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Field evaluation of effectiveness of subsurface porous pipe irrigation system on sweet corn (*Zea mays* L. *saccharata*) crop yield, water and fertilizer use efficiency

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Abstract
A field study was conducted at RTTC, Junagadh Agricultural University, Gujarat during the Rabi 2018, to study the effectiveness of subsurface porous pipe irrigation system on crop production. Treatments consisted of twelve treatment combinations of two depths of installation [20 cm (D_1) &30 cm (D_2)], two lateral porous pipe lengths [30 m (L_1) &45 m (L_2)], three fertigation levels [F_1-40 % (Recommended Dose of Fertilizer-RDF), F_2-70 % RDF and F_3-100 % RDF]) and a control (surface drip irrigation with no fertigation), respectively. Soil hydraulic study performed after the installation of irrigation system ensured its suitability for cultivation. Irrigation at 1.0 IW/CPE ratio [ratio of irrigation water (IW) and cumulative pan evaporation (CPE)] was maintained as same in all treatments including the control treatment. Interaction effect of installed depth, length and three fertigation levels on corn ear yield (t/ha), fertilizer and water use efficiencies were studied. The experimental results showed that the highest corn yield, fertilizer use efficiency, water use efficiency, net return and Benefit-Cost ratio were recorded in the treatment F2L2D2 (70 % RDF supplied through a subsurface porous pipe of 45 m length, installed at 30 cm depth) which gave a net return of ₹ 3,50,282/ha/season.The study revealed that the subsurface porous pipe irrigation system is an efficient and economically feasible irrigation method for sweet corn cultivation in semi-arid regions.

Keywords: Fertigation, Hydraulic study, Porous pipe, Subsurface irrigation, Sweet corn.

Introduction

The key opportunity for increasing the water use efficiency at the farm level lies in adopting suitable methods of water application. Several surface irrigation methods like furrow irrigation, basin irrigation and corrugation irrigation result in huge losses of water due to evaporation, seepage and percolation (Michael, 2013). To meet the increasing cost of energy as well as greater demand on the limited water resources, farm water losses need to be reduced by practicing water use efficient irrigation methods such as sprinkler, drip, etc. The development of simple, economically feasible, easily installed and maintained water-saving irrigation technologies for the arid and semi-arid regions would be more beneficial for rural farming communities. One of such techniques is the sub-surface irrigation method using flexible porous pipe laterals. Porous pipe is made with a combination of crumbed rubber and linear low-density polyethylene (LLDPE). As it is a subsurface irrigation system, the pipe is laid at a depth of about 20 to 30 cm below the ground surface, considering root depth of the crop. Subsurface porous pipe irrigation system works at low pressure allowing an auto-regulative functioning of the pipe (Duhrkoop et al., 2015). Therefore, it does not require a continuous electrical

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power supply, making it most suitable for rural areas, especially those facing irregular power supply. In a porous pipe, water oozes continuously under the influence of pressure head as well as soil suction. Water moves into the soil and wets the root zone vertically downward by gravity, laterally by soil suction, and vertically upward by soil suction and capillary action. As water is dispensed gradually and near the roots of plant, the use of water-soluble fertilizers along with irrigation water improves the yield of crops under subsurface porous pipe irrigation system.This method curtails the vaporization of the ammoniacal forms of nitrogen as well as deep percolation and subsequent leaching of nitrogen and potash fertilizers resulting in the more economical application of fertilizers. Soil evaporation can be reduced by 60 per cent through subsurface irrigation instead of surface irrigation (Hamada et al., 2015). Porous pipe is easy to install and requires minimal maintenance as it does not have sprinkler heads and emitters. Also, the damage by machines and other disturbances is minimal due to subsurface installation. It is easy for a farmer with limited education and experience to understand the basics of watering with porous pipes as the regular inspection of soil indicates the need for irrigation (Spicer, 2007). But, the clogging of micropores by suspended salts, silt or any other debris present in irrigation water is a major limitation in porous pipe irrigation. However, it can be eliminated with the installation of suitable filters in the system. Despite the advantages of porous pipe irrigation system, it is less popular and only very little information is available on the hydraulic characteristics.

Sweet corn (*Zea mays* L. *saccharata*) is a variety of maize with high sugar content. It is the third most important cereal crop after rice and wheat and is being grown throughout the year but mainly as a Kharif crop (Kumar and Dawson., 2019). A field experiment was conducted to evaluate the effect of subsurface porous pipe irrigation system on sweet corn production, water and fertilizer use efficiencies and its economic feasibility.

Materials and Methods

The field experiment was conducted during Rabi season 2017-2018, at Research Testing and Training Centre Farm, Junagadh Agricultural University, Junagadh (Gujarat). The study area is located at 21.5°N latitude and 70.44°E longitude with an altitude of 50 m above mean sea level. The soil in the experimental site is clay loam in texture with an infiltration capacity of 1 cm/hrs and bulk density of 1.43 g/cc, respectively. The climate of the study area is subtropical and semi-arid type. The average annual rainfall was 900 mm and the monthly mean of daily maximum and minimum temperature was ranged from 30.2^0 C to 38.9^0 C and 12.2^0 C to 22.2^0 C (as per 35-year weather data recorded at the JAU observatory).

Installation of the experimental setup and methodology

Field of size 21 m× 46 m was ploughed and leveled using a tractor-operated cultivator and blade harrow. Then, furrows of 20 cm and 30 cm depths (chosen according to root depth of crop) and 30 m and 45 m lengths were made using a tractor-drawn furrow opener. A total of 24 furrows were made such that each treatment contains two furrows. The spacing between two successive furrows was maintained as 90 cm. After the furrow preparation, porous pipe lateral of 16 mm inner diameter and lengths 30 and 45 m was buried at 20 and 30 cm below the ground surface, at the bottom of the respective furrows.The field layout of the experiment is shown in Figure1. The lateral lengths 30 and 45 m were taken as a minimum and maximum lengths to compare the yield and economic return based on the extent of flow through each length. Furrows were refilled and leveled using a tractor-drawn leveler. The inlet of each porous pipe was connected to the sub-main line using a 16 mm plain lateral (1 m length) to leave a working space between sub-main and porous pipe inlets. To measure the quantity of water used, water meters of nominal size 15 mm (selected based on lateral size) were connected tothe starting point of each porous pipe laterals.

Statistical analysis of data was carried out to study the effects of different treatments and their combinations on crop yield. The experiment was carried out as control versus rest (C Vs R) in Factorial Completely Randomized Design (FCRD) with three replications per treatment (Panse and Sukhatme, 1998). The data collected from each treatment were analysed statistically as 3 x 2 x 2 factorial experiment. The data analysis and analysis of variance were done using Microsoft Excel 2013. Significant differences among different treatments were compared using Critical Differences (CD) values at a 5% level of significance. Based on FRCD, the 13 treatments were allocated randomly to the whole set of experimental units, without making any effort to group the experimental units in any way for more homogeneity. The entire experimental area was divided into 13 experimental units to include the control treatment too. The experimental design is flexible as any number of treatments or replications can be used. The number of replications for different treatments need not be equal and can vary from treatment to treatment. However, here the number of replications for the experiment was fixed as three.

The sweet corn variety used for this experiment was Sugar-75, a variety of maize with high sugar content. Double-row planting method with a spacing of 0.30 m within the treatment and 0.60 m between the treatments was used. Porous pipe lateral to lateral spacing was 0.90 m. The experiment was undertaken with three fertigation levels *viz.,* 40 % RDF (F_1), 70 % RDF (F_2) and 100 % RDF, two lengths of porous pipe lateral *viz.,* 30 m (L_1) and 45 m (L_2) and two depths of installation beneath the ground surface *viz.,* 20 cm (D_1) and 30 cm (D_2), respectively. The same irrigation level at 1.0 IW/CPE ratio [ratio of irrigation water (IW) and cumulative pan evaporation (CPE)] was maintained in all treatments. Also, a surface drip irrigation system (at 1.0 IW/CPE ratio with no fertigation) was installed as a control treatment to compare the results. Altogether, there were thirteen treatment combinations including the control. A list of different treatment combinations is shown in Table 1. Harvesting of sweet corn ears was started 25 days after flowering (i.e., 92 DAS) from net plots of respective treatments. The response of sweet corn crop to subsurface porous pipe irrigation and fertigation was evaluated based on corn ear yield and fertilizer use efficiency (FUE) and Water use efficiency (WUE).

Soil hydraulic study

After the installation of the irrigation setup, a soil hydraulic study was conducted to know the wetting front advance and moisture distribution pattern in the soil. Irrigation water was passed through chosen twelve different combinations of porous pipes of lengths 30 and 45 m, installed at depths 20 and 30 cm, for 2, 3 and 4 hrs. The input pressure was

Table 1. Treatment details

Treatments		Recommended Dose of Fertilizer (RDF) %	Length of porous pipe (L) m	Depth of installation beneath the soil (D) cm
T1	$F_1L_1D_1$	40	30	20
T2	$F_1L_1D_2$	40	30	30
T3	$F_1L_2D_1$	40	45	20
T4	$F_1L_2D_2$	40	45	30
T5	$F_2L_1D_1$	70	30	20
T6	$F_2L_1D_2$	70	30	30
T7	$F_2L_2D_1$	70	45	20
T8	$F_2L_2D_2$	70	45	30
T9	$F_3L_1D_1$	100	30	20
T10	$F_3L_1D_2$	100	30	30
T11	$F_3L_2D_1$	100	45	20
T12	$F_2L_2D_2$	100	45	30
T13		Control- surface drip irrigation with no fertigation		

maintained at 1 m pressure head by means of a control valve and digital manometer. Wetting front advance (horizontal, vertical upward movements) in the soil was measured after 48 hours of irrigation termination. Measurements were taken by making trenches across every line at a 10 m distance from starting, middle and end points respectively. Soil samples were collected from the center of the lateral and both sides of the lateral (at 5 and 10 cm distance away from the center) to study the soil moisture distribution extend. Three sets of such samples were collected from each lateral. The samples were subjected to oven drying at 105^{o} C for 24 hours to determine the moisture content using the gravimetric method.

Irrigation scheduling

The method used to estimate ET_C was the crop coefficient (K_C) algorithm as per Doorenbos and Pruitt 1975, where the crop factor was multiplied by reference evapotranspiration (ETo) to compute ET_C (Equation 1). Penman-Monteith method as given in FAO-56 (Allen et al., 1998) was used for the computation of reference evapotranspiration (Equation 2). The same irrigation level (1.0 IW/CPE) was applied for all the treatments

$$ET_{C} = K_C * ET_0 \quad (1)$$

$$ET_0 \quad (2)$$

Where,

$$ET_C = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)}$$

Crop evapotranspiration [mm/day]; K_C= Crop factor; ET_0 = reference evapotranspiration [mm/day]; Rn = net radiation at the crop surface [MJ/m^2/day^1]; G = soil heat flux density [MJ/ m^2/day]; T= mean daily air temperature at 2 m height [°C]; u_2= wind speed at 2 m height [m/ s]; e_s= saturation vapor pressure [kPa]; e_a= actual vapor pressure [kPa]; (e_s – e_a)= saturation vapor pressure deficit [kPa]; Δ = slope of vapor pressure curve [kPa/ °C]; γ = psychrometric constant [k Pa/ °C].

The total irrigation water requirement as per irrigation level was calculated using the equation :

$$IW\ (mm/day) = L*ET_c\ ;$$
$$\text{Here, } L=1.0\ IW/CPE \quad (3)$$

Where, IW = Depth of water to be applied (mm/day); L = level of irrigation (IW/CPE); ET_C = cumulative crop evapotranspiration from day preceding irrigation.

Water application rate, time of operation and water use efficiency of porous pipe and drip irrigation emitters (Control) were calculated using the following equations.

Porous pipe Irrigation Rate IR (mm/hr) =

$$\frac{\text{Porous pipe emitting rate (lph/m)}}{\text{Porous pipe spacing } (m)} \quad (4)$$

Drip Irrigation Rate IR (mm/hr) =

$$\frac{\text{Dipper discharge (lph/m)}}{\text{Lateral spacing g } (m) \text{ x pipe spacin g } (m)} \quad (5)$$

Irrigation time (hrs/day) =

$$\frac{\text{IW (mm/day)}}{\text{Irrigation rate (mm/hr)}} \quad (6)$$

Water Use Efficiency, WUE (kg/ ha-mm) =

$$\frac{\text{Yield (kg/ha)}}{\text{Total amount of water used (mm)}} \quad (7)$$

Fertigation scheduling

Recommended dose of fertilizer for sweet corn is 120:60:60 kg/ha (JAU recommendation, 2018). A full dose of phosphorous (100 kg of 60 % concentrated phosphoric acid) was supplied uniformly to all treatments through porous pipe as the basal dose. The amount of nitrogen (urea) and potassium [Muriate of potash (MOP)] required under different treatments were supplied as five splits in 15 days intervals, starting from 25 days after sowing (DAS) to 85 DAS. Total quantity of fertilizer supplied under each treatment is shown in Table 2.

The fertilizer use efficiency (FUE) was computed as,

FUE =

$$\frac{\text{Yield (kg/ha)}}{\text{Total quantity of fertiliser used used (mm)}} \quad (8)$$

Table 2. Total quantity of fertilizer applied (kg/ha)

Fertilizer	N-P-K Composition (%)	Quantity of fertilizer (kg/ha)		
		100 % RDF	70% RDF	40% RDF
Urea (N)	46-0-0	260.87	182.61	104.35
MOP	0-0-60	100	70	40
Phosphoric acid (P)- Basal dose	0-60-0	100 kg/ha to all treatments		

Economic analysis

The total cost of cultivation includes expenses incurred on land preparation, the common cost of cultivation of sweet corn, cost of fertilizer, and fixed seasonal cost of irrigation. The fixed cost of irrigation (FCI) for porous pipe and surface drip irrigation systems consists of the seasonal cost of the pumping system and the cost of irrigation components with installation charge.

Total Cost of Cultivation,

$$TCC = CCC+CT+CF+FCI$$

Where, TCC = Total cost of cultivation (₹/ha/season); CCC = Common cost of cultivation of sweet corn (₹/ha/season); CT = Cost of trench preparation (₹/ha/season); CF = Cost of fertigation (₹/ha/season); FCI = Fixed seasonal cost of irrigation (₹/ha/season).

Gross return (₹/ha) was calculated based on prevailing market price of the green cob. The net return (₹/ha) was obtained by deducting the cost of cultivation from the gross return of the respective treatment. The Benefit-Cost ratio (BCR) was worked out for each treatment by dividing the gross return by total cost of cultivation.

Results and Discussion

Irrigation water use

Monthly average amount of irrigation water applied and time of operation under subsurface porous pipe as well as surface drip (control) irrigation is shown in Table 3. The seasonal amountof water applied (mm) under both irrigation systems at 100% irrigation level was found approximately the same (508 mm). Even though both the irrigation methods consumed the same amount of irrigation water, the calculated time of operation was greater in a porous pipe irrigation system compared to surface drip irrigation. However, as the irrigation water is applied at a low flow rate through the porous pipe, over a long period of time at frequent intervals with a low-pressure delivery system, the water is used efficiently by the crop, minimizing deep percolation and evaporation.

Soil hydraulic study

For the installed irrigation system to be successful, lateral wetting front advance on both sides of the porous pipe and upward capillary movement of water should favour active growth of root system to get sufficient water for physiological growth and yield. The wetted bulb in the soil layer below the porous pipe could not be measured because of the

Table 3. Depth of irrigation water applied and time of operation of irrigation system

Month	ET_0 (mm)	K_C	ET_C (mm)	L*	Subsurface porous pipe			Surface Drip (Control)		
					IR (mm/hrs)	T_0(hrs)	IW(mm)	IR (mm/hrs)	T_0(hrs)	IW (mm)
December	3.30	0.69	2.26	1.0	3.88	0.59	2.26	11.11	0.20	2.26
January	2.95	0.76	2.25	1.0	3.88	0.58	2.26	11.11	0.20	2.27
February	3.89	1.12	4.39	1.0	3.88	1.13	4.39	11.11	0.39	4.38
March	5.53	1.17	6.46	1.0	3.88	1.67	6.46	11.11	0.58	6.45
April	6.05	1.11	6.74	1.0	3.88	1.74	6.74	11.11	0.61	6.74

$*L = \frac{IW}{CPE}$

Table 4. Advance of wetting front measured in horizontal and vertical directions during 2, 3 &4 hours of operation of irrigation system

Total length of porous pipe(cm)	Depth of installation (cm)	Length of porous pipe from inlet (cm)	Wetting front (cm)								
			H1			H2			V		
			2 hrs	3 hrs	4 hrs	2 hrs	3 hrs	4 hrs	2 hrs	3 hrs	4 hrs
30	30	10	12	20	25	12	20	25	10	20	15
		15	12	20	25	13	20	26	12	20	15
		20	16	26	28	16	26	28	14	26	18
30	20	10	10	19	20	10	19	20	10	19	15
		15	10	20	22	10	20	23	12	20	20
		20	12	22	26	13	22	30	12	22	20
45	30	10	22	20	26	22	20	26	15	20	18
		22.5	22	20	26	22	20	26	15	20	18
		35	23	24	30	24	24	28	15	24	15
45	20	10	13	15	22	13	15	23	14	15	16
		22.5	18	20	25	18	20	25	15	20	18
		35	20	20	26	20	20	25	15	20	20

H1, H2– length of horizontal advance of water from both sides of porous pipe, V- Vertical upward advance of water from depth of installation of porous pipe

residual moisture content in it. The results of wetting front advance at 2, 3 and 4 hours of operation of irrigation are presented in Table 4. It was evident from the data recorded in Table 4 that, lateral advance wetting front increases with an increase in time of operation and depth of installation. Because a gain in pressure head was observed from inlet to the end of porous pipe laterals due to the slight increase of land slope towards the end. Soil samples were collected from the center and the sides of the lateral at a distance of 5 cm, and 10 cm away from the center. The samples collected for all combinations of the length of lateral, depth of installation and time of operation were subjected for oven drying to determine soil moisture content using the gravimetric method. Average soil moisture content obtained from the gravimetric method is depicted graphically in Figures 2 (a) to (d). The average soil moisture content is found to be higher under 30 cm depth of installation compared to that of 20 cm depth. As per the initial hydraulic study, the discharge through porous pipe increases with the depth of installation from 20 to 30 cm. This finding is in close agreement with the result reported by Panchariya (2001).

Effect of different treatments on crop yield

The effect of individual treatments on crop yield is shown in Table 5. Among three fertilizer levels, significantly higher corn ear yields of 30.572 t/ha and 30.418 t/ha were obtained under F2 (70 % RDF) and F3 (100 % RDF). A similar result on fertigation was reported by Patil and Mahadkar (2011) in sweet corn under drip irrigation. Crop under control treatment (surface drip) yielded comparatively lower corn ear 15.750 t/ha, however, it was at par with the yield (18.693 t/ha) obtained under the

Table5. Effect of individual treatments on sweet corn ear yield (t/ha)

Treatments	Yield (t/ha) Corn ear yield
Fertilizer level	
F_1	18.693
F_2	30.572
F_3	30.418
C.D. at 5%	1.80
Length	
L_1	25.899
L_2	27.223
C.D. at 5%	NS
Depth	
D_1	24.152
D_2	28.970
C.D. at 5%	1.47
Control	
C	15.75
C.D. at 5% (C v/s R)	3.00

*C. D- Critical difference

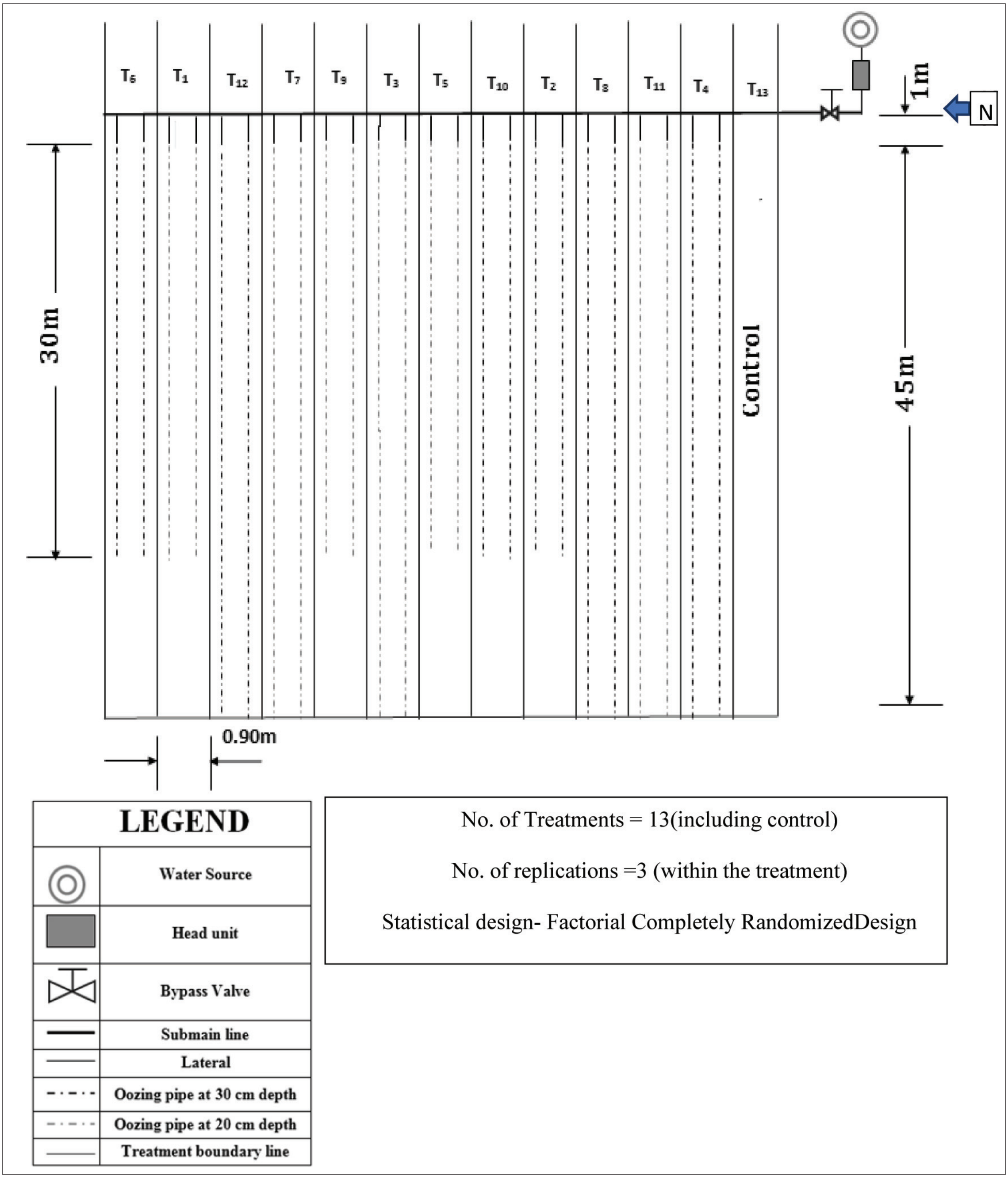

Figure 1. Field layout of the experiment

treatment F3 (40 % RDF through subsurface porous pipe irrigation). In the case of depth of installation, crop under 30 cm depth recorded significantly higher ear yield of (28.970 t/ha) compared to yield under 20 cm depth (24.150 t/ha) and control (15.57 t/ha). Similar results were observed by Hernandez et al. (1991) and Douh and Boujelben (2011) in sweet corn under subsurface drip irrigation. Active root zone depth of sweet corn ranges from 30 to 60 cm. So, the application of water and nutrients directly near the root zone increases the water use efficiency and minimizes the evaporation loss,

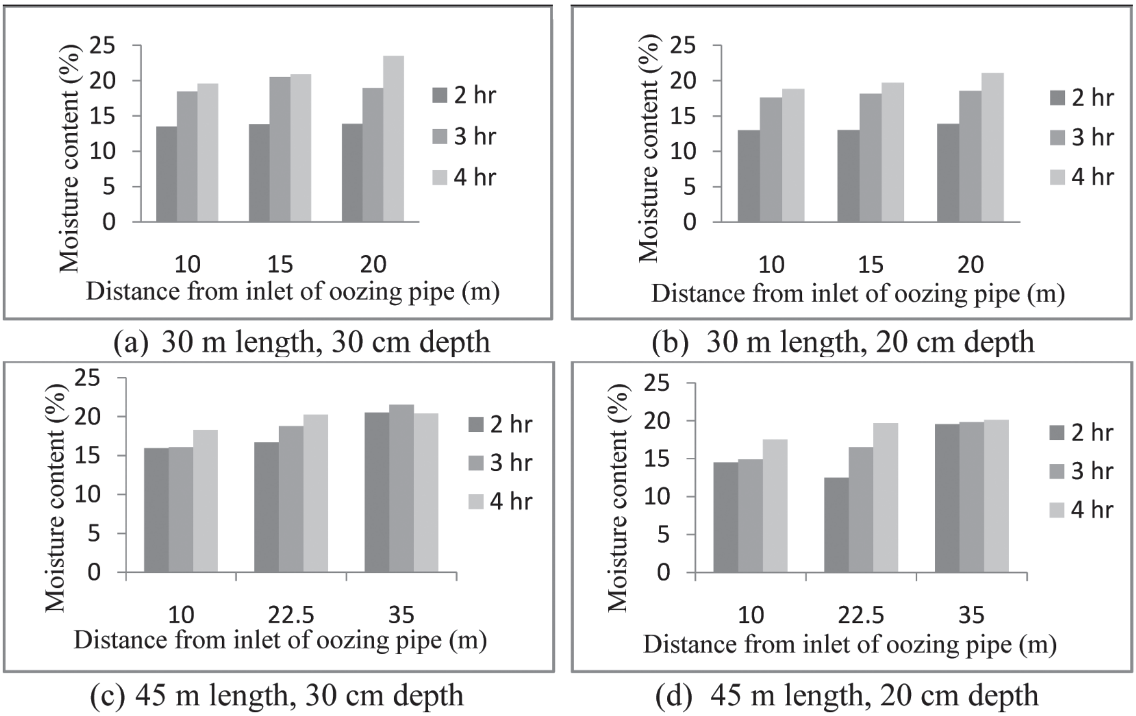

Figure 2. (a) to (d). Average soil moisture content observed under different combinations of selected lengths and depths for 2, 3 and 4 hours of operation of irrigation

Table 6. Interaction effect of different treatments on corn ear yield (t/ha)

Length	Corn ear yield (t/ha) Fertigation			
	F_1	F_2	F_3	Mean
L_1	17.992	29.556	30.150	25.899
L_2	19.395	31.587	30.686	27.223
Mean	18.693	30.572	30.418	
C. D at 5%		NS		

Depth	Corn ear yield (t/ha) Fertigation			
	F_1	F_2	F_3	Mean
D_1	17.702	26.155	28.599	24.152
D_2	19.685	34.988	32.237	28.970
Mean	18.693	30.572	30.418	
C.D at 5%		2.93		

Depth	Corn ear yield (t/ha) Length		
	L_1	L_2	Mean
D_1	23.236	25.067	24.152
D_2	28.562	29.378	28.970
Mean	25.899	27.223	
C.D at 5%			NS

* C.D- Critical difference

which in turn improves the crop yield. However, the length of the porous pipe had no significant effect on corn ear yield.

The interaction effect of fertilizer level and depth of installation resulted in considerably higher ear yield (34.988 t/ha) under the treatment F2D2 (70 % RDF and 30 cm depth of installation), however, it was similar to that of treatment F3D2 (100 % RDF and 30 cm depth of installation). Interaction effects of different treatments on crop yield are shown in Table 6. Among all the treatments under subsurface irrigation, F1D1 (40 % RDF and 20 cm depth of installation) recorded the lowest ear yield of 17.702 t/ha and it was similar to the control (15.570 t/ha). But at the same time ear yield under the combination F1D2 (40 % RDF and 30 cm depth of installation) was found significantly higher than that of control by 26.42 %. The observed responses to these treatments prove that fertigation using subsurface porous pipe irrigation can effectively manage the placement and availability of nutrients.

Table 7. Fertilizer and Water use efficiency (FUE &WUE) under different treatments

Treatments	Yield(kg/ha)	Fertilizersupplied (kg/ha)	Irrigation waterapplied(mm)	WUE (kg/ha-mm)	FUE
T_1	16140	144.35	507.87	31.78	111.81
T_2	19840	144.35	507.87	39.07	137.45
T_3	19260	144.35	507.87	38.51	133.43
T_4	19530	144.35	507.87	38.45	135.30
T_5	24400	252.61	507.87	48.04	96.59
T_6	34710	252.61	507.87	68.34	137.41
T_7	27910	252.61	507.87	54.96	110.49
T_8	35270	252.61	507.87	69.45	139.62
T_9	29170	360.87	507.87	57.44	80.83
T_{10}	31130	360.87	507.87	61.30	86.26
T_{11}	28030	360.87	507.87	55.20	77.67
T_{12}	33340	360.87	507.87	65.65	92.39
T_{13}	15570	-	507.87	31.01	-

Similar results were reported by Siyal et al. (2011) who found that subsurface porous clay pipe irrigation is effective in saving water and increasing crop production compared to surface irrigation methods.

Fertilizer use efficiency (FUE) and water use efficiency (WUE)

In this study, to make the experimental results more obvious, the fertilizer use efficiency (FUE) and water use efficiency (WUE) under each treatment were calculated (Table 7). Higher fertilizer use efficiencies (139.62 and 137.41) were recorded under the treatment combination of 70 % RDF and 30cm depth (i.e., T_8- F2L2D2 & T_6- $F_2L_1D_2$). That is, these treatment combinations recorded maximum corn yield with minimum use of fertilizers. Similarly, for the same level of irrigation water applied (1.0 IW/CPE), maximum WUE was also recorded under the treatments T_8 and T_6 (68.34 kg/ha-mm and 69.45 kg/ha-mm). At the same time, the water use efficiency obtained under control treatment (31.01 kg/ha-mm) was found comparatively low. Subsurface porous pipe irrigation system applies water directly into the root zone and therefore resulted in less evaporation with high water use efficiency, which is one of the salient advantages of this irrigation method (Camp, 1998). Hence, the choice of subsurface porous pipe irrigation system could markedly improve the availability and absorption of water and nutrients by minimizing the leaching and evaporation losses. This in turn results in a significant increase in crop production as well as quality.

Economic analysis

The data regarding economic analysis on irrigation and crop production are presented in Table 8. The total cost of cultivation was noted maximum (₹ 74,327/ha/season) under the treatment T_{10} (100 % RDF, 30 m length & 30cm depth) compared to other treatments. Gross return (₹ /ha) was calculated on the basis of prevailing market price of the green cob. The market price of sweet corn prevailing during the season was ₹ 12 per kg. The highest gross return of ₹ 4,23,240/ha/season and net returns of ₹ 3,50,282/ha/season were recorded under the treatment T_8 (70% RDF, 45m length & 30 cm depth). In addition, the treatment T_8 (5.80) showed the highest Benefit-Cost Ratio (BCR) of 5.80 compared to all other treatments (Table 9). So, it may be suggested that additional income could be earned by cultivating sweet corn through subsurface porous pipe irrigation with a substantial saving in input resources.

Finally, it may be concluded that the use of subsurface porous pipe irrigation system is a good option not only for water and fertilizer saving but also for improved crop production and yield. The maximum corn ear yield (34.988 t/ha) has been observed in the treatment supplied with 70% RDF

Table 8. Economic analysis of different treatments

Treatments	TCC([1] /ha/season)	Yield(kg/ha)	GR([1] /ha/season)	NR([1] /ha/season)	BCR
T_1	72,286.32	16140	1,93,680	1,21,393.68	2.68
T_2	72,786.32	19840	2,38.080	1,65,293.68	3.27
T_3	71,687.19	19260	2,31,120	1,59,432.81	3.22
T_4	72,187.19	19530	2,34,360	1,62,172.81	3.25
T_5	73,056.93	24400	2,92,800	2,19,743.07	4.01
T_6	73,556.93	34710	4,16,520	3,42,963.07	5.66
T_7	72,457.80	27910	3,34,920	2,62,462.20	4.62
T_8	72,957.80	35270	4,23,240	3,50,282.20	5.80
T_9	73,827.54	29170	3,50,040	2,76,212.46	4.74
T_{10}	74,327.54	31130	3,73,560	2,99,232.46	5.03
T_{11}	73,228.42	28030	3,36,360	2,63,131.59	4.59
T_{12}	73,728.42	33340	4,00,080	3,26,351.59	5.43
T_{13} - Control	72,833.19	15750	1,89,000	1,16,166.81	2.59

and 30 cm depth of installation of porous pipe. This translates to a saving in fertilizer usage by 30 %. Also, overall results in the treatment with subsurface porous pipe irrigation and 40 % RDF were superior compared to surface drip irrigation with no fertigation.The subsurface porous pipe irrigation system maintained a nearly dry soil surface which minimized the evaporation loss and consequently increased WUE by 26 %. Similar results were reported by KunzeI et al. (2021), where the suitability of the porous pipe for subsurface irrigation of lettuce was compared with the surface drip irrigation system. Results showed that with the porous pipe system 35 % less water was used, along with a 9 % increase in total fresh biomass and significantly higher water use efficiency as compared to drip irrigation. Hence, the installed subsurface porous pipe irrigation system operating at 1 m pressure head has been found as the best method for irrigation and fertigation for sweet corn cultivation. Even though the land preparation and installation of subsurface porous pipe is labour intensive, overall results were found better compared to surface drip irrigation. Therefore, it can be considered as a sustainable alternative for sweet corn crop irrigation in Junagadh and similar subtropical environments.

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