Pak. J. Agri. Sci., Vol. 55(X), xxx-xxx; 2018
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/18.7552
http://www.pakjas.com.pk

IMPROVING THE PRODUCTIVITY AND SUGAR RECOVERY OF CANE BY POTASH NUTRITION UNDER DIFFERENT PLANTING METHODS

Muhammad Waqas Aslam Cheema[1,*], Riaz Ahmad[1], Abdul Khaliq[1] and Rashid Ahmad[1]

Department of Agronomy, University of Agriculture-38040, Faisalabad, Pakistan
[*]Corresponding author's e-mail: waqasaslamcheema2006@gmail.com

Potassium-nutrition is a subject of great consideration, as research has revealed its importance in increasing sugar recovery in sugarcane. While it cannot achieve its genetic expression of yield without proper planting technology. Therefore, the present study was conducted to optimize the planting method and K level to improve the yield and sugar recovery of sugarcane at University of Agriculture Faisalabad in 2014-2016. Treatments comprised of four planting methods viz. i) 90 cm spaced pits with a diameter of 90 cm, ii) 90 cm spaced pits with a diameter of 90 cm in diagonal fashion, iii) 90 cm spaced double row strips and iv) 120 cm spaced trench planting in combination with four K nutrition levels i.e., 0, 100, 200 and 300 kg/ha K_2O. Results revealed that K application improved the growth, cane yield and sugar recovery irrespective of planting method. However, maximum number of tillers were recorded in sugarcane sown in diagonal pit planting at 90 cm with 100 kg/ha K_2O. Likewise, Leaf area index and net assimilation rate were substantially improved with K application in all planting methods. More cane weight (15%) was obtained at sugarcane sown in 120 cm spaced trenches with 200 kg/ha K_2O during both the years. Stripped cane yield was maximum in diagonal pit planting at 90 cm with 100 kg/ha K_2O (113.7 t/ha) during the plant crop year and diagonal pit plantation + 200 kg/ha K_2O (98.22 t/ha) during the ratoon crop year. Likewise, maximum potassium use efficiency (KUE) i.e. 99.5 and 88.2 kg /kg were recorded in planting of sugarcane in diagonal pits at 90 cm with 100 kg/ha K_2O during plant crop year and 120 cm trenches +100 kg/ha K_2O during the ratoon crop year, respectively. Sugar recovery was also enhanced by all the K nutrition levels over control. The cultivation of sugarcane in 90 cm spaced pits with the supplementation of potash at 100 kg/ha gave the maximum sugar yield of 15.8 t/ha in plant crop year and 13.2 t/ha in the ratoon crop year. The combined economic analysis over two years (plant + ratoon year) revealed that sugarcane planting was more beneficial at 120 cm spaced trenches, with 100 kg potash/ha (3678$); which was followed by 90 cm diagonal pit plantation +100 kg/ha K_2O which gave the combined benefits of 3611$. Sugar cane may be planted in 90 cm diagonal pits and 120 cm spaced trenches with 100 kg/ha potash to improve the cane yield and sugar recovery.
Keywords: Sugarcane, planting methods, potash nutrition, sugar recovery

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is major cash crop of Pakistan, as it provides raw materials to sugar and allied industries, while it contributes about 3.2% in value addition product to country's GDP. In Pakistan, sugarcane is being cultivated on more than 1.2 million hectares with average yield of about 60 t/ha, far less than potential yield of 120 t/ha (Govt. of Pakistan, 2016). This yield gap is due to many factors like unapproved varieties, improper planting methods, imbalance fertilization, sugarcane pest especially borers, diseases like red rot, drought and lodging issues (Abbas *et al.,* 2016) but among these, major two factors are the imbalance fertilization especially use of potassium (K) fertilizer and improper planting methods (Ehsanullah *et al.,* 2011; Ghaffar *et al.,* 2012).

Sugarcane is a highly exhaustive crop and it mines large amounts of nitrogen, phosphorus and potassium nutrients from the soil for its growth. It has been found that sugarcane extracts about 205 kg N, 55 kg P_2O_5, 275 kg K_2O, 30 kg S, 3.5 kg Fe, 1.2 kg Mn, 0.6 kg Zn and 0.2 kg Cu from the soil for a cane yield of 100 t/ha (Singh, 2007). Higher extraction of K by sugarcane is related to its synthesis and translocation of sucrose from leaves to the storage tissues in stalks (El-Tilib *et al*., 2004), helps in phloem loading and unloading (Shukla *et al.*, 2009) and augments the activity of NO_3^{-1} which increases the nitrogen uptake (Chohan *et al.,* 2013). Potassium is not only essential for sucrose activity but it also promotes resistance to pests and disease in sugarcane (Krauss, 2001). Hunsigi (2001) observed that K application helps sugarcane crop to reach maturity. Thus, the addition of adequate potash nutrition is necessary.

The second major issue in cane production is inappropriate geometrical arrangement or planting patterns. Farmers have been using flat sowing method of sugarcane since decades. Although this method of sugarcane plantation is easy to practice but it leads to poor sprouting (30-35%) of sugarcane setts due to unavailability of adequate moisture from of the soil (Singh, 2002). Moreover, vegetative growth is less in closed spacing (Smit and Singels, 2006). Hence, there was a dire need for new and promising planting patterns in sugarcane to attain better yield.

New techniques of sugarcane plantation are getting popular since last decade these include pit plantation of sugarcane, trench plantation, double strip sowing of sugarcane (Chattha *et al.,* 2007), ring pit method and chip bud technology (Jain *et al.,* 2006). All these planting methods are aimed to improve the growth and biomass production (Bashir and Saeed, 2000) with higher sugar recovery (Singh *et al.,* 2009) and have the advantage of being mechanically operated which reduces the labor cost, increase precision and ultimately increasing the stripped cane yield and sugar recovery with greater net field benefits (Nalewade *et al.,* 2018). There are many studies available regarding the effect of planting method and K application on growth, yield and sugar recovery of sugarcane. However, the interaction of different planting methods with K nutrition on sugar recovery and KUE has rarely been studied. Therefore, the present study was conducted to optimize the K application in different planting methods to improve the growth, cane yield, sugar recovery and KUE of sugarcane. The specific objective of this study was to evaluate the economics of K fertilization in combination with different planting methods in sugarcane.

MATERIALS AND METHODS

***Experimental site and treatments*:** A field experiment was conducted for two consecutive years during 2013-14 and 2015-16 at Agronomic Research Area, Department of Agronomy, University of Agriculture, Faisalabad (1.25°N latitude, 73.09°E longitude, altitude 184 m). After the first harvest (2013-14), the second crop (2015-16) was kept as ratoon. The experimental soil was sandy loam with EC, 0.34, pH 8.20, organic matter 0.72% and nitrogen 0.03% while extractable phosphorus (5.8 ppm), potassium (140 ppm) and DTPA extractable Zn (0.89).

Experimental treatments were executed in randomized complete block design (RCBD) in split plot arrangements. The planting patterns, i.e. 90 cm spaced pits with diameter 90 cm (90 by 90 pits), 90 cm spaced pits with diameter 90 cm in diagonal fashion (90 by 90 d-pits), 90 cm spaced double row strips (90 SDRS) and 120 cm spaced trenches (120 ST) were kept in main plots whilst potassium levels i.e., 0, 100, 200 and 300 kg/ha K_2O were kept in subplots. The plot size for 90 cm spaced pits, Diagonal pit plantation and 120 cm spaced pits was 5.4 m × 8 m whereas plot size for 90 cm spaced double row strips was 3.6 m× 8 m.

***Field preparation*:** During 2013-14, for plant crop, the land was leveled by laser land leveler. Disk plough and disk harrow were used for pulverizing the soil followed by planking. Pits (90 cm in depth and 90 cm apart in distance from either of four sides) were made mechanically by pit hole digger operated by 75 HP tractor. Pits were then irrigated with 100 mm water to settle down the loose soil. Similar procedures were adopted while digging 90 cm spaced pits of the diameter of 90 cm in a diagonal arrangement in this system except a fifth pit was also dug in between these four

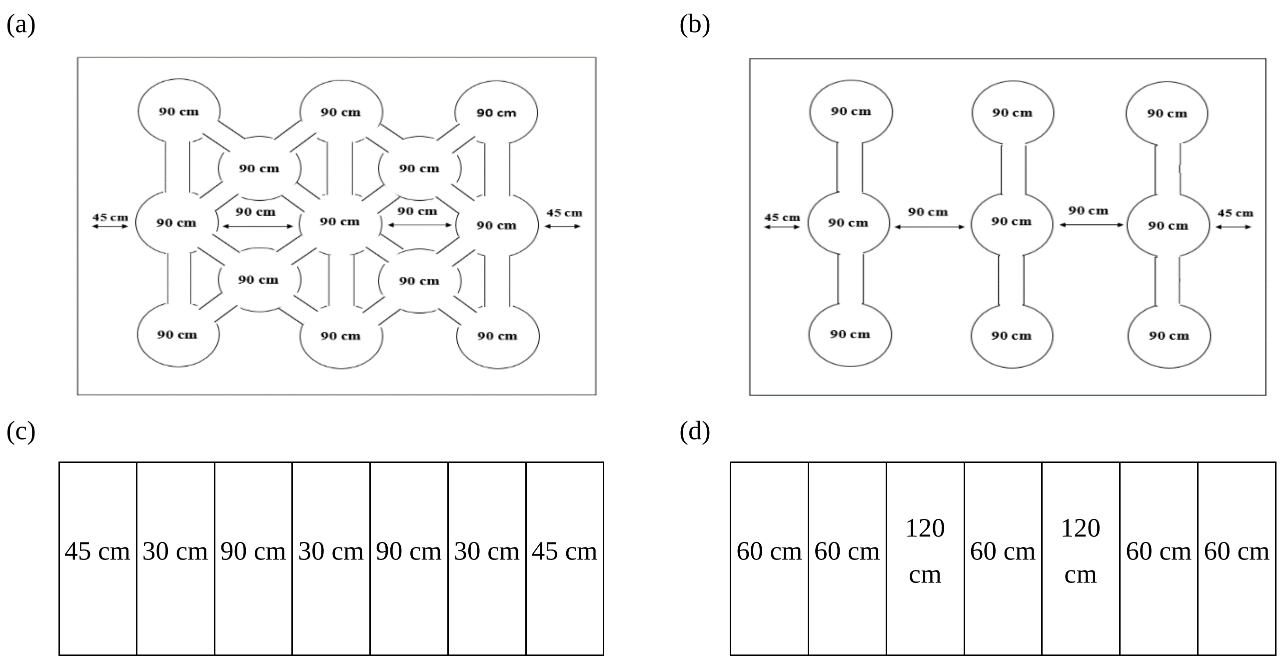

Figure 1. Schematic diagram of different planting patterns: (a) Diagonal pit plantation of sugarcane in 90 cm (b) 90 cm spaced pit plantation (c) 90 cm spaced double row strips (d) 120 cm spaced trenches.

pits. Trenches at the uniform spacing of 120 cm were made using tractor mounted ridger.

***Crop husbandry*:** The sugarcane variety 2003-USS-127 was planted on 7th October 2013. This variety is originated from canal point Florida, USA which is recommended for lodging resistant because of greater fiber contents and also has adequate sugar recovery level. Fertilizers were applied at the rate of 175 kg N, 112 kg P_2O_5, while K was applied according to the experimental treatments, however, recommended dose of potassium for sugarcane is 112 kg/ha. All of phosphorous, potash and half of the nitrogen were applied at the time of sowing in the form of DAP (diammonium phosphate), SOP (sulphate of potash) and urea, respectively. Remaining nitrogen was equally applied in splits at tillering and grand growth stages. For the ratoon crop, about 30% more phosphorus and nitrogen fertilizer were applied. Potash nutrition treatments were applied according to the treatment plan. In total 64-acre-inches irrigation water was applied from sowing to harvesting of the crop during both years in addition to rainfall. Chlorpyriphos at 2.5 L/ha solution for the prevention of red rot and termite attack was applied at sowing time. Carbofuran (3% G) granules at 35 kg/ha were applied for the purpose of controlling borer attack in sugarcane crop. The weeds were controlled manually.

***Crop harvest*:** The plant crop was harvested when it reached physiological maturity on 10th of March 2015, after it was kept as ratoon crop for the second-year trial. The ratoon crop (2nd-year trial) was harvested on 21st February 2016. The total duration of Planted crop was 14 months (60 weeks), however, the time for the ratoon crop was 11 months (50 weeks).

Observations

***Morphological and yield traits*:** Germination or sprouting percentage was calculated according to following formula.

$$\text{Germination percentage} = \frac{\text{No. of buds germinated}}{\text{Total no. of buds}} \times 100$$

Number of sprouts or tillers/m^2 was calculated at 90 days after sowing. The internodal length was measured by selecting random 10 stripped canes from each plot and lengths were measured in cm and then averaged. Leaf area index was calculated by following formula.

$$Leaf\ area\ index\ (LAI) = Leaf\ area/land\ area\ .$$

Leaf area duration was calculated by the formula given by Hunt (1978).

$$\text{Leaf area duration (LAD)} = \frac{\text{LAI}_1 + \text{LAI}_2}{2} \times (t_2 - t_1)$$

LAI_1 describes the leaf area index of first 30 days. LAI_2 describes the leaf area index taken after 60 days at 2nd time. While net assimilation was measured by using the following formula by Hunt (1978).

$$\text{Net Assimilation Rate (NAR)} = \frac{\text{TDM}}{\text{LAD}}$$

Cane weight was calculated by weighing 20 single canes from each plot and then averaged. Number of millable canes per unit area was calculated by counting the total number of canes from each treatment and then presented on m^2 basis. Stripped cane yield was obtained by weighing all stripped canes. Agronomic potassium use efficiency was calculated by following formula (SSSP, 1994).

$$\text{Agronomic } K^+ \text{ use efficency} = \frac{\text{Stripped cane yield(F)} - \text{Stripped cane yield(C)}}{\text{Fertilizer Nutrient applied (K)}}$$

Stripped cane yield $_{(F)}$ = stripped cane yield when crop was fertilized, Stripped cane yield $_{(C)}$ = stripped cane yield where no fertilizer was applied (control)

***Sugar quality traits*:** Commercial cane sugar was calculated by selecting 10 canes from each plot and finding out the value of Brix% by hydrometer. Polarity% was measured by polarity meter of cane juice extracted from those 10 canes and then putting these values in formula given by (Spenser and meads, 1963).

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

Total sugar recovery was calculated by multiplying commercial cane sugar with 0.94 (correction factor). Total sugar yield was determined by following formula.

$$\text{Sugar yield (t/ha)} = \frac{\text{Stripped cane yield(t/ha)} \times \text{Commercial Cane sugar(CCS)}}{100}$$

***Statistical and economic analysis*:** Data collected from this experiment were statistically analyzed by computer package STATISTIX 8.2 (analytical software, Tallahassee, FL, USA) and differences among the treatment means were compared by using least significant difference (LSD) test at 5% probability (Steel *et al.*, 1997) Economic and marginal analyses were carried out according to the principles laid out by Byrelee (CIMMYT, 1988**)**.

RESULTS

Results revealed that planting methods did not significantly affect the tillers during first crop year while results were significant during the second year of study. Moreover, K application significantly affected the number of tillers during both the years. Interaction of planting method and K application was also significant for number of tillers during both study years. Maximum number of tillers /m^2 were recorded for 120 ST and trench planting at 100 kg K_2O and 90 SDRS at 300 kg K_2O during plant crop year, whereas during ratoon crop year it was maximum in 90 by 90 pits with 100 kg K_2O application. Potassium application has a positive effect on the internodal distance of sugarcane during both plant crop and ratoon crop year. However, with the increase of K_2O application beyond 100 kg ha^{-1}, no significant effect was recorded. In ratoon crop year a linear increase in internodal length was recorded up to 200 kg/ha K_2O (Table 1). The internodal length was significantly affected by planting patterns as maximum length during plant crop was recorded in 90 by 90 d-pits (13.99 cm) while maximum

Table 1. Number of tillers and internodal length as affected by various planting methods and K application rates.

Planting methods	2014-15 (Planted crop)					2015-16 (Ratoon crop)				
	Potash application									
	0	100 kg ha^{-1}	200 kg ha^{-1}	300 kg ha^{-1}	Mean (P)	0	100 kg ha^{-1}	200 kg/ha^{-1}	300 kg ha^{-1}	Mean (P)
	Number of tillers /sprouts m^{-2}									
Pit planting@90	12.51d	14.28ab	13.68a-d	14.91a	13.85	12.80d	13.43a-d	13.17cd	13.17cd	13.14B
Diagonal pits@90	12.74cd	14.69a	14.29ab	14.06abc	13.94	13.20bcd	14.16a	13.56a-d	13.67abc	13.64A
Double row strips	12.86cd	14.35ab	13.77a-d	14.77a	13.94	13.57a-d	13.97ab	13.93abc	13.70abc	13.79A
Trenches@120cm	13.29bcd	14.79a	13.94abc	13.68a-d	13.93	12.80d	13.93abc	13.70abc	13.23bcd	13.42AB
Mean (K)	12.85B	14.53A	13.92A	14.36A		13.09C	13.87A	13.59AB	13.44BC	
LSD ≤ 0.05	K=0.68; P =0.58; P.A× P.M=1.30					K= 0.38; P = 0.39; K× P = 0.82				
	Internodal length(cm)									
Pit planting@90	11.61e	13.49bcd	13.33bcd	13.33bcd	12.94B	13.23fg	13.75a	13.77a	13.62a-d	13.59A
Diagonal pits@90	11.98de	16.38a	14.34b	13.26bcd	13.99A	13.35efg	13.40d-g	13.64abc	13.35efg	13.43B
Double row strips	12.17de	12.83b-e	12.54cde	12.97b-e	12.63B	13.50b-e	13.69ab	13.74a	13.58a-d	13.63A
Trenches@120cm	12.89b-e	13.58bcd	13.81bc	13.36bcd	13.41AB	13.18g	13.48b-e	13.55a-e	13.44c-f	13.41B
Mean (K)	12.16C	14.07A	13.50AB	13.23B		13.32C	13.58AB	13.6A	13.50B	
LSD ≤ 0.05	K= 0.72; P = 0.99; P.A× P.M=1.59					K= 0.10; P = 0.14; K× P =0.23				

Trend analysis for potash nutrition treatments	Number of sprouts (tillers)		Internodal length (cm)	
	2014	2015	2014	2015
Linear	*	Ns	*	*
Quadratic	*	*	*	*
Cubic	*	Ns	*	ns

K= Potash application; P= Planting methods; *=Significant ($P<0.05$); ns =Non-significant; Capital alphabetical letters (A, B, C, D) with mean values represent the significant differences for main effects, while small alphabetical letters (a, b, c…) represent the interaction between planting methods and potash nutrition.

internodal length was attained in 90 SDRS (13.63cm) during the ratoon crop year (Table 1).

Leaf area index showed a linear increase in response to potash application up to the levels of 200 kg ha^{-1} (6.91) during both the years, however, the addition of more potash (300 kg/ha) did not significantly increase the leaf area index. Similar trends were observed by cumulative leaf area duration and net assimilation rate in response to K_2O application (Table 2). Planting methods had no significant effect on leaf area index during the plant crop year but during the ratoon crop year, 90 by 90 pits (6.53) were best among all other planting methods in increasing leaf area index. Interaction of 90 by 90 pits and 200 kg /ha (7.02 during the plant crop and 6.70 during the ratoon crop year) has increased the leaf area index to a maximum extent during both years of study. Planting methods also significantly affected leaf area duration and net assimilation rate. It was found that 90 by 90 pits produced the maximum leaf area duration during the plant crop year (1002 days) and ratoon crop year (965 days), whereas 90 by 90 d-pits provided the highest value for the net assimilation rate during plant crop year (3.46 kg m^{-2} day^{-1}) and ratoon crop year (3.16 kg /m^2/ day) (Table 2).

A significant increase in cane weight was recorded by the application of 100 kg K_2O ha^{-1} (0.92 kg) which is statistically at par with the application of 200 kg/ha K_2O (0.9 kg) and 300 kg/ha K_2O (0.90 kg) during the plant crop year whereas a linear increase was observed in cane weight up to 200 kg/ha K_2O (0.89 kg) (Table 3). Increase in application beyond 200 kg/ha had a substantial inverse effect on cane weight during the ratoon crop year. Amongst the planting methods, 120 ST produced healthier canes with 11-16% and 2-6% more cane weight than that of others during plant crop and ratoon crop year. The sugarcane plantation at 120 cm trenches with 200 kg/ha potash nutrition improved cane weight during both years (1.03 kg during plant crop year and 0.93 kg during the ratoon crop year). Number of millable canes was significantly influenced by the application of potash nutrition during both plant crop and ratoon crop year. The increase of about 9-10% in plant population in comparison with control was observed in the plant crop year. Overall millable canes were 6-8% less in ratoon crop year than that of plant crop year. In the planting patterns, 90 by 90 d-pits (12.57 canes/m^2 during plant crop year and 11.20 canes/m^2 during the ratoon crop year) resulted in more production of millable canes than all other planting patterns (Table 3). The best combination was observed with 90 by 90 d-pits at 200 kg ha^{-1} potassium application during plant crop year (12.83 canes/ m) and 90 by 90 d-pits at 100 kg K_2O ha^{-1} during the ratoon crop year (11.55 canes /m^2).

Stripped cane yield was increased during plant crop and ratoon crop year by the application of potash nutrition (Table 4). However, 90 by 90 d-pits proved to be the best planting method amongst all other in producing the striped cane yield during both the years with 106.95 and 96.42 t /ha yield, respectively.

Table 2. Leaf area index, leaf area duration and Net assimilation rate as affected by various planting methods and K application rates.

planting methods	2014-15 (Planted crop)					2015-16 (Ratoon crop)				
	Potash application									
	0	100 kg ha^{-1}	200 kg ha^{-1}	300kgha^{-1}	Mean (P)	0	100 kgha^{-1}	200 kg/ha^{-1}	300 kgha^{-1}	Mean (P)
	Maximum leaf area index									
Pit planting at 90	6.35f	6.76a-e	7.02a	6.49def	6.66	6.15cd	6.55ab	6.70a	6.73a	6.53A
Diagonal pits@90	6.79a-e	6.77a-e	6.89abc	6.73a-f	6.80	5.89d	6.52ab	6.51ab	6.39abc	6.33AB
Double row strips	6.44ef	6.54b-f	6.84a-d	6.79a-e	6.65	5.33e	6.28bc	6.53ab	6.35bc	6.12B
Trenches@120cm	6.50c-f	6.77a-e	6.90ab	6.68a-f	6.71	5.53e	6.29bc	6.45abc	6.41abc	6.17B
Mean (K)	6.52C	6.71B	6.91A	6.67BC		5.73C	6.41B	6.55A	6.47AB	
LSD ≤ 0.05	K=0.24; P=0.18; K × P=0.39					K = 0.14; P =0.25; K × P =0.34				
	Cumulative leaf area duration									
Pit planting@90	983.91bc	1001.80bc	1027.01a	998.24	1002.74A	934.02de	980.98ab	982.99a	965.34abc	965.83A
Diagonal pits@90	925.54d	986.98bc	996.80bc	995.66bc	976.24B	879.14f	978.15	988.81a	973.74abc	954.96A
Double row strips	942.23d	981.29c	993.94bc	991.69bc	977.29B	815.99g	900.06	970.73abc	928.66de	903.86B
Trenches@120cm	936.99d	1000.21bc	1006.69ab	989.07bc	983.24B	894.13f	943.91cd	987.60a	948.40bcd	943.51A
Mean (K)	947.17C	992.57B	1006.11A	993.66B		880.82C	950.78B	982.53A	954.04B	
LSD ≤ 0.05	K =10.27; P =15.27; K × P = 23.95					K =14.53 ; P = 23.16 ; K × P =34.25				
	Net assimilation rate									
Pit planting@90	2.94	3.22c	3.23c	3.08d	3.12B	2.87ef	2.95de	2.90ef	2.95de	2.92B
Diagonal pits@90	3.43b	3.58a	3.45b	3.38b	3.46A	3.07bcd	3.15b	3.31a	3.11bc	3.16A
Double row strips	2.50f	2.55f	2.52f	2.58f	2.53C	2.47h	2.64g	2.80f	2.56gh	2.62C
Trenches@120cm	3.11d	3.17cd	3.18cd	3.12cd	3.15B	2.90ef	3.09bcd	2.97cde	2.99cde	2.99B
Mean (K)	2.99C	3.13A	3.09AB	3.04BC		2.83C	2.96AB	3.00A	2.90AB	
LSD ≤ 0.05	K =0.05 ; P =0.06 ; K × P =0.17					K = 0.27; P =0.44; K × P =0.67				

K= Potash application; P= Planting methods; *=Significant (P<0.05); ns =Non-significant; Capital alphabetical letters (A, B, C, D) with mean values represent the significant differences for main effects, while small alphabetical letters (a, b, c…) represent the interaction between planting methods and potash nutrition.

Table 3. Cane weight (kg) and number of millable cane (m^2) as affected by various planting methods and K application rates.

planting methods	2014-15 (Plant crop)					2015-16(Ratoon crop)				
	Potash application									
	0	100 kg ha^{-1}	200 kg ha^{-1}	300kgha^{-1}	Mean (P)	0	100 kgha^{-1}	200 kg/ha^{-1}	300 kgha^{-1}	Mean (P)
	Cane weight (kg)									
Pit planting@90	0.87efg	0.91d	0.88ef	0.91d	0.89B	0.87bcd	0.86bcd	0.85cde	0.86bcd	0.86B
Diagonal pits@90	0.84ghi	0.90de	0.85ghi	0.86fgh	0.86C	0.87bcd	0.86bcd	0.89abc	0.85de	0.87B
Double row strips	0.82i	0.85f-i	0.85f-i	0.85ghi	0.84C	0.81f	0.81f	0.88bcd	0.81ef	0.83C
Trenches@120cm	0.98bc	1.01ab	1.03a	0.98bc	1.00A	0.87bcd	0.90ab	0.93a	0.87bcd	0.89A
Mean (K)	0.88C	0.92A	0.90AB	0.90B		0.85B	0.86B	0.89A	0.85B	
LSD ≤ 0.05	K =0.026; P =0.015 K × P = 0.035					K = 0.021; P =0.013; K× P=0.036				
	Number of millable canes (m^2)									
Pit planting@90	11.08f	12.14e	12.49cd	12.41d	12.03B	10.15e	10.60b	10.37cd	10.48bcd	10.40B
Diagonal pits@90	12.14e	12.63bc	12.83a	12.69ab	12.57A	10.50bcd	11.55a	11.35a	11.41a	11.20A
Double row strips	8.54j	8.64j	9.18i	8.59j	8.74D	8.32g	9.12f	9.29f	9.18f	8.98D
Trenches@120cm	9.15i	10.13h	10.39g	10.29g	9.99C	9.12f	10.38cd	10.56bc	10.34de	10.10C
Mean (K)	10.23D	10.88C	11.22A	11.00B		9.52B	10.41A	10.39A	10.35A	
LSD ≤ 0.05	K=0.094 ; P= 0.07; K× P =0.16					K=0.098 ;P= 0.12 ; K× P =1.87				

K= Potash application; P= Planting methods; *=Significant (P<0.05); ns =Non-significant; Capital alphabetical letters (A, B, C, D) with mean values represent the significant differences for main effects, while small alphabetical letters (a, b, c…) represent the interaction between planting methods and potash nutrition.

Table 4. Stripped cane yield (t/ha) and Agronomic efficiency of nutrients (kg/kg) as affected by various planting methods and K application rates.

Planting methods	2014-15 (Plant crop)					2015-16(Ratoon crop)				
	Potash application									
	0	100 kg ha^{-1}	200 kg ha^{-1}	300kgha^{-1}	Mean(P)	0	100 kgha^{-1}	200 kg/ha^{-1}	300 kgha^{-1}	Mean(P)
	Stripped cane yield (t/ha)									
Pit planting@90	93.69f	103.64de	102.98de	104.96cd	101.32B	86.13de	91.52c	90.11cd	89.94cd	89.42B
Diagonal pits@90	103.72de	113.65a	108.12a	109.32b	106.95A	93.36bc	96.87ab	98.22a	97.24ab	96.42A
Double row strips	74.99h	78.38g	80.76g	78.29g	78.11C	72.86f	73.80f	74.87f	74.12f	73.91C
Trenches@120cm	94.64f	102.16de	101.48e	101.25e	99.88B	84.53e	92.76c	91.52c	90.37c	89.79B
Mean (K)	91.76B	98.21A	98.33A	97.95A		84.22B	88.74A	88.68A	87.92A	
LSD ≤ 0.05	K=1.55; P =1.91; K× P =3.28					K=1.07; P = 2.080; K× P = 3.77				
	Agronomic efficiency of nutrients									
Pit planting@90	----	99.45a	46.43b	37.54bc	45.85A	----	53.87bc	19.88de	12.70de	21.61AB
Diagonal pits@90	----	99.30a	21.98cd	18.43cd	34.93AB	----	59.70ab	24.28cde	12.92de	24.23AB
Double row strips	----	33.90bc	28.83c	10.98cd	18.43B	----	13.17de	10.07de	4.21de	6.86B
Trenches@120cm	----	75.20ab	34.18bc	22.02cd	32.85AB	----	88.19a	34.92bcd	19.46de	35.64A
Mean (K)	----	76.96A	32.86B	22.24B		----	53.73A	22.29B	12.32BC	
LSD ≤ 0.05	K=12.43; P =23.27; K× P =35.70					K=12.62 ; P =26.33 ; K× P 34.10				

Trend analysis	Leaf area index		Leaf area duration		Net assimilation rate		Number of millable canes		Stripped cane yield (kg/ha)		Potassium Use efficiency		Single cane weight (kg)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Linear	*	*	*	*	*	*	ns	ns	*	ns	*	*	ns	ns
Quadratic	*	*	*	*	*	*	*	*	*	Ns	*	*	*	*
Cubic	ns	ns	ns	ns	*	*	*	*	Ns	Ns	Ns	Ns	*	*

K= Potash application; P= Planting methods; *=Significant (P<0.05); ns =Non-significant; Capital alphabetical letters (A, B, C, D) with mean values represent the significant differences for main effects, while small alphabetical letters (a, b, c…) represent the interaction between planting methods and potash nutrition.

Interaction of 90 by 90 d-pits and 200 kg/ha favored the production of maximum stripped cane yield during both plant crop and ratoon crop year i.e. 113.64 and 98.22 t/ha, respectively.

High potash use efficiency was recorded where 100 kg/ha K_2O was applied (Table 4). This trend realized additional cane yield of 76.96 kg for plant crop and 53.73 kg for ratoon crop with the application of 1 kg of potash nutrition in comparison with control and it was 14% more efficient than that of 200 kg/ha K_2O. 90 by 90 pits showed high potassium use efficiency (45.85 kg/kg) during the plant crop year; whereas it was achieved by using 120 ST (35.64 kg/kg) during the ratoon crop year. Interaction of 90 by 90 pits with 100kg/ha (99.30 kg/kg) during the plant crop year and 120 ST with 100 kg/ha (88.19 kg /kg) during the ratoon crop year was effective in increasing KUE.

A linear increase in commercial cane sugar and total sugar recovery was found with the application of potash nutrition during both plant crop and ratoon crop year (Table 5). Planting methods and K did not make any significant contribution to the commercial cane sugar during the plant crop year; however, 90 by 90 pits increased 14.11% commercial cane sugar in ratoon crop year and 13.23% and 13.31%, respectively, sugar recovery in both years. Sugar yield was substantially increased by the addition of potash nutrition up to 200 kg K_2O /ha in the plant crop year; however, it showed a linear trend in ratoon crop year. Diagonal pit plantation gave maximum production of sugar during both plant and ratoon years (15.08 and 12.65 t/ha, respectively). Plantation of sugarcane in 90 by 90 d-pits and application of 100 kg K_2O/ha provided the maximum sugar yield during plant crop and ratoon crop year, i.e. 15.79 and 13.17 t /ha, respectively (Table 5).

In addition to this, it was found that all of the treatments had higher BCR (> 1) in both plant crop and ratoon crop year, however the combined two years benefits revealed more economic benefits (3678$) when sugarcane was planted in 120 ST with 100 kg /ha K nutrition which is followed by 3611$ in 90 by 90 d-pits with 100 kg /ha K_2O (Table 6).

Table 5. Commercial cane sugar, Total sugar recovery and total sugar yield as affected by various planting methods and K application rates.

Planting methods	2014-15 (Plant crop)					2015-16 (Ratoon crop)				
	Potash application (K_2O)									
	0	100 kg ha^{-1}	200 kg ha^{-1}	300kgha^{-1}	Mean (P)	0	100 kgha^{-1}	200 kg/ha^{-1}	300 kgha^{-1}	Mean (P)
Commercial cane sugar										
Pit planting@90	13.30	14.45	14.59	14.32	14.17A	13.49ef	14.55a	14.35ab	14.05a-e	14.11A
Diagonal pits@90	13.58	13.89	14.31	13.72	13.87B	13.47ef	14.15a-d	13.91a-e	14.03a-e	13.89AB
Double row strips	13.27	14.13	14.18	13.65	13.81B	13.82b-f	13.70def	13.74def	14.29abc	13.89AB
Trenches@120cm	13.25	13.62	13.95	13.65	13.62B	13.74b-f	13.24f	13.59def	14.18a-d	13.69B
Mean	13.35C	14.02B	14.26A	13.83B		13.63B	13.91AB	13.90AB	14.14A	
LSD ≤ 0.05	K=0.21; P=0.10; K× P =0.42					K=0.252; P=0.34; K× P =0.64				
Total sugar recovery										
Pit planting@90	12.50g	13.59ab	13.13cde	13.72a	13.23A	12.96a-d	13.56a	13.51ab	13.21abc	13.31A
Diagonal pits@90	12.76efg	13.13cde	13.45abc	12.90def	13.06B	12.71cd	13.26abc	12.80cd	13.37abc	13.03AB
Double row strips	12.60fg	13.28bcd	13.33abc	12.83efg	13.01B	12.92a-d	12.93a-d	13.06a-d	13.35abc	13.06AB
Trenches@120cm	12.46g	12.80efg	13.11cde	12.83efg	12.80C	12.42d	12.83bcd	12.83bcd	13.26abc	12.84B
Mean	12.58B	13.20A	13.25A	13.07A		12.75B	13.14AB	13.05AB	13.30A	
LSD ≤ 0.05	K=0.20; P=0.15; K× P =0.38					K=0.38.; P=0.28; K× P =0.71				
Total sugar yield (t/ha)										
Pit planting@90	12.46d	14.97b	15.02b	15.03b	14.37B	11.15de	12.41bcd	12.17cd	11.88cde	11.90B
Diagonal pits@90	14.08 c	15.79 a	15.47ab	14.99b	15.08 A	11.87cde	13.17a	12.57abc	13.00ab	12.65A
Double row strips	9.95g	11.08ef	11.45e	10.68f	10.79 D	9.41h	9.59h	9.78gh	9.90gh	9.67D
Trenches@120cm	12.54d	13.91c	14.15c	13.82 c	13.60 C	10.50fg	11.98cd	11.74de	11.98cd	11.55C
Mean	12.26C	13.94A	14.02A	13.63B		10.73B	11.79A	11.56A	11.69A	
LSD ≤ 0.05	K=0.30; P =0.29; K× P =0.62					K=0.38; P=0.34; K× P =0.75				

Trend analysis	Commercial cane sugar		Total sugar recovery		Total sugar yield (tha^{-1})	
	2014	2015	2014	2015	2014	2015
Linear	*	*	*	*	*	*
Quadratic	*	*	*	Ns	*	*
Cubic	ns	ns	ns	Ns	ns	ns

K= Potash application; P= Planting methods; *=Significant (P<0.05); ns =Non-significant; Capital alphabetical letters (A, B, C, D) with mean values represent the significant differences for main effects, while small alphabetical letters (a, b, c…) represent the interaction between planting methods and potash nutrition.

Table 6. Net field benefits and benefit cost ratio by the application of potash under different planting methods in plant crop year (2013-14) and ratoon crop year 2015-16.

Treat.	2014-15 (Plant crop) Stripped yield (t/ha)	Adjusted yield (t/ha)	Total income (Rs.)	Total cost (Rs.)	Benefit cost ratio	Net benefits (Rs.)	Net benefits in $	2015-16 (Ratoon crop) Stripped yield (t/ha)	Adjusted yield (t/ha)	Total income (Rs.)	Total cost (Rs.)	Benefit cost ratio	Net benefits (Rs.)	Net benefits in $	Two year profit in US$
P_1K_0	93.69	84.321	389984	267014	1.46	122970	1173	86.13	77.517	358516	150482	2.38	208034	1984	3157
P_1K_1	103.64	93.276	431401	293694	1.47	137707	1313	91.52	82.368	380952	175638	2.17	205314	1958	3271
P_1K_2	102.98	92.682	428654	316130	1.36	112523	1073	90.11	81.099	375082	197774	1.90	177308	1691	2764
P_1K_3	104.96	94.464	436896	338922	1.29	97973	934	89.94	80.946	374375	219706	1.70	154669	1475	2409
P_2K_0	103.72	93.348	431734	292921	1.47	138813	1324	93.36	84.024	388611	153374	2.53	235237	2243	3567
P_2K_1	113.65	102.285	473068	319893	1.48	153174	1461	96.87	87.183	403221	177778	2.27	225443	2150	3611
P_2K_2	108.12	97.308	450049	340381	1.32	109668	1046	98.22	88.398	408840	201018	2.03	207822	1982	3028
P_2K_3	109.32	98.388	455044	362861	1.25	92183	879	97.24	87.516	404761	222626	1.82	182135	1737	2616
P_3K_0	74.99	67.491	312145	214968	1.45	97177	927	72.86	65.574	303279	145174	2.09	158105	1508	2435
P_3K_1	78.38	70.542	326256	239324	1.36	86932	829	73.8	66.420	307192	168550	1.82	138642	1322	2151
P_3K_2	80.76	72.684	336163	262976	1.28	73187	698	74.87	67.383	311646	191678	1.63	119968	1144	1842
P_3K_3	78.29	70.461	325882	283988	1.15	41893	399	74.12	66.708	308524	213378	1.45	95146	907	1306
P_4K_0	94.64	85.176	393939	223584	1.76	170354	1625	84.53	76.077	351856	149842	2.35	202014	1927	3552
P_4K_1	102.16	91.944	425241	249592	1.70	175648	1675	92.76	83.484	386113	176134	2.19	209979	2003	3678
P_4K_2	101.48	91.332	422410	272020	1.55	150390	1434	91.52	82.368	380952	198338	1.92	182614	1742	3176
P_4K_3	101.25	91.125	421453	293928	1.43	127524	1216	90.37	81.333	376165	219878	1.71	156287	1490	2706

P_1k_0 = 90 cm spaced circular pits+0 kg/ha K_2O; P_1K_1 = 90 cm spaced circular pits+100 kg/ha K_2O; P_1K_2 = 90 cm spaced circular pits+200 kg/ha K_2O; P_1K_3 = 90 cm spaced circular pits+300 kg/ha K_2O; P_2K_0 = 90 cm spaced circular pits in diagonal fashion+0 kg/ha K_2O; P_2K_1 = 90 cm spaced circular pits in diagonal fashion+100 kg/ha K_2O; P_2K_2 = 90 cm spaced circular pits in a diagonal fashion+200 kg/ha K_2O; P_2K_3 = 90 cm spaced circular pits in a diagonal arrangement+300 kg/ha K_2O; P_3K_0 = 90 cm spaced double row strips+0 kg/ha K_2O; P_3K_1 = 90 cm spaced double row strips+100 kg/ha K_2O; P_3K_2 = 90 cm spaced double row strips+200 kg/ha K_2O; P_3K_3 = 90 cm spaced double row strips+300 kg/ha K_2O; P_4K_0 = 120 cm spaced trenches+0 kg/ha K_2O; P_4K_1 = 120 cm spaced trenches+100 kg/ha K_2O; P_4K_2 = 120 cm spaced trenches+200 kg/ha K_2O; P_4K_3 = 120 cm spaced trenches+300 kg/ha K_2O; Two year profit in US$: Combined profits of plant crop year (2013-14) and ratoon crop year (2015-16).

DISCUSSION

Adequate fertilizers and proper planting methods are essential for all crops especially sugarcane because of its nutrient mining ability. Results revealed that sprouting capability of sugarcane was neither affected by potassium application nor by planting methods because sugarcane sett sprouting is dependent upon cane portion, availability of glucose to seedling, soil moisture and proper temperature (Sime, 2013). Potash nutrition has significant effect on tillering of sugarcane (Table 1). In general potassium is transported to the roots via diffusion; therefore applied potassium will be available in solution form in the rhizosphere. Previously it was reported that emergence of tillers is highly dependent on nutrient in the rhizosphere (Oliviria *et al.*, 2004). Net assimilation rate of sugarcane was enhanced by potassium application because potassium speed up the nutrient flow and is directly involved in phloem loading and unloading (IPI, 2016) and fastens the speed of translocation of assimilates. Amongst the planting methods, 90 by 90 d-pits gave the maximum net assimilation rate; which may be due to extensive root system in pit plantation and better localized nutrient and water uptake by the cane plants in diagonal planting system.

Single cane weight was found be more in case of 100 kg K_2O /ha and 120 ST during the plant crop year and 200 kg K_2O /ha during the ratoon crop year (Table 3). This means that during ratooning more potash nutrition is required for phloem loading and translocation of assimilates. The microenvironment available through trench planting may have favored the crop to get more girth, resultantly more cane weight was achieved. Number of millable canes/m^2 increased linearly by the potash application during both plant crop and ratoon crop year. These findings correlate with the findings of Hussain *et al.* (2017), who stated that increased application of potash has a positive and linear effect on number of millable canes. Moreover, 90 by 90 d-pits produced more number of millable canes, which may be due to more seed rate per square meter than that of other plantation schemes. Higher stripped cane yield was also produced by 90 by 90 d-pits that may be related to higher seed rate in this planting method than that of 120 ST; where canes with more weight were obtained. Furthermore, high stripped cane yield in 90 by 90 d-pits may be due to efficient use of resources and environmental factors to explore the genetic potential of cane during the developmental period (Tena *et al.*, 2016). Potash nutrition enhanced the stripped cane yield of sugarcane during both the years of study. Under field condition, stripped cane yield response to potash nutrition depends upon the soil reserves of potassium whether these are exchangeable or non-exchangeable resources (Kingston *et al*., 2009). Moreover, stripped cane yield in ratoon crop in sub-continent is believed to be in between 50-55 t/ha as compared to planted crop yield which is above 70 t/ha (Lal and Singh, 2008). The ratoon crop yield can well be managed by appropriate planting methods like pit plantation and trench plantation in combination with the Potash nutrition as depicted by the results because bud initiation and sprouting can be bettered by proper uptake of nutrients (Shukla *et al.*, 2009b). The obtained higher potassium use efficiency was increased with 100 kg K_2O/ha during both the years, as each additional 76.96 kg plant biomass during plant crop year and 53.54 kg during ratooning, were produced with the input of 1 kg of potash application. In case of planting methods, 90 by 90 pits gave maximum potassium use efficiency during the plant crop year and trenches gave maximum potassium use efficiency during the ratoon crop year. Localized application in pits and trenches favored the efficient utility of nutrients especially macronutrients (K), as they are placed in the closest vicinity of the roots (Yadav, 2004).

Sugar recovery of sugarcane was improved by all level of potash application during the plant crop and ratoon crop year, because of the fact that sugarcane juice is abundant in ash contents and ash contents are abundant in potassium. Therefore, an application of potash fertilizer to the already soil deficient in potassium, will increase the polarity % and reduce the fiber% in the juice (a significant reduction in starch contents) (Mayer and Wood, 2001). Moreover, it has been stated that potassium is as an essential element in the productivity and sugar recovery of sugarcane ratoon (Weber *et al.*, 2002). Sugar yield is the product of commercial cane sugar and stripped cane yield; therefore, a treatment combination of 100 kg K_2O/ha and 90 by 90 d-pits gave the maximum yield during the plant crop as well as ratoon crop year (Table 5).The higher number of millable canes and cane weight resulted in higher stripped cane yield and hence, contributed to higher economic benefits. Combined net benefits of both plant and ratoon year revealed that 120 ST +100 kg/ha K_2O gave maximum field benefits/net returns of 3678$. The reason may be that land preparation, mechanical pit plantation, the shaping of pits and sowing of 30 double budded setts during the plant crop year was expensive and did not contribute significantly to cover the costs with appreciable benefits. Hence even stripped cane yield is higher in case of 90 by 90 d-pits than all other systems, however, 120 ST was found more economical due to less cost of field preparation for trench planting.

***Conclusion*:** It can be concluded that K application at 100 kg/ha is sufficient for attaining higher sugar recovery. Amongst different planting methods, 120 cm spaced trench planting has been found to be economically feasible for plant and ratoon planting of sugarcane crop.

***Acknowledgment*:** Authors are grateful for the financial support by Higher Education Commission of Pakistan for this research.

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