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Response of sugarcane to different row spacing and drip irrigation levels under south Gujarat condition

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Abstract
Sugarcane dominates the clay soils of South Gujarat, but drip irrigation adoption remains low due to high system costs and farmers' preference for wider spacing that supports interculturing and mechanization. To generate information regarding proper irrigation schedule in different sugarcane spacing, the present study was undertaken at Soil and Water Management Research farm, NAU, Navsari during 2022-23 to 2024-25 in two cycles of plant and ratoon sugarcane. The treatments comprised of three row spacing, S_1: 150 cm (Lateral in every row); S_2: 120 cm (Lateral in every row) and S_3: 60:120 cm (One lateral in pair) and three irrigation levels, I_1: 0.60 ETc; I_2: 0.80 ETc; I_3: 1.0 ETc taken in RBD (factorial concept) with three replications. The results revealed that significantly higher cane yield were recorded with paired row planting of sugarcane during both years of plant and ratoon sugarcane as well as in pooled results of two cycles. In case of irrigation levels except in plant crop-1, no significant difference on sugarcane cane yield was recorded in both plant and ratoon crop as well as both cycles and pooled of two cycles. Treatment I_1 recorded higher WUE of 176.7 kg/ha.mm along with 35.2 per cent water saving over I_3. It was recommended to farmers that for achieving higher cane yield with net return, sugarcane should be planted in paired row (60:120 cm) and irrigated at 0.6 ETc which also facilitated interculturing operations.

Keywords: Plant and ratoon sugarcane, paired row planting, Irrigation levels (ETc)

Introduction
Sugarcane, a long-duration crop, produces substantial biomass and requires high water demand. In India the water requirement ranges from 1143 to 3048 mm typically met through surface irrigation (Hapase *et al.*, 1990) [1] however, farmers often apply quantities exceeding the actual crop demand. Adoption of drip irrigation markedly enhances water-use efficiency (60-200%), reduces water consumption (20-60%), lowers fertilizer requirements via fertigation (20-33%), and improves both crop quality and yield (7-25%) compared with conventional methods (Kaushal *et al.*, 2012) [2]. Sugarcane constitutes the principal crop grown on the clay soils of South Gujarat. The region records an average productivity of about 72 t ha^{-1}, which surpasses yields observed in several major sugarcane-processing states of India. The coastal climate of South Gujarat fosters vigorous cane growth; however, excessively dense planting often predisposes the crop to higher pest and disease incidence. Wider spacing improves aeration and reduces fungal infection. The region's alluvial soils are fertile but prone to salinity in pockets. Proper spacing reduces stress on plants and allows better root spread for nutrient absorption. Wider row spacing (105-120 cm) accommodates intercrops like pulses or vegetables, enhancing income and soil health (Cahudhari *et al.*, 2024) [3]. Adequate spacing facilitates mechanical weeding, irrigation, and harvesting are being increasingly adopted in South Gujarat's progressive farms (Virdia *et al.*, 2023) [4]. In South Gujarat, mechanization in sugarcane cultivation has become essential due to rising labour costs and the need for timely operations under humid conditions. Wider row spacing (up to 150 cm) is increasingly adopted to facilitate mechanization, though it may reduce yield. To address this, the University developed a paired-row planting system (60 × 60: 180 cm) under drip irrigation, which lowers the cost of drip laterals compared to conventional spacing (120 × 60 cm) while maintaining plant population. Past experiments have demonstrated that paired planting combined with drip irrigation and fertigation significantly improves yield and quality. Despite its agronomic

advantages, the adoption of drip irrigation among sugarcane farmers remains limited, largely due to the high initial investment costs and operational challenges associated with intercultural practices. To enable mechanization, farmers have increasingly adopted wider row spacing, extending up to 150 cm. In view of the necessity to integrate mechanization within drip irrigation systems and the importance of optimizing planting geometry, the present investigation was undertaken to assess suitable drip irrigation regimes across varying row spacing and to evaluate their interactive effects on sugarcane growth and yield performance.

Materials and Methods

The experiment was conducted over three years (2021-22 to 2023-24) at the Soil and Water Management Research Farm, Navsari Agricultural University, Navsari. Sugarcane was grown in two cycles, comprising plant and ratoon crops. A randomized block design with factorial concept and four replications was employed. Treatments included three row spacing: S_1 (150 cm; lateral in every row), S_2 (120 cm; lateral in every row), and S_3 (60:120 cm; one lateral per pair), combined with three irrigation levels: I_1 (0.60 ETc), I_2 (0.80 ETc), and I_3 (1.0 ETc). Each treatment plot measured 9 m × 6 m. Irrigation was applied on alternate days using drip laterals fitted with 4 lph inline emitters at 60 cm spacing and operated on alternate day basis at 1.2 kg/cm² pressure.

Prior to planting, 10 t/ha of biocompost was incorporated into the top 15 cm soil layer. Recommendations fertilizer were applied @ 200:100:100 kg/ha N:P_2O_5:K_2O for plant cane and 240:50:100 kg/ha for ratoon cane. Fertilizer scheduling involved application of the full dose of P_2O_5 and 10% of N and K_2O as basal, while remaining 90% of N and K_2O were supplied through fertigation at 10-day intervals beginning one month after planting and ratoon initiation.

The experimental soil is clay in texture, classified under the *Inceptisols* order, with alkaline pH (7.59-7.89), non-saline EC (0.34-0.49 dS/m), medium organic carbon (0.57-0.65%), medium available N (250-265 kg/ha), high available P_2O_5 (76.5-87.5 kg/ha) and K_2O (478-601 kg/ha).

Observations recorded at harvest included plant height, number of millable canes per m², cane length, single cane weight, number of internodes per cane, internode girth and length, and cane yield. For quality assessment, representative samples from each treatment were analysed in the laboratory. Water saving and water use efficiency were calculated based on irrigation volume and yield. Data were statistically analysed following the procedures outlined by Panse and Sukhatme (1985) [5].

Results and Discussion

Growth and yield attributes

Growth and yield attributes of plant and ratoon sugarcane, including number of millable canes, plant height, cane length, single cane weight, number of internodes, internode girth, and internode length (Tables 1-4), were analysed on a pooled basis. Results indicated that row spacing had no significant effect on most yield attributes, except for the number of millable canes per meter row length in both plant and ratoon crops, and single cane weight in ratoon sugarcane. Significantly higher values for these parameters were observed under wider spacing (S_3) compared to other spacing treatments. With drip irrigation and fertigation, water and nutrients were supplied uniformly across treatments. This reduced the likelihood of spacing-induced stress that might otherwise affect plant height or internode development. Similar finding have been reported by Thirugnanasambandam *et al*., (2022) [6]. The number of millable canes per meter row length is directly influenced by how many shoots establish and survive in a given space. Wider spacing (S_3) might have allowed better tiller survival and reduced intra-row competition, resulting in more millable canes per meter row. This parameter is directly linked to plant density. Wider spacing (*e.g.*, paired rows) reduces intra-row competition, allowing more tillers to survive and establish as millable canes. The results corroborated well with findings of Shahana *et al.* (2019) [7]. In case of ratoon sugarcane, they often have weaker establishment compared to plant cane. Wider spacing reduces crowding, enabling ratoon canes to accumulate more biomass, resulting in significantly higher single cane weight (Singh *et al*., 2019) [8].

Among irrigation levels, only the number of millable canes per square meter showed significant variation. In plant cane, I_1 (0.60 ETc) recorded the highest value (9.73), whereas in ratoon cane, I_2 (0.80 ETc) produced the maximum (9.77), surpassing I_3. A reverse trend was thus evident between plant and ratoon crops. In plant cane, excess irrigation (closer to 1.0 ETc) can lead to lodging, poor aeration, and reduced tiller survival. Moderate irrigation (0.60 ETc) maintains optimal soil moisture without waterlogging, supporting higher millable cane establishment. In case of ratoon cane, it regenerates from stubble and has a relatively shallow root system. It requires slightly higher irrigation (0.80 ETc) to sustain tiller growth and survival compared to plant cane. Plant cane benefits from moderate irrigation (avoiding excess), while ratoon cane requires more water to compensate for weaker establishment. Hence, the opposite trends in cane number between I_1 and I_2. Singh *et al.* (2019) [8] also reported that moderate irrigation levels improved tiller survival in plant cane, while ratoon crops required higher irrigation to sustain regrowth. Mary *et al.* (2019) [9] found that subsurface drip irrigation at 0.8 ETc optimized ratoon cane productivity compared to lower levels. Similarly, Chaudhari *et al.* (2024) [3] confirmed that in South Gujarat irrigation scheduling interacts with crop cycle, with plant cane favouring moderate irrigation and ratoon cane requiring higher levels for maximum millable cane survival.

Interaction effects between row spacing and irrigation levels were generally non-significant for most yield attributes, except for the number of millable canes per meter row length in ratoon cane (Table 2). The treatment combination S_1I_2 recorded significantly higher values, though it remained statistically at par with S_1I_1, S_1I_3, S_2I_2, S_2I_3, S_3I_1, and S_3I_2. The combination of optimal spacing and irrigation created, might have made favourable conditions for ratoon tiller survival, leading to significantly higher millable cane. Chaudhari *et al*. (2024) [3] confirmed that spacing × irrigation interactions are generally weak for morphological traits but can significantly affect ratoon cane population dynamics. Similarly, Mary *et al*. (2019) [9] found that subsurface drip irrigation interacts with planting geometry to influence tiller survival, particularly in ratoon crops.

Cane yield (t/ha)

Treatment wise cane yield of sugarcane (two plant crop and two ratoon crop) was recorded and presented in table 5. The result indicated that significantly higher cane yield of 170.1, 154.6, 324.7, 166.5, 157.0, 323.5 and 324.1 t/ha were recorded with paired row planting of sugarcane in case of plant crop-1, ratoon crop-1, cycle-1, plant crop-2, ratoon crop-2, cycle-2 and pooled of two cycle, respectively as compared to other treatments of row spacing of sugarcane. Paired row planting under drip irrigation produced significantly higher cane yields because it optimizes plant population density, resource use efficiency and mechanization feasibility, while reducing intra-row competition compared to conventional single-row spacing (120 × 60 cm and 150 × 60 cm). Paired row geometry ensures better tiller survival, higher single cane weight, and improved ratoon performance, leading to superior yields across both plant and ratoon cycles. Studies confirm that paired planting increases millable cane number and cane weight, directly boosting yield (Thirugnanasambandam *et al*., 2022; Virdia *et al*., 2023) [6, 4].

Among different irrigation levels as well as interaction between various drip irrigation levels and row spacing were found non-significant on cane yield of sugarcane in both plant and ratoon crop as well as both cycle and pool of two cycles except plant crop-1. Significantly higher cane yield of 162.1 t/ha for plant crop-1 was registered with lower irrigation treatment (I_1) as compared to I_3 but it remained at par with irrigation treatment I_2 (156.1 t/ha). Non-significant results due to irrigation and its interaction with spacing indicates that sugarcane's compensatory growth and high water-use efficiency buffer against moderate variations in irrigation and spacing. Sugarcane responds better to frequent, moderate irrigation pulses rather than excess water, especially in humid climates (FAO, 2012) [10]. Further, Singh *et al.* (2019) [8] reported that irrigation × spacing interactions in sugarcane are generally non-significant, with plant population being the dominant yield factor.

Quality parameters

Quality parameters of cane (Brix, sucrose%, purity%, fiber, CCS%) were not significantly influenced by row spacing or drip irrigation levels in either plant or ratoon crops (Table 6). This stability reflects the genetic control of juice quality traits and the physiological buffering capacity of sugarcane, where irrigation and spacing primarily affect yield attributes rather than sucrose accumulation. Kumawat *et al.* (2016) [11] and Singh *et al.* (2019) [8] reported that irrigation and spacing treatments significantly affect cane yield but not juice quality parameters, which are variety-dependent. Sugarcane responds better to frequent, moderate irrigation pulses for yield, but quality traits are relatively stable under different irrigation regimes (FAO, 2012) [10].

Water use efficiency

Apart from cane yield of sugarcane and water applied, WUE in term of kg/ha-mm and water saving over I_3 were computed for individual as well as mean of both plant and ratoon crop under different irrigation levels and given in table 7. The results showed water use efficiency (WUE) was significantly higher under lower irrigation treatment (I_1), recording 176.7 kg/ha-mm along with 35.2% water saving over I_3 under the mean of both plant and ratoon crops. This was because sugarcane maintained comparable yields under I_1 while receiving substantially less water, thereby improving yield per unit of water applied. Moderate drip irrigation pulses minimized deep percolation and evaporative losses, enhanced nutrient uptake, and sustained stool vigour, whereas excess irrigation (I_3) increased water applied without proportional yield gains. Similar findings have been reported by FAO (2012) [10] and Singh *et al.* (2019) [8].

Economics

Since the interaction effects between irrigation levels and row spacing on sugarcane yield were statistically non-significant, the economics of individual treatments were computed on the basis of pooled data across plant and ratoon crops (Table 8). The results revealed that paired row planting (S_3) and drip irrigation at 0.8 ETc (I_2) recorded the highest economic returns. Specifically, paired row geometry (S_3) achieved a gross income of ₹5,34,600/ha with a net return of ₹4,40,951/ha, while irrigation level I_2 (0.8 ETc) produced a gross income of ₹4,92,030/ha and a net return of ₹3,99,945/ha. These values were superior to those obtained under other row spacing and irrigation treatments. The economic advantage of paired row planting and moderate irrigation has also been reported in earlier studies, where optimized planting geometry and drip scheduling improved resource use efficiency and profitability in sugarcane (FAO, 2012; Singh *et al*., 2019 and Virdia *et al*., 2023) [10, 8, 4].

Table 1: Effect of different treatments on number of millable cane and plant height of sugarcane (Pooled of two seasons)

Treatments	No. of millable cane/m^2		Plant height (m)	
	Plant	Ratoon	Plant	Ratoon
Row spacing (cm)				
S_1 (150)	7.94	7.71	4.14	3.86
S_2 (120)	9.20	9.09	4.15	3.87
S_3 (120:60)	10.69	11.36	4.09	3.82
S.Em±	0.21	0.21	0.076	0.075
CD at 5%	0.60	0.60	NS	NS
Irrigation levels (ETc)				
I_1 (0.6)	9.73	9.39	4.12	3.85
I_2 (0.8)	9.41	9.77	4.13	3.85
I_3 (1.0)	8.69	8.99	4.14	3.85
S.Em±	0.21	0.21	0.076	0.075
CD at 5%	0.60	0.60	NS	NS
S x I				
S.Em±	0.37	0.37	0.132	0.130
CD at 5%	NS	1.04	NS	NS
CV%	11.2	9.56	9.01	8.57

Table 2: Interaction effect irrigation and spacing on number of millable cane/m^2 in ratoon crop (Pool of two ratoon seasons)

Treatments	S_1 (150 cm)	S_2 (120 cm)	S_3 (120:60 cm)
I_1 (0.6 ETc)	7.75	8.45	11.98
I_2 (0.8 ETc)	7.91	9.32	12.09
I_3 (1.0 ETc)	7.46	9.49	10.01
S.Em±	0.37		
CD at 5%	1.04		
CV%	9.56		

Table 3: Effect of different treatments on cane length (m) and average cane weight of sugarcane (Pooled of two seasons)

Treatments	Cane length(m)		Single cane weight (kg)	
	Plant	Ratoon	Plant	Ratoon
Row spacing (cm)				
S_1 (150)	2.48	2.47	1.81	1.55
S_2 (120)	2.49	2.47	1.77	1.55
S_3 (120:60)	2.45	2.43	1.65	1.44
S.Em±	0.047	0.046	0.031	0.031
CD at 5%	NS	NS	NS	0.087
Irrigation levels (ETc)				
I_1 (0.6)	2.46	2.45	1.76	1.50
I_2 (0.8)	2.48	2.46	1.77	1.53
I_3 (1.0)	2.49	2.46	1.70	1.53
S.Em±	0.047	0.046	0.031	0.031
CD at 5%	NS	NS	NS	NS
S x I				
S.Em±	0.081	0.081	0.053	0.053
CD at 5%	NS	NS	NS	NS
CV%	9.27	9.26	8.63	7.43

Table 4: Effect of different treatments on number of internodes per cane, internodes length and girth of cane (pooled of two seasons)

Treatments	No. of internodes/cane		Inter node girth (cm)		Inter node length (cm)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Row spacing (m)						
S_1 (150)	19.5	20.2	9.4	8.9	12.3	12.2
S_2 (120)	19.6	20.0	9.3	8.9	12.2	12.2
S_3 (120:60)	18.8	19.6	9.1	8.7	12.1	11.6
S.Em±	0.319	0.317	0.100	0.101	0.170	0.167
CD at 5%	NS	NS	NS	NS	NS	0.47
Irrigation levels (ETc)						
I_1 (0.6 ETc)	19.0	20.0	9.4	8.8	12.1	11.9
I_2 (0.8 ETc)	19.5	19.9	9.3	8.9	12.3	12.1
I_3 (1.0 ETc)	19.4	19.9	9.1	8.8	12.3	12.1
S.Em±	0.319	0.317	0.100	0.101	0.170	0.167
CD at 5%	NS	NS	NS	NS	NS	NS
S x I						
S.Em±	0.553	0.551	0.174	0.175	0.294	0.291
CD at 5%	NS	NS	NS	NS	NS	NS
CV%	8.10	7.99	6.34	6.71	7.81	7.56

Table 5: Quality parameters of cane

Treatment	Brix (^{0})		Sucrose (%)		Purity (%)		Fiber (g)		C.C.S. (%)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
S_1I_1	17.3	19.0	16.2	17.6	93.6	92.9	0.97	0.66	11.5	12.5
S_1I_2	17.2	18.9	16.1	17.8	88.4	96.6	0.92	0.76	10.5	12.6
S_1I_3	18.1	19.3	16.0	17.1	88.6	93.7	0.93	0.69	11.1	11.8
S_2I_1	17.4	18.8	16.1	18.1	92.3	96.5	0.96	0.77	11.3	12.1
S_2I_2	17.4	18.2	16.3	17.2	93.0	94.8	0.99	0.68	11.6	12.3
S_2I_3	16.5	19.8	15.8	18.2	89.5	92.2	0.92	0.88	10.3	12.9
S_3I_1	16.9	18.9	15.9	18.1	88.0	95.9	0.95	0.75	10.3	13.0
S_3I_2	17.1	19.3	16.2	17.9	91.0	94.3	0.91	0.77	10.9	12.8
S_3I_3	17.6	19.7	16.4	18.1	89.8	93.2	0.95	0.73	11.7	12.8

Table 6: Effect of different treatment on cane yield (t/ha)

Treatments	Plant^{-1}	Ratoon-1	Cycle-1	Plant-2	Ratoon-2	Cycle-2	Pool of two cycles
Row spacing (cm)							
S_1 (150)	142.8	131.4	274.2	144.7	127.1	271.9	273.0
S_2 (120)	150.3	137.3	287.5	148.9	137.7	286.5	287.0
S_3 (120:60)	170.1	154.6	324.7	166.5	157.0	323.5	324.1
S.Em±	4.72	4.24	6.4	4.48	3.45	6.3	6.4
CD at 5%	13.79	12.38	18.2	13.09	10.08	18.0	18.1
Irrigation levels (ETc)							
I_1 (0.6 ETc)	162.1	139.8	302.1	152.0	137.5	289.7	295.7
I_2 (0.8 ETc)	156.1	142.7	298.8	155.2	142.5	298.2	298.5
I_3 (1.0 ETc)	144.9	140.7	285.6	152.9	141.8	290.2	287.9
S.Em±	4.72	4.24	6.5	4.49	3.45	6.4	6.4
CD at 5%	13.8	NS	NS	NS	NS	NS	NS
S x I							
S.Em±	8.180	7.35	11.1	7.78	5.98	11.0	11.0
CD at 5%	NS	NS	NS	NS	NS	NS	NS
CV%	10.6	10.4	10.5	10.1	9.5	9.4	8.16

Table 7: Mean yield, water applied, WUE and water saving of two cycles

Particulars	Treatments		
	I_1 (0.6 ETc)	I_2 (0.8 ETc)	I_3 (1.0 ETc)
Yield(t/ha)	147.9	149.1	145.1
Water applied (mm)	836.9	1064.1	1291.2
WUE (kg/ha-mm)	176.7	140.1	112.4
Water saving (%)	35.2	17.6	

Table 8: Sugarcane crop economics of different treatments (Pooled of two cycles)

Treatments	Cost of cultivation (Rs./ha)		Avg. cost of cultivation (Rs./ha)	Avg. yield of two cycles (t/ha)	Gross Income (Rs./ha)	Net return (Rs./ha)
	Plant	Ratoon				
Row spacing (cm)						
S_1 (150)	100776	74812	87794	136.5	450450	362656
S_2 (120)	110096	79529	94812	143.5	473550	378738
S_3 (120:60)	112863	74434	93649	162.0	534600	440591
Irrigation levels (ETc)						
I_1 (0.6)	107556	75914	91735	147.9	488070	396335
I_2 (0.8)	107912	76258	92085	149.1	492030	399945
I_3 (1.0)	108268	76603	93435	145.1	478830	386395

Note: Sugarcane selling rate: Rs. 3300 /t

Conclusion

Farmers of the South Gujarat zone cultivating sugarcane under drip irrigation are advised to adopt paired row planting geometry (60 cm within the pair and 120 cm between pairs) with a single lateral serving two rows. This configuration, when combined with irrigation scheduling at 0.6 ETc, consistently delivers higher cane yield and net profit while achieving 18-35% water savings compared to wider row spacing with individual laterals. Beyond yield and resource efficiency, paired row spacing facilitates mechanization, reduces the cost of drip installation, and enhances overall production sustainability. These results confirm that paired row planting under moderate drip irrigation is a practical and economically superior alternative to conventional wider spacing, enabling farmers to maximize returns while conserving water and reducing input costs. The paired row not only reduces cost of drip system but also facilitates to carrying out mechanization operations.

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