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Characterization and Classification of Soils in the Central Parts of Prakasam District in Andhra Pradesh, India

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A B S T R A C T

Seven typical pedons from Gundlasamudram, Vallaipalem, Peddaalavalapadu, Vijayalaxmipuram, Rajupalem, Gangapalem and Bakkireddipalem villages representing the major land forms in the central parts of Prakasam district of Andhra Pradesh *viz.*, uplands and plains, developed from granite-gneiss 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 alkaline to alkali (pH 7.63 to 10.48) in reaction, non-saline and had iso-hyperthermic temperature and ustic soil moisture regimes. Texture, organic carbon, CEC and base saturation in the profiles ranged from sandy loam to clay, 0.14 to 0.72 per cent, 9.14 to 53.85 cmol (p^+) kg^{-1} and 61.95 to 92.78 per cent, respectively. Soils were low in available nitrogen, medium in available phosphorus, medium to high in available potassium and high in available sulphur (except only one sample). However, the soils were sufficient in DTPA-extractable Zn in surface horizons (except in the pedons 2 and 4 and in the subsurface horizons of pedon 1) and sufficient in DTPA-extractable Fe (except in the second horizon of pedon 1) Cu and Mn. Pedons 3 and 6 were grouped under Entisols due to absence of sub-surface diagnostic horizon and were classified as Lithic Ustorthent, 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. Due to the presence of vertic features like slickensides, pressurefaces, cracks and presence of more than 30 % clay in all the horizons, the pedon 2 was grouped under Vertisols and classified as Typic Haplusterts. Recommendations were made based on the soil fertility for better crop production without deteriorating the soil health.

Introduction

Soil is one of the most important natural resources for existence of living creatures. Yet, it is non-renewable and finite natural resource. Indiscriminate use of soil coupled with lack of proper management has led to its degradation echoing the concerns of the planners, researchers and farmers (Sharma, 2006). This calls for a scientific approach in studying, management and development of this natural resource at various levels. Soil resource inventory provides an insight into the potentialities and limitations for its best management. It also provides adequate information in terms of land forms, 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 pertaining to Prakasam district in general and in the central parts of the district in particular. Hence, present study was taken up to characterize, classify and evaluate the soils in central parts of Prakasam district.

Materials and Methods

Study area

The study area is located between 14^{o} 57′ and 16^{o} 17′ North latitudes and 78^{o} 43′ and 80^{o} 25′ East longitudes with an altitude ranging from 50 to 94 m (msl). Soils in the central parts of Prakasam district have been mainly developed from granite-gneiss parent materials with calcareousness in some profiles (Table 1). The area is classified under semi-arid monsoonic climate with distinct summer, winter and rainy seasons. The area receives a mean annual precipitation of 747 mm. The mean annual temperature of the study area was 29.49°C, with a mean summer temperature of 32.33°C and mean winter temperature of 26.09°C. The maximum temperature recorded in the study area in the last 10 years is 44.60°C, in the month of May and the minimum temperature recorded is 20.36°C, in the month of January. The soil moisture regime (SMR) has been computed as ustic and the soil temperature regime (STR) as iso-hyperthermic. The natural vegetation observed in this area comprises of species like *Acacia nilotica, Borassus flabellifer, Parthenium hysterophorus, Calotropis gigantia, Prosopis juliflora, Tamarindus indica, Azadirachta indica, Cassia auriculata, Ziziphus mauritiana and Cyperus rotundus 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 and 12 pedons located on plains and uplands were studied. Seven typical pedons from soil correlation exercise were selected from the study area in the central parts of Prakasam district. These seven typical pedons were studied in detail for their morphological properties (Table 2) in the field as per the procedure outlined in the Soil Survey Manual (Soil Survey Division Staff, 2000). Based on the field observations, horizon-wise soil samples were collected from the selected profiles in the study area and were analyzed for their physical, physico-chemical properties and available major and micro nutrient status using standard procedures. The soils were then classified taxonomically following their characteristics observed from the field and laboratory studies (Soil Survey Staff, 2014).

Results and Discussion

Soil morphology

The soils in study area were found to be shallow to very deep with poorly to well-drained conditions. The distinctness of horizon boundaries was clear to gradual and their topography was smooth to wavy. Colour notations of studied profiles have shown hue ranging from 2.5YR to 10YR. Profiles 1, 2 and 6 have shown hue 10YR with values 3-4 and chrome of 2-4. Profiles 4 and 5 have shown hue 7.5YR with values 3-4 and chrome of 3-4. Profile 7 has hue of 5YR with values 3-4 and chrome of 3-4, where as profile 3 has hue of 2.5YR with values 3-4 and chrome of 4-6.

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 loam 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 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), friable to very firm (moist) and slightly sticky and slightly 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, 2, 4, 5 and 7 exhibited a cambic (Bw) sub-surface diagnostic horizon and pedon 2 had shown presence of Bss horizon also. However, pedons 3 and 6 did not have any diagnostic horizon. Strong to violent effervescence with dilute HCl was observed in all the pedons except in the surface horizon of pedon 3.

Soil characteristics

Physical characteristics

Details of physical characteristics of soils in the study area are presented in table 3. Particle size analysis data revealed that the clay content varied from 15.82 to 49.26 per cent. Increase in clay content with depth in all the pedons might be due to downward translocation of finer particles from the surface layers (Murthy, 1988). Silt content ranged from 6.85 to 23.32 % and its content in general increased with depth. However, it exhibited an irregular trend with depth, in pedons 1 and 2, which might be due to variations in weathering of parent material or *in situ* formation (Satish Kumar and Naidu, 2012). Sand constituted the bulk of mechanical fractions (35.26-77.33 %), which indicates the siliceous nature of parent material.

Bulk density of different horizons of the pedons in the study area varied from 1.15 to 1.79 Mg m^{-3}. Variations in bulk density of these soils were attributed to high amounts of expanding type clay minerals. Similar findings were also 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, which was 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 in the lower layers (Coughlan *et al.*, 1986). The lower bulk density observed in the surface layers was due to continuous cultivation, high organic matter and higher biotic activities (Vara Prasad Rao *et al.*, 2008). Particle density of soil horizons in the pedons of study area ranged between 2.35-2.68 Mg m^{-3}. Particle density, in general, followed an increasing trend with depth, but was more or less uniform within the pedons (Gurumurthy *et al.*, 1996). Water holding capacity of different pedons in the study area varied from 18.54 to 46.60 per cent. These variations were due to the differences in depth, clay, silt, sand and organic carbon contents. Low water holding capacity in sandy soils was due to high sand and less clay content which was also evident by the high significant and negative correlation (r = -0.806**) found between water holding capacity and sand content. The irregular trend of water holding capacity with depth in pedons 1 and 2 was due to the eluviation and illuviation of finer fractions in different horizons.

Physico-chemical characteristics

Soils in the study area are slightly alkaline to alkali in nature with pH varying from 7.63 to 10.48. This 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 had shown low electrical conductivity values ranging from 0.04 to 1.38 dS m^{-1}, indicating non-saline nature of these soils. The low electrical conductivity was due to free drainage conditions which favoured the removal of released bases by percolating and drainage water (Table 4).

Organic carbon content of soils in the study area was found to be low to medium and varied from 0.14 to 0.72 per cent (Table 4). The low carbon content in the soils might be due to the prevalence of tropical condition, which results in faster degradation of organic matter coupled with low vegetation cover, there by leaving less organic carbon in the soils (Nayak *et al.*, 2002). The organic carbon content decreased with depth in all the pedons. Relatively high organic carbon content in the surface horizons is due to the addition of plant residues and farm yard manure to surface horizons (Ashokkumar and Jagdish Prasad, 2010).

CEC in pedons of the study area varied from 9.14 to 53.85 cmol (p^+) kg^{-1} soil, which corresponds to clay content, type of clay mineral and organic carbon content present in these soils. Free $CaCO_3$ ranged from 5.42 to 17.64 per cent in these soils 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 (Ashokkumar and Jagdish Prasad, 2010). The $CaCO_3$ content increased with depth in all the pedons (except the lowest horizon in pedon 7) which was due to leaching of calcium and its subsequent precipitation due to high pH level. Pedon 7 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 horizons (Singh and Agrawal 2005).

Exchangeable bases in all pedons of the study area were in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ on the exchange complex. The percent base saturation (BSP) ranged from 61.95 to 92.78 per cent. The higher values of BSP observed is due to higher amount of Ca^{+2} ions occupying the exchange sites on the colloidal sites. The ratio between CEC and clay (CEC: clay) ranged from 0.28 to 1.22 and the CEC: clay ratio was used to identify the clay mineralogy (Ashokkumar and Jagdish Prasad, 2010).

Soil genesis

Soil profile examination in the study area showed distinctive horizontal layers, some of which were clearly visible. Significant changes were observed as these soils were developed from relatively unconsolidated parent material. Pedons 3 and 6 were developed from granite-gneiss; pedons 2, 4, 5 and 7 relatively more unconsolidated weathered granite-gneiss, whereas pedon 1 was developed from weathered calcareous gneiss parent material. 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 (Simonson, 1959). 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 continuous addition of organic matter through leaf fall, stubbles, roots and organic manures applied to the surface layers only (Bhaskar *et al.*, 2004). Further, organic carbon was leached to lower layers also along with the percolating water (Leelavathi *et al.*, 2009)

Soil formation was followed by translocation of material from one point to another within the soil. In this phase, eluviation and illuviation processes were of great significance. Development of B horizons in the pedons 1, 2, 4, 5 and 7 was the result of eluviation and illuviation processes within the profiles. Due to these processes the cambic horizon (Bw) was formed. However, these processes were not operated in the pedons 3 and 6, thus no horizon development was observed in sub-surface layers of these pedons.

Soil forming processes like transformation of minerals and organic substances result in change in colour and structure in sub-soil leading to the development of cambic horizon (Bw) in pedons 1, 2, 4, 5 and 7. The study area has semi-arid monsoonic type of climate with high summer temperatures with scarce rainfall. Natural vegetation observed in the study area were perennial trees, annuals and short grasses. Topography of the study area varied from nearly level plains to very gently sloping. The influence of climate, topography and vegetation acting on parent material over a period of time resulted in development of different soils *viz.,* Entisols, Inceptisols and Vertisols in the study area.

Soil taxonomy

Based on the soil morphological, physical and physico-chemical properties, the typifying pedons were classified into the orders Entisols, Inceptisols and Vertisols according to Soil Taxonomy (Soil Survey Staff, 2014). Pedons 3 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 2 was classified under Vertisols due to presence of vertic features such as slickensides, pressure faces, and cracks in the B horizon.

The pedons 1, 4, 5 and 7 were classified under Ustepts at sub-order level due to ustic soil moisture regime and under Haplustepts at great group level as they did not show either duripan or calcic horizon and the base saturation was more than 60% at a depth between 0.25 to 0.75 m from the surface. All these four pedons did not show lithic contact with in 50 cm from the soil surface or any vertic properties. Hence, these pedons were logically classified as Typic Haplustepts at sub-group level.

The pedon 2 was classified under usterts at sub-order level due to presence of ustic soil moisture regime. At great group level, it was classified under Haplusterts due to the absence of salic, gypsic, calcic or petro calcic horizons within 100 cm of mineral soil surface.

Table.1 Landscape characteristics of pedons

Pedons / Villages	Location	Elevation above mean sea level (m)	Physiography	Slope (%)	Drainage	Parent material
P1 Gundlasamudram	15°34′57 39″ N 79°36′54 10″ E	94	Uplands	1-3	Well drained	Weathered calcareous gneiss
P2 Vallaipalem	15°28′57 58″ N 79°45′43 94″ E	50	Plains	0-1	Imperfectly drained	Weathered granite-gneiss
P3 Pedda alavalapadu	15°25′58 91″ N 79°44′54 37″ E	51	Uplands	1-3	Well drained	Granite-gneiss
P4 Vijayalaxmipuram	15°27′13 89″ N 79°41′28 22″ E	70	Uplands	1-3	Well drained	Weathered granite-gneiss
P5 Rajupalem	15°29′02 98″ N 79°39′39 08″ E	80	Uplands	1-3	Well drained	Weathered granite-gneiss
P6 Gangapalem	15°39′ 03 26″ N 79°45′49 35″ E	77	Uplands	1-3	Well drained	Granite-gneiss
P7 Bakkireddipalem	15°37′22 92″ N 79°46′10 78″ E	65	Plains	0-1	Moderately well drained	Weathered granite-gneiss

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	0.00-0.11	10 YR 3/3	10 YR 3/3	c	m	1	sbk	h	fi	sp	ev	c	s	m	f	-	-	
A12	0.11-0.20	10 YR 3/2	10 YR 4/2	c	c	2	sbk	vh	fi	vsvp	ev	c	s	f	f	-	-	
Bw	0.20-0.32	10 YR 3/3	10 YR 3/3	c	c	1	abk	vh	fi	vsvp	ev	g	w	f	f	-	-	Pressure faces
Cr	0.32	Weathered calcareous gneiss																
Pedon 2	**Typic Haplusterts (Plains)**																	
Ap	0.00-0.08	10 YR 4/3	10 YR 4/2	scl	m	1	sbk	sh	fr	ssps	ev	c	s	m	f	-	-	
Bw1	0.08-0.32	10 YR 4/4	10 YR 4/4	sc	m	2	sbk	h	fi	sp	ev	g	s	f	f	-	-	
Bw2	0.32-0.47	10 YR 4/4	10 YR 4/3	sc	m	2	sbk	h	fi	sp	ev	g	s	f	f	-	-	
Bss1	0.47-0.64	10 YR 3/3	10 YR 3/4	c	c	3	sbk	vh	vfi	sp	ev	g	s	f	f	-	-	
Bss2	0.64-0.81	10 YR 3/3	10 YR 3/3	c	c	3	abk	vh	vfi	vsvp	ev	g	s	f	f	-	-	
Bss3	0.81-1.10	10 YR 3/4	10 YR 3/4	c	c	3	abk	vh	vfi	vsvp	ev	g	s	f	f	-	-	
Cr	1.10	Weathered granite-gneiss																
Pedon 3	**Lithic Ustorthents (Uplands)**																	
Ap	0.00-0.09	2.5 YR 3/4	2.5 YR 4/6	scl	m	2	sbk	sh	fi	sp	-	c	s	f	f	f	c	
2A1	0.09-0.20	2.5 YR 3/4	2.5 YR 3/4	cl	c	3	abk	h	vfi	sp	es	g	w	f	f	f	f	
C +	1.15	Alluvium																
Pedon 4	**Typic Haplustepts (Uplands)**																	
Ap	0.00-0.10	7.5 YR 3/3	7.5 YR 3/4	scl	m	2	sbk	sh	fr	ssps	ev	c	s	m	f	-	-	
2Bw1	0.10-0.28	7.5 YR 3/4	7.5 YR 4/4	cl	m	2	sbk	h	fi	sp	ev	c	s	f	f	-	-	
2Bw2	0.28-0.43	7.5 YR 3/4	7.5 YR 4/4	cl	m	2	sbk	h	fi	vsvp	ev	g	s	f	f	-	-	
Cr	0.43	Weathered granite-gneiss																

Table.2 (Contd.).

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 (Uplands)**																	
Ap	0.00-0.13	7.5 YR 3/4	7.5 YR 3/4	sl	f	1	sbk	s	fr	ssps	ev	c	s	c	f	f	c	
2Bw	0.13-0.33	7.5 YR 3/3	7.5 YR 3/4	scl	m	2	sbk	sh	fr	sp	ev	g	s	f	f	f	f	
Cr	0.33	Weathered granite-gneiss																
Pedon 6	**Lithic Ustorthents (Uplands)**																	
Ap	0.00-0.10	10 YR 3/2	10 YR 4/2	scl	m	2	sbk	sh	fr	ssps	ev	c	s	f	m	f	c	
A1	0.10-0.20	10 YR 3/2	10 YR 4/3	scl	m	2	sbk	sh	fr	ssps	ev	c	s	f	f	f	f	
R	0.20	Granite-gneiss																
Pedon 7	**Typic Haplustepts (Plains)**																	
Ap	0.00-0.10	5 YR 3/4	5 YR 4/4	scl	f	1	sbk	sh	fr	ssps	es	c	s	f	f	f	f	
Bw1	0.10-0.26	5 YR 3/3	5 YR 4/3	scl	f	2	sbk	sh	fr	ssps	es	g	s	f	f	f	f	
Bw2	0.26-0.46	5 YR 3/3	5 YR 4/3	sc	f	2	sbk	h	fr	sp	es	g	s	f	f	f	f	
Cr	0.46	Weathered granite-gneiss																

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

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 (Uplands)**						
Ap	0.00-0.11	37.79	15.12	47.09	1.15	2.37	35.46
A12	0.11-0.20	37.99	19.15	42.86	1.19	2.41	33.31
Bw	0.20-0.32	37.72	13.02	49.26	1.34	2.43	43.83
Cr	0.32	Weathered calcareous gneiss					
Pedon 2	**Typic Haplusterts (Plains)**						
Ap	0.00-0.08	50.70	14.52	34.78	1.36	2.35	32.80
Bw1	0.08-0.32	48.11	13.04	38.85	1.37	2.41	36.33
Bw2	0.32-0.47	48.52	11.28	43.20	1.43	2.47	42.62
Bss1	0.47-0.64	41.32	13.20	45.48	1.42	2.52	39.24
Bss2	0.64-0.81	36.17	16.55	47.28	1.47	2.52	46.38
Bss3	0.81-1.10	35.26	17.73	47.01	1.52	2.56	46.60
Cr	1.10	Weathered granite-gneiss					
Pedon 3	**Lithic Ustorthents (Uplands)**						
Ap	0.00-0.09	55.96	9.74	34.30	1.43	2.49	23.36
2A1	0.09-0.20	40.33	23.32	36.35	1.51	2.50	29.27
R	0.20	Granite-gneiss					
Pedon 4	**Typic Haplustepts (Uplands)**						
Ap	0.00-0.10	62.61	11.54	25.85	1.46	2.52	23.17
2Bw1	0.10-0.28	44.74	20.12	35.14	1.48	2.51	26.74
2Bw2	0.28-0.43	41.07	22.62	36.31	1.52	2.54	30.15
Cr	0.43	Weathered granite-gneiss					
Pedon 5	**Typic Haplustepts (Uplands)**						
Ap	0.00-0.13	77.33	6.85	15.82	1.47	2.56	18.54
2Bw	0.13-0.33	60.48	14.75	24.77	1.51	2.53	23.52
Cr	0.33	Weathered granite-gneiss					
Pedon 6	**Lithic Ustorthents (Uplands)**						
Ap	0.00-0.10	64.35	9.14	26.51	1.57	2.48	22.54
A1	0.10-0.20	61.16	9.48	29.36	1.66	2.47	24.66
R	0.20	Granite-gneiss					
Pedon 7	**Typic Haplustepts (Plains)**						
Ap	0.00-0.10	68.78	7.65	23.57	1.69	2.67	24.89
Bw1	0.10-0.26	58.38	8.68	32.94	1.76	2.61	26.75
Bw2	0.26-0.46	51.94	9.17	38.89	1.79	2.68	31.54
Cr	0.46	Weathered granite-gneiss					

Table.4 Physico-chemical properties of the soils

Pedon No. & Horizon	Depth (m)	pH (1:2.5)	EC (dsm^{-1})	Organic carbon ($g\ kg^{-1}$)	$CaCO_3$ (%)	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 (Uplands)											
Ap	0.00-0.11	9.35	0.06	0.65	10.54	50.12	31.05	10.95	7.36	0.78	86.07
A12	0.11-0.20	9.53	0.06	0.58	10.90	52.09	32.40	10.75	7.56	0.63	87.04
Bw	0.20-0.32	9.56	0.05	0.39	11.86	53.85	33.05	11.00	7.82	0.50	86.41
Cr	0.32	Weathered calcareous gneiss									
Pedon 2. Typic Haplusterts (Plains)											
Ap	0.00-0.08	9.86	0.82	0.36	10.37	14.35	6.05	2.21	0.56	0.07	61.95
Bw1	0.08-0.32	9.88	1.32	0.26	11.16	31.72	14.10	4.35	1.42	0.18	63.21
Bw2	0.32-0.47	9.86	1.32	0.22	11.34	40.37	22.85	2.05	0.10	0.22	62.47
Bss1	0.47-0.64	10.00	0.95	0.23	11.45	46.07	29.65	10.35	1.32	0.76	84.83
Bss2	0.64-0.81	9.87	1.38	0.19	11.72	43.38	27.10	9.50	1.28	0.62	88.75
Bss3	0.81-1.10	9.82	1.26	0.16	11.86	33.87	20.50	7.95	1.12	0.52	88.84
Cr	1.10	Weathered granite-gneiss									
Pedon 3. Lithic Ustorthents (Uplands)											
Ap	0.00-0.09	7.68	0.05	0.58	5.42	16.16	8.05	4.75	0.20	0.18	81.56
2A1	0.09-0.20	7.86	0.06	0.43	6.86	36.58	24.45	7.90	1.36	0.23	92.78
R	0.20	Granite-gneiss									
Pedon 4. Typic Haplustepts (Uplands)											
Ap	0.00-0.10	10.48	0.04	0.58	14.52	10.05	5.65	2.15	0.44	0.34	85.37
2Bw1	0.10-0.28	10.44	0.04	0.39	15.26	14.49	7.30	3.90	0.42	0.32	82.40
2Bw2	0.28-0.43	10.09	1.04	0.34	17.64	16.26	7.55	4.85	0.40	0.27	80.38
Cr	0.43	Weathered granite-gneiss									
Pedon 5. Typic Haplustepts (Uplands)											
Ap	0.00-0.13	8.31	0.06	0.72	10.35	15.87	9.50	4.45	0.72	0.58	85.34
2Bw	0.13-0.33	8.09	0.06	0.63	10.71	17.28	10.25	4.90	0.82	0.71	86.51
Cr	0.33	Weathered granite-gneiss									
Pedon 6. Lithic Ustorthents (Uplands)											
Ap	0.00-0.10	7.91	0.09	0.19	10.12	17.03	10.55	4.55	0.77	0.72	87.18
A1	0.10-0.20	8.02	0.20	0.14	11.54	17.38	10.30	4.90	0.82	0.74	91.19
R	0.20	Granite-gneiss									
Pedon 7. Typic Haplustepts (Plains)											
Ap	0.00-0.10	7.65	0.27	0.26	8.66	10.05	5.65	2.15	0.42	0.37	85.47
Bw1	0.10-0.26	7.63	0.22	0.21	7.53	9.14	4.85	1.35	0.66	0.52	80.74
Bw2	0.26-0.46	7.92	0.36	0.18	8.92	28.12	12.35	4.80	0.92	0.34	65.47
Cr	0.46	Weathered granite-gneiss									

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 (Uplands)									
Ap	0.00-0.11	88	17.20	315	27.21	0.92	0.72	6.32	12.30
A12	0.11-0.20	75	15.68	309	23.52	0.55	0.81	4.06	11.83
Bw	0.20-0.32	88	16.18	334	18.24	0.43	0.70	5.24	9.76
Cr	0.32	Weathered calcareous gneiss							
Pedon 2	**Typic Haplusterts (Plains)**								
Ap	0.00-0.08	88	15.32	166	20.42	0.48	0.72	9.12	9.88
Bw1	0.08-0.32	75	13.24	149	17.52	0.39	0.69	8.34	11.20
Bw2	0.32-0.47	75	14.56	214	14.74	0.48	0.74	8.15	12.73
Bss1	0.47-0.64	63	16.32	259	12.56	0.31	0.79	7.48	14.91
Bss2	0.64-0.81	88	15.34	391	10.08	0.49	0.86	8.07	10.56
Bss3	0.81-1.10	63	17.47	379	12.35	0.13	1.26	7.48	9.32
Cr	1.10	Weathered granite-gneiss							
Pedon 3	**Lithic Ustorthents (Uplands)**								
Ap	0.00-0.09	88	15.65	257	16.03	0.64	0.61	6.19	3.88
2A1	0.09-0.20	188	21.62	161	12.53	0.60	0.34	5.82	2.92
R	0.20	Granite-gneiss							
Pedon 4	**Typic Haplustepts (Uplands)**								
Ap	0.00-0.10	251	17.69	158	31.32	0.59	1.06	7.40	10.55
2Bw1	0.10-0.28	113	16.63	170	28.31	0.52	1.26	7.22	6.45
2Bw2	0.28-0.43	75	15.84	137	23.68	0.41	1.92	6.73	5.26
Cr	0.43	Weathered granite-gneiss							
Pedon 5	**Typic Haplustepts (Uplands)**								
Ap	0.00-0.13	138	14.25	173	18.83	0.65	1.21	6.04	8.44
2Bw	0.13-0.33	113	15.36	140	14.35	0.63	1.35	5.69	7.23
Cr	0.33	Weathered granite-gneiss							
Pedon 6	**Lithic Ustorthents (Uplands)**								
Ap	0.00-0.10	188	24.03	166	14.08	0.93	1.75	9.92	17.60
A1	0.10-0.20	176	18.71	139	12.36	0.88	1.70	7.86	13.85
R	0.20	Granite-gneiss							
Pedon 7	**Typic Haplustepts (Plains)**								
Ap	0.00-0.10	188	21.42	286	13.58	0.64	1.86	16.52	21.16
Bw1	0.10-0.26	163	17.84	258	11.23	0.62	1.82	12.82	18.16
Bw2	0.26-0.46	125	18.36	224	9.62	0.47	1.54	12.48	16.54
Cr	0.46	Weathered granite-gneiss							

The pedons 3 and 6 were placed under Psamments at sub-order level because of high sand fraction, absence of any diagnostic horizon and not showing permanent saturation with water. These were grouped under Ustipsamments at great group level due to the presence of ustic soil moisture regime. Finally, they are classified under Typic Ustipsamments at sub-group level as they showed typical characteristics of Ustipsamments.

Soil fertility

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

Macronutrients

The available N content in the study area varied from 63 to 251 kg ha^{-1} (Table 5) throughout the depth. Available nitrogen content 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 also, the depleted nitrogen from soils is supplemented by external addition of fertilizers at regular intervals during crop cultivation (Satish Kumar and Naidu, 2012).

The available P content ranged from 13.24 to 24.03 kg ha^{-1} in soils of the study area. The highest available phosphorus was found in the surface horizons and decreased with depth, which might be due to the confinement of crop cultivation to the rhizosphere and supplementing the depleted phosphorus by external fertilizers and presence of free iron oxide and exchangeable Al^{3+} in smaller amounts (Thangasamy *et al.,* 2005). The relatively low phosphorus contents in sub-surface horizons were due to the fixation of released phosphorus by clay minerals and oxides of iron and aluminum.

The available K content of soils in the study area ranged from 137 to 391 kg ha^{-1}. The highest available potassium was found in the surface horizons and showed more or less a decreasing trend with depth, which might be attributed to more intense weathering, release of labile K from organic residues, upward translocation of potassium from lower depths along with capillary raise of ground water and application of K fertilizers (Sharma and Anil Kumar, 2003). The available sulphur in soils varied from 9.62 to 31.32 mg kg^{-1}. The available sulphur was found to be more in the surface horizons than sub-surface horizons due to higher amounts of organic matter in surface layers.

Micronutrients

The DTPA-extractable Zn in the study area ranged from 0.13 to 0.93 mg kg^{-1} soil. Considering 0.6 mg kg^{-1} soil (Lindsay and Norvell, 1978) as critical level for available zinc, the pedons 2 and 4 were found to be deficient in available zinc throughout their depth. All other pedons were found to be sufficient in available Zn content (except in the A12 and Bw horizons of pedon 1 and Bw2 horizon of pedon 7). The low available zinc was due to calcareousness, high pH and low organic matter which have resulted in the formation of insoluble compounds of zinc or insoluble calcium zincate (Rattan and Sharma, 2004).

The DTPA-extractable Fe content varied from 4.06 to 16.52 mg kg^{-1} soil. According to the critical limit of 4.5 mg kg^{-1} soil, as given by Lindsay and Norvell (1978), the soils were found sufficient in available iron content. The distribution of available iron in general did not follow any definite pattern. The surface horizons contained more available Fe than sub-surface horizons in all the pedons in the study area, which is 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 have decreased the availability of Fe (Vijaya Kumar *et al.*, 2013).

The DTPA-extractable copper (0.34 to 1.92 mg kg^{-1}) and manganese (2.92 to 21.16 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 (Lindsay and Norvell, 1978). The higher concentrations of available copper and manganese in these soils might be due to higher biological activity and the chelating effect of organic compounds that are released during the decomposition of organic matter left after crop harvesting (Verma *et al.*, 2005).

Soils in the study area from central parts of Prakasam district were shallow to very deep in depth, weakly alkaline to alkali 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^{+}, respectively. The soils were low in available nitrogen, medium in available phosphorus, medium to high in available potassium and sufficient in available sulphur. However, soils were deficient in available zinc (except in the pedons 2 and 4 and in the subsurface horizons of pedon 1), and sufficient in available iron, copper and manganese. The soils of the study area were classified as Lithic Ustorthents (pedons 3 and 6), Typic Haplustepts (pedons 1, 4, 5 and 7) and Typic Haplusterts (pedon 2). The present study in the central parts of Prakasam district revealed that soil test based judicious application of organic materials in combination with chemical fertilizers to these soils not only helps in achieving sustainable higher yields in different crops, but also sustains the soil productivity for future generations without deteriorating soil health.

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