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Physical and chemical properties of soils affecting drainage in Upper Wardha command area

A. R. GHAWADE, P. R. KADU AND S. K. RAY[1]

Department of Soil Science and Agricultural Chemistry, College of Agriculture, Nagpur– 440 001, India
[1]National bureau of Soil Survey & Land Use Planning, Amravati Road, Nagpur-440 010, India

Abstract : Soil characteristics and hydraulic properties of six pedons of Vertisols of Upper Wardha command area were studied in relation to irrigation management. The soils are very deep, clayey (52.7 to 65.1 %), having water dispersible clay of 16.0 to 26.5 %, coefficient of linear extensibility (COLE) of 0.15 to 0.27 cm cm^{-1} and saturated hydraulic conductivity (sHC) of 0.01 to 1.44 cm hr^{-1}. These soils are non-saline (ECe < 4 dS m^{-1}) and exchangeable sodium percentage (ESP) and exchangeable magnesium percentage (EMP) ranged from 1.9 to 17.5 and 29.7 to 46, respectively. Due to injudicious and faulty irrigation system since 1997, the problems of salt accumulation and development of sodicity have emerged in these soils. The reduction in the hydraulic conductivity, poor internal drainage and problems of performing agriculture on a sustainable basis may be attributed to development of sodicity in these soils.

Additional key words: *Hydraulic properties, sodicity, water management*

Introduction

Occurrence of salt affected soils is common in Vertisols in arid and semi-arid regions. With expanding canal irrigation, problems of salinity and waterlogging have emerged within the command areas. The cause of waterlogging and salinity/alkalinity in most cases is being ascribed to faulty irrigation water management. Understanding of physical and chemical characteristics of soils of the command area are pre-requisites for scientific management of an irrigation system. Therefore, the knowledge of properties of soils (hydraulic conductivity and drainage) responsible for controlling water movement through soils, root water extraction, contribution of ground water table, crop water use and irrigation scheduling (Singh *et al.* 1994) is a must before undertaking any irrigation water management programmes. Thus, the present investigation in Upper Wardha command area was initiated to analyse the soil characteristics responsible for waterlogging or soil salinization/ alkalinazation which will help undertake proper water management strategies to arrest these degradation processes.

Materials and Methods

The study area of the Upper Wardha irrigation project lies between 21°10' to 21°18' N latitude and 78°15' to 78°15' E longitude. Six pedons from Vertisols occurring in Ashti tahsil of Wardha district, Maharashtra were selected. This comprises the left bank canal head zone which is the first area to receive irrigation water. Soils in this command area have developed from basalt and its alluvium.

The average elevation of the study area varies from 320 to 400 m above MSL and the climate is semi-arid, subtropical with an annual rainfall of 979 mm. The dominant crops of the area are cotton (*Gossypium spp.*), sorghum (*Sorghum bicolor*), pigeon pea (*Cajanas cajan*), soybean (*Glycine max*), sugarcane (*Saccharum officinarum*), wheat (*Triticum spp.*) and gram (*Cicer arietinum*).

Table 1. Brief morphometric description of soils

Depth (cm)	Horizon	Munsell colour (moist)	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Effervescence	Concretions	Other Features
Pedon 1 : Belora (Typic Haplusterts)										
0-15	Ap	10YR 3/3	Clay	2 m sbk	sh	fr	sssp	Slight	f c	Well developed slickensides below 75 cm depth
15-45	A1	10YR 3/3	Clay	2 m sbk	h	fr	ssp	Strong	f c	
45-75	Bw	10YR 3/3	Clay	2 m sbk	h	fr	sp	Strong	m c	
75-105	Bss1	10YR 3/2	Clay	2 m abk	h	fi	svp	Violent	m c	
105-145	Bss2	10YR 3/3	Clay	2 m abk	h	fi	vsvp	Violent	m m	
Pedon 2 : Kinhala (Typic Haplusterts)										
0-20	Ap	10YR 3/3	Clay	2 m sbk	h	fr	sp	Slight	f f	Slickensides below 35 cm depth.
20-35	Bw	10YR 3/1	Clay	2 m abk	h	fr	sp	Slight	f c	
35-55	Bss1	10YR 3/2	Clay	2 m abk	vh	fi	vsvp	Slight	f c	
55-75	Bss2	10YR 3/1	Clay	2 m abk	vh	fi	vsvp	Strong	m m	
75-100	BC	10YR 5/4	Clay	2 m sbk	h	fi	svp	Violent	m m	
Pedon 3 : Sujatpur (Sodic Haplusterts)										
0-20	Ap	10YR 4/2	Clay	2 m sbk	h	fr	sssp	Slight	f c	Slickensides below 60 cm depth.
20-37	A1	10YR 3/2	Clay	2 m sbk	h	fr	sp	Strong	f c	
37-60	Bw	10YR 3/2	Clay	2 m abk	h	fi	svp	Strong	f c	
60-100	Bss1	10YR 3/1	Clay	2 m abk	vh	vfi	vsvp	Strong	m c	
100-145	Bss2	10YR 3/1	Clay	2 m abk	vh	vfi	vsvp	Violent	m m	
Pedon 4 : Bharaswada (Typic Haplusterts)										
0-18	Ap	10YR 3/2	Clay	2 m sbk	h	fr	sp	Slight	f c	Slickensides below 40 cm depth .
18-40	Bw	10YR 3/2	Clay	2 m abk	h	fi	sp	Slight	f c	
40-73	Bss1	10YR 3/1	Clay	2 m abk	vh	fi	svp	Strong	m c	
73-120	Bss2	10YR 3/1	Clay	2 m abk	vh	fi	vsvp	Strong	m m	
Pedon 5 : Deogoan (Typic Haplusterts)										
0-18	Ap	10YR 3/2	Clay	2 m sbk	h	fr	sp	Slight	f c	Slickensides below 65 cm depth.
18-40	A1	10YR 3/1	Clay	2 m abk	h	fi	sp	Strong	f c	
40-65	Bw	10YR 3/1	Clay	2 m abk	h	fi	svp	Strong	m c	
65-90	Bss1	10YR 3/2	Clay	2 m abk	vh	fi	vsvp	Strong	m m	
90-120	Bss2	10YR 3/1	Clay	2 m abk	vh	vfi	vsvp	Violent	m m	
Pedon 6 : Chistur (Typic Haplusterts)										
0-20	Ap	10YR 3/3	Clay	2 m sbk	h	fr	sp	Slight	f c	Slickensides below 78 cm depth.
20-45	A1	10YR 3/2	Clay	2 m sbk	h	fr	sp	Slight	f c	
45-78	Bw	10YR 3/2	Clay	2 m abk	h	fi	svp	Strong	f c	
78-100	Bss1	10YR 3/1	Clay	2 m abk	vh	fi	vsvp	Strong	m m	
100-140	Bss2	10YR 3/1	Clay	2 m abk	vh	fi	vsvp	Strong	m m	

The site and morphological characteristics of these soils were recorded and horizonwise soil samples were collected (Soil Survey Division Staff 1995). The mechanical composition of soils was estimated by following international pipette method (Piper 1966). For estimation of saturated hydraulic conductivity, 200 g of air dry sample (< 2 mm) dumped in one motion in the permeameter that was fitted with a screen and filter paper. The permeameter was then tapped 100 times to attain a uniform bulk density. After saturating the soil with distilled water, the saturated hydraulic conductivity was measured using the constant head method of Richards (1954). Water dispersible clay (WDC) was estimated by U.S.D.A. method (1972) and coefficient of linear extensibility (COLE) by methods outlined in Schafer and Singer (1976).

The fine earth fraction was analysed for pH, exchangeable cations, cation exchange capacity (CEC) according to method outlined by Jackson (1973). The saturation extract of soils was analysed for ECe and water soluble cations and anions (Richards 1954).

Table 2. Physical properties of soils

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	sHC (cm hr^{-1})	COLE (cm cm^{-1})	VSP (%)	Water dispersible Clay (%)
Pedon 1 : Belora							
0-15	8.9	36.6	54.5	1.37	0.21	77.2	16.0
15-45	10.0	35.8	54.2	1.16	0.20	72.8	17.5
45-75	10.6	36.0	53.4	1.12	0.21	75.2	16.7
75-105	9.0	34.6	56.4	0.65	0.22	81.6	20.5
105-145	12.1	30.0	57.9	0.45	0.16	68.5	21.2
Pedon 2 : Kinhala							
0-20	10.0	34.9	55.1	0.52	0.23	86.1	22.2
20-35	8.5	35.1	56.4	0.56	0.21	75.2	24.5
35-55	11.7	30.6	57.7	0.50	0.20	72.8	25.5
55-75	9.2	32.6	58.2	0.38	0.23	86.1	26.0
75-100	16.6	29.5	53.9	1.10	0.15	52.1	17.3
Pedon 3 : Sujatpur							
0-20	9.5	37.8	52.7	0.48	0.20	72.8	22.0
20-37	7.9	35.4	56.7	0.08	0.23	86.1	21.5
37-60	10.1	27.3	62.6	0.02	0.25	95.3	23.7
60-100	9.4	26.8	63.8	0.01	0.27	100.0	24.5
100-145	10.3	24.6	65.1	0.01	0.26	100.0	23.2
Pedon 4 : Bharaswada							
0-18	9.0	34.3	56.7	0.62	0.20	72.8	20.0
18-40	9.4	33.2	57.4	0.88	0.21	75.2	21.7
40-73	10.5	30.2	59.3	1.34	0.23	86.1	22.7
73-120	11.1	26.8	62.1	1.21	0.23	86.1	23.7
Pedon 5 : Devgaon							
0-18	11.4	31.0	57.6	0.25	0.23	86.1	25.7
18-40	12.7	28.6	58.7	0.23	0.22	81.6	24.7
40-65	14.2	26.0	59.8	0.25	0.21	77.2	25.5
65-90	13.8	24.6	61.6	0.12	0.23	86.1	26.5
90-130	15.3	23.3	61.4	0.06	0.19	68.5	26.2
Pedon 6 : Chistur							
0-20	10.8	33.2	56.0	1.44	0.18	64.3	24.2
20-45	11.5	31.9	56.6	0.67	0.19	68.5	23.5
45-78	13.9	27.6	58.5	1.32	0.19	68.5	24.5
78-100	10.9	28.3	60.8	0.14	0.20	72.8	23.0
100-140	13.6	25.1	61.3	0.29	0.18	64.3	24.7

Results and Discussion

Morphological properties

Table 1 presents the morphometric properties of the soils. The depth of the soils varied from 100 to 145 cm and their colour varied from dark brown (10 YR 3/3M) to very dark gray (10 YR 3/1M). The surface horizons of all the pedons had subangular blocky structure and hard (dry), friable (moist) and sticky (wet) consistency (Table 1). However, subsurface horizons had angular blocky structure and was hard to very hard (dry) and firm to very firm (moist) consistency (see table-1). These soils showed well developed slickensides (35 cm onwards) with wedge shaped aggregates that broke into angular blocks. The effervescence with dilute HCl was slight in surface horizons and strong to violent in subsurface horizons. The occurrence of iron and manganese concretions in pedon 3 and 5 reflects the poor drainage condition of these soils.

Physical characteristics

The physical properties of the soils are presented in table 2. The soils were clayey and clay content ranged from 52.7 to 65.1%. The silt and sand content ranged from 23.3 to 36.6% and 7.9 to 16.6%, respectively. The water dispersible clay ranged between 16.0 and 26.5% which increased with depth. The COLE and volumetric shrinkage potential (VSP) varied from 0.15 to 0.27 cm cm^{-1} and 52.1 to 100 %, respectively. The saturated hydraulic conductivity (HC) ranged from 0.01 to 1.44 cm hr^{-1} and, in general, it decreased with depth. The HC had significant negative correlation with clay (r= -0.53 at 1% level), WDC (r= -0.52 at 1% level) and COLE (r= -0.40 at 5% level) (Kadu *et al.* 1993).

Chemical Properties

The chemical properties of the soils are presented in table 3. The soils were calcareous and moderately to strongly alkaline in reaction with pH ranging from 7.5 to 8.8. The organic carbon content varied from 1.7 to 9.9 g kg^{-1}. The CEC of the soils were high [46.7 to 61.8 cmol(p^+)kg^{-1}] due to high clay content and predominance of smectite which was evidenced from the CEC/clay ratio (in the order of 0.85 to 1.05). The base saturation ranged from 84 to 99 %. Among the exchangeable cations, Ca was dominant followed by Mg, Na and K in all the pedons except in Bss horizons of pedons 3 and 5, where Mg was found to be dominant. The exchangeable Ca decreased and exchangeable Mg increased with depth. The Ca/Mg ratio was normally between 0.7 to 2.1.

All the soils had ECe less than 4 dSm^{-1} indicating no salinity hazard (Table 3). However, exchangeable sodium percentage (ESP) showed a very wide variation ranging from 1.9 to 17.5 and exchangeable magnesium percentage (EMP) ranged from 29.7 to 46.0. The sodium adsorption ratio (SAR) of the soil saturation extracts ranged from 1.8 to 14.1.

In the Upper Wardha command area, farmers are cultivating 2 to 3 crops in a year or grow crops like sugarcane with canal irrigation. Farmers irrigate the crops by flooding and most of the sub-canals are unlined with uncontrolled seepage. The soils in the area are derived from basaltic alluvium rich in bases and are potentially able to supply Ca, Mg and Na cations. Furthermore, the Deccan basalt is rich in plagioclase feldspars, which is a good source of Na (Pal *et al.* 1989). The introduction of canal irrigation accelerated their dissolution. The quality of canal irrigation water used in this area was C_2S_1 as per US salinity laboratory (Richards 1954), indicating medium salinity and low sodium. Varade *et al.* (1985), Bharambe *et al.* (1992) and Ray *et al.* (2000) reported that the problems of waterlogging and soil salinity are mainly due to unscientific method of irrigation coupled with tendency of farmers to over irrigate their land, topographic situation, aridity of climate, ground water rise (Somawanshi and Patil 1986) and its quality change due to canal seepage and poor drainability of these soils. Drainage of Vertisols is not good, which is further affected due to high sodicity. The presence of sodium further reduces the hydraulic conductivity and relative internal drainage class of the soils of the study area (Table 4). The soil drainage classes were derived as per USDA Soil Survey Manual (Soil Survey Division Staff 1995). The pedons 1 and 4 having ESP

Table 3. Chemical properties of soils

Depth (cm)	pH (1:2.5 soil: H_2O)	ECe (dS m^{-1})	Org. C (g kg^{-1})	$CaCO_3$ (%)	Extractable bases Ca	Mg	Na	K	CEC	Base saturation (%)	ESP*	EMP⁺	Exch. Ca/Mg	SAR $(mmol_c l^{-1})^{1/2}$
					<---------- cmol (p^+) kg^{-1}	----------	----------	----------	---------->					
Pedon 1 : Belora														
0-15	7.8	1.4	5.7	7.2	30.1	14.6	2.9	1.2	49.2	99	5.9	29.7	2.1	3.6
15-45	7.9	0.8	5.3	9.3	27.3	17.9	2.2	1.0	50.1	97	4.4	35.7	1.5	2.8
45-75	8.0	0.8	4.2	9.3	24.8	18.9	1.9	0.8	49.5	94	3.8	38.2	1.3	2.1
75-105	8.1	0.8	3.5	13.3	23.7	20.2	2.9	0.8	51.4	93	5.6	39.3	1.2	2.6
105-145	8.1	1.0	2.4	16.2	23.0	21.4	3.4	0.8	52.3	93	6.5	40.9	1.1	3.4
Pedon 2 : Kinhala														
0-20	7.7	1.2	9.9	6.5	22.3	17.5	4.2	1.7	46.7	98	9.0	37.5	1.3	4.4
20-35	7.8	1.2	6.5	8.1	22.9	16.2	3.6	1.5	48.5	91	7.4	33.4	1.4	3.5
35-55	7.9	1.0	5.6	9.3	21.2	19.5	3.6	1.2	49.6	92	7.3	39.3	1.1	3.4
55-75	7.9	1.0	4.3	11.0	19.5	21.1	3.5	1.0	51.2	88	6.8	41.2	0.9	4.2
75-100	8.0	0.8	3.7	13.3	24.3	15.7	2.2	1.0	49.2	88	4.5	31.9	1.5	2.7
Pedon 3 : Sujatpur														
0-20	8.3	1.9	7.2	18.8	30.2	19.5	4.1	1.4	55.8	99	7.3	34.9	1.5	6.7
20-37	8.6	2.1	5.3	10.6	29.1	19.8	4.6	1.2	55.8	98	8.2	35.5	1.5	8.2
37-60	8.7	2.2	4.6	13.1	25.2	23.5	8.4	1.3	59.6	98	14.1	39.4	1.1	10.7
60-100	8.8	2.5	3.4	11.8	20.3	27.2	10.6	1.4	61.4	97	17.3	44.3	0.7	11.5
100-145	8.8	1.8	2.4	6.3	18.7	28.4	10.8	1.7	61.8	96	17.5	46.0	0.7	14.1
Pedon 4 : Bharaswada														
0-18	7.9	1.3	7.0	8.6	30.5	16.4	1.0	1.7	52.6	94	1.9	31.2	1.9	1.8
18-40	7.9	0.9	6.5	13.5	28.7	18.6	3.0	1.5	54.1	96	5.5	34.4	1.5	3.2
40-73	8.3	1.1	6.3	6.0	27.5	18.9	2.5	1.2	55.2	91	4.5	34.2	1.5	2.2
73-120	8.5	1.1	5.3	9.5	25.9	20.8	2.7	1.1	56.7	89	4.8	36.7	1.2	2.3
Pedon 5 : Devgaon														
0-18	7.6	2.5	6.1	7.3	25.4	16.1	8.9	1.3	53.5	97	16.6	30.1	1.6	10.8
18-40	7.7	1.3	3.6	8.4	27.1	16.8	6.0	1.1	53.2	96	11.3	31.6	1.6	7.2
40-65	8.2	1.1	2.9	7.9	25.5	17.4	5.9	0.9	53.8	92	11.0	32.3	1.5	6.8
65-90	8.2	1.2	1.8	11.8	23.7	19.7	5.6	0.8	54.8	91	10.2	35.9	1.2	6.0
90-130	8.4	1.1	1.8	12.0	21.1	21.6	2.7	0.9	55.3	84	4.9	39.1	1.0	3.6
Pedon 6 : Chistur														
0-20	7.5	1.4	4.5	6.5	28.9	17.9	1.1	1.7	52.3	95	2.1	34.2	1.6	2.5
20-45	7.8	1.1	3.0	6.8	28.3	18.4	2.8	1.5	53.1	96	5.3	34.7	1.5	4.7
45-78	8.2	1.0	1.8	7.2	26.4	21.6	1.8	1.6	52.4	98	3.4	41.2	1.2	3.6
78-100	8.0	1.0	1.8	11.4	23.9	22.0	6.3	1.2	55.4	96	11.4	39.7	1.1	9.8
100-140	7.9	1.3	1.7	11.3	22.8	21.2	5.0	1.2	54.2	93	9.2	39.1	1.1	8.4

* ESP = Exchangeable sodium percentage, ⁺EMP = Exchangeable magnesium percentage

1.9 to 6.5 have been grouped under imperfectly drained class, pedons 2 and 6 (ESP 4.5 to 11.4) under poorly drained class and pedons 3 and 5 (ESP 4.9 to 17.5) under very poorly drained class (Table 4). Similar results were also reported by Kadu *et al.* (1993) for soils of the Purna valley.

The above results suggest that the hydraulic properties of the soils of this command area were significantly impaired by the increase in sodium content of these soils as shown by the significant negative correlation between HC and ESP (r= -0.73 at 1 % level) and HC and SAR (r= -0.73 at 1 % level). It has been observed that magnesium alongwith sodium is also responsible for the impairment of HC because magnesium is also capable of effective dispersion in soil systems (Balpande *et al.*1996, Vaidya and Pal 2002). This is also reflected by negative significant correlation between HC and EMP + ESP (r= -0.70 at 1 % level) and positive significant correlation between HC and exchangeable Ca/Mg ratio (r= 0.53 at 1 % level). The correlation indicates that the saturation of these soils, not only with Na ions, but also with Mg ions leads to greater dispersion of clay and thereby clogging of small pores in the soil. In other words, Mg ions are less efficient than Ca ions in flocculating soil colloids (Rengaswamy *et al.*1986). The hydraulic properties of soils are impaired initially by Mg which are further aggravated by Na (Kadu *et al.* 2003). The significant positive correlation between WDC and ESP (r = 0.40 at 5 % level) indicate that the impairment of hydraulic properties was largely due to dispersion of clay which can be caused by sodium and magnesium. The general increase of both COLE and WDC and the decrease of HC with depth suggest that the swelling of clay smectite, together with dispersion of clay have adversely affected the hydraulic properties of these soils. (Balpande *et al.* 1996; Kadu *et al.* 2003).

These soils have high moisture storage capacity and very low hydraulic conductivity and thus get flooded during rainy season. Therefore, proper selection of crops and provision of surface drainage are essential for sustainable crop production. There is possibility of development of perched water table conditions in some parts within the command area. Irrigation with longer interval are recommended for these soils. Monitoring of ground water table and salinity/sodicity of soils are essential in order to take timely remedial measures in the event of development of perched water table conditions.

Table 4. ECe, ESP, sHC and drainage class of soils

Pedon	**ECe (dS m^{-1})**	**ESP**	**sHC (cm hr^{-1})**	**Drainage class**
Belora	0.8 – 1.4	3.8 to 6.5	0.45 to 1.37	Imperfectly or somewhat poorly drained
Kinhala	0.8 – 1.2	4.5 to 9.0	0.38 to 1.1	Poorly drained
Sujatpur	1.8 – 2.5	7.3 to 17.5	0.01 to 0.48	Very poorly drained
Bharaswada	0.9 – 1.3	1.9 to 5.5	0.62 to 1.34	Imperfectly or somewhat poorly drained
Devgaon	1.1 – 2.5	4.9 to 16.6	0.06 to 0.25	Very poorly drained
Chistur	1.0 – 1.4	2.1 to 11.4	0.29 to 1.44	Poorly drained.

References

Balpande, S. S., Deshpande, S. B. and Pal, D. K. (1996). Factors and processes of soil degradation in Vertisols of the Purna valley, Maharashtra, India. *Land Degradation and Development* **7**, 313 - 323.

Bharambe, P. R., Rodge, R. P. and Ambegaonkar, P. R. (1992). Depth and quality of underground water as affected by canal irrigation. *Journal of the Indian Society of Soil Science* **40**, 344-347.

Jackson, M.L. (1973). Soil Chemical Analysis. Prentice Hall of India, New Delhi.

Kadu, P.R., Pal, D. K. and Deshpande, S. B., (1993). Effect of low exchangeable sodium on hydraulic conductivity and drainage in shrink-swell soils of Purna valley, Maharashtra. *Clay Research* **12**, 65-70.

Kadu, P.R., Vaidya, P.H., Balpande, S.S., Satyawati, P.L.A. and Pal, D.K. (2003). Use of hydraulic conductivity to evaluate the suitability of Vertisols for deep rooted crops in semi arid parts of central India. *Soil Use and Management* **19**, 208-216.

Pal, D. K., Deshpande, S. B., Venugopal, K. R. and Kalbande, A. R. (1989). Formation of di-and tri-octahedral smectite as evidence for paleoclimatic changes in southern and central peninsular India. *Geoderma* **45**, 175-184.

Piper, C.S. (1966). Soil and Plant Analysis. Hans Publishers, Bombay, India.

Ray, S. K., Gajbhiye, K. S., Challa, O., Jagdish Prasad, Singh, S.R., Anantwar, S. G., Gaikwad, M. S. and Padihar, S. K. (2000). Systematic soil survey to identify potential soil sodicity areas in parts of Tawa Command, Madhya Pradesh. *Journal of the Indian Society of Soil Science* **48**, 346-351.

Rengaswamy, P., Greene, R.S.B. and Ford, G.W. (1986). Influence of magnesium on aggregate stability in sodic red brown earths. *Australian Journal of Soil Research* **24**, 229 – 237.

Richards, L.A. (Ed) (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Agriculture Handbook, Vol. 60, US Department of Agriculture, Government Printing Office, Washington, DC.

Schafer, W. M. and Singer, M. J. (1976). A new method for measuring swell-shrink potential using soil paste. *Soil Science Society of America Journal* **40**, 805-806.

Singh, R., Bhargava, G.P. and Tiwari, C. B. (1994). Hydraulic characteristics of some Entisols, Inceptisols and Vertisols and their role in salt and water management. *Journal of the Indian Society of Soil Science* **42**, 341-346.

Soil Survey Division Staff (1995). Soil Survey Manual, Handbk. 18, US Department of Agriculture, Government Printing Office, Washington D.C.

Somawanshi, R. B. and Patil, A. H. (1986). Effects of irrigation and location of canal on the salinity of soil and underground water from different soil series. *Journal of Maharashtra Agricultural Universities* **11**, 1-3.

U.S.D.A. (1972). Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples. Soil Conservation Service, US Department of Agriculture, Government Printing Office, Washington D.C.

Vaidya, P. H. and Pal, D. K. (2002). Microtopography as a factor in the degradation of Vertisols in central India. *Land Degradation and Development* **13**, 429-445.

Varade, S. B., Palaskar, M. S. and More, S.D. (1985). Characteristics of salt affected Vertisols in canal command. *Journal of Maharashtra Agricultural Universities* **10**, 115-118.

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