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Temporal variability and drain spacing effect of sub surface drainage system on drain water properties in adsali sugarcane grown in sodic vertisol

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Abstract
A field experiment was conducted during 2024-25 at the Agricultural Research Station, Kasbe Digraj, Sangli (Maharashtra, India) to assess the temporal variability and effect of different drain spacings of a subsurface drainage system (SSDS) on drain water properties in adsali sugarcane grown on sodic vertisols. The SSDS was installed at 1.2 m depth with lateral spacings of 15, 25, and 40 m, along with a control (no drainage). Standard reclamation practices including gypsum application (5 t ha^{-1}) and dhaincha green manuring were followed. Drain water samples were periodically collected after rainfall and irrigation events and analyzed for pH, electrical conductivity (EC), Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-}, Cl^{-}, and sodium adsorption ratio (SAR). Results indicated that total annual water use was 314.92 lakh L ha^{-1}, of which 63.38% was drained through the SSDS. The 40 m drain spacing recorded significantly lower mean values of pH (7.26), EC (2.87 dS m^{-1}), and SAR (2.95) compared to the control (7.51, 6.92 dS m^{-1}, and 3.69, respectively). Ion concentrations of HCO_3^{-}, Ca^{2+}, Mg^{2+}, Na^{+}, and Cl^{-} also decreased with increasing drain spacing, though differences among 15, 25, and 40 m were statistically non-significant. Temporal variation in drain water quality was observed across months, influenced by fertilizer applications and seasonal rainfall. Overall, the 40 m drain spacing was found most effective in reducing salt and ion losses, improving drain water quality, and minimizing environmental impacts under sodic vertisol conditions cultivated with adsali sugarcane.

Keywords: Subsurface drainage, drain spacing, sodic vertisol, adsali sugarcane

Introduction
Soil salinization and sodification is a global and dynamic problem and is projected to increase in future under climate change scenarios. The global figure of soil salinization have been reported as 952.2 million ha. According to an estimate, 20% of total cultivated and 33% of irrigated agricultural lands worldwide are afflicted by high salinity. Around 52 million ha lands are salt-affected in South Asia. In India, around 6.73 million ha area is salt affected, which is around 2.1% of geographical area and 5% of net cultivated area of the country, is salt-affected, of which 2.96 million ha is saline and the rest 3.77 million ha is sodic. Nearly 75% of salt-affected soils in the country exist in the states of Gujarat (2.23 million ha), Uttar Pradesh (1.37 million ha), Maharashtra (0.61 million ha), West Bengal (0.44 million ha), and Rajasthan (0.38 million ha). The salinized areas in India continue to increase each year due to introduction of irrigation in new areas. The rate of increase is around 10% annually. According to Sharma et al. (2014) [12], unless preventive/ameliorative attempts are taken, the salt-affected areas are estimated to treble, i.e., increase from 6.74 to 16.2 million ha by 2050. In Maharashtra, the area of salt affected soils is 6.06 lakh ha area (1.84 lakh ha saline and 4.22 lakh ha sodic soils).

Subsurface drainage systems is one of the most effective strategies to reclaim and manage problematic soils. Agriculture Research Station, Kasbe Digraj recommended subsurface drainage system (1.25 m depth and lateral spacing of 25 m) with integrated use of gypsum (50% of gypsum requirement) and green manuring (*Dhaincha*) for improvement of deep black saline-sodic soils. The technology is widely adopted in salt affected soils of Krishna command area of South Maharashtra, however, most of the farmers installed SSDS with closer drain spacing's (10-20 m). Subsurface drainage helps to lower water tables, prevent water-logging, control soil salinity, reduces surface runoff, of contaminants attached to the sediment into surface waters. Based on the extent of soil salinity, irrigation management and crop to be grown, depth and spacing of laterals (between two laterals) in SSD system will vary. In the process of reclamation through subsurface drainage system, soluble salts in the soil profile are leached or flushed down through irrigation water and discharge into natural drain or streams which finally discharge into the river. The quality of drain discharge will be different than the irrigation water applied (Canal water) as it carries soluble salts from the soil profile. Drainage water that flows over or through the soil will pick up a variety of dissolved and suspended substances and soil particles.

Considering the water and nutrient losses through close drain spaced systems and its adverse effect on environment; the experiment was planed with objectives to find out the temporal variability and effect of different drain spacings of sub surface drainage system on drain water properties in adsali sugarcane grown in sodic vertisol.

Methodology

A field experiment on "Drain water properties as influenced by different drain spacing of sub surface drainage system in sodic vertisol" was conducted during 2024-25 at Agricultural Research Station, Kasbe Digraj, Sangli of Maharashtra State (India). Geographically, the location of the experimental site was N 16^0 53' 404" latitude and E 074^0 30' 691" longitude. This tract is lying in plain zone of upper Krishna basin. The soil of the experimental area is grouped under sodic verisol, comprises member of fine montmorillionite clay having high swell-shrink property, characterized by very high clay content (58.40 %), very low hydraulic conductivity (0.15 cm hr^{-1}), highly alkaline (pHs 8.41) with high exchangeable sodium percentage (32.04), medium in soil organic carbon content (6.27 g kg_{-1}), low in soil available Nitrogen (161.35 kg ha^{-1}) and Phosphorus (13.32 kg ha^{-1}) whereas very high in Potassium (431.3 kg ha^{-1}).

A subsurface drainage system was installed in the month of March 2024 with 80 mm diameter perforated pipes at 120 cm drainage depth with 15, 25 and 40 m spacings between laterals. Each drain spacing was hydrologically isolated by 20 m buffer space in between the treatments. *Dhainacha*, green manuring crop was taken and *in situ* incorporation of the *Dhainacha* was done at flowering stage. Broadcasting of gypsum @ 5 t ha^{-1} as a soil amendment was done at the time of green manuring crop incorporation in soil. Ridges and Furrow were opened at 135 cm spacing between two furrows. Two eye bud sets of sugarcane variety Co 86032 were planted in furrow with 135 X 30 cm spacing. The recommended dose of nutrients to adsali sugarcane was 500:200:200 N, P_2O_5 and K_2O kg ha^{-1} given through commercial grade urea (46 % N), single superphosphate (16% P_2O_5) and muriate of potash (60% K_2O). Nitrogen fertilizer dose was applied in 4 split (10 % recommended dose at planting and 12 week after planting, 40 % recommended dose after 8 week and at earthing up stage. Phosphorus and Potassium fertilizer dose were applied in 2 equal split at planting and at earthing up of adsali sugarcane. Total 22 irrigatons of 10 cm depth were given in one year span of adsali sugaracne.

The metrological data of daily rainfall, maximum and minimum temperature, maximum and minimum relative humidity were obtained from Automated Weather Station installed at Agriculture Research Station, Kasbe Digraj, total 963 mm rainfall was received during the experimentation in 69 rainy days. The effective rainfall was computed using the method mentioned in FAO Document No. 25. Month wise precipitation volume is calculated by multiplying effective rainfall (mm) and treatment area (m^2). Month wise irrigation water volume (m^3) was calculated by multiplying treatment area (m^2) × water depth (m). The crop evapotranspiration water loss is calculated by using formula ETc = Kc X ETo. The ETo values were obtained from Automated Weather Station, K Digraj. Dingre *et al.*, 2021 [4] estimated Kc values irrigated sugarcane were used for evapotranspiration water loss. The water balance is governed by the basic physical principle of conservation of mass (Easton) *i.e.* Inputs = output + change in soil moisture storage. Accordingly Drain water = (Precipitation water + Irrigation Water) - (ETc water + Change in soil moisture).

Water sampling from each treatment of 15, 25 and 40 m drain spacing of sub surface drainage system was done periodically. Periodical drain flow water was done from drain chamber at 24, 48 and 72 hrs after effective rainfall as well as 24, 48 and 72 hrs after each irrigation. In case of control treatment (without drainage system) a sampling chamber was inserted in soil at 120 cm depth, the bottom end of the chamber was kept open so as to collect the soil water at 120 cm depth. The top end of the chamber was kept 1 m above the soil surface and kept close to avoid entry of runoff and rain water. The percolated water in a sampling chamber was collected 24, 48 and 72 hrs after irrigation or rainfall and used for analysis after filtration. The water sample were analysed for nutrient concentration. The data obtained was statistically analysed with z test for comparison between treatments.

Results

Water footprint of adsali sugarcane

A month wise temporal variation in water footprint of adsali sugarcane grown in sodic vertisol with sub surface drainage system was presented in table 1. During one year of growth span of adsali sugarcane on sodic vertisol, 314.92 lakh litre ha^{-1} water was used. Out of total water used in one year span, 80.20 lakh litre ha^{-1} water (*i.e* 30.14 % of total water used) came from precipitation whereas remaining 69.86 % water (*i.e* 220 lakh litre ha^{-1}) was came from 23 irrigation. Also out of total water consumed, 63.38 per cent water (*i.e* 199.60 lakh litre water ha^{-1}) was drained out from sub surface drainage system in adsali sugarcane. The water requirement of sugarcane (ETc) was 36.62 per cent of total water applied to adsali sugarcane.

pH of Drain Flow Water

The effect of different drain spacing of sub surface drainage system on temporal variation in drainwater pH was presented in table 4.2. The drain spacing of sub surface drainage system recorded significant change in drain water pH from adsali sugarcane grown on sodic vertisol.

The drain water pH value varies from 7.1 to 7.6. The treatment of 40 m drain spacing recorded lower annual average drain water pH (7.26), whereas higher annual average pH observed in control treatment (7.51). The annual average pH of dainwater flow water from 40, drain spacing treatments of sub surface drainage system (7.26) were found significantly lower as compare to soil water pH from 15 m drain spacing treatments of sub surface drainage system and control treatment (7.40 and 7.5, respectively). Whereas, drain water pH of 40 m drain spacing and 25 m drain spacing were found non-significant .This might be due to relatively high leaching of SO_4^{2-} and Cl^- ions in drain flow water in closer spacing as compare to wider lateral spacing of subsurface drainage system. Similar findings were also reported by Mallika (2017) [8].

A high standard variation in drain water pH from control treatment (0.144) indicates high seasonal variation in soil water pH in control treatment. Whereas, lower temporal variation in drainflow water pH of different drain spacing was found as compare to control treatment.

EC of Drain Flow Water

The **electrical conductivity (EC)** of drain flow water is a key indicator of its **quality. EC of water** depends on the presence of **dissolved** salts ions. The effect of different drain spacing of sub surface drainage system on temporal variation in drainwater EC was presented in table 4.3. The drain spacing of sub surface drainage system recorded significant change in drain water EC from adsali sugarcane grown on sodic vertisol.

The drain water EC varies between 2.34 to 7.67 dS m^{-1}. The treatment of 40 m drain spacing recorded lower average annual drain water EC (2.87 dS m^{-1}), whereas higher average annual EC was recorded in control treatment (6.92 dS m^{-1}).

The treatment of 40 m drain spacing of subsurface drainage system recorded significantly low EC of drainflow water (2.87 dS m^{-1}) as compared to 25 and 15 m drain spacing of subsurface drainage system (3.19 and 3.25 dS m^{-1}, respectively), whereas, the EC of 15 m and 25 m drain spacing of subsurface drainage system were found at par with each other. This might be due to relatively high leaching of soluble salts in closer spacing as compare to wider lateral spacing of subsurface drainage system. Similar findings were also reported by Shrikantagouda *et al.* (2019)

A higher standard variation of drain water EC in all the treatments indicates high temporal variation in drain water EC. The higer drainwater EC values were observed in the summer months (*i.e* March to May) whereas comparatively lower EC values observed was in the rainy season month (*i.e* June to August)

Ca ion concentration in Drain Flow Water

The effect of different drain spacing of sub surface drainage system on temporal variation of drainwater Ca^{++} concentration was presented in table 4.4.

The drain water Ca^{++} concentration varies from 8.00 to 58.60 meq L^{-1}. The treatment of 40 m drain spacing recorded lower average annual drainflow water Ca^{++} concentration (30.12 meq L^{-1}), whereas higher average annual Ca^{++} concentration was recorded in control treatment (50.31 meq L^{-1}). The z score for Ca^{++} concentration in control treatments *vs* 15, 25 and 40 m drain spacing was found higher than critical z value (1.93) indicates significant higher Ca^{++} concentration in control as compare to Ca^{++} concentration in all the tested drain spacing of subsurface drainage system. The Ca^{++} concentration in 15 m, 25 m, and 40 m drain spacings were found non-significant.

Monthwise temporal variability was observed in Ca^{++} concentration of drain flow water in all the treatments. In all the drain spacings treatments, Ca^{++} concentration of drain flow water was found lower in June and July 2025, whereas higher Ca^{++} concentration was found in the month January 2025. This might be due to application of second split of SSP fertilizer which contains Ca salts subsequently leached in drain flow water.

Mg ion concentration in Drain Flow Water

The effect of different drain spacing of sub surface drainage system on temporal variation of drainwater Mg^{++} concentration was presented in table 4.5.

The drain water Mg^{++} concentration varies from 2.80 to 18.70 meq L^{-1}. Among the different treatments of drain spacing of subsurface drainage system, lower average annual Mg^{++} concentration in drain flow water was observed in 40 m drain spacing (6.50 meq L^{-1}.), whereas higher average annual Mg^{++} concentration was observed in control (11.43 meq L^{-1}). The z score for Mg^{++} concentration in control treatments *vs* 15, 25 and 40 m drain spacing was found higher than critical z value (1.93) indicates significant higher Mg^{++} concentration in control as compare to Mg^{++} concentration in all the tested drain spacing of subsurface drainage system. The Mg^{++} concentration in 15 m, 25 m, and 40 m drain spacings were found non-significant.

Na ion concentration in Drain Flow Water

The effect of different drain spacing of sub surface drainage system on temporal variation of drainwater Na^+ concentration was presented in table 4.6.

The drain water Na^{++} concentration varies from 10.40 to 25.06 meq L^{-1}. Among the different treatments of drain spacing of subsurface drainage system, lower average annual Na^+ concentration in drain flow water was observed in 40 m drain spacing (11.54 meq L^{-1}.), whereas higher average annual Na^+ concentration was observed in control (20.55 meq L^{-1}). The z score for Na^+ concentration in control treatments *vs* 15, 25 and 40 m drain spacing was found higher than critical z value (1.93) indicates significant higher Na^+ concentration in control as compare to Na^+ concentration in all the tested drain spacing of subsurface drainage system. The Na^+ concentration of drain flow water from 15, 25 and 40 m drain spacings of subsurface drainage system were found non-significant.

Monthwise temporal variability was observed in Na^+ concentration of drain flow water in all the treatments. In all the drain spacings treatments, Na^+ concentration of drain flow water was found higher in month of August, 2024. This is due to application of gypsum in sodic vertisol in the month of August 2024 responsible for replace of Na ions with Ca ion in exchange complex, this leads to Na ions into soil solution and subsequently in drain flow water.

HCO_3 ion concentration Drain Flow Water

The effect of different drain spacing of sub surface drainage system on temporal variation of drainwater HCO_3^- concentration was presented in table 4.7. The drain spacing of sub surface drainage system in adsali sugarcane grown on sodic vertisol recorded significant change in HCO_3^- concentration of drain flow water.

The drain water HCO_3^- concentration varies from 5.7 to 15.8 meq L^{-1}. Among the different treatments of drain spacing of subsurface drainage system, lower average annual HCO_3^- concentration in drain flow water was found in 40 m drain spacing (8.21 meq L^{-1}), whereas higher average annual HCO_3^- concentration was reported in control (10.95 meq L^{-1}). The z score for HCO_3^- concentration in control treatments *vs* 15, 25 and 40 m drain spacing was found higher than critical z value (1.93) indicates significant higher HCO_3^- concentration in control as compare to HCO_3^- concentration in all the tested drain spacing of subsurface drainage system. The average annual HCO_3^- concentration in drainflow water from 40 m drain spacing of sub surface drainage system (8.21 meq L^{-1}) was found significant lower as compared to average annual HCO_3^- concentration in drainflow water 15 m drain spacing of sub surface drainage system (9.47 meq L^{-1}) (z score = 2.72) . This might be due to higher drainage coefficient value (*i.e* high drain outflow within short period) in close drain spacing as compare to wider drain spacing of sub surface drainage system leads to desorption of exchangeable HCO_3 ions from clay complex. The average annual HCO_3^- concentration in drainflow water from 15 and 25 m drain spacing of sub surface drainage system were found at par with each other.

The month wise temporal variability was observed in HCO_3^- concentration of drain flow water in all the treatments. HCO_3^- concentration was found higher in the month of April 2025, whereas, lower HCO_3^- concentration was found in the month of September 2024 in all drain spacing's treatments. This might be due to dilution effect of soil solution with rainwater in September 2024 produces lower HCO_3^- concentration. The higher HCO_3^- concentration in the month of April 2025 might be because of concentration of soil solution due to high evaporation in summer season.

Cl ion concentration Drain Flow Water

The effect of different drain spacing of sub surface drainage system on temporal variation of drainwater Cl^- concentration was presented in table 4.8. The drain spacing of sub surface drainage system in adsali sugarcane grown on sodic vertisol recorded significant change in Cl^- concentration of drain water.

The drain water Cl^- concentration varies from 0.14 to 13.43 meq L^{-1}. Among the different treatments of drain spacing of subsurface drainage system, lower average annual HCO_3^- concentration in drain flow water was found in 40 m drain spacing (0.21 meq L^{-1}), whereas, higher average annual HCO_3^- concentration was reported in control (9.24 meq L^{-1}). The z score for Cl^- concentration in control treatments *vs* 15, 25 and 40 m drain spacing was found higher than critical z value (1.93) indicates significant higher Cl^- concentration in control as compare to Cl^- concentration in all the tested drain spacing of subsurface drainage system. The Cl^- concentration in 15 m, 25 m, and 40 m drain spacings were found non-significant.

The month wise temporal variability was observed in Cl^- concentration of drain flow water in all the treatments. Cl^- concentration was found high in the month of August 2025 and February 2025. This might be due to split application of Muriate of potash fertilizer to adsali sugarcane in the month of August 2024 and January 2025 which subsequently came into soil solution and drainflow water.

8 SAR of Drain flow water

The effect of different drain spacing of sub surface drainage system on temporal variation of drainwater Sodium Adsorption Ratio (SAR) from adsali sugarcane grown on sodic vertisol was presented in table 4.6.

The SAR of drainflow water from adsali sugarcane grown on sodic vertisol varies from 1.94 to 4.22. Among the different treatments of drain spacing of subsurface drainage system, lower average annual SAR value of drain flow water was recorded in 40 m drain spacing (2.95), whereas higher average annual SAR value was observed in control (3.69). The z score for SAR of drainwater in control treatments *vs* 15, 25 and 40 m drain spacing was found higher than critical z value (1.93) indicates significant higher SAR values in control as compare to SAR values in all the tested drain spacing of subsurface drainage system. The average annual SAR of drainflow water from 40 m drain spacing of sub surface drainage system (2.95) was found significant lower as compared to average annual average annual SAR of drainflow water from 15 m drain spacing of sub surface drainage system (3.10) (z score = 3.26) . This might be due to higher drainage coefficient value (*i.e* high drain outflow within short period) in close drain spacing as compare to wider drain spacing of sub surface drainage system leads to higher desorption of exchangeable Na^+ ions from clay complex. The average annual SAR of drainflow water from 15 and 25 m drain spacing of sub surface drainage system were found at par with each other. The results are consistent with the findings reported by Meti *et al.*

Table 1: Monthwise temporal variation water footprint of adsali sugarcane grown on sodic vertisol**.**

Month	Rainwater (L/ha)	Irrigation water (L/ha)	Total water (L/ha)	Sugarcane ETc (L/ha)	Drainflow discharge (L/ha)
Aug-24	1786000	2000000	3786000	629300	3156700
Sep-24	1344000	2000000	3344000	579000	2765000
Oct-24	1252000	2000000	3252000	719200	2532800
Nov-24	170000	2000000	2170000	693000	1477000
Dec-24	320000	2000000	2320000	706800	1613200
Jan-25	0	3000000	3000000	976500	2023500
Feb-25	0	2000000	2000000	1066800	933200
Mar-25	56000	3000000	3056000	1618200	1437800
Apr-25	132000	3000000	3132000	1734000	1398000
May-25	2350000	1000000	3350000	1624400	1725600
Jun-25	1280000	0	1280000	717000	563000
Jul-25	802000	0	802000	468100	333900
Total	94,92,000	2,20,00,000	3,14,92,000	1,15,32,300	1,99,59,700

Table 2: Effect of sub surface drainage system drain spacing on pH of drain water in sodic vertisol.

Treatments Months	pH of drain water			
	Control	15 DDS	25 DDS	40 DDS
August-2024	7.4	7.4	7.4	7.3
Sept -2024	7.3	7.2	7.3	7.3
Oct -2024	7.4	7.4	7.2	7.2
Nov-2024	7.3	7.3	7.2	7.1
Dec-2024	7.5	7.5	7.5	7.3
Jan-2025	7.6	7.4	7.2	7.2
Feb-2025	7.6	7.5	7.4	7.2
March-2025	7.7	7.4	7.4	7.3
April-2025	7.8	7.5	7.3	7.2
May-2025	7.5	7.4	7.3	7.3
June-2025	7.5	7.4	7.3	7.3
July-2025	7.5	7.4	7.3	7.4
Mean	7.51	7.40	7.32	7.26
SD	0.144	0.082	0.090	0.076
				z score
Control *vs* 15 DDS				2.683
Control *vs* 25 DDS				4.704
Control *vs* 40 DDS				6.271
15 DDS *vs* 25 DDS				2.431
15 DDS *vs* 40 DDS				4.133
25 DDS *vs* 40 DDS				1.680

Table 3: Effect of sub surface drainage system drain spacing on Electric Conductivity of drain water in sodic vertisol

Treatments Months	EC of drain water (dS m^{-1})			
	Control	15 DDS	25 DDS	40 DDS
August-2024	5.61	3.68	3.69	3.38
Sept -2024	6.23	3.03	3.31	2.96
Oct -2024	6.11	3.29	3.37	2.87
Nov-2024	6.23	3.01	3.22	2.08
Dec-2024	6.85	3.25	3.16	3.03
Jan-2025	6.95	3.51	3.20	3.17
Feb-2025	7.25	3.34	3.28	3.27
March-2025	7.42	3.35	3.24	2.93
April-2025	7.62	3.25	3.14	2.84
May-2025	7.67	3.04	3.32	2.81
June-2025	7.53	3.12	2.50	2.34
July-2025	7.58	3.10	2.84	2.71
Mean	6.92	3.25	3.19	2.87
SD	5.61	3.68	3.69	3.38
				z score
Control *vs* 15 DDS				28.061
Control *vs* 25 DDS				27.644
Control *vs* 40 DDS				29.080
15 DDS *vs* 25 DDS				0.889
15 DDS *vs* 40 DDS				5.133
25 DDS *vs* 40 DDS				3.976

Table 4: Effect of different drain spacings of SSD system on drain water Calcium ion concentration of adsali sugarcane grown in sodic vertisol.

Treatments Months	Ca^{++} of drain water (meq L^{-1})			
	Control	15 DS	25 DS	40 DS
August-2024	34.20	34.50	34.10	32.60
Sept -2024	35.80	35.40	32.10	33.90
Oct -2024	53.20	51.00	49.00	42.00
Nov-2024	58.50	57.00	48.30	50.90
Dec-2024	58.60	45.60	45.10	45.40
Jan-2025	58.50	51.50	50.30	50.40
Feb-2025	56.20	48.20	45.40	45.20
March-2025	58.20	18.30	17.90	16.10
April-2025	58.50	18.50	15.70	12.80
May-2025	57.60	16.80	14.20	9.20
June-2025	36.20	8.00	9.40	9.80
July-2025	38.20	9.10	10.60	13.20
Mean	50.31	32.82	31.01	30.12
SD	10.18	17.14	15.77	16.07
				z score
Control *vs* 15 DS				5.022
Control *vs* 25 DS				5.873
Control *vs* 40 DS				6.067
15 DS *vs* 25 DS				0.454
15 DS *vs* 40 DS				0.669
25 DS *vs* 40 DS				0.228

Table 5: Effect of different drain spacings of SSD system on drain water Magnesium ion concentration of adsali sugarcane grown in sodic vertisol.

Treatments Months	Mg^{++} of drain water (meq L^{-1})			
	Control	15 DS	25 DS	40 DS
August-2024	11.40	12.00	14.20	10.90
Sept -2024	9.60	9.10	9.70	7.50
Oct -2024	6.30	4.50	4.20	10.50
Nov-2024	6.70	6.20	16.40	5.50
Dec-2024	9.90	18.90	5.10	7.40
Jan-2025	11.00	7.40	5.30	4.30
Feb-2025	13.40	2.80	3.60	4.00
March-2025	11.40	5.10	3.60	5.80
April-2025	11.60	4.10	1.70	4.20
May-2025	12.90	4.70	5.00	2.80
June-2025	18.70	12.00	15.70	10.40
July-2025	14.30	9.30	8.60	4.70
Mean	11.43	8.01	7.76	6.50
SD	3.18	4.39	4.90	2.70
				z score
Control *vs* 15 DS				3.645
Control *vs* 25 DS				3.392
Control *vs* 40 DS				6.753
15 DS *vs* 25 DS				0.222
15 DS *vs* 40 DS				1.704
25 DS *vs* 40 DS				1.312

Table 6: Effect of different drain spacings of SSD system on drain water Sodium ion concentration of adsali sugarcane grown in sodic vertisol.

Treatments Months	Na^{+} of drain water (meq L^{-1})			
	Control	15 DS	25 DS	40 DS
August-2024	14.40	14.40	14.40	13.68
Sept -2024	15.67	13.68	12.96	12.96
Oct -2024	16.56	13.68	13.32	12.60
Nov-2024	17.52	13.32	12.96	10.80
Dec-2024	20.52	12.48	11.70	11.31
Jan-2025	21.55	13.65	11.70	10.14
Feb-2025	24.62	13.26	12.87	12.48
March-2025	24.52	12.87	12.09	11.70
April-2025	24.67	11.62	11.14	10.66
May-2025	25.06	12.59	11.62	10.66

June-2025	21.01	12.61	11.56	11.03
July-2025	20.50	11.96	11.44	10.40
Mean	20.55	13.01	12.31	11.54
SD	3.62	0.77	0.94	1.09
				z score
Control *vs* 15 DS				10.586
Control *vs* 25 DS				11.509
Control *vs* 40 DS				12.528
15 DS *vs* 25 DS				2.168
15 DS *vs* 40 DS				4.472
25 DS *vs* 40 DS				2.308

Table 7: Effect of different drain spacings of SSD system on drain water bicarbonate ion concentration of adsali sugarcane grown in sodic vertisol.

Treatments Months	HCO_3^- of drain water (meq L^{-1})			
	Control	**15 DS**	**25 DS**	**40 DS**
August-2024	7.2	7.5	6.3	6.3
Sept -2024	7.8	6.9	6.3	5.7
Oct -2024	8.1	8	7.7	7
Nov-2024	8.2	7.5	7.4	7.1
Dec-2024	11.5	10.8	10.4	10.2
Jan-2025	11.2	8.9	8.3	8.1
Feb-2025	11.1	8.5	8.6	8.5
March-2025	12.2	10	9.1	8
April-2025	12.6	12.6	10.9	11.6
May-2025	15.8	13.7	12.4	8.6
June-2025	13.3	9.5	9.5	8.7
July-2025	12.4	9.7	9.2	8.7
Mean	10.95	9.47	8.84	8.21
SD	2.62	2.08	1.82	1.62
				z score
Control *vs* 15 DS				2.563
Control *vs* 25 DS				3.808
Control *vs* 40 DS				5.128
15 DS *vs* 25 DS				1.292
15 DS *vs* 40 DS				2.725
25 DS *vs* 40 DS				1.473

Table 8: Effect of different drain spacings of SSD system on drain water chloride ion concentration of adsali sugarcane grown in sodic vertisol.

Treatments Months	Cl^- of drain water (meq L^{-1})			
	Control	**15 DS**	**25 DS**	**40 DS**
August-2024	6.26	0.32	0.29	0.28
Sept -2024	6.35	0.25	0.24	0.21
Oct -2024	6.38	0.30	0.29	0.27
Nov-2024	9.93	0.26	0.24	0.22
Dec-2024	10.10	0.23	0.20	0.18
Jan-2025	10.21	0.24	0.20	0.23
Feb-2025	10.86	0.32	0.33	0.29
March-2025	11.99	0.26	0.25	0.22
April-2025	11.96	0.19	0.17	0.17
May-2025	13.43	0.18	0.18	0.17
June-2025	6.35	0.21	0.20	0.14
July-2025	7.08	0.21	0.18	0.14
Mean	9.24	0.25	0.23	0.21
SD	2.51	0.04	0.05	0.05
				z score
Control *vs* 15 DS				4.32
Control *vs* 25 DS				5.31
Control *vs* 40 DS				4.97
15 DS *vs* 25 DS				0.69
15 DS *vs* 40 DS				0.89
25 DS *vs* 40 DS				0.28

Table 9: Effect of different drain spacings of SSD system on drain water SAR of adsali sugarcane grown in sodic vertisol.

Treatments Months	SAR of drain water			
	Control	**15 DS**	**25 DS**	**40 DS**
August-2024	3.02	2.99	2.93	2.93
Sept -2024	3.29	2.90	2.83	2.85
Oct -2024	3.04	2.60	2.58	2.46
Nov-2024	3.07	2.37	2.28	2.03
Dec-2024	3.51	2.20	2.34	2.20
Jan-2025	3.66	2.52	2.22	1.94
Feb-2025	4.17	2.63	2.60	2.52
March-2025	4.16	3.76	3.69	3.54
April-2025	4.17	3.46	3.78	3.66
May-2025	4.22	3.84	3.75	4.35
June-2025	4.01	3.99	3.26	3.47
July-2025	4.00	3.94	3.69	3.48
Mean	3.69	3.10	3.00	2.95
SD	0.47	0.63	0.59	0.72
				z score
Control *vs* 15 DS				21.85
Control *vs* 25 DS				21.89
Control *vs* 40 DS				21.94
15 DS *vs* 25 DS				1.43
15 DS *vs* 40 DS				3.26
25 DS *vs* 40 DS				1.67

Conclusion

1. A significant low value of pH, SAR and HCO_3 ion concentration of drain water were found in 40 m drain spacing of SSDS as compare to 15 m drain spacing.
2. The drain water EC in 40 m drain spacing of SSDS was significant low as compare to 15 and 25 m drain spacing of SSDS.
3. The variation in concentration of Ca^{++}, Mg^{++}, Na^{+}, and Cl^{-} ions in 15 m, 25 m, and 40 m drain spacings were found non-significant.

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