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Water Use Efficiency, Yield and Quality of Sugar Beet Grown under Center Pivot and Fixed Sprinkler Irrigation Systems as Affected by Water Deficit and Boron Application.

El Hamdi, Kh. H. [1]; M. M El-Shazly[2]; A. A. Mosa[1] and M. E. R. El Dereny[1]
[1] Soils Department, Faculty of Agriculture, Mansoura University
[2] Soil, Water and Environment Institute, Agriculture Research Center.

ABSTRACT

A field experiment was conducted at a private farm located at Wadi El Natrun District, Al Behaira Governorate (30°484' N latitude and 30°497' E longitude) during seasons of 2013-2014 and 2014-2015 to evaluate the effect of irrigation techniques, deficit irrigation levels and spraying with boron on water use efficiency, yield and quality of sugar beet (*Beta vulgaris* L.). Eighteen treatments were arranged in a split- split plot design with three replicates, which were the simple combinations of two methods of sprinkler irrigation system (fixed sprinkler and center pivot), three deficit irrigation levels i.e. 60, 80 and 100% of the full irrigation water requirement (IWR) (ETc. = 589 mm fed.$^{-1}$) and three levels of foliar application of boron (without boron, 1.0 and 1.5 g L^{-1}). Results indicated that sugar beet grown under center pivot irrigation system produced higher values of quantitative yield indices at 190 days after sowing including, root length (cm), root diameter (cm), root fresh weight (g plant^{-1}), and root yield (Mg fed^{-1}) compared to sprinkler irrigation system in the two growing seasons. In addition, sugar and purity percentages were significantly higher under center pivot than fixed sprinkler irrigation system. Meanwhile, impurities concentration (i.e. Na, K and α- amino N) was higher under fixed sprinkler than center pivot irrigation system. Deficit irrigation level of 60% from IWR achieved the lowest mean values of all quantitative yield characteristics and the highest concentrations of impurities. Meanwhile, the highest root length was obtained under the deficit irrigation level of 80% from IWR. The maximum values of quantitative yield characteristics, sugar and purity percentages were achieved under 100% from full IWR. Foliar application of boron at rate of 1.5 g L^{-1} led to an increase in root length, diameter, fresh weight and yield compared to control treatment. In addition, sugar and purity percentages were the highest under this treatment. On contrary, the impurities (Na, K and α- amino N) concentrations were significantly the lowest under rate of 1.5 g L^{-1}. Center pivot irrigation system improved the water use efficiency (WUE) as compared to fixed sprinkler irrigation system under different deficit irrigation levels as following; 10.0, 10.5 and 9.1 *vs*.8.2, 8.7 and 7.6 kg m^{-3} in the first season and 10.2, 11.2 and 9.6 *vs*. 8.8, 9.2 and 7.9 kg m^{-3} in the second season with 60, 80 and 100% from IWR, respectively). It could be concluded that, sugar beet plants irrigated by center pivot system using 80% from IWR and foliar application with boron at rate of 1.5 g L^{-1} is recommended for obtaining the highest yield of sugar beet with higher sucrose productivity and purity during manufacturing process.

Keywords: Sugar beet, water deficit, water use efficiency, boron fertilization, center pivot system, fixed sprinkler irrigation system.

INTRODUCTION

According to the Egyptian Ministry of Agriculture and Land Reclamation, the total cultivated area of sugar beet in the year 2015/2016 was 555585 feddans with an estimated root yield of 16.7 Mg fed^{-1} and sugar productivity of 1265597 Mg (57.61% of the total sugar productivity in Egypt). In this regard, the steadily progressive increase in the Egyptian population and the gap between total sugar production (2196877 Mg) and consumption (3200000 Mg) resulted in a tremendous crisis in the sugar market in Egypt (MARL 2017). This crisis was associated with another steadily increase in the global sugar prices and a high reduction in the Egyptian currency value. Consequently, maximizing sugar production in Egypt is a national target to overcome this crisis through expansion in sugar beet cultivation in the newly reclaimed soils, taking into consideration huge water consumption of sugar cane.

The specific problems of sandy soils management (in particular their low water holding capacity and nutrient supply potential) require using an efficient irrigation system for water and nutrients absorption (Selim *et al*., 2009; Selim and Mosa 2012). Modern irrigation systems i.e. drip and sprinkler irrigation, have been widely used for maximizing water use efficiency in poor sandy soils. These systems, however, need to a lot of operation and maintenance costs. The operation costs of sprinkler irrigation include pumping source, piping, nozzles, energy source, manpower and maintenance follow up. On the other hand, drip irrigation system requires additional costs in regular maintenance and fertilizers control. Recently, attention has been directed towards center pivot irrigation system as one of the most efficient sprinkler irrigation techniques for water application in sandy-textured soils. As compared with other irrigation systems, center pivot can cover larger areas with higher application efficiency because of its movable pipe structure that rotates around a central point connected to a water supply (Waller and Yitayew, 2016). Beside irrigation systems, other modern water application techniques should be investigated in arid and semi-arid regions for more efficient use of limited water resources. Among them, deficit irrigation scheduling proved its effectiveness based on its non-sophisticated operation and higher use efficiency (Topak *et al.,* 2011).

Among different micronutrients, boron (B) is by far the most important required nutrient for sugar beet growth optimization. Without an adequate supply of boron, quantitative and qualitative yield characteristics of sugar beet may sharply depress. Severe B deficiency causes complex symptoms in sugar beet known as hollow heart and root rot. Most of soil boron is associated with organic matter fraction. Because of low-organic matter content of sandy soil, foliar application of B is required to overcome B deficiency in plants grown under sandy soil conditions. According to its well-known function in sugar translocation in roots, it is necessary to include boron in the sugar beet fertilization program. The scientific hypothesis of its vital role in sugars translocation depends on interaction with pristine sugars to form sugar-borate complexes (an ionizable form), which is greatly mobile than the non-ionized sugar molecules (Hoffmann 2010). In addition, despite the intensive research concerning the effect of boron supplementation on sugary crops optimization, little has been done to evaluate the effect of late doses application. It is hypothesized that B application in the late growth stages of sugar beet could accelerate the sugars translocation from shoots to roots.

The main objectives of this research are to evaluate the effect of different irrigation systems (center pivot and fixed sprinkler irrigation systems), deficit irrigation levels (60, 80 and 100% from IWR) and foliar application of boron (1.0 and 1.5 g L^{-1}) on water use efficiency, quantitative and qualitative yield and yield characteristics of sugar beet crop.

MATERIALS AND METHODS

A field experiment was carried out in a sandy textured-soil (*Typic Torripsamments*) located at a private farm in Wadi El Natrun District, Al Behaira Governorate (30°484' N latitude and 30°497' E longitude) during the two successive seasons 2013-14 and 2014-15 to evaluate the effect of water deficit and spraying with boron on yield and quality of sugar beet grown under center pivot and fixed sprinkler irrigation systems. In a split- split plot design with three replicates, main plots were assigned to sprinkler irrigation techniques: center pivot irrigation and fixed sprinkler irrigation. The theoretical irrigation water requirements were estimated using the CROPWAT model (Penman–Monteith method) and were based on historical data from the nearest weather station (El Sadat weather station) that was located 15 km from the experimental site. Deficit irrigation levels were presented in sub plots as follows: 60%, 80% and 100% of calculated irrigation water requirements (according to Allen *et al.,* 1998 formula; ETc = ETo x Kc). Boron fertilization rates were randomly distributed in sub- sub plots as follow: control (without fertilization), 1.0 g boron L^{-1} (5.88 g boric acid L^{-1}) and 1.5 g boron L^{-1} (8.82 g boric acid L^{-1}).

Each treatment was replicated three times. Thus, the total numbers of plots were 54 plots. Plot area was 10.8 m^2 (2.0 m long and 5.4 m wide) including 12 rows. The soil was ploughed twice and leveled before sowing. Sugar beet (*Beta vulgaris* L.) mono-germ variety (Elmo) was used from Strube GmbH and Co.KG. Germany. Seeds were mechanically cultivated by a planter (2.0 cm, 0.45 m spacing between rows and 0.17 m distance between seeds) on October 1, during the two studied seasons. Some soil physical and chemical properties were determined using the methods described by Hesse (1971) as shown in Table 1. Irrigation water used in the experiment was pumped from a groundwater source. Representative water samples were collected and analyzed for pH, EC and soluble cations and anions according to Chapman and Pratt (1982). Nitrogen and phosphorus requirements of sugar beet (114, 19 kg fed^{-1} N and P, respectively) were applied from two combined fertilizer sources (18-44-0 and 40-5-0) according to the growth stage. However, potassium and magnesium were applied at rates of 10 and 2.7 kg fed^{-1} in forms of potassium sulphate (K 41.0%) and magnesium sulphate (Mg 10.8%), respectively. Foliar boron applications (in the form of boric acid 17.4%) were applied twice (60 and 150 days after sowing) at rates of 1.0 and 1.5 g L^{-1} using hydraulic boom sprayer dragged by a tractor (150 L fed^{-1}).

At harvest time (190 days after sowing), representative samples from five plants were randomly collected from each sub-plots to determine the following traits:

1- Root length(cm).
2- Root diameter (cm).
3- Root fresh weight (g $plant^{-1}$).
4- Root yield (Mg $fed.^{-1}$).

Juice quality and its chemical traits were determined at the quality laboratory, El Nile Sugar Factory, Alexandria, Egypt. Sodium (Na) and potassium (K), alpha amino nitrogen (α- amino N) concentrations (expressed as a mill equivalent 100 g^{-1} of beet) and sucrose percentage were estimated according to the procedure of Sugar Company by an Automatic Sugar Polarimetric described by Cooke and Scott (1993). Purity percentage was calculated using the formula of Carruthers and Oldfield (1961):

Purity percentage % = {(Sucrose % - Sugar loss %) / Sucrose % x 100}

Where, sugar loss % ={ (0.29) + 0.343 (K + Na) + 0.094 (α- amino N)} according to Harvey and Dutton (1993).

Water use efficiency was calculated according to the formula of Howell (2001):

WUE = root yield (kg fed^{-1}) / applied amount of water (m^3 fed^{-1})

All statistical analyses were performed using analysis of variance technique by means of COSTATE Computer Software (V. 6.303, CoHort, USA, 1998-2004) as described by Gomez and Gomez, (1984). Treatment means were compared using Duncan's multiple range test at the 5% level of probability according to Waller and Duncan (1969).

Table 1. Some physical and chemical properties of experimental soil during 2013-14 and 2014-15 seasons.

Soil properties		Values seasons 2013-14	2014-15
Particle size distribution	Sand (%)	93.2	93.0
	Silt (%)	4.8	5.1
	Clay (%)	2.0	1.9
	Soil texture	Sandy	Sandy
Some physical and chemical properties	Field capacity (%)	15.0	15.0
	Saturation (%)	30.0	30.0
	Calcium carbonate (%)	12.2	11.5
	O.M. (%)	0.39	0.45
	pH (1:2.5)	7.81	7.90
	EC (dSm^{-1}) sat. soil paste	2.27	2.37
Soluble cations (cmol L^{-1})	Ca^{2+}	5.3	4.1
	Mg^{2+}	7.6	6.6
	Na^{+}	11.4	9.8
	K^{+}	3.4	3.2
Soluble anions (cmol L^{-1})	CO_3^{2-}	N.D.	N.D.
	HCO_3^{-}	6.3	5.5
	Cl^{-}	13.5	12.0
	SO_4^{2-}	7.9	6.2
Available nutrients	Olsen-P (mg kg^{-1} soil)	1.42	1.54
	K (mg kg^{-1} soil)	17.2	18.4
Total nitrogen	N (mg kg^{-1} soil)	3.4	3.7

***N.D. means not detected**

Table 2. Chemical analysis of well water during 2013-14 and 2014-15 seasons.

Season	pH	EC (dSm^{-1})	Soluble cations (cmol L^{-1}) Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Soluble anions (cmol L^{-1}) CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
2013-14	8.05	0.85	1.43	1.56	3.3	1.27	N.D.*	3.1	4.15	2.31
2014-15	8.17	0.97	1.73	1.59	4.13	1.15	N.D.*	3.3	4.8	2.5

***N.D. means not detected**

RESULTS AND DISCUSSION

1-Root length (cm plant^{-1}), root diameter (cm plant^{-1}), root fresh weight (g plant^{-1}) and root yield (Mg fed^{-1}):

Data presented in Table 3 show the effect of different irrigation systems, deficit water levels and boron fertilization on root length (cm), root diameter (cm), root fresh weight (g plant^{-1}), and root yield (Mg fed^{-1}) of sugar beet at harvest stage (190 days) in the two seasons. It is obvious that center pivot irrigation system obtained higher values of quantitative yield characteristics than fixed sprinkler irrigation system. The increase of quantitative yield characteristics obtained by center pivot system was 7.6 and 7.5% for root length, 7.4 and 6.8% for root diameter, 6.9 and 6.4% for root fresh weight and 6.9 and 6.5% for root yield, respectively in the first and second seasons comparing with fixed sprinkler irrigation system. As mentioned above, center pivot system has a desirable effect on the uniformity of water distribution system, which led to an increase of water depth in soil compared to fixed sprinkler irrigation system.

Concerning the effect of different deficit irrigation levels, data in Table 3 clearly show a superiority to the second level (80% from IWR) as compared to 60 and 100% from IWR. The high productivity of the moderately deficit irrigation level could be attributed to the production of chemical signals inside the plant root cells (e.g. abscisic acid), which translocated to plant leaves allowing the plant for better adaptation against drought (Sahin *et al.,* 2014). On the other hand, the sever deficit irrigation level (60% from IWR) led to avoid water from reaching the lower layers (below 30 cm). This water deficit level, therefore, was not efficient to deliver water to the deep roots of sugar beets (Eid and Ibrahim 2010). Vazifedousta *et al*., (2008) reported that the economic yield production by deficit irrigation could be achieved by applying 1.0 m^3 of water for 1.1 kg dry material. In this regard, Sharifi *et al*., (2002) recorded a dramatic yield reduction in sugar productivity by about 16 and 39.7% with reducing water application from 1000 to 725 and 655 mm, respectively.

Table 3. Root length (cm plant^{-1}), root diameter (cm plant^{-1}), root fresh weight (g plant^{-1}) and root yield (Mg fed^{-1}) of sugar beet as affected by irrigation systems, deficit irrigation levels and boron fertilization rates in the two successive seasons.

Treatments			characters							
Irrigation systems	Deficit irrigation levels	Boron rates	Root length (cm plant^{-1})		Root diameter (cm plant^{-1})		Root fresh weight (g plant^{-1})		Root yield (*Mg fed^{-1})	
			Season							
			1st	2nd	1st	2nd	1st	2nd	1st	2nd
Center pivot	60 %	B_0	30.10	31.60	8.80	9.40 k	370.00	370.00	17.00	17.00
		B_1	33.80	35.20	10.10	10.60 i	380.00	380.00	17.50	17.50
		B_2	35.70	35.90	10.80	11.30 g	390.00	400.00	17.90	18.40
	80 %	B_0	31.20	33.10	10.10	10.60 i	500.00	523.00	23.00	24.10
		B_1	34.80	36.00	11.60	12.20 e	510.00	545.00	23.50	25.10
		B_2	38.00	38.90	12.40	13.00 c	590.00	620.00	27.10	28.50
	100 %	B_0	31.00	32.80	11.10	11.70 f	550.00	566.50	25.30	26.10
		B_1	34.30	35.20	12.80	13.40 b	572.00	589.20	26.30	27.10
		B_2	36.80	37.50	13.70	13.70 a	610.00	660.00	28.10	30.40
Fixed sprinkler	60 %	B_0	28.00	29.40	8.20	8.70 l	344.10	344.10	15.80	15.80
		B_1	31.40	32.70	9.40	9.90 j	353.40	412.00	16.30	19.00
		B_2	33.20	33.40	10.00	10.50 i	362.70	372.00	16.70	17.10
	80 %	B_0	29.00	30.80	9.40	9.90 j	465.00	486.40	21.40	22.40
		B_1	32.40	33.50	10.80	11.30 i	483.60	506.90	22.20	23.30
		B_2	35.30	36.20	11.60	12.10 e	548.00	576.60	25.20	26.50
	100 %	B_0	28.80	30.50	10.40	10.90 h	511.50	526.80	23.50	24.20
		B_1	31.90	32.70	11.90	12.50 d	532.00	547.90	24.50	25.20
		B_2	34.20	34.90	12.70	13.40 b	585.00	600.00	26.90	27.60
Mean values as affected by irrigation systems	Center pivot		33.97a	35.13a	11.27a	11.77a	496.89a	517.08a	22.8a	23.8a
	Fixed sprinkler		31.58b	32.68b	10.49b	11.02b	465.03b	485.86b	21.3b	22.3b
Mean values as affected by deficit irrigation levels	60%		32.03c	33.03c	9.55 c	10.07c	366.70 c	379.68c	16.87 c	17.47 c
	80%		33.45a	34.75a	10.98 b	11.52b	516.10 b	542.98b	23.73b	24.98 b
	100%		32.83b	33.93b	12.10 a	12.60a	560.08 a	581.73a	25.77 a	26.77 a
Mean values as affected by boron fertilization rates	B_0 (Without B)		29.68c	31.37c	9.67c	10.20 c	456.77 c	469.47c	21.00c	21.60 c
	B_1 1.0 g L^{-1}		33.10b	34.22b	11.10b	11.65 b	471.83 b	496.83b	21.72b	22.87 b
	B_2 1.5 g L^{-1}		35.53a	36.13a	11.87a	12.33 a	514.28 a	538.10a	23.65a	24.75 a

*Mg= 1000 kg.

Foliar application of boron at rates of 1.0 and 1.5 g L^{-1} resulted in significant improvement in quantitative yield characteristics. Boron rate of 1.0 g L^{-1} caused an increase by 11.51 and 9.09% for root length, 14.83 and 14.22% for root diameter, 3.30 and 5.83% for root fresh weight and 3.14 and 5.86% for root yield, respectively in the first and second seasons. Meanwhile, boron rate of 1.5 g L^{-1} resulted in an increase by 19.71 and 15.2% for root length, 22.76 and 20.92% for root diameter, 12.95 and 14.62% for root fresh weight and 12.62 and 14.58% for root yield, respectively in the first and second seasons. This significant effect of boron fertilization reflects its vital role as an important nutrient for sugar beet nutrition through its promoting effect to cell wall formation, carbohydrate metabolism and sugar translocation (Ishii and Matsunaga, 1996). Several negative effects on sugar beet plant growth and production are associated with boron deficiency including: reduction in cell division, hindering root elongation, reduction in leaf expansion, malformations in plant roots (e.g. hollow heart phenomenon) and dropping in fertility (Ibrahim, 2006; Takano *et al*., 2008 and El-Kamash, 2007). The highest mean values of sugar beet root yield were 28.1 and 30.4 Mg fed^{-1} produced from the combination with 1.5 g L^{-1} and 100% from IWR under center pivot system in the first and second seasons, respectively.

2- Sucrose (%), sodium, potassium, alpha amino-N contents (meq 100 g^{-1} beet) and purity (%) of sugar beet.

Data illustrated in Table 4 show an improving effect on yield quality indices of sugar beet grown under center pivot irrigation system. Sucrose percentage increased by 3.19 and 4.15% with a noticeable increase in purity (90.04 *vs.* 89.08% and 89.46 *vs.* 88.40% for center pivot and fixed sprinkler irrigation systems, respectively in the first and second seasons). In this regard, N, K and α-amino N contents show a sharp reduction in plants grown under center pivot irrigation system. Sodium, potassium and amino-nitrogen are naturally-occurring constituents of the sugar beet root. These constituents are classified as impurities, which impede sucrose extraction during routine factory operations. Increasing the concentration of these impurities in sugar beet roots could be combined to estimate percentage of sucrose loss to molasses; thus, reduction in the net sugar production (Campbell and Fugate, 2015).

Table 4. Sucrose (%), sodium, potassium, alpha amino-N contents (meq 100 g^{-1} beet) and purity (%) of sugar beet root as affected by irrigation systems, deficit irrigation levels and boron fertilization rates in the two successive seasons.

Treatments			characters									
Irrigation systems	Deficit irrigation levels	Boron rates	Sucrose (%)		Na content (meq 100 g^{-1})		K content (meq 100 g^{-1})		α-amino N content (meq 100 g^{-1})		Purity (%)	
			Season									
			1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Center pivot	60 %	B_0	18.8	18.5	1.21	1.26	4.0 d	4.2 bc	1.43	1.69	88.07	87.28
		B_1	19.1	18.9	1.05	1.09	3.8 f	4.0 de	1.11	1.23	89.08	88.46
		B_2	19.4	19.2	0.45	0.47	3.5 h	3.6 fg	1.03	1.17	90.91	90.53
	80 %	B_0	19.1	18.7	1.17	1.22	3.9 e	4.1 cd	1.35	1.60	88.56	87.73
		B_1	19.6	19.2	0.83	0.86	3.5 h	3.6 fg	0.95	1.09	90.36	89.85
		B_2	20.0	19.6	0.47	0.49	3.1 k	3.2 h	0.78	0.85	91.96	91.55
	100 %	B_0	19.0	18.6	1.23	1.28	3.8 f	4.0 de	1.35	1.42	88.57	87.82
		B_1	20.0	19.6	0.74	0.77	3.1 k	3.2 h	1.21	1.40	91.28	90.78
		B_2	19.8	19.4	0.55	0.57	3.2 j	3.3 h	0.74	0.82	91.58	91.15
Fixed sprinkler	60 %	B_0	18.2	17.8	1.33	1.38	4.2 b	4.3 b	1.46	1.72	87.05	86.33
		B_1	18.5	18.1	1.16	1.20	4.0 d	4.3 b	1.13	1.25	88.14	87.15
		B_2	18.8	18.5	0.50	0.51	3.8 f	3.5 g	1.05	1.19	89.97	90.26
	80 %	B_0	18.5	18.0	1.29	1.34	4.3 a	4.5 a	1.38	1.63	87.20	86.22
		B_1	19.0	18.4	0.91	0.95	3.7 g	3.7 f	0.97	1.11	89.53	89.04
		B_2	19.4	18.8	0.52	0.54	3.2 j	3.3 h	0.80	0.87	91.43	90.91
	100 %	B_0	18.4	17.9	1.35	1.41	4.1 c	4.1 cd	1.38	1.45	87.39	86.89
		B_1	19.4	18.8	0.81	0.85	3.4 i	3.9 e	1.23	1.43	90.33	88.94
		B_2	19.2	18.6	0.61	0.63	3.5 h	3.7 f	0.75	0.84	90.67	89.90
Mean values as affected by irrigation systems		Center pivot	19.42a	19.08 a	0.86b	0.89b	3.54b	3.69b	1.11b	1.25b	90.04a	89.46a
		Fixed sprinkler	18.82b	18.32b	0.94a	0.98a	3.80a	3.92a	1.13a	1.28a	89.08b	88.40b
Mean values as affected by deficit irrigation levels		60%	18.80b	18.50c	0.95a	0.99a	3.88a	3.98a	1.20a	1.38a	88.87b	88.34b
		80%	19.27a	18.78b	0.87c	0.90c	3.62b	3.73b	1.04c	1.19c	89.84a	89.22a
		100%	19.30a	18.82a	0.88b	0.92b	3.52c	3.70c	1.11b	1.23b	89.97a	89.25a
Mean values as affected by boron fertilization rates		B_0 (without B)	18.67c	18.25c	1.26a	1.32a	4.05a	4.20a	1.39a	1.59a	87.81c	87.05c
		B_1 (1 g L^{-1})	19.27b	18.83b	0.92b	0.95b	3.58b	3.78b	1.10b	1.25b	89.79b	89.04b
		B_2 (1.5 g L^{-1})	19.43a	19.02a	0.52c	0.54c	3.38c	3.43c	0.86c	0.96c	91.09a	90.72a

The promoting effect of center pivot irrigation system on maximizing sucrose percentage and improving purity could be attributed to the better distribution of irrigation water application; thus, improving nutrients use efficiency (particularly nitrogen), and increasing root growth and elongation in the rhizosphere. The enhancement of nitrogen use efficacy might lead to a reduction in α-amino N formation in roots. Furthermore, this better uniformity of water distribution in the root zone might accelerate the continuous leaching of accumulated salts in soil. Consequently, reducing the uptake of sodium by plants. This finding is in harmony with those obtained by Ortiz *et al.*, (2012) who confirmed that sugar beet grown under center pivot irrigation system had a good root quality with high sugar percentage and low concentrations of impurities.

The productivity of sucrose percentage under different deficit water levels was comparable (Table 4). However, a slight increase was observed with 100% from IWR treatment (19.30 and 18.82%) as compared to 80% treatment (19.72 and 18.78%) followed by 60% treatment (18.80 and 18.50%) in the two successive seasons, respectively. This could be attributed to the reduction of impurities (Na, K and α-amino N) formation in plant roots (Bloch *et al.*, 2006), and consequently improving operational processing of sucrose extraction.

Foliar application of boron resulted in a significant increase in sucrose productivity (19.43, 19.02% and 19.72, 18.83% with 1.5 and 1.0 g L^{-1}, respectively in the two seasons) as compared to the control treatment (18.67 and 18.25%). This obvious increase in sucrose productivity was associated with a progressive reduction in impurities and subsequently increase in the purity percentage. Sodium concentration decreased by (59.1 and 59.1%) and (27.4 and 28.0%) due to foliar boron rate of 1.5 and 1.0 g L^{-1}, respectively in the two successive seasons (Table 4). Potassium contents show also a reduction by (16.5 and 18.3%) and (11.5 and 10.0%) with 1.5 and 1.0 g L^{-1}, respectively in first and second seasons. Meanwhile, this reduction was very sharp with α-amino N by (38.3 and

39.6%) and (20.9 and 21.4%) with 1.5 and 1.0 g L^{-1}, respectively. The high productivity of sucrose following boron application might be revealed to the encouraging effect of glucose formation in roots and phloem sap; thus, improving sucrose productivity at the harvesting stage (Armin and Asgharipour, 2012; Soliman, 2014). Beside its role in sugar synthesis, boron has another vital role in sugars transformation from source to sink as the borate form is easier for translocation than other sugar forms (Menisy 2009). The highest mean values of potassium content 4.3 and 4.5 meq 100 g^{-1} beet were obtained from the combination of control treatment of boron (without B) and treatment of deficit water level 80% from IWR under fixed sprinkler irrigation system, respectively in first and second seasons.

3-Water use efficiency (WUE).

Center pivot irrigation system improved the WUE as compared with fixed sprinkler irrigation system under different deficit irrigation levels (10.0, 10.5 and 9.1 *vs*. 8.2, 8.7 and 7.6 kg m^{-3} in the first season) and (10.2, 11.2 and 9.6 *vs*. 8.8, 9.2 and 7.9 kg m^{-3} in the second season with 60, 80 and 100% from IWR, respectively) as shown in Figures 1 and 2. Center pivot irrigation system uses long, single-pipe laterals moving in a circle around a central point, and linear move sprinkler irrigation systems that move in straight lines. This system applies water just above or in the plant canopy using small sprinklers, sprayers or bubblers. Therefore, water losses are minimized significantly due to neutralizing the effect on environmental conditions (e.g. wind and heat). Not only maximizing water uniformity distribution, but also its important role in maximizing nutrients utilization efficiency will maximize crop productivity; thus, improving water use efficiency. The highest mean values of WUE 11.7 and 12.3 kg m^{-3} were recorded from the combination of boron rate 1.5 g L^{-1} and treatment of deficit irrigation 80% from IWR under center pivot irrigation system, respectively in first and second seasons.

Although less root yields obtained from treatments with water stress treatments, it has higher WUE values. WUE values are generally high under increasing water stress conditions. Topak *et al.,* (2011) confirmed that sugar beet crop is well adapted to deficit irrigation scheduling criteria with considering that the economic sustainability, which means that sugar beet can maintain in deficit irrigation treatments. Moreover, the maximum WUE didn`t occur at maximum evapotranspiration for sugar beet and usually occurred at evapotranspiration levels less than the maximum.

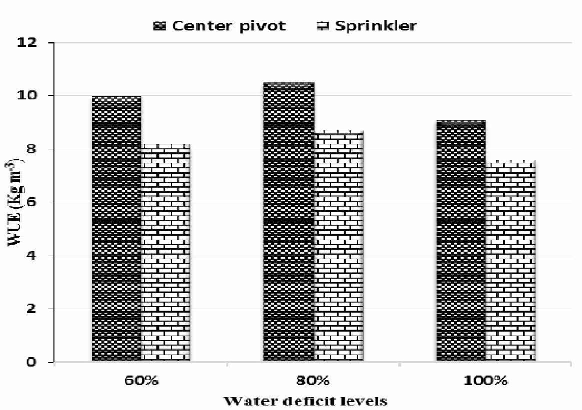

Figure 1. Water use efficiency of sugar beet under center pivot and fixed sprinkler irrigation system in season 2013-14

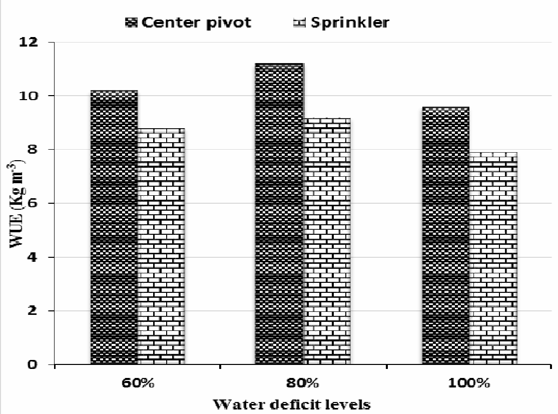

Figure 2. Water use efficiency of sugar beet under center pivot and fixed sprinkler irrigation system in season 2014-15

CONCLUSION

It could be concluded that irrigating sugar beet plants with 80% from its full irrigation water requirements under center pivot irrigation system and spraying boron at rate of 1.5 g L^{-1} resulted in the highest yield of sugar beet per cubic meter of water with a high sucrose and purity percentages during manufacturing process.

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كفاءة استخدام المياه، محصول وجودة بنجر السكر النامي تحت نظم الري المحوري والرش الثابت وتأثير الإجهاد المائي والتسميد بالبورون

خالد حسن الحامدي[1]، مجدي محمد الشاذلي[2]، أحمد على موسى[1] و محمد السيد راضي الدرينى[1].

[1] قسم الأراضي – كلية الزراعة – جامعة المنصورة.

[2] معهد الأراضي والمياه -مركز البحوث الزراعية.

أجريت تجربة حقلية بمزرعة خاصة بوادي النطرون -محافظة البحيرة (دائرة عرض 30.484 شمالا وخط طول 30.497 شرقا) خلال موسمى2013-2014 وموسم 2014-2015 لتقييم تأثير تقنيات الري، معدلات الإجهاد المائي والتسميد الورقي بالبورون على محصول وجودة السكر لنبات بنجر السكر. تم توزيع 18 معاملة في تصميم القطع المنشقة مرتين في ثلاث مكررات والتي تمثل نظامي الري (المحوري والري بالرش الثابت)، ثلاثة مستويات للإجهاد المائي (60، 80 و100% من احتياجات الري الكاملة) وثلاثة مستويات من التسميد الورقي بالبورون (بدون ، 1.0 و 1.5 جرام/اللتر). أظهرت النتائج أن بنجر السكر النامي تحت نظام الري المحوري أظهر أعلي محصول وذلك عند عمر الحصاد 190 يوم من الزراعة والتي تتمثل في طول الجذر (سم)، قطر الجذر (سم)، الوزن الطازج للجذر (جرام/نبات)، ومحصول الجذور (الطن/الفدان) مقارنة بنظام الرش الثابت. بالإضافة لذلك، كان محصول السكر ونسبة النقاوة أعلي معنويا تحت نظام الري المحوري مقارنة بنظام الرش الثابت. بينما كان تركيز معوقات الاستخلاص (الصوديوم – البوتاسيوم – الألفا أمينو نيتروجين) أعلي في نظام الرش الثابت مقارنة بنظام الري المحوري. حقق معدل الإجهاد المائي (60% من مقنن الري) أقل دلائل إنتاج محصوليه وأعلي تركيز لمعوقات الاستخلاص. كان مدلول أعلي طول جذر مصاحبا لمعدل العجز 80%، بينما كانت أعلي نتائج قطر الجذر، وزن الجذر الطازج/النبات، محصول الجذور، نسبة السكر والنقاوة مصاحبة للمعاملة 100% من مقنن الري المائي. أدي إضافة عنصر البورون بمعدل 1.5 جرام/اللتر إلي زيادة طول الجذر، قطره، والمحصول الطازج بالنسبة للنبات والمحصول الكلي مقارنة بالمعاملات الأخرى. بالإضافة لذلك، محتوي السكر والنقاوة كانا أعلي في هذه المعاملة. علي النقيض، كان تركيز معوقات الاستخلاص أقل عند إضافة البورون بمعدل 1.5 جرام/اللتر. أدي اتباع نظام الري المحوري إلي تحسين كفاءة استخدام المياه مقارنة بنظام الري بالرش الثابت تحت معدلات الإجهاد المائي المختلفة (10.0، 10.5 و9.1 مقابل 8.2 ، 8.7 و 7.6 كجم م$^{-3}$ في الموسم الأول ، 10.2 ، 11.2 و 9.6مقابل 8.8، 9.2 – 7.9 كجم م$^{-3}$ في الموسم الثاني لمعدلات 60%و 80%و 100% من مقنن الرى علي التوالي).