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Original Research Article

Characterization and Classification of Soils of Drought Prone Area of Krishna Valley in Marathwada Region of Maharashtra, India

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A B S T R A C T

Fifteen representative pedons from different topographic unit of Krishna valley in Marathwada region were characterized and classified. The soils were very shallow to very deep (17 to 150 cm) in depth, black (10YR 2.5/1) to very pale brown (10YR 7/4) in colour, loam to clayey in texture and medium weak subangular blocky to medium strong angular blocky in structure.The bulk density in surface and subsurface soils ranged from 1.28 to 1.78 Mg m^{-3} whereas in murrum (Cr horizon) layer it was ranged 1.89 to 2.38 Mg m^{-3}.The soils were slightly to moderately alkaline in reaction, the electrical conductivity was < 1 dSm^{-1}, very low to medium in organic carbon content and calcareous in nature. The calcium was the dominant cation followed by magnesium, sodium and potassium. Taxonomically, these soils were classified as Typic Ustorthents, Typic Haplustepts, Vertic Haplustepts, Typic Haplusterts, Calcic Haplusterts and Sodic Haplusterts. The morphological, physical and chemical properties of soil were differing in relation to microtopographic position of soil profile.

Keywords

Soil classification, Morphological, Physical, Chemical characteristics

Introduction

Soil is one of the most precious natural resource, which provides a medium for plant growth to meet our food and fiber need. Agricultural technologies that lead to green revolution resulted in the degradation of this precious natural resource owing to over exploitation under intensive irrigation and cultivation with mis-management. Due to this soil has reached a stage of fatigue resulting in the decline of productivity and fertility of soil. In order to meet the ever increasing food requirement for growing population, it is essential that soil and water resources should be used judiciously. Indiscriminate use of land resources, in general lead to their degradation and in turn decline in productivity. They need to be used according to their capacity to satisfy the needs of its inhabitants. This can be achieved through proper investigation of land resources and their scientific evaluation. Land suitability evaluation is the process of estimating the potential of land for land use planning (Sys *et al*. 1991).

In Maharashtra, most of the soils have developed over basaltic parent materials and are heavier in texture and productive. Most of the soils of North-East part of the Krishna valley are shallow to moderately deep soils are generally underlined by murrum layer. The murrum (Saprolite) layer has been

defined by Tamhane*et al*.(1976) as stony and gravelly layer below the solum. Some soils of Krishna valley are highly calcareous in nature, the $CaCO_3$ deposits are concentrated into layers that may be very hard and impermeable to water. These caliche layers are formed by rainfall leaching the salts to a particular depth in the soils at which water content is very low that carbonates precipitate (Jackson and Erie, 1973). Taxonomic and pedogenic classification and characterization of these soils is of importance for land use planning and soil resource management under the existing subtropical climatic conditions. The present investigation was undertaken to characterize and classify the soils of Krishna valley in Marathwada region of Maharashtra.

Materials and Methods

Geographically the North-East part of the Krishna valley in Marathwada region of Maharashtra is located between 18^0 07' 83" to 18^0 37' 96" N latitudes and 75^0 17'14" to 75^0 49'14" E longitudes. The general elevation of area ranges from 507 to 797 m above mean sea level. The climate of the area is hot, dry, sub humid with mean annual rainfall of 870 mm and mean maximum and minimum air temperature are 33.4^0C and 18.6^0C, respectively. Based on topographic position fifteen pedons were selected, exposed and studied morphometrically (Soil Survey Staff, 2015). The horizonwise soil samples were collected, processed and analyzed for physico-chemical properties using standard analytical techniques. Particle size analysis was carried out by international pipette method (Jackson, 1979). Water retention characteristics were determined by pressure plate apparatus and PAWC determined by expression suggested by Gardner *et al*. (1984). Bulk density of soils was determined by clod coating technique (Black, 1965). The pH, EC, organic carbon, $CaCO_3$, exchangeable cations and cation exchange capacity (CEC) were determined by standard procedure (Jackson, 1973). The soils were classified as per keys to soil taxonomy (Soil Survey Staff, 2015).

Results and Discussion

Morphological characteristics

The morphological characteristics of the soils were presented in table 1. The soils of Krishna valley in Marathwada region were very shallow to very deep (17 to 150 cm) in depth. The depth of soil was gradually decreases with increasing elevation.The soils of the study area were black (10YR 2.5/1) to very pale brown (10YR 7/4) in colour. The black colour of soil mainly due to presence of titaniferrous magnetite and 1 to 2 per cent soluble humus (Annet, 1910). The soil structure of the study area varies from medium, weak, sub-angular blocky to medium, strong, angular blocky in structure.The soil consistency varied from smooth to very hard in dry condition, friable to firm in moist condition and non sticky, non plastic to very sticky, very plastic in wet condition. The soil consistency closely associated with proportion of sand, silt and clay. In soils of Calcic Haplusterts (P_3 and P_4) very hard consistency in Bss_1 horizon were observed in dry condition. This may be attributed to high amount of $CaCO_3$, it tends to have a cementing effect (Ann McCauley *et al*. 2005).

Physical characteristics

The data on physical characteristics of soils were presented in table 2. The surface and subsurface soils had lower bulk density values (1.28 to 1.78 Mg m^{-3}) as compared to murrum (Cr horizon) layer (1.89 to 2.38 Mg m^{-3}). The lower bulk density in surface soil

than subsurface may be due to higher organic matter and less compactness. High bulk density value in subsurface layers may be due to smectite clay and over burden leading to compaction, slickensides, caused strong structural aggregate formation and high bulk density and root development have the inverse relationship (Gupta and Gupta, 1978). It was also observed that the soils of Sodic Haplusterts (P_{11}) and Calcic Haplusterts (P_3 and P_4) has high bulk density in Bss_1 and Bss_2 horizon, this may be due to high $CaCO_3$ (Table 3). The $CaCO_3$ tend to have a cementing effect and form a hardpan in subsurface layers which increases compactness (Ann McCauley *et al*. 2005). The saturated hydraulic conductivity as per weighted mean of soil profile depth of studied soils varies from 0.23 to 22.44 cm hr^{-1}. This variation is attributed to textural difference. The calcium carbonate influence the physical properties of soil both at the level of soil horizons and soil aggregates. The poor physical properties of many interior B-C subsoils, such as high bulk density and low macro porosity (Lewis *et al*. 1991) and more compacted and cemented at depth (Lavagne and Moutte, 1963) which inhibits infiltration rate and hydraulic conductivity of soils. However, it also observed that the hydraulic conductivity of SodicHaplusterts (P_{11}) was found lower (0.68 cm hr^{-1}). This might be due to high exchangeable sodium per cent at a depth, similar observations were reported by Balpande *et al*. (1996); Vaidya and Pal (2002). The soils of study area were silty clay loam to clayey in texture. The data indicated that soils developed on level topography showed higher clay content as compare to soil developed on undulating topographic position. Topography and slope were found to affect the particle size distribution.The moisture retention of soils mainly dependent upon the amount, size of clay fraction and type of clay minerals. The data (Table 2) indicated that moisture retention in soils varied from 18.37 to 53.06 per cent at 33 kPa and 11.37 to 29.35 per cent at 1500 kPa, in different horizons of pedons. In general, deep soils Typic Haplusterts (P_7), Calcic Haplusterts (P_3 and P_4) and Sodic Haplusterts (P_{11}) showed higher moisture retention, which may be attributed to the increase in clay and the smectite clay minerals that have large surface area to retain higher amount of water at high suction (Ali and Biswas, 1971).The available water capacity of the soils ranged from 4.10 to 29.23 per cent and plant available water capacity ranged between 59.98 to 392.15 mm. The murrum layer recorded low PAWC compared to their respective soil.PAWC was found to increase with depth of the soil. It has been recorded by Gardner *et al.* (1984) that the plant available water capacity is limited by rooting depth. The capacity of soils to store moisture for plant use is largely a function of their clay content, depth of soils and mineralogy of soil.

Chemical characteristics

The data pertaining to chemical characteristics of soils were presented in table 3. The soils were slightly to moderately alkaline in reaction with pH ranged from 7.10 to 8.27. The higher pH values in soils may be due to the accumulation of calcium carbonate, soluble salts washed down from upper elevation (Arnold and Venkateshwarlu, 1982) and basaltic parent material (Chinchmalatpure*et al*. 2000). Electrical conductivity of studied soils varied from 0.07 to 0.77 dSm^{-1}, which is well within safe limit.The organic carbon content of soils varied from 0.09 to 0.93 per cent in different horizons indicating that soils were very low tohigh in organic carbon content.

Table.1 Morphological characteristics of soils of Krishna valley in Marathwada region

Horizons	Depth (cm)	Boundary		Matrix colour	Texture	Structure	Consistency			Pores		Roots		Effervescences
		D	T				Dry	Moist	Wet	S	Q	S	Q	
Pedon-1 KhanapurTa. Washi Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-20	c	s	10YR3/3	sil	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	--
AC	20-29	a	s	10YR3/3	l	m1sbk	l	fr	sssp	vf	m	vf	m	--
Cr	29-50			10YR7/4	Weathered basalt									
Pedon-2 ShekapurTa. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, VerticHaplustepts)														
Ap	0-27	c	s	10YR3/1	sic	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	es
Bw1	27-50	c	s	10YR2.5/1	sic	m1sbk	s	fr	sssp	f	m	f	m	es
Bw2	50-64	c	s	10YR3/1	sic	m2sbk	s	fr	sssp	f	m	f	m	es
Cr	64-80			10YR7/2	sil	m 2 gr	Weathered basalt							
Pedon-3 Sirsav Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, Calcic Haplusterts)														
AP	0-20	c	s	10YR3/1	c	m2sbk	sh	fr	vsvp	vf, f	m, m	vf, f	m, m	es
Bw	20-33	c	s	10YR2.5/1	c	m3abk	vh	fi	vsvp	vf, f	f, f	vf, f	f, f	es
Bss1	33-60	c	s	10YR2.5/1	c	m3abk	vh	fi	vsvp	vf, f	f, f	vf, f	f, f	ev
Bss2	60-87	c	s	10YR3/2	c	m2abk	h	fi	vsvp	vf, f	f, f	vf, f	f, f	ev
Ck1	87-120	c	s	10YR4/3	c	m1abk	s	fr	sssp	f	f	m	c	ev
Ck2	120-150			10YR4/4	c	m1sbk	s	fr	sssp	f	f	m	c	ev
Pedon-4 AasuTa. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, Calcic Haplusterts)														
AP	0-26	c	s	10YR3/2	c	m2sbk	sh	fr	vsvp	vf, f	m, m	vf, f	m, m	ev
Bw	26-48	c	s	10YR3/1	c	m3abk	vh	fi	vsvp	vf, f	f, f	vf, f	f, f	ev
Bss1	48-66	c	s	10YR3/2	c	m3abk	vh	fi	vsvp	vf, f	f, f	vf, f	f, f	ev
Bss2	66-104	c	s	10YR3/2	c	m2abk	h	fi	vsvp	f	f	vf, f	f, f	ev
Ck	104-150			10YR4/3	c	m1sbk	s	fr	sssp	m	f	m	f	ev
Pedon-5 Dhagpimpri Ta. Paranda Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-11	c	s	10YR3/3	sicl	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	--
AC	11-26	c	s	10YR4/4	sicl	m1sbk	s	fr	sssp	vf	m	vf	m	--
Cr	26-50			10YR5/6	cl	m 1 gr	Weathered basalt							
Pedon-6 Khasapur Ta. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-8	c	s	10YR3/2	sic	m2abk	h	fr	vsvp	vf	m	vf	m	es
Bw1	8-15	c	s	10YR3/1	c	m2sbk	h	fr	vsvp	vf	m	vf	m	es
Bw2	15-26	g	w	10YR4/2	cl	m1gr	s	fr	sssp	f	f	f	f	es
Cr	26-42			10YR5/2	Weathered basalt									
Pedon-7 Sukta Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplusterts)														
Ap	0-17	c	s	10YR3/2	c	m2sbk	sh	fr	sssp	vf, f	m, m	vf, f	m, m	es
Bw	17-37	c	s	10YR4/3	c	m2sbk	sh	fr	vsvp	vf, f	m, f	vf, f	m, f	es
Bss1	37-57	c	s	10YR3/3	c	m2abk	h	fi	vsvp	vf, f	m, f	f, f	m, f	es
Bss2	57-74	c	w	10YR5/4	c	m2abk	h	fi	vsvp	vf, f	m, f	vf, f	m, f	es
BC	74-110	c	w	10YR5/3	c	m2sbk	s	fr	vsvp	c	m	m	c	es
Cr	110-150			10YR5/3	sic	m2sbk	s	fr	nsnp	-	-	-	-	es
Pedon-8 Pardi Ta. Washi Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-17	c	w	10YR5/3	sil	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m,	e

													m	
A2	17-32	c	w	10YR5/4	sil	m1sbk	s	fr	sssp	c	m	vf	m	es
AC	32-49	g	w	10YR6/3	sil	m1gr	s	fr	nsnp	c	f	vf	f	es
Cr	49-80			10YR4/6	scl	m2gr	Weathered basalt							

Horizons	Depth (cm)	Boundary		Matrix colour	Texture	Structure	Consistency			Pores		Roots		Effervescences
		D	T				Dry	Moist	Wet	S	Q	S	Q	
Pedon-9 Irachiwadi Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-22	c	s	10YR4/4	l	m1sbk	s	fr	nsnp	vf, f	m, m	vf, f	m, m	--
Bw	22-33	c	w	10YR4/4	l	m1sbk	s	fr	nsnp	f	m	f	m	--
Cr	33-50			10YR6/3	Weathered basalt									
Pedon-10 Walha Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-24	c	s	10YR3/3	cl	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	--
C	24-70			10YR6/2	scl	m2gr	s	fr	nsnp	f	m	f	f	--
Pedon-11 Pachpimpla Ta. Paranda Dist. Osmanabad (Very fine, Smectitic, Isohyperthermic, SodicHaplusterts)														
Ap	0-22	c	s	10YR3/2	c	m2sbk	sh	fr	vsvp	vf, f	m, m	vf, f	m, m	es
Bw	22-43	c	s	10YR3/2	c	m3abk	vh	fi	vsvp	vf, f	m, f	f	f	ev
Bss	43-75	c	s	10YR3/1	c	m3abk	vh	fi	vsvp	vf, f	f, f	f	f	ev
BC1	75-90	c	s	10YR3/3	c	m2abk	h	fi	vsvp	f	m	c	c	ev
BC2	90-150	-	-	10YR3/1	c	m2abk	s	fr	nsnp	-	-	-	-	ev
Pedon-12 Watephal Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-16	c	s	10YR4/4	c	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, f	--
Bw	16-35	c	s	10YR4/4	l	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, f	--
Cr	35-50	-	-	10YR4/4	l	m1gr	Weathered basalt							
Pedon-13 Shailgaon Ta. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, VerticHaplustepts)														
Ap	0-16	c	s	10YR3/4	c	m2sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	es
Bw1	16-33	c	s	10YR2.5/1	c	m2sbk	s	fr	sssp	vf	m	vf	m	es
Bw2	33-55	c	s	10YR2.5/1	sic	m2sbk	s	fr	sssp	vf	m	vf	m	ev
Cr	55-75	-	-	10YR5/2	sicl	m2gr	Weathered basalt							
Pedon-14 Jejala Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-17	c	s	10YR3/1	sic	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	--
Bw	17-27	c	s	10YR2.5/1	c	m1sbk	s	fr	sssp	vf	m	c	m	--
Cr	27-45	-	-	10YR3/3	sc	m2gr	Weathered basalt							
Pedon-15 Nali Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-17	c	s	10YR3/3	c	m1sbk	s	fr	sssp	vf, f	m, m	vf, f	m, m	--
Cr	17-35	-	-	10YR5/6	sl	m2gr	Weathered basalt							

Table.2 Physical characteristics of soils of Krishna valley in Marathwada region

Horizons	Depth (cm)	Coarse Fragment (%)	B D (Mg m^{-3})	HC (cm hr^{-1})	Particle size analysis(%)			Moisture retention (%)		AWC (%)	PAWC (mm)
					Sand	Silt	clay	33 kPa	1500 kPa		
Pedon-1 KhanapurTa. Washi Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)											
Ap	0-20	8.14	1.74	14.12	28.40	51.60	20.00	26.64	16.64	10.00	91.5
AC	20-29	9.75	1.77	15.84	38.90	36.10	25.00	27.06	16.87	10.19	
Cr	29-50	36.36	2.03	20.28	52.00	28.00	20.00	24.52	14.77	9.75	
Pedon-2 ShekapurTa. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, VerticHaplustepts)											
Ap	0-27	10.25	1.52	14.16	12.21	43.35	44.44	38.02	23.42	14.60	150
Bw1	27-50	10.41	1.55	15.71	13.81	44.08	42.11	37.36	23.11	14.25	
Bw2	50-64	13.15	1.58	17.35	15.31	42.47	42.22	25.69	18.20	7.49	
Cr	64-80	26.66	1.67	24.62	14.56	64.67	20.77	22.31	16.73	5.58	
Pedon-3 Sirsav Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, Calcic Haplusterts)											
AP	0-20	10.00	1.53	3.92	9.87	40.14	49.99	37.15	23.92	13.23	252.5
Bw	20-33	11.11	1.62	3.29	9.26	37.97	52.77	39.52	24.30	15.22	
Bss1	33-60	16.00	1.72	1.78	8.54	35.91	55.55	42.56	24.79	17.77	
Bss2	60-87	21.73	1.84	0.73	8.65	31.69	59.66	47.83	27.07	20.76	
Ck1	87-120	13.33	1.70	0.61	8.76	27.36	63.88	52.65	29.35	23.30	
Ck2	120-150	17.64	1.71	0.82	8.70	30.52	60.77	49.14	27.46	21.68	
Pedon-4 AasuTa. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, Calcic Haplusterts)											
AP	0-26	4.89	1.66	6.47	17.87	34.91	47.22	35.07	23.38	11.69	277.47
Bw	26-48	17.85	1.68	3.20	18.10	26.72	55.18	35.08	22.63	12.45	
Bss1	48-66	8.33	1.69	2.13	18.31	20.59	61.10	46.72	26.14	20.58	
Bss2	66-104	25.00	1.83	1.56	17.55	22.94	59.51	43.48	25.47	18.01	
Ck	104-150	38.46	1.94	1.12	17.26	26.41	56.33	38.21	24.55	13.66	
Pedon-5 Dhagpimpri Ta. Paranda Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)											
Ap	0-11	7.69	1.70	11.38	9.21	54.68	36.11	33.46	20.91	12.55	111.62
AC	11-26	18.51	1.71	15.65	10.32	61.10	28.58	30.65	18.12	12.53	
Cr	26-50	50.00	2.06	18.93	29.82	42.68	27.50	28.73	17.40	11.33	
Pedon-6 Khasapur Ta. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplustepts)											
Ap	0-8	11.53	1.61	2.97	5.71	45.96	48.33	39.76	23.40	16.36	84.91
Bw1	8-15	25.00	1.68	4.09	21.42	31.14	47.44	34.12	21.03	13.09	
Bw2	15-26	24.00	1.70	4.48	34.02	29.87	36.11	27.55	16.94	10.61	
Cr	26-42	28.39	1.83	10.12	31.54	37.69	30.77	24.38	14.61	9.77	
Pedon-7 Sukta Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplusterts)											
Ap	0-17	12.19	1.52	5.46	6.20	33.80	60.00	47.84	26.18	21.66	265.41
Bw	17-37	14.28	1.59	4.99	3.50	36.17	60.33	47.89	26.64	21.25	
Bss1	37-57	17.24	1.79	6.73	1.40	38.49	60.11	46.80	26.09	20.71	
Bss2	57-74	35.71	1.75	8.86	3.15	46.30	50.55	45.84	25.55	20.30	
BC	74-110	42.30	1.71	8.12	2.10	37.58	60.22	47.56	25.78	21.78	
Cr	110-150	44.25	1.89	11.62	2.60	42.40	55.00	46.11	25.34	20.77	
Pedon-8 Pardi Ta. Washi Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)											
Ap	0-17	6.66	1.28	15.74	14.20	60.14	25.66	32.34	19.97	12.37	
A2	17-32	10.76	1.40	18.87	18.49	56.40	25.11	33.11	21.64	11.47	

AC	32-49	39.09	1.44	20.41	30.40	49.60	20.00	28.63	17.21	11.42	164.21
Cr	49-80	45.15	2.39	24.53	52.46	22.10	25.44	29.59	17.43	12.16	
Horizons	Depth (cm)	Coarse Fragment (%)	B D ($Mg\ m^{-3}$)	HC ($cm\ hr^{-1}$)	Particle size analysis(%)			Moisture retention (%)		AWC (%)	PAWC (mm)
					Sand	Silt	clay	33 kPa	1500 kPa		
Pedon-9 Irachiwadi Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicHaplustepts)											
Ap	0-22	13.04	1.39	14.52	35.18	39.83	24.99	23.72	13.59	10.13	84.16
Bw	22-33	11.11	1.53	14.28	40.73	34.28	24.99	23.52	13.89	9.63	
Cr	33-50	37.50	2.29	23.79	37.65	43.80	18.55	20.87	11.37	9.50	
Pedon-10 Walha Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)											
Ap	0-24	14.70	1.41	11.47	21.26	38.75	39.99	36.99	21.62	15.37	89.54
C	24-70	45.25	1.99	18.60	48.14	27.75	24.11	22.15	18.05	4.10	
Pedon-11 Pachpimpla Ta. Paranda Dist. Osmanabad (Very fine, Smectitic, Isohyperthermic, SodicHaplusterts)											
Ap	0-22	9.52	1.78	2.65	4.66	31.46	63.88	40.38	20.24	20.14	392.15
Bw	22-43	10.71	1.67	1.34	4.96	32.93	62.11	46.21	21.63	24.58	
Bss1	43-75	20.68	1.74	0.28	5.21	30.91	63.88	51.60	23.48	28.12	
BC1	75-90	25.00	1.63	0.23	4.52	32.99	62.49	52.45	23.61	28.84	
BC2	90-150	26.66	1.82	0.30	3.71	35.19	61.10	53.06	23.83	29.23	
Pedon-12 Watephal Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicHaplustepts)											
Ap	0-16	7.69	1.48	14.32	18.20	34.58	47.22	36.46	19.30	17.16	111.11
Bw	16-35	6.66	1.53	14.78	38.18	36.83	24.99	32.81	17.55	15.26	
Cr	35-50	60.00	1.53	25.13	46.89	34.56	18.55	27.50	16.12	11.38	
Pedon-13 Shailgaon Ta. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, VerticHaplustepts)											
Ap	0-16	4.34	1.58	8.51	5.16	36.51	58.33	39.46	20.44	19.02	225.66
Bw1	16-33	8.33	1.73	8.14	7.24	35.99	56.77	40.37	21.51	18.86	
Bw2	33-55	12.50	1.73	7.65	3.71	40.74	55.55	32.61	16.10	16.51	
Cr	55-75	61.11	1.85	18.81	20.14	46.75	33.11	28.69	12.67	16.02	
Pedon-14 Jejala Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplustepts)											
Ap	0-17	11.11	1.59	12.24	7.88	47.68	44.44	42.79	23.40	19.39	126.97
Bw	17-27	10.71	1.64	12.90	6.43	24.13	69.44	43.78	24.45	19.33	
Cr	27-45	52.17	1.80	23.55	23.71	35.96	40.33	29.11	15.88	13.23	
Pedon-15 Nali Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)											
Ap	0-17	4.76	1.64	16.34	22.25	22.20	55.55	29.44	15.93	13.51	59.98
Cr	17-35	65.55	2.38	28.21	53.26	34.52	12.22	18.37	13.16	5.21	

Table.3 Chemical characteristics of soils of Krishna valley in Marathwada region of Maharashtra

Horizons	Depth (cm)	pH	EC (dSm^{-1})	O.C. (%)	$CaCO_3$ (%)	CEC [cmol (p^+) kg^{-1}]	Cations [cmol (p^+) kg^{-1}]				Sum of cations	B.S. (%)	ESP (%)	EMP (%)
							Ca^{++}	Mg^{++}	Na^+	K^+				
Pedon-1 KhanapurTa. Washi Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-20	7.22	0.18	0.33	4.81	33.98	14.8	12.8	1.55	0.18	29.33	86.31	4.56	37.67
AC	20-29	7.31	0.21	0.27	4.05	30.16	19.2	07.2	1.38	0.18	27.96	92.70	4.57	23.87
Cr	29-50	7.49	0.09	0.11	3.70	28.50	16.0	10.0	1.46	0.15	27.61	96.87	5.12	35.09

Pedon-2 ShekapurTa. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, VerticHaplustepts)														
Ap	0-27	7.46	0.17	0.77	14.72	57.41	39.6	14.0	1.55	0.85	56.0	97.54	2.69	24.39
Bw1	27-50	7.10	0.18	0.81	14.07	60.00	35.6	19.6	1.81	0.51	57.52	95.86	3.01	32.67
Bw2	50-64	7.38	0.20	0.32	14.14	54.82	33.6	18.8	1.90	0.49	54.79	99.94	3.46	34.29
Cr	64-80	7.47	0.21	0.24	21.73	41.85	19.6	16.4	1.62	0.36	37.98	91.62	3.87	39.19
Pedon-3 Sirsav Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, Calcic Haplusterts)														
AP	0-20	7.63	0.14	0.50	12.76	72.11	38.0	27.6	1.62	0.43	67.65	93.81	2.24	38.27
Bw	20-33	7.68	0.22	0.44	14.60	78.18	31.6	32.4	3.19	0.38	67.57	86.42	4.08	41.44
Bss1	33-60	8.03	0.28	0.58	16.87	67.26	33.2	25.2	4.32	0.33	63.05	93.74	6.42	37.47
Bss2	60-87	8.13	0.58	0.42	10.12	64.63	32.0	22.4	5.27	0.36	60.03	92.88	8.15	34.66
Ck1	87-120	8.21	0.33	0.37	10.49	58.54	32.4	11.2	4.66	0.31	48.57	82.96	7.96	19.13
Ck2	120-150	8.27	0.60	0.29	12.53	56.86	28.0	12.0	6.39	0.38	46.77	82.25	11.23	21.10
Pedon-4 AasuTa. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, Calcic Haplusterts)														
AP	0-26	7.57	0.16	0.62	14.83	72.19	44.0	23.6	1.03	0.64	69.27	95.95	1.42	32.69
Bw	26-48	7.62	0.21	0.46	15.75	73.24	29.6	28.8	1.38	0.36	60.14	82.11	1.88	39.32
Bss1	48-66	7.64	0.23	0.39	17.41	68.29	39.2	27.2	2.85	0.36	69.61	101.93	4.17	39.83
Bss2	66-104	7.81	0.31	0.37	10.57	65.64	24.8	30.8	4.23	0.33	60.16	91.65	6.44	46.92
Ck	104-150	7.93	0.77	0.39	11.84	57.11	27.6	20.2	6.39	0.33	54.52	95.46	11.18	35.37
Pedon-5 Dhagpimpri Ta. Paranda Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-11	7.59	0.07	0.31	1.95	34.83	16.4	10.0	0.51	0.20	24.57	86.08	1.46	28.71
AC	11-26	7.48	0.07	0.19	0.92	33.18	17.2	12.8	0.60	0.18	30.78	92.76	1.80	38.58
Cr	26-50	7.32	0.15	0.09	1.49	28.54	15.6	8.0	0.77	0.20	24.57	86.08	2.69	28.03
Pedon-6 Khasapur Ta. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-8	7.80	0.17	0.42	12.53	49.19	20.8	14.8	3.11	0.56	39.27	85.01	6.73	30.09
Bw1	8-15	7.91	0.18	0.48	13.80	48.27	23.6	12.8	3.45	0.62	40.47	89.39	7.62	26.52
Bw2	15-26	8.18	0.15	0.40	14.28	46.54	19.6	16.4	2.07	0.54	38.61	82.96	4.44	35.24
Cr	26-42	7.78	0.19	0.29	14.26	42.13	27.0	12.8	1.38	0.59	41.77	99.14	3.27	30.38
Pedon-7 Sukta Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplusterts)														
Ap	0-17	7.65	0.31	0.87	11.73	77.41	41.6	28.8	1.12	0.54	72.06	93.08	1.44	37.20
Bw	17-37	7.72	0.19	0.79	11.27	75.68	42.8	22.4	1.12	0.56	66.88	88.37	1.47	29.60
Bss1	37-57	7.76	0.18	0.66	12.08	70.87	31.2	35.6	1.12	0.62	68.54	96.71	1.58	50.23
Bss2	57-74	7.74	0.18	0.54	12.30	69.14	28.4	36.0	1.29	0.56	66.25	95.82	1.86	52.07
BC	74-110	7.81	0.19	0.33	12.65	70.00	37.2	25.6	1.38	0.51	64.69	92.41	1.97	36.57
Cr	110-150	7.81	0.18	0.19	13.24	52.72	28.2	20.0	1.46	0.33	49.99	94.82	2.76	37.94
Pedon-8 Pardi Ta. Washi Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-17	7.71	0.19	0.93	8.16	33.75	14.0	12.8	0.77	0.12	27.69	82.04	2.28	37.93
A2	17-32	7.72	0.13	0.76	11.36	35.66	14.2	14.4	0.69	0.10	29.39	82.41	1.93	40.38
AC	32-49	7.67	0.13	0.58	15.87	31.75	15.6	12.8	0.77	0.12	29.29	92.25	2.42	40.31
Cr	49-80	7.65	0.12	0.28	7.47	30.61	19.1	10.2	0.69	0.12	30.12	98.39	2.25	33.32

Horizons	Depth (cm)	pH	EC (dSm^{-1})	O.C. (%)	$CaCO_3$ (%)	CEC [cmol (p^+) kg^{-1}]	Cations [cmol (p^+) kg^{-1}]				Sum of cations	B.S. (%)	ESP (%)	EMP (%)
							Ca^{++}	Mg^{++}	Na^+	K^+				
Pedon-9 Irachiwadi Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-22	7.21	0.15	0.44	4.05	30.55	13.8	13.8	0.69	0.15	28.44	93.09	2.25	45.17
Bw	22-33	7.25	0.12	0.42	4.37	28.20	15.8	10.2	0.60	0.15	26.75	94.85	2.12	36.17
Cr	33-50	7.34	0.10	0.31	4.12	24.56	10.4	9.6	0.69	0.12	20.81	84.73	2.80	39.09

Pedon-10 Walha Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-24	7.45	0.13	0.64	5.17	39.68	13.2	10.8	0.86	0.25	25.11	70.37	2.41	27.22
C	24-70	7.48	0.16	0.17	4.94	32.22	10.2	8.4	1.46	0.25	20.31	63.03	4.53	26.07
Pedon-11 Pachpimpla Ta. Paranda Dist. Osmanabad (Very fine, Smectitic, Isohyperthermic, SodicHaplusterts)														
Ap	0-22	7.72	0.42	0.81	13.80	64.82	31.6	22.4	4.49	0.72	59.21	91.34	6.92	34.56
Bw	22-43	7.78	0.49	0.55	16.44	65.43	30.4	28.0	5.61	0.67	64.68	98.85	8.57	42.79
Bss1	43-75	7.84	0.54	0.40	17.02	63.09	20.4	34.4	9.42	0.59	64.81	102.72	14.93	54.53
BC1	75-90	7.91	0.62	0.29	17.87	65.88	17.2	38.4	9.93	0.54	66.07	100.28	15.07	58.29
BC2	90-150	8.00	0.67	0.21	15.29	59.09	19.2	38.0	10.02	0.62	67.84	114.80	16.95	64.31
Pedon-12 Watephal Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-16	7.69	0.12	0.37	3.22	40.59	22.0	14.8	0.77	0.18	37.75	93.00	1.89	36.46
Bw	16-35	7.76	0.10	0.33	5.40	37.54	20.6	13.6	0.69	0.20	35.09	93.47	1.83	36.23
Cr	35-50	7.74	0.10	0.11	2.30	32.31	15.8	10.4	0.95	0.07	27.22	84.24	2.94	32.19
Pedon-13 Shailgaon Ta. Paranda Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, VerticHaplustepts)														
Ap	0-16	7.78	0.17	0.58	15.06	70.54	39.6	25.6	1.55	0.90	67.65	95.90	2.19	36.29
Bw1	16-33	7.80	0.14	0.46	15.87	61.36	34.0	23.6	1.55	0.62	59.77	97.40	2.52	38.46
Bw2	33-55	7.83	0.16	0.48	16.90	63.09	32.8	19.2	1.72	0.36	54.08	85.71	2.72	30.43
Cr	55-75	7.88	0.16	0.23	23.11	47.53	31.2	11.2	1.72	0.38	44.50	93.62	3.61	23.56
Pedon-14 Jejala Ta. Bhoom Dist. Osmanabad (Fine, Smectitic, Isohyperthermic, TypicHaplustepts)														
Ap	0-17	7.58	0.24	0.72	1.95	58.75	40.0	16.0	1.29	0.33	57.62	98.07	2.19	27.23
Bw	17-27	7.49	0.36	0.76	2.53	67.35	46.4	12.0	1.29	0.25	59.94	88.99	1.91	17.82
Cr	27-45	7.52	0.33	0.35	1.03	48.90	30.4	15.2	2.33	0.28	48.21	98.58	4.76	31.08
Pedon-15 Nali Ta. Bhoom Dist. Osmanabad (Loamy, Smectitic, Isohyperthermic, TypicUstorthents)														
Ap	0-17	7.43	0.12	0.31	2.99	55.78	25.6	19.6	0.86	0.23	46.29	82.98	1.54	35.14
Cr	17-35	7.48	0.11	0.13	1.95	31.97	18.9	11.3	0.60	0.07	30.87	96.55	1.87	35.35

Table.4 Classification of soils of Krishna valley in Marathwada region of Maharashtra

PedonNo.	Order	Suborder	Great Group	Subgroup	Family
P_1	Entisols	Orthents	Ustorthents	TypicUstorthents	Loamy, smectitic, isohyperthermic
P_2	Inceptisols	Ustepts	Haplustepts	VerticHaplustepts	Fine, smectitic, isohyperthermic
P_3	Vertisols	Usterts	Haplusterts	Calcic Haplusterts	Fine, smectitic, isohyperthermic
P_4	Vertisols	Usterts	Haplusterts	Calcic Haplusterts	Fine, smectitic, isohyperthermic
P_5	Entisols	Orthents	Ustorthents	TypicUstorthents	Loamy, smectitic, isohyperthermic
P_6	Inceptisols	Ustepts	Haplustepts	TypicHaplustepts	Fine, smectitic, isohyperthermic
P_7	Vertisols	Usterts	Haplusterts	TypicHaplusterts	Fine, smectitic, isohyperthermic
P_8	Entisols	Orthents	Ustorthents	TypicUstorthents	Loamy, smectitic, isohyperthermic
P_9	Inceptisols	Ustepts	Haplustepts	TypicHaplustepts	Loamy, smectitic, isohyperthermic
P_{10}	Entisols	Orthents	Ustorthents	TypicUstorthents	Loamy, smectitic, isohyperthermic
P_{11}	Vertisols	Usterts	Haplusterts	SodicHaplusterts	Very-fine, smectitic, isohyperthermic
P_{12}	Inceptisols	Ustepts	Haplustepts	TypicHaplustepts	Loamy, smectitic, isohyperthermic
P_{13}	Inceptisols	Ustepts	Haplustepts	VerticHaplustepts	Fine, smectitic, isohyperthermic
P_{14}	Inceptisols	Ustepts	Haplustepts	TypicHaplustepts	Fine, smectitic, isohyperthermic
P_{15}	Entisols	Orthents	Ustorthents	TypicUstorthents	Loamy, smectitic, isohyperthermic

The soils of the area showed a decreasing trend of organic carbon content with increasing depth, which may be attributed to its rapid rate of mineralization at higher temperature and adequate soil moisture level in the surface soils (Sarkar*et al*. 2001). The calcium carbonate content of studied soils was ranged from 0.92 to 23.11 per cent indicating that the soils were calcareous in nature. However it was also observed that the concentration of $CaCO_3$ was less in soils of upper topographic position (Typic Ustorthents) than the lower topographic position (TypicHaplustepts and TypicHaplusterts), which may attributed to the leaching of $(HCO_3)_2$ which get precipitated down as calcium carbonate to the slope as well as at lower horizon. The high calcium carbonate in soil affects the available water capacity of the soil which has great influence on crop production under rainfed condition. High calcium carbonate affects the physical and chemical properties of soil and which may prevent the root penetration (Sys, 1985). High $CaCO_3$ tends to have a cementing effects, formation of subsurface hardpan, which restricted infiltration rate and soil aeration (Ann McCauley, 2005).The cation exchange capacity of soils ranged from 24.56 to 78.18 cmol (p^+) kg^{-1}. This variation due to high amount of clay content and to its smectitic clay mineralogy (Pal and Deshpande, 1987). The clay complex was dominated by exchangeable calcium, followed by exchangeable magnesium, sodium and potassium indicating the presence of calcium bearing minerals in parent material.The soils are base rich which ranged from 63.03 to 114.80 per cent. The base saturation values more than 100 per cent in soils of Calcic Haplusterts (P_4) and SodicHaplusterts (P_{11}) may be due to presence base contributing minerals such as zeolites in these black soils (Bhattacharyya *et al*. 1993 and Pal *et al*. 2006). The presence of zeolites even in the present day climate indicates that loss of bases during leaching of soils has been continuously replenished by the steady supply of bases from these zeolites and are responsible for more base saturation (Bhattacharyya *et al*. 1999).The exchangeable sodium per cent of the soils ranged from 1.42 to 16.95 per cent. In general, the ESP was increased with depth in all pedons except in pedons P_6, P_8 and P_9. The maximum ESP was observed in soils of SodicHaplusterts (P_{11}).The exchangeable magnesium percentage of the soils ranged from 17.82 to 64.31 per cent. The high amount of magnesium in soils can also cause poor physical properties, Mg^{2+} ions behaves more like a Na^+ ion in impairing hydraulic properties of cracking clay soils (Balpande*et al*. 1996).

Soil classification

Based on morphological, physical and chemical characteristics, the pedons under study have been classified (Table 4) as per keys to soil taxonomy (Soil Survey Staff, 2015). The dominant soils of the study area belonging to three order viz. Entisols, Inceptisols and Vertisols. The soils developed on gently to moderately sloping, undulating plain at elevated area (P_1, P_5, P_8, P_{10} and P_{15}) were lack of diagnostic subsurface horizons and qualify for the order Entisols and at sub group level these soils classified as TypicUstorthents. The Pedon P_2, P_6, P_9, P_{12}, P_{13} and P_{14} having Ochricepipedons followed by Cambic subsurface diagnostic horizons and hence, grouped under Inceptisols. At sub group level pedon P_6, P_9, P_{12} and P_{14} are classified as TypicHaplustepts and pedon P_2 and P_{13} classified as VerticHaplustepts. The soils of pedon P_3, P_4, P_7 and P_{11} were deep to very deep, black coloured, clayey (> 30 per cent) and characterized by deep and wide cracks, well developed slickenside and pressure

faces. Thus these soils were classified under the order Vertisols and at sub group level pedon P_3 and P_4 are Calcic Haplusterts, pedonP_{11} is SodicHaplusterts and pedon P_7 classified as TypicHaplusterts. The mineralogy classes of the soil families are smectitic and soil temperature class "isohyperthermic" for all the fifteen pedons based on mineralogical and climatic data, respectively.

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