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RESEARCH ARTICLE

Enhancing Sugarcane Plant–Ratoon Productivity Through Bud Chip Transplanting Geometry

Navnit Kumar[1]

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Abstract A field experiment was conducted for three consecutive seasons on sugarcane (*Saccharum* spp. hybrid complex) plant–ratoon system (2013–2016) at Sugarcane Research Institute, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, to study the effect of planting distance and row spacing on productivity of sugarcane planted with bud chip raised settlings by furrow-irrigated raised bed method of planting. The results revealed that growth and yield attributes, viz. leaf area index, drymatter accumulation, plant population, plant height, net assimilation rate, cane diameter and millable canes, were significantly influenced due to planting distance and row spacing. The mean higher cane yield (81.7 and 74.6 t/ha) in plant and ratoon crops was obtained at 30 cm planting distance. Though the differences between 30 and 45 cm planting distance were not significant, the higher benefit/cost ratio was obtained at 45 cm planting distance. Among row spacing, planting at 90 cm row spacing showed the highest drymatter accumulation (30.6 and 28.1 t/ha), millable canes (102,000 and 116,300/ha), net returns (Rs. 137,700 and 140,600/ha) and benefit/cost ratio (1.67 and 2.40) in plant and ratoon crops, respectively. Planting of bud chip raised settlings at 90 cm row spacing significantly increased the yield of plant and ratoon canes during all the years of experimentation as well as on mean basis. Sucrose content juice was not affected by planting distance and row spacing. Correlation studies between cane yield and sucrose content with different growth and yield parameters of sugarcane plant and ratoon crops indicated that the yield of sugarcane was significantly and positively correlated with most of the growth and yield parameters.

Keywords Bud chips · FIRB · Planting distance · Row spacing · Sugarcane

✉ Navnit Kumar
navnitsripusa@gmail.com

[1] Department of Agronomy, Sugarcane Research Institute, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar 848 125, India

Introduction

Sugarcane requires large quantities of seed cane (5–6 t/ha) under conventional system (2–3 bud setts) of planting that depends upon variety and planting material. This huge amount of seed cane poses a great threat in transport, handling and planting. Planting material plays an important role in deciding the cane productivity particularly in sub-tropical region where germination is a serious problem in sugarcane cultivation (Chand et al. 2011). The bud chip raised settlings can be a good source of planting material to ensure optimum plant population and equi-distant crop stand. These buds are less bulky, easily transportable and cost-effective seed material. Prasad and Sreenivasan (1996) used the bud chip method as a technology for easy transport of seed cane planting material. Narendranath (1992) opined that the bud chip raised seedlings were three times more cost-effective than conventional planting material. Furrow-irrigated raised bed method of planting is found to be a potential resource conservation technology in saving scarce natural resources such as water. Moreover, it is seen that population of the weeds in the field is generally low because weeds mostly colonize in moist furrow which could be controlled easily. It also enhances the competitive ability of the sugarcane crop against weeds. Planting geometry is an important agronomical practice which varies with the type of planting materials such as 3 bud setts, single bud setts and bud chip raised settlings. The bud chip raised settlings can be good source of planting material to ensure optimum plant population. Optimum planting distance for 3 bud setts of sugarcane is 90 cm in sub-tropical India, and the extent of reduction in cane yield at 150, 120 and 30:120 cm row spacing was to the tune of 32.9, 19.4 and 1.7%, respectively (Chakrawal and Kumar 2014). But information on appropriate planting geometry is not available under bud chip transplanted sugarcane plant–ratoon system. In conventional method, cost of the seed is the major part of cost of cultivation (Rs. 20,000–24,000/ha); however, this seed cost is reduced by 80% (Rs. 4000–4800/ha) in bud chip method. The present investigation was, therefore, carried out to optimize planting geometry for bud chip transplanted sugarcane plant–ratoon system under furrow-irrigated raised bed method of planting.

Materials and Methods

A field experiment was conducted for three cropping seasons (2013–2016) of sugarcane plant–ratoon system at Sugarcane Research Institute, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, located at 25°59′N, 85°40′E and 52.1 m above mean sea level in sub-humid sub-tropical climate with moderate rainfall, hot dry summer and cold winter. The soil of the experimental field was sandy loam in texture with alkaline in reaction (pH 8.2), low in organic carbon (0.43%), contained N (215 kg/ha), P (9 kg/ha) and K (105 kg/ha). Treatment comprising of 4 planting distances (30, 45, 60 and 75 cm) and 4 row spacings (90, 120, 150 and 30:120 cm) was arranged in randomized block design with three replications. The recommended dose of fertilizer was 150 kg N + 37.1 kg P + 49.8 kg K/ha for plant crop and 170 kg N + 21.8 kg P + 49.8 kg K/ha for ratoon crop. Entire dose of P and K and half of N to plant and ratoon crops of sugarcane were applied as basal in the form of urea, diammonium phosphate and muriate of potash. Remaining amount of the nitrogen was applied in two equal splits. For raising bud chip in nursery, a homogenous mixture was prepared with equal quantity of soil, sand and well-rotten compost. Buds were snatched from 10-month-old sugarcane seed crop and dipped in 0.1% carbendazim solution for 10 min. The bud chips were planted in upright position in pro trays and covered with the treated soil mixture. Ensure regular watering with a rose cane. 25-day-old settlings together with the mass of soil were transplanted to the main field as per treatment. Field establishment of transplanted settlings was 100%, and no gap filling was done in plant crop. Furrows were maintained up to the onset of monsoon, and after earthing up furrows were converted into ridges and ridges into furrows. After transplanting three light irrigations at 7.5 cm depth using Parshall flume were given till the settlings established. Four post-establishment irrigations were given up to the onset of monsoon rain. Sugarcane variety ‘BO 154’ was transplanted in the last week of February and ratooned in the second week of February during all the years of experimentation. Phorate 10 G @ 10 kg/ha was applied surrounding the settlings to protect them from insect–pests. Gap filling was done within a month for synchronizing the growth of ratoon crops. All the recommended package and practices were followed for raising the healthy plant and ratoon crops. The total rainfall during the crop growth period (February–January) was 980.8, 1112.5 and 932.6 mm in 2013–2014, 2014–2015 and 2015–2016, respectively. The sugarcane plant and ratoon crops were harvested in the first fortnight of February in all the years, detopped and detrashed and yield was expressed in t/ha. Observation on growth, yield attributes and cane yield in plant and ratoon canes was recorded at their respective growth and harvesting stages following standard procedures. The net assimilation rate (NAR) is expressed in g/m^2/day and mathematically calculated by using standard formula. Whole cane samples were taken at the time of harvest, cane juice was extracted with power crusher, and sucrose content in juice was estimated as per the method given by Spencer and Meade (1955). For working out the economics, the prevailing market price of every component in the last year of experimentation was considered.

Results and Discussion

Growth

Data pertaining to leaf area index at four crop growth stages have been recorded for both plant and ratoon crops (Table 1). LAI increased at a rapid rate from April to June. The decrease in LAI towards maturity of sugarcane was due to natural senescence of older leaves and mortality of late formed tillers. The planting distance had a significant influence on LAI at all the stages of growth. The maximum LAI at April (0.66 and 0.71), June (2.11 and 2.18), August (3.76 and 3.81) and October (4.15 and 4.19) was recorded at 30 cm planting distance which was statistically comparable to 45 cm planting distance on plant and ratoon crops, respectively. Results presented in Table 2 show that there were significant differences of planting distance on dry-matter accumulation at all the stages of growth. On an average, plants accumulated 1.96 and 2.15 per cent dry-matter up to April, 27.0 and 30.4% drymatter up to June, 51.2 and 53.5% drymatter up to August and 86.5 and

Table 1 Effect of planting distance and row spacing on leaf area index of sugarcane plant–ratoon system (pooled data of 3 years in plant crop and 2 years in ratoon crop)

Treatment	Plant crop				Ratoon crop			
	April	June	August	October	April	June	August	October
Planting distance (cm)								
30	0.66	2.11	3.76	4.15	0.71	2.18	3.81	4.19
45	0.63	2.01	3.67	4.05	0.67	2.07	3.72	4.13
60	0.52	1.44	2.98	3.51	0.58	1.51	3.05	3.58
75	0.48	1.40	2.75	3.01	0.51	1.43	2.86	3.08
SEm ±	0.011	0.038	0.075	0.084	0.013	0.038	0.078	0.087
CD (P = 0.05)	0.03	0.11	0.22	0.24	0.04	0.11	0.23	0.25
Row spacing (cm)								
90	0.60	2.03	3.65	4.09	0.65	2.07	3.69	4.12
120	0.58	1.76	3.25	3.61	0.61	1.79	3.32	3.68
150	0.48	1.10	2.55	2.91	0.50	1.20	2.69	3.02
30:120	0.63	2.07	3.71	4.11	0.71	2.12	3.74	4.16
SEm ±	0.011	0.038	0.075	0.084	0.013	0.038	0.078	0.087
CD (P = 0.05)	0.03	0.11	0.22	0.24	0.04	0.11	0.23	0.25

Table 2 Effect of planting distance and row spacing on drymatter accumulation (t/ha) of sugarcane plant–ratoon system (pooled data of 3 years in plant crop and 2 years in ratoon crop)

Treatment	Plant crop					Ratoon crop				
	April	June	August	October	December	April	June	August	October	December
Planting distance (cm)										
30	0.66	8.2	15.8	27.5	30.6	0.64	8.4	15.2	25.8	28.1
45	0.60	7.9	15.3	26.3	29.8	0.58	8.2	14.7	24.2	27.6
60	0.51	7.4	13.7	22.8	26.8	0.54	7.7	13.3	21.5	24.4
75	0.44	6.8	12.8	20.6	25.2	0.46	7.2	12.2	19.1	23.9
SEm ±	0.011	0.16	0.33	0.55	0.62	0.011	0.16	0.34	0.51	0.62
CD (P = 0.05)	0.03	0.5	0.9	1.6	1.8	0.03	0.5	1.0	1.5	1.8
Row spacing (cm)										
90	0.64	8.4	16.4	28.4	31.8	0.69	8.8	15.8	26.9	29.3
120	0.56	7.2	14.3	23.1	27.1	0.57	7.7	13.5	22.5	25.1
150	0.32	6.6	11.8	20.5	24.6	0.34	6.7	11.2	17.7	23.4
30:120	0.69	8.1	15.1	25.2	28.9	0.62	8.3	14.9	23.5	26.2
SEm ±	0.011	0.16	0.33	0.55	0.62	0.011	0.16	0.34	0.51	0.62
CD (P = 0.05)	0.03	0.5	0.9	1.6	1.8	0.03	0.5	1.0	1.5	1.8

87.3% drymatter up to October in plant and ratoon canes, respectively. However, rate of drymatter accumulation was the highest during April to June. The higher drymatter accumulation at all the stages of plant and ratoon canes was recorded at 30 cm planting distance which was statistically similar to 45 cm planting distance except during the month of April in both plant and ratoon canes (Table 2), where drymatter obtained at 30 cm planting distance was significantly higher over 45 cm planting distance. The effect of planting distance on net assimilation rate (NAR) was found to be significant in plant and ratoon canes at both the stages (Fig. 1). The maximum NAR (5.03 g/m^2/day) during June–August in plant crop was observed at 75 cm planting distance which was at par to 60 cm planting distance. The highest NAR values (4.96 g/m^2/day and 4.41 g/m^2/day) between August and October were recorded

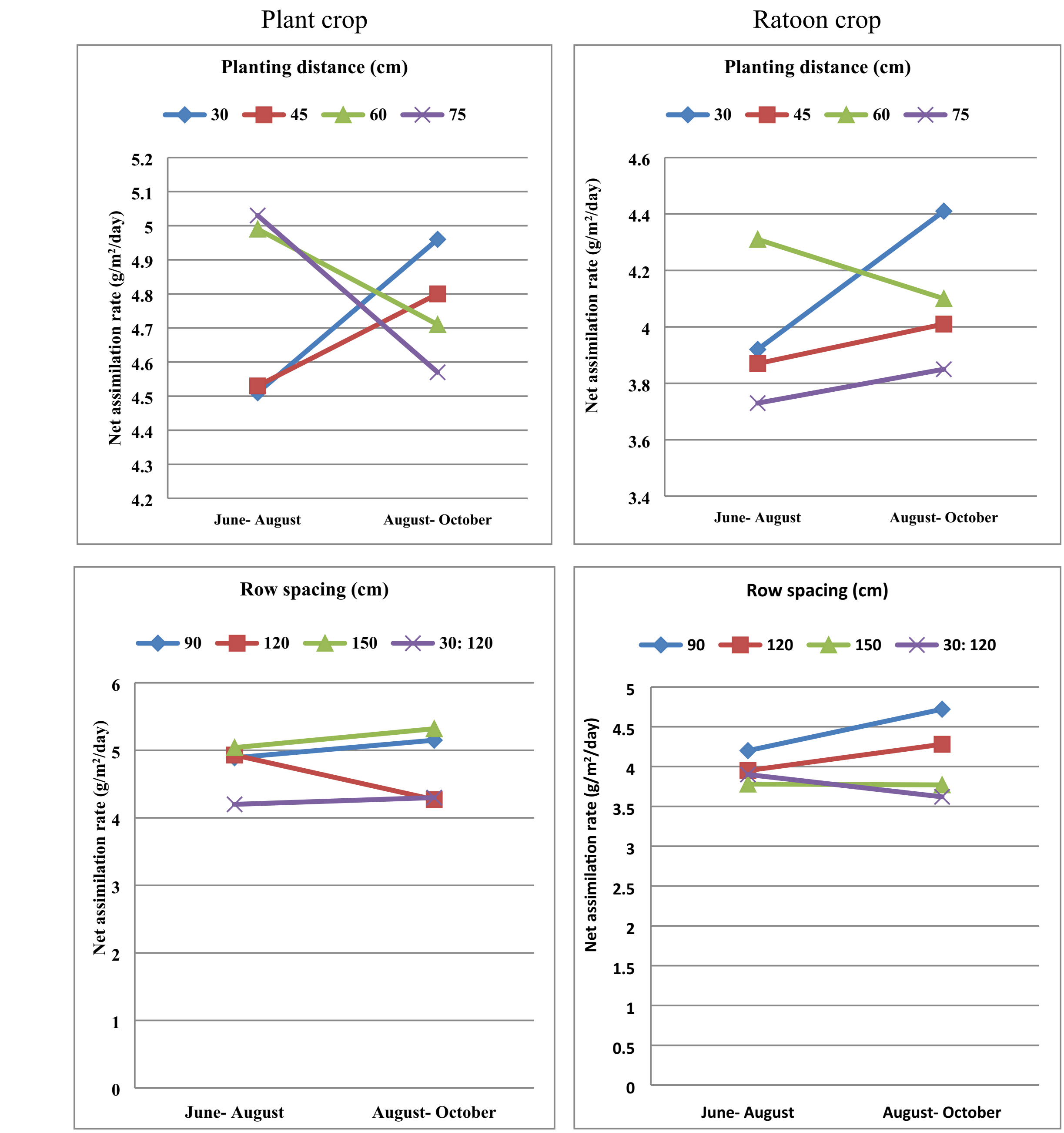

Fig. 1 Effect of planting distance and row spacing on net assimilation rate of sugarcane plant–ratoon system

at 30 cm planting distance and the lowest (4.57 and 3.85 g/m^2/day) at 75 cm planting distance in plant and ratoon canes, respectively. These results are in line with those of Sulistiono et al. (2017). The results indicate that 30 cm planting distance gave the maximum plant population, whereas 75 cm planting distance had the minimum plant population in both plant and ratoon canes (Tables 3, 4). The effect of planting distance on plant height was found to be significant on plant crop, and it was higher at 30 cm planting distance, but failed to affect it significantly on ratoon crop.

The maximum LAI at different growth stages in plant and ratoon canes was recorded at 30:120 cm (paired row) which was statistically on par with 90 cm row spacing (Table 1). However, Pawar et al. (2005) observed significantly higher LAI at 90 cm intersettling spacing. Ninety-centimetre row spacing recorded the highest drymatter accumulation in both plant and ratoon canes at all the stages of growth followed by 30:120 cm row spacing. The minimum drymatter accumulation at all the stages of growth in plant and ratoon canes was recorded at 150 cm row spacing (Table 2), and it was in agreement with Raskar

Table 3 Effect of planting distance and row spacing on growth, yield attributes, sucrose content and economics of sugarcane plant crop (pooled data of 3 years)

Treatment	Plant population (× 10^3/ha)	Plant height (cm)	Cane diameter (cm)	Millable canes (× 10^3/ha)	Single cane weight (g/plant)	Sucrose in juice (%)	Cost of cultivation (× 10^3Rs./ha)	Net returns (× 10^3 Rs./ha)	B/C ratio
Planting distance (cm)									
30	154.3	304	1.82	97.7	838	16.89	88.1	120.3	1.36
45	133.6	298	2.01	93.0	865	17.07	81.5	122.4	1.50
60	119.5	281	2.11	84.9	875	16.84	76.2	108.0	1.41
75	99.3	272	2.16	77.7	882	16.69	73.4	99.9	1.36
SEm ±	3.26	6.3	0.044	2.25	17.5	0.104	–	2.58	0.029
CD (P = 0.05)	9.1	18	0.13	6.3	NS	NS	–	7.4	0.08
Row spacing (cm)									
90	143.0	294	2.06	102.0	855	17.05	82.6	137.7	1.67
120	112.4	288	2.10	86.4	872	16.97	77.7	110.3	1.42
150	95.1	275	2.13	72.7	894	16.89	74.7	90.2	1.21
30:120	156.2	298	1.80	92.3	839	16.58	84.2	112.4	1.34
SEm ±	3.26	6.3	0.044	2.25	17.5	0.104	–	2.58	0.029
CD (P = 0.05)	9.1	18	0.13	6.3	51	NS	–	7.4	0.08

Table 4 Effect of planting distance and row spacing on growth, yield attributes, sucrose content and economics of sugarcane ratoon crop (pooled data of 2 years)

Treatment	Plant population (× 10^3/ha)	Plant height (cm)	Cane diameter (cm)	Millable canes (× 10^3/ha)	Single cane weight (g/plant)	Sucrose in juice (%)	Cost of cultivation (× 10^3Rs./ha)	Net returns (× 10^3Rs./ha)	B/C ratio
Planting distance (cm)									
30	173.5	288	1.77	111.0	674	16.94	61.4	128.8	2.10
45	151.7	289	1.88	106.3	694	17.46	57.9	129.5	2.24
60	136.3	274	2.07	97.4	710	17.37	56.1	113.8	2.02
75	114.5	268	2.11	90.0	722	16.75	55.1	106.7	1.94
SEm ±	5.31	6.5	0.043	3.35	14.3	0.170	–	3.41	0.057
CD (P = 0.05)	15.0	NS	0.12	9.4	41	NS	–	9.8	0.17
Row spacing (cm)									
90	161.3	285	1.95	116.3	683	17.37	58.5	140.6	2.40
120	128.9	278	2.04	96.7	710	17.30	56.6	115.9	2.05
150	108.8	268	2.07	85.5	730	17.13	55.4	101.4	1.83
30:120	177.2	288	1.77	106.1	677	16.72	60.0	120.9	2.02
SEm ±	5.31	6.5	0.043	3.35	14.3	0.170	–	3.41	0.057
CD (P = 0.05)	15.0	19	0.12	9.4	41	NS	–	9.8	0.17

and Bhoi (2005). The lowest drymatter accumulation at 150 cm row spacing was due to the drastic reduction in plant population at 150 cm row spacing. The maximum NAR (5.04 and 5.32 g/m^2/day) in plant canes during June–August and August–October was recorded at 150 cm row spacing. However, it was highest (4.20 and 4.72 g/m^2/day) at 90 cm row spacing in the case of ratoon crops during June–August and August–October, respectively (Fig. 1). The maximum plant population (156,200 and 177,200/ha) and plant height (298 and 288 cm) measured at 30:120 cm row spacing were statistically similar to 90 cm row spacing in plant and ratoon canes, respectively.

Yield Attributes, Cane Yield and Sucrose Content

Maximum cane diameter (2.16 and 2.11 cm) was recorded at 150 cm planting distance which was statistically comparable to 60 cm (2.11 and 2.07 cm) planting distance in plant and ratoon canes, respectively. The higher cane diameter at 75 cm planting distance might be attributed to more space in between plants and more sunlight interception, which led to thicker canes. Single cane weight measured in plant and ratoon canes at the time of harvesting was higher at 75 cm planting distance, which was lowest at 30 cm planting distance, while the variation was found non-significant for plant crops (Tables 3, 4). The highest millable canes (97,700 and 1,11000/ha) were recorded, when planting distance was 30 cm which remained statistically on par with 45 cm and significantly superior to rest of the planting distance in plant and ratoon canes, respectively. Effect of planting distance on plant and ratoon cane yield was significant in all the years of experimentation (Table 5). In 2013–2014 the maximum plant cane yield (85.2 t/ha) was recorded with 30 cm planting distance, but it was statistically on par with 45 cm planting distance (84.4 t/ha). Similar trend was noticed in the subsequent years and on mean basis. As plant crop, similar trend was observed in ratoon yield also. Planting of sugarcane with 30 cm planting distance resulted in 1.5, 11.8 and 16.5% higher ratoon cane yield in 2014–2015 over 45, 60 and 75 cm planting distance, respectively, while in 2015–2016 this increase was 1.5, 12.1 and 18.7%. The pooled analysis of ratoon yield data for both years also showed the same trend. The higher cane yield may be attributed to higher tillers and millable canes production. Similar results were also obtained by Singh et al. (2014) and Samant (2017). The variation in sucrose content juice was found to be non-significant in plant and ratoon canes. Though, marginally increase in sucrose content (17.07 and 17.46%) was noticed due to 45 cm planting distance in both plant and ratoon canes, respectively, which are in agreement with Patel et al. (2006). Among row spacing, cane diameter of plant and ratoon canes obtained at harvesting was significantly higher at 150 cm row spacing which was on par with 120 cm row spacing in plant crop and 90 and 120 cm row spacing in ratoon crop and all of these were significantly superior to 30:120 cm row spacing. The highest millable canes (102,000/ha and 116,300/ha) were recorded when row spacing was 90 cm, while it was minimum (72,700 and 85,500/ha) when row spacing was 150 cm in plant and ratoon crops, respectively. It was due to less number of plants accommodated at 150 cm row spacing (Tables 3, 4). Significantly, higher single cane weight (894 g/plant) was measured with 150 cm row spacing as compared to 30:120 cm row spacing in plant crop. Similarly in ratoon crop, higher single cane weight of 730 g/plant was obtained with 150 cm row spacing which was statistically comparable to 120 cm row spacing and significantly superior over 90 and 30:120 cm row spacing. Planting of sugarcane at 90 cm row spacing was found to be significantly superior over 120, 150 and 30:120 cm row spacing during all the 3 years of experimentation in plant cane yield and both the years of experimentation in ratoon cane yield (Table 5). On the basis of 3 years mean value, 90 cm

Table 5 Effect of planting distance and row spacing on cane yield (t/ha) of sugarcane plant–ratoon system

Treatment	Plant crop				Ratoon crop		
	2013–2014	2014–2015	2015–2016	Pooled	2014–2015	2015–2016	Pooled
Planting distance (cm)							
30	85.2	80.3	79.6	81.7	74.9	74.2	74.6
45	84.4	78.5	77.1	80.0	73.8	73.1	73.5
60	76.9	70.2	69.7	72.3	67.0	66.2	66.6
75	73.2	66.2	64.5	68.0	64.3	62.5	63.4
SEm ±	1.93	2.34	1.98	1.91	1.94	1.86	2.17
CD (P = 0.05)	5.6	6.8	5.7	5.4	5.6	5.4	6.1
Row spacing (cm)							
90	90.5	85.2	83.5	86.4	78.4	77.6	78.1
120	78.2	72.3	70.7	73.7	68.4	66.8	67.6
150	70.9	63.6	59.5	64.7	62.5	60.5	61.5
30:120	80.0	74.1	77.2	77.1	70.7	71.1	70.9
SEm ±	1.93	2.34	1.98	1.91	1.94	1.86	2.17
CD (P = 0.05)	5.6	6.8	5.7	5.4	5.6	5.4	6.1

Table 6 Correlation coefficients (*r*) of yield and sucrose content of sugarcane plant–ratoon system with different growth and yield attributes

Treatment	LAI at 240 DAP	Drymatter accumulation (t/ha)	Plant population ($\times 10^3$/ha)	Plant height (cm)	Cane diameter (cm)	Millable canes ($\times 10^3$/ha)	Single cane weight (g/plant)
Plant crop							
Planting distance (cm)							
Cane yield (t/ha)	0.738	0.966*	0.767	0.764	0.966**	0.955	0.987*
Sucrose (%)	0.825	0.930	0.771	0.856	0.988*	0.945	0.997**
Row spacing (cm)							
Cane yield (t/ha)	0.898	0.996**	0.788	0.821	0.307	0.994**	0.751
Sucrose (%)	0.211	0.141	0.446	0.337	0.871	0.106	0.483
Ratoon crop							
Planting distance (cm)							
Cane yield (t/ha)	0.987*	0.989**	0.950*	0.992**	0.971*	0.988**	0.949*
Sucrose (%)	0.481	0.247	0.248	0.430	0.128	0.332	0.142
Row spacing (cm)							
Cane yield (t/ha)	0.885	0.993**	0.788	0.836	0.494	0.993**	0.856
Sucrose (%)	0.197	0.257	0.445	0.312	0.755	0.070	0.328

*Significant at 5% probability level

** Significant at 1% probability level

row spacing also produced significantly higher cane yield (86.4 and 78.1 t/ha) followed by 30:120 cm row spacing in plant and ratoon crops, respectively. The magnitude of increase in mean cane yield at 90 cm row spacing over 30:120, 120 and 150 cm row spacing was 12.1, 17.2 and 33.5%, respectively, in plant crop and 10.2, 15.5 and 27.0%, respectively, in ratoon crop. Sucrose content juice did not vary significantly due to different row spacings, though higher values (17.05 and 17.37%) were obtained with 90 cm row spacing in plant and ratoon crops, respectively, and similarly reported by Khalid et al. (2015).

Economics

The maximum net returns (Rs. 122,400 and 129,500/ha) and B/C ratio (1.50 and 2.24) were recorded at 45 cm planting distance. Further decrease in planting distance from 45 to 30 cm gave slight reduction in net returns and B/C ratio, owing to the higher cost of seed and comparatively lower cane yield, but beyond 45 cm planting distance drastic reduction in net returns and B/C ratio were due to inadequate plant population. Effect of row spacing on net returns and B/C ratio was also found significant (Tables 3, 4). The highest net returns (Rs. 137,700/ha and 140,600/ha) and B/C ratio (1.67 and 2.40) in plant and ratoon crops, respectively, were obtained with 90 cm row spacing and the lowest at 150 cm row spacing.

Correlation Studies

Data presented in Table 6 indicate that cane yield of sugarcane plant and ratoons crops was positively and significantly correlated with most of the growth and yield attributing characters. Among planting distance in plant crops, drymatter accumulation (0.966*), cane diameter (0.999*), millable canes (0.955*) and single cane weight (0.987*) had significant and positive correlation with cane yield. However, in ratoon crops cane yield was significantly and positively correlated with LAI (0.987*), drymatter accumulation (0.989**), plant population (0.950*), plant height (0.992**), cane diameter (0.971*), millable canes (0.988**) and single cane weight (0.949*). Similarly, sucrose content was positively correlated with all the growth and yield of plant and ratoon crops, but the significant correlation was observed with cane diameter (0.988*) and single cane weight (0.997**) in plant crops only. Among row spacing, cane yield also had a positive and significant correlation with growth and yield attributes though highly significant and positive correlation of plant and ratoon canes to cane yield were observed with drymatter accumulation (0.996** and 0.993**) and millable canes (0.994** and 0.993**), respectively.

Compliance with Ethical Standards

Conflict of interest The author declares that he has no conflict of interest.

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