Agropedology 2014, 24 (02), 125-137

Studies on genesis, characterization and classification of soils in central and Eastern parts of Prakasam district in Andhra Pradesh

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Abstract: Seven typical pedons representing major land forms in central and eastrern parts of Prakasam district *viz.,* plains and uplands developed from granite-gneiss, sandstone and alluvium parent material under varying land use were studied for their morphological characteristics, physical and physico-chemical properties, soil genesis and nutrient status. Soils were shallow to very deep, slightly acidic to slightly alkaline (pH 6.02 to 8.45) in reaction, non-saline and had iso-hyperthermic temperature and ustic soil moisture regimes. Texture, organic carbon, CEC and base saturation were ranged from sand to clay in surface and sub-surface, 0.12 to 0.68 per cent, 3.48 to 48.74 cmol (p^+) kg^{-1} and 73.44 to 91.52 per cent, respectively. Soils were low in available nitrogen, medium in available phosphorus, low to high in available potassium and high in available sulphur. However, the soils were deficient in DTPA-extractable Zn and sufficient in Fe (except in pedon 6, surface horizon of pedon 4 and sub-surface horizons of pedon 2), Cu and Mn. Pedons 2 and 6 were grouped under Entisols due to absence of sub-surface diagnostic horizon and were classified as *Typic Ustipsamments* and *Typic Ustorthents*, respectively whereas pedons 1, 4, 5 and 7 were placed under Inceptisols due to presence of cambic (Bw) sub-surface diagnostic horizon and classified as *Typic Haplustepts* (pedons 1, 4 and 5) and *Lithic Haplustepts* (pedon 7). Due to the presence of vertic features like slickensies, pressure faces, cracks and presence of more than 30 % clay in all the horizons, the pedon 3 was grouped under Vertisols and classified as *Typic Haplusterts*. The soils were also evaluated for commonly grown crops of the area.

Key words: *Soil classification, soil survey, cambic horizon, soil fertility*

Introduction

Indiscriminate use of finite soil resources coupled with lack of management has led to degradation causing concern to planners, researchers and farmers. This calls for a scientific approach for development and management of these resources at various levels. Soil resource inventory provides an insight into potentialities and limitations for its effective management. It also provides adequate information in terms of land form, natural vegetation as well as characteristics of soils which can be utilized for land resources management and development (Manchanda *et al.* 2002). Rational utilization of land resources can be achieved by optimizing its use, which demands evaluation of land for alternative land use. Characterization, classification and evaluation of soils under different land uses are the first milestone in developing sustainable and eco-friendly land use models. No information is available especially on characterization, classification and genesis of soils of Prakasam district in general and in the central and eastern parts of the district in particular. Hence, present study was taken to characterize, classify and evaluate the soils in central and eastern parts of Prakasam district.

Material and Methods

Study area

The study area lies in between 14°57′ and 16°17′ latitudes and 78°43′ and 80°25′ longitudes with an altitude ranging from 6 to 87 m (msl). The soils have developed from granite-gneiss, sandstone and alluvium parent materials (Table 1). The area qualifies for semi-arid monsoon climate with distinct summer, winter and rainy seasons. It experiences mean annual precipitation of 747 mm. The mean annual temperature is 29.5°C with a mean summer temperature of 32.33°C and mean winter temperature of 26.1°C. The maximum temperature recorded for last 10 years is 44.6°C in the month of May and the minimum temperature is 20.4°C in the month of January. The soil moisture regime has been computed as ustic and temperature regime as *isohyperthermic*. The natural vegetation comprises of species like *Acacia nilotica, Borassus flabellifer, Prosopis juliflora, Calotropis gigantia, Tamarindus indica, Azadirachta indica, Cassia auriculata, Syzygium cumini, Pongomia pinnata, Eucalyptus* spp., *Parthenium hysterophorus, Lantana camera, Opuntia ficus-indica, Tephrosia purpuria, Cyperus rotundus* and *Cynodon dactylon, etc.*

Methodology

A reconnaissance soil survey was conducted in Prakasam district using toposheets with 1: 50,000 scale as per procedure outlined by AIS&LUS (1970). Auger bores, minipots, road cuts upland 10 pedons located on plains and uplands were studied. Soil correlation exercise yielded seven typical profiles in the central and eastern parts. These seven typical profiles were studied in detail for their morphological properties (Table 2) in the field as per the procedure outlined in Soil Survey Manual (Soil Survey Division Staff 2000). Horizon-wise soil samples collected from profiles were analysed for their physical, physico-chemical properties and available nutrient status using standard procedures. The soils were classified taxonomically (Soil Survey Staff 2014).

Table 1. Landscape characteristics of pedons

Pedons / Villages	Location	Elevation (m)	Physiography	Slope (%)	Drainage	Parent material
P1 Lakkavaram	15°40′55 91″ N 79°45′23 26″ E	87	Uplands	3-5	Well drained	Granite-gneiss
P2 Thalamalla	15°35′31 30″ N 79°43′58 11″ E	54	Plains	0-1	Imperfectly drained	Alluvium
P3 Surareddipalem	15°24′08 46″ N 80°03′54 06″ E	6	Plains	0-1	Moderately well drained	Alluvium
P4 Kothavaripalem	15°23′17 01″ N 79°50′55 22″ E	42	Uplands	3-5	Well drained	Weathered gneiss
P5 Uppalapadu	15°34′53 36″ N 79°45′47 97″ E	50	Plains	0-1	Moderately well drained	Weathered granite-gneiss
P6 Kandulur	15°25′38 42″ N 79°58′30 15″ E	23	Plains	0-1	Moderately well drained	Weathered sandstone
P7 Marlapadu	15°25′52 04″ N 79°58′09 56″ E	24	Plains	0-1	Moderately well drained	Sandstone

Table 2. Morphological characteristics of the soils

Pedon No.& Horizon	Depth (m)	Colour		Texture	Structure			Consistence			Efferve-scence	Boundary		Pores		Roots		Remarks
		Moist	Dry		S	G	T	Dry	Moist	Wet		D	T	S	Q	S	Q	
Pedon 1	Typic Haplustepts (Uplands)																	
Ap	0.00-0.10	7.5 YR 3/3	7.5 YR 4/3	Scl	f	1	sbk	sh	fi	ssps	Es	c	s	f	f	f	f	
Bw1	0.10-0.24	7.5 YR 3/2	7.5 YR 4/4	Sc	m	2	sbk	h	fi	sp	Es	g	s	f	f	f	f	
Bw2	0.24-0.45	7.5 YR 3/2	7.5 YR 3/3	Sc	m	2	sbk	h	fi	vsvp	Ev	g	s	f	f	f	f	
Bw3	0.45-0.70	7.5 YR 3/2	7.5 YR ¾	C	m	3	abk	vh	fi	vsvp	Ev	c	s	-	-	f	f	
R	0.70	Granite-gneiss																
Pedon 2	Typic Ustipsamments (Plains)																	
Ap	0.00-0.11	7.5 YR 4/3	7.5 YR 5/3	Sl	m	2	sbk	l	fr	ssps	Ev	c	s	f	f	f	m	
2A1	0.11-0.31	7.5 YR 4/4	7.5 YR 5/4	Ls	m	1	sbk	l	fr	ssps	Ev	g	s	f	f	f	m	
A2	0.31-0.48	7.5 YR 4/4	7.5 YR 5/4	Ls	m	1	sbk	l	fr	ssps	Ev	g	s	f	f	f	m	
A3	0.48-0.61	7.5 YR 5/3	7.5 YR 6/3	Ls	m	1	sbk	l	fr	ssps	Ev	g	s	f	f	f	f	
3A4	0.61-0.95	7.5 YR 5/3	7.5 YR 6/3	S	m	2	sg	l	l	s_0p_0	Ev	c	s	f	f	f	f	
4A5	0.95-1.20	7.5 YR 3/4	7.5 YR 5/4	S	m	2	sg	l	l	s_0p_0	Ev	c	s	m	f	-	-	
C +	1.20	Alluvium																
Pedon 3	Typic Haplusterts (Plains)																	
Ap	0.00-0.19	10 YR 3/2	10 YR 3/2	C	m	2	sbk	h	fi	sp	Es	c	s	f	c	f	c	
Bw	0.19-0.37	10 YR 3/2	10 YR 3/4	C	m	3	abk	vh	fi	vsvp	Ev	c	s	-	-	f	f	Pressure faces
Bss1	0.37-0.59	10 YR 3/2	10 YR 3/3	C	c	3	abk	vh	fi	vsvp	Ev	c	s	-	-	c	f	
Bss2	0.59-0.80	10 YR 3/2	10 YR 3/3	C	c	3	abk	vh	fi	vsvp	Ev	g	s	-	-	f	f	
Bss3	0.80-1.15	10 YR 3/2	10 YR 3/4	C	c	3	abk	vh	fi	vsvp	Ev	g	s	-	-	-	-	
C +	1.15	Alluvium																
Pedon 4	Typic Haplustepts (Uplands)																	
Ap	0.00-0.13	7.5 YR 4/4	7.5 YR 5/4	C	m	2	sbk	h	fi	vsvp	Ev	c	s	f	c	f	c	
Bw1	0.13-0.30	7.5 YR 4/3	7.5 YR 4/4	C	c	3	abk	vh	fi	vsvp	Ev	g	s	f	c	f	m	
Bw2	0.30-0.47	7.5 YR 4/3	7.5 YR 4/4	C	c	3	abk	vh	fi	vsvp	Ev	c	s	f	c	f	f	
Cr	0.47	Weathered gneiss																

Pedon No.& Horizon	Depth (m)	Colour		Texture	Structure			Consistence			Effer-vescence	Boundary		Pores		Roots		Remarks
		Moist	Dry		S	G	T	Dry	Moist	Wet		D	T	S	Q	S	Q	
Pedon 5	Typic Haplustepts (Plains)																	
Ap	0.00-0.12	10 YR 3/3	10 YR 4/3	c	M	2	sbk	sh	fi	vsvp	es	c	s	f	f	f	m	
Bw1	0.12-0.29	7.5 YR 3/3	7.5 YR 4/3	sc	M	2	sbk	h	fi	vsvp	ev	c	s	f	f	f	m	
Bw2	0.29-0.50	7.5 YR 3/3	7.5 YR 4/4	scl	M	2	sbk	s	fi	ssps	ev	c	s	f	f	f	f	
Cr	0.5	Weathered granite-gneiss																
Pedon 6	Typic Ustorthents (Plains)																	
Ap	0.00-0.20	2.5 YR ¾	2.5 YR 3/6	sc	F	2	sbk	sh	fr	sp	-	c	s	f	c	f	f	
A1	0.20-0.35	2.5 YR ¾	2.5 YR 3/6	scl	F	2	sbk	s	fr	sp	-	g	s	f	c	f	f	
Cr	0.35	Weathered sandstone																
Pedon 7	Lithic Haplustepts (Plains)																	
Ap	0.00-0.10	2.5 YR ¾	2.5 YR 3/6	scl	M	2	sbk	s	fr	sp	-	c	s	f	c	f	f	
Bw	0.10-0.34	2.5 YR ¾	2.5 YR 4/4	sc	M	2	abk	sh	fi	vsvp	-	c	w	f	f	f	f	
R	0.34	Sandstone																

Texture : c – clay, cl – clay loam, l – loam, s – sand, sl – sandy loam, scl – sandy clay loam, sc – sandy clay, ls – loamy sand
Structure : Size (S) – vf – very fine, f – fine, m – medium, c – coarse; Grade (G) – O – structureless, l – weak, 2 – moderate, 3 – strong; Type (T) cr – crumb, sg – single grain, abk – angular blocky, sbk – sub-angular blocky.
Consistence :
Dry : s – soft, l – loose, sh – slightly hard, h – hard, vh – very hard
Moist : l – loose, fr – friable, fi – firm, vfi – very firm
Wet : so – non-sticky, ss – slightly sticky, s – sticky, vs – very sticky; po – non-plastic, ps – slightly plastic, p – plastic, vp – very plastic
Cutans : Ty – type – t – Argillan, Th – Thickness, tn – thin, th – thick, Quantity (Q), p – patchy, c – continuous
Pores : Size (S) f – fine, m- medium, c- coarse; Q – Quantity, f – few, c – common, m - many
Roots : Size (S) f – fine, m- medium, c- coarse; Q – Quantity, f – few, c – common, m - many
Effervescence : es – strong effervescence, ev – violent effervescence
Boundary : D – Distinctness, c – clear, g – gradual, d – diffuse
T – Topography; s – smooth; w – wavy

These profiles were evaluated for their suitability using limitation method suggested by Sys *et al.* (1991). The landscape and soil requirements for common crops were matched with the generated data at different limitation levels: no (0), slight (1), moderate (2), severe (3), and very severe (4). The number and degrees of limitations suggested the suitability class of pedon for a particular crop. The potential land suitability classes were determined after considering the improvement measures to correct these limitations.

Results and Discussion

Soil morphology

The soils were shallow to very deep with imperfectly to well-drained. The horizon boundaries were clear to gradual in distinctness and smooth to wavy in topography. The colour varied from brown to dark browns in pedons 1 and 5, light brown to dark brown in pedon 2, very dark grayish brown to dark yellowish brown in pedon 3, dark reddish brown to dark red in pedon 6 and reddish brown to dark red in pedon 7 whereas it was brown in pedon 3 (moist and dry). The soil colour appears to be the function of chemical and mineralogical composition as well as textural make up of soils and conditioned by topographic position and moisture regime (Walia and Rao 1997). Textural class of the soils varied from sandy to clay. This textural variation might be due to differences in composition of parent material, topography, *in-situ* weathering and translocation of clay by eluviation and age of soils (Geetha Sireesha and Naidu 2013). The structure of the soils was single grain, sub-angular blocky and angular blocky. The blocky structure *i.e.,* angular and sub-angular blocky were attributed to the presence of higher quantities of clay fraction (Sharma *et al.* 2004).

The consistence of the soils varied from soft to very hard (dry), loose to firm (moist) and non sticky and non plastic to very sticky and very plastic (wet). Presence of sticky and plastic to very sticky and very plastic, firm to very firm and slightly hard to very hard consistence in wet, most and dry conditions, respectively may be due to high clay content of soil (Sarkar *et al.* 2001) and also due to dominance of smectite clay mineral (Leelavathi *et al*. 2010). Pedons 1, 3, 4, 5 and 7 exhibited a cambic (Bw) sub-surface diagnostic horizon and pedon 3 had shown presence of Bss horizon. However, pedons 2 and 6 did not have any diagnostic horizon. Strong to violent effervescence with dilute HCl was observed in all the pedons except pedons 6 and 7.

Soil characteristics

Physical characteristics: The data pertaining to particle size analysis (Table 3) revealed that the clay content varied from 2.03 to 57.24 per cent. Increase in clay content with depth in pedons 1, 4, 6 and 7 might be due to downward translocation of finer particles from the surface layers (Murthy 1988). The decrease in clay content with depth in pedons 2 and 5 might be due to variability of weathering in different horizons. Silt content in general exhibited an irregular trend with depth, which might be due to variation in weathering of parent material or *in situ* formation (Satish Kumar and Naidu 2012). Sand constitutes the bulk of mechanical fractions, which could be attributed to the siliceous nature of parent material.

The bulk density of different pedons varied from 1.27 to 1.93 Mg m^{-3} and the discrepancy in bulk density of these soils was attributed to high content of expanding type of clay minerals. Similar findings were reported by Ram Prakash and Seshagiri Rao (2002). Bulk density of sub-surface horizons was higher than that of surface horizons and increased with depth, this might be due to compaction of finer particles in deeper layers caused by the over-head weight of the surface layers (Thangasamy *et al*. 2005), high clay content in swelling clay soils (Ahuja *et al*. 1988) and lower organic matter and plant root concentration (Coughlan *et al*. 1986).

Table 3. Physical characteristics of the soils

Pedon No. & Horizon	Depth (m)	Sand (%) (0.05-2.0 mm)	Silt (%) (0.002-0.05 mm)	Clay (%) (<0.002 mm)	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Water holding capacity (%)
Pedon 1	*Typic Haplustepts* (Upland)						
Ap	0.00-0.10	56.44	11.26	32.30	1.43	2.47	33.62
Bw1	0.10-0.24	52.86	9.78	37.36	1.51	2.53	35.09
Bw2	0.24-0.45	47.12	12.76	40.12	1.52	2.56	37.22
Bw3	0.45-0.70	43.95	13.73	42.32	1.57	2.58	39.84
R	0.70	Granite-gneiss					
Pedon 2	*Typic Ustipsamments* (Plain)						
Ap	0.00-0.11	80.74	6.46	12.80	1.64	2.43	33.08
2A1	0.11-0.31	80.08	11.94	7.98	1.54	2.63	29.85
A2	0.31-0.48	80.37	11.43	8.20	1.93	2.54	30.76
A3	0.48-0.61	80.13	11.86	8.01	1.54	2.46	29.66
3A4	0.61-0.95	88.94	8.02	3.04	1.58	2.59	20.69
4A5	0.95-1.20	92.01	5.96	2.03	1.53	2.19	29.50
C +	1.20	Alluvium					
Pedon 3	*Typic Haplusterts* (Plain)						
Ap	0.00-0.19	23.88	23.79	52.33	1.41	2.48	53.62
Bw	0.19-0.37	19.24	26.84	53.92	1.39	2.46	54.88
Bss1	0.37-0.59	17.49	25.27	57.24	1.41	2.43	56.86
Bss2	0.59-0.80	23.14	22.08	54.78	1.44	2.47	54.34
Bss3	0.80-1.15	25.17	22.13	52.70	1.46	2.50	50.13
C +	1.15	Alluvium					
Pedon 4	*Typic Haplustepts* (Upland)						
Ap	0.00-0.13	40.32	11.56	48.12	1.27	2.42	51.85
Bw1	0.13-0.30	39.95	10.77	49.28	1.34	2.40	53.28
Bw2	0.30-0.47	38.16	10.13	51.71	1.38	2.45	54.82
Cr	0.47	Weathered gneiss					
Pedon 5	*Typic Haplustepts* (Plain)						
Ap	0.00-0.12	45.24	11.65	43.11	1.36	2.42	51.37
Bw1	0.12-0.29	48.77	14.79	36.44	1.43	2.57	45.73
Bw2	0.29-0.50	50.74	19.06	30.20	1.47	2.62	35.40
Cr	0.50	Weathered granite-gneiss					
Pedon 6	*Typic Ustorthents* (Plain)						
Ap	0.00-0.20	71.96	8.68	19.36	1.41	2.49	18.48
A1	0.20-0.35	64.39	9.15	26.46	1.58	2.48	22.55
Cr	0.35	Weathered sandstone					
Pedon 7	*Lithic Haplustepts* (Plain)						
Ap	0.00-0.10	54.34	17.69	27.97	1.43	2.45	30.14
Bw	0.10-0.34	57.65	6.18	36.17	1.48	2.52	32.92
R	0.34	Sandstone					

The lower bulk density in surface layers may be due to cultivation, high organic matter and biotic activities (Vara Prasad Rao *et al.* 2008). Water holding capacity of different pedons varied from 18.48 to 56.86 per cent. These variations were due to the differences in depth, clay, silt and organic carbon content. Low water holding capacity in sandy soils was due to high sand and less clay content as evident by highly significant and negative correlation (r = -0.806**) between water holding capacity and sand content. The irregular trend of water holding capacity with depth might be due to the eluviation and illuviation of finer fractions in different horizons.

Physico-chemical characteristics: The soils are slightly acidic to slightly alkaline in nature with pH varying from 6.02 to 8.45. This wide variation was attributed to the nature of the parent material, leaching, presence of calcium carbonate and exchangeable sodium (Shalima Devi and Anil Kumar 2010). All the pedons showed low electrical conductivity values ranging from 0.01 to 0.34 dS m^{-1}, indicating non saline nature. The low electrical conductivity may be due to free drainage conditions which favoured the removal of released bases by percolation and drainage (Table 4).

Organic carbon content of these soils was found to be low to medium and varied from 0.12 to 0.68 per cent (Table 4). The organic carbon content decreased with depth in all the pedons. This is attributed to the addition of plant residues and farm yard manure to surface horizons (Ashok Kumar and Jagdish Prasad 2010). The low carbon content in the soils might be attributed to the prevalence of tropical condition, where the degradation of organic matter occurs at a faster rate coupled with low vegetation cover, thereby leaving less organic carbon in the soils (Nayak *et al.* 2002).

The CEC in all the pedons estimated by ammonium acetate extract varied from 3.48 to 48.74 cmol (p^+) kg^{-1} soil which corresponds to clay content, organic carbon content and also type of clay mineral present in these soils. The free $CaCO_3$ was ranged from 4.57 to 13.44 per cent and the higher $CaCO_3$ content might be due to semi-arid climate which is responsible for the pedogenic processes resulting in the depletion of Ca^{+2} ions from the soil solution in the form of calcretes (Ashok Kumar and Jagdish Prasad 2010). The $CaCO_3$ content increased with depth in all the pedons except pedon 2, which might be due to leaching of calcium and its subsequent precipitation due to high pH level. Pedon 2 showed an irregular distribution with depth, which is attributed to variable nature of geological material that contributed to these soils or rapid leaching of carbonates from the porous sandy soils (Singh and Agrawal 2005).

Exchangeable bases in all pedons are in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ on the exchange complex. The base saturation (BSP) varied from 73.44 to 91.52 per cent. The higher values of per cent base saturation observed is due to higher amount of Ca^{+2} ions occupying the exchange sites on the colloidal sites. The ratio between CEC and clay ranged from 0.30 to 2.21 and the CEC : clay ratio was used to identify the clay mineralogy (Ashok Kumar and Jagdish Prasad, 2010).

Soil genesis

An examination of soil profiles showed distinctive horizontal layers, some of which were clearly visible. Significant changes were noted because the soils are developed from relatively unconsolidated parent material. Pedons 1, 4 and 5 are developed from grainite-gneiss / weathered gneiss, pedons 2 and 3 from alluvium parent material whereas pedons 6 and 7 are developed from sandstone. As per the outlines of Simonson (1959), high organic matter content was noticed due to accumulation of plant material and humus on the surface soils and to certain depth of sub-soil in all the pedons of the study area. The surface horizon in all these pedons was dark in colour as compared to sub-surface horizons due to accumulation of organic matter. Higher organic matter in the surface soils was due to addition of organic matter through leaf fall, stubbles, roots and organic manures restricting to the surface soils only (Bhaskar *et al.* 2004). Further, the organic carbon was leached to lower layers along with percolating water leading to its loss from the surface soils (Leelavathi *et al.* 2009)

Table 4. Physico-chemical properties of the soils

Pedon No. & Horizon	Depth (m)	pH (1:2.5)	EC (dsm^{-1})	Organic carbon ($g\ kg^{-1}$)	$CaCO_3$ ($g\ kg^{-1}$)	CEC (cmol (p^+) kg^{-1})	Exchangeable bases [cmol (p^+) kg^{-1}] (1 *N* NH_4OAc, pH 7.0)				Base saturation (%)
							Ca^{2+}	Mg^{2+}	Na^+	K^+	
Pedon 1. *Typic Haplustepts* (Upland)											
Ap	0.00-0.10	7.85	0.26	0.28	4.57	32.86	17.25	8.20	0.43	0.28	79.61
Bw1	0.10-0.24	7.68	0.26	0.24	7.76	35.62	19.50	8.15	0.92	0.43	81.41
Bw2	0.24-0.45	7.61	0.01	0.18	11.06	43.26	25.15	12.05	0.76	0.41	88.70
Bw3	0.45-0.70	7.94	0.34	0.13	12.85	47.68	27.75	12.80	0.64	0.32	87.06
R	0.70	Granite-gneiss									
Pedon 2. *Typic Ustipsamments* (Plain)											
Ap	0.00-0.11	8.05	0.10	0.62	12.83	15.87	9.45	4.45	0.72	0.64	89.86
2A1	0.11-0.31	8.08	0.08	0.45	12.65	14.60	8.50	4.25	0.78	0.68	83.29
A2	0.31-0.48	8.19	0.08	0.32	12.46	14.05	8.25	4.10	0.76	0.64	83.63
A3	0.48-0.61	8.30	0.10	0.29	13.44	13.68	8.25	3.65	0.73	0.62	80.77
3A4	0.61-0.95	8.36	0.09	0.22	10.73	4.68	2.50	1.05	0.72	0.07	75.93
4A5	0.95-1.20	8.45	0.06	0.15	12.52	3.48	1.85	0.85	0.43	0.06	73.44
C +	1.20	Alluvium									
Pedon 3. *Typic Haplusterts* (Plain)											
Ap	0.00-0.19	7.90	0.11	0.43	8.66	45.18	30.25	12.20	0.84	0.52	90.54
Bw	0.19-0.37	7.83	0.17	0.41	10.57	42.94	28.85	11.15	0.92	0.38	91.52
Bss1	0.37-0.59	7.93	0.11	0.30	11.36	44.48	30.65	10.35	0.86	0.42	90.77
Bss2	0.59-0.80	8.05	0.12	0.33	11.68	45.65	31.55	10.15	1.21	0.32	88.13
Bss3	0.80-1.15	8.16	0.14	0.18	12.64	48.74	32.25	11.55	1.43	0.18	87.27
C +	1.15	Alluvium									
Pedon 4. *Typic Haplustepts* (Upland)											
Ap	0.00-0.13	8.00	0.28	0.68	10.53	14.48	6.55	3.50	1.13	0.42	80.11
Bw1	0.13-0.30	7.79	0.30	0.39	10.96	15.26	6.85	3.75	0.88	0.36	77.59
Bw2	0.30-0.47	7.88	0.16	0.28	12.24	18.46	9.85	2.15	4.46	0.84	88.90
Cr	0.47	Weathered gneiss									
Pedon 5. *Typic Haplustepts* (Plain)											
Ap	0.00-0.12	7.86	0.25	0.36	6.54	40.16	20.35	13.75	0.73	0.56	88.12
Bw1	0.12-0.29	7.65	0.19	0.28	8.36	38.96	22.10	11.75	0.62	0.71	85.54
Bw2	0.29-0.50	7.23	0.28	0.25	8.67	31.87	19.15	7.45	0.83	0.42	87.39
Cr	0.50	Weathered granite-gneiss									
Pedon 6. *Typic Ustorthents* (Plain)											
Ap	0.00-0.20	7.26	0.18	0.27	10.23	40.02	20.35	13.80	0.74	0.53	88.51
A1	0.20-0.35	7.15	0.12	0.21	10.58	31.84	19.20	7.75	0.82	0.41	88.51
Cr	0.35	Weathered sandstone									
Pedon 7. *Lithic Haplustepts* (Plain)											
Ap	0.00-0.10	6.86	0.19	0.25	6.05	30.64	16.95	6.75	0.37	0.13	78.98
Bw	0.10-0.34	6.02	0.07	0.12	6.26	35.42	19.65	8.35	0.96	0.43	82.98
R	0.34	Sandstone									

Next to soil formation was translocation of material from one point to another within the soil. In this category eluviation and illuviation processes were of great importance. The development of B horizons in the pedons 1, 3, 4, 5 and 7 was a result of eluviation and illuviation. Due to these processes the cambic horizon was formed. However, these processes were not operated in the pedons 2 and 6, thus no soil development in sub-surface horizons resulted in these pedons.

The soil forming processes like transformation of minerals and organic substances lead to changes in colour and structure in the sub-soil leading to the development of cambic horizon (Bw) in pedons 1, 3, 4, 5 and 7. The study area has semi-arid climate with high summer temperature with scarce rainfall and monsoon climate. Natural vegetation in the study area includes perennial trees, annuals and short grasses. Further, the topography of the study area varied from gently sloping to nearly level plains. The interplay of climate, topography and vegetation acting on parent material over a period of time resulted in the development of different soils *viz.,* Entisols, Inceptisols and Vertisols in the study area.

Soil taxonomy

Based on morphological, physical and physico-chemical properties, the typifying pedons were classified according to Soil Taxonomy (Soil Survey Staff 2014) into the orders Entisols, Inceptisols and Vertisols. Pedons 2 and 6 which do not have any diagnostic horizons were classified under Entisols. Pedons 1, 4, 5 and 7 which exhibited cambic (Bw) sub-surface diagnostic horizon, were classified under Inceptisols. Pedon 3 was classified under Vertisols due to presence of vertic features such as slickensides, pressure faces, and cracks in B horizon.

Pedons 1, 4, 5 and 7 were grouped under Ustepts at sub-order level due to ustic soil moisture regime and Haplustepts at great group level because these pedons did not have either duripan or calcic horizon and base saturation was more than 60% at a depth between 0.25 to 0.75 m from the surface. Pedons 1, 4 and 5 did not have lithic contact within 50 cm from the soil surface and vertic properties. Hence, these pedons were logically classified as *Typic Haplustepts* at sub-group level. However, pedon 7 was classified under *Lithic Haplustepts* due to presence of lithic contact within 50 cm from mineral soil surface.

Pedon 3 was classified as usterts at sub-order level due to presence of ustic soil moisture regime. It was classified under Haplusterts at great group level due to absence of salic, gypsic, calcic or petro calcic horizons within 100 cm of mineral soil surface.

Pedon 2 was classified placed under Psamment at sub-order level because of loamy sand / sandy texture. This is kept under Ustipsamment at great group level due to the presence of ustic soil moisture regime. Further, it was classified as *Typic Ustipsamment* at sub-group level as it showed typical characteristics of Ustipsamment. Pedon 6 was placed under Orthents at sub-order level due to regular decrease in the organic carbon and Ustorthents at great group level due to ustic soil moisture regime. As it did not show any inter-gradation with any other taxa or any extra-gradation from the central concept, it was logically classified as *Typic Ustorthents* at sub-group level.

Soil fertility

Soil fertility exhibits the status of different soils with regard to the amount and availability of nutrients essential for plant growth.

Macronutrients: The available nitrogen varied from 75 to 213 kg ha^{-1} (Table 5) throughout the depth. However, available nitrogen was found to be maximum in surface horizons and decreased regularly with depth which is due to decreasing trend of organic carbon with depth and cultivation of crops are mainly confined to the surface horizon (rhizosphere) only and at regular intervals the depleted nitrogen is supplemented by the external addition of fertilizers during crop cultivation (Satish Kumar and Naidu 2012).

Table 5. Available macro and micro nutrients of the soils

Pedon No. & Horizon	Depth (m)	Available macronutrients				Available micronutrients			
		N	P	K	S	Zn	Cu	Fe	Mn
		---------- kg ha^{-1}----------			mg kg^{-1}	---------- mg kg^{-1}----------			
Pedon 1	*Typic Haplustepts* (Upland)								
Ap	0.00-0.10	213	17.45	249	17.25	0.37	0.59	5.67	9.61
Bw1	0.10-0.24	213	14.72	193	14.13	0.34	0.83	5.32	9.52
Bw2	0.24-0.45	188	14.24	199	12.81	0.38	0.80	4.97	8.61
Bw3	0.45-0.70	163	13.96	204	10.38	0.29	0.82	4.69	7.25
R	0.70	Granite-gneiss							
Pedon 2	*Typic Ustipsamments* (Plain)								
Ap	0.00-0.11	176	14.23	338	66.73	0.48	1.12	8.67	8.21
2A1	0.11-0.31	125	13.58	204	62.16	0.66	0.95	6.58	7.53
A2	0.31-0.48	138	14.52	164	60.93	0.36	0.47	5.23	4.89
A3	0.48-0.61	100	13.91	130	52.24	0.35	1.31	5.46	3.45
3A4	0.61-0.95	100	13.78	141	49.95	0.60	1.14	6.52	3.53
4A5	0.95-1.20	75	14.73	121	53.43	0.53	1.34	6.84	4.21
C +	1.20	Alluvium							
Pedon 3	*Typic Haplusterts* (Plain)								
Ap	0.00-0.19	163	21.66	516	18.26	0.42	0.63	8.20	13.31
Bw	0.19-0.37	113	15.32	453	16.59	0.39	0.56	7.93	12.84
Bss1	0.37-0.59	125	15.84	459	15.32	0.34	0.43	7.34	12.23
Bss2	0.59-0.80	188	15.06	419	13.12	0.27	0.46	6.28	10.58
Bss3	0.80-1.15	138	13.91	450	10.28	0.17	0.34	4.67	10.29
C +	1.15	Alluvium							
Pedon 4	*Typic Haplustepts* (Upland)								
Ap	0.00-0.13	176	23.25	105	16.15	0.64	0.65	7.07	15.53
Bw1	0.13-0.30	125	18.44	53	13.63	0.59	0.53	6.48	13.58
Bw2	0.30-0.47	138	24.03	83	9.84	0.46	0.48	6.13	11.62
Cr	0.47	Weathered gneiss							
Pedon 5	*Typic Haplustepts* (Plain)								
Ap	0.00-0.12	138	19.43	126	10.52	0.30	0.68	7.44	8.92
Bw1	0.12-0.29	113	17.65	142	9.78	0.26	0.48	6.72	7.13
Bw2	0.29-0.50	100	14.26	109	9.32	0.22	0.42	6.32	6.75
Cr	0.50	Weathered granite-gneiss							
Pedon 6	*Typic Ustorthents* (Plain)								
Ap	0.00-0.20	151	20.36	224	12.53	1.12	1.83	8.52	12.14
A1	0.20-0.35	151	17.65	187	11.28	1.15	1.43	10.05	10.64
Cr	0.35	Weathered sandstone							
Pedon 7	*Lithic Haplustepts* (Plain)								
Ap	0.00-0.10	138	22.46	67	18.41	0.49	0.57	7.07	8.53
Bw	0.10-0.34	176	19.22	118	15.12	0.49	0.35	4.67	8.52
R	0.34	Sandstone							

The available P ranged from 13.58 to 24.03 kg ha^{-1} in different locations within the study area. However, the highest available phosphorus was observed in the surface horizons and decreased with depth. It might be due to the confinement of crop cultivation to the rhizosphere and supplementing the depleted phosphorus by external sources *i.e.,* fertilizers and presence of free iron oxide and exchangeable Al^{3+} in smaller amounts (Thangasamy *et al.* 2005). The lower phosphorus content in sub-surface horizons as compared to surface horizon was due to the fixation of released phosphorus by clay minerals and oxides of iron and aluminium.

Available K in soils ranged from 53 to 516 kg ha^{-1}. The highest available potassium was observed in the surface horizons and showed more or less a decreasing trend with depth. This might be attributed to more intense weathering, release of labile K from organic residues, application of K fertilizers and upward translocation of potassium from lower depths along with capillary raise of ground water (Sharma and Anil Kumar 2003). The available sulphur in soils varied from 9.32 to 66.73 mg kg^{-1}. The available sulphur is more in surface horizons than sub-surface horizons due to higher amounts of organic matter in surface layers than in deeper layers.

Micronutrients: The DTPA-extractable Zn ranged from 0.17 to 1.15 mg kg^{-1} soil. Considering 0.6 mg kg^{-1} (Lindsay and Norvell 1978) soil as critical level for available zinc, these soils were mostly found to be deficient in available zinc (except in pedon 6, surface horizon of pedon 4 and sub-surface horizons of pedon 2). The low available zinc was possibly due to calcareousness, high pH and low organic matter which might have resulted in the formation of insoluble compounds of zinc or insoluble calcium zincate.

The DTPA-extractable Fe content varied from 4.67 to 10.05 mg kg^{-1} soil. According to the critical limit of 4.5 mg kg^{-1} soil of Lindsay and Norvell (1978), the soils were sufficient in available iron. The distribution of available iron in all the pedons did not show a definite pattern. The surface horizons contained more available Fe than sub-surface horizons. It might be due to accumulation of organic carbon in the surface horizons. 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 increased the availability of iron. The low iron content in sub-surface horizons might be due to precipitation of Fe^{+2} by calcium carbonate concretions in calcareous soils and higher pH of these soils, which might decreased the availability of Fe (Vijaya Kumar *et al.* 2013).

The DTPA-extractable copper (0.34 to 1.83 mg kg^{-1}) and manganese (3.45 to 15.53 mg kg^{-1}) were found to be sufficient in all the soils of the study area as these nutrients are well above their critical limits of 0.2 and 1.0 mg kg^{-1} respectively by Lindsay and Norvell (1978). The higher concentrations of available copper and manganese might be due to higher biological activity and the chelating of organic compounds, released during the decomposition of organic matter left after harvesting of crop (Verma *et al.* 2005).

Crop suitability evaluation: The suitability classes ranged from highly suitable (S1) to permanently not suitable (N2) for the evaluated crops. Pedons 2, 3, 5 and 7 were marginally suitable and pedons 1, 4 and 6 were permanently not suitable for rice. Pedons 1 and 3 were moderately suitable and pedons 2, 4, 5, 6 and 7 were marginally suitable for cotton. All the pedons (except 4) were marginally suitable for chickpea while pedon 4 was temporarily not suitable. Pedons 5 and 7 were marginally suitable for growing tabacco and the remaining five pedons were temporarily not suitable. Pedon 3 was highly suitable, pedons 1, 5, 6 and 7 were moderately suitable, pedon 2 was marginally suitable and pedon 4 is temporarily not suitable for growing sorghum crop. Shallow soil depth, wetness, organic organic and pH were limitations in all the pedons. Calcium carbonate was a limitation in all the pedons except in P7. Texture was limiting in all the pedons except P3 and P4. In addition, alkalinity was also a limiting factor for P5. The limitation levels of land characteristics varied from crop to crop.

Conclusion

The soils in the Eastern and central parts of Prakasam district were shallow to very deep in depth, slightly acidic to slightly alkaline in reaction, non-saline and low to medium in organic carbon and the exchangeable complex was dominated by Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+}. The soils were low in available nitrogen, medium in available phosphorus, low to high in available potassium and high in available sulphur. However, soils were deficient in available zinc (except in pedon 6, surface horizon of pedon 4 and sub-surface horizons of pedon 2), and sufficient in available iron, copper and manganese. The soils of the mandal were classified as *Typic Ustipsamments*, *Typic Ustorthents, Lithic Haplustepts, Typic Haplustepts* and *Typic Haplusterts*.

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Received : July, 2010 *Accepted : April, 2014*