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Impact of Potassium Fertilization and Cultivation Methods on Productivity and Water Use Efficiency of Sugarcane

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ABSTRACT

A field experiment was conducted at Shandaweel Agricultural Research Station, Sohag Governorate, Egypt (latitude 26° 34' N and longitude 31° 42' E and Elevation 61 meters from the sea level) for the two successive seasons of 2014/ 2015 (plant cane) and 2015/ 2016 (first ratoon), to examine the effect of potassium fertilization (0, 24 and 48 kg K_2O fed^{-1}) on sugarcane grown in clay loam soil under two cultivation methods, i.e. rows or on raised beds (water limited conditions). The experiment was laid out in a split plot design with four replicates. Results indicated that decreasing amount of irrigation water by growing sugarcane on raised beds caused significantly reduction in stalk height and milleable cane yield of the plant cane and 1st ratoon, while stalk diameter was significantly increased. N concentration in leaves and sugar yield were not significantly affected by cultivation methods in plant cane and first ratoon. The highest value of K % was obtained with growing on rows having normal water quantity in the 1st ratoon. Average of CU (actual evapotranspiration) values were 5233 and 4721.5 m^3 fed^{-1} in plant cane and 1st ratoon, respectively under growing on rows which were reduced by 25.66 and 29.77 % growing under raised beds conditions. Water use efficiency (WUE) was increased with decreasing irrigation water quantity under growing on raised beds conditions. On the other hand, applying 24 kg K_2O fed^{-1} significantly increased stalk height and milleable cane yield compared with control (without K) and 48 kg K_2O fed^{-1}. However, using 48 kg K_2O fed^{-1} gave the highest values of N and K% in leaves as well as stalk diameter and sugar recovery (SR %) in plant cane and 1st ratoon, except, purity (%) and sugar yield which were significantly increased by this rate in the 1st ratoon only. Generally, the highest significant values of stalk height and milleable cane yield were recorded with application of 24 kg K_2O fed^{-1} under normal irrigation water amount growing on rows. Whereas, a high rate of potassium (48 kg K_2O fed^{-1}) under growing on raised beds gave higher values of sugar recovery (%), sugar yield, purity (%) and WUE in the1st ratoon.

Keywords: Potassium fertilizer, cultivation methods, sugarcane, yield, purity and WUE

INTRODUCTION

Availability of water in soil together with an adequate supply of potassium are considered essential factors affecting the accumulation and storage of nutrients by plants, making its essential for the healthy growth and development of sugarcane crop. Sugarcane (*Saccharum officinarum L.*) is a high biomass producing crop that requires substantial input of both water and nutrients to achieve maximum yields. Water present about 75 % of sugarcane stalks and has a vital role in absorption and transporting of mineral nutrients from soil to plant roots and shoots. Wiedenfeld (2004) revealed that growth and yields of sugarcane responded primarily to the total amount of water applied. Mathew and Varughese (2005) also reported that irrigation positively influenced all attributes and nutrient uptake and appreciably increased the cane yield. They obtained the highest yield of 107.40 t ha^{-1} with water use efficiency of 1.28 t ha^{-1} m^3 water. Azevedo *et al.,* (2006) found that increases in sugarcane yield are directly and linearly correlated with increases in the consumption of water. Wiedenfeld and Enciso (2008) found that increasing irrigation levels increased sugar and sugarcane yields and sucrose content. Ghaffar *et al.,* (2013) reported that maximum cane and sugar yields were obtained where normal irrigation water was applied. Conversely, the application of a high irrigation water volume does not necessarily result in high yield. Solomon *et al.,* (2000) noted that excess water impede aeration due to water logging, causing yield reduction and also water losses Singh *et al.,* (2007) stated that water use by the ratoon crop was higher with increasing soil moisture regimes. WUE decreased with increasing irrigation water applied. Inadequate water supply acts as a retarding factor in nutrient uptake and reduces the yield proportionately. Ahmad *et al.,* (2002) reported that cane yield and commercial cane sugar gradually decreased as the moisture stress increased. In Egypt, sugarcane production faces some problems which developed by time. The main problems nowadays are the limited freshwater supply and water requirements which increased accompanying the increase in temperature degrees and wind speed as well as the reduction in the relative humidity. Thus, the first important step of Egyptian strategy is increasing productivity from unit area with the lowest irrigation water quantity and saving the irrigation water. Moreover, sugarcane is an exhaustive crop and depletes the soil potassium heavily. Potassium is an essential nutrient for sugarcane production and fulfils a number of important roles in plant growth. Its role in regulating the uptake of water and leaf stomatal opening in plants is of particular interest in view of the periodic drought conditions that affect the sugar industry (Gopalasundarum *et al*., 2012 &Wood and Schroeder 2004). In pot experiments, Sudama *et al*., (1998) showed that application of K at time of planting under water stress conditions significantly increased the stomatal diffusive resistance, thereby decreasing transpiration rate and increasing the leaf water potential, cane length, sucrose content in juice and cane yield. It also plays a significant role in controlling the hydration and osmotic concentration within the stomata guard cells. Presence of potassium makes sucrose production from simple sugars possible. This element contributes in production and neutralization of organic acids and increases product quality by balancing sugar and acids. It also strengthens cell walls and tissues and increases efficiency of nitrogen fertilizer (Mansouri, 2011). Many researchers recorded an increase of cane and sugar yields as a result of increasing the levels of potassium fertilization Kumar *et al.,* (2014), El-Geddawy *et al.,* (2015) and Gameh *et al.,* (2015). Jafarnejadi (2013) found that the highest sugarcane yield (147.5 ton ha^{-1}) was obtained from 200 kg ha^{-1} potassium chloride (1/4 at cultivation time and the rest in three times along with nitrogen fertilizer). Also, the highest sugar and purity percentages (12.9 and 89.7%) were obtained by this treatment. Hajjari *et al.*, (2015) showed that applying of potassium had no significant effect on stalk diameter. The highest stalk length (188.51cm), cane yield (111.62 ton ha^{-1}), sugar (10.86%) and purity (89.9%) were obtained in 200 kg K ha^{-1} as potassium sulfate. McCray and Powell (2016) noted that sugarcane yield and sucrose yield increased significantly to K fertilization in plant cane and first ratoon crop.

Therefore, the major objective of this study was to identify the appropriate potassium fertilizer level under water limited conditions for enhancing productivity and water use efficiency of sugarcane growing on raised beds under Sohag Governorate conditions.

MATERIALS AND METHODS

A field experiment was carried out at Shandaweel Agricultural Research Station, Sohag Governorate, Egypt (latitude 26° 34' N and longitude 31° 42' E and Elevation 61 meters from the sea level) in the two successive seasons of 2014/ 2015 (plant cane) and 2015/ 2016 (first ratoon) to study the effect of potassium fertilization of sugarcane grown on raised bed cultivation method (water limited conditions) on yield, and juice quality as well as water use efficiency (WUE) and consumptive use of water irrigation under surface irrigation system in Upper Egypt. Some physical and chemical properties of the experimental soil were analyzed before planting according to Black (1965) and Ryan *et al.,* (1996) as shown in Table1.

The experimental treatments were arranged in a split plot design with four replicates. The plot area was 21 m^2 (6×3.5 m^2). The main plots were allocated for two levels of irrigation water through two methods of cultivation, i.e. on rows and raised beds where the water amount was reduced by about 25-30% approximately. The sub plots were devoted for three levels of potassium application (0, 24 and 48 kg K_2O fed^{-1}). Each sub-plot consisted of six rows or three raised beds. Each row was 3.5 meters in length and 1.0 meter in width and each raised bed was 3.5 meters in length and 2 meters in width. The cane cuttings were planted on both sides of raised beds.

Table 1. Some physical and chemical properties of the experimental soil.

Properties	Value
Particle size distribution (%)	
Sand	24.11
Silt	47.46
Clay	28.43
Texture class	Clay loam
Bulk density (g cm^{-3})	1.34
Field capacity (% W/W)	27.6
Wilting point (% W/W)	15.5
Available water (%)	12.25
$CaCO_3$ (%)	2.70
pH (1:2.5 soil water susp.)	8.10
EC (dSm^{-1}, Soil paste ext.)	1.85
Organic matter (%)	1.46
Available macronutrients ($mgkg^{-1}$)	
N	25.31
P	10.76
K	218

Sugarcane variety G. 84-47 was planted on 20th of March 2014 and harvested after 12 months for plant cane and first ratoon. Phosphorus fertilizer as calcium super phosphate (15% P_2O_5) was added at the rate of 30 kg P_2O_5 fed^{-1} during the preparation of soil. Nitrogen fertilizer at the rate of 200 kg N fed^{-1} as urea (46% N) was splited into four equal doses; the first dose was added after two months from planting and the other doses were added at two- week intervals after the first one. The same rates of phosphorus and nitrogen were applied to the first ratoon. Potassium fertilizer was applied in the form of potassium sulphate (48 % K_2O) in two equal doses with the 1st and 4th nitrogen fertilizer doses. All treatments received the same sowing irrigation in plant cane, and the amounts of applied irrigation water were measured via a flow – meter attached to the irrigation pump in plant cane and first ratoon as shown in Tables 2 & 3. After 120 days from planting a random sample of plant top (Top visible dewlap (T.V.D.)) leaves was collected to determine N and K contents according to the method described by A.O.A.C. (1995).

Table 2. Amount of water (m^3 fed^{-1}) applied to plant cane (2014/2015) under the two cultivation methods and different levels of potassium fertilization.

Cultivation methods (A)	K-levels (kg K_2O fed^{-1}) (B)	No. of irrigation 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	T. water $m^3 fed^{-1}$/season	Mean
		Data of irrigation 10/4/2014	30/4	20/5	4/6	18/6	2/7	16/7	30/7	13/8	27/8	10/9	24/9	15/10	12/11	9/12	4/1/2015		
Row	Control	388	358	318	388	388	418	448	448	538	448	418	418	508	480	360	340	6664	416.5
	24	358	358	334	328	418	418	448	438	508	478	448	448	538	500	340	340	6700	418.8
	48	417	328	348	388	388	418	448	418	508	508	388	478	478	520	360	360	6753	422.06
Mean		387.7	348	333.3	368	398	418	448	434.7	518	478	418	448	508	500	353.3	346.7	20117	419.10
Raised bed	Control	300	240	258	300	300	328	328	328	388	358	328	358	328	320	280	260	5002	312.63
	24	328	260	288	328	300	276	328	358	350	358	328	300	388	340	300	240	5070	316.88
	48	358	240	228	328	300	300	358	322	418	328	328	300	358	360	260	240	5026	314.13
Mean		328.7	246.7	258	318.7	300	301.3	338	336	385.3	348	328	319.3	358	340	280	246.7	15098	314.54

Table 3. Amount of water (m^3 fed^{-1}) applied to first ratoon (2015/2016) under the two cultivation methods and different levels of potassium fertilization.

Cultivation methods (A)	K-levels (kg K_2O fed^{-1}) (B)	No. of irrigation 1	2	3	4	5	6	7	8	9	10	11	T. water m^3 fed^{-1}/season	Mean
		Data of irrigation 23/4/2015	18/5	7/6	23/6	11/7	28/7	18/8	14/9	10/10	3/11	16/12/2015		
Row	Control	560.6	528.6	488.0	405.6	600	648.0	660.0	642.2	600.4	620.0	620.0	6373.4	579.35
	24	432.2	497.2	478.8	406.2	600	666.0	682.2	640.0	600.0	607.0	627.8	6237.4	567.04
	48	502.0	466.0	454.8	418.0	600	664.4	684.2	643.8	598.40	603.6	640.0	6275.2	570.47
Mean		498.27	497.27	473.87	409.93	600	659.47	675.47	642.0	599.6	610.2	629.27	18886	572.30
Raised bed	Control	351.2	332.0	374.0	345.6	406.4	464.0	456.8	447.2	400.0	400.0	439.8	4417	401.55
	24	324.2	308.2	357.6	335.2	434.0	463.0	471.6	448.6	406.0	420.0	420.0	4388.4	398.95
	48	384.2	370.2	353.8	339.8	423.4	462.4	417.8	432.0	428.4	420.0	426.4	4458.4	405.31
Mean		353.20	336.80	361.8	340.2	421.27	463.13	448.73	442.6	411.47	413.33	428.73	13263.8	401.93

At harvest, plants of the two middle guarded rows and one raised bed of each treatment were harvested, topped and cleaned. Then, stalk height (cm), diameter (cm) and milleable cane yield (ton fed^{-1}) were recorded.

Juice quality and sugar yield:

A sample of twenty five stalks from each plot was taken at random, stripped, cleaned and squeezed to estimate the following traits.

Sucrose (%) of cane juice was determined using saccharometer according to **A.O.A.C. (1995).**

Juice purity percentage was calculated as in Satisha, *et al.,* (1996) using the follow formula: Juice Purity % = (Sucrose % ÷T.S.S %) ×100.

Sugar recovery percentage was calculated **according to Yadav and Sharma (1980).**

Recoverable sugar yield (ton fed^{-1}) was calculated according to the following equation as described by Mathur (1981), where:

Recoverable sugar yield (ton fed^{-1}) = cane yield (ton fed^{-1}) × sugar recovery%.

Water relations:

Actual water consumptive use (ET):

For determining water consumptive use, soil samples were collected just before and two days after each irrigation in 15cm increment from soil surface down to 60 cm of soil profile. Water consumptive use was calculated according to Israelsen and Hansen (1962) as follows:

$$CU = D \times Bd. \times (Q_1 - Q_2) / 100$$

Where:

CU = actual evapotranspiration ($m^3 fed^{-1}$).

D = irrigation soil depth (cm).

Bd. = bulk density of soil ($g\ cm^{-3}$)

Q_1 = percentage of soil moisture two days after irrigation.

Q_2 =percentage of soil moisture before next irrigation.

Seasonal water consumptive use:

The seasonal water use values for each treatment were obtained from the sum of water consumptive use of all irrigations from planting and until harvesting.

Water use efficiency (WUE):

Water use efficiency was calculated for all treatments according to the following formula (Vites, 1965).

$$WUE = Sugar\ (kg\ fed^{-1}) / water\ consumptive\ (m^3\ fed^{-1})$$

Statistical analysis:

Data were statistically analyzed according to Snedecor and Cochran (1980). Means of treatments were compared using the L.S.D. test at 5% probability.

RESULTS AND DISCUSSION

N and K % in leaves of sugar cane after 120 days from planting:

Data presented in Table 4 show that nitrogen concentration in leaves of sugarcane was not significantly affected by the two tested cultivation methods (rows and raised beds) in both plant cane and first ratoon. On the contrary, the irrigation in rows gave a pronounced significant effect on K % in leaves after 120 days from planting compared with the irrigation in raised beds in the 1st ratoon only.

Table 4. Effect of potassium fertilization and cultivation methods on N and K concentrations in leaves of the plant cane and first ratoon.

K- levels (kg K_2O fed^{-1}) (B)	N (%) Plant cane (2014/2015) Cultivation methods (A) Row	Raised bed	Mean	1st ratoon (2015/2016) Cultivation methods (A) Row	Raised bed	Mean
Control	2.20	2.17	2.19	2.15	2.14	2.15
24	2.35	2.28	2.32	2.23	2.19	2.21
48	2.43	2.40	2.42	2.32	2.27	2.30
Mean	2.33	2.28	----	2.23	2.20	----
L.S.D $_{0.05}$	A = N.S B = 0.084 A×B = N.S			A = N.S B = 0.027 A×B = N.S		
K-levels (kg $K_2O fed^{-1}$) (B)	K (%) Plant cane (2014/2015) Cultivation methods (A) Row	Raised bed	Mean	1st ratoon (2015/2016) Cultivation methods (A) Row	Raised bed	Mean
Control	1.70	1.68	1.69	1.55	1.51	1.53
24	1.87	1.82	1.85	1.76	1.69	1.73
48	1.96	1.90	1.93	1.84	1.75	1.80
Mean	1.84	1.80	----	1.72	1.65	----
L.S.D $_{0.05}$	A = N.S B = 0.060 A×B = N.S			A = 0.064 B = 0.042 A×B = N.S		

This significant effect may be due to that the availability of water in the soil increases the efficiency of nutrient absorption, especially with high – solubility nutrients such as nitrogen and potassium, since these will be available to the plants in the soil solution, thus facilitating the process of absorption (Dalri *et al.,* 2008).

In this connection, Costa *et al.,* (2016) found that increasing availability of water increased the accumulation of potassium in the leaves of sugarcane plants. However, nitrogen accumulation in leaves was not influenced by water treatments.

The effect of K fertilizer levels on nitrogen and potassium % in leaves of sugarcane plants was significant in plant cane and 1st ratoon. The results showed that the higher values of N and K% were obtained by adding the treatment of 48 kg K_2O fed^{-1} in both plant cane and 1st ratoon. The increments in N and K % in leaves of sugarcane plants with increasing the rates of potassium fertilizer application may be due to the role of potassium on plant nutrition, such as photosynthesis, translocation of nutrients, nitrogen uptake and synthesis of protein and starch (Hawkesford *et al.,* 2012). Also, increases in potassium accumulation in leaves may be linked to the crop ability to absorb large amounts of nutrients, especially when provided in excess (Silva *et al.,* 2007). Similar results were obtained by Ahmed and Ferweez (2004) who found that the highest values of N and K contents in cane leaves were recorded with applying 48 kg K_2O fed^{-1} in the two seasons. Kumar *et al.,* (2014) showed that application of potassium increased the K concentration in sugarcane index leaves (3rd whole leaf) at maximum growth stage for the first plant cane and ratoon crop.

The obtained results reveal that the interaction effect between cultivation methods (rows and raised beds) as well as K fertilizer treatments was insignificant on nitrogen and potassium % in leaves of sugarcane plants in plant cane and 1st ratoon.

Yield of sugarcane:

Data illustrated in Table 5 clear that stalk height (cm), stalk diameter (cm) and milleable cane yield (ton fed^{-1}) significantly affected by irrigation water quantities in both plant cane and 1st ratoon. The obtained results indicated that decreasing irrigation water quantity from 20117 m^3 in rows to 15098 m^3 in raised beds in the plant cane and from18886 m^3 in rows to 13263.8 m^3 in raised beds in the 1st ratoon reduced stalk height by 5.13 and 6.12 %, respectively. Similar trend was also observed with milleable cane yield which was significantly decreased by 9.42 and 7.74 % over the normal irrigation levels (on rows) in the plant cane and 1st ratoon respectively. While, applying irrigation water at raised beds resulted in the thickest stalk diameter compared to the other irrigation in both plant cane and 1st ratoon. These results may be due to the fact that water is an essential factor for the turgidity of leaf cells, lengthening of stalk cells as well as photosynthesis process, as mentioned by Van Dillewijn (1952), who stated that water is the most important food quantitatively for sugarcane. Higher irrigation levels caused more vegetative growth which resulted in dehydration and forced the conversion of total sugars to convertible sucrose and used them for growth compared to lower irrigation levels (Dorenboss and Kassam, 1979). Moreover, Rossler *et al.,* (2013) showed that water stress during the stalk elongation phase reduced cane yield by 6 to 11 t ha^{-1} (5 to 9 %). Such findings are in parallel with those of Bahrani *et al.,* (2009) who found that lower irrigation levels significantly decreased cane yield and the crop suffered the desiccating effect of high temperatures under water stress. Yahaya *et al.,* (2010) reported that length of milleable cane and cane yield reduced with increasing irrigation intervals in the two seasons. Ghaffar *et al.,* (2013) concluded that irrigation stress decreased the cane yield up to 47.17 % at 40 % moisture stress.

Table 5. Effect of potassium fertilization and cultivation methods on stalk height, stalk diameter and milleable cane yield in plant cane and first ratoon.

K- levels ($kg\ K_2O\ fed^{-1}$) (B)	**Stalk height (cm)**					
	Plant cane (2014/2015) Cultivation methods (A)			**1st ratoon (2015/2016) Cultivation methods (A)**		
	Row	**Raised bed**	**Mean**	**Row**	**Raised bed**	**Mean**
Control	276.75	255.30	266.03	308.67	288.00	298.34
24	285.25	273.38	279.31	321.83	300.83	311.33
48	277.50	267.75	272.63	310.00	293.22	301.61
Mean	279.83	265.48	----	313.50	294.02	----
L.S.D $_{0.05}$	A = 4.19 B = 3.08 A×B = 4.35			A = 3.86 B = 4.68 A×B = 6.62		
Stalk diameter (cm)						
K- levels ($kg\ K_2O\ fed^{-1}$) (B)	Plant cane (2014/2015) Cultivation methods (A)			1st ratoon (2015/2016) Cultivation methods (A)		
	Row	Raised bed	Mean	Row	Raised bed	Mean
Control	2.425	2.455	2.440	2.225	2.252	2.239
24	2.460	2.500	2.480	2.268	2.299	2.284
48	2.537	2.535	2.531	2.324	2.345	2.335
Mean	2.471	2.497	----	2.272	2.299	----
L.S.D $_{0.05}$	A = 0.024 B = 0.030 A×B = N.S			A = 0.032 B = 0.014 A×B =0.020		
cane yield ($ton\ fed^{-1}$) Milleable						
K- levels ($kg\ K_2O\ fed^{-1}$) (B)	Plant cane (2014/2015) Cultivation methods (A)			1st ratoon (2015/2016) Cultivation methods (A)		
	Row	Raised bed	Mean	Row	Raised bed	Mean
Control	62.40	56.28	59.34	61.30	56.40	58.85
24	67.28	61.70	64.49	65.07	60.70	62.89
48	65.90	59.18	62.54	63.60	58.17	60.89
Mean	65.19	59.05	----	63.32	58.42	----
L.S.D $_{0.05}$	A = 1.19 B = 1.76 A×B = 2.49			A = 2.67 B = 1.74 A×B = 2.46		

Concerning the effect of K fertilizer treatments, the results in Table 5 reveal that applying 24 kg K_2O fed^{-1} significantly increased stalk height and milleable cane yield compared with control (without K) or 48 kg K_2O

fed^{-1} in plant cane and 1st ratoon. Meanwhile, increasing K level up to 48 kg K_2O fed^{-1} significantly improved stalk diameter in plant cane and 1st ratoon. The increases in cane yield owing to K fertilizer level might be attributed to increasing nitrogen absorption which has increased dry matter therefore, stalks diameter increased. Also, potassium preparation is followed by cell enlargement due to potassium accumulation and lignifying of vessel systalk (Kholdbarin and Eslamzadeh, 2001). Potassium significantly increased the stomatal diffusive resistance, thereby decreasing transpiration rate, increasing the leaf water potential and thus increasing the size of cell, followed by sugar cane stalk elongation which resulted in yield increment as confirmed by Sudama *et al*. (1998). In this connection, Taha *et al.,* (2003) noted that potassium application significantly increased milleable cane diameter and cane yield in plant and ratoon crops. El-Geddawy *et al.,* (2015) found that increasing the applied dose of potassium fertilizer was accompanied by a significant increase in the values of stalk length and cane yield in both seasons. Hajjari *et al.*, (2015), Gameh *et al.,* (2015) and McCray and Powell (2016) showed that potassium sulfate significantly increased both stalk length and yield.

Data presented in Table 5 also exhibited that the interaction effect between cultivation methods (rows and raised beds) and potassium fertilizer levels were significant on stalk height and cane yield in plant cane and 1st ratoon. Also, stalk diameter followed the same trend in the 1st ratoon only. The highest values of stalk height (285.25 and 321.83cm) and cane yield (67.28 and 65.07 ton fed^{-1}) were recorded with normal irrigation water amounts in rows and using 24 kg K_2O fed^{-1} in plant cane and 1st ratoon, respectively. Moreover, the thickest stalk diameter value (2.345cm) was obtained with lower irrigation water quantity in raised beds and applying 48 kg K_2O fed^{-1} in the 1st ratoon crop. This increment in productivity of sugarcane may be due to the hydric soil conditions in the rhizosphere region are very important for the emergence and growth of sugarcane tillers, because most of the potassium is transported to the roots surface via diffusion; a process highly dependent on the soil water content according to Oliveira *et al.,* (2004).This trend was obtained by Karthikeyan *et al.,* (2003) reported that application of K up to 168.75 kg K_2O ha^{-1} increased cane length, cane diameter and cane yield under optimum amount of irrigation water.

Juice quality and sugar yield:

The results in Table 6 point out that sugar recovery (SR) percentage (%) in both plant cane and 1st ratoon was significantly affected by cultivation methods. The irrigation in rows induced significant increases in SR (%) which gave (2.11%) in the plant cane. While, the corresponding SR percentage in the first ratoon under irrigation in raised beds was (5.87%). Yet, purity percentage increased significantly by decreasing irrigation water quantity from 18886 m^3 in rows to 13263.8 m^3 in raised beds in the first ratoon only. The increase in purity percentage caused by decreasing irrigation water quantity (water stress) may be attributed to increasing sucrose percentage in stalk juice. These results are in accordance with those obtained by Yang *et al.,* (1995). On the contrary, sugar yield was not significantly affected by cultivation methods in plant cane and first ratoon.

Table 6. Effect of potassium fertilization and cultivation methods on sugar recovery, sugar yield and juice purity in plant cane and first ratoon.

K- levels (kg K_2O fed^{-1}) (B)	Sugar recovery (%)					
	Plant cane (2014/2015) Cultivation methods (A)			**1st ratoon (2015/2016) Cultivation methods (A)**		
	Row	**Raised bed**	**Mean**	**Row**	**Raised bed**	**Mean**
Control	12.73	12.70	12.72	11.69	13.12	12.41
24	12.73	12.75	12.74	12.60	12.52	12.56
48	13.68	12.90	13.29	13.02	13.86	13.44
Mean	13.05	12.78	----	12.44	13.17	----
L.S.D $_{0.05}$	A = 0.091 B = 0.111 A×B = 0.158			A = 0.203 B = 0.103 A×B = 0.146		
Sugar yield (ton fed^{-1})						
K- levels (kg K_2O fed^{-1}) (B)	Plant cane (2014/2015) Cultivation methods (A)			1st ratoon (2015/2016) Cultivation methods (A)		
	Row	Raised bed	Mean	Row	Raised bed	Mean
Control	7.94	7.15	7.55	7.17	7.40	7.29
24	8.56	7.87	8.22	8.20	7.60	7.90
48	9.01	7.64	8.32	8.28	8.06	8.17
Mean	8.50	7.55	----	7.88	7.69	----
L.S.D $_{0.05}$	A = N.S B = N.S A×B = N.S			A = N.S B = 0.202 A×B = 0.286		
Juice purity (%)						
K- levels (kg K_2O fed^{-1}) (B)	Plant cane (2014/2015) Cultivation methods (A)			1st ratoon (2015/2016) Cultivation methods (A)		
	Row	Raised bed	Mean	Row	Raised bed	Mean
Control	86.39	86.78	86.59	85.34	85.95	85.65
24	86.43	86.90	86.67	85.87	85.69	85.78
48	87.15	86.57	86.86	85.80	86.31	86.06
Mean	86.66	86.75	----	85.67	85.98	----
L.S.D $_{0.05}$	A = N.S B = N.S A×B = 0.342			A = 0.231 B = 0.238 A×B = 0.337		

For the effect of potassium fertilizer levels, data in Table 6 show that the high level of K fertilizer (48 kg K_2O fed^{-1}) gave the positive significant increases in SR percentage compared with the other levels of potassium in both plant cane and 1st ratoon. However, purity (%) and sugar yield were significantly affected by K fertilizer levels in the 1st ratoon only. The positive effect of potassium fertilization on SR and juice quality may be mainly due to the important role of K in encouraging translocation of sugars to the store tissue in the cane stalks, as well as the transformation of simple sugars to sucrose which cause an increase in sucrose and sugar recovery (Filho, 1985). This element contributes in production and neutralization of organic acids and increases product quality by balancing sugar and acids (Mansouri, 2011). In this connection, Kumar *et al.,* (2014) showed that sucrose (%) increased with application of 50 kg K_2O ha^{-1} for plant crop and ratoon crop. Hajjari *et al.*, (2015) found that applying 200 kg K ha^{-1} gave the highest values of sugar % and purity %. McCray and Powell (2016) also noted that sucrose yield increased significantly by K fertilization in both plant cane and first ratoon.

With respect to the interaction of the two studied factors, data in Table 6 reveal that the addition of 48 kg K_2O fed^{-1} gave the high significant values of sugar recovery and purity (%) as well as sugar yield (ton fed^{-1}) under irrigation in rows in plant cane and 1st ratoon, respectively. While, the same rate of K fertilizer under irrigation in raised beds gave a similar significant effect on these traits in the1st ratoon.

Crop –Water relations:

Seasonal applied irrigation water:

Total number of irrigation water application varied from16 in plant cane to 11 in first ratoon Tables 2 & 3. Total seasonal applied water quantities under irrigation in rows were 20117 and 18886 m^{-3} fed^{-1} and which are exceeded those with irrigation in raised beds by 33.24 and 42.39 % in plant cane and first ratoon, respectively. This expected result and it is attributable to more irrigation events applied under irrigation in rows. Abdel Reheem (2010) found that the lowest values of water applied were 7856.43 and 8565.57 m^{-3} fed^{-1} obtained from transplanting method and normal planting in beds respectively.

Water consumptive use (CU):

Data in Table 7 indicate the average values of actual water consumptive use as affected by cultivation methods in plant cane and 1st ratoon. Average CU values were 5233 and 4721.5 m^3 fed^{-1} under irrigation in rows which decreased by 25.66 and 29.77% under irrigation in raised beds in plant cane and 1st ratoon, respectively. The higher water consumptive use with irrigation in rows is due to higher cane yield under such irrigation level. This mean that water consumptive use increased as the availability of soil moisture increased in the root zone. Thus, inadequate water supply acts as a retarding factor in nutrient uptake and reduces the yield proportionately. These results are in consonance with those of Singh *et al.,* (2007) who stated that water use by the ratoon crop was higher with increasing soil moisture regimes. Wiedenfeld and Enciso (2008) proved that increasing irrigation levels increased sugar and sugar cane yields. Abdel Reheem (2010) also stated that planting in beds (normal and transplanting methods) gave the lowest values of actual water consumptive use (5445.75 and 5225.64 m^3 fed^{-1}) respectively.

Table 7. Effect of potassium fertilization and cultivation methods on water consumptive use (CU, m^3 water fed^{-1}) and water use efficiency (WUE, kg sugar m^{-3} water) in plant cane and first ratoon.

K- levels (kg K_2O fed^{-1}) (B)	Cu (m^3 water fed^{-1}) Plant cane (2014/2015) Cultivation methods (A)			1st ratoon (2015/2016) Cultivation methods (A)		
	Row	**Raised bed**	**Mean**	**Row**	**Raised bed**	**Mean**
Control	5173	3845	4509.0	4780.05	3312.75	4046.40
24	5267	3946	4606.5	4678.05	3291.30	3984.68
48	5259	3880	4569.5	4706.4	3343.80	4025.10
Mean	5233	3890.33	----	4721.5	3315.95	----
WUE (kg sugar m^{-3} water)						
K- levels (kg K_2O fed^{-1}) (B)	Plant cane (2014/2015) Cultivation methods (A)			1st ratoon (2015/2016) Cultivation methods (A)		
	Row	Raised bed	Mean	Row	Raised bed	Mean
Control	1.53	1.86	1.70	1.50	2.23	1.87
24	1.63	1.99	1.81	1.75	2.31	2.03
48	1.71	1.97	1.84	1.76	2.41	2.09
Mean	1.62	1.94	----	1.67	2.32	----

On the other hand, data in Table 7 show that water consumptive use was increased by K fertilization in favor of 24 kg K_2O fed^{-1} in the plant cane, while in the 1st ratoon showed an opposite trend. In connection, Khalil *et al.,* (2002) noted that water consumptive use of maize plants decreased as potassium levels increased in both seasons. Gameh *et al.,* (2015) stated that total water consumptive use (Et_a) values were increased as the level of potassium application increased at high soil moisture.

As for the interaction effect on CU, data reveal that the highest CU value (5267 m^3 fed^{-1}) was recorded by applying 24 kg K_2O fed^{-1} under irrigation in rows in the plant cane. While, the lowest CU value (3291.30 m^3 fed^{-1}) was obtained by adding 24 kg K_2O fed^{-1} under irrigation in raised beds in the1st ratoon.

Water Use Efficiency (WUE):

Water use efficiency is a tool for maximizing sugar production per each unit of water irrigation. The data of this character presented in Table 7 indicate that decreasing irrigation water quantity from 20117 m^3 in rows to 15098 m^3 in raised beds in the plant cane and from 18886 m^3 in rows to 13263.8 m^3 in raised beds in the1st ratoon augmented water use efficiency by 19.75 & 38.92% respectively. Similar results were reported by

Wiedenfeld and Enciso (2008) who reported that WUE declined with increasing water application level since yields did not significantly increased with increasing water application every year. Abdel Reheem (2010) found that the highest value of crop water use efficiency (10.68 kg m^3) was obtained with transplanting method in beds. Ghaffar *et al.,* (2013) showed that water use efficiency increased as water stress was imposed. The highest value of WUE was observed at 40% soil moisture stress.

Data also, indicate that application of 48 kg K_2O fed^{-1} produced the highest WUE (1.84 and 2.09 kg sugar m^{-3} water) in plant cane and 1st ratoon, respectively. This may be due to the increase in sugar yield by applying 48 kg K_2O fed^{-1}. In this respect, Dantas Junior and Chaves (2014) found that potassium fertilization increased WUE for the production of maize.

The highest value of WUE was recorded (2.41 kg sugar m^{-3} water) with irrigation in raised beds as interacted with using 48 kg K_2O fed^{-1} in the 1st ratoon.

CONCLUSION

Under the condition of the present experiment it could be suggested that applying 48 kg K_2O fed^{-1} under irrigation in raised beds to achieve the optimum quantity and quality of sugar yield as well as WUE (2.41 kg sugar m^{-3} water) and more water saving (29.77%) in the 1st ratoon.

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تأثير التسميد البوتاسي وطرق الزراعة على إنتاجية قصب السكر وكفاءة إستخدام المياة

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أقيمت تجربتان حقليتان فى أرض طينية طميية فى محطة البحوث الزراعية بشندويل، محافظة سوهاج ، مصر (الواقعة بين خطى عرض 34 26شمال و خطى طول 42 31 شرق وأرتفاع 61 من مستوى سطح البحر) خلال الموسمين المتتاليين2014 / 2015 (قصب غرس) و2015 /2016 (خلفة أولى) لدراسة تأثير التسميد البوتاسي (صفر ، 24 و 48 كجم بو$_2$أ / فدان) تحت طريقتين للزراعة على خطوط أوعلى مصاطب (تحت ظروف محدودية المياة) على قصب السكر. نفذت التجربة فى قطع منشقة مرة واحدة بأربع مكررات. أظهرت النتائج المتحصل عليها تناقص في أرتفاع العيدان ومحصول العيدان النظيفة معنوياً بتقليل كمية مياة الرى وذلك بزراعة قصب سكر على مصاطب فى القصب الغرس والخلفة الأولى , بينما زاد قطر العيدان معنوياً. ولكن لم تتأثر النسبة المئوية للنيتروجين في الأوراق ومحصول السكر معنوياً بطرق الزراعة فى القصب الغرس والخلفة الأولى. سجلت النسبة المئوية للبوتاسيوم أعلى قيمة عند الزراعة على خطوط وبتلقى كمية المياة العادية في الخلفة الأولى. وقد أشارت النتائج أيضاً أن متوسط الأستهلاك المائى الفعلي كانت 5233 و4721,5 م3 / فدان فى القصب الغرس والخلفة الأولى تحت ظروف الزراعة على خطوط بينما نقصت هذه المتوسطات عند الزراعة على مصاطب بمقدار25,66 و29,77% على التوالي مما زاد من كفاءة أستخدام المياة تحت ظروف الزراعة على مصاطب. من ناحية أخرى زاد أرتفاع العيدان ومحصول العيدان النظيفة معنوياً بأضافة 24 كجم بو$_2$أ / فدان مقارناً بالكنترول (بدون بوتاسيوم) و48 كجم بو$_2$أ /فدان . ومع ذلك أعطى أستخدام 48 كجم بو$_2$أ / فدان أعلى القيم فى النسبة المئوية للنيتروجين والبوتاسيوم في الأوراق وأيضاً قطر العيدان والسكر المحسوب فى القصب الغرس والخلفة الأولى فيماعدا النسبة المئوية للنقاوة ومحصول السكر اللذان زاد معنوياً بهذا المعدل فى الخلفة الأولى فقط. عموماً أظهرت النتائج المتحصل عليها إلى أن أضافة 24 كجم بو$_2$أ / فدان تحت ظروف الزراعة على خطوط والتي تروى بكمية مياة الرى العادية أعطى أعلى القيم معنوية فى أرتفاع العيدان ومحصول العيدان النظيفة . كما أعطى المعدل العالي من البوتاسيوم (48 كجم بو$_2$أ /فدان) والزراعة على مصاطب أعلى القيم في النسبة المئوية للسكر المحسوب , محصول السكر, النسبة المئوية للنقاوة وكفاءة أستخدام المياة فى الخلفة الأولى .