International
Research Journal of
APPLIED SCIENCES

Volume 01 | Issue 01 | 2019

SciRange
PUBLICATIONS
www.scirange.com

SciRange Open Access

International Research Journal of Applied Sciences Research Article

pISSN: 2663-5577, eISSN: 2663-5585

Boron Soil Application and Deficit Irrigation in Relation to Sugar Beet Production under Drip Irrigation System

[1]G. Abdel-Nasser and [2]Kh. T. Ben Abdalla

[1]Department of Soil and Agricultural Chemistry, Faculty of Agriculture (Saba Bacha), Alexandria University, Alexandria, Egypt
[2]Department of Soil and Water, Faculty of Agriculture, Azzaytuna University, Tripoli, Libya

ARTICLE INFORMATION

Received: October 14, 2018

Accepted: November 24, 2018

Published: January 31, 2019

Corresponding Author:
G. Abdel-Nasser,
Department of Soil and Agricultural Chemistry, Faculty of Agriculture (Saba Bacha), Alexandria University, Alexandria, Egypt

ABSTRACT

The aim of the present study was to evaluate the impact of deficit irrigation and boron soil applications on sugar beet productivity and quantitative and qualitative characteristics of sugar beet root yield under drip irrigation. A field experiment of drip-irrigated sugar beet (*Beta vulgaris* L.) conducted at the research field of the Nubaria Agricultural Research Station, Egypt at 30° 54' 21'' N, 29° 52' 15'' E and 11.0 m altitude above mean sea level during 2011/2012 growing season. Sugar beet plants thinned to one plant at distance of about 0.3 m on the rows at the 4th week after planting. The plots after emergence were irrigated by the drip irrigation method. The present study consisted of five treatments. The irrigation treatments based on replenishment of soil water depletion according to reference evapotranspiration (ET_0). The irrigation treatments were 40, 60, 80, 100 and 120% of ET_0. Soil boron applications were 0, 1, 2 and 4 kg B/fed. Sugar beet vegetative growth, sugar beet yield and yield components and juice quality and impurities content were determined. The results clearly indicated a significant effect (p>=0.01) of different irrigation regimes on all sugar beet growth characters, yield and yield characters. Irrigation at 80 or 100% of reverence evapotranspiration have the highest values of root yield and sugar yield, but not significantly different. Boron soil applications have a significant effect (p>=0.01) on all sugar beet growth, yield and yield components at 4 kg B/fed. The interaction between soil boron applications and water regimes was significant (p>= 0.01) for all yield characters. The best treatments for increasing the sugar beet yield and yield characters were 80% of ET_O irrigation regime with 4.0 kg B/fed.

Key words: Sugar beet, boron soil application, irrigation regime, deficit irrigation, drip irrigation

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) considered as the second sugar crop for sugar production in Egypt after sugarcane. Recently, sugar beet crop has an important position in Egyptian crop rotation as a winter crop not only infertile soils but also in poor, saline, alkaline and calcareous soils. It would economically grow in newly reclaimed soils. Boron is by far the most important trace element needed for sugar beet productivity because the deficiency of such element reflects the depression of yield and quality of roots[1]. Soil application and a foliar spray of boron is equally effective, hence the root fresh weight, sucrose %, root and top yields significantly increased by increasing boron levels[2].

The sugar beet crop has high requirements for boron. Boron is required for all plant growth stages. Adequate Boron nutrition is critical for high yields and quality of crops[3]. Also, the effect of foliar fertilization with Fertina B element (1.0 kg B ha^{-1}) on sugar beet root yield and quality compared with the control variant, root yield is higher by 13.86 t ha^{-1} (19.4%), sugar concentration higher by 1.46% (relative 10.8%) and sugar yield higher by 3.15 t ha^{-1} (39.5%). Based upon these results, foliar fertilization with 1.0 kg B ha^{-1} suggested for soils characterized by insufficient boron supply. It should be added through two top dressings, first prior leaves formation and second 10-14 days later[4].

Foliar spraying of boron increases root yield since roots absorbed boric acid and its uptake depends on soil pH and soil boron content[5]. It is due to chloroplast formation, sink limitations[6] and changes in cell wall which effects of boron deficit and led to secondary effects on plant metabolism, development and growth[7]. The application of boron rates from zero to 1.5 kg/acre increased root length, diameter and root yield. Moreover, increasing boron fertilizer up to 2.0 kg/acre resulted in the highest sugar yield (6.611 ton/acre)[8]. Sucrose and juice purity percentages increased by adding the higher concentration of boron might be attributed to decrease Na and K uptake in root juice. Similar results were recorded by Kristek *et al.*[4], Dordas *et al.*[9], Gezgin *et al.*[10] and Hellal *et al.*[11]. The highest root yield and sucrose concentration obtained by spraying with 12% boric acid[12].

Boron is by far the most important of the trace elements needed sugar beet because, without an adequate supply, the yield and quality of roots are very depressed[1]. Soil application, as well as, a foliar spray of boron is equally effective, hence the root fresh weight, sucrose %, root and top yields significantly increased by increasing boron levels[2].

The effect of foliar fertilization with Fertina B element (1.0 kg B ha^{-1}) on sugar beet root yield and quality was investigated compared to the control variant, root yield is higher by 13.86 t ha^{-1} (19.4%), sugar concentration higher by 1.46% (relative 10.8%) and sugar yield higher by 3.15 t ha^{-1} (39.5%). Based upon these results, foliar fertilization with 1.0 kg B ha^{-1} suggested for soils characterized by insufficient boron supply. It should be added through two top dressings, first prior leaves formation and second 10-14 days later[4].

The application of boron fertilizer of sugar beet cultivars significantly increase the root yield, yield components and increased recoverable sugar percent and sugar yield[8]. The optimum fertilization with minor elements such as boron is important for sugar beet plants grown in saline soil[13]. Boron is by far the most important of the trace elements needed sugar beet because, without an adequate supply, the yield and quality of roots are very depressed[1].

Therefore, the objective was to investigate the effect of different boron rates as the soil application on root yield and quality of some sugar beet cultivars grown under Nubaryia conditions in Egypt.

MATERIALS AND METHODS

Field experiment: The field experiment of drip-irrigated sugar beet (*Beta vulgaris* L.) conducted at the research field of the Nubaria Agricultural Research Station, Egypt at 30° 54' 21'' N latitude, 29° 52' 15'' E longitude and 11.0 m altitude above sea level during 2011/2012 growing season. The climate in this region is semi-arid with total annual precipitation of 123.0 mm. The experiment site has mild rainy winters and hot and dry summer. Daily rainfall recorded in the automatic weather station near the experimental site. The total rainfall within the growing season was 94.2 mm. All climatic parameters were recorded from Automatic Weather Station established in the Nubaria Agricultural Research Station nearby the experimental site (5 km distance), as shown in Table 1.

Table 1: Daily maximum, minimum and average temperature, wind speed, solar radiation and average daily reference evapotranspiration (ET_o) for the experimental site during the experimental period

Growing months	Average minimum daily temperature T_{min} (°C)	Average maximum daily temperature T_{max} (°C)	Average daily temperature T_{av} (°C)	Average daily wind speed U_2 (m sec^{-1})	Average precipitation (mm/month)	Average daily solar radiation (MJ m^{-2} day^{-1})	Daily reference evapotranspiration (mm day^{-1})
October, 2011	15.75	28.21	21.37	2.15	3.00	13.75	2.40
November, 2011	10.91	22.26	15.87	2.11	35.00	9.17	1.42
December, 2011	8.36	20.16	13.31	1.93	4.40	7.39	1.06
January, 2012	7.42	17.01	11.61	2.68	48.00	7.99	1.27
February, 2012	8.50	18.20	12.90	2.57	0.60	10.90	1.85
March, 2012	8.38	21.95	14.65	2.26	2.80	17.14	2.58
April, 2012	12.48	27.33	19.02	2.11	0.40	17.93	3.26

Table 2: Some soil physical and chemical properties of experimental site used in the present study

Soil parameters	0-30 cm depth	30-60 cm depth	Unit
Particle size distribution			
Sand	64.58	67.75	%
Silt	18.02	17.60	%
Clay	17.33	15.58	%
Textural class	Sandy loam	Sandy loam	-
Soil bulk density	1.47	1.49	Mg m^{-3}
Soil moisture content at field capacity	25.85	25.50	%
Soil moisture content at permanent wilting point	7.48	7.38	%
Plant available water content	18.37	18.12	%
Organic matter content (%)	0.73	0.29	%
Total calcium carbonate	24.10	25.81	%
Electrical Conductivity (EC_e), (1:1, soil: water extract)	7.27	7.43	dS m^{-1}
pH (1:1, soil : water suspension)	7.11	7.24	-
Soluble cations			
Ca^{2+}	7.74	7.10	me L^{-1}
Mg^{2+}	9.40	7.50	me L^{-1}
Na^{+}	59.92	51.23	me L^{-1}
K^{+}	2.15	1.75	me L^{-1}
Soluble anions			
$CO^{=}_3$	Trace	Trace	me L^{-1}
HCO^{-3}	4.50	3.64	me L^{-1}
Cl^{-}	29.90	25.60	me L^{-1}
$SO^{=}_4$	44.83	38.40	me L^{-1}
Available nutrients			
Nitrogen (N)	41.60	28.30	mg kg^{-1}
Phosphorus (P)	32.10	37.20	mg kg^{-1}
Potassium (K)	185.20	192.00	mg kg^{-1}
Iron (Fe)	0.50	0.75	mg kg^{-1}
Manganese (Mn)	3.00	3.49	mg kg^{-1}
Copper (Cu)	0.74	0.71	mg kg^{-1}
Zinc (Zn)	0.25	0.30	mg kg^{-1}
Boron (B)	0.57	0.34	mg kg^{-1}

Soil of the experimental site: Soil samples collected from each treatment to form a composite sample representing the soil of the experimental site for both surfaces (0-30 cm) and subsurface (30-60 cm). Some physical and chemical properties of the experimental field soil presented in Table 2. The soil properties performed according to the methods outlined by Carter and Gregorich[14].

Land preparation: The experimental site was subjected to leveling possess and then the drip irrigation network was established. A drip irrigation system designed for the experiment. Irrigation water was taken by a centrifugal pump, powered by a 3.88 kW engine from a well near the experimental site. The control unit consisted of a screen filter with 10 L sec^{-1} capacity, control valves and manometers mounted on the inlet and outlet of each unit. Distribution lines consisted of PVC pipe manifolds for each plot. The diameter of the polyethylene laterals was 16 mm and each lateral irrigated one plant row. The emitter discharge rate was 4 L h^{-1} at 100 kPa operating pressure. The actual emitter discharge rate calibrated before starting the experiment. The drip network calibration performed and the actual rate of emitter was 3.43 L h^{-1}.

Sugar beet cultivation: The sugar beet (*Beta vulgaris* L.) variety Gloria (polygerm) was planted on 13 October 2011 (DOY=286). Sugar beet plants thinned to one plant at distance of about 0.3 m on the rows at the 4th week after planting. The plots after emergence were irrigated by the drip irrigation method.

The experimental site fertilized using 45 kg P_2O_5 fed^{-1} as calcium superphosphate (15.5% P_2O_5) at land preparation, 60 kg N fed^{-1} as ammonium nitrate (33.5% N) at two equal doses, one after sowing and the second one month later and 60 kg K_2O fed^{-1} as potassium sulfate (48% K_2O) added at two equal doses, one after sowing and the second one month later.

Irrigation regimes: The present study consisted of five irrigation treatments. The irrigation treatments based on replenishment of soil water depletion according to the reference evapotranspiration (ET_o). The irrigation treatments were:

Table 3: Chemical analysis of water used for irrigation

Parameters	Value	Unit
pH	7.3	
EC_{iw}	2.70	dS m^{-1}
Soluble cations		
Ca^{+2}	6.90	me L^{-1}
Mg^{+2}	10.80	me L^{-1}
Na^{+}	8.96	me L^{-1}
K^{+}	0.28	me L^{-1}
Soluble anions		
$CO^{=}_3 + HCO^{-}_3$	4.85	me L^{-1}
Cl^{-}	7.07	me L^{-1}
$SO^{=}_4$	15.05	me L^{-1}
B	0.55	me L^{-1}
P	2.62	me L^{-1}

- I1 irrigation at 120% of ET_o
- I2 irrigation at 100% of ET_o
- I3 irrigation at 80% of ET_o
- I4 irrigation at 60% of ET_o
- I5 irrigation at 40% of ET_o

The irrigation treatments randomly distributed at the main plots.

Boron application: Four boron rates as boric acid (H_3BO_3, 17% B) (0, 0.5, 1.0 and 2.0 mg B kg^{-1} soil equal to 0, 1.0, 2. 0 and 4.0 kg B/fed) were randomly distributed in subplots where, the amount of boric acid was mixed with 4 kg of leached sand and distributed along the cultivation line around the plants.

Treatment layout conducted as factorial in Randomized Complete Block Design (RCBD) with three replications. There was 1.0 m separation between each plot in order to minimize lateral water movement among treatments. Each experimental plot was 25.0 m long and had a total area of 25.0 m^2 (1.0 m row wide). Table 3 shows the chemical analysis of water used for irrigation.

Soil water content measured by sampling a soil from each row with soil tube 0.025 m diameter at two depths i.e., 0-30 and 30-60 cm prior irrigation and determined by the gravimetric method. Soil water tension was monitored prior to each irrigation and after irrigation at surface and subsurface depths through electronic pressure transducer (electronic tensimeter).

Reference Evapotranspiration (ET_0): The ET_O is the reference evapotranspiration calculated with FAO Penman-Monteith equation[15], according to the climatic data collected from the Nubaria Weather Station. The equation expressed as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (1)$$

Where:

ET_o = Reference evapotranspiration (mm day^{-1})
R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1})
G = Soil heat flux density (MJ m^{-2} day^{-1} (Generally very small and assumed to be zero for daily calculations)
T = Mean daily air temperature at 2.0 m height (°C)
U_2 = Wind speed at 2 m height (m sec^{-1})
e_s = Saturation vapor pressure at 1.5 to 2.5 m height (kPa)
e_a = Actual vapor pressure at 1.5 to 2.5 m height (kPa)
e_s-e_a = Saturation vapor pressure deficit (kPa)
Δ = Slope vapor pressure-temperature curve (kPa °C^{-1})
γ = Psychrometric constant (kPa °C^{-1})

Crop Evapotranspiration (E_{tc}): Crop evapotranspiration (ET_c) is the water daily used by plants and calculated from the following equation[15]:

$$ET_c = K_c \times ET_0 \quad (2)$$

Where:
K_c is the crop coefficient.

Crop Water Requirements (CWR): The crop water requirements calculated according to the Penman-Monteith[15] by using the following equation[16]:

$$CWR = \frac{ET_{drip}}{E_i(1-LR)} \quad (3)$$

Where:

CWR = The crop water requirements (mm day^{-1})
ET_{drip} = The crop evapotranspiration under drip irrigation system (mm day^{-1})
E_i = The efficiency of irrigation system (assumed as 90% for drip irrigation system under the present conditions)
LR = The leaching requirements required for salt leaching in the root zone depth (assumed as 15%)

The ET_{drip} calculated as follows:

$$ET_{drip} = K_r \times K_c \times ET_o \quad (4)$$

Where:
K_r is the reduction factor that reflects the percent of soil covering by crop canopy. K_r can calculated by the equation described in Karmeli and Keller[17]:

Table 4: Crop coefficient (K_c) and development stages period for sugar beet

Growth stage	K_c	Stage period (days)
Initial	0.35	35
Crop development	0.35-1.15	55
Mid-season	1.15	65
Late-season	1.15-0.70	37

$$K_r = \frac{GC}{0.85} \tag{5}$$

Where:
GC is the ground cover fraction (plant canopy area divided by soil area occupied by one plant, assumed as 0.4).
K_c is the crop coefficient ranging from 0.35 (for initial stage) to 1.15 (for development stage) and 0.70 (for late stage) of sugar beet[15].
The length and crop coefficient (K_c) was needed for each of the 4 growth stages: initial, crop development, mid-season and late season stages. By considering the observed total length of the growing cycle, the length for the individual growth stages would be derived from the indicative lengths for sugar beet development stages[15] for the climatic region. Crop cycle length was 192 days (sowing date, 13 October 2011-harvest date, 22 April 2012). The length of each cropping stages adjusted by distributing the number of days relative to the indicative length of cropping stages given by Allen *et al.*[15]. The crop coefficients (K_c) collected from FAO[15] and presented in Table 4.

Crop water production function: The Crop Water Production Function (CWPF) reflects the benefit of applied water in production of dry matter or yield. The quadratic polynomial function of Helweg[18] expressed as follows:

$$Y_a = b_0 + b_1 \times W + b_2 \times W^2 \tag{6}$$

Where:
Y_a is the crop yield (kg fed^{-1}), W is the applied irrigation water (m^3 fed^{-1}) and b_0, b_1 and b_2 are the fitting coefficients.
When yield approaches its maximum(Y_{max}), the slope of the water production function against water applied =0, therefore the optimum applied water (W_{opt}) being calculated by differentiating the CWPF and equaling to zero, then the maximum predicted yield (Y_{max}) can be calculated by substituting W_{opt} in equation, then:

$$\begin{aligned} \partial Y / \partial W &= +b_1 + 2b_2 W = 0 \\ W_{opt} &= -b_1 / 2b_2 \\ Y_{max} &= b_0 + b_1 \times W_{opt} + b_2 \times W_{opt}^2 \end{aligned} \tag{7}$$

Water use efficiency: Irrigation Water Use Efficiency (IWUE) calculated as yield (kg fed^{-1}) divided by applied irrigation water. Applied Water (AW) (m^3 fed^{-1}) and Consumptive Water Use Efficiency (CWUE) was calculated as yield (kg fed^{-1}) divided by seasonal crop evapotranspiration (ET_c), mm ha^{-1} as described by Geerts and Raes[19]:

$$CWUE(kg\,m^{-3}) = \frac{Yield,\ kg\ fed^{-1}}{ET_c,\ mm\ fed^{-1}} \tag{8}$$

$$IWUE(kg\ m^{-3}) = \frac{Yield,\ kg\ fed^{-1}}{Applied\ water,\ m^3 fed^{-1}} \tag{9}$$

Sugar beet characteristics

Vegetative growth: One month before harvest, top of sugar beet sampled to determine the vegetative characters such as:

- Number of leaves/plant
- Leaf area/plant (cm^2)
- Top Fresh weight (g)
- Top water content (%)
- Total chlorophyll (mg/100 g plant)
- Dry matter content (%)

Sugar beet yield and yield components: At harvest time (192 days after sowing, DOY=112), the yield was collected from the each replicate and then computed based on one hectare and other characters were determined.

- Mean root fresh weight (RFW, kg fed^{-1})
- Root length (RL, cm)
- Root diameter (RD, cm)
- Total Soluble Solids (TSS, %)
- Root water content (RWC, %)
- Root dry matter content (RDM, %)
- Root/top ratio

Juice quality and impurities content: Yield data collected at harvest on 22 April 2012 (with growing season about 192 days long). Sugar beet plants of each plot were uprooted, topped, cleaned and weighed to determine root yield (kg ha^{-1}). Whereas, sugar yield per hectare estimated after taking subsamples from each plot (about 10 roots) as fully cleaned roots and sent to Nile Sugar Company Lab and Sugar Crops Institute at Nubaria to determine physiological and chemical characters.
Sucrose accumulation (% sugar in beet) and yield (t ha^{-1}) of beets per hectare were estimated on three replicate plants per

irrigation regime. Preparation of thick juice from sugar beet sub-samples (each sample was 10 kg of beet) on a laboratory scale, followed the method of Wieninger and Kubadinow[20], to establish the internal quality of sugar beet.

Alkalinity of sugar (AK) estimated as:

$$AK = \frac{K+Na}{\alpha N} \quad (10)$$

Where:
K and Na are alkali elements (determined by flame photometry) and aN is a-amino acid N (determined by blue number) described as mg/100 g.

Effective polarimetric assay of sugar (°S_e, %): Measuring the sucrose content of molasses, corrected as polarimetry without corrections (°S_t, %) minus percent of sucrose to molasses (°S_m, %), the latter calculated from the Eq. 11[21]:

$$^{\circ}S_m = 0.3492(K+Na) \text{ if } AK>=1.8$$
$$^{\circ}S_m = 0.6285(\alpha N) \text{ if } AK<1.8 \quad (11)$$

According to Pollach *et al.*[21], polarimetric assay of sugar measures the sucrose content of molasses sometimes more exactly than value corrected for raffinose.

Thick purity juice: (TPJ % = mg/100 g) was expressed as:

$$TPJ = 99.36 - 0.1427(K+Na+\alpha N)\times(100/^{\circ}S_e)$$
$$^{\circ}S_e = ^{\circ}S_t - ^{\circ}S_m \quad (12)$$

Sucrose (Pol, %): Juice sugar content of each treatment was determined by means of an Automatic Sugar Polarimetric according to McGinnus[22].

Total Soluble Solids (TSS) %: Which in turn recoverable sugar yield (kg fed^{-1}) deduced, applying the following formulae:

Recoverable sugar yield (RSY) (kg fed^{-1}) = Roots yield (kg fed^{-1}) × Recoverable sugar percent (%)

(13)

Recoverable sugar percent (RSP) (%) was deduced according to Harvey and Dutton[23] as:

$$\text{Corrected sugar content (ZB), \%} = \text{Pol(\%)} - (0.343(K+Na) + 0.094\alpha N + 0.29) \quad (14)$$

Where: Pol. % (Sucrose %) and K, Na and α- amino-N were determined as me 100 g^{-1} beet.

Gross sugar yield (GSY) (kg fed^{-1}) = Root yield (kg fed^{-1}) x Gross sugar percentage

(15)

White sugar yield (WSY) (kg fed^{-1}) = Root yield (kg fed^{-1}) x White sugar percentage

(16)

Losses sugar yield (LSY) (kg fed^{-1}) = Root yield (kg fed^{-1}) x Loss sugar percentage

(17)

Loss sugar content(LSC), % = Gross sugar content (%) - White sugar content (%)

(18)

Juice purity percentage calculated as:

$$\text{Juice purity, Qz(\%)} = ZB\times 100/Pol \quad (19)$$

Statistical analysis: All collected data for sugar beet yield and quality subjected to analysis of variance (ANOVA) according to Steel *et al.*[24]. The mean values compared according to Duncan's Multiple Range Test[25]. All statistical analyses performed using analysis of variance technique of "Statistics 8" computer software package[26].

RESULTS AND DISCUSSION

Sugar beet growth characters: The results presented in Table 5 shows the response of sugar beet growth characters to different irrigation regimes and boron soil applications. The results clearly indicated a significant (p>=0.01) effect of different irrigation regimes and boron applications on all sugar beet growth characters as compared with control (100% of ET_o). Irrigation regime at 100% ET_o gave the highest values of No. of leaves per plant (40.33), foliage fresh weight (760 g/plant) and top yield (10.5 ton fed^{-1}). The leaf area was highest at 80% of ET_o (4880.2 cm^2/plant). In addition, the foliage water content and total chlorophyll content (94.53% and 37.00 mg/100 g) attained at 120% of ET_o.
Boron soil applications have a significant effect (p>0.01) on all growth characters at a rate of 4.0 kg B/fed. The increases in growth characters were 32.76, 47.99, 57.42, 6.82, 0.64 and 21.54% for No. of leaves per plant, leaf area per plant, foliage fresh weight, top yield, foliage water content and total chlorophyll, respectively over no application of boron.

Table 5: Growth characters of sugar beet as affected by irrigation regimes and boron soil application

Treatments	No. of leaves/plant	Leaf area/plant (cm^2)	Foliage fresh weight (g/plant)	Shoot yield (ton fed^{-1})	Foliage water content (%)	Total chlorophyll (mg/100 g leaf)
Irrigation regime (% of ET_0), I						
40	32.50	3862.9	640.00	8.500	89.65	22.4
60	34.00	4138.2	649.17	9.250	91.04	24.5
80	37.00	4880.2	740.00	10.000	92.55	28.6
100	40.33	4448.3	760.00	10.500	93.02	31.5
120	37.50	4330.3	729.17	8.250	94.53	37.0
LSD (0.05)	0.16**	80.4**	24.53**	0.324*	2.16**	0.9**
Boron rate (kg B/fed), B						
0	31.53	3477.4	552.67	8.800	91.81	26.0
1.0	34.86	4050.0	642.00	9.800	92.08	28.0
2.0	37.26	4654.3	750.00	9.200	92.34	29.7
4.0	41.86	5146.2	870.00	9.400	92.40	31.6
LSD (0.05)	0.25**	68.8**	18.08**	0.218*	ns	0.6**
Interaction (I x B) (IXB)	**	**	**	*	ns	**

**0.05%, *0.01%, ns: Non-significant

All boron rates found to give a significant increase in the shoot and root yield of sugar beet as compared to the untreated plants. Application of 4.0 kg B/fed was the best for achieving maximum fresh shoot and root yield as compared to other boron treatments. However, the positive effect of Boron may be due to the boron role in cell elongation and turgidity where, in case of boron deficiency, plant leaves reported to be smaller, stiff and thick[27]. High boron doses above 50 ppm appeared to have toxic effects on plant growth.

The interaction between boron application and water regime was significant (p>=0.01) for all growth character except for foliage water content. The best treatments for increasing the growth characters were 100% of ET_o irrigation regime and 4.0 kg B/fed.

Yield and yield components: Table 6 shows sugar beet yield and yield component parameters as influenced by irrigation regime and boron applications treatments. The results clearly indicate a significant (p>=0.01) effect of irrigation regimes on sugar yield and yield components. Irrigation at 80% of ET_0, gave a highest values of root fresh weight (768.33 g/plant), root gross weight (20.484 ton fed^{-1}, root length (30.08 cm), root diameter (10.25 cm), but 120% of ET_0 gave the highest values of root water content (58.91%) and harvest index (51.46%). The percent increase of root gross yield of sugar beet at 80 of ET_0 was account as 2.79% over the common treatment (100% of ET_0).

According to the present results, to get maximum root yield of sugar beet under the present conditions of Nubaria region, it might be recommend irrigation at 80% of ET_0. This case of suitable soil water resulted in healthy plants; also, highest foliage yield consequently higher yield would obtain and vice versa regards the extra or less soil water availability. These results are in agreement with those of Bailey[28] and Emara[29].

Boron soil applications have the significant effect (p>0.01) on all sugar beet yield and yield components at 4 kg B/fed. The increases in yield characters were 92.79, 92.79, 22.37, 42.50, 4.32 and 3.32% for root fresh weight, root gross yield, root length, root diameter, root water content and harvest index, respectively over no application of boron.

The interaction between soil boron applications and water regimes was significant (p>= 0.01) for all yield characters. The best treatments for increasing the yield and yield characters were 80% of ET_O irrigation regime with 4.0 kg B/fed.

The application of boron at a rate of zero to 1.0 kg B/fed showed no significant effect in root length and diameter, root, top and sugar yields[30], whereas Gezgin *et al.*[10], found that root and sugar yields increased by increasing boron fertilizer.

Boron is by far considered one of the most important trace element needed for sugar beet because, without an adequate supply, the yield and quality of roots are very depressed, for this reason, boron application is important for sugar beet plants grown in sandy soils. The presence of boron is essential to facilitate sugar transport within the plant. This finding was supported by El-Hawary[13], however, adding boron fertilizer at a rate of 4.0 kg/fed results in a significant increase in all growth characters (Table 6), the highest values attained at 4.0 kg B/fed.

The increase in root yield estimated by 12.353 ton fed^{-1} at 4.0 kg B/fed compared with control ones (13.312 ton fed^{-1}). The application of boron at a rate of zero to 1.0 kg B/fed showed no significant effect in root length and diameter, root, top and sugar yields[31], whereas Gezgin *et al.*[10], found that root and sugar yields increased by increasing boron fertilizer. Data

Table 6: Sugar beet yield and yield components as affected by irrigation regimes and boron soil application

Treatments	Average root fresh weight (g/plant)	Root gross yield (ton fed^{-1})	Root length (cm)	Root diameter (cm)	Root water content (%)	HI (%)
Irrigation regime (% of ET_0), I						
40	634.17	16.907	28.17	9.50	54.78	48.76
60	735.83	19.617	28.75	9.75	56.24	45.28
80	768.33	20.484	30.08	10.25	57.17	43.93
100	747.50	19.928	28.92	10.16	58.17	42.53
120	742.50	19.795	28.92	9.91	58.91	51.46
LSD (0.05)	4.36**	0.12**	1.304*	0.1499**	3.29*	1.15**
Boron rate (kg B/fed), B						
0	499.33	13.312	25.93	8.00	55.99	45.84
1.0	678.67	18.058	28.47	9.73	56.04	43.37
2.0	763.33	20.351	29.73	10.53	57.78	48.99
4.0	962.67	25.665	31.73	11.40	58.41	47.36
LSD (0.05)	4.45**	0.12**	0.38**	0.1960**	2.08*	1.34**
Interaction (I X B)	**	**	**	**	*	**

HI: Harvest index, **0.05%, *0.01%

Table 7: Juice quality and impurities contents of sugar beet as affected by irrigation regimes

Treatments	Polarity or sucrose content (%)	TSS (%)	K (me/100 g)	Na (me/100 g)	α-N (me/100 g)	Alkaline coefficient (AK)	°S_m (%)	°S_e (%)	TPJ (%)	WSC (%)	WSY (ton fed^{-1})	GSY (ton fed^{-1})	LSY (ton fed^{-1})	Juice purity Qz (%)
Irrigation regime (% of ET_0), I														
40	17.97	21.17	6.50	1.05	3.20	2.38	2.64	15.33	89.30	14.96	2.28	2.76	0.48	81.39
60	17.80	21.25	6.31	1.00	3.56	2.06	2.55	14.32	88.48	14.79	2.58	3.16	0.58	82.27
80	17.78	21.67	5.83	0.97	3.41	1.99	2.38	15.27	89.80	14.73	3.25	3.89	0.65	83.30
100	17.64	21.25	5.64	1.01	2.69	2.59	2.32	15.46	90.72	14.74	3.68	4.44	0.73	83.13
120	16.87	20.92	6.28	1.08	2.73	2.71	2.57	14.23	89.83	13.70	3.83	4.56	0.76	82.67
LSD (0.05)	0.16**	0.13**	0.12**	0.022**	0.05**	0.068**	0.04**	0.15**	0.11**	0.14**	0.705**	0.86**	0.15**	0.21**
Boron rate (kg B/fed), B														
0	16.94	21.40	6.09	1.02	3.11	2.34	2.48	14.51	89.27	13.97	2.08	2.52	0.43	82.20
1.0	17.58	21.40	6.24	1.12	3.31	2.24	2.57	15.34	89.38	14.79	2.91	3.52	0.61	82.51
2.0	17.78	21.20	6.04	0.94	2.93	2.50	2.44	15.27	89.98	14.75	3.28	3.94	0.66	83.10
4.0	18.13	21.00	6.08	1.01	3.12	2.30	2.48	15.36	89.87	14.82	4.22	5.07	0.86	83.20
LSD (0.05)	0.15**	0.14**	0.09*	0.03**	0.06**	0.05**	0.03**	0.15**	0.17**	0.15**	1.087*	2.31*	0.22*	0.23**
Interaction (IXB)	**	**	**	**	**	**	**	**	**	**	*	*	*	**

TSS: Total Soluble Solids, °S_e: Assay of sugar, °S_m: Sucrose to molasses, TPJ: Thick Purity Juice, WSC: White Sugar Content, WSY: White Sugar Yield, GSY: Gross Sugar Yield, LSY: Losses sugar yield, **0.05%, *0.01%

in (Table 6) indicated that sugar beet affected by boron application at different rates. Root length and diameter, as well as, root weight were higher when sugar beet treated by 4.0 kg B/fed. Moreover, the yield of sugar beet and its technological properties was highly affected by micronutrients, especially boron fertilizer[32].

Juice quality and impurities contents: The results of juice quality and impurities contents are illustrated in Table 7. The different irrigation regimes significantly (p>=0.01) affected the juice quality and impurities contents of sugar beet. Irrigation at 40% of ET_0 gave the highest values of sucrose content (17.97%), K content (6.50 me/100 g root), the alkaline coefficient (2.38), percent of sucrose to molasses (2.64%) and effective polarimetric assay of sugar (15.33%). Irrigation at 60% of ET_O gave the highest value of a-N (3.56 me/100 g root). Irrigation at 80% of ET_o gave the highest values of TSS (21.67%) and juice purity (83.30%). In addition, TPJ and WSC attained 100% of ET_o. Irrigation at 120% of ET_o gave the highest values of WSY, GSY and LSY.

The increase in sugar yield was due to both increase in sugar content and root yield in which sugar yield adversely affected by water deficit. Increasing the impurities in the root of stressed plants decreased extraction of white sugar. Therefore, deficit irrigation improved sugar beet quality by reducing these impurities.

Alkaline coefficient (AK) considered as an indicator to determine the juice impurity. The AK affected by both the sodium+ potassium (Na+K) as nominator and a-amino-nitrogen (aN) as the dominator. Therefore, increasing the dominator, the AK will be decreased and vice versa. The threshold value of Ac was 1.8%, the values higher than 1.8% indicated that high purity sugar beet. The sugar crystallization process mainly affected the chemical characteristic of sugar beet juice. There was high sucrose content associated with low contents of K, Na and a-amino-N contents. It is also important for the stability of juice in the factory that the content of a-amino N would be maintains low in relation to that of K and Na. These results were in harmony with those obtained by El-Maghraby *et al.*[33].

The effect of irrigation water levels on Na content of roots was not consistent throughout the treatments. Sodium had significant variation among treatment. Na value ranged from 0.97 me/100 g root for 80% deficit irrigation to 1.08 me/100 g root for 120% deficit irrigation. Several researchers[34,35] reported that the effect of water deficit on Na content was less clear and varies between treatments. However, some studies showed that as deficit water increased, Na content decreased[36,37].

The sugar crystallization process mainly affected the chemical characteristics of sugar beet juice. There was high sucrose content associated with low contents of K, Na and alpha-amino-N and betaine contents. It is also important for the stability of juice in the factory that the content of alpha-amino-N would be maintains low in relation to that of K and Na ions[38].

Sugar content affected by irrigation regimes. Therefore, root sugar content generally increased in response to deficit irrigation treatment. Sugar beet roots accumulated more sugar (16.97% under 60% of ET_0) deficit irrigation than under any of the full and other deficit irrigation levels. Sucrose production from sugar beet depends on maximizing storage root growth over a long growing season. It was necessary to apply for a suitable irrigation program together with appropriate agricultural measures for taking a high sugar rate accumulation in the sugar beet production[39]. The increase in the sucrose rate of fresh root was due to a slower accumulation of water. Excess irrigation increased sugar beet yield, but sugar rates decreased[40].

Boron found to interact positively with irrigation to affect yield and yield components of sugar beet. Combination of 4.0 kg B/fed plus 80% of ET_O led to the highest values of root yield and its characteristics. Boron encourages proper nutrient balance and assimilation as well as synthesizes transport. It also reported that boron contributes to cell wall stability and proper binding of nitrogenous synthesizes[41]. Thus, the interaction between B and irrigation has a positive effect on yield quantity and quality. These results were in harmony with those obtained by El-Maghraby *et al.*[33]. On the other hand El-Geddawy *et al.*[30] and Nemeat Alla and El-Geddawy[42], pointed out that foliar spraying with micronutrients decreased TSS, while sucrose percent significantly increased.

Crop Water Production (WUE): Crop Water Production (CWP) expressed the productivity of water as related to yield and can be called Water Use Efficiency (WUE). The highest values attained at the highest water deficit. Increasing water deficit (such as 40% of ET_o) increased the water productivity or Irrigation Water-Use Efficiency (IWUE) due to decreased applied water. In general, IWUE values increased with decreased irrigation water applied (Table 8). The maximum value of IWUE was 12.037 tons root m^{-3} of applied water and 175.93 kg root mm^{-1} of consumed water (Table 8). Similar results reported by Zhang *et al.*[43] and Ali *et al.*[44]. Several

Table 8: Seasonal evapotranspiration and water parameters of sugar beet as affected by irrigation regimes

	Root yield		Sugar yield		White sugar yield	
	CWUE (kg mm^{-1})	IWUE (kg m^{-3})	CWUE (kg mm^{-1})	IWUE (kg m^{-3})	CWUE (kg mm^{-1})	IWUE (kg m^{-3})
Irrigation regime (% of ET_o), I						
40	175.93	12.037	28.698	1.964	23.700	1.621
60	136.04	10.880	21.903	1.753	17.859	1.428
80	106.57	9.384	20.250	1.783	16.852	1.484
100	82.93	7.777	18.996	1.782	15.951	1.496
120	68.66	6.684	15.397	1.500	12.762	1.242
LSD (0.05)	0.88**	0.04**	5.23**	0.41**	4.29**	0.34**
Boron rate (kg B/fed), B						
0	77.57	6.369	14.073	1.175	11.589	0.967
1.0	107.91	8.825	19.993	1.663	16.424	1.370
2.0	118.69	9.774	21.975	1.837	18.279	1.529
4.0	151.94	12.442	28.154	2.349	23.407	1.951
LSD (0.05)	0.67**	0.06**	8.3*	0.65*	6.90*	0.54*
Interaction (IXB)	**	**	*	*	*	*

CWUE: Consumptive Water-Use Efficiency, IWUE: Irrigation Water-Use Efficiency, **0.05%, *0.01%

explanation for the reason behind an increase in CWP with deficit irrigation as presented in the present study that deficit irrigation can increase the ratio of yield over crop water consumption (crop evapotranspiration) by (1) reducing water loss through unproductive evaporation and (2) increasing the proportion of root to total biomass[45,46].

Increasing water use efficiency in irrigated agriculture and promoting dryland farming will both play a significant role in maintaining food security. Egypt is a country of water scarcity due to general low precipitation, high evaporation and the temporal and spatial distribution of rainfall. Irrigation water, therefore, plays an essential role in agricultural practices and particularly in all crops cultivation. Sugar beet can grow in a wide range of climatic conditions and noted for its tolerance to salinity but drought stress is one of the major factors causing profit loss of the sugar beet crop. However, sugar beet would efficiently grow under a wide range of irrigation level, where it is readily adapted to limited irrigation because plants utilize deep stored soil water and recover quickly following water stress[47].

The results of sugar beet yield for different deficit irrigation indicated that the highest root yield (20.484 ton fed^{-1}) was attained for the 80% of ET_O deficit irrigation and the lowest one (16.907 ton fed^{-1}) at the 40% of ET_o (Table 6). When we consider the applied water, the IWUE was 12.037 kg root m^{-3} applied water at 40% of ET_0 and 6.684 kg root m^{-3} of applied water at 120% of ET_0. The values of WUE of white sugar were 23.700 kg white sugar m^{-3} of seasonal evapotranspiration (CWUE) and 1.621 kg white sugar m^{-3} of applied water (IWUE) at 40% of ET_0 deficit irrigation (Table 7). The increasing values of CWP in case of applied water were due to the less amount of applied water under the present field experiment. In this study observed that maximum WUE tends not to occur at maximum evapotranspiration for sugar beet and usually occurs at evapotranspiration less than maximum[48]. The range of WUE and IWUE obtained in this study were lower than that reported for irrigated sugar beet crop in other regions. Generally, CWUE and IWUE influenced by crop yield potential, the method of irrigation, the method used for estimate or measure evapotranspiration, crop environment and climatic characteristics of a region. So, higher values of WUE and IWUE may obtain for high-yielding varieties compared to low yielding one. Such results are in agreement with Al-Omran *et al.*[49].

Boron application increased the CWUS and IWUE (151.94 kg mm^{-1} and 12,442 kg m^{-3}, respectively at 4.0 kg B/fed treatment). The CWUE and IWUE increased by about 95.46 and 95.35%, respectively over the control treatment (no B applied). The increases of sugar yield were 100.05 and 99.91% for CWUE and IWUE, respectively over control treatment. The corresponding values for white sugar yield were 101.97 and 101.75, respectively.

Crop Water Production Function (CWPF): Crop Water Production Function (CWPF) reflects the benefits of applied water in the production of dry matter or yield. The quadratic polynomial function of Helweg[18] was used to fitting the data of applied water against the sugar beet yield and sugar content. Fitting the present data to the polynomial function for the different irrigation regime presented in Table 9 and 10. According to the mathematical analysis of the Crop Water Production Function (CWPF) against applied irrigation water, the predicted maximum root yield is 22.651 ton fed^{-1} and the computed applied water is 2683.3 m^3 /fed. The corresponding gross sugar yield and white sugar yield were 4.824 and 3.878 ton fed^{-1}, respectively at the same applied water (Table 9).

The mathematical analysis of the crop water production function (CWPF) against seasonal crop evapotranspiration, the predicted maximum root yield was 21.611 ton fed^{-1} and the optimum crop evapotranspiration is 243.0 mm/fed. The corresponding gross sugar yield and white sugar yield were 5.537 and 3.661 ton fed^{-1}, respectively (Table 10).

Table 9: Sugar beet water production function according to applied water (m^3/fed)

Parameters	Crop water production function	R^2	Optimum applied water (m^3 fed^{-1})	Max. yield (ton fed^{-1})
Root yield	Y=-1.0497+0.0161XW-3.0E-06*W^2	0.9333	2683.3	22.651
GSY	Y=-0.5293+0.0028XW-3.0E-07* W^2	0.9732	4666.7	6.004
WSY	Y=-0.3171+0.0021XW-2.0E-07* W^2	0.9716	5250.0	5.195

GSY: Gross sugar yield, WSY: White Sugar Yield

Table 10: Sugar beet water production function according to crop evapotranspiration

Parameters	Crop water production function	R^2	Optimum crop evapo-transpiration (m^3 fed^{-1})	Max. yield (ton fed^{-1})
Root yield	Y= 9.8008+ 0.0972*W -2.0E-04*W^2	0.9312	243.0	21.611
GSY	Y= 1.0714+ 0.0189*W -2.0E-05*W^2	0.9763	472.5	5.537
WSY	Y= 0.9234+ 0.0148*W -2.0E-05*W^2	0.9747	370.0	3.661

GSY: Gross Sugar Yield, WSY: White Sugar Yield

Table 11: Sugar beet water production function according to boron soil application

Parameters	Crop water production function	R^2	Optimum boron application (kg B/fed)	Max. yield (ton fed^{-1})
Root yield	$Y= -0.3075*X^2 + 4.2448*X + 13.533$	0.9925	6.9	28.132
GSY	$Y = -0.0593*X^2 + 0.8563*X + 2.575$	0.9888	7.2	5.661
WSY	$Y = -0.0509*X^2 + 0.7233*X + 2.122$	0.9904	7.1	4.689

GSY: Gross Sugar Yield, WSY: White Sugar Yield

For crop water production function (CWPF) of boron application, the predicted maximum root yield was 28.132 ton fed^{-1} and the optimum boron application was 6.9 kg B/fed. The corresponding gross sugar yield and white sugar yield were 5.661 and 4.689 ton fed^{-1}, respectively (Table 11).

The equilibrium between applied irrigation water and maximization of root, sugar, white sugar yields needed to decide the most optimum irrigation water. According to the present analysis, recommends applied water as 2683.3 m^3/fed to attain the optimizing values as 22.651, 6.004 and 5.195 ton fed^{-1} for root yield, gross sugar yield and white sugar yield, respectively.

The main advantage of deficit irrigation is that it maximizes the productivity of water. In addition, a certain reduction in yield observed, the quality of the yield (e.g., sugar content)[50]. In areas where water is the limiting factor for crop production, there maximizing the water productivity by deficit irrigation is often economically more profitable for the farmer than maximizing yield.

Deficit irrigation also entails a number of constraints such as (1) Crop response to drought stress should be studied carefully[51]. Determining optimal timing of irrigation applications was particularly difficult for crops with crop water production functions in which maximal water productivity was found within a small optimum range of ET, (2) Irrigators should have unrestricted access to irrigation water during sensitive growth stages. This is not always the case during periods of water storage[52] and (3) A minimum quantity of irrigation water should always be available for the application[53-55]. This is not always possible in extremely dry regions where irrigation water is scarce[56].

The increases in water productivity under deficit irrigation, can be attributed to the following reasons; (1) water loss through evaporation is reduced, (2) the negative effect of drought stress during specific phenological stages on biomass partitioning between reproductive and vegetative biomass(harvest index) reduced[57,58] due to increases the reproductive organs[59], (3) water production for the net assimilations of biomass is increased as drought stress is mitigated or crops become more hardened due to conservative behavior of biomass growth in response to transpiration[60], (4) water productivity for the net assimilations of biomass is increased due to the synergy between irrigation and fertilization[45] and (5) negative agronomic conditions are avoided during crop growth, such as pests, diseases, anaerobic conditions in the root zone due to water logging[61,62].

Determining optimal timing of irrigation applications was particularly difficult for crops with crop-water production functions, in which maximal water productivity was found within a small optimum range of ET[63].

CONCLUSION

According to findings it was concluded that deficit irrigation of sugar beet led to a decrease in root and sugar yields and seasonal evapotranspiration. Water-use efficiency values increased slightly with an increase in water deficit. Irrigation at 80% of the reference evapotranspiration with boron soil application at 4.0 kg B/fed use for sugar beet grown in semi-arid regions such as Nubaria to increase the root yield, gross and white sugar yield.

REFERENCES

1. Cooke, D.A. and R.K. Scott, 1993. The Sugar Beet Crop. Chapman and Hall London, pp: 262-265.
2. Jaszczolt, E., 1998. Effect of two methods of fertilizing sugar beet with trace elements on the yields of roots and sugar. Gazeta-Cukrownicza, 106: 232-234.
3. Allen, V.B. and D.J. Pilbeam, Ed., 2007. Handbook of plant nutrition. Books in soils, plants and the environment. Boron by Umesh C. Gupta, pp: 241-278.
4. Kristek, A., B. Stojic and S. Kristek, 2006. Effect of the foliar boron fertilization on sugar beet root yield and quality. Agric. Sci. Professional Review, 12: 1-7.
5. Gerendas, J. and B. Sattelmatcher, 1990. Influence of Nitrogen Form and Concentration on Growth and Ionic Balance of Tomato (*Lycoperiscum esculentum*) and Potato (*Solanum tuberosum*). In: Plant Nutration Physiology and Application (M.L. Van Beusichem, Ed.), Kluuwer Academic Dordrecht, pp: 33-37.
6. Terashima, I. and J.R. Evans, 1988. Effect of light and nitrogen nutrition on the organization of the photosynthetic apparatus in spinach. Plant Cell Physiol., 29: 143-155.
7. Loomis, W.D. and R.W. Durst, 1992. Chemistry and biology of boron. BioFactors, 3: 229-239.
8. Gobarah, M.E. and B.B. Mekki, 2005. Influence of boron application on yield and juice quality of some sugar beet cultivars grown under saline soil conditions. J. Appl. Sci. Res., 1: 373-379.

9. Dordas, C., G.E. Apostolides and O. Goundra, 2007. Boron application affects seed yield and seed quality of sugar beets. J. Agri. Sci., 145: 377-384.
10. Gezgin, S., M. Hamurcu and M. Apaydin, 2001. Effect of boron application on the yield and quality of sugar beet. Turk. J. Agric. For., 25: 89- 95.
11. Hellal, F.A., A.S. Taalab and A.M. Safaa, 2009. Influence of Nitrogen and Boron Nutrition on Nutrient Balance and Sugar Beet Yield Grown in Calcareous Soil. Ozean J. Applied Sci., 2: 1-10.
12. Armin, M. and M. Asgharipour, 2012. Effect of time and concentration of boron foliar application on yield and quality of sugar beet. Am.-Eurasian J. Agric. Environ. Sci., 12: 444-448.
13. El-Hawary, M.A., 1990. Influence of nitrogen, potassium and boron fertilizer levels on sugar beet under saline soil condition. J. Agric. Sci. Mansoura. Univ. Egypt, 24: 1573-1581.
14. Carter, M.R. and E.G. Gregorich, 2008. Soil Sampling and Methods of Analysis, 2nd Edn. Canadian Society of Soil Science; Boca Raton, FL: CRC Press, pp: 1264.
15. Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop evapotranspiration: Guidelines for computing crop requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome. Italy.
16. Cuenca, R.H., 1989. Irrigation System Design: An Engineering Approach. Prentice Hall, Inc., Englewood Cliffs, USA, pp: 552.
17. Karmeli, D. and J. Keller, 1975. Trickle irrigation design. Rain-Bird Sprinkler Mfg. Co., Glendora, Calif, pp:133.
18. Helweg, O.J., 1991. Functions of crop yield from applied water. Agron. J., 83: 769-773.
19. Geerts, S. and D. Raes, 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric. Water Manag., 96: 1275-1284.
20. Wieninger, L. and N. Kubadinow, 1971. Beziehungen zwischen Ru ̈benanalysen und technologischer Bevertung von Zuckerru ̈ben. Assem. Commun. Int. Technol. Sucr., 14: 523-538.
21. Pollach, G., W. Hein and G. Rosner, 1996. Definition der inneren Qua ̈litat von Zuckerruben-Definition of the internal quality of sugar beet. Zuckerind, 5: 332-344.
22. McGinnus, R.A., 1971. Sugar Beet Technology 2nd Ed. Sugar Beet Development Foundation, Fort., Color, USA.
23. Harvey, C.W. and J.V. Dutton, 1993. Root quality and processing in sugar beet crop: Science into practice. Cook, D.A. and Scott (Eds.). Published by Chapman and Hall, ISBN 0412-25132, pp: 571-617.
24. Steel, R.G.D., J.H. Torrie and D.A. Dicke, 1997. Principles and Procedures of Statistics. A Biometrical Approach. 3rd Edn., McGraw-Hill Inc, New York.
25. Duncan, D.B., 1955. Multiple range and multiple F-test. Biometric, 11: 1-42.
26. Statistix, 2003. Statistix 8.2, Analytical Software for Window. Tallahassee, FL.
27. Brown, P.H. and H. Hu, 1996. Phloem mobility of boron is species dependent: Evidence for phloem mobility in sorhitol-rich species. Ann. Bot., 77: 497-505.
28. Bailey, R.J., 1990. Irrigation crops and their management. Ipswich Farming Press, pp: 192.
29. Emara, T.K., 1996. Studies on the effect of some cultural practices on water parameters of sugar beet in North Delta Region. Ph.D. Thesis, Faculty of Agric., Mansoura Univ.
30. El-Geddawy, I.H., A.M. Abd-Elhakim and L.M. Saif, 2000. Multivariate analysis of yield and relative contribution of variables to its variation under some cultural practices in sugar beet. Egypt. J. Agric. Res., 78: 449-469.
31. El-Hawary, M.A., 1999. Influence of nitrogen, potassium and boron fertilizer levels on sugar beet under saline soil condition. J. Agric. Sci. Mansoura. Univ. Egypt, 24: 1573-1581.
32. Gobarah, M.E. and A.T. Thalooth, 2001. Effect of foliar application with some micronutrients on sugar beet grown in newly reclaimed sandy soil. II. Effect on yield and yield quality. J. Agric. Sci. Mansoura Univ., Egypt, 26: 5928-5928.
33. El-Maghraby, S. Samia, M.M. Shehata and Y. Tawfik, 1998. Effect of soil and foliar application of nitrogen and potassium on sugar beet. Egypt. J. Agric. Res., 76: 665-679.
34. Fabeiro, C., M. Santa Olalla, R. Lopez and A. Dominguez, 2003. Cultivation under controlled deficit irrigation condition in semi-arid climate. Agric. Water Manage., 62: 215-227.
35. Ober, E.S., M. Le Bloa, C.J.A. Clark, A. Royal, K.W. Jaggard and J.D. Pidgeon, 2005. Evaluation of physiological traits as indirect selection criteria for drought tolerance in sugar beet. Field Crops Res., 91: 231-249.
36. Tognetti, R., M. Palladino, A. Minnocci, S. Defline and A. Alvino, 2003. The response of sugar beet to drip and low-pressure sprinkler irrigation in Souther Italy. Agric. Water Manag., 60: 135-155.
37. Maralian, M., A. Tobeh, S. Seif Amiri, R. Didar-Talesh Mikail and A. Aghabarati, 2008. Effects of sowing date and limited irrigation on root yield and quality of sugar beet (*Beta vulgaris* L.). Asian J. Plant Sci., 7: 298-303.
38. Bosemark, N.P., 1993. Genetics and Breeding. Iin: Cooke, D.A. and R.K. Scott (Eds.). 1st Cd. The Sugar Beet Crop, Chapman and Hall, London, pp: 67-119.
39. Ucan, K. and C. Gencoglan, 2004. The effect of water deficit on yield and yield components of sugar beet. Turk. J. Agric. For., 28: 163-172.
40. Bilgin, Y., 1992. Seker pancari verim ve kalitesini ekleyen bazi faktorler (in Turkis). Turkiye Seker Fabrikalari A. S. Seker Enstitusu Seminer Notlari. Ankara, pp: 1-18.
41. Allen, V.B. and D.J. Pilbeam, Ed., 2007. Handbook of Plant Nutrition. Books in Soils, Plants and the Environment. Boron by Umesh C. Gupta, pp: 241-278.

42. Nemeat Alla, E.A.E. and I.B.M. El-Geddawy, 2001. Response of sugar beet to foliar spraying time with micronutrients under different levels of nitrogen and phosphorus fertilization. J. Agric. Res., Tanta Univ. Egypt, 27: 670-681.
43. Zhang, Y., E. Kendy, Y. Qiang, L. Changming, S. Yanjun and S. Hongyong, 2004. Effect of soil water deficit on evapotranspiration, crop yield and water use efficiency in the North China Plain. Agric. Water Manag., 64: 107-112.
44. Ali, M.A., M.R. Hoque, A.A. Hassn and A. Khair, 2007. Effects of deficit irrigation on yield, water productivity and economy. Agric. Water Manag., 92: 151-161.
45. Steduto, P. and R. Albrizio, 2005. Resource use-efficiency of field grown sunflower, sorghum, wheat and chickpea. II. Water use efficiency and comparison with radiation use efficiency. Agric. For. Meteorol., 130: 269-281.
46. Geerts, S. and D. Raes, 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric. Water Manag., 96: 1275-1284.
47. Monreal, J.A., E.T. Jimenez, E. Remesal, R. Morillo-Velarede and S. Garcia-Maurino, 2007. Proline content of sugar beet storage roots: response to water deficit and nitrogen fertilization at field conditions. Environ. Exp. Bot., 60: 257-267.
48. Fabeiro, C., M. Santa Olalla, R. Lopez and A. Dominguez, 2003. Cultivation under controlled deficit irrigation condition in semi-arid climate. Agric. Water Manage., 62: 215-227.
49. Al-Omran, A.M., I.I. Louki, A.A. Aly and M.E. Nadeem, 2013. Impact of deficit irrigation on soil salinity and cucumber yield under greenhouse condition in an arid environment. J. Agric. Sci. Tech., 15: 1247-1259.
50. Hueso, J. and J. Cuevas, 2008. Loquat as a crop model for successful deficit irrigation. Irrig. Sci., 26: 269-276.
51. Hsiao, T.C., 1973. Plant responses to water stress. Ann. Rev. Plant Physiol., 24: 519-570.
52. Zhang, H., 2003. Improving Water Productivity Through Deficit Irrigation: Examples from Syria, the North China Plain and Oregon, USA. In: Kijne, J.W., R. Barker and D. Molden (Eds.). Water Productivity in Agriculture: Limits and Opportunities for Improvement. International Water Management Institute, Colombo, Sri Lanka, pp: 301-309.
53. Zhang, H. and T. Oweis, 1999. Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agric. Water Manage., 38: 195-211.
54. Kang, S., L. Zhang, Y. Liang, X. Hu, H. Cai and B. Gu, 2002. Effects of limited irrigation on yield and water use efficiency of winter wheat in the Loess Plateau of China. Agric. Water Manage., 55: 203-216.
55. Geerts, S., D. Raes, M. Garcia, O. Condori, J. Mamani, R. Miranda, J. Cusicanqui, C. Taboada and J. Vacher, 2008b. Could deficit irrigation be a sustainable practice for quinoa (Chenopodium quinoa Willd.) in the Southern Bolivian Altiplano?. Agric. Water Manage., 95: 909-917.
56. Enfors, E.I. and L.J. Gordon, 2008. Dealing with drought: The challenge of using water system technologies to break dryland poverty traps: Local evidence on vulnerabilities and adaptations to global environmental change. Global Environ. Change, 18: 607-616.
57. Fereres, E. and M.A. Soriano, 2007. Deficit irrigation for reducing agricultural water use. Special issue on "Integrated approaches to sustain and improve plant production under drought stress". J. Exp. Bot., 58: 147-159.
58. Reynolds, M. and R. Tuberosa, 2008. Translational research impacting on crop productivity in drought-prone environments. Curr. Opin. Plant Biol., 11: 171-179.
59. Karam, F., R. Kabalan, J. Breidi, Y. Rouphael and T. Oweis, 2009. Yield and water production functions of two durum wheat cultivars grown under different irrigation and nitrogen regimes. Agric. Water Manage., 96: 603-615.
60. Steduto, P., T.C. Hsiao and E. Fereres, 2007. On the conservative behavior of biomass water productivity. Irrig. Sci., 25: 189-207.
61. Pereira, L.S., T. Oweis and A. Zairi, 2002. Irrigation management under water scarcity. Agric. Water Manage., 57: 175-206.
62. Geerts, S., D. Raes, M. Garcia, J. Vacher, R. Mamani, J. Mendoza, R. Huanca, B. Morales, R. Miranda, J. Cusicanqui and C. Taboada, 2008a. Introducing deficit irrigation to stablize yields of quinoa (*Chenopodium quinoa* Willd.). Eur. J. Agron., 28: 427-436.
63. Irmak, S., 2015. Interannual Variation in Long-Term Center Pivot–Irrigated Maize Evapotranspiration and Various Water Productivity Response Indices. I: Grain Yield, Actual and Basal Evapotranspiration, Irrigation-Yield Production Functions, Evapotranspiration-Yield Production Functions and Yield Response Factors. J. Irrig. Drain. Eng., 141: 5.