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# Response of Sugar Beet Yield to Deficit Irrigation under Drip Irrigation System

**G. Abdel-Nasser[1], Kh. T. BenAbdalla[2], A. M. Osman[3],**
**I. M. A. Goher[4], and K. M. Agami[5]**

[1]Soil and Agricultural Chemistry Dept., Faculty of Agriculture (Saba Bacha)-Alexandria University,
[2]Faculty of Agriculture, Soil and Water Dept., Azzaytuna University, Tripoli, Libya
[3] Water Requirements and Field Irrigation Dept., Nubaria Agricultural Research Station, Agricultural Research Center, Cairo, Egypt
[4]Head of Nubariya Sugar Crop Research Unit, Sugar Crops Research Institute, Agricultural Research Center, Egypt
[5]Department of Agronomy and Agricultural Practices, Sugar Crops Research Institute, Agricultural Research Center, Egypt

Corresponding author: G. Abdel-Nasser - e-mail: nasserga@gmail.com

**ABSTRACT:** A field experiment of drip-irrigated sugar beet (*Beta vulgaris*, L.) was 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. The aim of the present study was to evaluate the impact of deficit irrigation on sugar beet productivity, and quantitative and qualitative characteristics of sugar beet root yield under drip irrigation. The sugar beet (*Beta vulgaris*, L) variety Gloria (polygerm) was planted on 13 October 2011. Sugar beet plants were thinned to one plant at distance of about 0.3 m on the rows at the 4th week after planting. After emergence, the plots were irrigated by the drip irrigation method. The present study consisted of 5 treatments. The irrigation treatments were based on replenishment of soil water depletion according to reference evapotranspiration ($ET_0$). The irrigation treatments were: Irrigation at 40, 60, 80, 100 and 120% of $ET_0$. 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 of different irrigation regimes on all sugar beet growth characters except leaf area per plant and foliage water content as compared with control (100% of $ET_0$). The results also clearly indicated a significant effect of irrigation regimes on sugar beet yield and yield components. Irrigation at 40% of $ET_0$ gave a highest value of root length (32.7cm) and root diameter (13.0 cm), but 60 % of $ET_0$ gave the highest values of average root fresh weight (1500 g/plant) and root gross yield (100.0 ton/ha). The highest value of root/top ratio (1.31) was attained at irrigation with 120% of $ET_0$. The percent increase of root gross yield of sugar beet at 60% of $ET_0$ was account as 49.99%, for gross sugar yield was 45.66% and for white sugar yield was 44.16% over the common treatment (100% of $ET_0$). The different irrigation regimes significantly affected the juice quality and impurities contents of sugar beet. Irrigation at 40 and 60% of $ET_0$ gave the highest value of TSS (total soluble solids), 23.0%, white sugar yield (13.71 ton/ha), gross sugar yield (16.97 ton/ha) and loss sugar yield (3.26 ton/ha) were attained at 60% of $ET_0$. The highest values of polarity or sucrose content (17.76 %), effective polarimetric assay of sugar (15.46%), thick purity juice, TPJ (90.66%), white sugar content (14.94%) and juice purity (84.13%) were attained at 60% of $ET_0$. The increase in sugar yield was due to both increase in sugar content and root yield in which sugar yield was adversely affected by water deficit. Increasing the impurities in the root of stressed plants decreased extraction of white sugar. So, deficit irrigation improved sugar beet quality by reducing these impurities. The findings in this study strongly recommend that up to 60% deficit irrigation of sugar beet would be advantage if the farmers target is to maximize root and white sugar yield. But if the target is to put more area into production under limited water supply, irrigation at 40% of reference evapotranspiration in sugar beet may be feasible.

**Keywords:** sugar beet, irrigation deficit, limited irrigation, WUE, water productivity, sugar yield

## INTRODUCTION

Sugar beet is insensitive to water stress (Salter and Goode, 1967) and tolerates moderate soil water stress (Hills *et al*., 1990). Sugar beet is adapted to a wide range of climatic conditions and soil salinity (Katerji *et al*., 1997). On the other hand, controlled deficit irrigation pattern has been shown as an efficient tool for further research (Pidgeon *et al*., 2001; Tognetti *et al*., 2003; Shrestha *et al*., 2010). Kirda (2002) suggested low irrigation as the cause of higher sucrose concentration in sugar beet. Karimi and Naderi (2008) stated the positive role of late-season water and water deficit stresses in sugar yield rise, while Mirzaee and Rezvani (2007) found that drought stress adversely affected qualitative traits of sugar beet in Hamedān, Iran and revealed that irrigation withdrawal during late growing season resulted in the loss of qualitative characteristics of sugar beet including gross sugar percentage and extraction efficiency. Late-growing season moisture stress increases the impurities of sugar beet roots such as K and Na and consequently, significantly decreases sugar extraction efficiency and increases molasses percentage.

Until today, much research on the effects of deficit irrigation water on quantity and quality of sugar beet have been performed in during the last few years by different researchers (Jahadakbar *et al*., 2003; Mahmoodi *et al*., 2008; Hoffmann *et al*., 2009; Hassanli *et al*., 2010). Additionally, much research needs to be conducted on sugar beet producing regions where sugar beet grows with a shortage of water resources during the growing period.

The aim of the present study is to evaluate the effect of deficit irrigation on sugar beet productivity, water use efficiency, and quantitative and qualitative characteristics of sugar beet root yield under drip irrigation.

## MATERIALS AND METHODS

### Field experiment

The field experiment using drip-irrigated sugar beet (*Beta vulgaris*, L.) was 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. Climate in this region is semi-arid with total annual precipitation of 123.0 mm. The experimental site has mild rainy winters and hot and dry summer. The meteorological data were obtained from Central Laboratory for Agricultural Climate (CLAC), Ministry of Agriculture, Egypt. Some meteorological data for the experimental site are given in Table (1).

### Soil of the experimental site

Soil samples were collected from each treatment to form a composite sample representing the soil of the experimental site for both surface (0-30 cm) and subsurface (30-60 cm). Some physical and chemical properties of the experimental field soil are presented in Table (2). The soil properties were performed according to the procedures outlined in Carter and Gregorich (2008).

## Land preparation

The experimental site was subjected to leveling possess and then the drip irrigation network was established.

A drip irrigation system was 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 $s^{-1}$ 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 were 16 mm and each lateral irrigated one plant row. The inline emitter discharge rate was 4 l $h^{-1}$ at 100 kPa operating pressure. The actual emitter discharge rate was calibrated before starting the experiment. The drip network calibration was 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 13th October 2011 (Days of year =286). Sugar beet plants were thinned to one plant at distance of about 0.3 m on the rows at the 4th week after planting. After emergence, the plots were irrigated by the drip irrigation method.

Soil of the experimental site was fertilized using 150 kg $ha^{-1}$ as calcium superphosphate (15.5% $P_2O_5$) during land preparation and 150 kg $ha^{-1}$ as ammonium nitrate (33.5% N) at two equal doses, one after sowing and the second after one month later. 120 kg $ha^{-1}$ as potassium sulfate (48% $K_2O$) was added at two equal doses, one after sowing and the second after one month later.

## Irrigation regime

The present study consisted of 5 treatments. The irrigation treatments were based on replenishment of soil water depletion according to reference evapotranspiration ($ET_0$). The irrigation treatments were: Irrigation at 40% of $ET_0$, Irrigation at 60% of $ET_0$, Irrigation at 80% of $ET_0$, Irrigation at 100% of $ET_0$, and Irrigation at 120% of $ET_0$.

Treatments layout were conducted to a randomized complete block design 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 with two side cultivation). Table (3) shows the chemical analysis of water used for irrigation. Chemical analysis of water was done according the methods outlined in Eaton and Franson (2005).

Soil water content was 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 gravimetric method. Soil water tension was monitored prior each irrigation and after irrigation at surface and subsurface depths through electronic pressure transducer (electronic tensimeter).

Daily rainfall was recorded in the climate station near the experimental site (30° 54' 21'' N latitude, 29° 52' 16'' E longitude and 10 m altitude above mean sea level). The total rainfall within the growing season was 93.8 mm. All climatic parameters were recorded from Automatic Weather Station established in the Nubaria Agricultural Research Station nearby the experimental site (5 km distance), Table (1).

## Sugar Beet Characteristics

### Vegetative growth

One month before harvest, top of sugar beet was 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 $100g^{-1}$ plant), dry matter content (%).

### Sugar beet yield and yield components

At harvest time (192 days after sowing, Days of year=112), the yield was collected from the each replicate and then computed on the basis of one hectare and other character were determined i.e. Mean root fresh weight (RFW, kg $ha^{-1}$), 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 were collected at harvest on 22th April 2012 (with growing season about 192 days long). Sugar beet plants of each plot were up-rooted, topped, cleaned and weighed to determine root yield (kg/ha). Whereas, sugar yield per hectare was 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 (t $ha^{-1}$) and yield of sugar 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 (1971), to establish the internal quality of sugar beet.

**Alkalinity of sugar (Ak)** was estimated as:

$$AK = \frac{K+Na}{\alpha N} \quad meq100g^{-1}$$

Where:

K and Na are alkali elements (determined by flame photometry) and $\alpha$-amino N is estimated according to the procedure of Sugar Company by auto analyzer described by Bhador *et al*. (2010).

**Effective polarimetric assay of sugar (°$S_e$, %),** measuring the sucrose content of molasses, was corrected as polarimetry without corrections (**°$S_t$**, %) minus percent of sucrose to molasses **(°$S_m$, %)**, the latter calculated from the equation (Pollach *et al*., 1996):

$$^{\circ}S_m = 0.3492(K+Na) \text{ if } AK>=1.8$$

$$^{\circ}S_m = 0.6285(\alpha N) \text{ if } AK<1.8$$

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 $U_2$ ($m.s^{-1}$) | Average precipitation $P_e$ mm $month^{-1}$ | 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 | 8.5 | 18.2 | 12.9 | 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 |

Source of data is Central Laboratory for Agricultural Climate (CLAC), Ministry of Agriculture, Egypt

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 ($EC_{sw}$), (1:1, soil: water extract) dS/m | 7.27 | 7.43 | dS/m |
| pH (1:1, soil : water suspension) | 7.11 | 7.24 | - |
| **Water Soluble Cations:** | | | |
| $Ca^{2+}$ | 7.74 | 7.10 | meq/l |
| $Mg^{2+}$ | 9.40 | 7.50 | meq/l |
| $Na^{+}$ | 59.92 | 51.23 | meq/l |
| $K^{+}$ | 2.15 | 1.75 | meq/l |
| **Water Soluble Anions:** | | | |
| $CO^{=}_3$ | trace | trace | meq/l |
| $HCO^{-3}$ | 4.50 | 3.64 | meq/l |
| $Cl^{-}$ | 29.90 | 25.60 | meq/l |
| $SO^{=}_4$ | 44.83 | 38.40 | meq/l |
| **Available nutrients:** | | | |
| Nitrogen (N) | 41.6 | 28.3 | mg/kg |
| Phosphorus (P) | 32.1 | 37.2 | mg/kg |
| Potassium (K) | 185.2 | 192.7 | mg/kg |
| Iron (Fe) | 0.50 | 0.75 | mg/kg |
| Manganese (Mn) | 3.00 | 3.49 | mg/kg |
| Copper (Cu) | 0.74 | 0.71 | mg/kg |
| Zinc (Zn) | 0.25 | 0.30 | mg/kg |
| Boron (B) | 0.57 | 0.34 | mg/kg |

Table (3). Chemical analysis of water used for irrigation

| **Parameters** | **Value** | **Unit** |
|---|---|---|
| pH | 7.3 | - |
| $EC_{iw}$ | 2.70 | dS/m |
| **Water Soluble cations:** | | |
| $Ca^{+2}$ | 6.90 | meq/l |
| $Mg^{+2}$ | 10 .80 | meq/l |
| $Na^{+}$ | 8.96 | meq/l |
| $K^{+}$ | 0.28 | meq/l |
| **Water Soluble anions:** | | |
| $CO^{=}_{3} + HCO^{-}_{3}$ | 4.85 | meq/l |
| $Cl^{-}$ | 7.07 | meq/l |
| $SO^{=}_{4}$ | 15.05 | meq/l |
| B | 1.97 | mg/l |
| P | 2.62 | mg/l |

According to Pollach *et al.* (1996), polarimetric assay of sugar measures the sucrose content of molasses sometimes more exactly than value corrected for raffinose.

**Thick purity juice** (TPJ % = meq $100g^{-1}$) was expressed as:

$$TPJ=99.36-0.1427\left(K+Na+\alpha N\right)\times\left(100/{}^{o}S_{e}\right)$$

$${}^{\circ}S_{e} = {}^{\circ}S_{t} - {}^{\circ}S_{m}$$

**Sucrose % (Pol,%):** Juice sugar content of each treatment was estimated in fresh samples of sugar beet root by using Saccharometer according to the method described by A.O.A.C. (Ahadi and Sobhani, 2005).

**Total soluble solids (TSS),** %

**Recoverable sugar yield (kg/ha)** was deduced as described by Mohamed (2002), applying the following formulae:

**Recoverable sugar yield** (kg $ha^{-1}$) = roots yield (kg $ha^{-1}$) × recoverable sugar percent (%)

**Recoverable sugar percent** (%) was deduced according to Harvey and Dutton (1993) as:

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

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

**Gross sugar yield, GSY** (kg $ha^{-1}$) = root yield (kg $ha^{-1}$) x gross sugar percentage

**White sugar yield, WSY** (kg $ha^{-1}$) = root yield (kg $ha^{-1}$) x white sugar percentage

**Losses sugar yield**, **LSY** (kg $ha^{-1}$) = root yield (kg $ha^{-1}$) x loss sugar percentage

**Loss sugar content**, % = Gross sugar content (%) - white sugar content (%)

**Juice purity percentage** calculated as:

Juice purity,Qz(%)= ZB×100/Pol.

## Statistical Analysis

All collected data for sugar beet yield and quality were subjected to analysis of variance (ANOVA) according to Snedecor and Cochran (1991). The mean values were compared according to least significant difference Test (LSD test), Williams and Abdi (2010). All statistical analyses were performed using analysis of variance technique of "Statistix 8" computer software package (Statistix, 2003).

# RESULTS AND DISCUSSION

## Sugar beet growth characters

The results presented in Table (4) show the response of sugar beet growth characters to different irrigation regimes. The results clearly indicated a significant effect of different irrigation regimes on all sugar beet growth characters except leaf area per plant and foliage water content as compared with control (100% of $ET_0$). Irrigation regime at 100% $ET_0$ gave the highest values of no. of leaves per plant (42.3), leaf area per plant (6205.7 $cm^2$/plant) and total chlorophyll content(49.73 mg/100g leaf fresh weight), but the highest values of foliage fresh weight (1517.7 g/plant) and top yield (101.1 ton/ha) were attained at 60% of $ET_0$. The percent increase in top yield of sugar beet at 60% of $ET_0$ was account as 16.50% over the common treatment (100% of $ET_0$).

Table (4). Growth characters of sugar beet as affected by irrigation regimes

| Irrigation regime (% of $ET_0$) | Number of leaves/plant | Leaf area/plant ($cm^2$) | Foliage fresh weight (g/plant) | Top Yield ton/ha | Top water content (%) | Total chlorophyll (mg/100 g leaf) |
|---|---|---|---|---|---|---|
| 40 | 33.0 B | 5006.0 | 1093.4 B | 72.8 B | 92.84 A | 21.70 E |
| 60 | 40.7 AB | 5200.7 | 1517.7 A | 101.1 A | 93.20 A | 37.18 C |
| 80 | 39.0 AB | 5177.7 | 1218.9 B | 81.2 B | 94.70 A | 45.59 B |
| 100 | 42.3 A | 6205.7 | 1302.7 B | 86.7 AB | 94.95 A | 49.73 A |
| 120 | 35.7 AB | 5056.3 | 1300.5 B | 86.6 B | 95.66 A | 32.91 D |
| LSD(0.05) | $9.1678^{*}$ | $2937.2^{NS}$ | $215.43^{*}$ | $14.35^{*}$ | $4.22^{NS}$ | $3.89^{*}$ |

## Yield and yield components

Table (5) shows sugar beet yield and yield component parameters of sugar beet as influenced by irrigation regime treatments. The results clearly indicate a significant effect of irrigation regimes on sugar yield and yield components. Irrigation at 40% of $ET_0$ gave a highest value of root length (32.7cm) and root diameter(13.0 cm), but 60 % of $ET_0$ gave the highest values of average root fresh weight (1500 g/plant) and root gross yield (100.0 ton/ha). The highest value of root/top ratio (1.31) was attained at irrigation with 120% of $ET_0$. The percent increase of root gross yield of sugar beet at 60 of $ET_0$ was account as 49.99% over the common treatment (100% of $ET_0$).

According to the present results, to get maximum root yield of sugar beet under the present condition of Nubaria region, it might be recommended irrigation at 60% of $ET_0$. This case of suitable soil water resulted in healthy plants, also highest foliage yield consequently higher yield could be obtained and vise versa regards the extra or less soil water availability. These results are in agreement with those of Bailey (1990) and Emara (1996).

Table (5). Sugar beet yield and yield components as affected by irrigation regimes

| Irrigation regime (% of $ET_0$) | Average root fresh weight (g/plant) | Root gross yield (ton/ha) | Root length (cm) | Root diameter (cm) | Root water content (%) | Root/Top ratio |
|---|---|---|---|---|---|---|
| 40 | 1429 A | 95.24 A | 32.7 A | 13.0 A | 40.58 B | 1.310 A |
| 60 | 1500 A | 100.00 A | 30.3 AB | 11.7 AB | 42.26 A | 0.990 B |
| 80 | 1211 B | 80.74 B | 29.0 B | 10.0 BC | 44.26 A | 0.997 B |
| 100 | 1000 C | 66.67 C | 29.7AB | 9.00 C | 46.26 A | 0.770 C |
| 120 | 833 D | 55.56 D | 30.0AB | 8.33 C | 47.21 A | 0.653 C |
| LSD(0.05) | $131.15^*$ | $8.74^*$ | $3.55^*$ | $2.37^*$ | $2.60^*$ | $0.164^*$ |

## Juice quality and impurities contents

The results of juice quality and impurities content are illustrated in Table (6-1, 6-2). The different irrigation regimes significantly affected the juice quality and impurities contents of sugar beet. Irrigation at 40 and 60% of $ET_0$ gave the highest value of TSS (total soluble solids), 23.0%, but the highest values of K (6.62 meq/100g root), $\alpha$-amino N(4.39 meq/100g root), white sugar yield (13.71 ton/ha), gross sugar yield(16.97 ton/ha) and loss sugar yield (3.26 ton/ha) were attained at 60% of $ET_0$. The highest values of polarity or sucrose content (17.76 %), effective polarimetric assay of sugar (15.46%), thick purity juice, TPJ (90.66%), white sugar content (14.94%) and juice purity (84.13%) were attained at 80% of $ET_0$. Irrigation at 120% of $ET_0$ gave a highest value of Na content (1.69 meq/100g root).

The increase in sugar yield was due to both increase in sugar content and root yield in which sugar yield was adversely affected by water deficit.

Increasing the impurities in the root of stressed plants decreased extraction of white sugar. So, deficit irrigation improved sugar beet quality by reducing these impurities.

Alkaline coefficient (AK) is considered as an indicator to determine the juice impurity. The Ac is affected by both the sodium+ potassium (Na+K) as nominator and $\alpha$-amino-nitrogen ($\alpha$-amino N) as dominator. So, increasing the dominator, the Ac will be decreased and vise versa. The threshold value of Ac is 1.8%, the values higher than 1.8% indicated that high purity sugar beet. The chemical characteristic of sugar beet juice was mainly affected by the sugar crystallization process. There are high sucrose content associated with low contents of K, Na and $\alpha$-amino-N contents. It is also important for stability of juice in the factory that the content of $\alpha$-amino N would be maintained low in relation to that of K and Na.

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 0.83 me/100g root for 60% deficit irrigation to 1.69 meq/100g root for 120% deficit irrigation. Several researchers (Fabeiro *et al*., 2003; Ober *et al.,* 2005) reported that the effect of water deficit on Na content is less clear and varies between treatments. However, some studies showed that as deficit water increased, Na content decreased (Tognetti *et al*., 2003; Maralian *et al*., 2008).

Bosemark (1993) reported that the chemical characteristics of sugar beet juice were mainly affected by the sugar crystallization process. There are high sucrose content associated with low contents of K, Na and alpha-amino-N and betaine contents. It is also important for stability of juice in the factory that the content of alpha-amino-N would be maintained low in relation to that of K and Na ions.

Sugar content was affected by irrigation regimes. Therefore, root sugar content was 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 along growing season. It is necessary to apply a suitable irrigation program together with appropriate agricultural measures for taking a high sugar rate accumulation in the sugar beet production (Ucan and Gencoglan, 2004). The increase in the sucrose rate of fresh root is due to a slower accumulation of water. Excess irrigation increased sugar beet yield, but sugar rates decreased (Bilgin, 1992).

The increase in sucrose content was 1.72% at 80% of $ET_0$ over common treatment (100% of $ET_0$). The economical yield of sugar beet is white sugar content, white sugar yield and gross sugar yield. The corresponding increases were 4.66, 44.16 and 45.66% at 60% of $ET_0$ over the common treatment (100% of $ET_0$), respectively.

Table (6-1). Juice quality and impurities contents of sugar beet as affected by irrigation regimes

| Irrigation regime (% of $ET_0$) | Polarity or sucrose content (%) | TSS (%) | K meq/100g | Na meq/100g | α-amino N meq/100g | Alkaline coefficient (AK) meq/100g | °$S_m$ (%) |
|---|---|---|---|---|---|---|---|
| 40 | 16.63 AB | 23.00 A | 5.55 B | 1.10 B | 2.38 D | 2.79 A | 2.32 C |
| 60 | 16.96 AB | 23.00 A | 6.62 A | 0.83 C | 4.39 A | 1.70 D | 2.60 B |
| 80 | 17.76 A | 22.85 A | 5.75 A | 0.85 C | 2.82 C | 2.34 C | 2.30 C |
| 100 | 17.46 AB | 22.12 AB | 6.51 A | 1.18 B | 2.95 BC | 2.61 AB | 2.69 AB |
| 120 | 16.25 B | 21.67 B | 6.56 A | 1.69 A | 3.26 B | 2.53 BC | 2.88 A |
| LSD(0.05) | 1.35$^{*}$ | 1.05$^{*}$ | 0.65$^{*}$ | 0.18$^{*}$ | 0.36$^{*}$ | 0.19$^{*}$ | 0.27$^{*}$ |

Table (6-2). Juice quality and impurities contents of sugar beet as affected by irrigation regimes

| Irrigation regime (% of $ET_0$) | °$S_e$ (%) | TPJ (%) | WSC (%) | WSY (ton $ha^{-1}$) | GSY (ton $ha^{-1}$) | LSY (ton $ha^{-1}$) | Juice purity Qz (%) |
|---|---|---|---|---|---|---|---|
| 40 | 14.31 BC | 90.35 A | 13.84 BC | 13.22 A | 15.88 A | 2.67 B | 83.20 AB |
| 60 | 14.36 ABC | 87.59 C | 13.70 BC | 13.71 A | 16.97 A | 3.26 A | 80.79 CD |
| 80 | 15.46 A | 90.66 A | 14.94 A | 12.08 A | 14.36 A | 2.29 BC | 84.13 A |
| 100 | 14.77 AB | 89.08 B | 14.26 AB | 9.51 B | 11.65 B | 2.14 C | 81.64 BC |
| 120 | 13.37 C | 87.07 D | 12.82 C | 7.13 C | 9.04 B | 21.91 C | 78.92 D |
| LSD(0.05) | 1.10$^{*}$ | 0.45$^{*}$ | 1.08$^{*}$ | 2.14$^{*}$ | 2.63$^{*}$ | 0.49$^{*}$ | 2.12$^{*}$ |

Multi-regression results showed that there are a regression among sucrose content, root yield and root water content with white and gross sugar yields (as below), sugar content having highest effect on sugar yield.

$$WSY= 0.098348\times RY+0.972667\times SC-0.030033\times RWC \quad (R^2=0.9999)$$

$$GSY= 0.136747\times RY+0.717792\times SC-0.21579\times RWC \quad (R^2=0.9999)$$

$$WSC= -0.01783\times RY+1.357728\times SC-0.17606\times RWC \quad (R^2=0.9999)$$

Deficit irrigation also entails a number of constraints such as:

- crop response to drought stress should be studied carefully (Hsiao, 1973). Determining optimal timing of irrigation applications is particularly difficult for crops with crop water production functions in which maximal water productivity is found within a small optimum range of ET;
- irrigators should have unrestricted accress to irrigation water during sensitive growth stages. This is not always the case during periods of water storage (Zhang, 2003);
- a minimum quantity of irrigation water should always be available for application ( Zhang and Oweis, 1999; Kang *et al*., 2002; Geerts *et al*., 2008b). This is not always possible in extremely dry regions where irrigation water is scarce (Enfors and Gordon, 2008)

The increases in water productivity under deficit irrigation can be attributed to the following reasons:

- water loss through evaporation is reduced;
- the negative effect of drought stress during specific phenological stages on biomass partitioning between reproductive and vegetative biomass(harvest index) is reduced (Fereres and Soriano, 2007; Reynolds and Tuberosa, 2008) due to increases the reproductive organs(Karam *et al*., 2009);
- water production for the net assimilations of biomass is increased as drought stress is mitigated or crops become more hardened. This effect due to conservative behavior of biomass growth in response to transpiration (Steduto *et al*., 2007);
- water productivity for the net assimilations of biomass is increased due to the synergy between irrigation and fertilization (Steduto and Albrizio, 2005);
- negative agronomic conditions are avoided during crop growth, such as pests, diseases, anaeobic conditions in the root zone due to water logging (Pereira *et al*., 2002 ; Geerts *et al.,* 2008a).

In conclusion, the present study revealed that if water is limited and deficit irrigation is spread over growth season. The present findings were that deficit irrigation of sugar beet led to decrease in root and sugar yields and seasonal evapotranspiration. Water use efficiency values increased slightly with increase in water deficit. Irrigation at 60% of reference evapotranspiration (corresponding to 50% of soil moisture depletion) could be used for sugar beet grown in semi-arid regions such as Nubaria without decrease of root yield and white sugar yield. The findings in this study strongly recommend that up to 60% deficit irrigation of sugar beet would be advantage if the farmers target is to maximize root and white sugar yield. But if the target is to put more area into production under limited water supply, irrigation at 40% of reference evapotranspiration in sugar beet may be feasible. Also, this present results are good idea for scheduling irrigation with weather data instead of soil moisture data as confirmed with this study. Scheduling irrigation of sugar beet using weather data collected from nearby weather station is simple and accurate, in which requires the weather data and calculation of crop evapotranspiration using Penman-Monteith equation (Allen *et al*., 1998) or using any available computer software such as CROPWAT 8.0 (FAO, 2011) or AquaCrop 4.0 (Raes *et al*., 2012).

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## الملخص العربي

# استجابة محصول بنجر السكر لنقص الري تحت نظام الري بالتنقيط

**جمال عبد الناصر خليل[1], خالد الطاهر بن عبد الله[2], عبد السلام ميرغني عثمان[3],**
**ابراهيم محمد عبده جوهر[4] و كمال محمد عجمي[5]**

[1] قسم الاراضي والكيمياء الزراعية – كلية الزراعة (سابا باشا) – جامعة الاسكندرية
[2] قسم الاراضي والمياه كلية الزراعة – جامعة الزيتونة – طرابلس – ليبيا
[3] قسم المقننات المائية والري الحقلي – محطة البحوث الزراعية بالنوبارية – مركز البحوث الزراعية – الجيزة – مصر
[4] رئيس وحدة بحوث بنجر السكر بالنوبارية معهد بحوث المحاصيل السكرية – مركز البحوث الزراعية – الجيزة – مصر
[5] قسم بحوث المعاملات الزراعية – معهد بحوث المحاصيل السكرية – مركز البحوث الزراعية – الجيزة – مصر

أجريت تجربة حقلية لمحصول بنجر السكر تحت نظام الري بالتنقيط فى الحقول البحثية لمحطة التجارب الزراعية بالنوبارية – مصر خلال موسم النمو 2012/2011. الهدف من الدراسة الحالية هو تقييم تأثير نقص الري على انتاجية بنجر السكر وصفات جودة الجذور تحت نظام الري بالتنقيط. وقد تم زراعة بذور بنجر السكر صنف جلوريا (متعدد الاجنة) فى 13 اكتوبر 2011. وقد تم خف النباتات الى نبات واحد فى الجورة على مسافة 0.3 متر على طول الخط بابعاد بين الخطوط 0.5 متر فى عمر 4 اسابيع. بعد الانبات تم ري التجربة بالتنقيط طبقا للمعاملات المحددة. وقد تم تطبيق خمس معاملات ري على اساس معدل البخر–نتح المرجعي المقاس فى محطة الارصاد الجوية القريبة من موقع التجربة. كانت معاملات الري: 40, 60, 80, 100 و 120% من معدل البخر–نتح المرجعي . ثم تم تقدير النمو الخضري , محصول الجذور لبنجر السكر وخصائص الجذور, جودة العصير والنقاوة, محتوى السكروز, محصول السكر الكلي والسكر الابيض. أشارت النتائج بوضوح الى وجود تأثير معنوي لمعاملات الري على صفات النمو لبنجر السكر فيما عدا مساحة الاوراق لكل نبات والمحتوى المائي للمجموع الخضري مقارنة بمعاملة الكنترول (100% من البخر–نتح المرجعي). وقد أشارت النتائج الى وجود تأثير معنوي لنقص الري على محصول الجذور وخصائص الجذور. ولقد أعطى الري عند 40% من البخر–نتح المرجعي اعلى قيم لطول الجذور(32.7سم), قطر الجذور (13.0 سم) لكن أعطى 60% من البخر–نتح المرجعي اعلى قيم لمتوسط وزن الجذور الطازج (1500 جرام/ نبات) والمحصول الكلي للجذور (100 طن/ هكتار). وكانت النسبة المئوية لزيادة محصول الجذور الكلية عند 60% من البخر–نتح المرجعي حوالى 49.99% ومحصول السكر الكلي 45.66% و محصول السكر الابيض 44.16% فوق معاملة الكنترول (100% من البخر–نتح المرجعي) . كما أثرت معاملات الري المختلفة معنويا على جودة

العصير والنقاوة. فقد أعطى الري عند 60% أعلى قيم للمواد الصلبة الكلية (23.00%) بينما محصول السكر الابيض وصل الى 13.71 طن/هكتار , محصول السكر الكلي (16.97 طن/هكتار) والفقد فى السكر بعد الاستخلاص 3.26 طن/هكتار, بينما اعطى الري عند 80% اعلى نسبة سكروز (17.76%), اعلى نقاوة (90.66%), اعلى محصول للسكر الابيض (14.94 طن/هكتار). وتعزى الزيادة فى محصول السكر الى زيادة كلا من محتوى السكر ومحصول الجذور حيث ان محصول السكر يتناسب عكسيا مع نقص الماء. زيادة الشوائب فى الجذور للنباتات المعرضة للإجهاد المائي يقلل استخلاص السكر الابيض. لهذا فان نقص الري يمكن ان يحسن جودة بنجر السكر بتقليل الشوائب. ما تم التوصل اليه من الدراسة الحالية هو التوصية بمعدل ري حتى 60% من البخر–نتح المرجعي اذا كان هدف المزارع هو تعظيم محصول الجذور ومحصول السكر الابيض , لكن اذا كان هدف المزارع هو توفير مياه الري فان الري عند 40% من البخر نتح المرجعي يكون الافضل.