Characteristics and Drainage Interventions for Management of *Vertisols*

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Introduction

Vertisols are clay-rich soils that shrink and swell with changes in moisture content. During dry periods, the soil volume shrinks, and deep wide cracks form. The soil volume then expands as it gets wetted. This shrink/swell action creates serious engineering problems. In India, *Vertisols* and associated soils are found to occur in nearly four agro-climatic conditions of India *i.e* arid, semi-arid, dry sub-humid and moist sub-humid conditions. About 76.4 M ha of *Vertisols* occur in India which is 23.2% of the total geographical area of the country (Murthy *et al.*, 1982; Table 1). These soils are predominant in Maharashtra (29.9 M ha), Madhya Pradesh (16.7 M ha), Gujarat (8.2 M ha), Andhra Pradesh (7.2 M ha), Karnataka (6.9 M ha), Rajasthan (2.3 M ha) and Tamil Nadu (3.2 M ha). Of these, salt affected *Vertisols* measuring 0.54 M ha in Maharashtra, 0.12 M ha in Gujarat state and 0.034 M ha in Madhya Pradesh. Due to their high clay content, the physical properties of *Vertisols* are greatly influenced by moisture content; usually, these soils are too sticky and unworkable when wet, and very hard when dry. *Vertisols* are potentially a highly productive group of soils. The major factor contributing to the productivity of *Vertisols* in semi-arid environments is their high water-holding capacity; in areas of uncertain and variable rainfall, sometimes too much and often too little, the ability of a soil to store sufficient water to carry crops through droughty periods is of great importance. However, some characteristics of these soils do pose some problems for the cultivation of crops and some of the problems assume greater importance where the farmer has only small holdings and limited resources. The development of salinity and sodicity in black soils region is generally associated with poor drainage, waterlogging, injudicious use of irrigation water and continuous cropping with high water demanding crops. One effective way to reduce waterlogging and salinity problems is the land drainage. An understanding of the hydraulic properties of heavy clay soils is obviously of importance in assessing their potential for reclamation since the lack of flow of water through them is a constraint preventing reclamation (Abrol, *et al*, 1988). Nijland *et al*. (2005) clarified that the one effective way to reduce waterlogging and salinity problems is drainage and the objective of any form of land drainage is to control the position of the water table. Tuohy *et al*. (2015) mentioned that the mole drain is the also effective drainage method in Irish *Vertisols*.

Table 1. Distribution of *Vertisols* in India

Sr. No	State	Area (M ha)	Per cent of total black soil area of the country	Per cent of total geographical area of country
1	Maharashtra	29.9	39.1	9.1
2	Madhya Pradesh	16.7	22.0	5.0
3	Gujarat	8.2	10.7	2.5
4	Andhra Pradesh	7.2	9.4	2.2
5	Karnataka	6.9	9.0	2.1
6	Tamil Nadu	3.2	4.2	1.0
7	Rajasthan	2.3	3.0	0.7
8	Orissa	1.3	1.7	0.4
9	Bihar	0.7	0.9	0.2
Total		**76.4**	**100.0**	**23.2**

Characteristics of *Vertisols*

Morphological characteristics

The morphological characteristics comprise the expression, shape and orientation of the structural aggregates, depth and width of cracks developing on drying. The structural arrangement together with the wide cracks is probably the most striking morphological feature of *Vertisols*. In most cases the surface horizons exhibit large, well developed angular blocky or prismatic structures, while in the sub-soil wedge shaped structural elements of all sizes do occur. Important morphological characteristics such as soil colour, texture, element composition *etc*. are all uniform throughout the solumn. A calcic horizon or a concentration of soft powdery lime may be present in or below the vertic horizon. *Vertisols* differ in surface characteristics and these strongly influence their reaction to soil tillage operations.

Physical properties

With regard to drainage the physical properties like soil texture, soil structure and consistency, pore space and porosity, infiltration and permeability (hydraulic conductivity) and water content and soil moisture storage are considered to have major importance to clay soils The basic property of *Vertisols* that endows them with a high moisture-holding capacity is their clay content, which commonly lies between 40 to 60%. Soil structure in *Vertisols* is markedly affected by the wetting and drying cycles. The depth at which the different structural elements are expressed is also a function of the moisture conditions in the different parts of the profile. The surface structure of *Vertisols* may often consist of medium to fine granular aggregates forming a loose mulch of 2-10 cm thick (self-mulching). *Vertisols* tend to have distinctive structural elements in the major body of the soil in the form of sphenoidal blocky structures with smoothed surfaces of slickenside's reflecting seasonal expansion and contraction. Soil consistency has considerable influence on the ease of soil tillage (workability) and for clay soils depends largely on the soil moisture content of the soil. *Vertisols* are known for their extreme hardness when dry but can be friable when moist or sticky and plastic when wet. Timing of tillage operations are therefore important while a proper understanding of the extent of adhesiveness of clay soils will be useful to improve upon the efficiency of ploughing implements.

Dry *Vertisols* have a very hard consistence; wet *Vertisols* are (very) plastic and sticky. It is generally true that *Vertisols* are friable only over a narrow moisture range but their physical properties are greatly influenced by soluble salts and/or adsorbed sodium. Apart from the solid mineral fraction, organic matter and water; voids are another component of the soil volume. Voids include all space in the soil and relate to the arrangement of the primary constitutes rooting patterns, burrowing of animals or any other soil forming processes such as cracking, translocation leaching etc. There is large variety in the shape, size and origin of voids but emphasis is placed on the continuous and elongated voids which are of particular importance in drainage (also known as macropores). The porosity is indication of the total volume of voids of all sizes. In non–swelling soils, porosity usually ranges from 30-60%. In swelling soils it is related to the moisture content of the soil as swelling will have a strong effect on the voids. The other physical property of *Vertisols* is hydraulic conductivity which varies among different groups, salt content and bulk density. Infiltration of water in dry *Vertisols* with surface mulch or fine tilth is initially rapid. However, once the surface soil is thoroughly wetted and cracks have closed, the rate of water infiltration becomes almost nil. If, at this stage, the rains continue (or irrigation is prolonged), *Vertisols* flood readily. *Vertisols*, by and large, are soils with good water holding properties. However, a large proportion of all water held between the basic crystal units; is not available to plants. When these soils are irrigated, the high seepage leads to a shallow water table build-up causing secondary salinisation or sodiumisation. Although the *Vertisols* have very high potential productivity with favorable climatic conditions still these soils remain underutilized owing to number of management problems *viz*., low water infiltration rate, narrow workable moisture rage, poor soil tilth and characteristically poor internal drainage. The hydraulic conductively of the *Vertisols* is generally very low (Table 2). Due to vertical heterogeneity in the root zone, the hydraulic conductivity displays appreciable reduction with increased soil depth such that, in many cases, the soil profile becomes virtually impermeable at a depth of 1m or more (Kauraw and Gupta, 1985). Such conditions become ideal for development of perched water table following rains. This leads to excessive soil moisture content in the root zone unless appropriate provision is made for drainage.

Table 2. Hydraulic conductivity (terminal infiltration rate) of some *Vertisols*

Location	**Infiltration rate, mm hr^{-1}**
Indore (M.P)	12.6
Jabalpur (M.P)	4.7
Hyderabad (A.P)	0.2
Rahuri (Maharashtra)	6.4
Satna, Patera (M.P)	4.0
Pabhani series (Maharashtra)	7.0
Sundra series (M.P)	5.0

Source: Gupta and Ranade (1988); Gupta and Verma (1983); Gupta *et al.* (1979) and Gupta *et al.* (1994)

In black soils, the ESP beyond 10 leads to structural degradation (Gupta and Verma, 1983) due to high degree of clay dispersion (Table 3). The dispersed clay clogs the pores and induces increased water retention at all suctions (Sharma *et al*., 1998). With higher water retention and increasing moisture content (Table 4) deep cracks do not develop in sodic *Vertisols* (Sharma, 1990; Verma and Sharma, 1998). The crops grown on sodic black clay soils suffer mainly on account of poor aeration of the root zone, reduced moisture availability, crusting on drying, hindrance in infiltration of irrigation water, poor nutrient availability.

Table 3. Physico-chemical properties of Sodic *Vertisols* (Indore) at ESP levels

ESP	**pH**	**EC_2 (dSm^{-1})**	**Water dispersible clay,%**	**Bulk density at 15 cm (Mg m^{-3})**	**Infiltration rate (mm hr^{-1})**
6.2	7.9	0.8	16.3	1.62	12.6
10.0	8.1	1.4	26.3	1.58	5.7
15.6	8.1	1.8	34.3	1.64	1.5
21.8	8.2	3.1	38.3	1.60	0.5
37.5	8.3	6.4	40.3	1.63	0.0
58.0	9.3	11.6	42.3	1.68	0.0

Table 4. Influence of alkalinity on cracking behaviour of black soils

Soil ESP	**Depth of crack, cm**	**Width of crack, cm**	**No. of flakes/m^{-2}**
6	>90	5-6	-
10	50	2-3	2-5
15	30	1-2	5-10
22	10	0.5-1.0	10-30
38	<2	0.2-0.3	30-50
58	0.1-0.2	0.05-0.10	80-100
>60	Negligible	Absent	Nil

Chemical characteristics

Most *Vertisols* have a high cation exchange capacity (CEC) and a high base saturation percentage. Dominant cations are Ca^{2+} and Mg^{2+} while Na^{+} plays an important role. The pH values are in the range of 6.0 to 8.0. Higher pH values (8.0-9.5) are seen in *Vertisols* with much ESP. Salinity in *Vertisols* may be inherited from the parent materials or may be caused by over-irrigation. In coastal regions *Vertisols* with high soluble salts and/or with low sulphates are seen. Leaching of excess salts is hardly possible. It is possible to flush salts that have precipitated on the wall of cracks. Chemical amelioration of the plough layer soil has only little effect on sub-soil sodicity, which restricts deep percolation. It has often been observed that after incorporation of chemical amendments, improvement in the physico-chemical properties is limited to the depth of mixing of the amendment. The untreated layer creates obstruction to percolating water. This is not only acts as an impediment to root growth but also causes development of perched water table following rain or irrigation, thereby reducing seedling emergence and inducement of aeration stress in the root zone. Even the ameliorated plough layer lacks adequate aeration because of high clay content and residual sodicity. Thus, under semi-arid climatic conditions the upland *kharif* crops grown on such soils suffer on account of poor aeration, particularly during heavy and incessant rain. The adverse effects on crop growth in such soil can be considerably mitigated by providing economically viable means of drainage.

Relation between salinity and sodicity in *Vertisols*

Studies conducted at ICAR-CSSRI, RRS, Bharuch to understand the effect of electrolyte concentration and SAR and/or ESP on flocculation and hydraulic conductivity (Ks) indicated that the ESP of soils increased with electrolyte concentration and SAR. The data also indicated that with increase in the ESP of soil, the critical coagulation concentration increases. An electrolyte concentration of 20 meq l^{-1} is necessary to cause flocculation of clayey soil at ESP of 6 and silty clayey soil at ESP of 10, beyond which, these soils undergo structural degradation. It is inferred from the study that at salinity of $\leq$ 2 dS m^{-1}, the *Vertisols* can be grouped as sodic if the ESP is > 6 and >10 in clayey and silty clayey soils, respectively. Similarly, at salinity of $\leq$ 4 dS m^{-1}, the *Vertisol* can be grouped as sodic if the ESP is > 13 and >21 in clayey and silty clayey soils, respectively. At higher salinity *ie.*, > 6 dS m^{-1} even at fairly high ESP also, the soil Ks and dispersion are not affected adversely. It can be fairly concluded that the coupled salinity and ESP values be considered as the limit for sodicity classification**.**

Main production constraints in *Vertisols*

Vertisols have a considerable potential for agricultural production but special management practices (tillage and water management) are required to secure sustained production. *Vertisols* are base rich soils and are capable of sustaining continuous cropping. They do not necessarily require a rest period for recovery because the pedoturbation brings subsoil to the surface. However, the overall productivity normally remains low, especially where no irrigation water is available. *Vertisols* are difficult to work - they are of very hard consistence when dry and very plastic and sticky when wet. Thus the workability of the soil is often limited to very short periods of optimal water status. *Vertisols* are imperfectly to poorly drained and leaching of soluble weathering products is limited. This is due to very low hydraulic conductivity of a *Vertisol i.e.,* once the soil has reached its field capacity, practically no water movement occurs. Flooding can be a major problem in areas with higher rainfall. Nitrogen is normally deficient as well as phosphorus. Phosphate fixation (as tricalcium phosphate) may occur but is not a major problem. Potassium contents are variable. Secondary elements and micronutrients are often deficient. Saline and sodic *Vertisols* may develop under irrigation, but they are rare under natural conditions.

The production constraints that prevail in *Vertisols* include:

- Much reduced permeability in swollen state so that both infiltration and internal drainage are very low,
- Poor aeration of wet soils and related root development,
- Narrow optimum moisture range for tillage and seeding operations,
- Germination and difficulties associated with rapid drying of granular surfaces and scaling and crusting,
- Salinity hazards associated with rising groundwater table and use of poor quality irrigation water, and
- Salinity and waterlogging development due to irrigation under canal command areas

Drainage intervention in salt affected and waterlogged *Vertisols*

Various technologies of surface and subsurface drainage to manage acceptable water regime and salt concentration in accordance to cropping pattern suitable for the region have been successfully experimented in different countries world over and accordingly design criteria have been established for the given region. Subsurface drainage has been widely adopted as an effective, quick and sustainable technology for water table and salinity control worldwide. Where as in most countries horizontal pipe drainage has been used, in Europe mole drainage has also been practiced successfully.

Subsurface drainage

Management of such soils involves basically the lowering of water table below root zone and leaching of excess salts. Leaching is essentially the displacement of saline soil solution with good quality water or with water of lower salt concentration. The salts displaced during leaching need to be removed by subsurface horizontal drainage system if the natural drainage of soil is impaired. Subsurface drainage has proved successful in the rehabilitation and conservation of irrigated lands in arid and semi-arid regions (Rao *et al.,* 1986). In India till date about 66084 ha area has been reclaimed using SSD. Out of 66084 ha, 26500 ha area is in Karnataka, 6500 ha area is in Maharashtra, 1300 ha area in Gujarat and 950 ha in Madhya Pradesh and 500 ha area in AP and Telgana. To go for drainage installation, a drainage planning is very much essential.

The preparation of plan

Drainage planning involves the preparation of a plan for solution to a drainage problem. The plan will generally consist of a number of measures to be taken and/or works to be constructed. In some cases the best solution to a drainage problem may well be a change in crop rotation, land use or farm practices and/or making the agricultural use of the land, which may be less susceptible to excess water. In most cases, however, the core of a drainage plan remains to construct some new drainage works suited to soil, climate, irrigation and geo-hydrological conditions and cropping pattern as the problem generally gets attention, when it is unmanageable by preventive methods. One should proceed as follows in deciding a drainage plan (Smedema and Rycroft, 1988).

1. Identification stage: The problem is identified mostly on the basis of available information with hardly any analysis or appraisal.
2. Reconnaissance/ Pre-feasibility stage: Information collected through reconnaissance type field investigations, preliminary diagnosis of the drainage problem, rough outline of possible solutions, delineation of the project area and its sub-divisions and evidence that the proposed project is promising and desirable.

3. Feasibility stage: Information collected through semi-detailed type of field investigations (mapping scale 1:10,000/50,000), presentation of the proposed plan in sufficient detail to demonstrate technical soundness and to enable cost estimation within ~10% accuracy. At this stage, information on hydraulic conductivity, drainable porosity, infiltration characteristics, soil salinity, depth of impermeable layer, aquifer parameters, groundwater fluctuation and quality, fresh water supplies, surface drainage network and the availability of outlets etc. is collected, which is a prerequisite for planning the drainage of waterlogged saline soils. In addition, knowledge on the drainage requirement of different crops and criterion for the drainage design is also required.

4. Final stage: Analysis of information collected through detailed investigations, elaboration of all plans to the extent that they can work as working documents. These include detailed plan and design, construction drawings and specifications.

Based on the research findings (Gupta, 2002) the following drain depth/spacing combinations are recommended (Table 5, 6 and 7).

Table 5. Guidelines on drain depth

Outlet conditions	Depth of the drains (m)	Optimum depth (m)
Gravity	0.9-1.2	1.1
Pumped	1.2-1.8	1.5

Table 6. Guidelines on drainage coefficient for subsurface drainage

Climatic Conditions	Range (mm day^{-1})	Optimum value (mm)
Arid	1-2	1
Semi-arid	1-3	2
Sub-humid	2-5	3

Table 7. Guidelines on lateral drain spacing

Soil texture	Spacing of drains (m)
Light textured	100-150
Medium textured	50-100
Heavy textured including *Vertisols*	30-50

Basic guidelines for Indian subsurface drainage design

Although Drainage manual (1978) and Drainage design factors (1986) have recommended general guidelines or installation procedure and drainage design parameters for more effective performance, yet on the basis of pilot studies undertaken in the past 50 years in India, few more guidelines have emerged which are mentioned below.

1. Before undertaking any drainage project into a problematic area, the primary data (technical, socioeconomic, geo-hydrological climate) and secondary (water quality) have to be collected, which are relevant to the particular area.

2. In past, cement concrete pipes were very popular in alkaline and saline areas because these pipes have not given any complaints up to 20 years in alkaline areas and 8 years in saline zones after installation. But nowadays PVC pipes are more popular than others due to its portability and light in weight.

3. Drainage depth is an issue of increase or decrease in cost of installation and also availability of machineries and labour. But it is depending on position of groundwater table, soil type and

hydraulic characteristics. For agricultural drainage, recommended depth of the lateral is 1.2 m because agricultural activities may damage the laterals.

4. Drain spacing is classified on the basis of the texture of the soil. The lateral spacing, size and grade (in %) for light-textured soils are ranging between 100 and 150 m, 100 mm and 0.10 %, respectively, 50 and 100 m, 125 mm and 0.075 % for medium-textured soil and 30 and 50 m, 150 mm and 0.05 % for heavy textured soils.
5. On the basis of climatic conditions, drainage coefficient has an optimum value which lies between 1 and 3 mm/day (i.e., arid region is a 1 mm/day, semiarid region is a 2 mm/day, and subhumid region is 3 mm/day).
6. Continuous movement of water in the pipe and aquifer system collects sediment in the pipes which may affect the performance of the drainage system. For resolving the problem, the provision of filters and envelopes on the drain pipes has to be adopted. Filter/envelope material is used to filter that surrounds drain pipe, and these are commonly used along with drain pipes (geotextile, polypropylene, coconut fiber, polystyrene and foam plastic). The traditional filter material is a combination of gravel and coarse sand.
7. Normally the drain effluent is disposed in the canal, salt-making ponds, fishpond, or it can be reused in crop production. The several methods have been suggested by researchers for effluent reuse in irrigation such as blending and mixing.

Subsurface drainage in *Vertisols*

As per documentary evidences, subsurface drainage has been experimented in India for the last 130 years or so. The first-ever subsurface drainage experiment to reclaim salt affected land was conducted by Mr. Robertson in 1873 (Gupta, 2002 and Gupta, 2003). Similarly, Manjari drainage scheme in Maharashtra state is located in Khadakwasala irrigation project near Pune, in the command of distributory No. 5 and 6 of old Mutha right bank canal. The drainage scheme for 30 ha was designed for reclamation of waterlogged black cotton soils of Mahatma Phule Krishi Vidyapeeth Rahuri 1981. The main causes of waterlogging were seepage from Mula right bank canal, excess irrigation on the upper part of field and percolation tank on the upper boundary of the field. The subsurface drainage system was provided after detailed drainage investigations. Though there were some success stories in past indicating identification of drainage problem and competence to tackle it, major achievements could be accomplished during the last forty years when a subsurface drainage based reclamation package was developed and implemented to cover about 66084 ha of waterlogged saline lands in eleven states of the country. Field studies at Bidaj (Gujarat) with open drains at a 15, 20 and 25 m drain spacing and 1.5 m depth in heavy textured highly saline soil and medium to high saline ground water resulted in an overall improvement in the salinity status of soil. Subsurface horizontal drainage provided in *Vertisols* of Mahi-Kadana command at Dabhou in Gujarat showed significant improvement in the root zone salinity conditions. Considering the severity and extent of waterlogging and secondary salinization problems in *Ukai Kakrapar* Command (UKC), Soil and Water Management Research Unit, Navsari Agricultural University (formerly Gujarat Agricultural University), Navsari conducted studies on subsurface drainage in 56 ha block at the farmers' fields situated in the jurisdiction of Chalthan Sugar Factory, Chalthan during 1984-85 to 1991-92. After installation of subsurface drainage, paddy and sugarcane yields were higher as compared to pre drainage yields. The pH and EC values also showed a decreasing trend with the progress of time after drainage. Similarly, Water and Land Management Institute, Anand (Gujarat) also conducted pilot scale demonstrations of subsurface drainage technology in Mahi Right Bank Canal Command during 1990-91. The soils were extremely saline and waterlogged and the area was almost lying barren. After installation of subsurface drainage, paddy crop was grown and yield level of 2 to 3 t/ha was achieved. Under Indo-Dutch Network Project, two pilot areas were selected in Ukai-Kakrapar Command. The important characteristics of both the pilot areas are given in Table 8. The distinct difference between both the pilot areas was cropping intensity *i.e.* in Segwa it was 116 per cent and only 48 per cent in Sisodara. This was mainly because of severity of waterlogging and salinity problems were more in Sisodara than in Segwa. The cropping intensity of 48 per cent in Sisodara suggests presence of barren land in pilot area. After completion of pre-project survey and analysis of drainage related parameters of soil, drainage design details were worked out and system installation work was initiated during 1998.

Table 8. Important characteristics of pilot area under subsurface drainage

S N	Particulars	Pilot area	
		Segwa	**Sisodra**
1.	Taluka/district	Kamrej/Surat	Ankleshwar/Bharuch
2.	Climate	Sub humid	Semi-arid
3.	Branch/minor	Surat branch/Segwa minor	Kosamba branch /Pandvai Minor
4.	Size of pilot area (ha)	188	169
5.	Cropping intensity (%)	116	48
6.	Major crops	Sugarcane, paddy	Sugarcane, paddy
7.	Major constraints	Waterlogging and initiation of salinization	Extreme waterlogging and high salinity/sodicity
8.	Source of irrigation water (ha)		
	Canal	76	76
	Well alone	37	--
	Drain	4	--
	Conjunctive use	26	--

At Segwa pilot site, singular and composite closed subsurface drainage (CSSD) systems were installed at 30, 45 and 60 m spacing with and without amendment and envelope. In all, 28.1 ha area was brought under CSSD in phased manner. While at Sisodara, only open subsurface drainage (OSSD) was laid out in 16 ha area with 30 and 60 m drain spacing. Both these pilot areas were monitored rigorously for soil, drain water, ground water level and crop yield parameters. The soluble salt content in soil (0-90 cm) under CSSD decreased from initial value of about 4.0 dS/m in 1998 to 1.0 dS/m in 2002. Similarly sodicity was also tended to decrease after installation of CSSD system at Segwa. Also there was increase in sugarcane yields with time by 35 percent as yield increased from 78-104 to 105-140 t/ha. In village Mulad, Taluka Olpad, district Surat, the salt affected *Vertisols* under sugarcane cultivation measuring about 45 hectare has been brought under the SSD with financial help from Nagar Palika Surat. The project was implemented during 2012 and till date is working successfully and farmers are reaping the good harvest from sugarcane crop with increment in yield to the tune of 2.5 to 3.0 times as compared to situation before SSD. By looking in to the success of the project individual farmers of the village and nearby villages have adopted SSD in their own fields and reaping benefit. The subsurface drainage system was also installed in the area of 8.81 ha in challis biga farm of ARS, Kasabe Digraj with salinity and waterlogging problem. The electrical conductivity ranged from 2.22 to 17.82 dS/m. The exchangeable sodium percentage was recorded in the range of 7.04 to 17.50. The hydraulic conductivity was 0.0236 to 0.0579 m/day. The water table fluctuation was recorded in the range of 0.265 to 1.85 m from the surface in different seasons. Perforated corrugated PVC pipes of 80 mm diameter was used for collector drain. The average depth of collector and lateral drains was 1.32 m. The spacing between two laterals was 25 m. Coarse sand filter and synthetic filter were used as filter envelope. The drainage inspection chambers were installed on collector drain. The drainage effluent was taken out by gravity and expenditure on pumping is minimized. The installation of drainage system could help to bring these barren soils under cultivation. Improvement in the crop yields was observed and during one year, EC and ESP both were decreased down by 5 to 6 units. A pilot project in waterlogged saline *Vertisols* of villages Ghodadara and Adadara in Bharuch district has been undertaken in the year 2016 with different drain spacing at 30 and 35 meters, respectively in one hectare area each. After installation of SSD and after first rainy season, it is found that the average EC_2 values of different soil layers up to 1.2 m depth at village Adadara site was reduced to 3.63-6.67 dS/m from 4.43-7.30 dS/m. The electrical conductivity of soils at surface layer at Adadara site was reduced up to 50% (EC_2 = 3.6 dS/m) from its initial EC_2 (7.6 dS/m).

Conclusion

The black cotton soils (*Vertisols*) are heavy textured soils with low permeability and are more prone to waterlogging and soil salinity if irrigated without proper drainage. These soils can be reclaimed by installing subsurface drainage system with proper design specifications. However drain spacing has to be kept smaller as compared to alluvial soils of Haryana and Punjab. At places where gravity outlets are available for the disposal of drainage water which reduces the pumping cost of the system, the success of SSD is visible in *Vertisols*. It has been proved that subsurface drainage is a successful technology to reclaim waterlogged and saline *Vertisols*. Considering the encouraging results of different studies, large scale implementation SSD project for reclamation of waterlogged saline heavy textured *Vertisols* in canal irrigated areas of Gujarat may be recommended. However, for large scale projects, environmental concerns on disposal of large volume of saline drainage water needs to be taken into consideration. Moreover, periodic monitoring of the system is required to carry out in order to check the effectiveness and efficiency of the system for better performance and effective leaching of salts.

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