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Soils of Thotapalli Major Irrigation Project of North- Coastal Andhra Pradesh: Physical and Chemical Properties

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Abstract: Physical and chemical properties of the soils were assessed for the ayacut area of Thotapalli major irrigation project of North-Coastal Andhra Pradesh. Six representative soil pedons were studied in Devarapalli, Gujjangivalasa, Patikivalasa, Gangada, Aamiti and Maddivalasa villages falling in ayacut area of Thotapalli major irrigation project. The soil texture ranged from sandy loam to sandy clay loam in upland pedons while sandy clay loam to clay in pedons under cultivated plains. In general, relatively low bulk density was recorded at surface horizons compared to sub-surface layers. Maximum water holding capacity, pore space and volume expansion increased with soil depth. The soils were acidic to alkaline in reaction, non-saline, low to medium in organic carbon content. The CEC ranged from 6.4 to 32.5 cmol (p+) kg^{-1}. The soil exchange complex was dominated by calcium followed by magnesium, sodium and potassium. The soils were found to be low in nitrogen, low to medium in phosphorus and medium to high in available potassium status. Manganese and copper were sufficient but zinc and iron were deficient in soils. The total silica (SiO_2) content of pedons varied from 48.10 to 71.40 per cent. Sesquioxide (R_2O_3) and the molar ratio of SiO_2 / R_2O_3 ranged from 19.01 to 32.4 per cent and varied from 3.74 to 6.59, respectively in different pedons. The SiO_2 / Al_2O_3 ratio and the SiO_2 / Fe_2O_3 ratio varied from 4.43 to 7.65 and from 13.7 to 47.8, respectively. A significant positive correlation of clay content with cation exchange capacity (CEC), maximum water holding capacity (MWHC) was observed. Sand content was positively correlated with silica and negatively correlated with MWHC and volume expansion. Soil organic carbon had a significant positive correlation with soil pore space, available nitrogen, phosphorous, potassium, zinc, manganese, copper and iron, but a negative correlation with soil bulk density. Soil pH was positively correlated with $CaCO_3$ but negatively correlated with available phosphorous, potassium, zinc, manganese, and copper and iron. Soil $CaCO_3$ content was negatively correlated with available phosphorous, potassium, zinc, manganese, and copper and iron of the soil.

Key words: *Soil characterization, soil physical properties, soil chemical properties*

Introduction

Timely and reliable information on soils regarding their nature, extent and distribution along with their potentials and limitations, is important for optimum and sustainable utilisation of land resources (Shalima Devi and Anil Kumar 2010). Thotapalli reservoir, a major irrigation project comprises parts of Srikakulam and Vizianagaram district in North coastal Andhra Pradesh. The project has proposed ayacut area of 1, 83,950 acres. The knowledge of soils to their extent,

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distribution, characteristics and potential use is essential for formulating the prospective land use plans. Necessity is always felt for soil database on ayacut area of the proposed irrigation project. However, so far, no effort has been made to study the genesis, characteristics and classification of these soils. Keeping these in view, the present investigation has been taken to characterise the soils of Srikakulam and Vizianagaram district under Thotapalli reservoir to maximise irrigation use efficiency and sustainable production.

Materials and Methods

The study area (18^0 12' to 18^0 32' N; 83^0 29' to 83^0 37' E) comprises parts of Srikakulam and Vizianagaram districts of the north coastal region of Andhra Pradesh under Thotapalli reservoir. Particle-size, bulk density (core sampler method) and particle density were determined by the specific gravity bottle method, as described by Piper (1966). Water holding capacity and volume expansion were determined by following the Keen Raczkowski's method as described by Sankaram (1966). Pore space was derived from the bulk density and particle density. Soil reaction (pH) and soluble salt concentration (EC) were estimated by the procedures outlined by Jackson (1973). The organic carbon content of the soil samples was estimated by Walkley and Black (1934) wet digestion method. Available nitrogen was assessed by the modified alkaline potassium permanganate method (Subbiah and Asija 1956). Available phosphorus in soil was extracted with 0.5 *M* $NaHCO_3$ of pH 8.5 and measured on a spectrophotometer (Olsen *et al.* 1954). Available soil potassium was extracted with neutral normal ammonium acetate and measured on flame photometer (Jackson 1973). Available sulphur was estimated by 0.15 % calcium chloride extraction method as outlined by Williams and Steinbergs (1959) and measurement of its concentration in the extracts by turbidimetric procedure using barium chloride (Verma 1977). Calcium carbonate content of soil samples was determined by titrimetry of Piper (1966). Exchangeable bases and cation exchange capacity (CEC) were determined by a centrifuge extraction procedure using neutral normal ammonium acetate as described by Bower *et al.* (1952). The available zinc, copper, iron and manganese in soils were extracted by DTPA and measured by atomic absorption spectrophotometer (Lindsay and Norvell 1978). Silica, sesquioxide, iron, alumina was assessed as per the procedure outlined by Hesse (1971).

Results and Discussion

Pedons 1 and 2 occurring on upland had sandy loam texture at the surface and sandy clay loam texture in sub-soils horizons. Pedon 3 and 5 of middle land had sandy clay loam throughout the depth (Table 1). Pedon 4 and 5 of plains had sandy clay loam to clay texture variations in soil texture were caused by the nature of parent material, *in-situ* weathering, and translocation of clay within soil pedon and age of soils. (Geetha Sireesha and Naidu 2013).

Bulk density of different horizons ranged from 1.33 to 1.62 Mg m^{-3} and increased with soil depth. There was significant negative correlation ($r = -0.696^{**}$) between bulk density and organic carbon. Prabavathi *et al.* (2017) also reported similar findings in soils of Belagavi district of Karnataka. The particle density of soils of the study area ranged from 2.56 to 2.72 Mg m^{-3}. The pore space in different horizons ranged from 37.45 to 48.88 per cent and decreased with depth. There was significant negative ($r = -0.959^{**}$) correlation between pore space and bulk density and positive correlation with the organic carbon content of soil ($r= 0.481^{*}$). The maximum water holding capacity (MWHC) in soils varied from 34.0 to 50.40 per cent and increased with depth. The soils of pedons 4 and 6 had high MWHC owing to high clay content. Satyavathi and Suryanayana Reddy (2003) also reported high water holding capacity in red and black soils of Northern Telangana. Pedons 1, 2, 3 and 5 showed relatively low MWHC. A significant positive correlation between MWHC and clay content ($r = 0.895^{**}$) and a significant negative correlation between MWHC and sand content ($r = -0.848^{**}$) was observed. The per cent volume expansion in soils varied from 3.10 to 30.1 per cent and had significant positive correlation ($r = +0.605^{**}$) with clay content. Relatively high volume expansion was associated with pedons 4 and 6 (17.5 to 30.10 per cent) due to shrink-swell nature of soils. Increase in volume expansion with the increase in clay content was also observed by Gurumurthy *et al.* (1996).

Table 1. Physical properties of soils

Horizon	Depth (m)	Coarse fraction (> 2.0 mm) (%)	Sand (%)	Silt (%)	Clay (%)	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Pore space (%)	Maximum water holding capacity (%)	Volume expansion (%)
Pedon 1: Devarapalli pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustalfs										
Ap	0.00-0.10	4.5	62.2	18.6	19.2	1.42	2.67	46.82	43.46	8.78
Bw	0.10-0.25	3.1	58.0	17.5	24.5	1.50	2.64	43.18	45.69	9.81
Bt_1	0.25-0.58	4.0	53.5	17.5	29.0	1.52	2.71	43.91	47.36	5.89
Bt_2	0.58-0.70	2.3	56.0	16.0	28.0	1.55	2.70	42.59	38.93	10.40
Bt_3	0.70-0.90	2.3	60.5	15.5	24.0	1.58	2.68	41.04	39.12	8.70
Bt_4	0.90-1.19+	3.0	58.0	17.0	25.0	1.59	2.63	39.54	38.65	9.00
Pedon 2: Gujjangivalasa pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustults										
Ap	0.00-0.10	5.0	76.5	10.9	12.6	1.40	2.71	48.34	45.36	3.10
Bt_1	0.10-0.22	5.1	68.0	14.8	17.2	1.52	2.68	43.28	45.15	4.56
Bt_2	0.22-0.40	6.9	69.1	10.4	20.5	1.59	2.65	40.00	42.89	3.56
Bt_3	0.40-0.70	6.9	67.8	11.0	21.2	1.61	2.62	38.55	43.56	4.16
Bt_4	0.70-0.98+	19.1	68.0	11.5	20.5	1.62	2.59	37.45	36.30	3.25
Pedon 3: Patikavalasa pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts										
Ap	0.00-0.10	5.43	61.3	14.4	24.3	1.42	2.64	46.21	43.00	12.80
Bw_1	0.10-0.30	5.64	60.5	13.0	26.5	1.49	2.68	44.40	42.56	14.40
Bw_2	0.30-0.50	5.13	58.2	16.1	25.7	1.55	2.66	41.73	41.14	15.00
Bw_3	0.50-0.80	6.01	59.9	13.6	26.5	1.60	2.59	38.22	38.56	11.40
Bw_4	0.80- 0.95+	8.03	63.2	12.5	24.3	1.61	2.61	38.31	36.60	9.30
Pedon 4: Gangada pedon : Fine, smectitic, isohyperthermic Vertic Haplustepts										
Ap	0.00-0.09	5.1	55.2	15.8	29.1	1.37	2.68	48.88	47.70	20.00
Bw_1	0.09-0.40	5.6	51.0	14.1	34.9	1.40	2.64	46.97	49.00	19.60
Bw_2	0.40-0.62	6.3	48.1	15.0	36.9	1.45	2.60	44.23	50.40	17.50
Bw_3	0.62-0.82	7.1	53.4	13.2	33.4	1.46	2.61	44.06	46.00	24.60
Bw_4	0.82-1.02+	21.5	54.3	14.1	31.6	1.51	2.56	41.02	42.10	17.50
Pedon 5: Aamiti pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts										
Ap	0.00-0.16	5.1	65.3	13.7	21.0	1.48	2.72	45.59	39.10	9.20
Bw_1	0.16-0.30	5.6	61.2	15.6	23.2	1.51	2.70	44.07	42.10	12.40
Bw_2	0.30-0.48	6.3	58.1	16.6	25.3	1.55	2.66	41.73	40.10	14.80
Bw_3	0.48-0.70	7.1	56.4	18.4	25.2	1.60	2.70	40.74	38.40	11.20
Bw_4	0.70-0.90+	26.3	61.4	15.0	23.6	1.61	2.66	39.47	34.00	9.80
Pedon 6: Maddivalasa pedon : Fine, smectitic, isohyperthermic Chromic Haplusterts										
Ap	0.00-0.13	0.8	43.0	18.9	38.1	1.33	2.58	48.45	44.10	26.50
Bw	0.13-0.32	0.8	41.5	17.0	41.5	1.41	2.64	46.59	49.60	28.60
Bss_1	0.32-0.55	0.4	39.0	17.0	44.0	1.45	2.60	44.23	46.60	30.10
Bss_2	0.55-0.74	0.5	39.0	18.9	42.1	1.41	2.58	45.35	44.60	28.00
Bss_3	0.74-1.15+	1.1	37.3	17.5	45.2	1.52	2.60	41.54	42.60	29.00

Physico-chemical characteristics

The pH of the soil ranged from 4.87 to 8.71. Pedons 3, 4 and 6 were slightly alkaline (Table 2). Pedon 2 had acidic pH, while pedons 1 and 5 were neutral in reaction. In pedons 3, 4 and 6, the soil pH increased with depth due to increasing trend of $CaCO_3$ with soil depth (Meena *et al.* 2014 and Visalakshi Devi *et al.* 2015). The electrical conductivity of the pedons ranged from 0.11 to 0.60 dS m^{-1}. The organic carbon content in soils of different horizons of pedons ranged from 0.110 to 0.619 per cent and decreased with soil depth as which surface layer got enriched with crop residue and addition of FYM. Warm climatic conditions of the study area caused rapid decomposition of organic matter resulting in low organic carbon content (Ashok Kumar and Jagdish Prasad 2010) in the soils. Calcium carbonate

Table 2. Physico-chemical properties of soils

Profile No. & horizon	Depth (m)	pH	E.C (dS m^{-1})	Organic carbon (%)	Total nitrogen (%)	C/N ratio	$CaCO_3$ (%)	CEC	Exchangeable bases				Base saturation (%)
									Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
								--------------cmol (p^+) kg^{-1} -------------					
Pedon 1: Devarapalli pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustalfs													
Ap	0.00-0.10	6.23	0.13	0.534	0.039	9.54	-	13.50	3.96	1.02	0.28	0.04	39.26
Bw	0.10-0.25	6.61	0.17	0.301	0.035	8.60	-	15.40	5.85	0.67	0.35	0.07	45.06
Bt_1	0.25-0.58	7.34	0.17	0.231	0.021	7.00	-	17.00	6.01	1.05	0.63	0.11	45.88
Bt_2	0.58-0.70	7.41	0.21	0.215	0.021	9.72	-	15.40	5.90	1.00	0.24	0.09	46.95
Bt_3	0.70-0.90	7.35	0.23	0.220	0.018	9.85	-	14.20	5.76	0.52	0.22	0.08	46.34
Bt_4	0.90-1.19+	7.48	0.23	0.205	0.012	8.40	-	14.20	5.72	0.60	0.21	0.10	46.69
Pedon 2: Gujjangivalasa pedon: Fine-loamy, mixed, isohyperthermic Typic Haplustults													
Ap	0.00-0.10	4.87	0.11	0.376	0.036	7.67	-	6.40	0.88	0.22	0.10	0.06	23.33
Bt_1	0.10-0.22	5.43	0.13	0.256	0.028	9.14	-	7.10	1.25	0.36	0.13	0.08	25.63
Bt_2	0.22-0.40	5.51	0.15	0.250	0.028	8.93	-	9.63	1.75	0.45	0.11	0.05	24.51
Bt_3	0.40-0.70	5.96	0.20	0.135	0.016	5.19	-	8.15	1.57	0.42	0.10	0.06	26.38
Bt_4	0.70-0.98+	5.50	0.26	0.123	0.014	5.13	-	8.15	1.72	0.48	0.14	0.05	29.33
Pedon 3: Patikavalasa pedon: Fine-loamy, mixed, isohyperthermic Typ ic Haplustepts													
Ap	0.00-0.10	7.23	0.19	0.330	0.031	10.65	1.3	15.30	8.35	1.05	0.25	0.10	63.73
Bw_1	0.10-0.30	7.48	0.20	0.226	0.020	7.53	3.4	17.20	8.86	1.01	0.72	0.12	62.27
Bw_2	0.30-0.50	7.54	0.22	0.196	0.017	6.53	3.0	14.20	7.36	1.31	0.28	0.09	63.66
Bw_3	0.50-0.80	7.91	0.23	0.180	0.014	6.43	7.0	11.70	6.90	1.22	0.33	0.06	72.74
Bw_4	0.80-0.95+	8.28	0.31	0.135	0.014	4.66	9.5	13.50	8.23	1.38	0.41	0.03	74.44
Pedon 4: Gangada pedon : Fine, smectitic, isohyperthermic Vertic Haplustepts													
Ap	0.00-0.09	7.88	0.39	0.450	0.054	9.06	3.15	27.35	20.80	2.18	0.71	0.13	87.09
Bw_1	0.09-0.40	8.04	0.43	0.316	0.036	8.78	6.30	31.80	24.70	2.24	0.80	0.11	87.58
Bw_2	0.40-0.62	8.26	0.44	0.291	0.030	9.70	7.10	29.50	20.30	3.82	1.17	0.09	86.03
Bw_3	0.62-0.82	8.50	0.47	0.253	0.028	9.04	9.8	30.10	20.20	3.50	1.19	0.13	83.12
Bw_4	0.82-1.02+	8.71	0.58	0.213	0.026	8.19	13.8	28.80	20.50	3.61	1.18	0.15	88.33
Pedon 5: Aamiti pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts													
Ap	0.00-0.16	6.53	0.24	0.520	0.054	9.07		16.80	4.83	1.12	0.35	0.14	38.33
Bw_1	0.16-0.30	7.20	0.26	0.376	0.035	10.74	-	14.90	4.83	1.61	0.32	0.17	44.60
Bw_2	0.30-0.48	7.61	0.31	0.226	0.034	6.65	-	14.90	4.10	1.50	0.48	0.09	42.40
Bw_3	0.48-0.70	7.14	0.39	0.110	0.023	6.36	1.1	16.10	4.10	1.80	0.52	0.08	40.37
Bw_4	0.70-0.90+	7.10	0.45	0.110	0.019	7.28	1.35	15.25	4.28	1.48	0.16	0.02	39.61
Pedon 6: Maddivalasa pedon : Fine, smectitic, isohyperthermic Chromic Haplustert													
Ap	0.00-0.13	7.80	0.48	0.619	0.032	13.09	-	29.10	18.90	2.18	0.50	0.10	74.50
Bw	0.13-0.32	8.16	0.56	0.302	0.024	7.21	1.1	32.50	20.10	3.04	1.32	0.18	75.82
Bss_1	0.32-0.55	8.12	0.45	0.231	0.017	8.56	1.1	32.50	20.00	3.35	1.25	0.12	76.06
Bss_2	0.55-0.74	8.04	0.53	0.110	0.015	8.40	1.5	28.90	19.80	3.25	1.15	0.12	84.15
Bss_3	0.74-1.15+	7.91	0.60	0.110	0.013	9.17	2.9	31.10	21.60	3.46	1.05	0.10	84.28

content in pedon 3 ranged from 1.3 to 9.5 % and 3.15 to 13.8 % in pedon 4 and increased with depth owing to leaching of bicarbonate from upper layer during the rainy season and their subsequent precipitation as carbonate in the lower layer (Leelavathi *et al.* 2009). The cation exchange capacity of the soils varied from 5.40 to 32.5 cmol (p+) kg^{-1} soil with irregular trend of distribution with depth. A significant positive correlation was found between CEC and per cent clay (r = 0.915**). The exchange complex of the soils was dominated by Ca^{+2} followed by Mg^{2+}. Exchangeable sodium was relatively higher in pedons 4 and 6.

Elemental Composition of the Soil

The total silica (SiO_2) content in soils varied from 48.10 to 71.40 per cent (Table 3) and decreased with depth. Pedons 1, 2, 3 and 5 had higher content of

Table 3. Chemical composition of the soils (silica and sesquioxides)

Pedon 1: Devarapalli pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustalf													
Ap	0.00-0.10	67.00	27.43	19.80	7.63	1.117	0.242	0.194	0.0478	4.62	5.75	23.4	4.06
Bw	0.10-0.25	69.10	26.41	20.10	6.31	1.152	0.237	0.197	0.0395	4.87	5.84	29.1	4.99
Bt1	0.25-0.58	61.60	25.84	19.80	6.04	1.027	0.232	0.194	0.0378	4.43	5.29	27.1	5.13
Bt2	0.58-0.70	66.10	29.05	21.90	7.15	1.102	0.259	0.215	0.0448	4.25	5.13	24.6	4.80
Bt3	0.70-0.90	70.00	25.70	18.10	7.60	1.167	0.225	0.177	0.0476	5.18	6.57	24.5	3.73
Bt4	0.90-1.19+	65.80	28.24	22.90	5.34	1.097	0.258	0.225	0.0334	4.25	4.88	32.8	6.71
Pedon 2: Gujjangivalasa pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustults													
Ap	0.00-0.10	71.40	27.80	17.70	10.10	1.190	0.237	0.174	0.0632	5.03	6.86	18.8	2.74
Bt_1	0.10-0.22	69.20	25.60	16.30	9.30	1.153	0.218	0.160	0.0582	5.29	7.22	19.8	2.74
Bt2	0.22-0.40	61.80	32.10	21.00	11.10	1.030	0.275	0.206	0.0695	3.74	5.00	14.8	2.96
Bt3	0.40-0.70	65.00	30.60	18.30	12.30	1.083	0.256	0.179	0.0770	4.22	6.04	14.1	2.33
Bt4	0.70-0.98+	65.80	32.40	19.60	12.80	1.097	0.272	0.192	0.0802	4.03	5.71	13.7	2.40
Pedon 3: Patikavalasa pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts													
Ap	0.00-0.10	63.15	28.41	21.50	6.91	1.053	0.254	0.211	0.0433	4.14	4.99	24.3	4.87
Bw1	0.10-0.30	66.14	26.94	20.90	6.04	1.102	0.243	0.205	0.0378	4.54	5.38	29.1	5.42
Bw2	0.30-0.50	61.25	23.00	18.20	4.80	1.021	0.208	0.178	0.0301	4.90	5.72	34.0	5.94
Bw3	0.50-0.80	59.80	25.93	20.90	5.03	0.997	0.236	0.205	0.0315	4.22	4.86	31.6	6.51
Bw4	0.80- 0.95+	61.25	24.01	19.50	4.51	1.021	0.219	0.191	0.0282	4.65	5.34	36.1	6.77
Pedon 4: Gangada pedon : Fine, Smectitic, isohyperthermic Vertic Haplustepts													
Ap	0.00-0.09	54.20	24.10	19.60	4.50	0.903	0.220	0.192	0.0282	4.10	4.70	32.1	6.82
Bw1	0.09-0.40	56.60	22.70	16.60	6.10	0.943	0.201	0.163	0.0382	4.69	5.80	24.7	4.26
Bw2	0.40-0.62	49.20	22.50	18.90	3.60	0.820	0.208	0.185	0.0225	3.95	4.43	36.4	8.22
Bw3	0.62-0.82	52.60	24.01	18.90	5.11	0.877	0.217	0.185	0.0320	4.03	4.73	27.4	5.79
Bw4	0.82-1.02+	48.10	22.03	17.50	4.53	0.802	0.200	0.172	0.0284	4.01	4.67	28.3	6.05
Pedon 5: Aamiti pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts													
Ap	0.00-0.16	60.60	26.94	17.60	9.34	1.010	0.231	0.173	0.0585	4.37	5.85	17.3	2.95
Bw1	0.16-0.30	57.10	23.30	15.70	7.60	0.952	0.202	0.154	0.0476	4.72	6.18	20.0	3.23
Bw2	0.30-0.48	62.50	24.70	17.10	7.60	1.042	0.215	0.168	0.0476	4.84	6.21	21.9	3.52
Bw3	0.48-0.70	57.30	25.10	16.80	8.30	0.955	0.217	0.165	0.0520	4.41	5.80	18.4	3.17
Bw4	0.70-0.90+	55.00	24.20	17.30	6.90	0.917	0.213	0.170	0.0432	4.31	5.40	21.2	3.93
Pedon 6: Maddivalasa pedon : Fine, smectic, isohyperthermic Chromic Haplustert													
Ap	0.00-0.13	68.40	19.01	15.20	3.81	1.140	0.173	0.149	0.0239	6.59	7.65	47.8	6.25
Bw	0.13-0.32	63.30	22.96	18.60	4.36	1.055	0.210	0.182	0.0273	5.03	5.79	38.6	6.68
Bss1	0.32-0.55	70.50	22.72	16.80	5.92	1.175	0.202	0.165	0.0371	5.82	7.13	31.7	4.44
Bss2	0.55-0.74	59.10	28.04	21.90	6.14	0.985	0.253	0.215	0.0384	3.89	4.59	25.6	5.58
Bss3	0.74-1.15+	58.60	22.03	17.20	4.83	0.977	0.199	0.169	0.0302	4.91	5.79	32.3	5.58

sand fraction had pedons 4 and 6. There was positive correlation of silica with sand (r = +0.537). Rama Lakshmi *et al.* (2001) also reported similar findings Sesquioxide (R_2O_3) content ranged from 19.01 (pedon 6) to 32.4 (pedon 2) per cent. Pedon 2 had the variations in sesquioxide content might be due to the parent material, physiography, soil drainage and overall pedo-chemical environment (Leelavathi *et al.* 2009).

The aluminium oxide content in soils varied from 15.2 (pedon 6) to 22.9 (pedon 9) per cent. An irregular trend of alumina with depth was observed in all the pedons. Aluminium oxide is the major fraction of the sesquioxides and hence it followed the pattern of sesquioxides distribution. The iron oxide content varied from 3.60 to 12.8 per cent with variation within a pedon but large variation between pedons. (Ramprakash and Seshagiri Rao 2002).

The molar concentration of sesquioxide ranged from 0.173 to 0.275 moles and if increased with depth in pedon 2, 3, 4 and 5. The highest value was associated with Bt2 horizon of pedon 2 and the lowest value in the surface Ap. The alumina ranged from 0.149 (pedon 6) to 0.225 (pedon 9) moles and increased with depth in pedon 2, 4, 5 and 6. The molar concentration of iron oxide ranged from 0.0225 to 0.0802 in different pedons being highest in pedon 2.

The molar ratio of SiO_2 / R_2O_3 varied from 3.74 to 6.59 in different pedons. SiO_2 / Al_2O_3 ratio and the SiO_2 / Fe_2O_3 ratio ranged from 4.43 to 7.65 and 13.7 to 47.8, respectively in different pedons. The molar ratio of Al_2O_3 / Fe_2O_3 varied from 2.33 to 8.22 among all the pedons. In general, wider SiO_2 / R_2O_3, SiO_2 / Al_2O_3 indicated that these soils are siliceous in nature. Pedons 4 and 6 had narrow ratio of the SiO_2 / R_2O_3 and SiO_2 / Al_2O_3 owing to relatively higher clay content and low sand content while, pedons 1, 2, 3 and 5 were associated with wider SiO_2 / R_2O_3 and SiO_2 / Al_2O_3 ratios, which could be ascribed to re-silication, a dominant process operating in these pedons. These results are in conformity with those of Ramprakash and Seshagiri Rao (2002).

Available macro nutrient status of soils

The available nitrogen content in the soils ranged from 32.9 to 111.3 kg ha^{-1} (Table 4) and decreased with depth. There was significant positive correlation (r = 0.832*) between available nitrogen and organic carbon as also reported by Satish Kumar and Naidu (2012). The available phosphorus (P_2O_5) ranged from 6.0 to 68.3 kg ha^{-1} and decreased with depth. In the surface horizon, the addition of organic matter and phosphatic fertilizer might have resulted in relatively higher available phosphorus (Visalakshi Devi *et al.* 2015). A significant positive correlation (r = 0.515**) was recorded between organic carbon and available phosphorus content of the soil, but negative correlation (r = -0.687**) between soil pH and available phosphorus of the soil.

The available potassium of the soils ranged from 109.4 to 575.16 kg ha^{-1} being low in pedon 1, 2 and 5 owing to coarse textured soils.

Available micronutrient status of soils

The available zinc content ranged from 0.08 to 0.66 Mg kg^{-1} with irregular distribution the pedons. The soils were deficient in available zinc barring Ap horizon of pedon 1, 5 and 6 decreased with depth. The available zinc was negatively correlation with soil pH (r = -0.623**) and positively correlated with soil organic carbon (r = 0.581**). The available copper content in soil varied from 0.36 to 2.64 Mg kg^{-1} and these soils were sufficient in available copper. Available Cu in soils was positively correlated with organic carbon content (r = 0.456*). The available iron content in soils ranged from 2.49 to 9.54 Mg kg^{-1} and decreased with depth. Considering the critical limit of 4.5 Mg kg^{-1} (Lindsay and Norvell 1978), the pedons 3, 4 and 6 were deficient and pedons 1, 2 and 5 were sufficient in available iron content. The organic carbon due to its affinity to influence the solubility and availability of iron by chelation effect might have protected the iron from oxidation and precipitation, which consequently resulted in sufficient available iron in soils. The available manganese content ranged from 6.55 to 22.13 Mg kg^{-1} and was sufficient in all the pedons against critical limit of 1.0 Mg kg^{-1} proposed by Lindsay and Norvell (1978). Available manganese was relatively high in the surface horizons and decreased with depth,

Table 4. Available macro and micronutrient contents of the soils

Profile No. & horizon	Depth (m)	Available macronutrients				Available micronutrients			
		N	P_2O_5	K_2O	S	Zn	Cu	Fe	Mn
		--------- ha^{-1}----------			mg kg^{-1}	---------------mg kg^{-1}---------------------			
Pedon 1: Devarapalli pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustalf									
Ap	0.00-0.10	94.1	68.3	488.16	77.4	0.66	2.40	7.68	22.13
Bw	0.10-0.25	81.5	39.3	240.90	72.5	0.27	1.56	4.94	11.32
Bt_1	0.25-0.58	70.6	46.2	266.28	62.8	0.12	2.56	6.23	16.85
Bt_2	0.58-0.70	70.6	18.5	318.15	62.0	0.14	1.32	5.16	16.85
Bt_3	0.70-0.90	64.3	23.9	300.06	60.6	0.09	2.06	4.88	13.66
Bt_4	0.90-1.19+	64.3	16.2	290.90	60.6	0.11	2.06	4.59	14.87
Pedon 2: Gujjangivalasa pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustults									
Ap	0.00-0.10	70.6	18.0	227.54	49.8	0.33	1.87	7.82	10.85
Bw	0.10-0.22	70.6	14.5	157.53	42.5	0.14	1.32	7.45	14.11
Bt_1	0.22-0.40	69.0	7.7	192.54	39.5	0.09	1.09	6.39	15.64
Bt_2	0.40-0.70	66.0	12.0	196.91	41.2	0.08	1.32	5.06	13.26
Bt_3	0.70-0.98+	64.3	12.0	205.66	35.4	0.09	1.18	7.13	9.86
Pedon 3: Patikavalasa pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts									
Ap	0.00-0.10	111.3	36.8	206.95	69.9	0.38	2.13	4.60	18.69
Bw_1	0.10-0.30	103.4	18.0	109.4	55.0	0.14	1.56	4.29	12.33
Bw_2	0.30-0.50	76.8	12.0	148.78	45.7	0.31	1.95	1.95	7.16
Bw_3	0.50-0.80	72.1	12.8	190.03	32.0	0.13	1.06	3.24	6.55
Bw_4	0.80- 0.95+	50.2	12.8	131.27	32.0	0.13	1.63	2.49	6.55
Pedon 4: Gangada pedon : Fine, smectitic, isohyperthermic Vertic Haplustepts									
Ap	0.00-0.09	81.5	24.0	343.89	72.5	0.30	2.64	3.94	13.04
Bw_1	0.09-0.40	39.2	09.1	475.16	65.0	0.11	2.41	4.12	12.31
Bw_2	0.40-0.62	32.9	12.4	497.04	60.6	0.09	2.00	3.56	9.28
Bw_3	0.62-0.82	36.1	10.0	300.80	62.9	0.09	0.86	2.90	8.00
Bw_4	0.82-1.02+	40.8	6.0	453.28	40.5	0.10	0.43	2.69	9.89
Pedon 5: Aamiti pedon : Fine-loamy, mixed, isohyperthermic Typic Haplustepts									
Ap	0.00-0.16	67.4	32.0	575.16	61.9	0.75	2.34	9.54	11.86
Bw_1	0.16-0.30	61.2	25.4	306.40	45.7	0.39	1.31	8.62	9.23
Bw_2	0.30-0.48	56.4	21.0	227.54	43.8	0.24	1.96	6.54	14.90
Bw_3	0.48-0.70	61.2	18.2	332.56	35.4	0.15	0.38	7.14	10.20
Bw_4	0.70-0.90+	48.6	10.8	244.4	35.4	0.09	0.36	5.12	9.6
Pedon 6: Maddivalasa pedon : Fine, smectitic, isohyperthermic Chromic Haplustert									
Ap	0.00-0.13	94.1	20.5	379.41	89.2	0.93	2.56	4.23	9.36
Bw	0.13-0.32	64.3	12.6	270.61	72.5	0.32	2.42	4.10	12.66
Bss_1	0.32-0.55	64.3	8.5	275.10	72.5	0.18	1.92	3.16	10.2
Bss_2	0.55-0.74	40.8	12.0	253.40	69.9	0.12	0.65	4.54	8.52
Bss_3	0.74-1.15+	50.2	6.5	235.50	55.0	0.12	0.39	3.94	6.81

Table 5. Correlation coefficients between various soil properties

Sr. No	Variables	Correlation coefficient (r)
1	Clay content *vs.* Volume ex pansion of soil	0.605**
2	Clay content *vs.* Maximum water holding capacity	0.895**
3	Clay content *vs.* Cation Exchange Capacity	0.915**
4	Sand content *vs*. Maximum water holding capacity	-0.848**
5	Sand content *vs.* Silica content	0.537*
6	Sand content *vs*. CEC	-0.683**
7	Soil pH *vs.* available phosphorus content of soil	-0.665**
8	Soil pH *vs.* available zinc content of soil	-0.623**
9	Soil pH and available iron	-0.697**
10	Soil pH *vs.* available copper content of soil	-0.436*
11	Soil pH *vs.* available manganese content of soil	-0.574*
12	Soil organic carbon content *vs.* available nitrogen content of soil	0.832**
13	Soil organic carbon content *vs.* available phosphorus	0.515*
14	Soil organic carbon content *vs.* available potassium	0.561*
15	Soil Organic carbon content *vs.* available zinc	0.580*
16	Soil organic carbon content *vs*. available copper	0.456*
17	Soil organic carbon content *vs.* available manganese	0.429*
18	Soil organic carbon content *vs.* available iron	0.623**
19	soil organic carbon content *vs.* bulk density	-0.696**
20	Pore space *vs.* bulk density	-0.959**
21	$CaCO_3$ content *vs.* soil pH	0.715**
22	$CaCO_3$ content *vs.* available phosphorus	-0.687**
23	$CaCO_3$ content *vs.* available Zinc	-0.581*
24	$CaCO_3$ content *vs.* available iron	-0.549*

***Significant at 5 % level of degrees of freedom**
****Significant at 1 % level of degrees of freedom**

which might be due to higher biological activity and organic carbon content in the surface horizons.

Conclusion

Soils of Thotapalli major irrigation project ayacut had texture ranging from sandy loam to clayey. Bulk density increased with depth but the reverse trend observed for pore space. Volume expansion and maximum water holding capacity were positively related with clay. The soils were acidic to alkaline in reaction and non-saline. Organic carbon was low to medium and decreased with depth. Available nitrogen content was low; available phosphorous was low to medium; available potassium was medium to high. The soils were deficient in available zinc and sufficient in available manganese and copper. The pedons 3, 4 and 6 had low available iron. The soils were siliceous in nature. There was a wider variation in molar concentrations and molar ratios of oxides of silicon, iron and aluminium oxides.

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