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Genesis, characterization and classification of soils from selected parts of Prakasam district in Andhra Pradesh, India

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Abstract
Seven typical pedons from Chimakurthi, Marrichetlapalem, Iapavaluru, Rudravaram, Taragudipadu, Chellapalem and Mainampadu villages representing major land forms in the selected parts of Prakasam district of Andhra Pradesh *viz.*, uplands and plains, developed from granite-gneiss parent material under varying land use were selected for the present study. These pedons were studied in detail for their morphological characteristics, soil genesis, physical and physico-chemical properties and nutrient status. Soils in the area were moderately deep to very deep, slightly alkaline to alkali (pH 7.24 to 10.35) in reaction, non-saline. They had ustic soil moisture regime and iso-hyperthermic temperature regime. Texture, organic carbon, CEC and base saturation in the profiles ranged from loamy sand to clay, 0.18 to 0.70 per cent, 8.65 to 51.48 cmol (p^+) kg^{-1} and 62.87 to 90.92 per cent, respectively. These soils were found to be low in available nitrogen, low to high in available phosphorus, medium to high in available potassium and sufficient in available sulphur (except in lower layers of pedon 2). They were found to be deficient in DTPA-extractable Zn (except in the surface horizons of pedons 3 and 4). However, they were sufficient in DTPA-extractable Fe (except in the Bw1 horizon of pedon 1), Cu (except in the 3A3 horizon of pedon 7) and Mn. The pedons 2 and 7 were grouped under Entisols due to absence of sub-surface diagnostic horizon and were classified as Typic Ustorthents at sub-group level; pedons 1, 3, 5 and 6 were placed under Inceptisols due to presence of cambic (BW) sub-surface diagnostic horizon and classified as Typic Haplustepts at sub-group level. The pedon 4 was grouped under Vertisols due to the presence of vertic features like slickensides, pressure faces, cracks and presence of more than 30 % clay in all the horizons and was classified as Typic Haplusterts at sub-group level. Location specific recommendations were made based on the physical, physico-chemical characteristics and fertility status of these soils for better and sustainable crop production besides conserving and improving the soil health.

Keywords: Soil classification, soil survey, cambic horizon, slickensides, pressure faces, soil fertility

Introduction
Soil is a very important natural resource that supports a vast range of living systems. However, it is non-renewable and finite natural resource. Indiscriminate use coupled with lack of proper management practices has led to its degradation to alarming levels echoing the concerns of the planners, researchers and farmers (Sharma, 2006) [1]. This shows that there is an urgent need for scientific study, management and development of this vital natural resource through various approaches at different levels. Soil resource inventory provides insights into its limitations and potentialities and provides opportunities for its best management. It also provides adequate information about land forms, natural vegetation as well as characteristics of soils which can be utilized for better land resources management and development (Manchanda *et al.*, 2002) [2]. Rational utilization of land resources can be achieved by optimizing its use, which demands evaluation of land for its alternative uses. Characterization, classification and evaluation of soils under different land uses is the first important step in developing sustainable and eco-friendly land use models. There is no sufficient information available especially on characterization, classification and genesis of soils pertaining to Andhra Pradesh in general and to Prakasam district in particular. Hence, present study was taken up to characterize, classify and evaluate the soils in selected parts of Prakasam district covering different land forms and types of soils.

Material and Methods
Description of the Study Area
Prakasam district in Andhra Pradesh is located between 14° 57′ and 16° 17′ North latitudes and 78° 43′ and 80° 25′ East longitudes. Soils in Prakasam district are mainly developed from granite-gneiss parent materials with calcareousness in some areas, while soils in some area

developed from alluvial parent material (Table 1). The study area is classified under semi-arid monsoonic climate with distinct summer, winter and rainy seasons. It receives a mean annual precipitation of 747 mm, of which about 93% is received during months of April to November. The mean annual temperature of the area is 29.49°C, with a mean summer and winter temperatures of 32.33°C and 26.09°C, respectively. 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) of the area is found to be ustic, while the soil temperature regime (STR) is 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, Tephrosia purpurea, Lantana camara, Opuntia ficus-indica and Cyperus rotundus, etc.* Commonly grown crops in the study area are rice, cotton, chickpea, tobacco, sorghum, turmeric, sesame, chilli, sugarcane, pigeonpea and maize etc.

Methodology

A reconnaissance soil survey was primarily conducted in Prakasam district using top sheets of 1:50,000 scale as per the procedure outlined by AIS & LUS (1970) [3]. Auger bores, minipots, road cuts and 13 pedons located on plains and uplands were studied. Seven typical pedons were selected through soil correlation exercise from the study area. A total of seven typical pedons representing the study area 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) [4]. Based on the observations at field, horizon-wise soil samples were collected from these profiles and were analyzed for their physical, physico-chemical properties and available major and micro nutrient status using standard procedures. Taxonomic classification of these soils was also done based on the characteristics observed from the field observations and laboratory studies (Soil Survey Staff, 2014) [5].

Results and Discussion

Soil Morphology

Soils in the study area were found to be moderately deep to very deep (28-110 cm) with moderately well-drained to well-drained conditions. Distinctness of horizon boundaries was found to be clear to gradual while the topography was smooth to wavy. According to the colour notations of studied profiles, horizons of these soils have the hue ranging from 2.5YR to 10YR. The profiles 1, 3 and 7 have shown hue of 10YR, with values of 3-4 and chrome of 2-3. Profiles 4 and 5 have shown hue of 7.5YR, with values of 3-4 and chrome of 2-4. Profile 6 has hue of 5YR with values of 3-4 and chrome of 3-4, whereas profile 2 has hue of 2.5YR with values 3-4 and chrome of 4. Soil colour appears to be the function of chemical and mineralogical composition as well as textural make up of soils and is conditioned by topographic position and moisture regime of the soil (Walia and Rao, 1997) [6]. Textural class of soils in the study area varied from loamy sand to clay. Textural variations in these soils might be due to differences in the composition of parent material, topography of the area, *in-situ* weathering and translocation of clay by eluviation and age of the soils (Geetha Sireesha and Naidu, 2013) [7]. Structure of the soils was found to be single grain, angular blocky and sub-angular blocky. Single grain structure was found in lower horizons of Inceptisols indicating lithological discontinuity of these soils (Sitanggang *et al.*, 2006) [8]. The blocky structure *i.e.*, angular and sub-angular blocky was attributed to the presence of high clay fraction (Meena *et al.*, 2012) [9].

The consistence of these soils varied from soft to very hard (dry), loose to firm (moist) and non-sticky-non plastic to very sticky-very plastic (wet). Presence of loose, friable and non-sticky and non-plastic consistence might be due to negligible or very small amount of expanding clay minerals (Thangasamy *et al.*, 2004) [10]. 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 (Lingade *et al.*, 2008) [11] and also due to dominance of smectite clay mineral. Pedons 1, 3, 4, 5 and 6 have exhibited a cambic (Bw) sub-surface diagnostic horizon while the pedon 4 has also shown presence of Bss horizon. However, pedons 2 and 7 did not have any diagnostic horizon. Strong to violent effervescence with dilute HCl was observed in all the pedons except in pedons 2 and 4.

Soil characteristics

Physical characteristics

Physical characteristics of soils in the study area are presented in Table 3. Clay content in the soils varied from 6.19 to 55.68 per cent. The general observation of increase in clay content with depth might be due to the downward translocation of finer particles from surface layers (Ramprakash and Seshagiri Rao, 2002) [12]. Silt content ranged from 5.25 to 27.66 % and its content in general increased with depth. However, it exhibited an irregular trend with depth, which might be due to variations in weathering of parent material or *in situ* formation. Sand constituted the bulk of mechanical fractions in pedons 1, 2 and 7 (40.62-82.23 %), which indicates the siliceous nature of parent material (Geetha Sireesha and Naidu, 2013) [7].

Different horizons of the pedons in the study area have shown bulk density varied from 1.38 to 1.54 Mg m^{-3}. 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) [13], and decreased organic matter content in the lower layers (Coughlan *et al*., 1986) [14]. 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) [15]. Particle density of soil horizons in the pedons of study area ranged between 2.43-2.63 Mg m^{-3}. Particle density was more or less uniform within the pedons (Gurumurthy *et al.*, 1996) [16]. Water holding capacity (WHC) of different pedons in the study area varied from 20.11 to 58.11 per cent. These variations in WHC were due to the differences in depth, clay, silt, sand and organic carbon contents (Thangasamy *et al.*, 2005) [13]. Low water holding capacity in light textured 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, similar findings of which were also reported by Singa Rao and Prabhu Prasadini (1998) [17]. The irregular trend of water holding capacity with depth in pedons 2, 4 and 7 was due to the eluviation and illuviation of finer fractions in different horizons.

Physico-chemical characteristics

Soils in the study area were found to be slightly alkaline to alkali in nature, with pH ranging from 7.24 to 10.35, which was attributed to the nature of the parent material, leaching, presence of calcium carbonate and exchangeable sodium (Shalima Devi and Anil Kumar, 2010) [18]. All the pedons had shown low electrical conductivity values ranging from 0.09 to 1.54 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 (Leelavathi *et al.*, 2009) [19].

Soils in the study area have shown low to medium organic carbon content which ranged from 0.18 to 0.70 per cent (Table 4). The low carbon content in the soils might be due to the prevalence of tropical condition, causing faster degradation of organic matter coupled with low vegetation cover (Nayak *et al.*, 2002) [20]. Organic carbon content decreased with depth in all the pedons. Organic carbon content was relatively high in the surface horizons which was due to the addition of plant residues and farm yard manure to surface horizons (Ashokkumar and Jagdish Prasad, 2010) [21].

Pedons of the study area had shown CEC ranging from 8.65 to 51.48 cmol (p^{+}) kg^{-1} soil, which corresponds to clay content, type of clay mineral and organic carbon content present in these soils (Sitanggang *et al.*, 2006) [8]. Free $CaCO_3$ content in these soils ranged from 5.32 to 18.58 per cent and presence of high $CaCO_3$ 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) [21]. The $CaCO_3$ content, in general, increased with depth in all the pedons (except in pedons 2 and 7) which was due to leaching of calcium and its subsequent precipitation due to high pH level. Pedons 2 and 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) [22].

Exchangeable bases in all pedons of the study area, in general, were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ on the exchange complex. The percent base saturation (BSP) ranged from 62.87 to 90.92 per cent. Higher values of BSP observed in these soils are due to higher amount of Ca^{2+} ions occupying the exchange sites on the colloidal surfaces. The CEC: clay ratio in the selected soils has ranged from 0.41 to 1.81 and the CEC: clay ratio was used to identify the clay mineralogy (Ashokkumar and Jagdish Prasad, 2010) [21].

Soil Genesis

Soil profile study in the representative area has shown distinctive horizontal layers, some of which were very clearly visible. Significant changes were also observed as these soils were developed from relatively unconsolidated parent material. Pedons 1, 3, 4 and 6 were developed from weathered gneiss; pedons 2 and 5 from weathered granite-gneiss, whereas pedon 7 was developed from alluvium parent material. Most of the pedons (1, 3, 4, 5 and 6) found to have lime in their parent material. Organic matter was found to be high 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 (Ram *et al.,* 2010) [23]. Surface horizons in all these pedons were darker compared to their sub-surface horizons due to accumulation of organic matter. The higher organic matter contents recorded in surface soils was due to continuous addition of organic matter through leaf fall, stubbles, roots and application of organic manures to the surface layers only (Bhaskar *et al.*, 2004) [24]. Some organic carbon was also leached from surface to lower layers along with the percolating water (Leelavathi *et al*., 2009) [19].

Soil formation was followed by translocation of materials from one point to another within the soil. During this phase, eluviation and illuviation processes play a significant role. Development of B horizons in the pedons 1, 3, 4, 5 and 6 was due to eluviation and illuviation processes within these profiles. Cambic horizon (Bw) was formed as a result of these processes. However, these processes were not operated in the pedons 2 and 7, 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 of sub-soil leading to the development of cambic horizon (Bw), which was found in the pedons 1, 3, 4, 5 and 6 (Niranjana *et al.*, 2011) [25].

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 (Satish Kumar and Naidu, 2012) [26]. 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 (Vara Prasad Rao *et al.,* 2008) [15].

Soil Taxonomy

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

The pedons 1, 3, 5 and 6 were classified under Ustepts at sub-order level due to presence of 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. And also, 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 under Typic Haplustepts at sub-group level (Niranjana *et al*., 2011) [25]. The pedon 4 was classified under usterts at sub-order level due to the 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. And at sub-group level it was classified under Typic Haplusterts due to absence of lithic contact within 100 cm of the mineral soil surface (Marathe *et al.,* 2003) [27].

The pedons 2 and 7 were placed under Orthents at sub-order level because 1) They did not permanently saturate with water and matrix was not reduced in all the horizons below 25 cm from the mineral soil surface 2) Three per cent or more (volume) fragments of diagnostic horizon were not observed at a depth of less than 100 cm 3) Absence of rock fragments and a texture of loamy fine sand or coarser 4) Showed a decrease in organic carbon with depth. These two pedons were grouped under Ustorthents at great group level due to the presence of ustic soil moisture regime. Finally, at sub-group level, they were classified under Typic Ustorthents as they showed typical characteristics of Ustorthents (Satish Kumar and Naidu, 2012) [26].

Soil fertility status

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

Macronutrients

Available N content in the soils of study area ranged from 88 to 251 kg ha^{-1} through the depth. It 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 the cultivation of crops is mainly confined to the surface horizon (rhizosphere) only and also, the depleted N from soils is supplemented by external addition of fertilizers at regular intervals during crop cultivation (Satish Kumar and Naidu, 2012) [26].

Available P content in the soils of the study area varied from 5.29 to 44.45 kg ha^{-1}. The available P, in general, was maximum 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. 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 (Thangasamy *et al.*, 2005) [13].

Available K content of soils in the study area ranged from 136 to 862 kg ha^{-1}. The highest available K, in general, 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 rise of ground water and application of K fertilizers (Sharma and Anil Kumar, 2003; Basavaraju *et al.*, 2005) [28, 29]. Available S in soils varied from 8.15 to 25.20 mg kg^{-1} and it was found to be more in the surface horizons than sub-surface horizons due to higher amounts of organic matter in surface layers (Sharma and Gangwar, 1997) [30].

Micronutrients

DTPA-extractable Zn in these soils varied from 0.16 to 0.66 mg kg^{-1} soil. Considering 0.6 mg kg^{-1} soil (Lindsay and Norvell, 1978) [31] as critical level for available zinc, the pedons 1, 2, 5, 6 and 7 were found to be deficient in available zinc throughout their depth. Pedons 3 and 4 were found to be sufficient in available Zn content in the surface horizons. The low available zinc, in general, 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 (Jagdish Prasad *et al.*, 2009) [32].

DTPA-extractable Fe content ranged from 3.96 to 12.86 mg kg^{-1} soil. According to the critical limit of 4.5 mg kg^{-1} soil, as given by Lindsay and Norvell (1978) [31], the soils were mostly found sufficient in available iron content. Available iron content, in general, followed a decreasing trend with depth, while it did not follow any definite pattern in pedons 4 and 5. Surface horizons of pedons contained more available Fe than sub-surface horizons in all the pedons (except pedon 5) in the study area, which is due to accumulation of organic carbon in the surface horizons. 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 (Vijaya Kumar *et al.*, 2013) [33].

DTPA-extractable Cu (0.13 to 1.19 mg kg^{-1}) and Mn (5.44 to 12.50 mg kg^{-1}) were found to be sufficient in all the soils of the study area (except 3A3 horizon for Cu) as these nutrients are well above their critical limits of 0.2 and 1.0 mg kg^{-1}, respectively (Lindsay and Norvell, 1978) [31]. The higher concentrations of available Cu and Mn 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; Verma *et al.*, 2007) [34, 35].

Table 1: Landscape characteristics of pedons in the study area

Pedons / Villages	Location	Elevation above mean sea level (m)	Physiography	Slope (%)	Drainage	Parent material
P1 Chimakurthi	15°35′20 69″ N 79°49′49 78″ E	75	Plains	0-1	Moderately well drained	Weathered gneiss mixed with lime
P2 Marrichetlapalem	15°33′10 50″ N 79°47′48 50″ E	60	Plains	0-1	Well drained	Weathered granite-gneiss
P3 Iapavaluru	15°40′39 53″ N 79°55′27 01″ E	37	Uplands	1-3	Well drained	Weathered gneiss mixed with lime
P4 Rudravaram	15°36′25 50″ N 79°58′35 35″ E	23	Plains	0-1	Moderately well drained	Weathered gneiss mixed with lime
P5 Taragudipadu	15°37′16 26″ N 79°54′08 61″ E	45	Plains	0-1	Moderately well drained	Weathered granite-gneiss mixed with lime
P6 Chellapalem	15°35′45 03″ N 79°57′37 92″ E	30	Uplands	1-3	Well drained	Weathered gneiss mixed with lime
P7 Mainampadu	15°33′32 96″ N 79°56′36 49″ E	27	Uplands	1-3	Well drained	Alluvium

Table 2: Morphological characteristics of pedons in the study area

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 (Plains)**																	
Ap	0.00-0.13	10 YR 3/2	10 YR 4/2	sc	f	1	sbk	h	fr	sp	ev	c	s	f	m	f	f	
Bw1	0.13-0.38	10 YR 3/3	10 YR 4/3	cl	m	2	abk	h	fi	vsvp	ev	g	w	f	m	f	f	
R	0.38	Weathered gneiss mixed with lime																
Pedon 2	**Typic Ustorthents (Plains)**																	
Ap	0.00-0.10	2.5 YR 3/4	2.5 YR 4/4	sl	f	1	sbk	l	l	sopo	-	c	s	f	f	f	c	
2A1	0.10-0.30	2.5 YR 3/4	2.5 YR 4/4	sl	f	0	sg	l	l	sopo	-	c	s	f	f	-	-	
2A2	0.30-0.48	2.5 YR 3/4	2.5 YR 4/4	ls	f	0	sg	l	l	sopo	-	c	s	f	m	f	f	
Cr	0.48	Weathered granite-gneiss																
Pedon 3	**Typic Haplustepts (Uplands)**																	
Ap	0.00-0.12	10 YR 3/3	10 YR 4/2	c	m	2	sbk	h	fr	sp	ev	c	s	f	m	f	f	
Bw	0.12-0.28	10 YR 3/3	10 YR 4/3	c	c	3	sbk	vh	fi	vsvp	ev	g	s	f	m	f	f	
R	0.28	Weathered gneiss mixed with lime																
Pedon 4	**Typic Haplusterts (Plains)**																	
Ap	0.00-0.12	7.5 YR 3/2	7.5 YR 4/2	c	m	2	sbk	h	fi	sp	-	c	s	f	f	f	f	
A1	0.12-0.25	7.5 YR 3/2	7.5 YR 4/3	c	c	3	abk	vh	fi	vsvp	-	g	s	f	f	f	f	
Bw	0.25-0.44	7.5 YR 3/2	7.5 YR 4/2	c	c	3	abk	vh	fi	vsvp	-	g	w	f	f	-	-	
Bss1	0.44-0.70	7.5 YR 3/2	7.5 YR 4/2	c	c	3	abk	vh	fi	vsvp	-	g	w	-	-	-	-	
Bss2	0.70-1.10	7.5 YR 3/2	7.5 YR 5/2	c	c	3	abk	vh	fi	vsvp	-	g	w	-	-	-	-	
Cr	1.10	Weathered gneiss mixed with lime																

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 (Plains)**																	
Ap	0.00-0.15	7.5 YR 3/2	7.5 YR 3/4	c	m	1	sbk	h	fi	sp	es	c	s	f	f	f	f	
2Bw1	0.15-0.30	7.5 YR 3/2	7.5 YR 3/3	c	c	3	abk	vh	fi	vsvp	es	c	s	-	-	f	f	Pressure faces
3Bw2	0.30-0.42	7.5 YR 3/2	7.5 YR 3/4	c	c	3	abk	vh	fi	vsvp	es	c	s	-	-	f	f	Pressure faces
Cr	0.42	Weathered granite-gneiss mixed with lime																
Pedon 6	**Typic Haplustepts (Uplands)**																	
Ap	0.00-0.08	5 YR 4/3	5 YR 4/4	c	m	2	sbk	h	fi	sp	ev	c	s	m	f	f	c	
Bw	0.08-0.29	5 YR 3/3	5 YR 3/4	c	m	2	abk	vh	fi	vsvp	ev	c	s	c	f	f	c	
Cr	0.29	Weathered gneiss mixed with lime																
Pedon 7	**Typic Ustorthents (Uplands)**																	
Ap	0.00-0.05	10 YR 3/3	10 YR 4/3	scl	f	3	sbk	sh	fi	sp	ev	c	s	f	f	f	m	
2A1	0.05-0.15	10 YR 4/2	10 YR 4/2	sl	m	2	abk	s	fr	sopo	ev	c	s	-	-	f	m	
2A2	0.15-0.28	7.5 YR 3/3	7.5 YR 3/4	sl	m	2	sbk	s	fr	sopo	es	c	s	-	-	c	f	
3A3	0.28-0.56	7.5 YR 3/3	7.5 YR 3/4	ls	f	0	sg	s	l	sopo	es	g	s	-	-	-	-	
C +	0.56	Alluvium																

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 – structure less, 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 pedons in the study area

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 (Plains)**						
Ap	0.00-0.13	44.65	19.47	35.88	1.48	2.51	26.74
Bw1	0.13-0.38	40.62	22.56	36.82	1.52	2.54	30.15
R	0.38	Weathered gneiss mixed with lime					
Pedon 2	**Typic Ustorthents (Plains)**						
Ap	0.00-0.10	66.89	23.24	9.87	1.49	2.53	21.53

2A1	0.10-0.30	72.65	19.38	7.97	1.51	2.51	21.20
2A2	0.30-0.48	76.26	17.55	6.19	1.54	2.56	20.11
Cr	0.48	Weathered granite-gneiss					
Pedon 3	**Typic Haplustepts (Uplands)**						
Ap	0.00-0.12	28.18	26.63	45.19	1.42	2.61	56.43
Bw	0.12-0.28	33.62	18.51	47.87	1.49	2.53	57.63
Cr	0.28	Weathered gneiss mixed with lime					
Pedon 4	**Typic Haplusterts (Plains)**						
Ap	0.00-0.12	25.92	24.73	49.35	1.43	2.48	52.52
A1	0.12-0.25	19.98	25.52	54.50	1.40	2.46	53.47
Bw	0.25-0.44	19.16	27.66	53.18	1.38	2.43	54.92
Bss1	0.44-0.70	29.82	23.26	46.92	1.45	2.49	47.53
Bss2	0.70-1.10	31.35	21.83	46.82	1.47	2.52	41.46
Cr	1.10	Weathered gneiss mixed with lime					
Pedon 5	**Typic Haplustepts (Plains)**						
Ap	0.00-0.15	32.73	19.64	47.63	1.42	2.61	52.67
2Bw1	0.15-0.30	36.23	14.82	48.95	1.47	2.53	56.05
3Bw2	0.30-0.42	25.73	18.59	55.68	1.53	2.59	58.11
Cr	0.42	Weathered granite-gneiss mixed with lime					
Pedon 6	**Typic Haplustepts (Uplands)**						
Ap	0.00-0.08	29.08	25.59	45.33	1.42	2.63	56.42
Bw	0.08-0.29	32.96	19.45	47.59	1.49	2.54	57.68
Cr	0.29	Weathered gneiss mixed with lime					
Pedon 7	**Typic Ustorthents (Uplands)**						
Ap	0.00-0.05	71.46	6.42	22.12	1.48	2.53	33.67
2A1	0.05-0.15	73.81	9.86	16.33	1.51	2.52	31.42
2A2	0.15-0.28	79.34	6.18	14.48	1.52	2.54	28.62
3A3	0.28-0.56	82.23	5.25	12.52			
C +	0.56	Alluvium					

Table 4: Physico-chemical properties of soils in the study area

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 (Plains)											
Ap	0.00-0.13	7.79	0.10	0.70	11.56	40.32	22.85	2.15	0.12	0.23	62.87
Bw1	0.13-0.38	8.51	0.12	0.53	12.44	34.18	23.25	8.60	0.64	0.32	85.16
R	0.38	Weathered gneiss mixed with lime									
Pedon 2. Typic Ustorthents (Plains)											
Ap	0.00-0.10	7.24	0.23	0.42	6.06	15.86	9.50	4.55	0.76	0.58	86.17
2A1	0.10-0.30	7.46	0.19	0.34	5.32	12.35	6.50	3.55	0.26	0.21	85.18
2A2	0.30-0.48	7.63	0.37	0.30	7.25	8.70	4.65	2.30	0.16	0.13	83.22
Cr	0.48	Weathered granite-gneiss									
Pedon 3. Typic Haplustepts (Uplands)											
Ap	0.00-0.12	7.95	0.10	0.21	12.25	19.57	9.95	1.90	2.60	1.15	79.71
Bw	0.12-0.28	7.96	0.13	0.18	12.62	19.45	9.75	2.15	2.41	0.12	74.19
Cr	0.28	Weathered gneiss mixed with lime									
Pedon 4. Typic Haplusterts (Plains)											
Ap	0.00-0.12	8.06	0.09	0.54	14.53	46.18	35.10	8.15	0.82	0.54	90.31
A1	0.12-0.25	8.16	0.10	0.42	15.34	48.94	35.65	10.00	1.34	0.51	89.11
Bw	0.25-0.44	8.13	0.12	0.42	15.31	50.43	36.25	9.85	2.31	0.44	90.92
Bss1	0.44-0.70	7.61	0.39	0.38	16.53	51.48	33.95	12.15	2.76	0.42	89.90
Bss2	0.70-1.10	7.46	0.36	0.31	18.58	49.74	31.15	12.45	2.98	0.32	88.26
Cr	1.10	Weathered gneiss mixed with lime									
Pedon 5. Typic Haplustepts (Plains)											
Ap	0.00-0.15	7.81	0.17	0.35	6.05	40.68	28.25	7.55	0.82	0.53	86.41
2Bw1	0.15-0.30	7.86	0.15	0.32	7.53	37.92	26.45	5.60	0.84	0.68	88.53
3Bw2	0.30-0.42	8.24	0.11	0.27	7.76	29.86	19.25	4.70	0.72	0.78	85.23
Cr	0.42	Weathered granite-gneiss mixed with lime									
Pedon 6. Typic Haplustepts (Uplands)											
Ap	0.00-0.08	7.72	0.16	0.42	13.52	34.61	22.45	7.10	0.76	0.52	89.08
Bw	0.08-0.29	7.82	0.10	0.36	13.94	35.69	23.75	6.40	0.92	0.38	88.12
Cr	0.29	Weathered gneiss mixed with lime									
Pedon 7. Typic Ustorthents (Uplands)											
Ap	0.00-0.05	9.64	0.59	0.38	13.25	16.28	8.15	4.65	0.23	0.21	81.33
2A1	0.05-0.15	10.35	1.54	0.33	12.73	12.28	6.50	3.25	0.25	0.22	83.22
2A2	0.15-0.28	9.86	1.54	0.26	10.27	11.64	6.45	2.40	0.18	0.20	79.30
3A3	0.28-0.56	9.80	1.54	0.22	11.76	8.65	4.10	2.25	0.16	0.14	76.88
C +	0.56	Alluvium									

Table 5: Available macro and micro nutrient status of soils in the study area

Pedon No. & Horizon	Depth (m)	Available macronutrients				Available micronutrients			
		N P K			S mg kg^{-1}	Zn Cu Fe Mn			
		---------- kg ha^{-1}----------				---------- mg kg^{-1}----------			
Pedon 1 Typic Haplustepts (Plains)									
Ap	0.00-0.13	125	18.78	451	15.16	0.36	0.89	5.17	12.47
Bw1	0.13-0.38	113	20.33	285	12.63	0.24	0.65	3.96	9.68
R	0.38	Weathered gneiss mixed with lime							
Pedon 2	**Typic Ustorthents (Plains)**								
Ap	0.00-0.10	188	44.45	174	14.96	0.49	0.72	12.86	10.96
2A1	0.10-0.30	176	32.26	152	9.26	0.47	0.68	12.82	12.38
2A2	0.30-0.48	151	28.64	136	8.15	0.41	0.63	11.64	11.06
Cr	0.48	Weathered granite-gneiss							
Pedon 3	**Typic Haplustepts (Uplands)**								
Ap	0.00-0.12	201	25.39	726	12.16	0.63	0.63	6.56	9.52
Bw	0.12-0.28	188	34.55	862	10.63	0.47	0.76	6.43	9.21
Cr	0.28	Weathered gneiss mixed with lime							
Pedon 4	**Typic Haplusterts (Plains)**								
Ap	0.00-0.12	251	16.84	525	25.20	0.66	0.67	7.43	12.50
A1	0.12-0.25	163	19.56	505	20.36	0.59	0.62	7.63	11.35
Bw	0.25-0.44	125	14.72	440	19.62	0.53	0.56	7.15	11.62
Bss1	0.44-0.70	125	15.08	426	16.81	0.43	0.66	6.58	9.37
Bss2	0.70-1.10	113	14.74	470	13.26	0.36	0.54	5.36	7.26
Cr	1.10	Weathered gneiss mixed with lime							
Pedon 5	**Typic Haplustepts (Plains)**								
Ap	0.00-0.15	151	5.29	375	18.85	0.36	1.19	6.57	11.24
2Bw1	0.15-0.30	125	6.84	324	14.92	0.32	1.15	4.86	9.12
3Bw2	0.30-0.42	100	5.43	283	13.53	0.28	1.17	5.53	10.26
Cr	0.42	Weathered granite-gneiss mixed with lime							
Pedon 6	**Typic Haplustepts (Uplands)**								
Ap	0.00-0.08	163	19.26	176	12.24	0.16	0.48	7.24	9.17
Bw	0.08-0.29	163	18.24	156	11.58	0.23	0.42	7.13	9.65
Cr	0.29	Weathered gneiss mixed with lime							
Pedon 7	**Typic Ustorthents (Uplands)**								
Ap	0.00-0.05	176	21.31	197	23.22	0.44	0.36	9.11	10.79
2A1	0.05-0.15	100	18.26	357	19.68	0.28	0.32	8.25	8.63
2A2	0.15-0.28	113	17.57	256	17.34	0.34	0.25	7.34	7.26
3A3	0.28-0.56	88	16.13	276	13.25	0.21	0.13	5.24	5.44
C +	0.56	Alluvium							

Conclusion

Soils of the study area from selected parts of Prakasam district were moderately deep to very deep, slightly 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, low to high in available phosphorus, medium to high in available potassium and sufficient (except in lower layers of pedon 2) in available sulphur. These soils were found to be deficient in available zinc (except in the surface horizons of pedons 3 and 4), and sufficient in available iron (except in the Bw1 horizon of pedon 1), copper (except in the 3A3 horizon of pedon 7) and manganese. The soils of the study area were classified as Typic Ustorthents (pedons 2 and 7), Typic Haplustepts (pedons 1, 3, 5 and 6) and Typic Haplusterts (pedon 4). The present study conducted in the selected parts of Prakasam district in Andhra Pradesh 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 productivity of these soils for future generations.

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