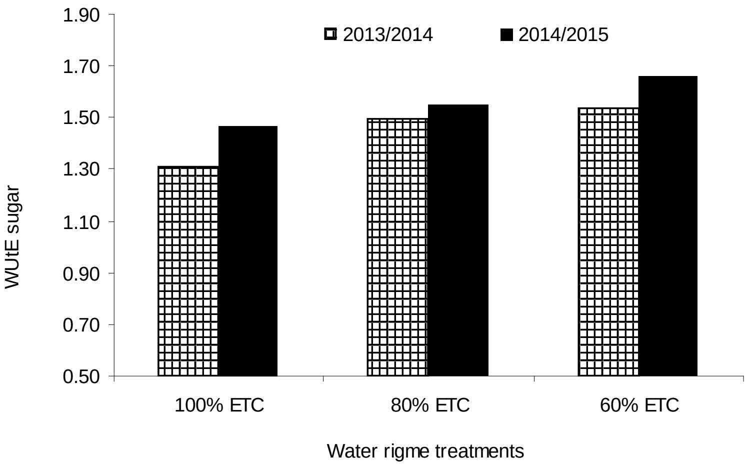

Fig. 4: Water use efficiency for sugar yield as affected by irrigation regimes.

CONCLUSION

Under conditions of El-Bostan area, El-Buhira Governorate, the combination of "Supplying sugar beet with irrigation water at 80% ET (2191 m^3 water/fed) + 100 kg N + 48 kg K_2O/fed" can be recommended to get the best quality traits. However, applying irrigation water at 100% ET_c (2739 m^3 water/fed) + 120 kg N + 48 kg K_2O/fed" can be recommended to get the highest yields of top, root and sugar/fed. The highest WUE for root and sugar yield was obtained with 60 % ET_c.

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تأثير نقص الري والتسميد النيتروجينى والبوتاسى على إنتاجية بنجر السُكَّر في الأراضي الرملية

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مركز البحوث الزراعية ، الجيزة ، مصر

المُلخَّص العربى

أُقيمت تجربتان حقليتان في أرض رملية بمزرعة علي مبارك التجريبية – منطقة البستان – جنوب التحرير – محافظة البحيرة في موسمي 2014/2013 و 2015/2014 لتحديد كمية مياه الرى الكافية وأمثل مستوى من السماد النيتروجينى والبوتاسى للحصول على أكبر حاصل وجودة من بنجر السُكَّر تحت نظام الري بالتنقيط ، وتحقيق أعلى كفاءة لإستخدام الماء. إشتملت الدراسة على ثلاثة مستويات من الإجهاد المائي (60 ، 80 و100 % من الإحتياج المائى المحسوب للمحصول "نتح-بخر") ، ومستويين من السماد البوتاسي (24 و 48 كجم بو$_2$أ/فدان) وثلاثة مستويات من السماد النيتروجيني (80 ، 100 و120 كجم ن/فدان) ، بالإضافة إلي تقدير كفاءة إستخدام الماء. استخدم تصميم القطع المنشقة مرة واحدة فى ثلاث مكررات ، حيث وضعت مستويات الرى في القطع الرئيسية ، بينما وزع التوافق بين مستويات السماد البوتاسي والنيتروجيني في القطع الشقية. تم زراعة الصنف "سارة" عديد الأجنة في كلا الموسمين.

أظهرت النتائج أن نباتات بنجر السُكَّر المروية عند 80% "نتح-بخر" أعطت زيادة معنوية في طول وقطر الجذر والكلوروفيل "أ" و "ب" والنسب المئوية للسُكَّروز والسُكَّر المُستخلَص في كلا الموسمين ، ونسبة النقاوة في الموسم الأول فقط. أعطت النباتات المروية عند 100% "نتح-بخر" زيادة معنوية في دليل مساحة الأوراق ومحتوي الجذور من البوتاسيوم والألفا أمينو نيتروجين وحاصل الأوراق والجذور والسُكَّر/فدان في كلا الموسمين.

أدت زيادة مستوي السماد البوتاسي إلي 48 كجم بو$_2$أ/فدان إلي زيادة معنوية في كل الصفات المدروسة عدا نسبة النقاوة التي انخفضت معنويا وذلك في كلا الموسمين ، بينما لم تصل نسبة الزيادة في السكر المستخلص إلي حد المعنوية في

الموسم الأول. تم الحصول على زيادة معنوية فى طول وقطر الجذر ومحتوي الجذور من الصوديوم والبوتاسيوم والألفا أمينو نيتروجين والكلوروفيل "أ" و "ب" والكاروتينيدات ودليل مساحة الأوراق وحاصل الأوراق والجذور والسُكَّر/فدان بزيادة مستوي السماد النيتروجيني حتي 120 كجم نيتروجين/فدان ، في حين حققت إضافة 100 كجم نيتروجين/فدان أعلي قيم معنوية للنسب المئوية للسُكَّروز والسُكَّر المُستخلَص والنقاوة في الموسمين.

أدي التوافق بين كمية المياه المُضافة عند 80% "نتح-بخر" والتسميد البوتاسي بإضافة 48 كجم بو$_2$أ/فدان إلي أعلي قيم لطول الجذر والكلوروفيل "أ" و "ب والنسب المئوية للسُكَّروز والسُكَّر المُستخلَص في كلا الموسمين وذلك مقارنة بمستويات الري الأخرى. أدي التوافق بين كمية المياه المُضافة عند 100% "نتح-بخر" وإضافة 48 كجم بو$_2$أ/فدان إلي زيادة حاصل الجذور/فدان معنوياً في الموسمين ، وقطر الجذر ودليل مساحة الأوراق وحاصل السُكَّر/فدان في الموسم الأول وذلك مقارنة بمستويات الري الأخرى. أدت إضافة مياه الرى عند 100% "نتح-بخر" و120 كجم نيتروجين/فدان لزيادة معنوية في قطر الجذر ودليل مساحة الأوراق وحاصل الأوراق والجذور والسُكَّر/فدان في الموسمين وذلك مقارنة بمستويات الري الأخرى. زادت النسب المئوية للسُكَّروز والسُكَّر المُستخلَص والنقاوة معنوياً بإضافة مياه الرى عند 80% "نتح-بخر" و100 كجم نيتروجين/فدان في كلا الموسمين وذلك مقارنة بمستويات الري الأخرى. أدت إضافة 48 كجم بو$_2$أ/فدان و 100 كجم ن/فدان إلي تحقيق أعلي قيم معنوية للنسب المئوية للسُكَّروز والسُكَّر المُستخلَص في الموسم الأول.

إزدادت قيمة "كفاءة إستخدام المياه" لكلٍ من حاصل الجذور والسُكَّر بنقص كمية المياه المضافة فى الموسمين.

تحت ظروف منطقة البستان بمحافظة البحيرة ، يمكن التوصية بتطبيق التوليفة (80% من الاحتياجات المائية المحسوبة للمحصول "نتح-بخر" + 48 كجم بو$_2$أ/فدان + 100 كجم ن/فدان) للحصول علي أفضل صفات جودة للعصير ، في حين يمكن تطبيق التوليفة (100% من الاحتياجات المائية المحسوبة للمحصول "نتح-بخر" + 48 كجم بو2أ/فدان + 120 كجم ن/فدان) للحصول علي أعلي حاصل للأوراق والجذور والسُكَّر للفدان.