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Physical properties of waterlogged vertisols under subsurface drainage system with different drain spacings and depths

■ **SHRIMANT D. RATHOD, SUDHIR D. DAHIWALKAR, SUNIL D. GORANTIWAR, BHIMRAO M. KAMBLE AND MUKUND G. SHINDE**

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See end of the Paper for authors' affiliation

Correspondence to :

SHRIMANT D. RATHOD
NARP, Agricultural Research Station, Kasbe Digraj, Tal. Miraj, SANGLI (M.S.) INDIA
Email : sdrathod2004@gmail.com

■ **ABSTRACT :** The field investigation entitled "Physical properties of waterlogged Vertisols under subsurface drainage system with different drain spacings and depths" was conducted on farmer's field at village Mouje Digraj which was located 3 km away from Agricultural Research Station, Kasbe Digraj, district Sangli (Maharashtra), India during *Adsali* sugarcane season (16-18 months crop duration) of 2012-13 to 2013-14. In order to fulfill the objective of the study, the bulk density, particle density, total porosity and basic infiltration rate of soil were determined at initial and 18 months after drainage with respect to twelve treatment combinations consisting of four drain spacings of (10, 20, 30 and 40 m) and three drain depths (0.75, 1.0 and 1.25 m). It was found that the subsurface drainage system with drain spacing of 10 m and drain depth of 1.25 m recorded highest per cent improvements in bulk density (20.99%), particle density (6.10%), total porosity (13.74%) and basic infiltration rate of soil (13.75%) following 18 months of drainage. However, these per cent improvements in physical properties of soil under different treatment combinations of drain spacings and drain depths were followed decreasing trends from the closer to wider spaced drains under fixed drain depth *i.e.* 10 m > 20 m > 30 m > 40 m and from deeper to shallower drain depth under fixed drain spacing *i.e.*, 1.25 m > 1.0 m > 0.75 m. Further, the difference between maximum and minimum values of per cent improvement of these physical properties of soil among 12 different treatments combinations were not too large (3.05 to 8.41%) which was within the 10 per cent variation. Considering the economics of twelve different combinations of drain spacings and drain depths, the drain spacing of 40 m and drain depth of 1.25 m were found optimal for economically feasible production of sugarcane and optimum physical properties of waterlogged Vertisols of Maharashtra.

■ **KEY WORDS :** Drain spacings, Depths, Physical properties, Subsurface drainage system, Sugarcane, Waterlogged vertisols

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The area under salinization and alkalinisation in India were estimated at 2.96 and 3.77 Mha, whereas in Maharashtra these were estimated at 0.184 and 0.423 Mha, respectively (CSSRI, 2007). Nearly, half of the area under salt affected soil (SAS) is located in the Indo-Gangetic alluvial plain stretching from northwestern Punjab to the sunderban delta in the East. The remaining 20 per cent SAS lies in the arid part of Rajasthan, Punjab and Haryana; in the humid coastal belts of Malabar of Kerala, and along the narrow coastal line in Andhra Pradesh, Tamil Nadu, Maharashtra, Orissa and West Bengal. About 30 per cent of the SAS occur in the deep and medium black soils region covering the States of Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu. Severely waterlogged saline soils occur in about 2 Mha areas in the arid/semi-arid parts of the north western states of Haryana, Punjab, Rajasthan and Gujarat. Similarly more than 1 Mha salt affected soils each in coastal and black cotton heavy soils (Vertisols) regions of India have specific moisture stress and salinity problems (Thatte *et al.*, 2009). Of the salt affected Vertisols in India, around 0.54 Mha land is spread in Maharashtra, 0.12 Mha in Gujarat and 0.034 Mha in Madhya Pradesh (Nayak *et al.*, 2003).

Due to salinity and water-logging of Vertisols, the productive soil has been converted into unproductive one and causing a great economical loss (Postel, 1999). Further, these salt affected soils affect the crop yield due to waterlogging and excess accumulation of salts in the root zone. The best example is that of sugarcane in Maharashtra as the productivity of sugarcane reduced from more than 150 t ha^{-1} during the initial stages of introduction of irrigation to 50-60 t ha^{-1} after waterlogging and salinity of soil (Rathod *et al.*, 2011). In all such cases of the Vertisols, where productivity is either low or has declined or the lands have gone barren; drainage improvement through subsurface drainage system (SSDS) is required. However, the main purpose of SSDS is to provide a better environment for the crop growth and increase crop productivity without compromising the environment. Therefore, it is important to use the best design in order to prevent productivity loss either by over draining or under designing. While selecting the optimal combination of drain spacing (DS) and drain depth (DD), the effect of SSDS with different combinations of drain spacings (DSs) and drain depths (DDs) on physico-chemical and hydrological improvement of waterlogged-salt affected Vertisols is to be studied. This paper focuses on improvements of physical properties of waterlogged Vertisols under SSDS with different combinations of DSs and DDs. It is observed from reviews that very few studies were reported with respect to the effect different combinations of DSs and DDs on physical properties soil. Sharma *et al.* (2000); Bharambe *et al.* (2001); Omonode (2006) and Zhou *et al.* (2013) showed that the closer spaced and deep drains performed better as compare to widely spaced and shallow drains. However, Carter and Camp (1994), Sharma (2006); Shakya and Singh (2010) and Jafari-Talukolaee *et al.* (2016) recommended the higher DSs for better economics, optimum soil properties and higher crop yield. These results motivated to conduct the field investigation on improvement in physical properties of waterlogged Vertisols under SSDS with different combination of DSs and DDs.

■ METHODOLOGY

Experimental details :

The field investigation entitled "Optimization of subsurface drain spacing and depth for sugarcane (*Saccharum officinarum* L.) under waterlogged Vertisols of Maharashtra" was conducted on farmer's field at village Mouje Digraj which was located 3 km away from Agricultural Research Station, Kasbe Digraj, Dist. Sangli (M.S.), India during *Adsali* sugarcane season (16-18 months crop duration) of 2012-13 to 2013-14. Experiment was carried out in split plot design with four DSs of 10, 20, 30 and 40 m as a main factor and three DDs of 0.75, 1.00 and 1.25 m as sub-factor, and replicated thrice. This formed the following twelve combinations of drain spacings DSs and DDs.

– $S_{10}D_{0.75}$: SSDS with DS of 10 m and DD of 0.75 m
– $S_{10}D_{1.0}$: SSDS with DS of 10 m and DD of 1.00 m
– $S_{10}D_{1.25}$: SSDS with DS of 10 m and DD of 1.25 m
– $S_{20}D_{0.75}$: SSDS with DS of 20 m and DD of 0.75 m
– $S_{20}D_{1.0}$: SSDS with DS of 20 m and DD of 1.00 m
– $S_{20}D_{1.25}$: SSDS with DS of 20 m and DD of 1.25 m
– $S_{30}D_{0.75}$: SSDS with DS of 30 m and DD of 0.75 m
– $S_{30}D_{1.0}$: SSDS with DS of 30 m and DD of 1.00 m
– $S_{30}D_{1.25}$: SSDS with DS of 30 m and DD of 1.25 m
– $S_{40}D_{0.75}$: SSDS with DS of 40 m and DD of 0.75 m
– $S_{40}D_{1.0}$: SSDS with DS of 40 m and DD of 1.00 m
– $S_{40}D_{1.25}$: SSDS with DS of 40 m and DD of 1.25 m

The experimental size of 216 m x 54 m was surveyed with Dumpy Level at 18 m x 18 m grid for the contour map and layout of SSDS. The parallel SSDS (gridiron) was installed as per layout of 12 treatment combinations of DSs and DDs by using 80 mm diameter perforated corrugated PVC drainage pipes with geo-textile synthetic filter as lateral drains and non-perforated corrugated PVC pipe of 80 mm diameter as a collector drain. These lateral drains were connected to the collector drain at a grade of 0.2 per cent. The collector drain was laid on a uniform grade of 0.2 per cent. The soil was clayey in texture as clay content was 59.73 per cent. The field capacity, permanent wilting point and bulk density of soil were 41.11 per cent, 20.80 per cent and 1.30 g/cc, respectively. The pH and electrical conductivity of soil were 7.65 to 7.93 and 0.49 to 1.15 dS m^{-1}, respectively. The quality of irrigation was C_1S_1 (low salinity and sodium hazards) in *Kharif* and C_2S_1 (medium salinity and low sodicity hazards) in both *Rabi* and summer season. The irrigation interval was generally 25-30 days due to rotational supply system of co-operative lift irrigated scheme. Hence, the excess application of irrigation water per irrigation is the common practice and created waterlogging at the experimental site. The water table depth was within 0.6 m in rainy season and 1 to 1.5 m in winter and summer season. The *Adsali* sugarcane (variety: Co-86032) was planted at 1.37 m x 0.3 m spacing during 1-3rd August, 2012 and harvested during 25-29th December, 2013. The agronomic practices, irrigation applications, fertilizer applications and plant protection practices were common to all treatments.

Determination of physical properties of soil :

The bulk density, particle density and total porosity of soil were calculated by using standard procedures described in Table A at initial and after harvest of sugarcane *i.e.*, 18 months after drainage (MAD) at 0-30, 30-60, 60-90 and 90-120 cm soil depth. Further, bulk density, particle density and total porosity of soil were averaged for 0-120 cm soil profile and used for studying the per cent improvements affected due to SSDS with 12 different combinations of DSs and DDs. The basic infiltration rate of soil was calculated for 12 combinations of DSs and DDs at initial and 18 MAD.

Table A : Methods to determine physical properties of soil		
Sr. No.	Details	Methods
1.	Bulk density of soil (g/cc)	Core sampler method (Dastane, 1967)
2.	Particle density of soil (g/cc)	Pycnometer method (Blake, 1965)
3.	Total porosity of soil (%)	Calculated by using PD and BD of soil (Brady and Weil, 1996)
4.	Basic infiltration rate of soil (mm hr^{-1})	Cylindrical Infiltrometer method (Parr and Bertrand, 1960)

The per cent improvement in physical properties soil were calculated by following equation :

$$\% \text{ improvement} = \frac{(P_0 - P_f)}{P_0} \times 100$$

where,

Po = Initial value of physical property and P_f is the final (18 MAD) physical property value.

Statistical analysis :

It is observed form review of literature that most of the researchers studied the per cent improvement of physical properties of soil after SSDS. Further, the split plot design with four main factors and three sub-factors with three replications were used for statistical analysis of cost economics of sugarcane under different combinations of DSs and DDs (Panse and Sukhatme, 1967).

■ RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Effect of SSDS with different combinations of DSs and DDs on physical properties of soil :

The data regarding physical properties of soil *viz.*, bulk density, particle density, total porosity and basic infiltration rate of soil were measured by using standard procedures as described in methodology. The results on it are discussed in this section and the data on it are presented in Table 1 to 4.

Bulk density of soil :

The bulk density of soil at 0-30, 30-60, 60-90 and 90-120 cm depth at initial and 18 MAD under various treatment combinations were determined and the average bulk density values of 0-120 cm soil profile are reported in Table 1. It is seen from Table 1 that the bulk density of soil was decreased after installation of SSDS in all treatment combinations. Accordingly, the bulk density of 0-120 cm soil profile were improved from 1.30 g/cc to 1.02, 1.03, 1.06, 1.07, 1.07, 1.09, 1.08, 1.10, 1.12, 1.08, 1.10 and 1.13 g/cc in $S_{10}D_{1.25}$, $S_{10}D_{1.0}$, $S_{10}D_{0.75}$, $S_{20}D_{1.25}$, $S_{20}D_{1.0}$, $S_{20}D_{0.75}$, $S_{30}D_{1.25}$, $S_{30}D_{1.0}$, $S_{30}D_{0.75}$, $S_{40}D_{1.25}$, $S_{40}D_{1.0}$, $S_{40}D_{0.75}$ treatment combinations, respectively. The clayey soil having bulk density <1.10

g/cc is an indicator of ideal bulk densities for plant growth (Anonymous, 2011). It is, therefore, most of the treatment combinations recorded better sugarcane yield after installation of SSDS.

While looking towards the per cent improvement in bulk density of soil, the treatment combination $S_{10}D_{1.25}$ recorded highest per cent improvement of 20.99 per cent. This might be due to the higher drainage co-efficient (6.93 mm day^{-1}), drainable porosity of soil (10.58%) and leaching of soluble salts (59.44%) recorded in $S_{10}D_{1.25}$ treatment combination. Whereas, the lowest per cent improvement in bulk density of soil was recorded in $S_{40}D_{0.75}$ (12.58%). This might be due to that this treatment combination recorded lowest drainage co-efficient (0.72 mm day^{-1}), drainable porosity of soil (1.65%) and leaching of soluble salts (25.26%). It is further observed that the per cent improvement in bulk density of soil was decreased from deep DD (1.25 m) to shallow DD (0.75 m) under fixed DS *i.e.*, $S_{10}D_{1.25}$ (20.99%) > $S_{10}D_{1.0}$ (20.22%) > $S_{10}D_{0.75}$ (18.60%); $S_{20}D_{1.25}$ (17.82%) > $S_{20}D_{1.0}$ (17.13%) > $S_{20}D_{0.75}$ (15.97%); $S_{30}D_{1.25}$ (16.51%) > $S_{30}D_{1.0}$ (15.51%) > $S_{30}D_{0.75}$ (13.81%) and $S_{40}D_{1.25}$ (16.36%) > $S_{40}D_{1.0}$ (14.89%) > $S_{40}D_{0.75}$ (12.58 %); and from closer DS (10 m) to wider DS (40 m) under fixed DD *i.e.*, $S_{10}D_{0.75}$ (18.60%) > $S_{20}D_{0.75}$ (15.97%) > $S_{30}D_{0.75}$ (13.81%) > $S_{40}D_{0.75}$ (12.58%); $S_{10}D_{1.0}$ (20.22%) > $S_{20}D_{1.0}$ (17.13%) > $S_{30}D_{1.0}$ (15.51%) > $S_{40}D_{1.0}$ (14.89%) and $S_{10}D_{1.25}$ (20.99%) > $S_{20}D_{1.25}$ (17.82%) > $S_{30}D_{1.25}$ (16.51%) > $S_{40}D_{1.25}$ (16.36%).

The overall per cent improvement order in bulk density of soil under different combinations of DS and DD were $S_{10}D_{1.25}$ (20.99%) > $S_{10}D_{1.0}$ (20.22%) > $S_{10}D_{0.75}$ (18.60%) > $S_{20}D_{1.25}$ (17.82%) > $S_{20}D_{1.0}$

Table 1 : Effect of SSDS with different combinations of DSs and DDs on bulk density of soil (g/cc)

Sr. No.	Treatments	Initial bulk density of soil	Final bulk density of soil (18 MAD)	% improvement in bulk density of soil after drainage
1.	$S_{10}D_{0.75}$	1.30	1.06	18.60
2.	$S_{10}D_{1.0}$	1.30	1.03	20.22
3.	$S_{10}D_{1.25}$	1.30	1.02	20.99
4.	$S_{20}D_{0.75}$	1.30	1.09	15.97
5.	$S_{20}D_{1.0}$	1.30	1.07	17.13
6.	$S_{20}D_{1.25}$	1.30	1.06	17.82
7.	$S_{30}D_{0.75}$	1.30	1.12	13.81
8.	$S_{30}D_{1.0}$	1.30	1.10	15.51
9.	$S_{30}D_{1.25}$	1.30	1.08	16.51
10.	$S_{40}D_{0.75}$	1.30	1.13	12.58
11.	$S_{40}D_{1.0}$	1.30	1.10	14.89
12.	$S_{40}D_{1.25}$	1.30	1.08	16.36

Table 2 : Effect of SSDS with different combinations of DSs and DDs on particle density of soil (g/cc)

Sr. No.	Treatments	Initial particle density of soil	Final particle density of soil (18 MAD)	% improvement in particle density of soil after drainage
1.	$S_{10}D_{0.75}$	2.79	2.64	5.17
2.	$S_{10}D_{1.0}$	2.79	2.63	5.53
3.	$S_{10}D_{1.25}$	2.79	2.62	6.10
4.	$S_{20}D_{0.75}$	2.79	2.69	3.55
5.	$S_{20}D_{1.0}$	2.79	2.66	4.67
6.	$S_{20}D_{1.25}$	2.79	2.65	4.92
7.	$S_{30}D_{0.75}$	2.79	2.69	3.34
8.	$S_{30}D_{1.0}$	2.79	2.68	3.82
9.	$S_{30}D_{1.25}$	2.79	2.66	4.60
10.	$S_{40}D_{0.75}$	2.79	2.70	3.05
11.	$S_{40}D_{1.0}$	2.79	2.68	3.81
12.	$S_{40}D_{1.25}$	2.79	2.67	4.31

(17.13%) > $S_{30}D_{1.25}$ (16.51%) > $S_{40}D_{1.25}$ (16.36%) > $S_{20}D_{0.75}$ (15.97%) > $S_{30}D_{1.0}$ (15.51 %) > $S_{40}D_{1.0}$ (14.89%) > $S_{30}D_{0.75}$ (13.81%) > $S_{40}D_{0.75}$ (12.58%). Zhou *et al.* (2013) reported 1.38 to 2.78 per cent improvement in bulk density of soil after 6 months of SSD in China. Bharambe *et al.* (2001); Pradeep *et al.* (2005) and Omonode (2006) also found improvement in bulk density of soil after SSDS.

Particle density of soil :

The particle density of soil at 0-30, 30-60, 60-90 and 90-120 cm depth at initial and 18 MAD under various treatment combinations were determined and the averaged particle density values of 0-120 cm soil profile are reported in Table 2.

As described in Table 2, the particle density of soil was slightly improved *i.e.*, 3.05 to 6.10 per cent after installation of SSDS (18 MAD) as per different treatment combinations because it is the density of solids/minerals presents in soils and can't change too much even within different textural groups of soils. The general range of particle density of soil is from 2.60 to 2.80 g/cc and an ideal value of 2.65 g/cc. Here, the particle density of the experimental soil after drainage was near about 2.66 g/cc. It is also observed that the per cent improvement in particle density of soil was recorded highest under the treatment combinations of $S_{10}D_{1.25}$ (6.10%) followed by $S_{20}D_{1.25}$ (5.53%). The lowest per cent decrease in particle density of soil was observed in treatment combination of $S_{40}D_{0.75}$ (3.05%) followed by $S_{30}D_{0.75}$ (3.34%).

It is further observed from Table 2 that the per cent improvement in particle density of soil among different

Table 3 : Effect of SSDS with different combinations DSs and DDs on total porosity of soil (%)

Sr. No.	Treatments	Initial total porosity of soil	Final total porosity of soil (18 MAD)	% Improvement in total porosity of soil after drainage
1.	$S_{10}D_{0.75}$	53.48	60.06	12.30
2.	$S_{10}D_{1.0}$	53.48	60.73	13.56
3.	$S_{10}D_{1.25}$	53.48	60.83	13.74
4.	$S_{20}D_{0.75}$	53.48	59.46	11.18
5.	$S_{20}D_{1.0}$	53.48	59.56	11.37
6.	$S_{20}D_{1.25}$	53.48	59.79	11.80
7.	$S_{30}D_{0.75}$	53.84	58.42	8.51
8.	$S_{30}D_{1.0}$	53.48	59.09	10.49
9.	$S_{30}D_{1.25}$	53.48	59.31	10.90
10.	$S_{40}D_{0.75}$	53.48	57.97	8.40
11.	$S_{40}D_{1.0}$	53.48	58.82	9.99
12.	$S_{40}D_{1.25}$	53.48	59.30	10.88

Table 4 : Effect of SSDS with different combinations of DSs and DDs on IR_b of soil (mm hr^{-1})

Sr. No.	Treatments	Initial IR_b of soil	Final IR_b of soil (18 MAD)	% Improvement of IR_b of soil after drainage
1.	$S_{10}D_{0.75}$	4.29	4.75	10.72
2.	$S_{10}D_{1.0}$	4.29	4.80	11.89
3.	$S_{10}D_{1.25}$	4.29	4.88	13.75
4.	$S_{20}D_{0.75}$	4.29	4.68	9.09
5.	$S_{20}D_{1.0}$	4.29	4.72	10.02
6.	$S_{20}D_{1.25}$	4.29	4.77	11.19
7.	$S_{30}D_{0.75}$	4.29	4.62	7.69
8.	$S_{30}D_{1.0}$	4.29	4.66	8.62
9.	$S_{30}D_{1.25}$	4.29	4.71	9.79
10.	$S_{40}D_{0.75}$	4.29	4.58	6.76
11.	$S_{40}D_{1.0}$	4.29	4.62	7.69
12.	$S_{40}D_{1.25}$	4.29	4.67	8.86

treatment combinations of DSs and DDs were increased from shallow DD to high DD under constant DS *i.e.*, $S_{10}D_{0.75}$ (5.17%) < $S_{10}D_{1.0}$ (5.53%) < $S_{10}D_{1.25}$ (6.10%); $S_{20}D_{0.75}$ (3.55%) < $S_{20}D_{1.0}$ (4.67%) < $S_{20}D_{1.25}$ (4.92%); $S_{30}D_{0.75}$ (3.34%) < $S_{30}D_{1.0}$ (3.82%) < $S_{30}D_{1.25}$ (4.60%) and $S_{40}D_{0.75}$ (3.05%) < $S_{40}D_{1.0}$ (3.81%) < $S_{40}D_{1.25}$ (4.31%); and decreased from closer DS to wider DS under fixed DD *i.e.*, $S_{10}D_{0.75}$ (5.17%) > $S_{20}D_{0.75}$ (3.55%) > $S_{30}D_{0.75}$ (3.34%) > $S_{40}D_{0.75}$ (3.05%); $S_{10}D_{1.0}$ (5.33%) > $S_{20}D_{1.0}$ (4.67%) > $S_{30}D_{1.0}$ (3.82%) > $S_{40}D_{1.0}$ (3.81%) and $S_{10}D_{1.25}$ (6.10%) > $S_{20}D_{1.25}$ (4.92%) > $S_{30}D_{1.25}$ (4.60%) > $S_{40}D_{1.25}$ (4.31%). The overall per cent improvement trends in particle density of soil under different combinations of DSs and DDs were $S_{10}D_{1.25}$ (6.10%) > $S_{10}D_{1.0}$ (5.40%) > $S_{10}D_{0.75}$ (5.17%) > $S_{20}D_{1.25}$ (4.92%) > $S_{20}D_{1.0}$ (4.67%) > $S_{30}D_{1.25}$ (4.60%) > $S_{40}D_{1.25}$ (4.31%) > $S_{30}D_{1.0}$ (3.82%) > $S_{40}D_{1.0}$ (3.81%) > $S_{20}D_{0.75}$ (3.55%) > $S_{30}D_{0.75}$ (3.34%) > $S_{40}D_{0.75}$ (3.05%). These per cent variations in particle density of soil were might be due to reduction in BD of soil, leaching of soluble salts and fine clays and improvement of soil porosity in different treatment combinations of DSs and DDs.

Total porosity of soil :

The total porosity of soil at 0-30, 30-60, 60-90 and 90-120 cm depth at initial and 18 MAD under various treatment combinations were determined by using bulk and particle densities and the average total porosity values of 0-120 cm soil profile are reported in Table 3.

It is seen from Table 3 that the per cent improvements in total porosity of soil were decreased after drainage from DD of 1.25 to 0.75 m DD under fixed DS *i.e.*, $S_{10}D_{1.25}$ (13.74%) > $S_{10}D_{1.0}$ (13.56%) > $S_{10}D_{0.75}$ (12.30%); $S_{20}D_{1.25}$ (11.80%) > $S_{20}D_{1.0}$ (11.37%) > $S_{20}D_{0.75}$ (11.18%); $S_{30}D_{1.25}$ (10.90%) > $S_{30}D_{1.0}$ (10.49%) > $S_{30}D_{0.75}$ (8.51%) and $S_{40}D_{1.25}$ (10.88%) > $S_{40}D_{1.0}$ (9.99%) > $S_{40}D_{0.75}$ (8.40%); and from 10 to 40 m DS under fixed DD *i.e.*, $S_{10}D_{0.75}$ (12.30%) > $S_{20}D_{0.75}$ (11.18%) > $S_{30}D_{0.75}$ (8.51%) > $S_{40}D_{0.75}$ (8.40%); $S_{10}D_{1.0}$ (13.56%) > $S_{20}D_{1.0}$ (11.37%) > $S_{30}D_{1.0}$ (10.49%) > $S_{40}D_{1.0}$ (9.99%) and $S_{10}D_{1.25}$ (13.74%) > $S_{20}D_{1.25}$ (11.80%) > $S_{30}D_{1.25}$ (10.90%) > $S_{40}D_{1.25}$ (10.88%). These per cent improvements in total porosity of soil were might be due to variations in drainage co-efficient, drainable porosity, WT drop rate, leaching of soluble salts and better penetration of sugarcane roots at greater soil depth under different treatment combinations. This helped in overall optimum growth of sugarcane by increasing the water holding capacity of soil, internal movement of water and nutrients through soil pores, better aeration and more supply of oxygen demand to plant roots.

It is further observed from Table 3 that the per cent improvement in total porosity of soil profile was recorded highest in $S_{10}D_{1.25}$ (13.74%) followed by $S_{10}D_{1.0}$ (13.56%), $S_{10}D_{0.75}$ (12.30%), $S_{20}D_{1.25}$ (11.80%), $S_{20}D_{1.0}$ (11.37%), $S_{20}D_{0.75}$ (11.18%), $S_{30}D_{1.25}$ (10.90%), $S_{40}D_{1.25}$ (10.88%), $S_{30}D_{1.0}$ (10.49%), $S_{40}D_{1.0}$ (9.99%), $S_{30}D_{0.75}$

Table 5 : Effect of SSDS with different DSs and DDs on cost economics of sugarcane under waterlogged Vertisols

Treatments	Gross monetary returns (Rs. ha^{-1})	Net monetary returns (Rs. ha^{-1})	B:C
Drain spacing			
S_1 (10 m)	332980.79	92794.54	1.39
S_2 (20 m)	415158.92	178982.05	1.76
S_3 (30 m)	486778.80	251358.62	2.07
S_4 (40 m)	545814.38	311213.92	2.33
S.E.±	12425.08	12425.08	0.05
C.D. (P=0.05)	42996.46	42996.46	0.18
Drain depth			
D_1 (0.75 m)	400021.89	163749.74	1.70
D_2 (1.0 m)	442734.54	206131.04	1.88
D_3 (1.25 m)	492793.24	255881.07	2.08
S.E.±	10284.40	10284.40	0.04
C.D. (P=0.05)	30832.63	30832.63	0.13
Interaction S.E.±	20568.81	17141.31	0.09
C.D. (P=0.05)	NS	NS	NS

NS=Non-significant

(8.51 %) and $S_{40}D_{0.75}$ (8.40%). Zhou *et al.* (2013) found that the per cent improvement in soil porosity was 0.81 to 5.47 per cent just after 6 months of SSDS at coastal resorts of China. Pradeep *et al.* (2005) and Omonode (2006) also found per cent improvement in total porosity of soil due to SSDS.

Basic infiltration rate of soil :

The basic infiltration rate of soil (IR_b) before and 18 MAD under various treatment combinations were determined by double ring infiltrometer method and results are reported in Table 4.

It is observed from Table 4 that the per cent improvement in IR_b of soil was observed highest in $S_{10}D_{1.25}$ (13.75%) treatment combinations followed by $S_{10}D_{1.0}$ (11.89%). This might be due to that the $S_{10}D_{1.25}$ treatment combination recorded more per cent improvements in total porosity (13.74%), bulk density of soil (21%), particle density of soil (6.10%), drainable porosity of soil (10.58%) and leaching of soluble salts from 0-120 cm soil profile (59.44%). Whereas, this per cent improvement in IR_b of soil was observed lowest in the treatment combination $S_{40}D_{0.75}$ (6.76%) followed by both $S_{30}D_{0.75}$ and $S_{40}D_{1.0}$ (7.69%) because the treatment $S_{40}D_{0.75}$ recorded less per cent improvements in total porosity of soil (8.40%), bulk density of soil (12.58%), particle density of soil (3.05%), drainable porosity of soil (1.65%) and desalinization of soil (25.26%). Further, the order of per cent improvement of IR_b of soil under different combinations of DSs and DDs were $S_{10}D_{1.25}$ (13.75%), $S_{10}D_{1.0}$ (11.89%), $S_{20}D_{1.25}$ (11.19%), $S_{10}D_{0.75}$ (10.72%), $S_{20}D_{1.0}$ (10.02%), $S_{30}D_{1.25}$ (9.79%), $S_{20}D_{0.75}$ (9.09%), $S_{40}D_{1.25}$ (8.86%), $S_{30}D_{1.0}$ (8.62%), $S_{30}D_{0.75}$ and $S_{40}D_{1.0}$ (7.69 %), and $S_{40}D_{0.75}$ (6.76%). These per cent improvements in IR_b of soil increased the drainage of surface water and avoided the surface waterlogging due to heavy rains and excess applied irrigation water. Bharambe *et al.* (2001); Pradeep *et al.* (2005) and Jung *et al.* (2010) reported the improvement in IR_b of soil after SSDS.

Selection of optimal DS and DD of SSDS for sugarcane under waterlogged vertisols :

The results showed that the $S_{10}D_{1.25}$ treatment combination reported highest per cent improvements in physical properties (bulk density, particle density, total porosity and IR_b of soil) of waterlogged Vertisols. However, the differences between maximum and minimum values of per cent improvements in these physical properties of vertisols among different combinations of DSs and DDs were not too large (3.05-8.41%) *i.e.* within 10 per cent variations. Under this situation, the economically feasible production of crops under less (slow) drainage of water or slow improvement in soil properties was the acceptable phenomena at global level. In view to this, economic viability of different treatment combinations for sugarcane under waterlogged Vertisols was worked out for final selection of DS and DD and the data on it are shown in Table 5.

As described in Table 5, the economic analysis of SSDS with different combinations of DSs and DDs revealed that the DS of 40 m were recorded significantly highest gross monetary returns (5,45,814.38 Rs. ha^{-1}), net monetary returns (3,11,213.92 Rs. ha^{-1}) and B:C (2.33) followed by DSs of 30 m, 20 m and 10 m. The higher spaced drain recorded superior economics as compare to closely spaced drains. This might be due to the less adoption cost and high yield of sugarcane recorded under wider spaced drains of 40 m. The high yield of sugarcane might be due to slow drainage and less NO_3-N losses under wider spaced drains of 40 m [Nash *et al.* (2014); Nangia *et al.* (2009); Randall (2004); Randall and Mulla (2001) and Mitsch *et al*. (2001) etc.], more water-logging tolerance of sugarcane (Glaz and Morris, 2010 and Glaz *et al*., 2004) and more sensitivity towards deficit moisture conditions (Doorenbos and Kassam, 1979) as the yield response factor (Ky) >1.2 (FAO, 2015). Whereas, the deep drains of 1.25 m recorded significantly highest gross monetary returns (4,92,793.24 Rs. ha^{-1}), net monetary returns (2,55,881.92 Rs. ha^{-1}) and B:C ratio (2.08) followed by DDs of 1.0 and 0.75 m as the deeper drains provided faster and better physical properties of soil at greater soil depth for deep rooted crops like sugarcane.

Thus, the DS of 40 m and DD of 1.25 m were found economically optimal among other DSs and DDs for sugarcane under waterlogged Vertisols of Maharashtra. Carter and Camp (1994) reported that there was no statistically significant sugarcane yield advantage to subsurface drains spaced closer than 42 m. Shakya and Singh (2010) recommended the SSDS with 80 m DS and DD of 1.75 m for optimum water table depth of 1.2 m, economically viable and kept the effective root zone salt free instead of 40 and 60 m DS for paddywheat rotation. Jafari-Talukolaee *et al.* (2016) also recommended 30 m DS and DD of 0.9 m instead of 15 m DS and DD of 0.65 m for optimum properties of soil and higher canola yield in Iran. Tiwari and Goel (2015) also reported that the DS should be within 30-50 m for fine textured soils, DD > 1.2 m and drainage co-efficient of 2 mm day^{-1} for semi-arid regions. In this investigation the highest sugarcane yield was obtained under DS of 40 m, DD of 1.25 m and drainage co-efficient = 2.18 mm day^{-1}. Hence, the previous research works supported to the present research outputs as well.

Conclusion :

The DS of 40 m and DD of 1.25 m is recommended for economically viable production of waterlogging tolerant and deep rooted crops like sugarcane and optimum physical properties of waterlogged Vertisols of Maharashtra.

Authors' affiliations:

SUDHIR D. DAHIWALKAR AND SUNIL D. GORANTIWAR, Department of Irrigation and Drainage Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri, AHMEDNAGAR (M.S.) INDIA
Email : sdahiwalka@yahoo.co.in; sdgorantiwar@gmail.com

BHIMRAO M. KAMBLE, Agricultural Research Station, SANGLI (M.S.) INDIA
Email : bmkamble2007@gmail.com

MUKUND G. SHINDE, Department of Soil and Water Conservation Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri, AHMEDNAGAR (M.S.) INDIA
Email : mgshinde@rediffmail.com

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