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Full Length Research Paper

Comparative study of subsurface drip irrigation and flood irrigation systems for quality and yield of sugarcane

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Subsurface drip irrigation (SDI) is a most advanced method of irrigation that facilitates the irrigation of crop / plants with small amounts of water through the T- tapes placed below the soil surface. Depth of T-tape and requirement of water depends upon soil type and crop under observations. Experiments for comparative study of SDI with flood irrigation for yield and quality were conducted on sugarcane crop from 2005 - 2008 with 3-varieties i.e. HSF-240, HS- 12 and CSSG-668 on an area of 6 ha. Drip tapes were buried manually in the middle of the ridges on an area of 3 ha with subplot size for each variety of 1 ha compared with flood irrigated crop of 3 ha with subplot of 1 ha for each variety. Flood irrigation system showed better results for growth, yield and quality of sugarcane than SDI. Germination % and tillers/plant did not show any significant difference under both irrigation systems. SDI resulted to lower mill- able cane, cane yield, crop growth rate (CGR) and net assimilation rate (NAR). Harvest index % (HI) had no significant effect on both irrigation systems. Higher leaf relative water contents (LRWC) obtained under flood irrigation showed higher accumulation of water supplied through flood system. Similarly, quality attributes (juice extraction, purity %, recovery % cane and sugar yield t/ha) showed superior behavior under flood irrigation than SDI. Flood irrigation system provided net benefits ranging from Rs. 56130 – Rs. 82760 / ha while SDI resulted in loss from Rs. 127345 to 157910 / ha. Maximum income benefit was recorded in CSSG-668 variety (Rs. 82760 / ha) and maximum loss in HSF-240 variety (Rs. 157910 / ha) under SDI. SDI helped to save water from 11 - 18% over flood irrigation system that had no significant contribution in net benefits. This loss may be due to the major problems faced by SDI system that led to blockage, damaged of T-tapes, filtration obstructions due to high ferrous contents in irrigated water, higher initial cost, management, that resulted to net economic loss in sugarcane. Irrigated water was unfit with high ferrous contents that resulted to blockage of T -tapes. SDI saved 18% water as compared to flood irrigation system. It was concluded that SDI is not a superior system of irrigation for sugarcane in developing countries like Pakistan where water is unfit for irrigation. Its high installation cost, breakage and clogging resulted to net economic loss. SDI might be a superior system where water is fit for irrigation, free of ferrous and low installation costs.

Key words: SDI, flood irrigation, sugarcane, yield, quality.

INTRODUCTION

Sugarcane (*Saccharum officinarum*) is an important crop globally not only for sugar production, but also increasingly as a bioenergy crop due to its phenomenal dry matter production capacity. Irrigation quantum is one of the most important abiotic stress factors limiting sugarcane production, worldwide. However, water for

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irrigation is a limited and continuous resource and its effective management is critical, not only in reducing wasteful usage, but also in reducing production costs and sustaining productivity (Qureshi and Afghan, 2005).

It has been worked out that to produce one tone of cane, about 200 - 250 tons of water is required. The availability of water for sugarcane crop is almost static even decreasing in cane growing areas over the years. There is an imperative need to optimize production of sugarcane by efficiently managing water resources and their reliability (Afghan, 2003). Genotype, severity of water deficit, and the stage of development affect the reduction of cane and sugar yields. There is a linear relationship between the growth rate of sugarcane and the optimum soil moisture regimes, because the vegetative growth is of economic importance in this crop (Aguilera et al., 1999).

The major limiting factor on the expansion of irrigated agriculture throughout the world is the lack of water. Water demand is increasing due to fast population growth rates, improvement in living standards, improvement in industry and municipality, and global warming (Kirnak, 2006). However for various reasons, the available water for irrigation purposes has been declined rapidly, while the demand of irrigation water has been growing fast (Saleth, 1996). In such conditions of scarcity, efficient use of irrigation water is essential to enhance the benefits of irrigation. The flood method of irrigation is widely practiced in the world agriculture and it has been considered much loss of water by evaporation and distribution (Rosegrant, 1997). Since efficient use of irrigation water is of paramount importance for sustainable agriculture development, different measures have been introduced to conserve water. This was the background for the induction of subsurface drip irrigation (Narayanmoorthy, 2004).

Subsurface drip irrigation (SDI) is a most advanced method of irrigation that facilitates the irrigation of crop/plants with small amounts of water through the T-tape placed below the soil surface. Depth of T -tape and requirement of water depends upon soil type and crop under observations. One of the most commonly discussed aspects of SDI system is installation depth of drip lateral. Determining the appropriate depth of installation involves consideration of soil structure, texture, and crop's root development pattern. Site-wise and crop-wise variations of these parameters preclude the possibility of farming general recommendations for installation depths of SDI system (Patel and Rajput, 2007).

One of the greatest challenges faced by irrigators using SDI is crop establishment. Establishment with SDI relies on unsaturated water movement from the buried source to the seed or seedling. Establishment is therefore affected by distance to source, soil texture, structure, and antecedent water content (Wiedenfeld, 2003). Different results have been obtained in different crops for yield and quality under SDI. Crops having low water requirements produced good yield and quality while, crops having high water requirement like sugarcane showed failure of SDI due to its high installation costs and very low yield. SDI was not able to fulfill water requirements of the crop that resulted in economic loss in sugarcane through SDI over flood irrigation method (Amanullah et al., 2006).

In review of above study, the objective of present study was to asses the comparison of flood irrigation system with subsurface drip tape irrigation for yield, quality and water consumption in sugarcane and its impact on economic benefits.

MATERIALS AND METHODS

The experiments to study the comparison between subsurface drip tape irrigation (SDI) and flood irrigation systems was laid out at Shakarganj Sugar Research Institute (SSRI) farm, Jhang-Pakistan during 2005 - 2008 on an area of 6 ha. Soil used for these experiments was sandy loam.

SDI system based on T-tapes was installed with assistantship of Rainmakers (Pvt) Lahore, Pakistan. T-tapes model 512-40-250 having diameter 16 mm, tape thickness 12 mm and tape discharge 250 L/h/100 m of length were imported from T-systems Australia PTY Ltd. It had water filtration unit at the base of system with 200-mesh filtrations supply. T-tapes had water flow rate 2 mm per h with emission uniformity 95%. T-tapes were placed manually in the middle of the ridges with depth of 15 cm on an area of 3 ha. There were 3 sub plots of 1 ha comprising for each variety. T-tapes were laid out in continuous lengths connected with a main single PVC pipe (Diameter 5.08 cm) with separate opening valves for each sub-plot. A water pump of 7.5 hp (MECO company, RPM-2850, head size 2½) was placed on this system for sucking of water from water tank prepared under pre-existing water turbine of 15 hp (MECO company, RPM-1400, head size 3½, bore depth 200 ft.). Each sub-plot was irrigated separately by controlling valves functions. A fertilizer tank was installed at the base of the system for fertilizer application. Diagrammatic representation of the whole system is given in Figure 1.

Sowing of three sugarcane varieties i.e. HSF-240, HS-12 and CSSG-668 with 3-replicates was done in autumn 2005 - 2008 with seed rate of 75000 double-bedded setts per hectares. Setts were placed on either side of T-tapes with row-to-row distance of 5 ft. Thus T-tape was in direct contact with both sided setts.

For comparison of SDI with flood irrigation system, separate sowing of three sugarcane varieties HSF-240, HS-12 and CSSG-668 with 3-replicates was done in autumn 2005 - 2008 with seed rate of 75000 double-bedded setts per ha on area of 3 ha with sub-plot of 1 ha for each variety with row-to-row distance of 5 ft. Irrigation was applied as normal and recommended basis by monitoring soil moisture through tensiometers and evapotranspiration of the crop. Fertilizer was applied as recommended dozes NPK (150-100-100) for both systems of irrigations. Fresh sugarcane sowing was done at each year of experiment with same procedure as described above for both irrigation systems.

Data of following parameters was collected for both flood and T-tapes irrigation systems:

1. Germination %
2. Number of Tillers/plant
3. Mill-able Canes (t / ha)
4. Cane yield (t / ha)
5. Crop Growth Rate (CGR) $gm^{-2} D^{-1}$
6. Net Assimilation Rate (NAR) $gm^{-2} D^{-1}$
7. Harvest Index (%)
8. Juice Extraction %
9. Juice purity (%)

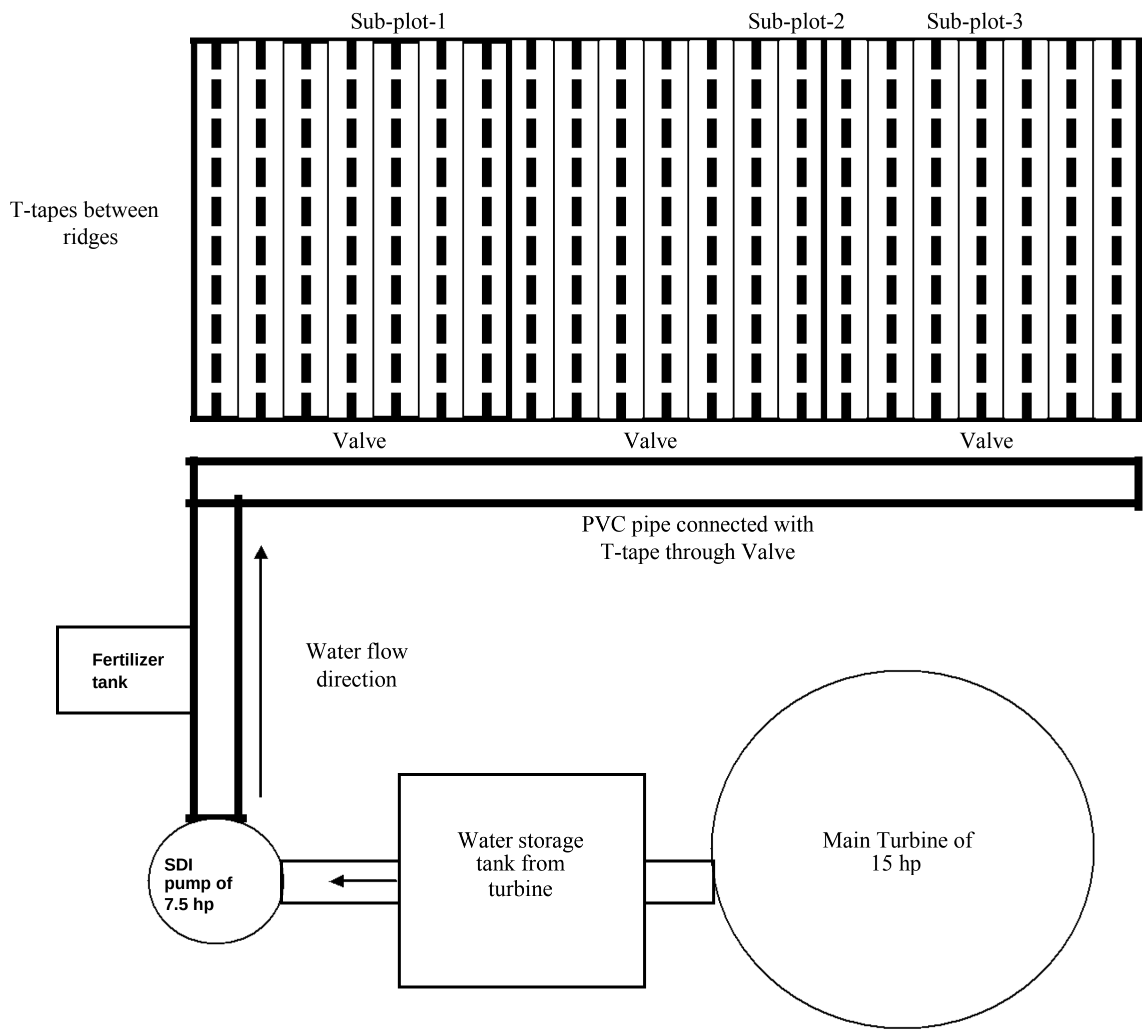

Figure 1. Layout of T-tapes system for sugar cane.

10. Sugar recovery % cane
11. Sugar yield (t / ha)
12. Economic analysis (Rs ha^{-1}) and water saving %
13. Analysis of irrigated water

After 45 days of sowing, number of seedlings sprouted per unit area was counted. Germination percentage was calculated by sprouted seedlings divided by total number of buds per unit area multiply with 100. Number of tillers/plant in each plot was counted after 120 days of germination with the following formulae:

$$\text{Tiller / plant} = \frac{\text{Total number of tillers - Germination count}}{\text{Germination count}} \times 100$$

Number of millable canes in each plot was counted at harvest in the month of December of each experiment year and converted to hectare basis. For Cane yield all stripped canes of each plot was weighed at harvest and transformed to t/ha. Crop Growth Rate (CGR) was determined by using the following formula:

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \quad (\text{gm}^{-2}\ \text{D}^{-1})$$

W_1 = Shoot dry weight m^{-2} at time t_1, W_2 = Shoot dry weight m^{-2} at time t_2, T_1 = time of 1st harvest and T_2 = time of 2nd harvest.
Net Assimilation Rate (NAR) was determined by using the method as follows:

$$\text{NAR} = \frac{\text{TDM}}{\text{LAD}} \quad (\text{gm}^{-2}\ \text{day}^{-1})$$

TDM = Total shoot dry matter and LAD = Leaf area duration
Harvest index (HI) for each treatment was calculated by using the method as follows:

$$\text{HI} = \frac{\text{Stripped cane yield}}{\text{Unstripped cane yield}} \times 100$$

Leaf relative water contents (RWC) % was measured on a newly expanded leaf detached from three plants per treatment in the late evening. Each leaf was re-cut under water and weighed to determine the leaf fresh mass (FM). Then, the leaf was covered with a plastic bag, and kept for rehydration with the cut end immersed in water in a dark cold room at 4°C for 24 h. After rehydration, each leaf was weighed to determine the turgid mass

(TM), and then oven-dried at 80°C for 48 h to determine dry mass (DM). RWC (%) was calculated as follows:

RWC (%) = 100 x (FM - DM) / (TM - DM).

Juice extraction % was calculated as:

$$\text{Juice extraction (\%)} = \frac{\text{Juice weight (g)}}{\text{Cake weight (g)}} \times 100$$

Juice purity (%) was obtained as Pol % of Juice divided by Brix % of Juice

Sugar recovery % cane for each treatment was calculated by using the formula as follows:

$$\text{Sugar Recovery (\%)} = \frac{\text{S (J-M) X Pol \% X 0.65 X 0.98}}{\text{J (S-M)}}$$

Where; S = Sugar 100%, J = Juice purity, M = Molasses purity = 35% and Pol % = Pol % juice (sucrose %) (Sucrose content is often referred to as per cent pol, with pol being derived from the name of the machine that measures the sucrose content, a polarimeter).

Juice extraction = 0.65 and Boiling house efficiency = 0.98. Total sugar yield / ha was calculated for each treatment by using the following method:

$$\text{Total sugar (t / ha)} = \frac{\text{Sugar recovery x Stripped-cane yield (t / ha)}}{100}$$

Economic analysis was calculated by subtracting the total variable cost from the gross benefits for each irrigation and variety. Input and output cost for each irrigation was converted to Rs ha^{-1}. Water saving was calculated by the calculation of readings of outlet flow meter placed from both systems that was of 67.75 m^3 / h.

Analysis of water use for drip tape and flood irrigation was same and its analysis was carried at Soil and Water analysis Laboratory of Shakarganj sugar Research Institute, Jhang.

Analysis of variance technique was employed in carrying out statistical analysis of data collected (Steel and Torrie, 1980). Various treatment means were compared with Least Significant Difference (LSD) Test.

RESULTS

Results obtained from subsurface drip tape irrigation and flood irrigations are given below:

Germination %

Data regarding germination % is presented in Table 1. It showed that there was no significant statistical difference for germination % between subsurface drip tape and flood irrigated sugarcane during all the years studied. Pooled means from 2005 - 2008 also showed non-significant difference for germination % under both system of irrigation (Table 1). Although there was a significant difference among varieties for germination % that may be due to differences in genetic make-up each variety had. Both irrigation systems fulfilled the water requirement of sugarcane crop for germination equally. From pooled means it was noted that maximum germination of 60 and 58.4% was present in CSSG-688 under flood and SDI irrigation respectively.

Number of tillers / plant

Statistically almost equal numbers of tillers were counted in each variety under SDI and flood irrigation systems during each year from 2005 - 2008 (Table 1). There was a significant difference among varieties for tillers per plant. Pooled mean form 2005 - 2008 showed non-significant difference of SDI and flood irrigation system on tillers on sugarcane varieties. It was clear from these results that SDI system had same efficiency to fulfill the water requirement of sugarcane crop for tillers production as flood irrigation system. Maximum number of tillers was counted in CSSG-688 under both types of irrigation systems.

Mill-able canes (000 ha)

Data for mill-able canes in Table 1 showed the significant difference between subsurface drip tape and flood irrigation system and also among the varieties of sugarcane during 2005 - 2008. Pooled means of 3-years also showed a significant difference for mill able canes under both type of irrigation systems. From pooled means it was noted that there were, 86.0, 65.8 and 79.5 mill-able cane (000 ha) in varieties HSF-240, HS-12 and CSSG - 668 respectively under SDI system. In contrast under flood irrigation it had 103.0, 98.6 and 104.9 mill-able canes (000 ha) for varieties HSF-240, HS-12 and CSSG-668 respectively (Table 1).

Cane yield (t / ha)

Cane yield of the sugarcane depends upon mill-able cane produced. Results obtained for calculation of cane yield on year basis were given in Table-1. Results of cane yield were similar as obtained for mill-able canes. There was higher cane yield in flood irrigation system as compared to SDI. From pooled means (2005 - 2008), it showed that cane yield of 105, 98.5 and 118.1 tons / ha was noted in varieties HSF-240, HS-12 and CSSG-668 respectively under flood irrigation system. While under subsurface drip tapes, there were 80.4, 88.7 and 83.9 cane yield (t/ha) for varieties HSF-240, HS-12 and CSSG-668 respectively. This difference of cane yield may be due to high water requirement of the crop during maturity stage that could not be attained through drip tapes.

Crop growth rate (CGR) $gm^{-2}D^{-1}$

Results regarding CGR are presented in Table 2. Low

Table 1. Comparison of subsurface drip irrigation vs. flood irrigation system for biometric traits in sugarcane

Varieties	2005 - 2006		2006 - 2007		2007 - 2008		Pooled means (2005- 2008)	
	Drip tape	Flood irrigation	Drip tape	Flood irrigation	Drip tape	Flood irrigation	Drip tape	Flood irrigation
Germination %								
HSF-240	56.6±1.1 aB	57.3±1.5 aB	55.6±2.1 aA	54.3+3.1 aB	55.8±1.5 aB	56.2±1.1 aB	56.0±1.5 aA	55.9±1.9 aB
HS-12	59.6±2.5 aA	58.7±2.6 aB	49.6±1.9 aB	51.2±1.5 aC	55.5+2.3 aB	54.6±3.1 aC	54.9±2.2 aB	54.8±2.4 aB
CSSG-668	59.4±3.1 aA	60.1+1.2 aA	56.9±2.3 aA	58.9±2.2 aA	58.9 ±2.0 aA	60.2±2.9 aA	58.4±4.0 aA	60.0±2.1 aA
Number of tillers/plant								
HSF-240	1.88+0.01aB	1.91±0.02 aB	2.06±0.02 aA	2.12±0.03aA	2.19±0.01aB	2.24±0.05aA	1.98±0.01bB	2.09±0.03aB
HS-12	1.69±0.01aC	1.78+0.03aC	1.83±0.02 aC	1.95+0.02aB	2.06±0.03aC	2.11+0.02aB	1.86±0.02aC	1.94±0.02aC
CSSG-668	2.07±0.04aA	2.11±0.01aA	1.99±0.04 aB	2.01±0.01aA	2.31±0.03aA	2.45±0.04aA	2.12±0.04aA	2.19±0.02aA
Mill-able cane (000 ha)								
HSF-240	82.3±2.1bA	97.5±3.2aB	85.2±1.1bA	100.5±2.3aB	90.5±2.3bA	111.2±4.0aC	86.0±1.8bA	103.0±3.1aA
HS-12	64.0±1.9bB	85.0±2.5aC	65.6±2.4bC	95.6±1.8aC	68.0±3.2bC	115.2±3.3aB	65.8±2.5bC	98.6±2.5aB
CSSG-668	80.6±2.6bA	101.5±3.6aA	72.3±1.6bB	104.6±2.3 aA	85.6±1.6bB	108.6±2.9aA	79.5±1.9bB	104.9±2.9aA
Yield (t/ha)								
HSF-240	76.5±1.6bB	104.3±3.6aB	82.6±1.6bA	109.5±2.1aB	82.2±2.2bB	101.3±2.5aC	80.4±1.6bC	105.0±1.6aB
HS-12	62.6±2.1bC	98.2±2.8aC	57.9±2.3bC	90.9±3.2aC	77.2±3.2bC	106.5±1.9aB	88.7±2.3bA	98.5±2.3aC
CSSG-668	84.0±3.2bA	118.2±4.1aA	77.5±3.2bB	111.6±1.5aA	90.3±1.9bA	124.6±2.3aA	83.9±1.8bB	118.1±1.9aA

Small letter indicates difference between drip tape and flood irrigation system within year and capital letter shows mean difference among sugarcane varieties (HSF-240, HS-12 and CSSG-668) within year

Table 2. Comparison of subsurface drip irrigation vs. flood irrigation system for growth attributes in sugarcane

Varieties	2005 - 2006		2006 - 2007		2007 - 2008		Pooled means (2005 - 2008)	
	Drip tape	Flood irrigation	Drip tape	Flood irrigation	Drip tape	Flood irrigation	Drip tape	Flood irrigation
Crop growth rate (CGR) gm^{-2} D^{-1}								
HSF-240	0.09±0.01bB	0.12±0.02aC	0.06±0.01bB	0.16±0.01aB	0.07±0.01bB	0.14±0.03aB	0.07±0.01bB	0.14±0.02aB
HS-12	0.07±0.01bC	0.17±0.01aB	0.09±0.01bA	0.14±0.03aC	0.06±0.01bC	0.16±0.04aA	0.07±0.01bB	0.15±0.03aB
CSSG-668	0.11±0.01bA	0.19±0.02aA	0.09±0.01bA	0.21±0.04aA	0.08±0.01bA	0.12±0.01aC	0.09±0.01bA	0.17±0.02aA
Net assimilation rate (NAR) gm^{-2} D^{-1}								
HSF-240	0.11+0.01bB	0.22±0.04aB	0.14±0.03bB	0.25±0.04aA	0.19±0.02bA	0.27±0.05aA	0.14±0.02bA	0.24±0.04aB
HS-12	0.13±0.02bA	0.21±0.02aB	0.17±0.02bA	0.21±0.04aB	0.14±0.05bB	0.23±0.05aB	0.15±0.03bA	0.21±0.03aC
CSSG-668	0.15±0.02bA	0.26±0.03aA	0.16±0.01bA	0.28±0.03aA	0.18±0.04bA	0.26±0.03aA	0.15±0.02bA	0.27±0.03aA
Harvest index (%)								
HSF-240	75.2±2.1aB	71.2±2.1bB	70.6±2.6aA	72.6±3.4bA	77.8±1.1aA	76.3±2.0aA	74.5±1.9aA	73.8±2.9aA
HS-12	65.2±1.1aA	67.1±1.1aA	60.9±2.1aB	55.6±2.8bB	56.9±1.2aB	61.9±1.4bB	61.5±1.5aB	61.0±2.1aB
CSSG-668	71.6±3.2aC	69.9±3.2aC	68.5±2.2aA	69.2±1.6aB	76.2±1.9aA	75.2±2.3bA	72.1±2.4aA	71.4±1.7aA
Leaf relative water contents (RWC)								
HSF-240	45.2±1.1aA	85.9±2.3bA	51.3±1.5aA	77.4±2.9bB	36.6±1.2aC	80.6±2.0bA	44.3±1.3aA	81.3±2.4bA
HS-12	35.6±1.6aC	80.8±2.2bB	46.5±1.2aB	72.1±1.6bC	52.6±2.2aA	75.2±1.4bB	44.9±1.4aA	76.0±1.7bB
CSSG-668	39.3±2.2aB	77.6±1.4bC	38.9±3.1aC	80.2±2.1bA	43.1±1.1aB	79.1±2.3bA	39.7±2.2aB	78.9±1.9bA

Small letter indicates difference between drip tape and flood irrigation system within year and capital letter shows mean difference among sugarcane varieties (HSF-240, HS-12 and CSSG-668) within year.

Table 3. Comparison of subsurface drip irrigation vs. flood irrigation system for quality attributes in sugarcane

Varieties	2005 - 2006		2006 - 2007		2007 - 2008		Pooled means (2005 - 2008)	
	Drip tape	Flood irrigation	Drip tape	Flood irrigation	Drip tape	Flood irrigation	Drip tape	Flood irrigation
Juice extraction %								
HSF-240	55.6±2.1 bC	72.5±1.5 aB	58.6±1.9bC	74.1±1.5 aB	51.1±3.7 bC	72.6±3.1 aB	55.1±2.6bC	73.1±2.0aB
HS-12	58.9±1.6 bB	69.8±2.4aC	60.2±2.6bB	65.2±2.6aC	56.2±2.2 bB	68.8±2.3aC	58.4±2.1bB	67.9±2.4aC
CSSG-668	67.3±2.8bA	75.7+1.2aA	64.3±1.8bA	77.7+1.2aA	61.6±2.3bA	74.7+1.1aA	64.4±2.3bA	76.0±1.2aA
Juice purity (%)								
HSF-240	75.7+3.1bB	80.2+1.1 aC	71.1+1.5bC	82.3+2.1 aB	77.5+2.6 bA	83.2+1.5 aB	74.7±2.4bB	81.9±1.6aB
HS-12	71.5±2.6bC	82.3±1.9 aB	76.4±2.6bB	80.5±3.6 aB	73.3±1.3 bB	85.6±2.2 aA	73.7±2.1bB	82.8±2.6aB
CSSG-668	77.7±0.09bA	85.6±2.4aA	78.7±1.4bA	86.1±1.0aA	76.4±2.3bA	85.8±1.6aA	77.6±1.3bA	85.8±1.7aA
Sugar recovery % cane (average from month of October to December)								
HSF-240	8.6±0.09aA	10.9±0.03aA	8.5±0.05bA	10.2±0.01aA	8.8±0.06bA	10.1±0.06aB	8.6±0.07bA	10.4±0.03aA
HS-12	7.9±0.06aB	10.1±0.01aB	7.4±0.04bB	9.8±0.06aB	9.6±0.03bB	9.6±0.05aC	7.8±0.04bB	9.8±0.04aB
CSSG-668	8.8±0.04aA	10.6±0.07aA	8.1±0.08bA	10.5±0.01aA	10.4±0.01bA	10.4±0.03aA	8.5±0.04bA	10.5±0.04aA
Sugar yield (t/ha)								
HSF-240	6.5 ±0.01bB	11.3±0.02aC	7.0±0.05bA	11.1±0.06aA	7.2±0.04bB	10.2±0.03aC	6.9±0.03bB	10.8±0.03aB
HS-12	4.9±0.03bC	9.9±0.01aB	4.2±0.03bC	8.9±0.03aB	6.4±0.05bC	10.2±0.06aB	5.2±0.04bC	9.7±0.03aC
CSSG-668	7.3±0.01bA	12.5±0.04aA	6.3±0.01bB	12.1±0.02aAB	7.9±0.04bA	12.9±0.01aA	7.2±0.01bA	12.5±0.03aA

Small letter indicates difference between drip tape and flood irrigation system within year and capital letter shows mean difference among sugarcane varieties (HSF-240, HS-12 and CSSG-668) within year

CGR was noted in SDI during 3 years and also in pooled means of 2005 - 2008. There was also a significant difference among varieties that may be due to its genetic make for its growth pattern. Flood irrigation showed higher CGR results among all varieties and each year under study. CGR was almost double in flood irrigation over subsurface drip tape irrigation (Table 2 Pooled means).

Net assimilation rate (NAR) $gm^{-2}D^{-1}$

There was a significant difference between NAR under subsurface drip tape and flood irrigation system among all varieties (Table 2) within each year and pooled means (2005 - 2008). From varieties, CSSG-668 had overall higher NAR (0.27) under flood irrigation and minimum (0.14) was present in HSF-240 at SDI system.

Harvest index % (HI)

Data regarding harvest index (HI) showed that both irrigation system had non-significant effect on HI (Table 2). This is due to equal yield of unstriped and stripped cane yields within each irrigation systems, although it was significantly different in comparison of SDI and flood irrigation system.

Leaf relative water contents (LRWC) %

Data for LRWC is presented in Table 2. It is clear from the results that LRWC was lower under SDI and it was higher under flood irrigation system during 3 years of experiment and in polled means (2005 - 2008). It ranged from 76.0 - 81.3% LRWC in pooled means of flood irrigation system while under SDI it ranged from 39.7 - 44.9%. This is due to higher water irrigated through flood than SDI that resulted to higher LRWC in leaves of sugarcane rather than SDI system.

Juice extraction %

Higher percentage of juice extraction was observed in flood irrigation system as compared to subsurface drip tape irrigation (Table 3). Same pattern of results was found during 3 years of experiments and pooled means. Variations among varieties were also highly significant for Juice extraction. This may be due to high water availability to sugarcane through flood rather than

Table 4. Comparison of subsurface drip irrigation vs. flood irrigation system for economic benefits for pooled means (2004-07) on hector basis in sugarcane.

Varieties	Cane yield (tons/ha)	Gross income (Rs.) (1500/ton)	Cost That Varied						Net outcomes (Rs.) on Cane Yield basis/ha	Water saved (%) over flood irrigation
			a. Installation cost (Drip tapes system)	b. Cost of fertilizer	c. Irrigation charges	d. Electricity charges	Labour charges+ repairments	Total cost (Rs.)		
Drip tape irrigation										
HSF-240	80.4	120600	50000	8500	0	124400	95610	278510	-157910	15
HS-12	88.7	133050	50000	8500	0	115120	88150	261770	-128720	18
CSSG-668	83.9	125850	50000	8500	0	105540	89155	253195	-127345	11
Flood irrigation										
HSF-240	105.0	157500	0	8500	38400	0	48000	94900	62600	0
HS-12	98.5	147750	0	8500	35120	0	48000	91620	56130	0
CSSG-668	118.1	177150	0	8500	37890	0	48000	94390	82760	0

subsurface drip tapes that resulted to higher juice extraction %.

Juice purity %

In flood irrigation sugarcane, 80% juice purity was obtained while the crops irrigated through subsurface drip tapes had 70% juice purity % (Table 3). In pooled means of 3 years data, it was noted that variety CSSG- 668 had higher juice purity under both irrigation system as compared to HS-12 and HSF-240. Water availability was an important source for purity and quality of sugarcane.

Sugar recovery % cane

Results regarding sugar recovery % cane were presented in Table 3. Sugar recovery % cane was calculated from the month of October to December.

Higher sugar recovery % cane was noted in sugarcane irrigated through flood system as compared to subsurface drip tapes during 3 years of experiment and in pooled means. Varieties HSF-240 and CSSG-668 had higher sugar recovery % cane that was statistically equal in both varieties while, HS- 12 had lower sugar recovery % cane under both irrigation systems (Table 3 pooled means). This was due to higher juice extraction and purity % in these varieties under flood irrigation system.

Sugar yield (t / ha)

Higher yield and sugar recovery % cane under flood irrigation system resulted higher sugar yield (Table 3). Same trend was observed during all the years of study. Maximum sugar yield was noted in all the varieties under flood irrigation system. Among them CSSG-668 had maximum sugar yield that was 12.5 t / ha. Crop irrigated through subsurface drip tapes showed lower sugar yield among all the varieties and all the years.

Economic analysis and water saving

Economic analysis of the experiment calculated on the basis of three years pooled means for cane yield and water saved on 1 ha basis is presented in Table 4. Data showed that experiments conducted under subsurface drip tapes had economic loss due to high system installation cost, electricity charges and labour wages plus repairment cost.

Economic loss ranging from Rs. 127345 to 157910 was calculated under SDI. In contrast flood irrigation system gave net benefit of Rs. 82760 in variety CSSG-668. In subsurface drip tapes the water saving was 11 - 18% over flood irrigation system that had non-significant value for economic benefits.

Table 5. Analysis of irrigated water used for comparison of subsurface drip irrigation vs. flood irrigation system

S/N	Parameters	Unit	Concentrations/values
1	pH	--	8.1
2	EC	dS/m	2.2
3	TSS (Total soluble salts)	ppm	1427
4	Bi-carbonates	me/l	6.5
5	Chloride	me/l	12
6	Sodium	me/l	4.5
7	Ca+Mg	me/l	5.6
8	SAR (Sodium absorption ratio)	--	2.14
9	RSC (Residual sodium carbonates)	me/l	2.34
10	Fe (Ferrous)	me/l	21.4

Analysis of irrigated water

For both type of systems (SDI and flood), irrigated water was same. Results for analysis of water were given in Table 5. It showed that water was unfit for irrigation. It has high ferrous contents that resulted to blockage of T-tapes. This caused low water supply and increased high repairment cost and resulted to poor crop growth and economic loss.

Problems faced for SDI

1. Initial investment cost was higher than for other forms of irrigation.
2. Management requirements were higher.
3. Rodent, insect, and human labor caused damage to components and created potential sources of leaks.
4. Water distribution in the soil was limited.
5. One of the biggest problems encountered under SDI was clogging of emitters. The small openings were easily clogged by soil particles, organic matter, bacterial slime, algae or chemical precipitates. The micro irrigation system required very good filtration (most often recommended is 200 mesh filtration degrees) even with a good quality water supply.

DISCUSSIONS

From the above results it was apparent that flood irrigation had improved effects on sugarcane crop as compared to SDI. Flood irrigation resulted to better growth, higher cane and sugar yield and net economic benefits. On the other hand SDI resulted to poor growth, cane and sugar yield with economic loss due to its high installation cost and failure to fulfill the water requirements of sugarcane crop. Similar, results were described by Lamm and Trooien (2001). Results of lower yield and high economic loss in different crops under SDI were reported by Hills and Brenes (2001).

Judicious use of water is one of the main factors which govern the cane yields and sugar recovery. The life cycle of sugarcane plant is divided into four distinct phases namely: germination phase (from planting to 60th day); formative phase (from 60th day of planting to 130th day); growth phase (from 130th to 250th day) and maturity phase of 250th to 365th day (Trooien et al., 2002). The water requirement of the crop varies greatly with growth phase and environmental conditions, particularly climate and soil type (Norum et al., 2001) . Growth stage and maturity stage have more water requirements than germination and formative stage (Kumar, 2007). SDI was suitable for early growth stages than were germination to tillering stages. At these stages, sugarcane had less water requirement than later maturity stages. Higher LRWC witnessed by plants under flood irrigation showed higher accumulation of water supplied through flood system in contrast to SDI that failed to supply much water. This was the major disadvantage of SDI as claimed by Trooien et al. (2002).

SDI was useful for conservation of water 11 - 18% that had no economic value for net income. Similarly, this finding is in consonance with the work of Neufeld (2001) who reported water conservation of 20 - 25% under SDI. SDI system had also major problem of breakage and clogging of emitters that resulted in increasing high cost (Alam and Dumler, 2002).

Conclusions

It was concluded that SDI is not a superior system of irrigation for sugarcane in developing countries like Pakistan where water is unfit for irrigation having high ferrous contents. Its high installation cost, breakage and clogging resulted in economic loss. SDI might be a superior system where water is fit for irrigation, free of ferrous and low installation costs.

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