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RESEARCH ARTICLE

Water Productivity of Sugarcane Influenced by Planting Techniques, Mulching and Irrigation Scheduling in Indo-Gangetic Plains of India

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Abstract Sugarcane is one of the most suitable alternative crops to predominant rice–wheat cropping system in indo-Gangetic plains of India. However, grand growth period of this crop coincides with hot and dry summer months having higher evaporative demands which raise the crop water requirement during this period, thus narrowing its scope of being an alternative to rice–wheat cropping system. To enhance water productivity of sugarcane field, experiments were conducted at Punjab Agricultural University, Regional Research Stations, Faridkot and Kapurthala during spring 2016, 2017 and 2018 on planting methods and irrigation scheduling. Four planting methods comprised of P_1: conventional flat (75 cm apart) with mulching @ 6 ha^{-1}, P_2: conventional flat without mulch, P_3: paired row trench planting (30:120 cm) with mulch and P_4: paired row trench planting without mulch as main plots and three irrigation schedules, i.e., irrigation at 0.60, 0.80 and 1.00 IW/CPE as subplots factors in split plot design. The results revealed that paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1} resulted into 162% and 123% higher apparent water productivity than conventional flat planted crop without mulch at Faridkot and Kapurthala, respectively. In paired row trench planting, irrigation water application was 58.4% and 52.0% lesser than conventional flat planted crop at Faridkot and Kapurthala, respectively, as water was applied only in trenches which actually curtailed the wettable area to 40%. Mulching in conventional flat planted crop improved the cane yield by 10.3% over non-mulch flat planted crop at Kapurthala, but this difference was only 6.1% in paired row trench planted crop at Faridkot. At Kapurthala, mulching in paired row trench planted crop enhanced the cane yield by 8.8%, but in conventional flat planted crop, this increase was up to 6.9%. On the basis of these results, it can be concluded that the planting sugarcane in paired row trench planting system with mulch @ 6 t ha^{-1} is the most viable planting system in sugarcane to attain higher crop and water productivity. Based on the availability of irrigation water, crop can either be irrigated at 0.6 or 0.8 IW/CPE for higher total and apparent water productivity and higher water-use efficiency. Higher benefit/cost ratio (mean over locations) is obtained under paired row trench planting with mulch and irrigation scheduling at 0.8 IW/CPE.

Keywords Apparent water productivity · Sugarcane yield · IW/CPE · Sugarcane planting methods · Mulching

Introduction

Sugarcane is an important commercial crop grown in a wide range of climate, ranging from subtropical to tropical conditions between 32°N and 32°S latitude. It is cultivated in 121 countries which contribute more than 80% of the world's total sugar production. Brazil, India, China and Thailand are the major sugarcane producing countries which contribute more than 60% of the global production (Anonymous 2016). In India, sugarcane is being cultivated on 5.2 million hectares (Ram 2018) and is the second largest producer of sugarcane next to Brazil by contributing

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nearly 15% and 25% of global sugar and sugarcane, respectively. Sugarcane being a long duration crop requires 1400–1500 mm of water in the subtropics (Solomon 2012). Crop growth rate is linearly correlated with optimum soil moisture availability throughout the crop growing period (Singh and Mohan 1994), whereas cane yield is linearly correlated with actual evapotranspiration (Carr and Knox 2011). In India, about 35% of the total area under sugarcane receives optimum irrigation and remaining 65% area receives either sub-optimum or no irrigation (Lal and Shukla 2000). In northwestern part of the country, sugarcane crop passes through moisture stress, especially, during the pre-monsoon period which commences in April and extends up to end June coupled with high evaporative demand requires frequent irrigation. Formative phase is the moisture sensitive crop growth stage; moisture stress at this stage resulted in considerable yield losses. In India, Punjab is also facing an acute shortage of irrigation water and generates a gap of 8.9 BCM (billion cubic meter) between demand and supply per annum; consequently, groundwater is being depleted at an alarming rate. At present, groundwater table is lowering at a rate of 55.0 mm per annum.

Different planting methods have been developed to improve sugarcane productivity and water-use efficiency. Furrow irrigated raised bed (FIRB) improves bud sprouting in sugarcane, thus producing higher number of shoots per unit area compared to conventional flat planting and paired row trench planting. However, millable canes were significantly higher in paired row planting than FIRB and conventional flat planting, whereas FIRB and paired row planting produced statistically similar cane and sugar yield (Singh 2012; Singh and Brar 2015). However, Bhullar et al. (2008) observed the highest number of shoots and millable canes in trench planted sugarcane over paired row trenches and pits. Alternate skip furrow irrigation with green manure mulching was found to enhance water-use efficiency without reduction in cane yield (Thimmegowda and Nagaraja 2019). Sugarcane is a long duration crop and considerable growth period passes through drier months with high evaporative demand. Straw mulching proves quite beneficial under such situations because it not only covers soil surface to check direct evaporation but also creates a barrier for solar radiation falling on soil surface and reduced weeds growth too. A crop residue layer reduces the surface evaporation up to half of its magnitude compared to what could be expected from a bare soil (Denmead et al. 1997). Ball et al. (1993) recorded 43% higher total dry matter production with sugarcane ratoon crop over non-mulch crop. Yield responses of 7–10 t ha^{-1} with additional availability of water to the quantum 100–200 mm with mulching were also reported by Kingston et al. (2005). Retention of crop residues layer on soil surface showed considerable yield improvement in low rainfall areas but showed either negative or negligible response in humid and low-temperature areas (De Beer et al. 1995; Kingston et al. 2005). Retaining soil cover not only reduces the soil moisture losses to the extent of 70% but also optimizes the mean soil surface temperature, minimizes soil erosion, improves soil physicochemical properties and soil micro-biota as well (Braunbeck and Magalhoes 2010). Straw mulching at 10 t ha^{-1} (50% of the total straw produced in the sugarcane field) is sufficient to attain higher cane weight than 15 t ha^{-1} (75%) or 20 t ha^{-1} (100%) (Aquino et al. 2017). Poor water-use efficiency in sugarcane which is approximately 50% of what could be achieved theoretically is mainly low adoption rate of irrigation technologies (Olivier and Singels 2003). Thus, the present study was undertaken to find out the effects of planting techniques, mulching and irrigation scheduling as well as their interaction effect to get higher water productivity in sugarcane.

Materials and Methods

Experimental Site

The study was conducted at Punjab Agricultural University, Regional Research Station, Faridkot and Kapurthala during spring 2016, 2017 and 2018. Faridkot is located at 30 ° 40’ N, 74 ° 74’ E and is 200 m above from sea level, whereas the Kapurthala lies between 31 ° 22’N and 75 ° 22’ E and at a 229 m above sea level. Faridkot is semiarid (dry) with annual rainfall of 400 mm, major part of which is received during the months of July, August and September. In this zone, the soils are light to medium in texture and groundwater is brackish. The normal annual rainfall of Kapurthala is 779 mm, 75% of which is received through southwest monsoon and remaining 25% through western disturbances and thunderstorms. The soil of the experimental field at Faridkot was sandy loam, slightly alkaline in pH (8.7), having electrical conductivity (EC) of 0.37 dScm^{-1}, tested low in organic carbon (0.35%), medium in available P (15.0 kg ha^{-1}) and medium in available K (256 kg ha^{-1}), whereas at Kapurthala, soil was silty loam in texture, neutral in pH (7.1), having electrical conductivity of 0.38 dScm^{-1}, medium in organic carbon (0.45%), medium in available P (17.9 kg ha^{-1}) and available K (257 kg ha^{-1}).

Weather

Weather data were recorded from automatic weather station located around 300 m away from the experimental sites at both locations during crop seasons of 2016, 2017 and 2018 and is presented in Figs. 1 and 2. At Faridkot,

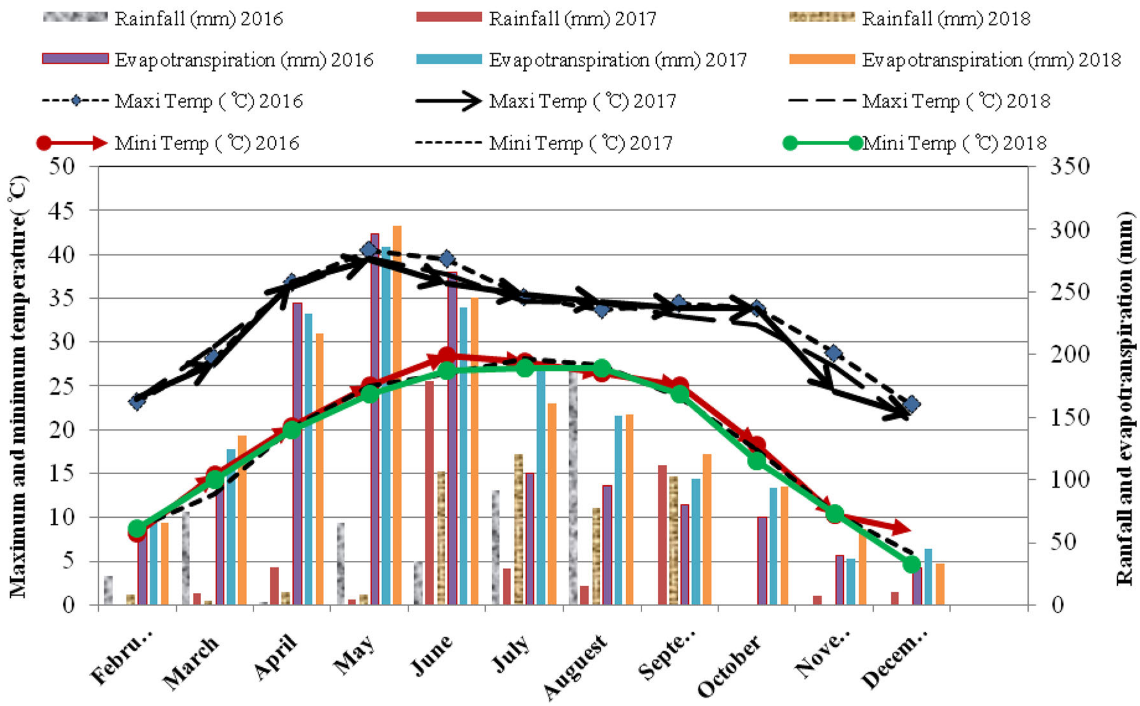

Fig. 1 Meteorological weather parameters during the crop periods at Faridkot

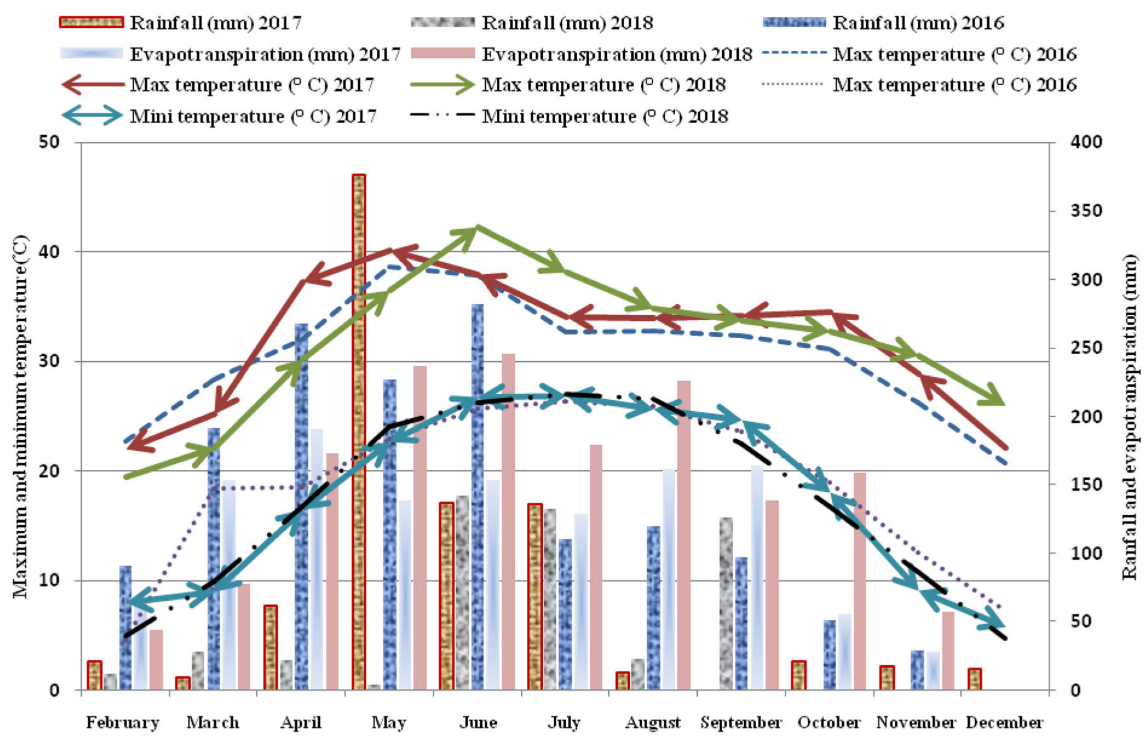

Fig. 2 Meteorological weather parameters during the crop periods at Kapurthala

maximum rainfall was received during the month of August every year and mean maximum and mean minimum temperatures were recorded in the month of May and December, respectively, every year. At Kapurthala, the mean maximum temperature was highest (40.2 °C) in the month of May, 2017, whereas in June, it was maximum (42.3 °C) during year 2018. Mean minimum temperature of 4.6 °C was recorded in the month of February 2016, whereas its lowest value was recorded in the months of December 2017 and 2018. Rainfall of 633.3, 863.5 and 506.5 mm was received during years 2016, 2017 and 2018, respectively. Evapotranspiration was comparatively higher during years 2016 (1523.5 mm) and 2018 (1569.5 mm) than year 2017 (1280 mm).

Experimental Details and Crop Management

The experiment consisted of 12 treatments combinations (4 × 3) laid out in split plot design. The main plots were allocated with four planting methods, i.e., P_1: conventional flat (sugarcane planted at 75 cm row spacing) with mulching @ 6 t/ha, P_2: conventional flat without mulch, P_3: paired row trench planting (30:120 cm, 2 rows of sugarcane in 30 cm trench with spacing between two trenches 120 cm) with mulch and P_4: paired row trench planting without mulch. Irrigation schedules, i.e., irrigation at 0.60, 0.80 and 1.00 IW/CPE, were allotted to subplots. IW/CPE ratio, where IW refers to irrigation water and CPE is the cumulative pan evaporation. The experiments were replicated three times. Sugarcane variety Co 118 was planted in spring 2016 and spring 2017, whereas variety CoPb 92 was planted during spring 2018 at Faridkot. At Kapurthala, sugarcane varieties Co 238 in spring 2016, CoPb 93 in spring 2017 and CoPb 92 in spring 2018 were planted in this experiment. Prior to planting, seed cane setts were treated in 0.25% solution of Tilt 25 EC (propiconazole). The cane setts were then placed at the bottom of trenches/furrows @ 12 buds per meter row length. Sugarcane trash @ 6 t ha^{-1} was applied three days after planting of crop. To prevent the attack of termite, Regent 0.3 G (fipronil) @ 25 kg ha^{-1} was applied along the setts before covering with soil. Sugarcane was planted in sufficient moisture conditions to ensure good germination and subsequent irrigations were applied as per designated irrigation schedules by using meteorological approach based upon CPE was calculated as the sum of daily evaporation from standard USWB Class A open pan, and irrigation was applied at attaining the pre-calculated value of CPE for a constant depth of irrigation water (75 mm). Irrigation water applied to each plot was measured with a water meter. All the plots were separated with double bunds to prevent the flow of water from one plot to another. Entire plot area of conventional flat planted crop was irrigated, whereas only trenches were irrigated in paired row trench planted crop which consequently reduced the wettable area to 40%, i.e., 30 cm (trench)+30 cm (15 cm + 15 cm wettable area both sides of trench) out of 150 cm of the 30:120 cm. Irrigation water applied during crop growing season was calculated by cumulating the depth of water delivered to each treatment plot for each irrigation, and their cumulative value was calculated on the basis of total number of irrigations applied. Average of three years of total irrigation water applied and total water applied (including rainfall) at both locations is given (Tables 1 and 2). Irrigation was stopped 20 days prior to crop harvesting.

Observations Recorded

Cane Yield and Yield Attributes

Cane yield was obtained by manual harvesting of net plot to avoid the border effect. The harvested canes were stripped off manually and immature top cane part was removed with the help of specialized sickle and weighed for cane yield. Total number of millable canes (NMC) were manually counted from net plots and converted into thousands per hectare. Single cane weight was measured from 10 randomly selected canes from each plot, and their respective values are presented as mean. The cane diameter was measured from top, middle and basal part of the cane with the help of Vernier caliper, and mean of three values was considered as cane diameter (cm).

Total and Apparent Water Productivity

Total water productivity (TWP) is the economic yield produced per unit of water applied which include both irrigation water applied and water received through rainfall, whereas apparent water productivity (AWP) is the productivity per unit of irrigation water applied. The apparent water productivity (AWP) and total water productivity (TWP) were estimated as a function of sugar yield (Singh and Brar 2015).

$$\text{AWP}\left(\text{kg m}^{-3}\right)=\frac{\text{Cane yield}\left(\text{kg ha}^{-1}\right)}{\text{Irrigation water applied }\left(m^3ha^{-1}\right)}$$

$$TWP\left(\text{kg m}^{-3}\right)=\frac{\textit{Cane yield}\left(\text{Kg ha}^{-1}\right)}{\textit{Total water}\text{ expenses}\left(\text{m}^3\text{ha}^{-1}\right)}$$

In 2018, consumptive use of water was calculated by using the following formula:

$$CU_j = 0.6\ or\ 0.8\sum_{K=1}^{N} E_K + \sum_{i=100}^{n}\frac{M\text{i} - M\text{ii}}{100}\times As_{\text{i}}\times D_i + E_{RF} + GWC$$

$$CU=\sum_{j=1}^{n} CU_j$$

where CU = Consumptive use of water or seasonal ETa (cm)$CU=\sum_{j=1}^{n} CU_j$ = Summation of consumptive use of water (cm) of n number of crop growth intervals when j is equal to one growth interval.$\sum_{k=1}^{n} E_k$ = Summation of actual pan evaporation for N number of irrigation days, i.e.,

Table 1 Irrigation water (cm) applied to sugarcane at Faridkot and Kapurthala (pooled mean of three years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1 IW/CPE (0.6)	I_2 IW/CPE (0.8)	I_3 IW/CPE (1.0)	Mean	I_1 IW/CPE (0.6)	I_2 IW/CPE(0.8)	I_3 IW/CPE (1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	70.0	87.5	115.0	90.8	56.2	70.0	87.5	71.2
P2 Conventional flat (75 cm) without mulch	70.0	87.5	115.0	90.8	56.2	70.0	87.5	71.2
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	29.5	36.5	47.5	37.8	27.7	33.5	41.5	34.2
P4: Paired row trench planting (30:120 cm) without mulch	29.5	36.5	47.5	37.8	27.7	33.5	41.5	34.2
Mean	49.8	62.0	81.3		42.0	51.8	64.5	

Table 2 Total water (cm) applied to sugarcane at Faridkot and Kapurthala (pooled mean of three years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1 IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/CPE(0.8)	I_3IW/CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	111.1	129.7	155.3	132.0	87.5	98.2	114.3	97.6
P2 Conventional flat (75 cm) without mulch	111.1	129.7	155.3	132.0	87.5	98.2	114.3	97.6
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	73.9	82.1	91.1	82.4	62.8	65.6	72.2	66.1
P4: Paired row trench planting (30:120 cm) without mulch	74.7	82.9	91.9	83.2	63.8	66.5	73.1	67.1
Mean	92.7	106.1	123.4		75.4	82.1	93.5	

between the days of sampling before and after k^{th} irrigation.$\sum_{i=1}^{n}$ = Summation of consumptive use of water of n number of interval between two irrigations, when I is equal to one layer in an interval.Mi = Moisture percent on dry weight basis after irrigation application in i^{th} layer of soil profile.Mii= Moisture percent on dry weight basis before irrigation application in i^{th} layer of soil profile.As_i = Apparent specific gravity of ith layer of soil profile.D_i=-Depth of ith layer of soil profile (cm).E_{RF} = Effective rainfall (cm) in the j^{th} growth interval0.6 = Constant for cooler months (November–February)0.7 = Constant for months (March–April and September–October)0.8 = Constant for hotter months (May–August)

The water-use efficiency was calculated by the formula:

$$WUE = \frac{Y}{U}$$

where WUE = Water-use efficiency (kg m^{-3}).Y = Cane yield (kg ha^{-1}).U = Water use by the crop (m^3 ha^{-1}).

Results and Discussion

Planting Methods

Pooled mean of three years revealed that sugarcane planted in paired row trenches produced higher number of millable canes in comparison with conventional flat planted crop (Table 3). A significant response of mulching was also observed in terms of production of higher NMC in mulched crop than non-mulch crop irrespective of planting methods. Paired row trench planting of sugarcane with mulching produced significantly higher number of millable canes than paired row trench planting without mulching, conventional flat planting with and without mulching at both locations. Conventional flat planted crop with mulch (P_1) produced statistically similar NMC to paired row trench planted crop without mulch (P_4). Paired row trench planting with mulch produced 6.1%, 12.0% and 5.6% higher NMC over conventional planting with and without mulch and paired row trench planting without mulch, respectively, at Faridkot, whereas at Kapurthala, NMC in paired

Table 3 Number of millable canes (000/ha) of sugarcane under varying planting methods and irrigation schedule Faridkot and Kapurthala (pooled for 3 years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/CPE(0.8)	I_3IW/CPE (1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	95.66	98.84	100.52	98.34	89.71	95.95	97.08	94.25
P2 Conventional flat (75 cm) without mulch	90.08	93.95	97.39	93.81	83.65	86.28	94.17	88.03
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	101.06	104.75	107.10	104.30	92.19	103.91	103.98	100.03
P4: Paired row trench planting (30:120 cm) without mulch	95.04	99.04	102.01	98.70	89.56	96.47	100.70	95.58
Mean	95.46	99.15	101.76		88.78	95.65	98.98	

LSD (p = 0.05)

MOP = 3.13; IS = 2.7

Interaction = NS

MOP = 2.80; IS = 2.42

Interaction = NS

*MOP; methods of planting, IS; irrigation scheduling

row trench planting of sugarcane with mulch were 6.1, 13.6 and 4.6% higher over conventional planting with, without mulch and paired row trench planting without mulch. Number of millable canes depend upon shoot population. Paired row trench planting provides ample space among the paired rows to have an advantage of border to each row which inters insure better utilization of sunlight to enhance the photosynthetic activity. Improved microclimatic condition and better sprouting and tillering in paired row trench planting contributed in production of higher number of millable canes and cane yield in sugarcane Prem et al. 2017; Singh and Brar 2015).

At Faridkot, conventional flat planting with mulch produced the canes having significantly higher cane weight (1.49 kg) than cane produced in paired row trench planted crop with mulch (1.42 kg), conventional flat planting without mulch (1.38 kg) and paired row trench planted crop without mulch (1.28 kg). The single cane weight in conventional flat planted crop with mulch was 5.1%, 8.2%, and 16.9% heavier than single cane weight of paired row trench planted crop with mulch, conventional flat planted without mulch and paired row trench planted crop without mulch, respectively. Although the similar trend of single cane weight was also observed at Kapurthala, these differences were 4.7%, 7.2% and 9.5% over paired row trench planting with mulch, conventional flat planting without mulch and paired row trench planting without mulch, respectively (Table 4). The narrow differences in single cane weight under different planting methods at Kapurthala might be because of the variation in the total rainfall received during the crop growth period. Faridkot is characterized as semiarid region which received total average annual rainfall of 400 mm, whereas Kapurthala received 779 mm annual rainfall. Total rainfall of 484 mm, 396 mm and 437.7 mm was received during the crop period of 2016, 2017 and 2018 at Faridkot, whereas at Kapurthala, total rainfall of 626 mm, 795.5 mm and 490 mm was received during 2016, 2017 and 2018, respectively. Thus at Faridkot, crop mulching showed more beneficial effect in production of thick canes in comparison with Kapurthala. Mulching ensures adequate soil moisture supply throughout the crop growth period by limiting evaporation (Akhtar et al. 2001) and suppression of weeds (Uwah and Iwo 2011; Camargo et al. 2017; Chitodkar et al. 2006) and hence facilitates in production of thick canes.

Cane yield depends on number of millable canes and weight of single millable cane. Pooled mean of three years data on cane yield revealed that paired row trench planted crop produced higher cane yield over conventional flat planted crop (Table 5). At Faridkot, paired row trench planting of sugarcane with mulch produced highest cane yield of 102.2 t ha^{-1} that was significantly higher over paired row trench planting without mulch, conventional flat planting with mulch and without mulch. Conventional flat planting of sugarcane with mulch produced cane yield of 94.0 t ha^{-1} that was statistically similar to cane yield (92.6 t ha^{-1}) produced under paired row trench planting without mulch, but it was significantly higher over

Table 4 Single cane weight (kg) of sugarcane under varying planting methods and irrigation schedule Faridkot and Kapurthala (pooled for 3 years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1 IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/ CPE(0.8)	I_3IW/ CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	1.41	1.52	1.55	1.49	1.13	1.20	1.26	1.19
P2 Conventional flat (75 cm) without mulch	1.26	1.42	1.46	1.38	1.07	1.12	1.10	1.12
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	1.38	1.41	1.47	1.42	1.12	1.14	1.10	1.14
P4: Paired row trench planting (30:120 cm) without mulch	1.16	1.28	1.39	1.28	1.02	1.13	1.10	1.09
Mean	1.30	1.41	1.47		1.08	1.15	1.14	

LSD (p = 0.05)

MOP = 0.08; IS = 0.07

Interaction = NS

MOP = 0.03; IS = 0.03

Interaction = NS

*MOP; methods of planting, IS; irrigation scheduling

Table 5 Cane yield (t ha^{-1}) of sugarcane under varying planting methods and irrigation schedule Faridkot and Kapurthala (pooled for 3 years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/ CPE(0.8)	I_3IW/ CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	88.0	94.7	99.2	94.0	90.8	97.1	101.1	96.4
P2 Conventional flat (75 cm) without mulch	76.1	87.0	92.5	85.2	80.6	94.2	95.8	90.2
P3: Paired row trench planting (30:120 cm) with mulch @6 t ha^{-1}	92.6	105.0	109.1	102.2	98.4	103.3	107.4	103.0
P4: Paired row trench planting (30:120 cm) without mulch	79.7	95.0	103.0	92.6	89.1	95.6	99.5	94.7
Mean	84.1	95.4	101.0		89.7	97.5	101.0	

LSD (p = 0.05)

MOP = 3.5; IS = 3.1

Interaction = NS

MOP = 2.7; IS = 2.4

Interaction = NS

*MOP; methods of planting, IS; irrigation scheduling

conventional flat planting without mulch 85.2 t ha^{-1}). Higher cane yield in paired row trench planting system might be due to more conducive crop growth environment, more inter-row space to ensure border effect among paired rows, higher light interception, more aeration, non-lodging and better utilization nutrients (Singh et al. 2015; Katiyar et al. 2013; Gupta et al., 2004). Prabhakar et al. (2014) and Kumavat et al. (2016) also recorded higher number of millable canes and cane yield in paired row trench planting over conventional planting in sugarcane.

Irrigation Scheduling

The number of millable canes in response to irrigation schedules showed increasing trends with increase in the value of IW/CPE from 0.6 to 1.0 (Table 3). At IW/CPE ratio of 1.0, highest number of NMC were produced, which were significantly higher than IW/CPE ratio of 0.6 but were statistically similar to IW/CPE of 0.80 at both locations. The percent difference in production of NMC at IW/CPE of 1.0 was 12.9% and 2.6% over IW/CPE 0.6 and 0.8, respectively, at Faridkot, whereas at Kapurthala, these differences were 11.5% and 3.5% over IW/CPE 0.6 and 0.8, respectively (Table 3).

The highest value of single cane weight 1.47 kg was recorded at 1.0 IW/CPE ratio which was statistically similar to the single cane weight at 0.8 IW/CPE (1.41 kg), but it was significantly higher over single cane weight produced at 0.6 IW/CPE (1.30 kg) at Faridkot. Similar trends of single cane weight with respect to irrigation schedules were also observed at Kapurthala location also. At IW/CPE ratio 0.8, the single cane weight was 1.15 kg that was statistically similar to single cane weight recorded at IW/CPE ratio 1.0 (1.14 kg), but it was significantly higher over single cane weight obtained at 0.6 (1.08 kg) IW/CPE (Table 4). Adequate moisture supply throughout the crop growth period, improved microclimatic conditions and enhanced physiological processes at 1.0 IW/CPR ratio are the possible reasons for production of heavier canes in sugarcane (Singh and Brar 2015).

Significant response in cane yield with respect to irrigation schedules was also found at both locations. Cane yield of (101.0 t ha^{-1}) was obtained at 1.0 IW/CPE at both locations. Cane yield at 1.0 IW/CPE ratio was 20.1% and 5.9% higher over 0.6 and 0.8 IW/CPE at Faridkot and 12.6% and 3.6% higher over 0.6 and 0.8 IW/CPE at Kapurthala. Frequent irrigation at 1.0 IW/CPE improves the microclimatic conditions of crop which promoted the tiller production and thus resulted in production of higher cane yield.

Planting Methods × Irrigation Scheduling

The interaction effect of planting methods and irrigation scheduling with respect to number of millable canes, single cane weight and cane yield was found to be nonsignificant. However, it was significant in total and apparent water productivity at both locations. The apparent and total crop water productivity showed decreasing trend with respect to increasing IW/CPE due to increase in volume of irrigation water applied. At Faridkot, higher value of AWP (31.7 kg m^{-3}) was obtained in paired row trench planting with mulch when irrigated at 0.6 IW/CPE and it was significantly higher over rest of treatment combination (Table 6). The apparent water productivity of crop planted in paired row trenches without mulch was statistically similar either irrigated at 0.6 or 0.8 IW/CPE ratio. Similar trend of AWP was also observed in conventional flat planted crop when either irrigated at 0.6 or 0.8 IW/CPE ratio at Faridkot. At Kapurthala, AWP under paired row trench planting with mulch (36.8 kg m^{-3}) was the highest at 0.6 IW/CPE followed by paired row trench planting (32.9 kg m^{-3}) without mulch at 0.6 IW/CPE. Sugarcane planted under conventional flat system with or without mulch resulted into statistically similar AWP irrigated either at 0.6 or 0.8 IW/CPE. Paired row trench planting with mulching resulted in 162% and 123% higher apparent water productivity as compared conventional flat planting with mulching at Faridkot and Kapurthala (Table 6). Higher cane yield with lesser water application in paired row trench planting system compared to conventional flat plant system might be the reason of higher AWP in paired row trench planting system. These findings corroborated the findings of Singh and Brar (2015) who also reported higher AWP and TWP in paired row planting than conventional planting but were statistically at par with FIRB (furrow irrigated raised bed) planting system.

The highest value of total water productivity was recorded in paired row trench planting with mulch at 0.8 IW/CPE at Faridkot that was statistically similar to 0.6 IW/CPE under same planting system, but it was significantly higher over total water productivity values obtained under all remaining treatment combinations. Total water productivity obtained under irrigation scheduling of 0.6 IW/CPE and 1.0 IW/CPE was also statistically similar (Table 7). At Kapurthala, although the interaction between planting method and irrigation scheduling was nonsignificant, it showed almost similar trend as obtained at Faridkot location.

Consumptive use of water is the sum of water required for transpiration and evaporation from adjacent soil surface. Consumptive use of water is comparatively lower in paired row trench planting than conventional flat planting irrespective of mulching which did not cause considerable differences in consumptive use at both locations (Table 8). However, these differences were wider in response to irrigation schedules. Consumptive water use at 1.0 IW/CPW was 17.0% and 8.4% higher over 0.6 and 0.8 IW/CPE at Faridkot, whereas at Kapurthala, these were 10.7% and 5.9% over 0.6 and 0.8 IW/CPE. Lower consumptive use of water in paired row trench planting system is mainly because the lesser quantity of water was applied to moist the trench zone only which reduced the soil wet able area by 40%. Similarly, higher consumptive use in irrigation at 1.0 IW/CPE was due to higher quantity of irrigation water application (120.8 cm and 116.4 cm) compared to 0.8 and 0.6 IW/CPE at both locations (Table 8).

Higher cane yield in paired row trench planted crop resulted higher water-use efficiency compared to conventional flat planted crop. Water-use efficiency of paired row trench planted crop with mulch was 9.5 kg m^{-3} and 9.6 kg m^{-3} at Faridkot and Kapurthala, respectively

Table 6 Apparent water productivity (kg m^{-3}) of sugarcane at Faridkot and Kapurthala (pooled for 3 years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1 IW/CPE (0.6)	I_2 IW/CPE (0.8)	I_3 IW/CPE (1.0)	Mean	I_1 IW/CPE (0.6)	I_2 IW/ CPE(0.8)	I_3 IW/ CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	12.6	10.9	8.6	10.7	16.2	14.0	11.7	14.0
P2 Conventional flat (75 cm) without mulch	10.9	10.0	8.1	9.6	14.3	13.6	11.1	13.0
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	31.7	29.1	23.1	28.0	36.8	31.0	26.0	31.2
P4: Paired row trench planting (30:120 cm) without mulch	27.2	26.2	21.9	25.1	32.9	28.7	24.1	28.5
Mean	20.6	19.0	15.4		25.0	21.8	18.2	

LSD (p = 0.05)

MOP = 0.9; IS = 0.8

Interaction = 1.5

MOP = 0.7; IS = 0.6

Interaction = 1.2

*MOP; methods of planting, IS; irrigation scheduling

Table 7 Total water productivity (kg m^{-3}) of sugarcane at Faridkot and Kapurthala (pooled for 3 years)

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1IW/CPE (0.6)	I_2W/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/ CPE(0.8)	I_3IW/ CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	7.9	7.3	6.4	7.2	10.8	10.5	9.2	10.2
P2 Conventional flat (75 cm) without mulch	6.9	6.7	6.0	6.5	9.6	10.1	8.8	9.5
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	12.6	12.9	12.1	12.5	17.2	17.1	15.7	16.6
P4: Paired row trench planting (30:120 cm) without mulch	10.7	11.6	11.3	11.2	15.4	15.7	14.5	15.2
Mean	9.5	9.6	8.9		13.2	13.4	12.0	

LSD (p = 0.05)

MOP = 0.4; IS = 0.4

Interaction = 0.7

MOP = 0.4; IS = 0.3

Interaction = NS

*MOP; methods of planting, IS; irrigation scheduling

(Table 9). Irrigation at 0.6 IW/CPE recorded highest water-use efficiency at both locations with numerical values of 8.7 kg m^{-3} and 8.8 kg m^{-3}at Faridkot and Kapurthala, respectively. Sugarcane planting in paired row trenches with mulch irrigated at 0.8 IW/CPE ratio resulted into higher benefit/cost ratio (mean over location) in comparison with rest of planting methods and irrigation schedules Table 10.

Conclusion

Sugarcane being a wide spaced crop, irrigation application to entire field requires large amount of water. Irrigating only trenches in paired row trench planting technique of sugarcane (30:120 cm) considerably reduced wettable area to 40% and saved irrigation water. Based on the results obtained, it has been concluded that paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1} is the best

Table 8 Consumptive use of water (cm) in sugarcane at Faridkot and Kapurthala

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1 IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/CPE(0.8)	I_3IW/CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	108.5	118.5	133.2	120.1	106.1	114.4	125.9	115.5
P2 Conventional flat (75 cm) without mulch	107.7	117.7	132.7	119.4	105.0	114.3	124	114.4
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	98.9	105.7	109.5	104.7	105.2	106	108.9	106.7
P4: Paired row trench planting (30:120 cm) without mulch	97.8	103.6	107.9	103.1	104	104.8	106.8	105.2
Mean	103.2	111.4	120.8		105.1	109.9	116.4	

*MOP; methods of planting, IS; irrigation scheduling

Table 9 Water-use efficiency (kg m^{-3}) of sugarcane at Faridkot and Kapurthala

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/CPE(0.8)	I_3IW/CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	8.4	8.0	7.4	7.9	8.6	8.5	8.2	8.4
P2 Conventional flat (75 cm) without mulch	7.9	7.6	7.0	7.5	8.2	8.5	7.8	8.2
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	9.6	9.5	9.6	9.5	9.4	9.6	9.9	9.6
P4: Paired row trench planting (30:120 cm) without mulch	9.0	9.0	9.0	9.0	9.1	9.1	9.2	9.1
Mean	8.7	8.5	8.2		8.8	8.9	8.8	

*MOP; methods of planting, IS; irrigation scheduling

Table 10 Benefit/cost ratio of sugarcane under different planting system and irrigation schedules at Faridkot and Kapurthala

Planting methods/irrigation schedule (IW/CPE)	Faridkot				Kapurthala			
	I_1 IW/CPE (0.6)	I_2IW/CPE (0.8)	I_3IW/CPE (1.0)	Mean	I_1IW/CPE (0.6)	I_2IW/CPE(0.8)	I_3IW/CPE(1.0)	Mean
P_1: Conventional flat (75 cm) with mulch @ 6 t ha^{-1}	1.44	1.47	1.49	1.47	1.46	1.53	1.64	1.54
P2 Conventional flat (75 cm) without mulch	1.36	1.44	1.43	1.41	1.41	1.61	1.56	1.56
P3: Paired row trench planting (30:120 cm) with mulch @ 6 t ha^{-1}	1.47	1.57	1.56	1.53	1.58	1.60	1.74	1.74
P4: Paired row trench planting (30:120 cm) without mulch	1.40	1.46	1.46	1.44	1.56	1.51	1.54	1.54
Mean	1.42	1.49	1.49		1.50	1.56	1.62	

planting system in sugarcane to attain higher crop and water productivity and higher benefit/cost ratio in sugarcane. The crop should be irrigated at 0.8 IW/CPE for higher total and apparent water productivity and water-use efficiency the crop in sugarcane.

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