Sugar Tech (May-June 2021) 23(3):536–545
https://doi.org/10.1007/s12355-020-00924-w

RESEARCH ARTICLE

Improvement in Productivity and Profitability of Sugarcane Through Drip Fertigation in North Indian Conditions

Kuldeep Singh[1] · A. S. Brar[2] · Sudhir Kumar Mishra[1]

Received: 10 June 2020 / Accepted: 9 November 2020 / Published online: 25 November 2020

Abstract Sugarcane, an important agro-industrial crop in India, plays a pivotal role in Indian economy. Sugar industry is the second largest industry of India next to textile. In North India, rice–wheat is the predominant cropping system and Punjab has contributed 25.8% and 37.8% rice and wheat to central pool of the country during 2018–2019, respectively. But due to degradation of natural resources, over exploitation of underground water and monoculture limitations, there is need to diversify some area from rice to sugarcane which offers a good scope for diversification and to enhance profitability of the farmers. But, due to long tillering phase of sugarcane, during summer months irrigation water requirement of this crop is also high. So need of the hour is to study the water-saving technologies for getting more crop per drop. For this purpose, a field experiment was conducted for 3 years, i.e., 2014–2015, 2015–2016 (plant crop) and 2016–2017 (ratoon crop) at research farm of Punjab Agricultural University, Regional Research Station, Faridkot, Punjab, India. The experiment was laid out in split plot design keeping three irrigation schedules of drip irrigation at 60, 80 and 100% cumulative pan evaporation (CPE) to wide bed and furrow paired row planting (paired row trench planting) of sugarcane at 30–30: 120 cm row spacing in main plots and three fertigation levels of 60, 80 and 100% recommended N (RDN, 150 kg N/ha for plant crop and 225 kg N/ha for ratoon crop) in subplots, with an extra control of standard practice having flood irrigation and 100% RDN by line top dressing in three replications. Drip irrigation was applied at 3 days interval in paired row planting system, and fertigation was given in ten equal splits as per treatment. During 2014–2015 and 2015–2016, crop irrigated with drip at 100% CPE recorded the highest cane yield which was significantly better than drip irrigation at 60 and 80% CPE. Fertigation with 100% RDN recorded the highest cane yield which was significantly better than 80 and 60% RDN during 2014–2015 and 2015–2016, but during ratoon 2016–2017, cane yield was statistically at par between 80% RDN and 100% RDN. Drip irrigation at 100% CPE with 100% RDN recorded significantly higher cane yield than standard practice of surface flood irrigation and soil application of fertilizer to the tune of 15.6, 27.0 and 19.3% during 2014–2015, 2015–2016 (plant) and 2016–2017 (ratoon), respectively. The highest net returns of Rs. 150,900, 175808, 201666 per ha were recorded at 100% CPE and 100% RDN level during 2014–2015, 2015–2016 and 2016–2017, respectively.

Keywords Sugarcane yield · Drip irrigation · Fertigation · Irrigation scheduling · Economic productivity

✉ Kuldeep Singh
kuldeep@pau.edu

[1] Punjab Agricultural University, Regional Research Station, Faridkot, Punjab, India

[2] Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab, India

Introduction

Sugarcane an important agro-industrial crop in India and sugar industry is the second largest industry of India next to textile. According to Indian Sugar Mills Association, during 2018–19, there were 532 sugar factories in operation, and for these factories, sugarcane was grown on an area of about 5502 thousand ha with production of 4142 lakh tonnes. Sugarcane is a renewable, natural agricultural resource because it provides sugar, besides biofuel, fiber, fertilizer and myriad of by-products/co-products with ecological sustainability. Rice–wheat is the predominant cropping system in Punjab, Haryana and Western Uttar Pradesh. Punjab has contributed 25.8% and 37.8% rice and wheat, respectively, to central pool of the country during 2018–2019 (Anonymous 2019). But due to degradation of natural resources, over exploitation of underground water and monoculture limitations, there is need to diversify some area from rice to sugarcane which offers a good scope for diversification and to enhance profitability of the farmers in these states. Due to long tillering phase of sugarcane, during summer months irrigation water requirement of sugarcane is also more. Generally, sugarcane is planted during spring season from mid-February to last week of March and remained in field for next 10–11 months. For increasing area under sugarcane or increasing per unit sugarcane productivity, judicious use of natural resources is prerequisite. So need of the hour is to study water-saving technologies for getting more crop per drop, because water is a precious natural resource, vital for sustaining life on the earth and critical input for crop production. Water differs from other inputs used in agriculture at least in three ways, firstly it is required in huge quantity, secondly it cannot be applied in a single dose and needs to be applied at a definite interval, thirdly, it governs the response of other inputs (Singh 2012). So, enhancement of water use efficiency in crop production is of great concern because of the increasing demand of water (Hatfield et al. 2001). Globally, per capita availability of fresh water is continuously decreasing because of increasing demand from domestic, industrial as well as agricultural sectors. In comparison of the average 91% in South Asia, India shares 90% of the total volume of water used for irrigation purpose (Lacombe et al. 2019) and with 230 km^3/year extraction, India is the highest groundwater user worldwide (Shah 2010).

The great challenge for agricultural sector is to produce more food from less water by increasing crop water productivity (Sander et al. 2004). Maintenance of adequate moisture in soil profile through irrigation is an important prerequisite to reap the rich harvest of sugarcane crop because rainfall is very scanty during spring season in north India. Efficient method of irrigation for the sugarcane crop not only saves water, but also realizes higher productivity. There is a positive linear relationship between the growth rate and optimum soil moisture because only vegetative growth is of economic importance in sugarcane (Singh and Mohan 1994). Formative phase of the crop, in which the crop remains young and tender, coincides with hot and desiccating summer; hence, optimum soil moisture is of paramount importance to get the good yields. Lal and Shukla (2000) reported that only 35% of the total area under sugarcane receives optimum irrigation and remaining 65% area is under sub-optimum irrigation or un-irrigated. In tropical India, the number of irrigations being applied to sugarcane ranged from 30 to 36, while, in the subtropics 8–12 irrigations are required with an irrigation depth of 80 mm per irrigation. Hence, water requirement of sugarcane in India varies widely from 1143 to 3048 mm (Hapase et al. 1990). Scientists have worked to enhance irrigation water use efficiency to the tune of 1.5–2.5 times through devising advance irrigation methods or modifying existing surface irrigation techniques. It is generally accepted that adoption of scientific irrigation method by farmers is far below the expectations and farmers need more comprehensive technological support that is simpler to use, and can be integrated into farm management. Non-optimum yields of sugarcane are obtained by maintaining very high moisture in entire rhizosphere during the entire growing season, until about one month before harvest. Thus, irrigation scheduling based on climatological approach is need of the hour for increasing water use efficiency in sugarcane. Irrigation scheduling based on pan evaporation reduces the irrigation requirement without any adverse effect on the yields because in this method every drop of rainwater and level of evaporation is accounted. The major advantage of this approach is that farmers need not change the amount of water applied from one to other irrigation. Irrigation based on this approach permits the computation of a time table for the irrigation provided the pattern of pan evaporation does not show much yearly variation during the growing period (Singh et al. 2007). Hence, it becomes imperative to investigate the new methods of irrigation to emphasize the efficient water resource utilizations to attain a higher level of production per unit of water. Border method of irrigation is generally practiced because of convenience which leads to significant wastage of water. Therefore, development of irrigation technique which ensures large coverage of area with a given quantity of water without any adverse effect on yield is need of the hour. Drip irrigation gives a good scope for reducing crop water requirement because drip provides precise and site-specific water and nutrient application near the root zone of the plant. Water productivity of a crop can be improved greatly by using drip irrigation, under limited water applications system by decreasing the leaching loses (Kaur and Brar 2016). Water saving by drip irrigation system varied from 12 to 84% in different crops besides increasing the productivity of crops (Ramah 2008). Moreover, farmers in subtropical India are now adopting wider row planting for ease in mechanical harvesting, so less number of laterals are required for drip irrigation. Hence, the present study was planned, to find out the water-efficient drip fertigation schedule for higher productivity and profitability from spring sugarcane.

Materials and Methods

Experimental Site Characteristics

Field experiment was conducted for three years, i.e., 2014–2015, 2015–2016 (plant crop) and 2016–2017 (ratoon crop) at research farm of Punjab Agricultural University, Regional Research Station, Faridkot, Punjab, India. The research farm is located at an altitude of 211 m above mean sea level and is intersected at 30° 40′ N latitude and 74° 44′ E longitudes. Geologically, this region is a part of the Indo-Gangetic alluvial plains in Trans-Gangetic plain agro-climatic zone of India. The whole expanse of these plains is formed with varying monotony of Pleistocene and recent alluvial deposits of the rivers of Indo-Gangetic system, which have completely shrouded the old land surface.

Weather and Climate Details

The experimental area is characterized as semiarid climate with average annual rainfall about 420 mm, 70–80% of which is received as monsoonal rains from July to September. The weekly weather parameters have large fluctuations among the years (Fig. 1). Range of the mean monthly minimum and maximum air temperature was between 13.0 °C (2014–2015) & 15.7 °C (2016–2017) and 42.7 °C (2016–2017) & 44.2 °C (2014–2015), respectively. Extremely hot days (i.e., maximum temperature > 40 °C) prevailed for 4 weeks during 2016, 3 weeks during 2014 and 2 weeks during 2015 and 2017 each. Similarly, the warmest nights in the number of three, one, four and three have been experienced during the respective years. Similarly, range of relative humidity was 18–91% during 2014–2015, 21–91% during 2015–2016 and 17–96% during 2016–2017. Total amount of rainfall over crop season was 578.9 mm during 2014–2015, 708.2 (2015–2016) and 500.7 mm (2016–2017). Hence, high variation in the amount of the total rainfall of the crop season is clearly visible. Maximum weekly rainfall was 213.5, 97.5, 88.5 and 90.8 mm during these successive years. However, in the year 2014–2015, total evaporation recorded was 591.2 mm during pre-monsoon (February–May) season, 879.6 mm during monsoon (June–September) season and 235.1 mm during post-monsoon (September–January) season. Likewise, during 2015–2016 and 2016–2017, evaporation was 576.2 and 653.0 mm, 725.0 and 575.5 mm and 201.6 and 192.1 mm, respectively, during pre-monsoon, monsoon and post-monsoon seasons. Total annual evaporation was 1705.9, 1502.8 and 1420.6 mm during respective planting years. Thus, in comparison of the excessive seasonal evaporation, shortfall in the rainfall amount was recorded by 33.9, 47.1 and 35.2%, during 2014–2015, 2015–2016 and 2016–2017, respectively.

Soil Type and Experimental Methodology

The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 8.1), normal in EC (0.34 m mhos/cm), medium in OC (0.40%) as well as in available P (9.8 kg/ha) but high in available K (521 kg/ha). The experiment was laid out in split plot design keeping three irrigation schedules of drip irrigation at 60, 80 and 100% cumulative pan evaporation (CPE) wide bed and furrow paired row planting (paired row trench planting) at 30–30: 120 cm row spacing in main plots and three fertigation levels of 60, 80 and 100% recommended N (RDN, 150 kg N/ha for plant crop and 225 kg N/ha for ratoon crop) in subplots, with an extra control of standard

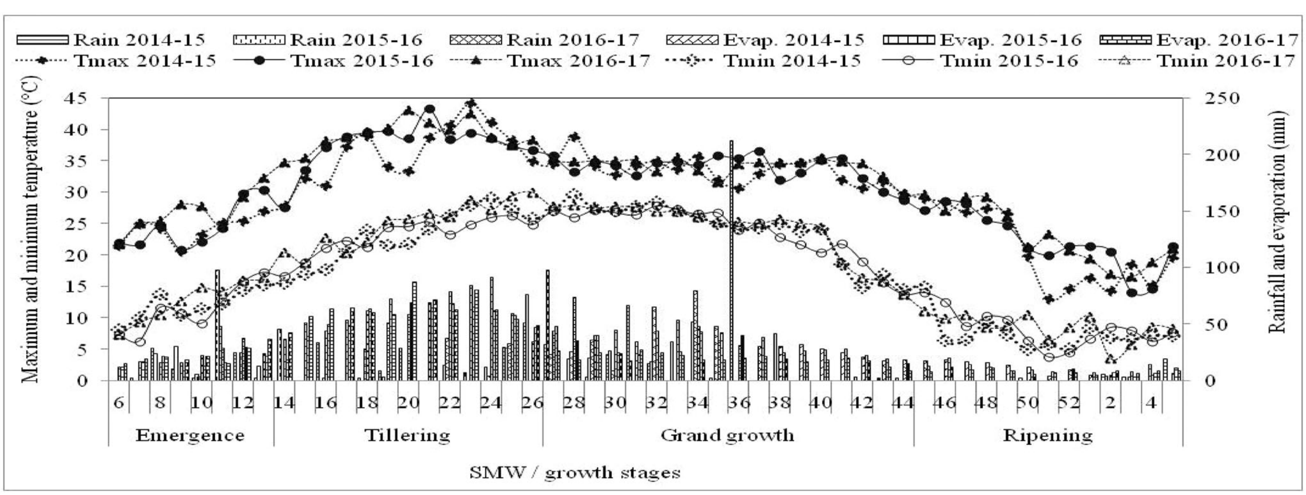

Fig. 1 Year-wise variation in weekly weather parameters at Faridkot

(recommended/farmer's) practice having flood irrigation (check basin method) and 100% RDN by line top dressing in two splits to plant crop and in three splits to ratoon. Sugarcane cultivar CoJ 88 (mid-late maturing), tolerant to the prevalent pathotypes of red rot disease, an excellent ratooner was planted during 2014–2015, 2015–2016 (plant crop) and 2016–2017 (ratoon crop). Because of excellent quality of jaggery, it is very popular among the farmers. The healthy and disease-free seed canes of cultivar CoJ 88 were planted on 22.02.2014 and 27.03.2015 using 1,50,000 buds/ha in wide bed and furrow paired row planting (paired row planting at 120: 30 cm). After placing the three budded cane setts in furrows, the setts were immediately covered with 5 cm soil. The ratoon initiation of 2015–2016 harvested crop was done on 15.01.2016 for taking ratoon crop during 2016–2017. Standard package of practices recommended by Punjab Agricultural University (https://www.pau.edu/content/pf/pp_kharif.pdf) were followed to raise a healthy crop during crop season (Anonymous 2014). In standard practice, plant crop was raised with 150 kg N/ha applied in two equal splits at first irrigation after germination and in May–June months. Similarly, for ratoon crop, the nitrogen @ 225 kg/ha was applied in three equal doses, i.e., one-third of nitrogen in February with first hoeing, one-third in April and the remaining one-third in May. To drip fertigation, nitrogen application as per treatments was started in the month of April and completed in 90–100 days in 10 equal splits and urea was the source of nitrogen. Since soil of the experimental field was medium in available phosphorous, P-containing fertilizer was not applied during study period. Both plant and ratoon crops in drip method were irrigated as per the treatments. Drip irrigation was applied at 3 days interval keeping wettable area 40% in wide bed and furrow paired row planting system and fertigation was given in ten equal splits as per treatment. At every 3 days intervals, irrigation water equal to sum of corresponding 3 days CPE was applied through surface drip lateral lines well connected to the sub-main line. As per treatments, each plot was drip-irrigated with lateral pipeline installed in rows at 150 cm apart having in-built drippers at 20 cm distance with a discharge of 2.2 lph. For computation of the amount of water given to different plots, a water meter was installed on PVC pipe. The amount of water applied in irrigation was summed up to find out the total quantity of irrigation water applied during entire crop growing season. Total 12, 12 and 11 irrigations were applied in standard (recommended/farmer's) practice during 2014–2015, 2015–2016 and 2016–2017, respectively. The depth of irrigation was 75 mm except in 2015–2016 when one heavy pre-sowing irrigation of 100 mm was applied.

Apparent water productivity (AWP) was estimated with respect to applied irrigation water using following formulae already reported by Brar et al. (2012).

$$\text{AWP}\left(\text{kg/m}^3\right) = \text{Cane yield/IWA},$$

where AWP is apparent water productivity (kg/m^3), cane yield (t/ha) and IWA is irrigation water applied (m^3/ha).

Recording of Growth, Yield and Juice Parameters

Data on various growth and yield parameters were recorded for each treatment plot. Number of shoots, millable canes as well as the length, girth and weight of canes were manually recorded, whereas after topping and trash stripping, the final cane yield was recorded. Analysis of juice quality was done after weighting and crushing through three-roller miller. A subsample of crushed cane juice was analyzed for brix (total solids) by a brix hygrometer. Commercial cane sugar percent (CCS) was calculated by using the formula of Sastry and Chari (1960). Percent CCS was multiplied with cane yield to get sugar yield.

Computation of Economics of Sugarcane Cultivation

Based on prevailing market price, total variable cost per hectare was accounted for sugarcane seed, fertilizer, pesticide, herbicide, irrigation, human labor, tractor operation, transportation, etc. Gross returns were accounted by taking price of sugarcane @ Rs. 2850, Rs. 2950 and Rs. 3000 per ton during 2014–2015, 2015–2016 and 2016–2017, respectively. Finally, net return was computed by subtracting the total variable cost from the gross return. Ratio of net return over total variable cost was considered as the benefit:cost (B:C) ratio.

Statistical Analysis

Statistical analysis of different parameters was done to study the effect of drip irrigation and nitrogen fertigation *vis-à-vis* control. The data were analyzed and functional analysis of variance was performed to determine the effect of different levels of nitrogen and water applied through drip irrigation in comparison to control and their interactions. Analysis of variance was performed using Proc GLM procedure of SAS version 9.3 (SAS, 2017 Institute, Inc., Cary, NC, USA) during all the years of experimentation. Fisher's least significant difference test (LSD) was used to compare the difference between means at 5% probability level.

Results and Discussion

Growth and Yield Contributing Characters

Among different drip irrigation and fertigation schedules, the growth and yield attributes of sugarcane were superior with drip irrigation at 100% CPE and 100% RDN than the existing standard practices (control). The water stress influences the crop but, stem and leaves growth of sugarcane largely affected than other organs (Lakshmanan and Robinson 2014). Our results also revealed that the improvement in number of shoots by drip irrigation at 100% CPE over the standard practices was 4.2, 0.4 and 3.6% during 2014–2015, 2015–2016 and 2016–2017, respectively (Table 1). Fertigation of 100% RDN was beneficial over the standard practices by 8.4, 1.8 and 6.7%, respectively. The drip irrigation regimes and fertigation levels both significantly affected the number of millable canes (NMC). There was 1.6, 4.1 and 8.7% increase in NMC by drip irrigation at 100% CPE over standard practice of flood irrigation during 2014–2015, 2015–2016 and 2016–2017, respectively. Similar increase by 100% RDN fertigation was 1.8, 4.5 and 8.2%, respectively. Likewise, the surface drip irrigation regimes and fertigation levels had profound influence on the cane length. Drip irrigation at 100% CPE recorded 1.8 to 3.1 and 2.3% higher and 100% RDN fertigation gave 0.6, 4.5 and 0.5% cane length over control during three years, respectively. Cane girth ranged from 2.28 to 2.54 cm during 2014–2015, 2.27–2.56 cm during 2015–2016, 2.30–2.47 cm during 2016–2017, respectively, while, from the standard practices during respective years it was 2.47, 2.30 and 2.30 cm, respectively. Gradual increase in the amount of irrigation water using surface drip system and the fertilizer doses through fertigation levels, substantially enhanced the cane weight. During 2014–2015, 2015–2016 and 2016–2017, cane weight was higher by 9.2, 0.7 and 0.7% under 100% CPE drip irrigation regimes and 9.9, 2.2 and 2.7% higher than control under 100% RDN fertigation level. Among different irrigation regimes and fertilizer levels under drip irrigation treatments, 100% CPE and 100% RDN were better than their lower levels.

Sugarcane Yield

Results revealed that drip irrigation regimes had significant effect on yield of sugarcane (Table 2). Under standard practice of conventional irrigation, cane yield of 73.6, 71.1 and 80.3 t/ha was recorded during 2014–2015, 2015–2016 (plant crop) and 2016–2017 (ratoon crop), respectively. The ratoon yield was better because variety was good ratooner. The sugarcane crop irrigated at 100% CPE exhibited maximum yield by 80.6, 84.5 and 89.7 t/ha during 2014–2015, 2015–2016 and 2016–2017, respectively. Drip irrigation at 100% CPE with 100% RDN recorded significantly higher cane yield than standard practice having flood irrigation and 100% RDN by line top dressing to the tune of 15.6, 27.0 and 19.3% during

Table 1 Effect of drip irrigation and fertigation schedules on growth and yield contributing characters of sugarcane during 2014–2017

Treatments	2014–2015					2015–2016					2016–2017				
	No. of shoots (000/ha)	NMC (000/ha)	Cane length (cm)	Cane girth (cm)	Cane wt (g)	No. of shoots (000/ha)	NMC (000/ha)	Cane length (cm)	Cane girth (cm)	Cane wt (g)	No. of shoots (000/ha)	NMC (000/ha)	Cane length (cm)	Cane girth (cm)	Cane weight (g)
Drip irrigation schedules															
60% CPE	179.7	102.7	152	2.52	729	118.9	85.3	184	2.28	714	197.9	92.8	184	2.31	820
80% CPE	183.1	107.0	166	2.54	829	122.6	91.6	193	2.28	768	206.2	105.4	223	2.32	886
100% CPE	187.3	117.7	170	2.54	807	125.2	94.6	197	2.33	811	209.3	110.8	223	2.38	846
CD (5%)	NS	9.1	NS	NS	43	NS	4.7	NS	NS	NS	NS	10.2	NS	NS	NS
Fertigation levels															
60% RDN	172.7	102.1	156	2.51	767	116.6	85.7	182	2.27	703	191.4	94.5	202	2.27	791
80% RDN	182.6	107.5	164	2.53	786	123.2	90.7	192	2.30	767	206.2	104.7	209	2.34	857
100% RDN	194.9	117.9	168	2.56	812	126.9	95.0	200	2.32	823	215.6	110.3	219	2.40	904
CD (5%)	9.2	9.7	NS	NS	NS	4.8	5.2	11	NS	72	10.8	10.7	12	NS	71
Standard practice	179.8	120.2	167	2.47	739	124.7	90.9	191	2.3	805	212	101.9	228	2.40	880
CD (5%)	12.99	11.89	NS	NS	64	6.1	7.1	NS	NS	NS	16.0	11.9	NS	NS	NS

Standard practice = Flood irrigation and fertilizer by line top dressing

Table 2 Effect of drip irrigation and fertigation schedules on sugarcane yield (t/ha) 2014–2017

Drip irrigation schedules	Fertigation levels			Mean	Standard practice
	60% RDN 2014–2015	80% RDN	100% RDN		
60% CPE	46.4	55.6	61.6	54.5	–
80% CPE	59.1	74.2	80.4	71.3	–
100% CPE	75.3	81.3	85.1	80.6	–
Mean	60.3	70.4	75.7		–
Standard practice	–	–	–	–	73.6
CD (5%)	IS = 5.0, FS = 5.0, SP versus IS × FS = 6.6				
	2015–2016				
60% CPE	59.4	66.9	70.3	65.5	–
80% CPE	70.5	79.7	82.5	77.6	–
100% CPE	77.2	86.1	90.3	84.5	–
Mean	69.0	77.6	81.0		–
Standard practice	–	–	–	–	71.1
CD (5%)	IS = 5.7, FS = 6.2, SP versus IS × FS = 7.2				
	2016–2017 (Ratoon)				
60% CPE	66.7	77.8	89.7	78.1	–
80% CPE	75.3	85.6	88.1	83.0	–
100% CPE	82.8	90.6	95.8	89.7	–
Mean	74.9	84.7	91.2		–
Standard practice	–	–	–	–	80.3
CD (5%)	IS = 7.3, FS = 5.3, SP versus IS × FS = 6.6				

IS irrigation schedules, *FS* fertigation schedule, *SP* standard practice (flood irrigation and fertilizer by line top dressing)

2014–2015, 2015–2016 and 2016–2017, respectively. Due to relatively less availability of water, the reduced irrigation level (60% CPE) experienced desiccating effect of high temperatures during hot months, hence recorded least cane yield of 54.5 and 65.5 t/ha for plant crops (2014–2015 and 2015–2016) and 78.1 t/ha for ratoon crop (2016–2017). Higher N application increased the cane yield and vice versa. The highest cane yield was obtained due to improvement in the number of millable canes and cane weight (Table 1). In 2014–2015, 2015–2016 and 2016–2017, the mean cane yield was 75.7, 81.0 and 91.2 t/ha under 100% RDN level, 70.4, 77.6 and 84.7 t/ha under 80% RDN and 60.3, 69.0 and 74.9 t/ha under 60% RDN. In comparison of 60% and 80% of RDN, the crop supplied with 100% RDN experienced the increased yield of plant sugarcane by 25.5 and 7.5% higher in 2014–2015, 17.4 and 4.4% higher in 2015–2016 and, 21.8 and 7.7% higher in ratoon crop (2016–2017), respectively. The response of sugarcane to N fertilizer decreased when water stress increases similar to Wiedenfeld (2000). Again, response of N application for cane yield production was better in ratoon than plant crop. Being a long duration and high biomass producing crop, the sugarcane consumes large amounts of N fertilizer though, excess N application may reduce the juice quality; hence, just before ripening phase of sugarcane, uptake of most of the soil N is essential. Similarly, under Indian Punjab conditions, Singh and Brar (2015) observed the profound increase in cane yield with successive increase in irrigation frequency from 0.5 to 1.0 IW: CPE with highest cane (78.7 t/ha) and sugar (10.46 t/ha) yields from wide bed and furrow paired row planted sugarcane irrigated at 1.0 IW: CPE.

Sugarcane Juice Quality

Among different drip irrigation schedules, 100% CPE-based irrigation application showed better results over the crop irrigated with 80% and 60% CPE-based irrigation (Table 3). Percentage of sucrose and CCS were not affected by irrigation schedule and fertilizer levels. Sugar yield (CCS t/ha) was the highest with 100% CPE during all the three years of study. During 2014–2015, sugar yield with standard practice of flood irrigation (9.24 t/ha) was at par with 80% (8.91 t/ha) and 100% CPE (10.10 t/ha) with drip irrigation and was significantly better than 60% CPE (6.75 t/ha). During 2015–2016 and 2016–2017, sugar yield with drip irrigation at 60% and 80% CPE was at par with standard practice of flood irrigation. But at 100% CPE and 100% RDN, sugar yield was significantly better than standard practice of flood irrigation. Sugar yield depends on CCS % and cane yield so, it has trend similar to cane yield. Increased sugar yield with higher fertilizer levels has been already reported by Sinha et al. (2005) and Jagtap et al. (2006). Sucrose % and CCS % were statistically at par with all fertilizer levels but trend of their lower values at higher fertilizer was observed during all the years of study. In the context of sugarcane response to varying doses of N application Isa (2004) opined that the nitrogen applied at high rates during end of grand growth period lowered the sucrose contents and divert the dry matter accumulation toward growth rather than toward storage.

Water Productivity Functions

Results revealed that during 2014–2015, 2015–2016 and 2016–2017, total irrigation water applied was 32.6, 32.2 and 30.0 cm (under 60% CPE), 45.4, 40.1 and 40.0 cm (under 80% CPE) and 53.8, 47.7 and 50.0 cm (under 100% CPE), respectively. But, amount of the irrigation water applied during respective years under standard practice was 90.0, 92.5 and 82.5 cm (Table 4). Thus, among the years, in comparison of standard irrigation practices 39.4 to 48.4% water saving was reported with 100% CPE. This saving of irrigation water was even more at 80% and 60% CPE drip irrigation. Results of different years study also revealed that the apparent water productivity (AWP) correspondingly decreased with the incremental irrigation levels. It was higher with limited irrigation water provided through drip system and vice versa. During 2014–2015, 2015–2016 and 2016–2017, AWP 8.2, 7.7 and 9.7 kg/m^3, respectively, have been found under standard practice of flood irrigation. The highest range of AWP (16.9–26.0 kg/m^3) recorded when crop was supplied with 60% CPE, whereas application of the water at 80% CPE recorded AWP between 15.7 and 20.9 kg/m^3. The lowest AWP (15.8–20.9 kg/m^3) could be observed by 100% CPE and 100% RDN treatment. Results clearly depicted that the ratoon crop was more efficient to AWP than the plant crop of sugarcane. However, AWP linearly increased with increasing fertilizer level and reached maximum when full dose of fertilizer was applied to the crop. Noticeably, the standard practices recorded least AWP both under plant as well as ratoon crop of sugarcane. In Pakistan, Rabnawaz et al. (2015) reported 2.22 to 3.50 kg/m^3 water productivity for sugarcane, while in subtropical India, Singh et al. (2007) recorded 7.1 kg/m^3 water productivity for plant sugarcane and 6.3 kg/m^3 for ratoon crops.

Monetary Returns

As much as the inputs like irrigation and/or fertilizer increased the cost of cultivation correspondingly enhanced.

Table 3 Effect of drip irrigation and fertigation schedules on quality characters of sugarcane during 2014–2017

Treatments	2014–2015			2015–2016			2016–2017		
	Sucrose (%)	CCS (%)	CCS (t/ha)	Sucrose (%)	CCS (%)	CCS (t/ha)	Sucrose (%)	CCS (%)	CCS (t/ha)
Drip irrigation schedules									
60% CPE	17.77	12.41	6.75	18.31	12.72	8.34	18.23	12.61	9.82
80% CPE	17.74	12.52	8.91	18.32	12.83	9.95	18.32	12.75	10.56
100% CPE	17.97	12.53	10.10	18.05	12.60	10.66	18.62	13.01	11.64
CD (5%)	NS	NS	0.39	NS	NS	0.53	NS	NS	NS
Fertigation levels									
60% RDN	17.99	12.65	7.63	18.32	12.76	8.82	18.69	13.04	9.75
80% RDN	17.87	12.46	8.77	18.16	12.69	9.84	18.45	12.86	10.88
100% RDN	17.61	12.34	9.37	18.19	12.7	10.29	18.03	12.48	11.39
CD (5%)	NS	NS	0.85	NS	NS	0.98	NS	NS	0.56
Standard practice	18.00	12.57	9.24	18.22	12.65	9.0	18.23	12.82	10.28
CD (5%)	NS	NS	0.95	NS	NS	1.04	NS	NS	0.83

I_1: drip irrigation at 60% CPE, I_2: drip irrigation at 80% CPE, I_3: drip irrigation at 100% CPE, N1: 60% recommended dose of nitrogen (RDN), N2: 80% RDN, N3: 100% RDN, Standard practice = Flood irrigation and fertilizer by line top dressing

Table 4 Effect of drip fertigation schedules on irrigation water applied (cm) and irrigation water productivity (kg/m^3) of sugarcane during 2014–2017

Drip irrigation schedules	Fertigation levels			Mean	Standard practice	Fertigation levels			Mean	Standard practice
	60% RDN	80% RDN	100% RDN			60% RDN	80% RDN	100% RDN		
	Irrigation water applied (2014–2015)					Apparent water productivity (2014–2015)				
60% CPE	32.2	32.2	32.2	32.2	–	14.4	17.3	19.1	16.9	
80% CPE	45.4	45.4	45.4	45.4	–	13.0	16.3	17.7	15.7	
100% CPE	53.8	53.8	53.8	53.8	–	14.0	15.1	15.8	15.0	
Mean	45.4	45.4	45.4		–	13.8	16.2	17.6		
Standard practice					90.0			–	–	8.2
CD (5%)	–					IS = 1.16, FS = 1.16, SP versus IS × FS = 1.44				
	Irrigation water applied (2015–2016)					Apparent water productivity (2015–2016)				
60% CPE	32.6	32.6	32.6	32.6	–	18.2	20.5	21.6	20.2	–
80% CPE	40.1	40.1	40.1	40.1	–	17.6	19.9	20.6	19.4	–
100% CPE	47.7	47.7	47.7	47.7	–	16.2	18.1	18.9	17.6	–
Mean	40.1	40.1	40.1		–	17.3	19.5	20.4		–
Standard practice	–	–	–	–	92.5	–	–	–	–	7.7
CD (5%)	–					IS = 1.4, FS = 1.7, SP versus IS × FS = 1.9				
	Irrigation water applied (2016–2017)—Ratoon					Apparent water productivity (2016–2017)—Ratoon				
60% CPE	30.0	30.0	30.0	30.0	–	22.2	25.9	29.9	26.0	–
80% CPE	40.0	40.0	40.0	40.0	–	18.8	21.4	22.0	20.9	–
100% CPE	50.0	50.0	50.0	50.0	–	16.6	18.1	19.2	17.8	–
Mean	40.0	40.0	40.0		–	19.2	21.8	23.7		–
Standard practice	–	–	–	–	82.5	–	–	–	–	9.7
CD (5%)	–					IS = 1.7, FS = 1.4, SP versus IS × FS = 1.7				

IS irrigation schedules, *FS* fertigation schedule, *SP* standard practice (flood irrigation and fertilizer by line top dressing)

Under standard practice of sugarcane, cultivation expenses were very high (Rs. 94,309 and 93,575 per ha) for plant crops raised during 2014–2015 and 2015–2016 but, in ratoon crop during 2016–2017, expenditure was minimized by Rs. 5555–6289/ha (Table 5). Because ratoon crop was maintained from the preceding plant crop hence, cost of seed, field preparation and tillage expenses were saved. Though 100% RDN and 100% CPE-based cultivation consumed Rs. 91,182, 90,098 and 85,046/ha, these expenses were comparatively lower than recommended standard practice. Thus, in comparison of standard practice for farmers, total saving was Rs. 3127, 3477 and 2974/ha from full dose of (100%) RDN and CPE, during 2014–2015, 2015–2016 and 2016–2017. Similarly, reduced dose of RDN and CPE by 80 and 60% was able to save Rs. 3929–4009/ha and Rs. 4845–5439/ha, respectively, over standard practice. In the previous study, Singh et al. (2019) in south-western Punjab reported highest average net return of Rs. 140,892/ha in wheat (November sown) + sugarcane (planted in furrows during February) because of high cane yield (82 t/ha) and wheat yield (49.6 q/ha), under furrow irrigated raised bed (FIRB) system.

Among drip irrigation regimes, the highest net return recorded under 100% CPE level was 150,900, 175,808 Rs./ha (from plant crop) and 201,666 Rs./ha (from ratoon crop) raised during 2014–2015, 2015–2016 and 2016–2017, respectively. Conversely, 60% CPE level recorded statistically least net returns of 86,182, 118,465 and 185,115 Rs./ha from respective crops raised over the years. The lowest net returns (115,451, 116,170 and 152,880 Rs./ha) were obtained from the standard practices.

During 2014–2015 and 2015–2016, maximum B:C ratio (1.59 and 1.85) proved the superiority of the 100% CPE-based irrigation schedules over 80% and 60% CPE-based irrigated plant crop of sugarcane (Table 5). Likewise, the ratoon sugarcane crop tremendously improved the economical advantage of B:C 2.27 both under limited as well as full amount of irrigation water. The scrutiny of the data

Table 5 Effect of drip fertigation schedules on cost of cultivation, net returns and B:C of sugarcane during 2014–2017

Drip irrigation schedules	Fertigation levels			Mean	Standard practice	Fertigation levels			Mean	Standard practice	Fertigation levels			Mean	Standard practice
	60% RDN	80% RDN	100% RDN			60% RDN	80% RDN	100% RDN			60% RDN	80% RDN	100% RDN		
	Cost of cultivation (Rs/ha) (2014–2015)					Net returns (Rs/ha) (2014–2015)					Benefit:cost (2014–2015)				
60 % CPE	88,339	88,894	89,378	88,870	–	43,901	69,566	86,182	66,550	–	0.51	0.81	0.99	0.77	
80% CPE	89,681	90,365	90,854	90,300	–	78,754	12,1105	13,8286	11,2715	–	0.92	1.40	1.59	1.30	
100% CPE	90,713	91,198	91,635	91,182	–	123,892	140,507	150,900	138,433	–	1.43	1.62	1.73	1.59	
Mean	89,578	90,152	90,622		–	82,182	110,393	125,123		–	0.95	1.27	1.44		
Standard practice					94,309					115,451					1.33
	Cost of cultivation (Rs/ha) (2015–2016)					Net returns (Rs/ha) (2015–2016)					Benefit:cost (2015–2016)				
60 % CPE	87,975	88,492	88,920	88,463	–	87,255	108,863	118,465	104,861	–	1.02	1.27	1.37	1.22	
80% CPE	88,823	89,378	89,793	89,331	–	119,152	145,737	153,582	139,490	–	1.39	1.69	1.77	1.62	
100% CPE	89,584	90,132	90,577	90,098	–	138,156	163,863	175,808	159,276	–	1.61	1.9	2.03	1.85	
Mean	88,794	89,334	89,763		–	114,854	139,488	149,285		–	1.34	1.62	1.72		
Standard practice					93,575					116,170					1.35
	Cost of cultivation (Rs/ha) (2016–2017) Ratoon					Net returns (Rs/ha) (2016–2017) Ratoon					Benefit:cost (2016–2017) Ratoon				
60 % CPE	82,371	83,169	83,985	83,175	–	117,729	150,231	185,115	151,025	–	1.47	1.86	2.27	1.87	
80% CPE	83,367	84,148	84,758	84,091	–	142,533	172,652	179,542	164,909	–	1.78	2.13	2.2	2.04	
100% CPE	84,339	85,065	85,734	85,046	–	164,061	186,735	201,666	184,154	–	2.04	2.3	2.47	2.27	
Mean	83,359	84,127	84,826		–	141,441	169,873	18,8774		–	1.76	2.1	2.31		
Standard practice					88,020					152,880					1.88

clearly indicated the corresponding improvement of financial benefits with increased water amount through the drip systems. The combination of the limited water and limited fertilizer application in the sugarcane exhibited least B:C ratio (0.95, 1.34 & 1.76) hence, the lowest minimum net returns (Rs. 82,182, 114,854 and 141,441/ha, respectively) than remaining two treatments. The predominant standard practice was always inferior than 80 and 100% CPE-based irrigation except during 2014–2015, where benefit:cost ratio and net returns of 80% CPE were less than the standard practices.

Conclusion

In north India especially in Punjab, Haryana and western UP, rice–wheat is the predominant cropping system, but due to degradation of natural resources and monoculture limitations, there is need to diversify some area from this cropping system. Sugarcane offers good opportunity for diversification of cropping system of the state and can enhance the profitability of the farmers. Sugarcane farmers are adopting wider row crop planting mainly due to availability of high yielding varieties. This wider row planting technique makes drip irrigation economical because less number of laterals are required and the initial cost of drip irrigation installation is reduced. Moreover, Indian Government is also giving subsidy to encourage the farmers for drip irrigation. Maximum water productivity was obtained with limited irrigation water provided through drip system and vice versa that was increased with increasing fertilizer level up to 100% RDN. Among drip irrigation regimes, the net returns were ranged from 150,900 to 175,808 Rs./ha from plant crop and 201,666 Rs./ha from ratoon crop. For plant crop, B:C ratio ranged from 0.51 (60% RDN and 60% CPE) to 2.03 (100% RDN and 100% CPE) that was 2.47 for ratoon crop from 100% RDN and 100% CPE. Thus, for getting maximum benefits from plant and ratoon crop of sugarcane, drip irrigation based on 100% CPE and N fertigation based on 100% RDN should be followed by the farmers especially under semi-arid environment.

Authors Contribution The authors conceived idea, analyzed data and drafted manuscript for publication. All authors have read and approved the final manuscript.

Compliance with Ethical Standards

Conflict of interest The authors declare that there was no conflict of interest.

References

Anonymous. 2014. *Package of practices for the crops of Punjab (Kharif 2014)*, Vol. 31, No. 1, 77–93. Ludhiana: Publisher-Punjab Agricultural University.

Anonymous. 2019. Invest Punjab: Business First. *Punjab Bureau of Investment Promotion*. http://investpunjab.gov.in/assets/docs/Agro_and_food_processing_sector.pdf. pp. 6.

Brar, S.K., S.S. Mahal, A.S. Brar, K.K. Vashist, N. Sharma, and G.S. Buttar. 2012. Transplanting time and seedling age affect water productivity, rice yield and quality in north-west India. *Agricultural Water Management* 115: 217–222.

Hapase, D.G., B.B. Gunjal, and A.S. Deshmukh. 1990. Irrigation management for sugarcane. In *Recent advances in sugarcane*, ed. P.N. Rao, 248–270. Vuyyuru: K.C.P. Sugar and Industries Corporation Ltd.

Hatfield, J.L., T.J. Sauer, and J.H. Prueger. 2001. Managing soils to archive greater water use efficiency: A review. *Agronomy Journal* 93: 271–280.

Isa, D.W. 2004. *Nitrogen dynamics in sugarcane field*. Ph. D. thesis for Award of Degree of Doctor of Applied Biological Science of Ghent University, Belgium. pp. 244.

Jagtap, S.M., M.B. Jadhav, and R.V. Kulkarm. 2006. Effect of levels of NPK on yield and quality of suru sugarcane (cv. Co. 7527). *Indian Sugar* 56: 35–40.

Kaur, A., and A.S. Brar. 2016. Influence of mulching and irrigation scheduling on productivity and water use of turmeric (*Curcuma longa* L.) in north-western India. *Irrigation Science* 34: 261–269.

Lacombe, G., P. Chinnasamy, and A. Nicol. 2019. *Review of climate change science, knowledge and impacts on water resources in South Asia. Background Paper 1*. Colombo, Sri Lanka: International Water Management Institute (IWMI). (Climate Risks and Solutions: Adaptation Frameworks for Water Resources Planning, Development and Management in South Asia) pp 73.

Lakshmanan, P., and N. Robinson. 2014. Stress physiology: Abiotic stresses. In *Sugarcane: Physiology, biochemistry, and functional biology*, ed. P.H. Mooreand and F.C. Botha, 411–434. Chichester: Wiley.

Lal, M., and S.K. Shukla. 2000. Production practices for sugarcane. In *50 years of sugarcane research in India*, ed. H.N. Shahi, A.K. Srivastava and O.K. Sinha, 131–152.

Rabnawaz, M.J., T. Sarwar Khan, and M.J. Khan. 2015. Comparative study of crop water productivity at farm level under public and civil canal irrigation systems in Peshawar, Pakistan. *Sarhad Journal of Agriculture* 31: 175–182.

Ramah, K. 2008. *Study on drip fertigation in maize based cropping system*. Ph.D. Dissertation, Tamil Nadu Agricultural University, Coimbatore, 78–230.

Sander, J., W. Zwart, and G.M. Bastianssen. 2004. Review of measured water crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural Water Management* 692: 115–133.

Sastry, S.K., and A.V. Chari. 1960. *Proc. 4th Bien. Conf. Sugarcane Res. and Dev. Workers, India*, 145–159.

Shah, T. 2010. *Taming the anarchy: Groundwater governance in South Asia*. New Delhi: Routledge.

Singh, I. 2012. Optimizing irrigation schedule in sugarcane (*Saccharum* spp. Hybrid complex) under different planting methods in sub-tropical India. *Indian Journal of Sugarcane Technology* 27(2): 68–72.

Singh, K., and A.S. Brar. 2015. Effect of planting methods and irrigation schedules on cane yield, quality, economics and water productivity of spring sugarcane (*Saccharum officinarum*) in South Western Punjab. *Indian Journal of Agronomy* 60(4): 601–605.

Singh, K., S.K. Mishra, and V. Singh. 2019. Sugarcane and wheat productivity under different cropping systems. *Sugar Tech* 21(3): 415–420.

Singh, P.N., and S.C. Mohan. 1994. Water use and yield response of sugarcane under different irrigation schedules and nitrogen levels in a subtropical region. *Agricultural Water Management* 26: 253–264.

Singh, P.N., S.K. Shukla, and V.K. Bhatnagar. 2007. Optimizing soil moisture regime to increase water use efficiency of sugarcane (*Saccharum* spp. Hybrid complex) in subtropical India. *Agricultural Water Management* 90: 95–100.

Sinha, V.P., H. Singh, and B.K. Singh. 2005. Effect of genotype and fertility levels on growth, yield and quality of sugarcane under rainfed conditions. *Indian Sugar* 55: 23–26.

Wiedenfeld, R.P. 2000. Water stress during sugarcane growth periods on yield and response to N fertilization. *Agricultural Water Management* 43: 173–182.