Growth, Productivity, Quality and some Physiological Parameters of Sugar Beet as Affected by Potassium Fertilization and Water Stress

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Abstract: The present work was carried out during two winter seasons 2013/14 and 2014/2015 in order to investigate the effect of potassium fertilizer (0, 36 and 72 kg/feddan, one feddan=0.42ha) and different irrigation levels (irrigation after depletion of 40% from field capacity (Normal irrigation or well water), 60% from field capacity (Moderate irrigation) and 80% from field capacity (Severe water stress) on growth, productivity, quality and some physiological parameters of sugar beet plants. The results indicated that the highest number of leaves, top fresh weight and top dry weight were obtained by applying well water in combination with high K rate, while the lowest was produced with plants subjected under severe water stress in combination with untreated potassium. However, the plants exposed to severe drought stress associated with potassium rates produced higher values of osmotic pressure and proline contents than that obtained by other treatments received moderate or well water associated with the same potassium rates at all growth stages. Applications of normal irrigation x high potassium rate produced highest total carbohydrates at 105 DAP. The present results indicated also, irrigation plants with normal irrigation resulted in the highest root and top yields, while the plants exposed to severe drought stress with unfertilized plants produced the least root and top yields. The same trends were noticed with gross, white and losses sugar yields. Applied of all irrigation treatments in combination with high rate of potassium resulted in an increase in sucrose %, however applied of 80% FC in combination with 72 kg K/feddan produced the highest sucrose percentage followed with applying 60% FC under the same potassium level. On the other hand, irrigated plants with 40% FC in combination with untreated plants resulted in the lowest sucrose percentage. Also, application of 80% FC in combination with 36 or 72kg K/feddan produced an increase in purity percentage; while the plants had no potassium fertilizer produced the least purity percentage when irrigated with well water. Concerning, the K content in juice, the results showed a gradually increase by increasing potassium up to high rate under all irrigation treatments, however under the three irrigation treatments the contents of K seem to be the same, which no differences was noticed among them. On contrary, Na and α-amino nitrogen contents were decreased gradually under all irrigation treatments; however the lowest Na and α-amino nitrogen contents were obtained by using normal irrigation in combination with high potassium rate, respectively. The results in also indicated that TSS %, white and loss sugar yields were gradually increased by increasing potassium fertilizer up to high rate with all irrigation treatments, where the applied well water with unfertilized treatment showed the least content of these traits.

Key words: Sugar beet, Water stress, Potassium fertilizer, Yield, Quality, Proline

INTRODUCTION

Nowadays, Egypt face problem in amount of irrigation water due to increasing population year after year which resulted in increasing demand of water and also for increasing the extended of new reclaimed lands. Sugar beet (*Beta vulgaris* L.) is considered as an important sugar crop in Egypt and it is considered the second crop after sugarcane for sugar production. The great importance of sugar beet crop due to its ability to grown successfully in saline and calcareous soils in addition in newly reclaimed lands as economic crop, but also for production higher of sugar under these conditions as compared with sugar cane. Most of these areas face some stress problems, i.e. shortage of irrigation water, salinity and unbalance nutrient elements. Thus, increasing sugar beet productivity and quality with lowest irrigation water quantity is considered the first important step of Egyptian Ministry of Agriculture and Land Reclamation strategy for increasing crops production by using limited irrigation water. The severity of water deficit stress on plant function can range from mild to severe depending on the degree and extent of the stress (Jaleel and Llorente, 2009). Water deficits can limit growth and influence a host of physiological functions in plants to a greater extent than any other environmental factor (Cattivelli et al., 2008). Bloch and Hoffmann (2005) found that four sugar beet cultivars differed significantly in root and leaf dry matter mass. Choluj *et al.* (2004) reported that water withholding reduced plant growth, dry matter accumulation and final yield when imposed at successive growth stages, which was partially compensated by increasing the fraction of assimilate partitioned to storage. In sugar beet, white sugar yield is a component of accumulated dry weight of the roots, and the maximum white sugar yield was obtained with increasing the dry weight accumulation in roots (Ranji *et al.,* 2000). Soleymani *et al.* (2012) reported that the highest TDM was produced by plants irrigated by applying 150% of their water demand and root yield significantly increased as plants water demand percentage was increased. Also, Sadeghi-Shoae *et al.* (2013) pointed that application of well irrigation could increase total WUE and produced a greater total dry matter, while deficit irrigation decreased WUE and produced less dry matter compared to normal irrigation. Probably, the increase in due to increasing sugar content when plants exposed to water stress (Firoozabadi et al., 2003). Usually, the total impurities of root will increase to maintaining turgor by osmotic adjustment under drought stress conditions (Smith et al., 1977). Ramazan *et al.* (2011) and Soleymani *et al.,* (2012) found that increasing water deficits resulted in a relatively lower root and white sugar yields., while Mehrandish *et al.,* (2012), Tohidloo *et al.*, (2012) and El–Hawary *et al.,* (2013) indicated that decreasing irrigation water quantity reduced the root yield and quality of sugar beet. Jahad Akbar *et al* (2002) showed that deficit irrigation reduced yield, gross sugar and sodium of roots and increased harmful nitrogen. They also stated that with increasing irrigation water, root sodium was increased, while sugar content was decreased. Ober *et al.* (2004) and Pigeon *et al.* (2006) found significant variation in sucrose yield among several hybrids grown in water deficit conditions. Under water stress conditions, sugar beet sucrose storage has been found to be reduced as a result of the accumulation of ions and solutes (Hoffmann, 2010). Unfortunately, α-amino-N compounds, glycine betaine and proline (Gzik 1996, Rover and Buttner 1999), along with sodium and potassium which accumulate in sugar beet tap root following water stress, are principal impurities that reduce sugar beet quality for processing by inhibiting crystallisation during processing (Clarke et al. 1993). In addition, the efficiency of the sugar extraction process is dependent on the concentration of solutes other than sucrose (K+, Na+, amino acids and glycine betaine) and the interrelationships among accumulation of sucrose and these so-called impurities are important determinants of root quality. While, Soleymani *et al.* (2012) reported that irrigation produced highest sugar percentage (17.48%) was obtained from the treatment of irrigation to supply 100% of crop water demand and the lowest one (15.12%) was obtained from control treatment followed by the treatment of irrigation to supply 150% of crop water demand (15.48%). Who also reported that the lowest Na content was obtained from the treatment of irrigation to supply 100% of crop water demand, while the highest one was obtained from the treatment of irrigation to supply 125% of crop water demand. Other researchers have introduced Na as one of the most important impurities of sugar beet roots, too and have stated that its content in root has a negative correlation with white sugar percentage (Cooke and Scott, 1993).

Application of potassium to plants leads to enhancing the photosynthetic activity, translocation of sucrose from the leaves and its accumulation in roots. The effect of potassium treatment on the studied growth parameters indicating that, number of green leaves/plant, as well as, total fresh weight/plant and total dry weight/plant were increased by increasing potassium fertilizer rates (Abdel El-Wahab *et al.*, 1996, Abdel-Motagally and Attia, 2009 and Hellal *et al.,* 2013). These increases may be due to that potassium fertilizer is a mobile element in the plant tissues and it plays an important role in photosynthesis through carbohydrate metabolism, osmotic regulation, nitrogen uptake, protein synthesis, translocation of assimilates. Salami and Saadat (2013) and Wang *et al.*,(2013) mentioned that potassium plays significant roles in increasing the root elongation, depth, maintaining turgor by reducing water loss and it enhances the photosynthetic products translocation from the source leaves to the sink organs which subsequently increases the plant dry matter and leads to an increase in the storage root growth. Neseim *et al.*, (2014) and Abdelaal *et al.*, (2015) found that, potassium application up to high rates increased the leaves fresh and dry weights. Nafei *et al.*, (2010) reported that potassium fertilizer increased the fresh weight/plant, total soluble solids % as well as sugar yield. In this regard, Fayed *et al.*, (2012) concluded that potassium application at rate 120 % of RDF fertilizer increased the yield and sugar production of sugar beet, as well as, juice purity and sucrose percentage. Similar trends were reported by Mehrandish *et al.,* (2012) and Seadh (2012), who found that potassium application increased root yield, shoot yield, impure sugar percent, pure sugar percent and sugar yield. While, Abdelaal *et al.*,(2015) and Hamad *et al.*, (2015) pointed that application of potassium at high rate increased the root length, root diameter, the percentage of α-N, Na, K as well as root and sugar yields. Potassium is essential for growth and is the main element used to maintain cell turgor (rigidity) and to regulate the water content of the plant **(**Rengel and Damon, 2008). Potassium play an important role in regulating osmotic potential, increasing water uptake ability of sugar beet plants (Zengin *et al.,* 2009).

MATERIALS AND METHODS

The present work was carried out to study the effect of three irrigation levels (irrigation after depletion of 40% from field capacity (Normal irrigation or well water), 60% from field capacity (Moderate irrigation) and 80% from field capacity (Severe water stress) and potassium fertilizer rates (0, 36 and 72 kg/feddan, one feddan = 0.42ha) at the Faculty of Agriculture, Moshtohor, Benha University, Egypt during two winter seasons 2013/14 and 2014/15 on growth, some physiological parameters, root yield and its components, as well as root quality of sugar beet (*Beta vulgaris* L.) cv. Farida. The experimental design was split-plot with four replications. The main plots were devoted to the irrigation treatments, while potassium fertilizer rates in sub-plots, respectively. The moisture percentages of field capacity was 40.07and 39.11 in the 1st season at the depths of 0-30 and 30-60 cm, while in the 2nd season was 41.02 and 38.81, respectively. The soil texture is clay, sand 33.08 %, silt 12.86%, clay 54.06%, pH 7.83, EC 1.26 dSm^{-1}, $CaCO_3$ 33.22 $mgkg^{-1}$, OM 19.9gkg^{-1}, available N 58.14, P16.13 and K 208.10 ppm as average of two seasons according to Jackson (1970). The experimental unit area was 10.5 square meters consisting of five ridges (3.5 m long and 60 cm width). Seeds were sown at a rate of 4 kg/feddan in 29th and 24th September 2013/14 and 2014/15 seasons, on one side of ridge in hills 15 cm apart between the hills, respectively. The preceding crop was maize in both seasons. Phosphorus fertilizer was applied before sowing at a rate of 150kg/feddan calcium super phosphate (15.5% P_2O_5). Nitrogen fertilizer has been added at a rate of 80 kg N/feddan as Urea (46% N) in two equal doses at 30 and 45 days after planting. Normal cultural practices of growing sugar beet were done according to the recommendations of this district. At 70, 90 and 105 days after planting (DAP) random samples of 5 sugar beet plants from each plot were taken to estimate the number of leaves per plant, fresh and dry weights (g) in the whole plant. At the same time of growth periods free proline was determined in fresh leaves material according to the method described by Bates *et al*. (1973). Total carbohydrates in dry leaves were determined according the methods described by Dubois *et al*. (1956). Osmotic pressure in the cell sap of fresh leaves was also estimated by using hand refractometer; the corresponding values of osmotic pressure (Atm) were then obtained from tables given by Gusev (1960).

At harvest time, a sample of 5 plants was randomly taken from each plot to determine the following characteristics:

1- Root length (cm).
2- Root diameter (cm).
3- Root weight (g/plant).
4- Top weight (g/plant).
5- Root yield (ton/feddan).
6- Top yield (ton/feddan).
7- Gross sugar yield (ton/feddan) = Root yield (ton/feddan) x gross sugar (%).
8- White sugar yield (ton/feddan) = Root yield (ton/feddan) x white sugar (%).
9- Loss sugar yield (kg/feddan) = Root yield (kg/feddan) x loss sugar (%).

Root Quality

A representative sample of sugar beet roots from each treatment was taken to estimate the technological characteristics as follow:

Total Soluble Solids (TSS %): It was measured in juice of fresh roots by using hand refractmeter.

Sucrose % (Gross Sugar %): Sucrose (expressed as Pol %) in fresh samples by Automatic Sugar Polarimetric according to McGinnus (1971).

Purity %: Purity % was calculated according to the following equation:

$$Purity\% = \frac{Sucrose\%}{TSS\%} x100$$

Sodium and Potassium Contents in the Juice: By auto analyzer described by Cooke and Scott (1993).

Alpha Amino Nitrogen Content in meq/100 g of Root: was determined by Automatic Sugar Polarimetric.

Extractable White Sugar %: calculated according to Harvey and Dutton (1993) as follow:

$$Z_B = \text{pol}-[0.343(K+Na) + 0.094\ N_{Bi} + 0.29]$$

Where:

Z_B = Corrected sugar content (% per beet) or extractable white sugar

Pol = Gross sugar %

N_{Bi} = α-amino-N determined by the “blue number method”.

Loss Sugar % = Gross sugar % - white sugar %

Statistical Analysis: The analysis of variance procedure of split-split plot design according to Snedecor and Cochran (1980) by using CoStat programme. The combined analysis of two seasons was done according to Steel and Torrie (1980) and the treatments means were compared using Duncan's Multiple Range Test (1955) at 5% of probability and LSD test at 5% of probability used for the interaction between irrigation, weed control treatments and potassium fertilizer levels.

RESULTS AND DISCUSSION

Effect of water stress

Data presented in Table 1 indicated that the differences between the three water stress levels concerning the studied characters i.e., number of leaves, fresh and dry weights of the top /plant at 75, 90 and 105 days after planting were significant at all growth stages in the combined analysis of two successive seasons. Number of leaves/plant was differed among the three water stress levels; irrigation after depletion of 40% from field capacity was superior in increasing number of leaves/plant at all growth stages than the other two water stress levels (Irrigation after depletion of 60 and 80% from field capacity). Also, Irrigation after depletion of 40% from field capacity had more fresh weight of the top /plant and also dry matter accumulation/plant in comparison to irrigation at 60 or 80% FC. Choluj *et al.,* (2004) indicated that the growth of sugar beet plants when expose to drought stress applied at different growth stages was affected, which imposed to moderate water stress resulted in reduction dry matter accumulation and leaf assimilatory expansion when imposed at successive growth stages, especially in the case of earlier stress application. Mohammadian *et al.,* (2005) stated that leaf and shoot dry weights were decreased under drought stress compared to non-stress conditions and the decrease was more pronounced as the rate of stress increased. This result had been also reported by Neseim *et al*., (2014) they reported that drought stress has significantly reduced both fresh and dry weights of leaves at 130 and 180 days from planting.

Table 1: Effect of irrigation treatments and potassium fertilizer levels on some growth characters of sugar beet (combined analysis of 2013/14 and 2014/15 seasons).

Treatments		Number of leaves/plant			Fresh weight of the top			Dry weight of the top		
		Days after sowing								
		75	90	105	75	90	105	75	90	105
Irrigation treatments	40% from	16.26a	18.46	20.32a	201.21	238.58	271.00	22.78	28.33a	34.11a
	60% from	15.07b	17.12	18.79b	173.32	211.31	235.83	19.88	25.10b	30.69b
	80% from	14.42c	16.47	17.98c	163.26	197.98	207.98	18.93	23.53c	28.18c
K-levels (Kg/fed.)	0	13.54c	15.40	16.91c	160.06	192.39	212.20	18.33	22.86c	27.62c
	36	15.68b	17.83	19.51b	184.01	221.73	244.59	21.07	26.34b	31.79b
	72	16.53a	18.83	20.67a	193.73	233.75	258.02	22.18	27.76a	33.57a

The means followed by the same letter(s) in the same column are not significantly different (0.05).
DAP: Days after planting. FC: Field Capacity

Effect of Potassium fertilizer

The effect of potassium treatment on the studied growth parameters indicating that in both seasons, number of green leaves/ plant as well as total fresh weight/plant and total dry weight/plant at all growth stages in the two growing seasons were increased significantly by increasing potassium fertilizers rates up to 72 kg K/feddan. There is a gradually increased in these growth characters as plants advanced in plant age up to 105 DAP. Such increases in these characters estimated by 22.84, 21.59 and 21.51% by applying high potassium rate (72 kg K/feddan) at 105 DAP, respectively (Table 1). Other studies reported that potassium increased the fresh weight/plant (Nafei *et al.*, 2010 and Abido 2012). Also, the growth characters (shoot weight) were significantly increased by applying potassium up to 120 Kg K_2O ha^{-1} (Hellal *et al.*, 2013). These results are in harmony with findings of Abdelaal *et al.*, (2015), who cleared that fertilization of potassium at high rate of 48 kg K_2O/feddan gave the highest values of growth characters, while application of potassium at rate of 24 kg K_2O/feddan recorded the lowest values in all characters (Table 1).

Effect of the interaction between water stress levels and potassium fertilizer levels

Data presented in Table 2 indicated that the interaction between irrigation treatments and potassium fertilizer levels were significantly different in all growth characters at all growth stages. Data in Table 2 cleared that sugar beet plants produced more leaves when receiving more K rates during the three growth stages. Irrigation sugar beet plants with full water (40% FC) was the best followed by irrigation with moderate irrigation (60% FC) resulted in more number of leaves, fresh weight and dry weight of the top /plant when receiving high K rates up to 72 kg K_2O/feddan at all growth stages in both seasons. However, when plants exposed to severe drought stress (80% FC) in combination with high K rate decreased all growth characters at all growth stages. Similar trends were reported by Neseim *et al.,* (2014), found that increasing the applied of potassium fertilizer from 50 to 75 kg/feddan subjected under water stress conditions increased root and leaves growth; fresh and dry weights of roots and leaves, root diameter and number of leaves as well as root to shoot ratio at 130 and 180 days from planting. Our results indicated also the highest number of leaves (21.94), top fresh weight (292.29 g) and top dry weight (36.81 g) were obtained by applying well water in combination of high K rate at 105 DAP, respectively, while the lowest (15.93,184.73 g and 25.03 g) was produced with plants subjected to severe water stress in combination with untreated potassium. This is means that K is needed for vital processes and its beneficial effect in translocation of carbohydrates to the storage organs. These results are in agreement with those obtained by Choluj *et al.*, (2004), Abo Shady *et al.*,(2010) and Abdelaal *et al.*, (2015), who pointed that fertilization of potassium at rate of 48 kg K_2O/feddan gave the highest values of growth characters, while application of potassium at rate of 24 kg K_2O/feddan recorded the lowest values in all characters.

Table 2: Effect of the interaction between irrigation treatments and potassium fertilizer levels on some growth characters of sugar beet (combined analysis of 2013/14 and 2014/15 seasons).

Irrigation from FC %	Potassium Fertilizer (kg/faddan)	Number of leaves/plant			Fresh weight of the top /plant			Dry weight of the top /plant		
		Days after sowing								
		75	90	105	75	90	105	75	90	105
40	0	14.57	16.50	18.17g	181.48	213.73f	242.94	20.55	25.39f	30.61e
	36	16.76	18.98	20.84b	206.69	244.98	277.78	23.39	29.08b	34.90b
	72	17.47	19.90	21.94a	215.47	257.03	292.29	24.39	30.52a	36.81a
60	0	13.33	15.12	16.64h	153.97	187.75	208.95	17.67	22.31h	27.20g
	36	15.47	17.59	19.25e	177.62	216.97	242.19	20.38	25.77d	31.52d
	72	16.42	18.66	20.49c	188.37	229.22	256.34	21.60	27.22c	33.36c
80	0	12.74	14.57	15.93i	144.74	175.68i	184.73	16.78	20.89i	25.03h
	36	14.83	16.91	18.44f	167.70f	203.24	213.79f	19.44	24.15g	28.96f
	72	15.70	17.93	19.57d	177.34	215.00	225.43	20.56	25.54e	30.54e

The means followed by the same letter(s) in the same column are not significantly different (0.05).
DAP: Days after planting. FC: Field capacity

Physiological parameters

Effect of water stress:

Drought is undoubtedly the most important environmental stress for sugar beet production and it is becoming an increasingly severe problem in many regions of the world and maintenance of sugar beet water pressure during water deficit is essential for continued growth and can be achieved by osmotic adjustment mechanisms resulting from the accumulation of compatible solutes (such as proline, sugars and sucrose) in the cytoplasm (Verbruggen and Hermans, 2008 and Passioura, 2007). Data presented in Table 3 showed that application of different irrigation treatments affected on osmotic pressure, proline accumulation in fresh leaves and total carbohydrates in dry leaves of sugar beet plants at different growth stages. In general, there are gradually increased in osmotic pressure contents by increasing the plant age up to 105 DAP by applying all irrigation treatments. However, the plants exposed to severe drought stress (80% FC) increased the osmotic pressure in cell sap of sugar beet leaves at 75,90 and 105 DAP. On the other hand, the plants irrigated with well water (40% FC) recorded the lowest osmotic pressure in cell sap of leaves at all growth stages. The highest value (7.41 atm) was observed when plants subjected under severe water stress at 105 DAP; while the lowest

(5.80 atm) was recorded by applying 40% FC at 75 DAP. According to Simpson (1981) osmotic potential is a function of solute concentration in the cell, so the loss of water from the cell increased solute concentration which leads to reduction osmotic potential to more negative values. The adjustment of osmotic potential helps to maintain turgidity, which is necessary for continuing cell function and growth. Furthermore, Abd El Rahman *et al.*, (1986) noticed that water deficit increased the osmotic potential of peanut shoot sap. The accumulation of such compounds, mostly in the cytoplasm can protect cell membranes, proteins and metabolic machinery, which would preserve subcellular structure from damage as a result of cell dehydration (Di Martino *et al.*, 2006). Unfortunately, many investigations have not clearly differentiated between the osmoprotection and osmotic adjustment mechanisms and their respective roles in water-deficit response. It is often assumed that the increase in cellular osmolarity which results from the accumulation of compatible solutes is accompanied by influx or reduced efflux of water from cells, thus resulting in higher turgor and cell expansion (Zhang *et al.*, 1999).

Table 3: Effect of irrigation treatments and potassium fertilizer levels on some physiological characters of sugar beet (pooled data of two successive seasons).

Treatments		Osmotic pressure of leaves (Atm)			Proline content in fresh leaves (μmole/g fresh wt.)			Total carbohydrates in dry leaves (mg/g DW)		
		Days after sowing								
		75	90	105	75	90	105	75	90	105
Irrigation treatments	40% from	5.86	6.07	6.14	3.05	2.80	3.23	79.27	86.62	98.03
	60% from	6.20	6.36	6.46	3.53	3.34	2.93	75.45	80.78	88.61
	80% from	6.23	6.97	7.41	3.49	3.94	4.63	74.37	78.75	82.53
K-levels (kg/fed.)	0	6.34	6.69	6.88	3.52	3.53	3.74	72.57	78.09	86.11
	36	6.00	6.38	6.60	3.33	3.32	3.59	77.04	82.63	90.62
	72	5.95	6.33	6.54	3.23	3.23	3.46	79.48	85.04	93.07

DAP: Days after planting. FC: Field Capacity

The results in Table 3 also cleared that when plants exposed to severe drought stress the free proline accumulation was increased gradually as plant advanced in age, while irrigated plants with moderate irrigation or the plants received well water decreased the accumulation of free proline in the leaves, where the contents of free proline was decreased up to 2.80 and 2.93 µmole/g fw with applying normal or moderate irrigation at 90 and 105 DAP, respectively. On the other hand, the plants subjected under severe water stress produced highest proline content (4.63 µmole/g fw). Despite the close association between free proline accumulation and water shortage found in numerous works, proline concentration has not been considered yet as a safe parameter for describing the plant ability to withstand stress. Although the importance of proline accumulation in the adaptation of sugar beet plants to environmental stress has been demonstrated, information on signaling mechanisms that regulate proline synthesis and degradation is scarce. Liu *et al.,* (2011) reported that proline content increased only under moderate stress. Prolonged drought treatments significantly increased proline content under mild and/or moderate stress and severe drought stress. While, Nayyar and Walia (2003) pointed that under drought conditions, the accumulations of proline and soluble sugars seemed to be associated with drought tolerance in many plant species. The rate of proline accumulation was significantly higher in drought-tolerant cultivars than drought-sensitive cultivars of wheat.

Concerning, the total carbohydrates in the dry leaves of sugar beet plants, in general applied the all irrigation treatments showed a gradually decrease in the total carbohydrates by increasing the percentage of water depletion up to 80% FC at 75,90 and 105 DAP. However, at 105 DAP the total carbohydrates was increased up to 98.03 and 88.61mg/g dw when plants irrigated with well water or received moderate irrigation at 105 DAP, respectively. On the other hand, the plants irrigated with 80% FC produced the lowest total carbohydrates content (74.37 mg/g dw) (Table 3). Soluble sugars also contributed to improving drought tolerance of sugar beet (Choluj *et al.,* 2008).

Effect of potassium fertilizer

Sugar beet is classified as a plant that needs high potassium requirements, where more of it is absorbed by sugar beet than any other nutrient element. Potassium is greatly required by sugar beet. It is very mobile in plant tissues and was found throughout the plant. Data presented in Table 3 indicted that the applied of potassium fertilizer at different rates was affected on osmotic pressure, proline accumulation in the leaves and total carbohydrates in dry leaves. In general, at all growth stages the increasing of potassium application from 0 to 36 and /or 72 kg/feddan decreased the osmotic pressure in cell sap and also in proline content. Also, the contents of both osmotic pressure and proline were increased with increasing in plant age up to 105 DAP. In this connection, Fisher (1968) concluded that enough K^+ together with an equivalent amount of anion could account for decreasing osmotic pressure of guard cells which occur when stomata open. The highest contents (6.88 atm and 3.74 mg/g fw) were obtained with unfertilized treatments at 105 DAP, while the lowest (5.95 atm and 3.23 mg/g fw) were obtained by high rate of potassium (72 kg/feddan) at 75 DAP, respectively. On contrary, the total carbohydrates took an opposite trend, where by increasing the potassium up to high rate increased the total carbohydrates at all growth stages. Also, it showed a gradually increased as plants advanced in age up to 105 DAP. Application of high potassium rate produced highest (93.07 mg/g dw) at 105 DAP, while the unfertilized plants produced the lowest (72.57 mg/g dw) at 75 DAP, respectively (Table 3).

Effect of the interaction between irrigation levels and potassium fertilizer rates:

Applied of all irrigation treatments in combination with all potassium fertilizer rates increased the osmotic pressure in cell sap of leaves as plant age was advanced (Table 4). While, at the same treatments it was decreased gradually with increasing potassium rates up to high rate at 75, 90 and 105 DAP. However, the plants exposed to severe drought stress associated with potassium rates produced higher values of osmotic pressure than that obtained by other treatments received moderate or well water associated with the same potassium rates at all growth stages. McCree and Richardson (1987) reported that sugar beet plants posses on effective mechanism for osmotic adjustment. Synthesis of solutes should increase the osmotic pressure of cells to stabilize the water status of tissues. In this context, the proline content was increased only at 105 DAP with applying all irrigation treatments in combination with all potassium rates, where applied of 80% FC in combination with potassium rates resulted an increase in proline content compared to the treatments received 60% or 40% FC in combination with the same potassium rates at 105 DAP. The correlation between the degree of stress and proline concentration suggests, indeed, that the accumulation of proline really is useful indicator of stress in sugar beet (Putnik-Delić *et al.,* 2010). On the other hand, the total carbohydrates showed an increase as plants advanced in age at the same conditions, while on contrast it was decreased gradually with increasing potassium rates up to 72 kg/fad. Application of normal irrigation x high potassium rate produced highest total carbohydrates at 105 DAP (Table 4). Many tissues of stressed plants are likely to have an increased demand for rapidly metabolizable carbohydrate in order to initiate the responses that would guarantee stress tolerance. The mobilization of stored carbohydrates could increase the glucose content of the root as a consequence of sucrose catabolism (Hasegawa *et al.,* 2000). Stored carbohydrates could also be mobilized in order to synthesize proline to cope with drought stress. This fact allows the metabolism of carbohydrates and the synthesis of stress molecules whenever the environmental factors promote the response. In addition, K is needed for vital processes and its beneficial effect in translocation of carbohydrates to the storage organs. Saxena (1985) showed that K may favorably influence water relations of plants and maintain yield under water stress. Also, the osmotic pressure of the storage root was decreased with increasing K nutrition. Also, the osmotic pressure of the storage root was decreased with increasing K nutrition.

Table 4: Effect of interaction between irrigation treatments and potassium fertilizer levels on some physiological characters of sugar beet (pooled data of two successive seasons).

Irrigation from FC %	Potassium Fertilizer (kg/faddan)	Osmotic pressure of leaves			Proline content in fresh leaves (µmole/g fresh wt.)			Total carbohydrates in dry leaves (mg/g DW)		
		Days after sowing								
		75	90	105	75	90	105	75	90	105
40	0	6.08	6.29	6.34	3.23	2.99	3.37	75.44	82.83	94.24
	36	5.77	5.99	6.06	3.00	2.77	3.23	79.99	87.29	98.73
	72	5.73	5.94	6.01	2.90	2.65	3.08	82.37	89.73	101.13
60	0	6.47	6.57	6.71	3.68	3.52	3.07	71.57	76.96	84.70
	36	6.09	6.28	6.37	3.51	3.29	2.94	76.13	81.54	89.29
	72	6.05	6.24	6.30	3.41	3.22	2.77	78.64	83.85	91.84
80	0	6.48	7.22	7.58	3.64	4.09	4.77	70.70	74.85	78.79
	36	6.14	6.87	7.35	3.47	3.90	4.61	75.00	79.45	83.20
	72	6.06	6.82	7.30	3.38	3.81	4.52	77.43	81.94	85.60

DAP: Days after planting. FC: Field Capacity

Yield and yield components

Data presented in Table 5 indicated that the yield and yield components of sugar beet plants were significantly affected by applying different levels of water depletion from FC and different potassium fertilizer rates. In general, the all yield and yield components were increased with applying high rate (72kg/faddan) of potassium followed by applying 36 kg K/faddan under all water depletion levels. However, under the same levels of water depletion the untreated plants produced the lowest values of all yield and yield components. Under all water depletion there are gradually increases in root and top yields/plant with increasing potassium fertilizer up to 72 kg/faddan, however irrigation sugar beet plants with normal irrigation (40% FC) produced the highest root and top yields/plant (723.15 and 476.89g), while the lowest (576.65 and 360.63g) with untreated plants subjected under severe drought stress (80% FC). In this context, the root length showed an increase with increasing potassium rates with all irrigation treatments, however the highest root length (40.22 cm) was obtained when plants exposed to severe water stress and applied potassium at the rate of 72kgK/faddan. On contrary, plants received well water (40% FC) produced the least root length (30.64 cm) with unfertilized plants. Root diameter take an opposite trend in comparison to root length, it was increased by increasing potassium rates up to high level under all water depletion levels, however application of high level of potassium had the highest root diameter (8.55cm) when the plants irrigated with normal irrigation, while the unfertilized plants had the least root diameter (5.59 cm) when sugar beet plant exposed to severe drought stress (Table 5).These results are in agreement with those obtained by Abo-Shady *et al.* (2010), who reported that higher root length and diameter might be possible by the application of relatively low amounts of irrigation water with increasing K application. The increases in root length and diameter may be due to increasing in photosynthesis and translocation as assimilates to storage root by applying K on plant (Samwel *et al*., 1990 and Cooke and Scott, 1993). Concerning, the root and top yields (ton/feddan), it was observed that were increased gradually with increasing potassium up to high levels under all irrigation treatments. Such increase in root yield may be attributed to the increase of dry matter, transportation, accumulation and to some extent to an increase of root length and diameter. Hassanli *et al*. (2010) found that both the sugar beet yield (root yield) and sugar yield (pure sugar) were significantly affected by the irrigation interval. Also, the role of K could be explained through its need as cofactor (enzymes activator) for different enzymes. In addition, K is needed for vital processes and its beneficial effect in translocation of carbohydrates to the storage organs. Saxena (1985) showed that K may favorably influence water relations of plants and maintain yield under water stress. The present results indicated also, irrigation plants with normal irrigation resulted in the highest root and top yields (19.97 and 9.18 ton/feddan), while the plants exposed to severe drought stress with unfertilized plants produced the least root and top yields (14.42 and 6.97 ton/faddan), respectively. The same trends were noticed with gross, white and losses sugar yields (Table 5). White sugar yield is an important yield parameter for sugar beet because it is useful form of sugar that the consumer uses. Also, the most sugar losses in sugar factories resulted from the sugar in molasses, which is not crystallized. It is estimated by the major non-sugar components in the beet. Although the efficiency of sugar recovery depends to a large extent on the factory equipment, the beet quality is by fact the most important parameters affecting the process (Bosemark, 1993). Ramazan *et al.* (2011) and Soleymani *et al.*, (2012) found that increasing water deficits resulted in a relatively lower root and white sugar yields, while Mehrandish *et al.*, (2012), Tohidloo *et al.*, (2012) and El–Hawary *et al.*, (2013) indicated that decreasing irrigation water quantity reduced the root yield of sugar beet. Abo-Shady *et al.* (2010) showed that deficit irrigation reduced yield, gross sugar. The reduction in sugar yield due to decreasing irrigation water quantity may be attributed to the reduction effect of decreasing quantity of irrigation water on crop growth rate which led to decreased root yield/faddan resulted in decreasing sugar yield/faddan. These results are in harmony with those of El-Hennawy and El-Hawary (1995) and Ramazan *et al.* (2011). On the other hand, Emami (1999) and Seadh (2012) mentioned that sugar yield was significantly increased by increasing potassium rate. In addition, El-Taweel (1999) and Tawfic and Mostafa (2012) observed that moderate amount of K was enough to produce the highest value of root and sugar beet yield.

Table 5: Yield and yield components of sugar beet as affected by irrigation treatments and potassium fertilizer levels (combined analysis of 2013/14 and 2014/15 seasons).

Irrigation from FC %	Potassium Fertilizer (kg/faddan))	RW	TW	RL	RD	RY	TY	GSY	WSY	LSY
40	0	695.63c	456.6	30.64i	7.22	17.70	8.06e	2.96g	2.54g	418.05e
	36	717.98b	473.6	33.54	8.27	19.37	8.99b	3.44b	2.96b	479.24b
	72	723.15a	476.8	34.39f	8.55	19.97	9.18a	3.62a	3.11a	509.40a
60	0	640.31f	396.7	33.41	6.20	15.78	7.43h	2.72h	2.33h	387.66h
	36	658.71e	408.7	36.63	7.10	17.26	8.21d	3.16e	2.73e	436.52d
	72	663.89d	412.5	37.38	7.37	17.79	8.43c	3.33c	2.87c	460.49c
80	0	576.65i	360.6	35.91	5.59i	14.42	6.97i	2.62i	2.26i	354.20i
	36	593.03h	371.7	39.26	6.42	15.78	7.73g	3.05f	2.65f	397.08g
	72	599.09g	374.8	40.22	6.64	16.26f	7.93f	3.20d	2.79d	415.56f

RW: Root weight (g), TW: Top weight (g), RL: Root length (cm), RD: Root diameter (cm), RY: Root yield (ton / fad.), TY: Top yield (ton / fad.), GSY: Gross sugar yield (t/fad), WSY: White sugar yield (t/fad) and LSY: Losses sugar yield (kg/fad), The means followed by the same letter(s) in the same column are not significantly different (0.05). FC: Field Capacity

Quality parameters

In general, applied of all irrigation treatments in combination with high rate of potassium resulted in an increase in sucrose %, however applied of 80% FC in combination with 72 kg 23K/faddan produced the highest sucrose percentage (19.17) followed with applying 60% FC (18.21) under the same potassium level (Table 6). On the other hand, irrigated plants with 40% FC in combination with untreated plants resulted in the lowest sucrose percentage (16.28). Also, application of 80% FC in combination with 36 or 72kgK/faddan produced an increase in purity percentage (91.18 and 92.23), respectively, while the plants had no potassium fertilizer produced the least purity percentage (84.38) when irrigated with well water. Ibrahim *et al.* (2002) and Hilal (2005) found that purity percentage was significantly increased by increasing K fertilizer rates and water stress several weeks before harvest. Also, 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 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. Concerning, the K content in juice, the results showed a gradually increase by increasing potassium up to high rate under all irrigation treatments, however under the three irrigation treatments the contents of K seem to be the same, which no differences was noticed among them. On contrary, Na and α-amino nitrogen contents were decreased gradually under all irrigation treatments; however the lowest Na and α-amino nitrogen contents (1.65 and 2.48 meq/100g) were obtained by using normal irrigation in combination with high potassium rate, respectively. Jahad Akbar *et al.*(2002) showed that deficit irrigation reduced sodium of roots and increased harmful nitrogen. They also stated that with increasing irrigation water, root sodium increases and percent sugar beet roots decreases. Also decreasing irrigation water applied gave the lowest water absorption caused reduction uptake of nitrogen and potassium. On the other hand, sucrose % increased with decreasing irrigation levels due to decreasing root water content which led to increasing sucrose concentration in root cells (Ramazan *et al.* 2011). The results in Table 6 also indicated that TSS %, white and loss sugar yields were gradually increased by increasing potassium fertilizer up to high rate with all irrigation treatments, where the applied well water with unfertilized treatment showed the least content of these traits. However, Herlihy (1989) reported that the agronomic effect of K was to increase yield rather than quality, consistent with its dominant rate in increasing the sink capacity and mass of the storage root. Loue (1985) reported that application of 200 kg K_2O/ha increased sugar and K contents, whilst it reduced the harmful contents of alpha-amino-N and Na in sugar beet roots. Emami (1999) and Seadh (2012) mentioned that sugar percentage was significantly increased by increasing potassium rates. On the contrary, Salami and Saadat (2013) mentioned that the increased of cations contents might be associated with a decrease in the sucrose and purity percentage. In addition, El-Taweel (1999) and Tawfic and Mostafa (2012) observed that moderate amount of K was enough to produce the highest value of juice quality as sucrose percentage, purity percentage, whereas Carter (1986) pointed out that sucrose recovery efficiency from the sugar beet depends on the amounts and types of root and extracted juice impurities. The proportion and amount of K in the beet plant may be also important because of a positive correlation between K-fertilization and sucrose concentration in root. El-Sheref (2006) found that the gross sugar percentage in root juice was not significantly affected by increasing potassium rates from 24 to 48 kg K_2O/fad. On the other hand, the data collected by Zengin *et al.* (2009) indicated that gross and white sugar content was increased significantly by increasing K-fertilizer rates.

Table 6: Root quality of sugar beet plants as affected by irrigation treatments and potassium fertilizer levels (pooled data of two successive seasons).

Irrigation from FC %	Potassium Fertilizer (kg/faddan))	Sucrose (%)	Purity %	TSS (%)	K (meq/100 g beet)	Na (meq/100 g beet)	α-amino-N (meq/100 g beet)
40	0	16.28	84.38	19.30	3.50	1.77	2.52
	36	17.25	86.38	19.98	3.84	1.77	2.46
	72	17.61	86.30	20.40	4.14	1.65	2.44
60	0	16.79	86.12	19.49	3.51	2.03	2.58
	36	17.85	88.23	20.23	3.83	1.91	2.53
	72	18.21	88.38	20.60	4.15	1.78	2.51
80	0	17.67	89.73	19.69	3.53	2.01	2.69
	36	18.78	92.18	20.37	3.85	1.85	2.60
	72	19.17	92.23	20.78	4.17	1.69	2.48

FC: Field Capacity

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