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BASAL APPLICATION OF POTASSIUM NUTRITION ENHANCES CANE YIELD, JUICE QUALITY AND NET RETURNS OF SUGARCANE (*Saccharum Officinarum* L.)

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Potassium deficiency and low rainfall are severely affecting the stiffness of stem in sugarcane and resistance against harsh weather conditions prevailing in southern Punjab. Application of potassium can be helpful in ameliorating these hazardous effects. To evaluate the influence of potassium a field study was conducted for two successive years at Fatima Sugar Research and Development Center (FSRDC) Fatima Sugar Mill, Muzaffar Garh, (30.07° N, 71.19° E and 122 m altitude) Punjab, Pakistan. For this purpose, sugarcane cultivar HSF-242 was sown during 2012-14. Treatments comprised of two sources of Potassium (i.e. SOP and MOP) and four levels of potassium application @ zero, 75, 125 and 175 kg ha^{-1}. The agronomic traits were significantly affected by the application of two potassium (K) sources at different levels during both years of experimentation. The highest cane yield (131.55 and 138.74 t ha^{-1}) was achieved with 175 kg K_2O ha^{-1} while, lowest (45.48 and 52.93 t ha^{-1}) in control treatments during both the years. The quality parameters were also significantly affected by K applications during both the years. Higher CCS percentage (13.81 and 13.01) was noted in treatments applied with 125 kg K_2O ha^{-1}. The least CCS percentage (10.88 and 10.36) was noted in control treatments during both the years. An increased CSR (12.99%) was noted in treatments applied with 125 kg K_2O ha^{-1} while, the lowest (10.23%) in control treatments during both years. On the basis of two years study, it is recommended that Potassium fertilizer at the rate of 175 kg K_2O ha^{-1} in the form of SOP are considered pleasant to achieve the higher yield and quality of sugarcane crop.
Keywords: SOP, Starch contents, Sugar yield, Brix percentage.

INTRODUCTION

Sugarcane is high value cash crop of Pakistan and significantly important for sugar and sugar related industries in the national economy of our country (Ghaffar *et al*., 2011). Its production accounts 3.4% for agriculture's value addition and 0.6% in overall GDP. During 2015-16, the sugarcane crop occupied 1132 thousand hectares compared to the last year's area of 1141 thousand hectares showing a decline of 0.8%.
Presently, sugarcane is being grown all over the world in about a hundred countries. Pakistan ranks 8th in cane acreage among 10 major sugarcane producers of the world (GOP, 2015). The sugar industry is the second largest agro-based industry in Pakistan in which 87 mills have been working in their crushing season (GOP, 2015)**.** The sugar mills processed 80% of the cane produced (50 million tons) with an average of 9.68% sugar recovery (Naqvi, 2005).
Despite having a significant position among sugar producing countries, per hectare yield in Pakistan is not satisfactory (50.28 tons ha^{-1}) as compared to other main sugarcane growing countries worldwide (Sohu *et al*., 2008). The major factors responsible for the poor sugar and cane yield are; negligible sugarcane research, sub- standard farming practices like poor land preparation, inadequate and imbalanced use of chemical fertilizers, poor management of ratoon crops, lack of adequate irrigation and a lot of plant diseases and pests (Majeedano *et al*., 2004; Abbas *et al*., 2016). Whereas, this crop has a very high yield potential if proper agronomic practices, nutrient management and plant protection measures are provided.
The management of nutrients or fertilizers especially nitrogen, phosphorus and potassium is very important for better and sustainable growth, yield and quality of sugarcane (Omollo and Abayo, 2011; Bierman and Rosen, 2005). This is because, for millions of years, the cropping activity has replenished all the important nutrients of the soil especially primary macro nutrients to a greater extent. One kg of fertilizer nutrient applied produces about 8 kg of cereals, 2.5 kg of cotton and 114 kg of stripped sugarcane. Whereas, soils in Pakistan are almost 100%, 80-90% and 30% deficient in nitrogen (N), phosphorus (P) and potassium (K), respectively (GOP, 2014-15). Therefore, these important nutrients are supplemented for normal functioning of crop plants. The judicious use of N, P and K fertilizers have an imperative position in escalating cane and sugar yield. Simultaneous appliance of N, P and K significantly exaggerated plant height, number of canes, stem thickness, stripped yield of cane, juice and ethanol content and ultimately net cost benefit

ratio (Chohan *et al*., 2013; Mishra *et al*., 2014). The proper site-specific and genotype-specific nutrient management significantly improved growth, yield and quality of sugarcane (Sundara, 2011). A balanced supply of nutrients using organic and inorganic sources improved soil fertility status leading to better crop productions (Gopalasundaram *et al.*, 2012). The nutrient management should be site specific and target oriented (Alexopoulou *et al.*, 2013).

Potassium deficiency exerts a pessimistic effect on photosynthetic activity and transport of carbohydrate in sugarcane and increased potassium applications are required for higher economic returns (Khosa, 2002). As potassium is essential for the healthy plant growth of sugarcane which directly influences the formation of carbohydrates in leaves and transportation of sucrose to parenchyma of the stem. It is also necessary for photosynthetic activity, translocation and storage of sucrose and plays vital role in leaf stomata opening and moisture economy of plant (Wood and Schroeder, 2004; Thomas and Thomas, 2009). It activates nitrate reductase, an enzyme regulating protein synthesis (Patil, 2011). It is basic nutrient present in most abundant form in the cane juice because about 30-50% of ash in cane juice is in the form of K_2O. It is one of the most effective major nutrients influencing crop yield and quality (Prajapati and Modi, 2012).

Keeping in view the above discussion, it was hypothesized that potassium nutrition can improve the growth, yield and quality of sugarcane. In this regard, a two years study was planned with the objective to evaluate different sources of potassium at variable levels on yield, juice quality and economic returns of sugarcane.

MATERIALS AND METHODS

Experimental site, lay out plan and meteorological description**:** A field experiment was conducted to assess the influence of potassium applied at diverse levels and their variable sources by using different application methods on physiological, quality, growth and yield components of sugarcane (cv. HSF-242) keeping in view their economic impacts during growing seasons 2012-13 and 2013-14. Experiment was conducted at Fatima Sugar Research and Development Center (FSRDC) Fatima Sugar Mill, Muzaffar Garh, (30.07° N, 71.19° E and 122 m altitude) Punjab, Pakistan Experiment was laid out in randomized complete block design (RCBD) with split plot arrangement having three replicates with Net plot size of 26.75m^2 (3.65 m x 7.31 m). Soil sampling was done using soil auger up to a depth of 30 and 60 cm before sugarcane plantation to determine the soil nutrient status. Soil texture was sandy loam with 0.60 to 0.75% organic matter having moderate soil pH as shown in Table 1. Arid climate prevails in the region with an average annual rainfall of less than 150 mm. Comprehensive meteorological data was obtained from Muzaffar Garh weather station located near experimental field area during sugarcane experimental seasons presented in Figure 1.

Table 1. Soil characteristics of experimental site (2012-14).

Soil characteristics	2012-13		2013-14	
Soil sampling depth (cm)	30	60	30	60
A. Physical analysis				
Sand (%)	30	25	28	26
Silt (%)	44	46	47	50
Clay (%)	26	29	25	24
B. Chemical analysis				
EC (d Sm^{-1})	2.11	2.37	1.99	2.43
pH	7.70	8.00	7.50	7.60
Organic matter (%)	0.73	0.60	0.72	0.65
Nitrogen (%)	0.07	0.06	0.07	0.05
Available phosphorus (ppm)	4.75	3.97	5.66	4.47
Available potassium (ppm)	155.32	118.24	153.74	119.32
Sodium adsorption ratio	2.71	2.85	2.65	2.74
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam

(a)

(b)

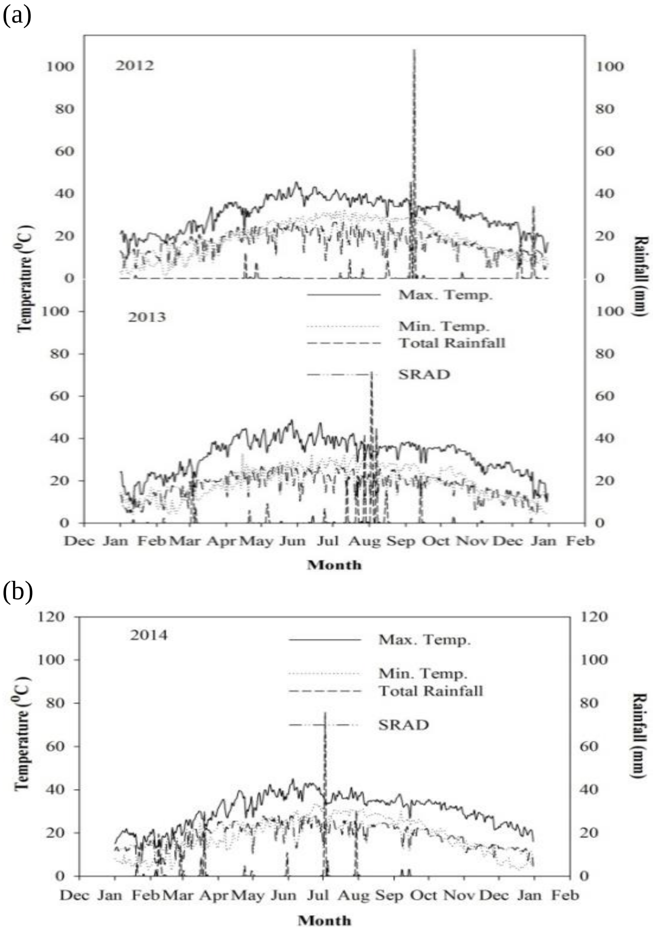


Figure 1. Daily minimum and maximum temperature, rainfall and solar radiation during 2012, 2013(a), 2014(b).

Experimental material:

***Sulphate of potash (SOP)*:** SOP contains 50% K_2O and 18% S and was applied at four different levels according to experimental treatments in third experiment. It was also applied as K source in other two experiments to meet the recommended fertilizer dose.

***Murate of potash (MOP)*:** MOP is a chloride based K fertilizer containing 60% K_2O and 48% Cl. It was used as second K source in third experiment and was also applied as per experimental treatments in their respective growing seasons.

***Observations*:** During research study, subsequent observational data were measured adopting standard procedures.

Quality parameters:

***Fiber content (%)*:** Fiber in stalk was determined with the help of given formula (Bashir, 1981).

$$\text{Cane fiber (\%)} = \frac{\text{Shredded and washed stalk,s dry weight (g)}}{\text{Sharedded stalk,s fresh weight (150 g)}} \times 100$$

***Starch content (%)*:** Cane samples were chopped, shredded and oven dried at 110 C^o. Very fine ground 4 gm samples were boiled for 18 minutes with 80 ml $CaCl_2$ solution. The solution was cooled and transferred to a 200 ml volumetric flask and made upto the mark. Colour developing reagents were added to 25ml samples taken in 100ml flask from 200ml solution. The filtrate was yellowish or brownish in colour and it was determined by using 5 ml 2 N acetic acid omitting KI solution.

***Brix percentage*:** Cane crusher was used to crush 10 canes per sample from every plot. Collection of cane juice was done into glass jars. Initial temperature of cane juice was measured. Brix hydrometer was used to record the reading of brix (%). Then, Schmitz's table was used to correct the recorded values of brix (Meade, 1963).

***Pol percentage*:** The concentration (in g solute per 100 g solution) of a solution of pure sucrose in water having the same optical rotation at the same temperature is termed as pol. Polari meter was used to record the values of the extracted juice of cane separately in every treatment. Then, Schmitz's table was used to calculate the sucrose content of cane juice (Meade, 1963).

***Purity percentage*:** The ratio of pol to brix expressed in percentage defines the purity% of a sample and was determined with the help of formula given below.

$$\text{Purity (\%)} = \frac{\text{Pol of stalk juice (\%)}}{\text{Brix of stalk juice (\%)}} \times 100$$

***Commercial cane sugar percentage (CCS %)*:** CCS (%) was calculated with the help of following formula (Meade, 1963).

$$\text{CCS (\%)} = 3\frac{P}{2}\left(1-\frac{F+5}{100}\right)-\frac{B}{2}\left(1-\frac{F+3}{100}\right)$$

In this formula, P= Pol percent of cane juice, B= Brix of cane juice, F= Fiber content of cane

***Cane sugar recovery percent (CSR %)*:** It refers to be the product of CCS percentage multiplied with a constant factor 0.94. CSR (%) was determined with the help of formula given below.

$$\text{CSR (\%)} = \text{CCS \%} \times 0.94$$

In this, 0.94 represents to net titer (Sugar losses)

***Economic analysis*:** Economic analysis was carried out and cost-benefit ratio was calculated as following.

Fixed cost (FC) includes similar cost on all the inputs used (seed, fertilizers, pesticide, weedicide, machinery charges, transportation, labour etc. and interest on working capital for all treatments during experimentations. Total variable cost (TVC) includes the additional expenses carried out for specific operations and inputs.

$$\text{Total cost (TC)} = \text{TVC} + \text{FC}$$

$$\text{Gross returns (GR)} = \text{Stripped cane yield (t ha}^{-1}\text{) x Cane price (Rs. ton}^{-1}\text{)}$$

$$\text{Net income} = \text{GR} - \text{TC}$$

$$\text{Benefit/ cost ratio} = \text{GR / TC}$$

***Statistical analysis*:** Data was compiled in Microsoft Excel 2007 and statistically analyzed using computer application Statistix 10. Fisher's analysis of variance technique was used to statistically analyze the collected data. Least significant difference (LSD) test at 5% probability was used to testify the significance of treatment means. The relationship between yield and yield contributing parameters was analyzed statistically by using regression and correlation analysis technique (Steel *et al*., 1997).

RESULTS

***Stripped cane yield (t ha^{-1})*:** It is evident form data (Table 2) that cane yield was not affected significantly by different potassium sources in 2012-13 while, significant differences between various treatments were noted during 2013-14. In 2012-13, average stripped cane yield was 92.32 and 87.80 t ha^{-1} with S_1 and S_2, respectively. During 2013-14, S_1 produced significantly more stripped cane yield (99.13 t ha^{-1}) than S_2 with 94.07 t ha^{-1}.

As for as different potash levels are concerned, there was a progressive increase in stripped cane yield with increasing potassium levels and highest cane yield (131.55 t ha^{-1}) was obtained with K_4 (175 kg K_2O ha^{-1}) followed by K_3 (125 kg K_2O ha^{-1}) with 107.11 t ha^{-1} in 2012-13. The treatments K_2 (75 kg K_2O ha^{-1}) also produced significantly better cane yield (76.11 t ha^{-1}) than control treatments (45.48 t ha^{-1}) with zero potash. Equivalent values varied in 2013-14, as 138.74, 113.21, 81.55 and 52.93 t ha^{-1} with K_4, K_3, K_2 and K_1, respectively.

The interactions among S x K combinations showed that S_1 K_4 (SOP at the rate of 175 kg K_2O ha^{-1}) with 135.58 t ha^{-1} stripped cane yield performed better than all other interactions

Table 2. Effect of potassium sources and levels on stripped cane yield, brix percentage, pol percentage and purity percentage during 2012-13 and 2013-14.

		Stripped cane yield (t ha^{-1})					
		2012-13			2013-14		
		Sources of Potash			Sources of Potash		
		SOP	MOP	Mean	SOP	MOP	Mean
Potassium levels	Control	45.70 d	45.26 d	45.48 d	53.43	52.43	52.93 d
	75 kg ha^{-1}	81.20 c	71.03 c	76.11 c	86.87	76.22	81.55 c
	125 kg ha^{-1}	106.83 b	107.38 b	107.11 b	113.25	113.17	113.21 b
	175 kg ha^{-1}	135.58 a	127.53 ab	131.55 a	142.99	134.49	138.74 a
	LSD : S= 1.11, 0.81, L=7.63, 7.39, S × L=9.41, 9.09, S= NS, 3.50, L=16.63, 16.10, S × L=NS, NS						
Potassium levels	Brix percentage						
	Control	17.33 a	17.90 a	17.61a	15.04 c	15.35 c	15.20 b
	75 kg ha^{-1}	17.80 a	18.60 a	18.20 a	16.45 bc	16.23 bc	16.34 b
	125 kg ha^{-1}	18.64 a	18.50 a	18.57 a	18.31 a	18.75 a	18.53 a
	175 kg ha^{-1}	18.20 a	18.30 a	18.25 a	17.99 ab	17.98 ab	17.99 a
	LSD : S=0.49, 0.35, L=1.07, 0.53, S × L=1.40, 0.74, S= NS, NS, L=NS, 1.17, S × L=NS, NS						
Potassium levels	Pol percentage						
	Control	13.97 a	14.35 a	14.16 b	12.14 b	13.30 ab	12.72 c
	75 kg ha^{-1}	15.09 a	15.10 a	15.09 ab	13.42 ab	13.32 ab	13.37 bc
	125 kg ha^{-1}	16.33 a	16.32 a	16.32 a	14.58 a	14.60 a	14.59 a
	175 kg ha^{-1}	15.86 a	15.47 a	15.66 ab	14.86 a	13.99 a	14.42 ab
	LSD : S=0.40, 0.26, L= 0.76, 0.50, S × L=1.02, 0.66, S=NS, NS, L=NS, 1.09, S × L= NS, NS						
Potassium levels	Purity percentage						
	Control	80.66 b	80.10 b	80.38 c	80.69 a	86.59 a	83.64 a
	75 kg ha^{-1}	85.26 ab	81.10 b	83.18 bc	81.99 a	82.34 a	82.16 a
	125 kg ha^{-1}	87.66 a	88.34 a	88.00 a	79.75 a	77.79 a	78.77 a
	175 kg ha^{-1}	87.33 a	84.81 ab	86.07 ab	82.54 a	77.77 a	80.16 a
	LSD : S=0.45, 0.83, L=1.99, 2.93, S × L=2.49, 3.69, S=NS, NS, L=4.35, NS, S × L=NS, NS						

while, minimum cane yield (45.26 t ha^{-1}) was noted in S_2 K_1 treatments during 2012-13. In 2013-14, the highest and least stripped cane yield (142.99 and 52.43 t ha^{-1}) was achieved with similar combinations of interactions simultaneously with similar trend. The overall net impact of all interactions appeared to be non-significant during two growing seasons.

***Brix percentage*: ** Data (Table 2) showed that brix percentage was affected non-significantly by various potassium sources applied during two sugarcane growing seasons. The average brix percentage was 17.99 and 18.32% with S_1 and S_2 respectively, during 2012-13. Similar trend for brix (16.95 and 17.08%) regarding $S_1$and S_2 respectively, were noted during 2013-14.

As for as different potassium fertilizer levels are concerned, brix percentage was not significantly affected during 2012-13. The average values for brix were 17.61, 18.20, 18.57 and 18.25 % in K_1, K_2, K_3 and K_4 treatments, respectively. During 2013-14, it was significantly influenced by increasing potassium application levels. The average values for brix with K_3 and K_4 were18.53 and 17.99% respectively, statistically similar to each other but significantly higher as compared to K_2 and K_1 with 16.34 and 15.20 % brix, respectively.

All the interactive effects between S x K combinations were observed to be non- significant during both years. In was found that maximum brix value (18.64%) was recorded with S_1 K_3 combinations while, minimum (17.33%) again in control treatments during 2012-13. Almost similar results were observed during second season also (2013-14). The highest and least brix percentage (18.75 and 15.04%, respectively) was noted in S_2 K_3 and control treatments.

***Pol percentage*: ** Impact of variable potassium sources on pol percentage was found to be non-significant during both seasons (Table 2). In 2012-13, average mean values regarding pol percentage for S_1 and S_2 were 15.31 and 15.31%, respectively. While during 2013-14, equivalent pol percentage values were 13.75 and 13.80% with S_1 and S_2, respectively.

As for as different potash levels are concerned, pol percentage remained non- significant during 2012-13 in which K_3, K_4, K_2 and K_1 with 16.33, 15.67, 15.10 and 14.17, pol percentage, respectively, were statistically indifferent to one another. Whereas, various potassium levels significantly affected pol percentage during 2013-14. The highest pol percentage (14.59%) was found in plots with K_3 (125 kg K_2O ha^{-1}) treatments which was statistically similar to K_4 (175 kg K_2O

ha^{-1}) with 14.42% pol. The minimum pol percentage (12.72%) was recorded in control treatments with zero potassium application.

The data regarding various interactions between sources and levels of potash showed that maximum pol percentage (16.33%) was achieved with S_1 K_3 treatments (SOP at the rate of 125 kg K_2O ha^{-1}) and lowest pol percentage (13.97%) with S_1 K_1 (no potash) interactions. Almost similar trend was confirmed during second season (2013-14) where S_1 K_4 gave higher pol percentage values (14.86%) than all other interactions while, least pol (12.14%) in control treatments. Overall impact of all interactions remained to be non-significant during both years.

***Purity percentage*:** Data presented (Table 2) clearly indicates that both sources of potash did not significantly impact purity percentage of sugarcane juice during both years. The average purity percentage with S_1 and S_2 was 85.22 and 83.59%, respectively, during 2012-13. In 2013-14, average values regarding purity were noted 81.24 and 81.12% for S_1 and S_2, respectively.

While, varying potassium levels significantly affected purity percentage only during 2012-13. Maximum purity percentage (88.00%) was found in treatments applied with K_3 (125 kg K_2O ha^{-1}) which was at par to K_4 (175 kg K_2O ha^{-1}) with 86.08% purity percentage. The treatments with K_2 and K_1 (75kg K_2O ha^{-1} and no potash) showed 83.18 and 80.38% purity percentage. In 2013-14, impact of potassium levels was recorded to be non-significant on purity percentage. The average mean values for K_1, K_2, K_3 and K_4 were 83.64, 82.16, 78.77 and 80.16%, respectively.

As regards various interactions between sources and potassium levels, the treatment combination of S_2 K_3 (MOP at the rate of 125 kg K_2O ha^{-1}) with 88.34 % purity percentage resulted in highest purity percentage as compared to all other interactions. Minimum purity percentage (80.10%) was found in control treatments where zero potassium was applied in 2012-13. Similar findings were confirmed for purity during second season. Overall conclusion for various interactive effects of treatments was found to be non-significant during both years.

***Commercial cane sugar percentage*:** Data (Table 3) represented that influence of potassium inorganic sources on commercial cane sugar percentage (CCS percent) was found to be non-significant during two seasons of sugarcane production. However, both sources showed 12.46 and 12.71% CCS with S_1 and S_2 respectively, during 2012-13. The average values ranged in 2013-14 with S_1 and S_2 were 11.81 and 11.96% CCS, respectively.

Differences between treatments at different potassium levels were found to be significant for CCS percent during both growing seasons of sugarcane. In 2012-13, increase in potassium levels increased CCS percent and the highest CCS percentage (13.81%) was noted in treatments applied with K_3 (125 kg K_2O ha^{-1}) which gave statistically similar results as with K_4 (175 kg K_2O ha^{-1}) producing 13.08% CCS. The least CCS percentage (12.58) with potassium was recorded in K_2

Table 3. Effect of potassium sources and levels on commercial cane sugar percentage, cane sugar recovery percent and total sugar yield during 2012-13 and 2013-14.

		2012-13			2013-14		
		Sources of Potash			Sources of Potash		
		SOP	MOP	Mean	SOP	MOP	Mean
	Commercial Cane Sugar percentage (CCS)						
Potassium levels	Control	10.80 d	10.96 d	10.88 c	10.45	10.26	10.36 c
	75 kg ha^{-1}	12.40 c	12.76 bc	12.58 b	11.67	12.02	11.84 b
	125 kg ha^{-1}	13.70 ab	13.93 a	13.81 a	12.91	13.12	13.01 a
	175 kg ha^{-1}	12.96 abc	13.20 abc	13.08 ab	12.21	12.42	12.32 ab
	LSD : S=0.17, 0.51, L=0.37, 0.47, S × L=0.48, 0.78, S=NS, NS, L=0.80, 1.04, S × L=NS, NS						
Potassium levels	Cane Sugar Recovery percent (CSR)						
	Control	10.15 d	10.31 d	10.23 c	10.23	10.07	10.15 c
	75 kg ha^{-1}	11.67 c	12.00 bc	11.82 b	11.42	11.76	11.59 b
	125 kg ha^{-1}	12.87 ab	13.10 a	12.98 a	12.64	12.86	12.75 a
	175 kg ha^{-1}	12.19 abc	12.40 abc	12.29 ab	11.95	12.17	12.06 ab
	LSD : S=0.16, 0.50, L=0.34, 0.47, S × L=0.45, 0.76, S=NS, NS, L=0.76, 1.02, S× L=NS, NS						
Potassium levels	Total sugar yield (t ha^{-1})						
	Control	4.64 c	4.75 c	4.70 c	5.47 c	5.36 c	5.42 c
	75 kg ha^{-1}	9.44 b	8.50 b	8.97 b	9.96 b	9.01 b	9.48 b
	125 kg ha^{-1}	13.79 a	14.16 a	13.98 a	14.33 a	14.65 a	14.49 a
	175 kg ha^{-1}	16.59 a	15.83 a	16.21 a	17.05 a	16.35 a	16.70 a
	LSD : S=0.15, 0.46, L=1.11, 1.12, S × L=1.37, 1.45, S= NS, NS, L= 2.42, 2.45, S× L=NS, NS						

S=Sources, L=Levels, NS= non-significant, SOP= Sulphate of Potash, MOP=Murate of Potash treatments (75kg K_2O ha^{-1}) which were significantly higher than control treatments (10.88%) where no potassium was applied. Corresponding values in 2013-14, were 10.36, 11.84, 13.01, and 12.32% with K_1, K_2, K_3 and K_4 treatments, respectively.

Interactive relations between sources and levels of potassium showed that maximum CCS percentage (13.93%) was achieved with S_2 K_3 (MOP at the rate of 125 kg K_2O ha^{-1}) and the lowest values 10.80% were noted in control treatments during 2012-13. Almost similar findings were noticed for various interactions during second growing season where S_2 K_3 and S_2 K_1 produced 13.12 and 10.26% CCS, respectively.

***Cane sugar recovery percent (CSR)*:** It is obvious from data that effect of various potassium sources was non-significant on CSR percentage during both seasons. The two sources S_2 and S_1 (MOP and SOP) showed 11.95 and 11.71% CSR, respectively, during 2012-13. Equal values in 2013-14 regarding CSR were 11.71 and 11.56%, respectively.

Increasing levels of potassium significantly influenced CSR percentage during both seasons as presented in data (Table 3). Maximum CSR (12.99%) was noted in treatments applied with 125 kg K_2O ha^{-1} which was at par (12.30%) to 175 kg K_2O ha^{-1} during 2012-13. The average CSR values were 11.83% with 75 kg K_2O ha^{-1} which was again significantly higher than control (10.23%) treatments. Almost similar observations regarding CSR were noted during second season also.

As for as, interactions among various potash fertilizer sources and alternative levels are concerned, data showed non-significant effect during both years of experiments. The highest CSR (13.10%) was recorded with S_2 K_3 interactions while, minimum (10.15%) with S_1 K_1 treatments during 2012-13. Almost similar trend in results was noticed during 2013-14.

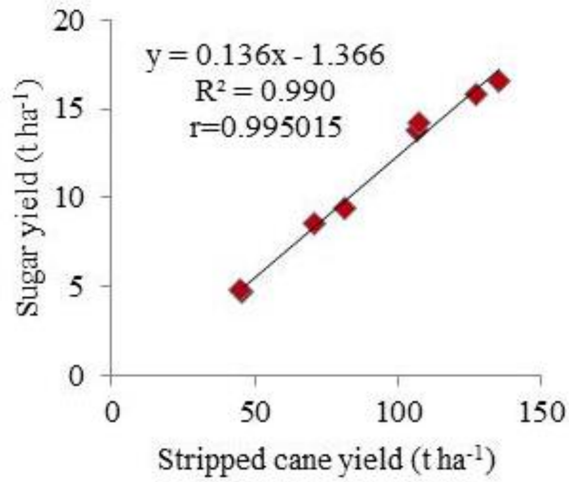
***Total sugar yield (t ha^{-1})*:** Both potassium inorganic nutrient sources showed non-significant impact on total sugar yields during two seasons (Table 3). The average sugar yield was 11.11 and 10.81 t ha^{-1} with S_1 and S_2, respectively in 2012-13. In 2013-14, equivalent values for S_1 and S_2 were 11.70 and 11.34 t ha^{-1}, respectively.

While, different potassium levels significantly affected sugar yields in both seasons (Table 3). Increasing rate of potassium fertilizer increased sugar yield significantly. Maximum sugar yield (16.21 t ha^{-1}) was obtained with K_4 (175 kg K_2O ha^{-1}) followed by 13.98 t ha^{-1} with K_3 (125 kg K_2O ha^{-1}) which was at par to K_4 in 2012-13. Potassium dose of 75 kg K_2O ha^{-1} also produced significantly higher sugar yield (8.97 t ha^{-1}) than control treatments (no potassium) with 4.70 t ha^{-1} sugar yields. In 2013-14, comparable average sugar yield was 16.70, 14.49, 9.48 and 5.42 t ha^{-1} with K_4, K_3, K_2 and K_1, respectively.

The treatment combination of S_1 K_4 (175 kg K_2O ha^{-1} in the form of SOP) during both seasons gave better sugar yield (16.59 and 17.05 t ha^{-1}, respectively) than all other interactions. The lowest sugar yield was obtained with no potash combinations during two growing seasons. Overall interactive effect of all combinations appeared to be non-significant during 2012-13 and 2013-14.

A linear and positive relationship was observed between sugar yield and CCS percentage with a common regression of 86.7 and 86.2% variance in data during two seasons (Fig. 2). Both sugar yield and stripped cane yield were strongly positive and linearly correlated and the common regression accounted for 99.5 and 99.3% variance during two years of experimentations.

(a)



(b)

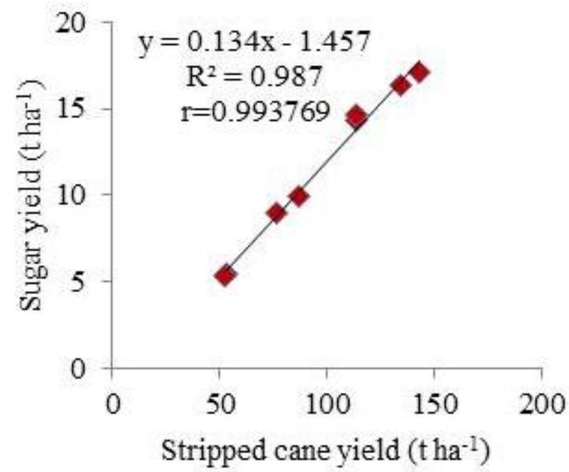


Figure 2. Relationship between sugar yield and stripped cane yield during 2012-13 (a) and 2013-14 (b).

***Economic analysis*:** Different K applications profoundly influenced net income of sugarcane productions during 2012-13 and 2013-14 (Table 4). In 2012-13, comparatively higher net income (Rs. 85390 ha^{-1}) was observed when SOP was used as K source while, MOP with Rs. 107828 ha^{-1} gave better net benefits during second year studies. As far as K Application levels are concerned, concurrent supply of K

Table 4. Effect of potassium sources and levels on economic returns of sugarcane production during 2012-13 and 2013-14.

	Sources	Variable cost (Rs.ha^{-1})	Yield (tha^{-1})	Gross return (Rs.ha^{-1})	Total cost of cultivation (Rs.ha^{-1})	Net income (Rs.ha^{-1})	Benefit-cost ratio
2012-13	SOP	52500	92.32	392360	306970	85390	1:28
	MOP	35000	87.80	373150	289470	83680	1:29
	Levels (kg ha^{-1})						
	Control	-	45.48	193290	254470	61180	0:76
	75 kg ha^{-1}	17500	76.11	323468	271970	51498	1:19
	125 kg ha^{-1}	29176	107.11	455218	283646	171572	1:60
	175 kg ha^{-1}	40828	131.55	559088	295298	263790	1:89
2013-14	Sources						
	SOP	66000	99.13	421303	320470	100833	1:31
	MOP	37500	94.07	399798	291970	107828	1:37
	Levels (kg ha^{-1})						
	Control	-	52.93	224953	254470	-29517	0:88
	75 kg ha^{-1}	20700	81.55	346588	275170	71418	1:26
	125 kg ha^{-1}	34510	113.21	481143	288980	192163	1:66
	175 kg ha^{-1}	48290	138.74	589645	302760	286885	1:95

SOP= Sulphate of Potash, MOP=Murat of Potash

levels improved net field profits and the highest net income (Rs 263790 and 286885 ha^{-1}) was observed in treatments applied with 175 kg K_2O ha^{-1} during two years of field experimentation.

DISCUSSION

Sugarcane yield and quality parameters were significantly improved during 2012-14 growing seasons due to the supplement of potassium, as it is an essential nutrient for plant development as well as plays numerous roles in plants, counting turgor pressure regulations, photosynthetic activity, stomatal action, deliver of sugar, proteins and starch production (Patil, 2011; Thomas and Thomas, 2009; Wood and Schroeder, 2004). The judicious use of K also influences the root elongation and thickness of the stem. In current study, significantly higher stripped cane yield was recorded in those treatments, where highest potassium application (S_1 K_4) in the form of SOP was applied as compared to control plots (S_2 K_1). Highest stripped cane yield was achieved by yield contributing parameters such as number of tillers, number of stalks, cane diameter and stalk length. This improved growth and yield was achieved due to application of potassium which increases the photosynthetic efficiency and improved availability of moisture and nutrients in plants.

Appropriate K sustenance increases N and P uptake while, N is one of the most important crop growth factors, influencing both productivity and crop quality. In current decades noteworthy yield augment have been attributed to uptake of nitrogen fertilizers away from every other agriculture inputs (Lofton *et al*., 2012). The whole K was applied as a basal input which might have improved tillering and root elongation by ensuring regular and sufficient supply during active and critical growth periods. For the period of the first 5 to 15 weeks later than sowing, the varieties show a quick and approximately linear growth patterns. Sugarcane has the ability to reach tiller stage quickly. Under encouraging circumstances, stalk numbers augment exponentially with time until an utmost of 20 to 30 stalks m^{-2} is reached by 4 to 6 months (Meki *et al*., 2015). Youkhana *et al*. (2013) observed that sugarcane roots deriving optimum moisture and nutrients can grow to the depth of more than 2.0 meters which are most importantly instigated by the supply of phosphorus regulated by K supplement.

Different studies provide the proof of K^+ in promoting the translocation of products (Ashraf *et al*., 2009). This endorsement will take place if preeminent level of K^+ diet cause one or more of the subsequent to boost net carbon substitute, phloem loading, transport sinks and metabolic exchange of sucrose in sink tissues (Shukla *et al*., 2009). A numeral of studies has revealed that net carbon swap over boost as a magnitude of augmented K^+ fertilization of crops (Khosa, 2002). As a cation, K accompanies the NO_3^- anion as it is elated from the roots to the shoot everywhere nitrate is diminished to NH_3 to be built-in into amino acids the precursor of all proteins. So, it might have augmented action of NO_3^- reductase enzyme, which amplified N uptake (El-Tilib *et al*., 2004). These findings were also in conformity to the findings of Ghaffar *et al*. (2010), Bokhtiar *et al*. (2011) and Chohan *et al*. (2013). They reported similar findings of the stripped cane yield in response of potassium application.

As far as cane quality parameters were concerned, Brix percentage, Pol percentage, Purity percentage, CCS percentage and CSR percent were recorded in increased concentrations with the gradual increase of potassium application to the cane. It was observed that with the application of potassium, quality of sugarcane in terms of various quality attributes was enhanced. Kandil *et al.* (2002a), Vijay *et al*. (2003) and Hunsigi (2011) reported similar findings that during potassium management studies, with the increasing levels of potassium applications quality parameters such as brix percentage and Pol percentage were improved. Potassium is engrossed through plants in better quantity than any other minerals constituent excluding nitrogen (Kumar *et al*., 2007).

The greater changing of biomass from leaf to stem is reliant upon continual deliver of K^+ all over the period (Medina *et al*., 2004). The crop roots take up K^+ from a broad variety of soil concentration, and were utilized to distinct plasma membrane, uptake systems with elevated and low affinity for K^+, correspondingly.

In adding up to the sucrose decrease with KCl appliance, we also confirmed the optimistic influence of K_2SO_4 on sucrose concentration. Even though there is no clear elucidation for this result, it might have resulted from the optimistic effect of SO_4^{2-} for the reason that sulfur acting as significant function in plant metabolism (in photosynthesis process and production of amino acids and proteins) as a vital macronutrient (Watanabe *et al*., 2016). During growing seasons like 2012-13 and 2013-14, sugarcane crop showed more vigorous growth which ultimately contributes towards good cane yield. This might be due to uninterrupted supply of potassium at different critical growth stages like emergence, tillering, grand growth, and physiological maturity, each of which usually lasts 1 to 3 months and compromised production approach at any stage ends with main loss in final production and quality of sugarcane (Lofton *et al*., 2012).

***Conclusion*:** The present study demonstrated that application of potassium at the rate of 175 kg K_2O ha^{-1} in the form of SOP was effective for enhancing productivity and quality of sugarcane, suggesting that this approach can be fundamental tool for increasing the yield in sugarcane fields.

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REFERENCES

Abbas, H.T., S.T. Sahi, A. Habib and S. Ahmed. 2016. Laboratory evaluation of fungicides and plant extracts against different strains of *Colletotrichum falcatum* the cause of red rot of sugarcane. Pak. J. Agri. Sci. 53:181-186.

Alexopoulou, E., S.L. Cosentino, N. Danalatos, D. Picco, S. Lips, D. van den Berg, A.L. Fernando, A. Monti, J.L. Tenorio, E. Kipriotis, S. Cadoux and S. Cook. 2013. New insights from the BIOKENAF project. Kenaf: A multi-purpose crop for several industrial applications. Green Energy and Tech., Springer, London. pp.177-203.

Ashraf, M., R. Ahmad, M. Afzal, M. A. Tahir, S. Kanwal and M.A. Maqsood. 2009. Potassium and silicon improve yield and juice quality in sugarcane (*Saccharum officinarum* L.) under salt stress. J. Agron. Crop Sci. 195:284-291.

Bashir, S. 1981. A study on the postharvest decline in quality of two sugarcane varieties at different storage conditions at various harvesting times. M.Sc. (Hons.) Agric. Thesis, Dept. Agron., Univ. Agri., Faisalabad, Pakistan.

Bierman, P.M. and C.J. Rosen. 2005. Nutrient cycling and maintaining soil fertility. J. Nutrient Mgt. Vegetable, Fruit and Nut Crops, Univ. Minnesota; pp.10-11.

Bokhtiar, S.M., G.C. Paul, K.M. Alam, M.A. Haque, A.T.M. Hamidullah, and B. Tirugnanasotkhi. 2011. The effects of soil test based potassium application and manures on yield and quality of sugarcane grown on a typical calcareous soil of Bangladesh. Res. Findings IPI. 27:9-13.

Chohan, M., U.A. Talpur, R.N. Pahnwar and S. Talpur. 2013. Effect of inorganic NPK different levels on yield and quality of sugarcane plant and ratoon crop. Int. J. Agron. Prod. 4:3668-3674.

El-Tilib, M.A., M.H. Elnasikh and E.A. Elamin. 2004. Phosphorus and potassium fertilization effects on growth attributes and yield of two sugarcane varieties grown on three soil series. J. Plant Nutr. 27:663-699.

Ghaffar, A., Ehsanullah, N. Akbar and S.H. Khan. 2011. Influence of zinc and iron on yield and quality of sugarcane planted under various trench spacings. Pak. J. Agri. Sci. 48:25-33.

Ghaffar, A., M.F. Saleem, A. Ali, and A.M. Ranjha. 2010. Effect of K_2O levels and its application time on growth and yield of sugarcane. J. Agric. Res. 48:315-325.

Gopalasundaram, P., A. Bhaskaran and P. Rakkiyappan. 2012. Integrated nutrient management in sugarcane. Sugar Technol. 14:3-20.

Government of Pakistan. Economic Survey. 2014-15. Finance Division, Economic Advisor's Wing, Islamabad, Pakistan. pp.27-31.

Hunsigi, G. 2011. Potassium management strategies to realize high yield and quality of sugarcane. Karnataka J. Agri. Sci. 24:45-47.

Kandil, A.A., M.A. Badawi, S.A. El-Moursy and U.M.A. Abdou. 2002. Effect of planting dates, nitrogen levels and bio fertilization treatments on growth attributes of sugar beet (*Beta vulgaris* L.). J. Agric. Sci., Mansoura Univ. 27:7247-7255.

Khosa, T.M. 2002. Effect of different levels and sources of potassium on growth, yield and quality of sugarcane. Better Crops Int. 16:14-15.

Kumar, S., N.S. Rana, R. Chandra and S. Kumar. 2007. Effect of phosphorus and potassium doses and their application schedule on yield, juice quality and nutrient use efficiency of sugarcane-ratoon crop sequence. J. Ind. Soc. Soil Sci. 55:505-508.

Lofton, J., B.S. Tubana, Y. Kanke, J. Teboh, H. Viator and M. Dalen. 2012. Estimating sugarcane yield potential using an in-season determination of normalized difference vegetative index. Sensors (Basel, Switzerland) 12:7529-7547.

Majeedano, H.I., Y.J. Minhas, A.D. Jarwar, S.D. Tunio and H.K. Puno. 2004. Effect of potash levels and methods of application on sugarcane yield. Pak. Sugar J. 18:17-19.

Meade, G.P. 1963. Cane Sugar Handbook, 8th Ed. John Wiley and Sons, Inc. New York.

Medina, N.H., M.L. Branco, M.A.G. da Silveira and R.B.B. Santos. 2013. Dynamic distribution of potassium in sugarcane. J. Environ. Radioactivity 126: 172-175.

Meki, M.N., J.R. Kiniry, A.H. Youkhana, S.E. Crow, R.M. Ogoshi, M.H. Nakahata, R. Tirado-Corbalá, R.G. Anderson, J. Osorio and J. Jeong. 2015. Two-year growth cycle sugarcane crop parameter attributes and their application in modeling. Agron. J. 107:1310-1320.

Mishra, J.S., N.S. Thakur, Kcwalanand, S.S. Rao and J.V. Patil. 2015. Response of sweet sorghum genotypes for biomass, grain yield and ethanol production under different fertility levels in rainfed conditions. Sugar Technol. 17: 204-209.

Naqvi, H.A. 2005. Pakistan Sugar Book. Pak. Soc. Sugar Technol., Mandi Baha-ud-Din, Punjab, Pakistan.

Omollo, J.O. and G.O. Abayo. 2011. Effect of phosphorus sources and rates on sugarcane yield and quality in Kibos, Nyando Zone. Innovations as key to the Green Revolution in Africa. Springer, Dordrecht. pp.533–537.

Patil, R.B. 2011. Role of potassium humate on growth and yield of soybean and black gram. Int. J. Pharma and Bio. Sci. 2:242-246.

Prajapati, K. and H.A. Modi. 2012. The importance of potassium in plant growth: A review. Ind. J. Plant Sci. 1:177-186.

Rakkiyappan, P., S. Thangavelu, K.V. Bhagyalakshmi and R. Radhamani. 2007. Uptake of nitrogen, phosphorus and potassium by some promising mid late maturing sugarcane clones. Sugar Technol. 9:23-27.

Shukla, S.K., R.L. Yadav, P.N. Singh and I. Singh. 2009. Potassium nutrition for improving stubble bud sprouting, dry matter partitioning, nutrient uptake and winter initiated sugarcane (*Saccharum spp*. hybrid complex) ratoon yield. Eur. J. Agron. 30:27-33.

Sohu, I.A., A.M. Khaskheli., P.A. Baloch and B.A. Abro. 2008. Evaluation of yield and yield contributing parameters of different sugarcane (*Saccharum officinarum*, L.) varieties under national uniform varietal trial. Pak. Sugar J. 23:7-10.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A biometrical approach, 3rd Ed. McGraw Hill Book Co., Inc., New York. pp.400-428.

Sundar, B. 2011. Agrotechnologies to enhance sugarcane productivity in India. Sugar Technol. 13:281-298.

Thomas, T.C. and A.C. Thomas. 2009. Vital role of potassium in the osmotic mechanism of stomata aperture modulation and its link with potassium deficiency. Plant Signal Behavior. 4:240–243.

Vijay, K., K.S. Verma and O.P. Sagwal. 2003. Effect of continuous application of different levels of potassium on yield and juice quality of sugarcane and economic return. Ind. Sugar. 52:911-917.

Watanabe, K., Y. Fukuzawa, S.I. Kawasaki, M. Ueno and Y. Kawamitsu. 2016. Effects of potassium chloride and potassium sulfate on sucrose concentration in sugarcane juice under pot conditions. Sugar Technol. 18:258-265.

Wood, A.W. and B.L. Schroeder. 2004. Potassium: A critical role in sugarcane production, particularly in drought conditions. In: Proc. Aust. Soc. Sugarcane Technol. 26: 1-11.