International Journal of Agriculture Sciences
ISSN: 0975-3710&E-ISSN: 0975-9107, Volume 9, Issue 29, 2017, pp.-4377-4381.
Available online at http://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000217

Research Article

WATER PRODUCTIVITY IN SUGARCANE UNDER SUBSURFACE DRIP IRRIGATION

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Received: May 10, 2017; Revised: May 31, 2017; Accepted: June 01, 2017; Published: June 24, 2017

Abstract- A field experiment was conducted at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri (M.S.) India to investigate comprehensive effect of mulch, irrigation regimes and irrigation intervals under subsurface drip on water productivity of sugarcane during the years 2014-15 and 2015-16. The results revealed that the total water requirement of *suru* and *ratoon* sugarcane under subsurface drip was varied from 590.3 to 980.6 mm. The water saving in subsurface drip (SSDI) was 13.6 to 62.9% in 80% ETc irrigation regime as compared to conventional method of irrigation. The water requirement in 2 days interval under SSDI was lower than 3 and 5 days irrigation regimes intervals. More water was saved in ratoon cane than plant cane. The agronomic and economic water productivities were increased with decreased irrigation regimes and increased irrigation intervals. It was also observed that additional area that can be brought under irrigation due to water saving in SSDI was varied from 0.14- 0.48 ha over surface drip (SDI) and 0.62- 0.77 ha over surface irrigation. The same water quantity of water was applied for mulch and no-mulch treatment. The maximum cane yield of 148.4 t ha^{-1} was observed in 80% irrigation regime of SSDI which was at par with SDI with 100% ETc water. Similarly, the mean yield in 60% ETc and 3 days irrigation regimes were remained at par with 80% ETc and 2 days irrigation intervals.

Keywords- Mulch, Irrigation regimes, Irrigation intervals, WUE and Water productivity

Citation: Bhingardeve S.D., et al., (2017) Water Productivity in Sugarcane under Subsurface Drip Irrigation. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 9, Issue 29, pp.-4377-4381.

Introduction

The sugarcane agriculture and industry in India plays a vital role towards socio-economic development in the rural areas by mobilizing rural resources and generating higher income and employment opportunities. Sugarcane cultivation is done in around 5 million ha of land in India and its production has fluctuated between 320 - 360 million tons in the past several years. India is the largest consumer of sugar and second largest producer in the world. Maharashtra and Uttar Pradesh alone, account for 60% of total sugarcane and sugar production in the country [1].

Sugarcane crop requires high water requirement and it ranges from 2000-3000 mm [2]. Due to inadequate supply of water, the heavy losses in yield may occur [3] and considering the production of sugarcane, about 250 tonnes of water is needed to produce one tone of sugarcane [4]. Irrigation water is often limited and costly input. Irrigation methods like subsurface drip offers many advantages over surface drip irrigation such as; reduced evaporation, efficient water use, greater water uniformity, enhanced growth, crop yield and quality [5]. Therefore, it is necessary to use efficient water to increase the productivity of sugarcane crop.

The term water productivity is used to denote the amount of yield of sugarcane in terms of rupees over volume of water applied in m^3 [6]. In the future, irrigated agriculture will take place under water scarcity. Irrigation management will shift from emphasizing production per unit area towards maximizing the production per unit of water consumed, i.e. the water productivity [7]. To cope with scarce supplies, deficit irrigation can be implemented. Deficit irrigation is defined as the deliberate application of water below full crop water requirements (crop evapotranspiration) such that a certain degree of water stress is allowed during the less sensitive crop growth stages that have little impact on yield [8]. This is done in order to increase the water use efficiency and assists in conserving limited water resources. As a result of the water scarcity, irrigation should begin when the crop comes under water stress severe enough to reduce crop yield or quality. Adequate amount of water is needed at the right time in order to get higher crop yield and should be applied to farmlands. It can be very well realised through adopting advanced irrigation methods like surface and subsurface drip irrigation. To attain this purpose, the present experiment was undertaken to find out the extent to which irrigation water requirement for sugarcane can be minimized with different irrigation regimes and irrigation intervals and its impact on sugarcane yield and water productivity.

Materials and Methods

The soil of experimental site was clay in texture with moderately alkaline in reaction with pH as 8.2 and electrical conductivity as 0.4 dS m^{-1}. The field capacity and permanent wilting point was 40.60 and 18.50%, respectively and bulk density as 1.39 Mg m^{-3}. Climatologically, experimental area falls in the semi-arid tropics. The total rainfall received during crop growth period of 2014-15 and 2015-16 was 349.5 mm in 27 rainy days and 273.8 mm in 25 rainy days, respectively. The experiment was carried out in strip-split plot design with three replications. The experiment consisted of two types of mulch(organic mulch and no-mulch), three irrigation regimes *viz;* 80%, 60%, 40% of crop evapo- transpiration (ETc), three irrigation intervals *viz;* 2, 3 and 5 days interval under subsurface drip irrigation (SSDI) and two control treatments of surface drip (SDI) and surface irrigation (SI). As the laterals are buried below ground surface, it minimizes evaporation losses and water and nutrients are applied directly in the vicinity of root zone in SSDI. The total water requirement under SSDI has been reported by many researchers as less than control methods. In order to test the performance of SSDI for sugarcane under deficit water scenarios, water equivalent to 40% to 80% of ETc were applied in present investigation.

The laterals of subsurface drip irrigation (SSDI) were buried at 20 cm depth in soil and the single eye bud setts of sugarcane cv. Phule-0265 were planted 25 cm below the ground surface. Mulch was applied in mulched treatments after germination of sugarcane at the rate of 5 t ha^{-1}. The planting was done using paired row planting method of 0.60 – 1.20 m x 0.25 m row to row spacing of 0.60 m and pair to pair spacing of 1.20 m. Single sub-suface lateral with 4 lph emitters at spacing of 0.50 m were used per pair of sugarcane rows, thus a distance between two lateral was maintained as 1.80 m.

Scheduling of irrigation: The irrigations were scheduled at 2, 3 and 5 days interval on the basis of climatological approach. The CPE of 2, 3 and 5 days was considered to estimate the water quantity of 2, 3 and 5 days irrigation interval, respectively. The irrigation for the control treatment of surface drip (100% ETc) was applied at alternate day. The daily pan evaporation data was recorded from USWB Class A pan evaporimeter. The daily evaporation data was collected from All India Co-ordinated Water Management Project, M.P.K.V., Rahuri (M.S). The water application was estimated by the following formula [9].

$$ETc = Ep * Kp * Kc$$

In which,

ETc = Evapotranspiration of crop (mm/days)

Ep = Pan evaporation (mm)

Kp= Pan factor (0.7) ,

Kc = Crop coefficient (stage wise)

$$\text{WR}= ETc * Wa \qquad [10]$$

Where,

WR = Actual evapotranspiaration of crop (mm)

Wa = Wettable area (60 per cent)

$$Gross\ WR = Ep * Kp * Kc * Ls * Es * \frac{Wa}{Irrigationefficiency\ (0.9)}$$

Where,

Gross WR = Water requirement (lit)

Ls = Spacing between two laterals (m)

Es = Spacing between two emitters (m)

The Kc values were estimated at 15 days intervals [Table-1] considering the value of 0.4 for tillering stage, 1.25 for grand growth stage and 0.7 for maturity stage of sugarcane crop (FAO paper no. 56).

The irrigations in surface irrigated plots were scheduled at 75 mm Cumulative Pan Evaporation (CPE) for plant and ratoon cane. Irrigation water applied for surface irrigation method (control treatment) was measured (lit min^{-1}) with the help of Replogle Flume at the head of water channel. The quantity of water to be applied per plot was calculated considering the available water holding capacity and effective root zone depth of the soil and the time required for irrigating the plot was worked using area-depth relationship as,

$$T = \frac{(A * D)}{Q}$$

Where,

T = Time of water application (min) ,

A = Area to be irrigated (m^2)

D = Depth of irrigation (m) ,

Q = Discharge of water (lit min^{-1})

Agronomic Water Productivity (AWP): AWP is the ratio of yield of marketable produce of the crop and the amount of total consumptive use of water during the period of process of evapotranspiration.

Table-1 *Kc values used for irrigation scheduling during plant and ratoon cane*

DAT	Kc values	2014-2015	Kc values	2015-2016
0-30	0.4	Till 28.3.2014	0.4	Till 24.4.2015
31-45	0.46	1-15.4.2014	0.5	25.4-9.5.2015
46-60	0.64	16-30.4.2014	0.8	10-24.5.2015
61-75	0.85	1-15.5.2014	1.02	25.5-8.6.2015
76-90	1.06	16-30.5.14	1.20	9-23.6.2015
91-105	1.21	31-14.6.2014	1.25	24.6-8.7.2015
106-120	1.25	15-30.6.2014	1.25	9-23.7.2015
121-135	1.25	1-15.7.2014	1.25	24.7-7.8.2015
136-150	1.25	16-30.7.2014	1.25	8-22.8.2015
151-165	1.25	31-14.8.2014	1.25	23.8-6.9.2015
166-180	1.25	15-30.8.2014	1.25	7-21.9.2015
181-195	1.25	31.8-14.9.2014	1.25	22.9-6.10.2015
196-210	1.25	15-30.9.2014	1.25	7-21.10.2015
211-225	1.25	1-15.10.2014	1.25	22.10-5.11.2015
226-240	1.25	16-30.10.2014	1.25	6-20.11.2015
241-255	1.25	31.10-14.11. 2014	1.25	21.11-5.12.2015
256-270	1.25	15-30.11.2014	1.21	6-20.12.2015
271-285	1.25	1-15.12.2014	1.11	21.12-4.1.2016
286-300	1.14	16-30.12.2014	0.98	5-19.1.2016
301-315	0.93	31.12.14-14.1.15	0.85	20.1-3.2.2016
316-330	0.72	15-30.1.2015	0.73	4-18.2.2016
331-345	0.69	31.1-14.2.2015	0.70	19.2-4.3.2016
346-360	0.67	15.2-1.3.2015	0.69	5-19.3.2016
361-365	0.65	2-17.3.2015	0.67	-

The water use efficiency was worked out by following formula.

$$\text{AWP}= \frac{Y}{WR} \qquad [11]$$

Where,

Y = Yield per unit area (kg ha^{-1}) and

WR = Water requirement (cm)

Economic Water Productivity (WP)

The classical concept of irrigation efficiency used by water engineers omitted economic values and looked at the actual evapo-transpiration against the total water diverted for crop production [12]. For agricultural systems, it is normal to represent WP in units of Rs m^{-3}. If economic production is measured in Rs ha^{-1}, water use in mm, the WP will be simple ration in Rs per ha-cm or Rs per.

Results and Discussion

Total Water requirement

The maximum water requirement was recorded in surface method of irrigation as 2716 and 2425 mm during plant and ratoon cane, respectively. In SDI, on an average, 1135.5 mm of total water was applied during plant and ratoon cane including effective rainfall; whereas, the average depth of irrigation water applied in SSDI with 80% ETc regime (I_1) was 953.8, 966.2 and 980.6 mm with 2, 3 and 5 days irrigation intervals, respectively. In 40% ETc irrigation regime (I_3), lowest amount of irrigation water was applied during both the seasons. Though, almost same amount of irrigation water was applied in different irrigation intervals, the total water used as per [Table-2] differed slightly due to the rounding off error and effective rainfall. The same quantity of water was applied in mulch and no-mulch conditions. The effective rainfall of 146.9 to 185.8 mm was observed in drip method of irrigation as against 240.7 mm in conventional method of irrigation.

Water saving

The average water saving in surface drip was observed to be 55.8% as compared to surface method of irrigation; whereas, the water saving in subsurface drip with 80 and 60% ETc water applied at 2 to 3 days interval was 62.6 and 69.6%, respectively over surface method of irrigation. The SSDI saved water to the extent of 15.5% in 80% ETc and 31.5% in 60% ETc as compared to SDI. Various researchers were reported that 53.43% water saving under subsurface drip irrigation as compared to furrow method of irrigation [13]. Similarly, the 3 and 4 days irrigation frequencies saved 32.7% and 47.8 % of irrigation water compared to 2 days irrigation frequency, respectively [14].

The water saving in SSDI with 80% ETc water at 2 to 3 days interval could irrigate 1.67ha additional area due to water saving as compared to surface method of irrigation. The results also indicated that, when 60% ETc water was applied to sugarcane through SSDI, the average additional area of 2.21 ha could be brought under irrigation than conventional method of irrigation [15-17].

Table-2 *Water requirements and water saving by sugarcane*

Particulars	Intervals	Irrigation regimes									Control treatments	
		80% ETc			60% ETc			40% ETc			SDI	SI
		Plant	Ratoon	Pooled	Plant	Ratoon	Pooled	Plant	Ratoon	Pooled	Pooled	Pooled
Actual water applied (mm)	2 days	854.2	759.6	**806.9**	660.6	589.7	**625.2**	467.1	419.8	**443.4**	908.6	2330.0
	3 days	844.9	754.2	**799.5**	653.7	585.6	**619.6**	462.4	417.1	**439.8**	-	-
	5 days	844.3	745.4	**794.8**	653.2	579	**616.1**	462.1	412.7	**437.4**	-	-
Effective rainfall (mm)	2 days	136.0	157.8	**146.9**	136.0	157.8	**146.9**	136.0	157.8	**146.9**	146.9	240.7
	3 days	155.9	177.5	**166.7**	155.9	177.5	**166.7**	155.9	177.5	**166.7**	-	-
	5 days	169.9	201.7	**185.8**	169.9	201.7	**185.8**	169.9	201.7	**185.8**	-	-
Total water used (mm)	2 days	990.2	917.4	**953.8**	796.7	747.5	**772.1**	603.1	577.6	**590.3**	1135.5	2570.7
	3 days	1056.8	931.7	**966.2**	865.6	763.2	**786.4**	674.4	594.6	**606.5**	-	-
	5 days	1090.0	947.1	**980.6**	899.0	780.7	**801.9**	707.9	614.4	**623.2**	-	-
Water saving (%) over SDI	2 days	16.35	15.63	**16.0**	32.70	31.26	**32.0**	49.05	46.88	**48.0**	--	-
	3 days	15.46	14.31	**14.9**	31.61	29.81	**30.7**	47.77	45.31	**46.5**		-
	5 days	14.33	12.90	**13.6**	30.47	28.20	**29.3**	46.61	43.49	**45.1**	-	-
Water saving (%) over SI	2 days	60.07	67.11	**62.9**	67.88	73.20	**69.9**	75.68	79.29	**77.0**	55.8	-
	3 days	59.65	66.59	**62.4**	67.36	72.63	**69.4**	75.07	78.68	**76.4**	-	-
	5 days	59.11	66.04	**61.8**	66.81	72.00	**68.8**	74.52	77.97	**75.7**	-	-
Increase in area over SDI (ha)	2 days	0.16	0.16	**0.16**	0.33	0.31	**0.32**	0.49	0.47	**0.48**	-	-
	3 days	0.15	0.14	**0.15**	0.32	0.30	**0.31**	0.48	0.45	**0.47**	-	-
	5 days	0.14	0.13	**0.14**	0.30	0.28	**0.29**	0.47	0.43	**0.45**	-	-
Increase in area over SI (ha)	2 days	0.60	0.67	**0.63**	0.68	0.73	**0.70**	0.76	0.79	**0.77**	0.56	-
	3 days	0.60	0.67	**0.62**	0.67	0.73	**0.69**	0.75	0.79	**0.76**	-	-
	5 days	0.59	0.66	**0.62**	0.67	0.72	**0.69**	0.75	0.78	**0.76**	-	-

- **Water applied at planting in plant and ratoon cane= 80mm**

Cane yield

Effect of mulch: The significantly highest cane yield was observed under mulch treatment in plant and ratoon cane [Table-3]. The pooled means showed 5.6 and 18.2% more yield in mulch than no-mulch and surface irrigation method [18-19]. In mulched treatments, the interculturing operation of earthing-up could not be undertaken properly; even then, the appropriate moisture at all growth stages resulted into enhanced growth and yield attributes *viz;* leaf area, plant height, number of internodes, internodal girth and cane weight; which resulted into better yield in mulched cane.

Effect of irrigation regimes: The 80% ETc irrigation regime produced significantly highest cane yield in plant cane (147.76 t ha^{-1}) and ratoon (149.12 t ha^{-1}). The sugarcane yield under 60% ETc irrigation regime (144.51 t ha^{-1}) was at par with the 80% ETc regime in plant cane and pooled means. Almost all the processes of plant require sufficient amount of water and its deficit in any process adversely affect the growth, development as well as cane yield as most of the processes are interlinked. Similarly, as the soil moisture with higher irrigation regimes increases optimal conditions in respect of nutrients, air, temperature, light, CO_2 and other factors of production, it responded progressively to increased cane yields with ETc levels [20]. As compared to other irrigation methods, SDI resulted 3.75% higher cane yield than mulch of SSDI and 19.37% more yield than surface irrigation due to 100% ETc water applied at every alternate days in surface drip irrigation (SDI) method.

Table-3 *Agronomic and economic water productivity of sugarcane*

Treatments	Yield (t ha^{-1})			AWP(Kg ha-mm $^{-1}$)			WP(Rs. m^{-3})		
	Plant	Ratoon	Pooled	Plant	Ratoon	Pooled	Plant	Ratoon	Pooled
Mulch									
M_1:Mulch	146.8	146.5	146.6	181.2	191.8	186.5	36.2	38.3	37.3
Mo:No-mulch	140.0	136.8	138.4	172.9	179.1	176.0	34.5	35.8	35.2
Irrigation regimes									
I_1: 80% ETc	147.7	149.1	148.4	147.5	160.0	153.7	29.5	32.0	30.7
I_2: 60% ETc	144.5	142.8	143.6	178.4	186.9	184.1	36.2	37.3	36.8
I_3: 40% ETc	137.9	133.0	135.5	223.5	223.4	223.4	44.6	44.6	44.6
Irrigation intervals									
D_1: 2 days	148.4	147.2	147.8	186.3	197.0	191.6	37.2	39.4	38.3
D_2: 3 days	147.4	143.3	145.4	182.1	194.7	188.4	36.4	38.9	37.6
D_3: 5 days	134.3	134.3	134.3	163.1	172.0	167.6	32.6	34.4	33.5
Control									
SDI:Surface drip	151.4	150.8	151.1	127.97	138.7	133.3	25.5	27.7	26.6
SI:Surface irrigation	119.0	118.2	118.6	43.8	43.5	46.3	8.7	9.7	9.2

Effect of irrigation intervals: The cane and sugar yield was significantly maximum with 2 days irrigation interval in both seasons and was at par in 3 days interval of irrigation s

Agronomic Water Productivity (AWP)

Effect of SSDI mulch: The AWP was maximum in mulch (181.28 and 191.83 kg $ha^{-1}mm^{-1}$) treatments in plant and ratoon cane, respectively due to highest yield; whereas, the AWP under SSDI was more than control treatments in plant and ratoon cane due to less water use by the crop. SSDI method improves the water use efficiency by minimizing the evaporative loss and delivering water directly to the root zone [23]. The WUE in mulch was 5.65% higher over non-mulch of SSDI, 28.53% over SDI and 75.18% over SI.

Effect of irrigation regimes: AWP increased with decreased irrigation regimes. There was maximum WUE (223.35 and 223.4 Kg $ha^{-1}mm^{-1}$) in 40% ETc irrigation regime of the plant and ratoon cane, respectively. Increased irrigation regimes showed decreased AWP; however, the relationship was not linear as the rate of increase in water amount was not linearly related with the corresponding increase in yield. The 40% ETc irrigation regime resulted into 31.21% higher AWP than 80% ETc irrigation regime of SSDI [24-25].

Effect of irrigation intervals: In all the irrigation intervals, 2 days irrigation interval achieved maximum AWP in both the seasons; but more value in ratoon cane (197.0 Kg ha mm^{-1}) than plant cane (186.3 Kg ha mm^{-1}). The AWP was observed to be not much differed between 2 and 3 days irrigation intervals in plant as well as ratoon cane [26].

Economic Water productivity

Effect of SSDI mulch: It was seen that the average water productivity was 5.66% higher in mulch (37.31 Rs. m^{-3}) than no-mulch treatment (35.20 Rs. m^{-3}) of SSDI. Though, the surface drip had higher cane production, the higher total water use resulted into lower WP in SDI as compared to SSDI. Thus, the WP in SSDI was 24.23 to 28.52% more than SDI and 73.69 to 75.18% higher over conventional furrow method of irrigation [13 & 27].

Effect of irrigation regimes: Irrigation regime of 40% ETc had maximum water productivity in plant (44.67 Rs. m^{-3}) and ratoon cane (44.69 Rs. m^{-3}) and was increased by 17.56 to 31.17% than higher irrigation regimes. The water productivity in 60% ETc irrigation regime was almost four times than that of conventional method of irrigation [28].

Effect of irrigation interval: Water productivity under 2 days irrigation interval was 37.25 and 39.40 Rs. m^{-3} higher than other irrigation intervals in plant and ratoon cane, respectively but the difference between 2 and 3 days was minimal.

Conclusions

1. The average water used in subsurface drip irrigation with 80% ETc was 967 mm as compared to 1135 mm in surface drip and 2570 mm in conventional method of irrigation. Thus, subsurface drip saved water to the extent of 13 to 32% over surface drip and 62.37% over surface irrigation. The water use was not influenced by different irrigation intervals.
2. Agronomic water productivity (184.18 kg ha^{-1}mm) and economic water productivity (and 36.84 Rs. m^{-3}) was more in 60% ETc irrigation regime than 80% ETc irrigation regime. Similarly, almost similar values of agronomic and economic water productivities were noted in 2 and 3 days irrigation intervals.

Acknowledgement / Funding: Author has thankful to all advisory committee members Prof. J.B. Shinde, Associate Professor of Agronomy, Dr. C.A. Nimbalkar, Associate Professor of Statistics and Dr. K.D. Kale, Asstt. Professor of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar, Maharashtra 413722 for their valuable guidance.

Author Contributions: All author equally contributed; This was the Ph.D Research by myself under guidance of Dr. D.D. Pawar (Research Guide), Er. S. K.Dingare and Dr. R.R. Hasure (Member, Advisory committee), Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar, Maharashtra 413722

Abbreviations: ETc- Crop Evapotranspiration, SSDI- Subsurface drip irrigation and SDI- Surface drip irrigation.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of Interest: None declared

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