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Performance Evaluation of Subsurface Drainage System under Waterlogged Saline Vertisols for Sugarcane Crop in Ukai Kakrapar Canal Command, Gujarat

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ABSTRACT

Crop productivity in canal command areas of India is declining due to waterlogging and soil salinization problems, and it is posing a big threat to livelihood security of small and marginal farmers. Subsurface drainage (SSD) technology, which restores favourable condition in the crop root zone by reclaiming waterlogged saline soils, can be one of the options to restore the crop productivity in such areas. The SSD system was installed at Mulad village in the Ukai Kakrapar canal command area, Gujarat, in the year 2012 to address the problem of drastic yield reduction of sugarcane due to twin problems of waterlogging and soil salinity in Vertisols. It was found that the SSD helped in desalination of soil profile as soil electrical conductivity was reduced to a range of 0.42 to 3.90 $dS.m^{-1}$ from its initial range of 1.2 to 7.3 $dS.m^{-1}$. Electrical conductivity of drained water was in the range of 1.3 to 4.4 $dS.m^{-1}$. Further, there was reduction in waterlogging condition, both surface and sub-surface, as water table lowered below crop root zone depth (depth of 0.6 m) and surface water ponding duration reduced to 6-8 days from earlier 25-30 days during peak monsoon days. Overall performance of SSD system was satisfactory as average sugarcane yield in the study area increased significantly from 39.29 to 97.29 $t.ha^{-1}$ as result of reduction in soil salinity and waterlogging in drainage area. Economic analysis also indicated 114% increase in benefit-cost ratio after SSD installation. Thus, large scale installation of SSD system for reclamation of waterlogged saline Vertisols is economically viable in the state of Gujarat.

Irrigated agriculture in India as well as in the world is under stress due to twin problems of waterlogging and soil salinity (Valipour, 2014). Out of the world's total irrigated area of 299 Mha, only 22% area has drainage facilities (Ritzema, 2016). In different canal commands of India, around 3.0 Mha area suffers from irrigation induced waterlogging and soil salinization. It is slightly less than half of the salt affected area (6.74 Mha) in India (Kamra and Sharma, 2016). Out of 3.0 Mha waterlogged saline area, more than 1.1 Mha area is located in Vertisols (black cotton soils and associated soils) regions in different states of India. By nature, Vertisols are low in hydraulic conductivity due to more presence of micro pores than macro pores. Therefore, these soils are more suitable for dry land agriculture. These soils suffer from surface and subsurface waterlogging and soil salinity, if proper drainage facility is not provided along with provision of irrigation. Thus, provision of subsurface drainage is essential for economically viable crop production on irrigated Vertisols (Rao *et al.*, 2009).

Worldwide huge crop yield losses are reported due to waterlogging and salinity under irrigated agriculture.

In case of sugarcane crop, 15-20% reduction in the cane yield and sugar recovery has been reported due to waterlogging (Sanghera and Jamwal, 2019). Appropriate drainage measures are needed to reduce waterlogging and soil salinity, and to enhance water productivity in the canal command areas (Vibhute *et al.*, 2016). The need of drainage provisions in irrigation projects has been well acknowledged by the researchers worldwide, and nowadays it is considered as an integral part of large irrigation schemes. Drainage helps in reducing soil submergence, soil salinity and improving root zone aeration and crop yields. Thus drainage improves land and water productivity and sometimes it creates new land available for agriculture, if land is abandoned due to waterlogging and soil salinity (Singh, 2019).

Subsurface drainage (SSD) has been practiced in 75-80% of irrigated area in Egypt, and 25-30% irrigated area in western USA (Tiwari and Goel, 2015). In India, SSD systems have been installed on about 61,084 ha area in different states till the year 2016 (Bundela *et al.*, 2016, Sharma *et al.*, 2016; Kamra *et al.*, 2019), and has been found as an effective technology for reclamation and management of waterlogged saline soils. Design of SSD system has been standardized for alluvial soils of North-west India through experimentation at village Sampla in Haryana (Rao *et al.*, 1986). The technology was widely adopted in the light textured soils of the states of Haryana and Punjab. Large scale SSD installations were done in India under Rajasthan Agricultural Drainage (RAJAD) project and Haryana Operational Pilot Project (HOPP) with Government support. The soils under RAJAD project were heavy. As far as Indian experience of managing waterlogging and soil salinity in heavy textured soils are concerned, first ever SSD system was tested in heavy textured soils of Maharashtra, much before Sampla study, at village Manjari located in Khadakwasala irrigation project near Pune (Anon., 1988). However, spread of SSD did not take place in Maharashtra and neighbouring states mainly because of high cost and lack of institutional support. Systematic studies conducted by Ritzema *et al.* (2008) under Indo-Dutch Network project in five different agro-climatic sub-regions of India proved the subsurface drainage (by pipe or by open drains) as technically feasible, cost-effective, and socially acceptable technology to reclaim waterlogged and saline land, and to sustain agriculture in irrigation commands under the prevailing soils, agro-climatic conditions and social settings.

An agreement between ICAR-Central Soil Salinity Research Institute and a private firm, M/S Rex Poly-extrusion Pvt. Ltd., in the year 2006 paved way to promote SSD systems on heavy soils (waterlogged saline Vertisols) in Maharashtra and Karnataka through Government departments, cooperative societies and individual farmers. It resulted in private investments in terms of public-private partnership for planning, design and implementation of large-scale drainage projects for waterlogged saline Vertisols in the states of Maharashtra and Karnataka (Kaledhonkar *et al.*, 2009). Rathod *et al.* (2020) evaluated different drain spacings and depths for waterlogged Vertisols of Sangli district of Maharashtra, and found that 30-50 m drain spacing and 1.2 m depth as suitable for waterlogged saline Vertisols.

Gujarat despite being a leader in cooperative system and for agricultural growth, large-scale adoption of SSD for reclamation and management of waterlogged saline soils did not take place. Till the year 2016, the area under SSD system in Gujarat was only 1,300 ha (Bundela *et al.*, 2016) as compared to total waterlogged area of 2,65,000 ha in the state (Anon., 2009). Large part of Ukai-kakrapar command area was under pigeon pea/cotton cultivation before the availability of canal water, but subsequently farmers shifted towards sugarcane cultivation. The injudicious use of canal water for sugarcane crop coupled with absence of drainage system, resulted in severe problems of waterlogging and secondary salinization.

During the year 2012, a commercial SSD installation was done on waterlogged saline Vertisols at village Mulad of Surat district (Gujarat) under the Ukai Kakrapar canal command area. Though subsurface drainage has been found as a technically feasible and cost-effective in reclamation of waterlogged and saline land, performance evaluation of large-scale SSD systems on heavy textured soils are needed to build up confidence in minds of planners and farmers as SSD is generally adopted on large scale through community participation. The main objective of this study was to evaluate the performance of the existing SSD system for its ability to reduce soil salinity and to improve drainage water quality, crop yield and to judge the economic feasibility for greater adoption of SSD systems in the state of Gujarat.

MATERIALS AND METHODS

Study Area

The study area is located in Mulad village (Surat district of Gujarat) having total geographic area of 923.60 ha, and falls under Ukai Kakrapar canal command area with geographical coordinates as 21° 24′ 13.42″ N latitudes and 72° 54′ 18.34″ E longitudes (Fig. 1). It has tropical climate and receives majority of the rainfall from June till late September. The area has flat topography with gentle uniform slope of 0.25% towards the north-east side. Sugarcane and rice are the main crops since commencement of canal irrigation in the region. In the study area, problems of both high groundwater table and prolonged surface water stagnation in monsoon were prevalent. The depth to watertable from ground surface ranged from 0.5 m to 2 m. During peak rainy days, heavy surface waterlogging was observed and ponding of water on ground surface remained for 25 to 30 days, which adversely affected crop growth. Since the past one decade, these soils have been suffering by twin problems of waterlogging and salinity due to interplay of number of factors like cultivation of high water demand crops (sugarcane), mono-cropping, and injudicious use of irrigation water without adequate provision of drainage. As a result, sugarcane yield varied from 32 to 44 $t.ha^{-1}$, and was uneconomical.

Drainage investigations were carried out in 45 ha area in the year 2011 to assess the status of area in terms of soil salinity, waterlogging and crop productivity before SSD installation, and also to work out design parameters of SSD system as design of SSD system is location-specific. Further, pre-drainage data on soil salinity, groundwater quality, depth to water table, crop yield, crop productivity, etc. were necessary for comparison with respective post–SSD data, to quantify the improvements in drainage area in different aspects as a part of evaluation process. The post-SSD data were collected after six years (2012-2018) of successful operation of the system.

Soil and Water Sampling and Analysis

Soil samples for three depths (0-0.3, 0.3-0.6 and 0.6-0.9 m) were collected using Edelman clay auger. The total study area was divided into seven blocks, representing homogenous units comprising field survey numbers of land belonging to thirteen farmers. Representative soil samples from different blocks were collected in the month of May 2011 from 45 ha area during pre-SSD condition. Similarly, the post-SSD soil sampling was done from the same site on per ha basis (total 45 soil sampling locations) in the month of May 2018, and the average data of soil analysis were arranged block-wise. This was done to get adequate representation to each block. Pre-SSD samples were analysed at Soil and Water Testing Laboratory of Rajarambapu Patil Sahakari Sakhar Karkhana Ltd., Rajaramnagar, district Sangli (Maharashtra), while post-SSD soil samples were analysed in the laboratory of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Bharuch, using standard methodologies (Richards, 1954) for properties like electrical conductivity of saturation extract (ECe), soil saturation paste pH (pHs), and sodium adsorption ratio (SAR). Groundwater samples during pre- and post-SSD condition were

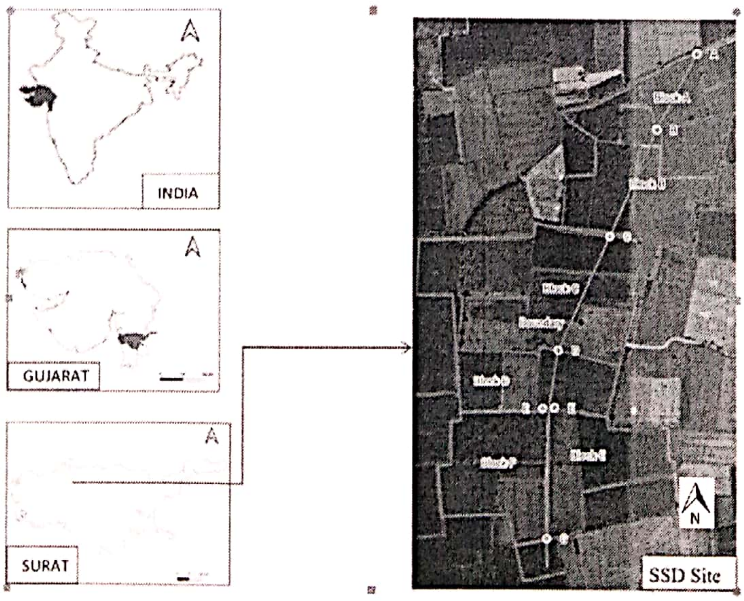

Fig. 1: Location map of Mulad SSD project, Gujarat

collected from seven sumps and were analysed for pH, EC, soluble cations and anions, SAR following standard procedure (Richards, 1954). The pH was estimated using an Analab digital pH meter (Model: Analab pHCal), with pH range of 0 to 14 and 0.01 pH resolution. This instrument was calibrated with 7.0 and 9.2 pH standard buffer solution with temperature range (0-100° C). The EC was estimated using a conductivity meter (Model: Systronics digital conductivity meter 304) with conductivity range of 0 µS to 200 mS, 1.0 cell constant, conductivity resolution of 0.1 µS and accuracy of ±1% with temperature range of 0-100° C. It was calibrated by 0.01 N KCl aqueous solution having conductivity of 1.412 mS at 25°C. Among soluble cations, Na and K were estimated using flame photometer (Model: Systronics Flame Photometer 128), which was a micro-controller based instruments with calibration of Na and K standards with low to high concentration mode (10 to 100 ppm) without dilution (inbuilt curve fitting software) having full scale sensitivity of 1.0 and 2.0 ppm, resolution of 0.01 and 0.02 ppm for sodium and potassium, respectively, and with accuracy range of ±1 to 2% (Low to high concentration mode). Among soluble anions, SO_4^{2-} was estimated with the help of a colorimeter (PG Instruments Ltd. made UV-VIS Spectrophotometer Model: T60V) at wave length of 420 nm with a blue filter. This instrument devising of 325 nm-1100 nm wave length range with wave length accuracy of ±2 nm (with automatic wavelength correction); having ±3% T (0-100% T) photometric accuracy and -0.3-3 Abs photometric range.

Saturated hydraulic conductivity of soils from five representative locations in the study area was estimated using Rossetta Lite v. 10 model (Schaap *et al.*, 2001). This model used ANN technique based on per cent sand, silt and clay which were determined using International Pipette method (Piper, 1966) as input parameters. The mathematic expression of model is given below:

$$K(S_e) = K_0 S_e^L \left\{1 - \left[1 - S_e^{n/(n-1)}\right]^{1-1/n}\right\}^2 \quad \ldots(1)$$

Where,

S_e = Effective saturation,

K_0 = Fitted matching point at saturation, $cm.d^{-1}$,

L = Empirical pore tortuosity parameter, and

n = Curve shape parameter.

The model results provided average values of seven hydraulic parameters viz. θ_s, θ_r, α, n, K_s, K_0 and L of different textural classes. The value of saturated hydraulic conductivity was estimated for actual textured condition.

The pre-drainage average sugarcane yield in the area varied from 32 $t.ha^{-1}$ to 44 $t.ha^{-1}$. Water productivity of sugarcane crop was calculated by considering yield of sugarcane per unit quantity of irrigation water applied. For south Gujarat region, the required depth of irrigation water using flood irrigation for sugarcane crop was reported as 1.2 m (Savani *et al.*, 2012), and the same value was used for calculation of water productivity in this study. In similar way, post drainage water productivity of sugarcane was calculated.

Design Parameters of SSD

Appropriate drain depth and spacing as per the soil hydraulic conditions were required for effective functioning of drainage system. In the present study, drain spacing was computed using the Hooghoudt equation (Hooghoudt, 1940) for the steady state flow condition. The Hooghoudt equation is written as:

$$L^2 = \frac{4\,K_s\,h\,(h + 2\,d)}{q} \quad \ldots(2)$$

Where,

L = Drain spacing, m,

K_s = Saturated hydraulic conductivity, $m.d^{-1}$,

d = Depth of impervious layer from bottom of drain, m,

h = Hydraulic head above the drains, m, and

q = Drainage coefficient or drain discharge rate per unit surface area, $m.d^{-1}$.

The average of estimated saturated hydraulic conductivity i.e. 0.18 $m.d^{-1}$ (Table 1) was taken for design of subsurface drainage system, and the impervious layer was at 6.8 m below the bottom of the drain. The hydraulic head above the drains and drainage coefficient were taken as 0.2 m and 2.0 mm d^{-1}, respectively. Sugarcane is a crop with high water requirement and hence drainage coefficient of 2 $mm.d^{-1}$ was taken instead of 1.5 $mm.d^{-1}$. As water table was to be maintained at 1 m from the ground level on an average, design drain depth was adopted as 1.2 m. It was assumed that it would meet agronomic requirement of crop. The calculated drain spacing was 31.5 m, and therefore 30 m drain spacing was adopted in this study.

Table 1. Estimated saturated hydraulic conductivity using different particle sizes

Location	Sand, %	Silt, %	Clay, %	K_s, $m.d^{-1}$
1	16	20	64	0.179
2	18	16	66	0.161
3	12	24	64	0.202
4	20	18	62	0.167
5	22	20	58	0.175
			Average	0.177

Layout of SSD System

The layout diagram of SSD system is given in Fig. 2. The composite SSD layout system was adopted in the study as open drain was available at some distance from the SSD installation. As excess water from different fields was to be carried away to the open drain, laterals were laid in herringbone pattern to take the advantage of the available field slope. Total seven inspection chambers i.e. sumps (from A to G) were installed in series, and the water from lowest sump (sump A) was carried away through polyvinyl chloride (PVC) pipe of 0.25 m diameter and discharged into the open drain situated at a distance of 450 m. The 2.5-3.0 mm thick synthetic non-woven fabric type filter material, having 230 $g.m^{-2}$ weight and 75-150 micron opening size, was used as envelope material for laterals. The laterals were installed with an average slope of 0.05% to 0.1%, while collector was also installed at 0.06% to 0.16% slope.

Sugarcane Crop Yield and Economics

The pre-SSD and post-SSD yield data of sugarcane were collected from the individual farmers. There were thirteen farmers in the study area, and subsequently the yield of each block was calculated by taking average value of the yield from farmers representing that particular block.

Economic analysis of SSD was based on the collection of primary (yield data) and secondary (components for cost of cultivation, sugarcane price) data from different sources like farmers, panchayat office, sugarcane mill, etc. The primary data was collected from 13 farmer respondents of SSD project area through personal interviews following a comprehensive interview schedule with open and close ended questions. The data related to socio-economic status of farmers, farm inputs requirement and the yield of the major crops were also collected. The costs of all input and output parameters of crop production along with cost of SSD installation were combined to derive average representative values for estimation of benefit-cost ratio of SSD technology. In general, the SSD system

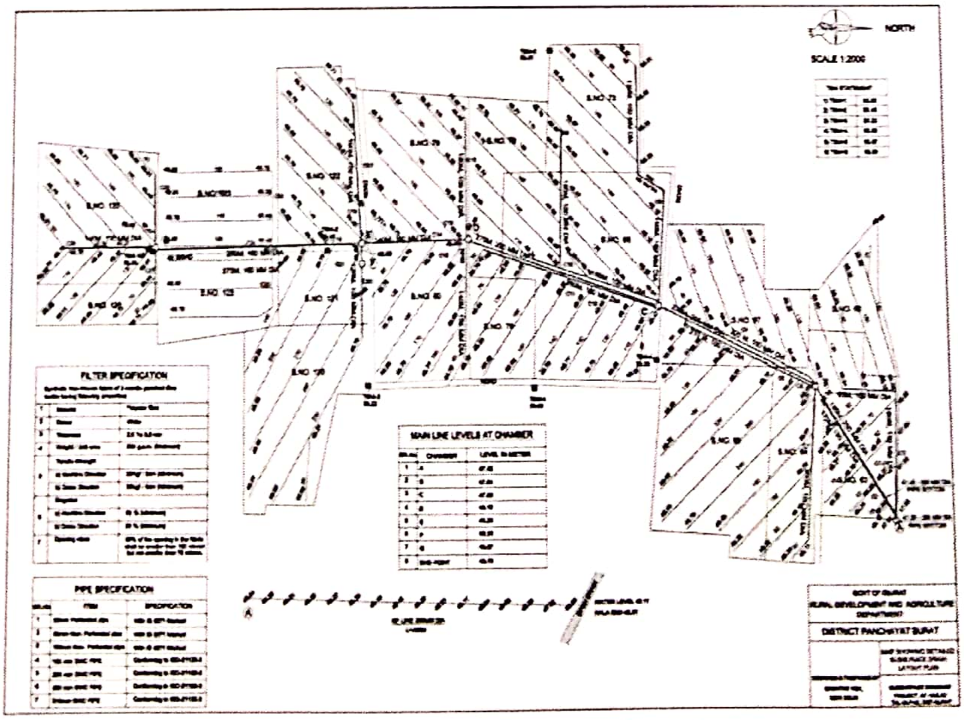

Fig. 2: Layout diagram of SSD system in study area

has an economic life of minimum 30 years (Bundela *et al.*, 2017). However, for the safer side in Vertisols, the life of SSD system was considered as 25 years for converting total cost of SSD system into annual cost. The cost of sugarcane cultivation was estimated by taking into account the cost of different field operations like ploughing, harrowing, seed material, labour, irrigation, fertilisers and manure. The cost under all heads remained the same in the pre- and post-SSD situation, except the cost of manures, fertilizer, weedicides and labour.

RESULTS AND DISCUSSION

Performance Evaluation of Drainage System

Soil Salinity

During pre-SSD condition, it was observed that these soils had moderate salinity as EC_e values ranged from 1.2 $dS.m^{-1}$ to 7.3 $dS.m^{-1}$ with relatively higher salinity in surface layer (0-0.3 m) inhibiting optimum crop growth. Block A, C, E and F had EC_e greater than 4 $dS.m^{-1}$ up to 0.9 m soil depth (Fig. 3), and were saline in nature. Remaining 3 blocks were also facing the problems of increasing levels of soil salinity. Soil pH_s ranged from 7.4 to 8.5, showing moderately alkaline nature of soils and SAR ranged from 1.2 to 26.2 (Fig. 3).

The changes in soil properties like EC_e and SAR of different soil layers in different blocks before and after SSD installation are depicted in Figs. 4 and 5, respectively, indicating the impact of the SSD on soil properties. The changes in ECe values in all blocks at 0-0.3, 0.3-0.6 and 0.6-0.9 m soil depths after installation of SSD system are shown in Fig. 4. Soil EC_e which was in the range of 1.2 to 7.3 $dS.m^{-1}$ before installation of SSD decreased to a range of 0.47- 3.9 $dS.m^{-1}$. Furthermore, EC_e values of all the blocks, except block F, were reduced below 2 $dS.m^{-1}$ which showed that soil became non-saline in the area after operation of the SSD. Block A witnessed more than 60% reduction in soil salinity across all the three soil depths. The highest EC reduction of 75% was observed in the top layer (0-0.3 m) of block C, whereas 67% and 54% reduction in soil ECe was observed in 0.3-0.6 m and 0.6-0.9 m soil layers, respectively. Moreover, some soil layers (0-0.3 m of block B, 0.3-0.6 m of block G, and 0.6-0.9 m of block F) which had low initial soil EC_e did not show any significant changes in EC_e. The reduction in soil salinity after SSD installation and operation was dependent on initial soil salinity and amount of irrigation water used for leaching salts.

There was slight decrease in the pHs value of all blocks, except some layers like in all 3 layers of block E, and 0.3-0.6 m layer of block F. This increase in pH value could be attributed to sharp decline in SAR because of high leaching of salts that can be seen in term of drastic reduction in EC values also.

The change in SAR values of different soil layers in all 7 blocks of the study area are shown in Fig. 5. It was observed that SAR values were less than 10 for all the blocks. The 0.3-0.6 m soil layers of blocks E and F, which had very high SAR values before installation of SSD, were drastically reduced from 26.2 and 18.1 to 5.0 and 4.1, respectively. Though there was increase in SAR values in blocks like E and F (0-0.3 m depth) and blocks like C and D (0.6-0.9 m depth), but the value was still less than 5. It might be due to redistribution of salts during leaching process.

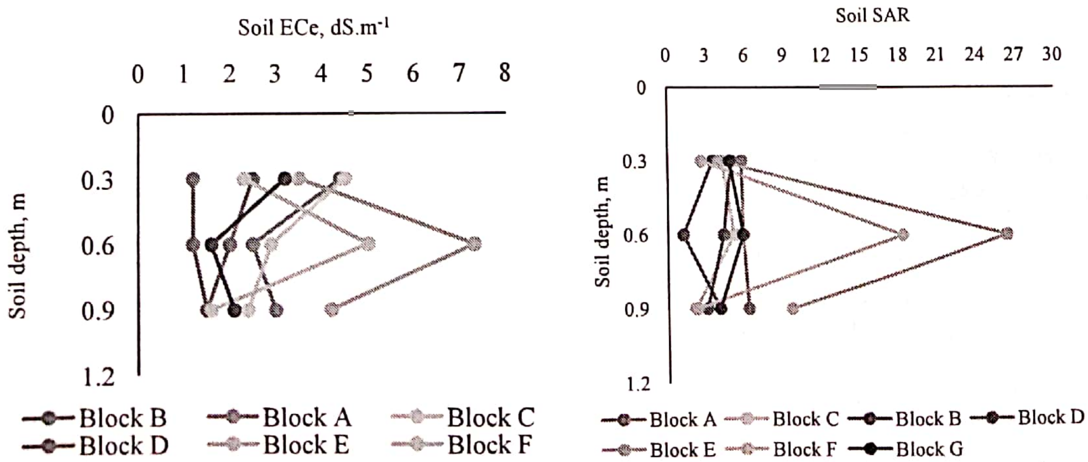

Fig. 3: Block-wise initial soil ECe and SAR values

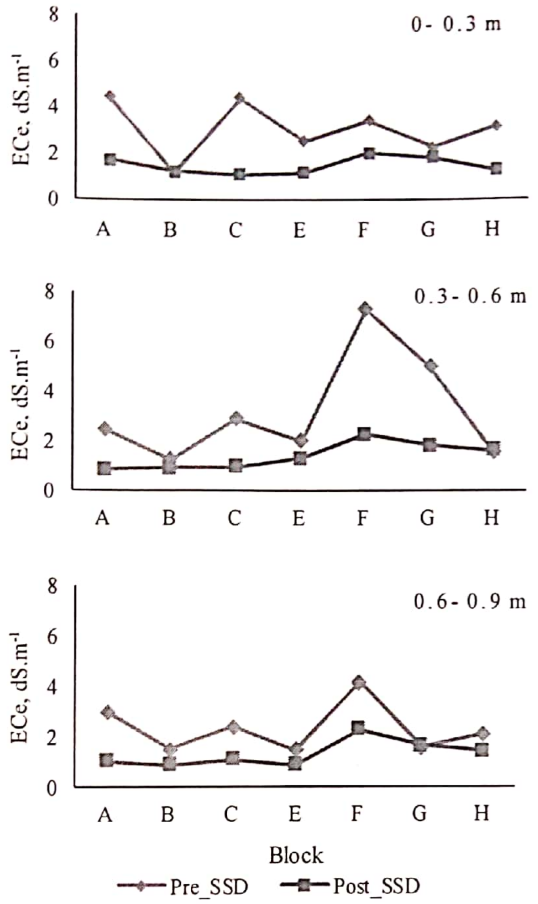

Fig. 4: Block-wise pre- and post-SSD changes in ECe values at different soil depths

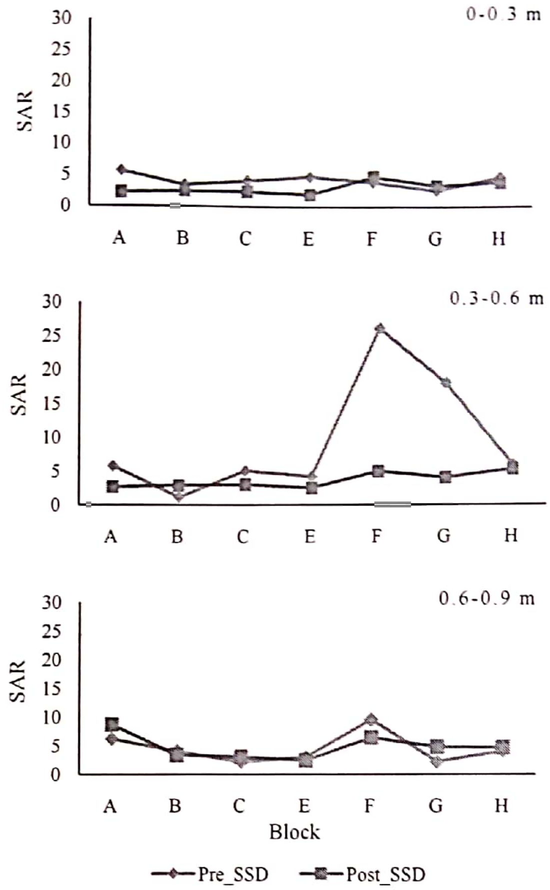

Fig. 5: Block-wise pre- and post-SSD changes in SAR values at different soil depths

The details of overall reduction in ECe, pHs and SAR of various soil layers are given in Table 2. The average soil EC_e was reduced by about 50%, whereas pHs showed marginal reduction up to 10% in all soil layers. There was reduction in average SAR up to 0.6 m soil depth while there was slight increase in SAR for 0.6-0.9 m soil layer. These properties thus indicated improvement in soil condition as compared to initial status of soils.

Groundwater Salinity and Waterlogging

Groundwater in the area was saline in nature with EC values varied from 1.4 to 4.9 dS.m^{-1}. The EC values were higher than the permissible limit of 2 dS.m^{-1} for irrigation water in the study area. The pH of groundwater was within the normal range of 7.6 to 8.3 for the entire study area. But, SAR values (5.9 to 31.1) were more than the permissible limit of 10 in five blocks indicating tendency for creation of alkalinity/sodicity problems in soil with the use of groundwater for irrigation. The salinity and sodicity hazards with use of available water were expected to be much serious considering high clay content and smectite as the dominant clay mineral with high swell-shrink potential.

Analysis of water samples collected from all 7 sumps of drainage system revealed that electrical conductivity (EC) of drain water varied from 1.3 to 4.4 dS.m^{-1} (Fig. 6), and was expected to reduce further below 2.0 dS.m^{-1} with time. It was found that EC of water samples of all sumps, except sumps C and D, was reduced to less than 4 dS.m^{-1} after SSD during May, 2018. Similar results were also reported by Raju *et al.* (2016). The EC values of water samples from the sumps, namely C and D, were relatively high because of ponding and subsequently evaporation of water. The post-SSD pH values of water from the sumps were slightly less. The

Table 2. Depth-wise average changes in different soil parameters

Sl. No.	Depth, m	Average ECe, $dS.m^{-1}$		Change in ECe, %	Average pH,		Change in pH, %	Average SAR,		Change in SAR, %
		Initial	Final		Initial	Final		Initial	Final	
1.	0-0.3	3.07	1.48	(-)51.9	7.99	7.24	(-)9.5	4.23	3.07	(-)27.5
2.	0.3-0.6	3.21	1.39	(-)56.6	7.92	7.41	(-)6.5	9.49	3.66	(-)61.4
3.	0.6-0.9	2.30	1.31	(-)43.2	8.10	7.48	(-)7.7	4.43	4.75	7.2

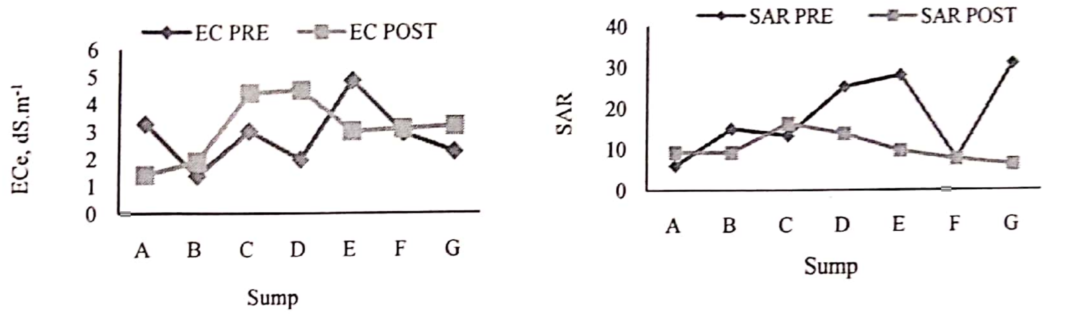

Fig. 6: Pre-SSD and post-SSD changes in EC and SAR of water of different sumps

SAR values were less than 10 for all sumps, except sump C and D. There was high reduction in the SAR values in case of sumps E and G.

The post-SSD analysis of the chemical composition of drainage water (Fig. 7) revealed that sodium was the dominant cation, which constituted about 62% to 78% of total cations followed by magnesium (19% to 30%), calcium (3% to 11%) and potassium (0% to 4%). In case of anions, chloride was dominant anion, which constituted about 44% to 70% of total anions followed by sulphur (11% to 28%), carbonates (6% to 22%) and bicarbonates (4% to 12%). The chemical composition of drainage water gave idea of chemical composition of soil solution, and it was useful in management of soils. The presence of carbonates and bicarbonates indicated that these soils will have tendency towards slight alkalinity development, and use of green manuring after certain time interval could be useful to maintain soil health and crop productivity.

The depth of water table and days required to subside the ponded water during peak rainy season were considered as indicators to judge the improvement in waterlogging conditions during post-SSD period. The waterlogging conditions reduced after installation of the SSD as depth to water table was 0.6 m from ground surface, indicating favourable environment for sugarcane crop. Most root biomass of sugarcane was found close to the surface, and then declined approximately exponentially with depth (Smith *et al.*, 2005). Typically, approximately 50% of the root biomass of sugarcane occurred in top 0.2 m of soils and 85% in the top 0.6 m (Blackburn, 1984). Moreover,

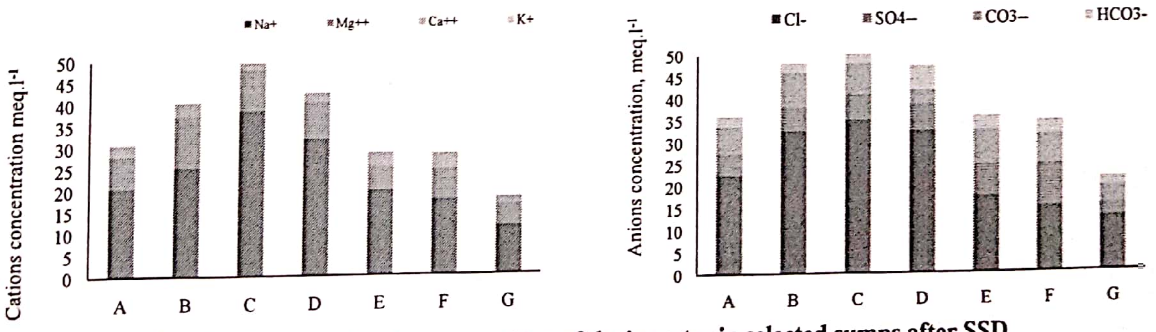

Fig. 7: Cation and anion composition of drain water in selected sumps after SSD

duration of surface ponding was reduced considerably to 6-8 days.

With improvement in drainage water quality with time, it could be easily used for irrigation purpose. Further, drainage water volume can be reduced drastically; if irrigation water use efficiency is improved in drainage area. However, techniques for improving water management including drip irrigation, controlled drainage, etc. are to be adopted after reclamation leaching is completed successfully. These measures would improve irrigation water productivity while reducing drainage volume further.

Improvement in Crop and Water Productivity

Yield and water productivity data of sugarcane before and after implementation of SSD are summarized in Table 3. It was observed that sugarcane yield increased from the range of 32 $t.ha^{-1}$ to 44 $t.ha^{-1}$ to the range of 88 $t.ha^{-1}$ to 107 $t.ha^{-1}$ in different blocks due to SSD installation. The results of crop yield were found in agreement with the findings of Gupta (2015) who observed 100% increase in yield at several places where SSD were installed in India. The water productivity of sugarcane crop ranged from 2.67 to 3.67 $kg.m^{-3}$, and 7.33 to 8.92 $kg.m^{-3}$ during pre- and post-SSD conditions, respectively. A significant increase in crop yield could be attributed to the direct positive effect of the SSD system in lowering the water table, and thereby improving root aeration, reducing soil salinity, creating favourable conditions for better availability of nutrients to plants as well as improving physical conditions of soil.

Economic Analysis

The combined expenditure on cost of cultivation of sugarcane and SSD cost was worked out as ₹ 78,270/- per ha and ₹ 91,076/- per ha in pre-and post- SSD scenarios, respectively, indicating 16.4% increase in average cost of crop cultivation after SSD installation. This increase in cost of cultivation might be due to increase in cost of manure, fertilizers, weedicide and labour with time. The corresponding increase in annual gross income (Table 4) was from ₹ 78,580/- per ha to ₹ 1,94,580/- per ha during post-SSD period, indicating 147.6% increase. The net income increased enormously from ₹ 310/- per ha to ₹ 1,03,504/- per ha due to SSD. The increase in gross and net income occurred largely due to increase in crop yield with intervention of SSD technology. The benefit-cost ratio in drainage project area increased from 1.00 during pre-SSD to 2.14 post-SSD, indicating 114% increase. The results of B: C ratio were in agreement with the findings of Raju *et al.* (2017), who observed

Table 3. Block-wise pre- and post-SSD yield and water productivity of sugarcane

Block	Sugarcane yield, $t.ha^{-1}$		Water productivity, $kg.m^{-3}$	
	Pre-SSD	Post-SSD	Pre-SSD	Post-SSD
A	40	88	3.33	7.33
B	38	91	3.17	7.58
C	32	98	2.67	8.17
D	41	96	3.42	8.00
E	39	103	3.25	8.58
F	44	98	3.67	8.17
G	41	107	3.42	8.92

Table 4. Economics of sugarcane cultivation during pre- and post-SSD

Sl. No.	Particular	Pre-SSD	Post- SSD
1.	Average yield, $t.ha^{-1}$	39.29	97.29
2	Gross income, $₹.ha^{-1}$	78580	194580
3.	Cost of cultivation, $₹.ha^{-1}$	78270	87698
4.	SSD implementation cost, $₹.ha^{-1}.year^{-1}$	-	3378
5.	Net income, $₹.ha^{-1}$	310	103504
6.	B:C (Benefit: Cost) ratio	1.00	2.14

up to 134% increase in B-C ratio for sugarcane crop in Maharashtra.

CONCLUSIONS

The inherent soil properties like very low hydraulic conductivity and narrow workable soil moisture range have always been considered as hurdles in getting potentially higher crop outcomes from highly fertile Vertisols. Injudicious use of irrigation water is creating problems of waterlogging and salinity. In present performance evaluation study, SSD system installed at Mulad village with 30 m drain spacing and average 1.2 m drain depth was found effective in ameliorating the waterlogged saline Vertisols in the area. The system resulted in reduction of soil salinity up to 0.9 m depth from initial levels of 1.2 -7.3 $dS.m^{-1}$ to 0.47 - 3.90 $dS.m^{-1}$ during the year 2018, and soils of the entire project area had become non-saline. Moreover, the waterlogging situation in the area was reduced with lowering of water table beyond crop root zone, and considerable reduction in duration of water ponding during peak rainy season. The technology was also economically viable as farmers' income increased appreciably, with benefit-cost ratio increasing from 1.00 to 2.14. The results suggest that large-scale implementation of SSD projects for reclamation of waterlogged saline Vertisols in canal irrigated areas of Gujarat could be undertaken through establishment of appropriate nodal agency. Nonetheless, for large-scale projects, proper removal and disposal of high volume of generated drainage water from SSD system also needs due consideration in environment-friendly way.

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