Journal of the Indian Society of Soil Science, Vol. 67, No. 2, pp 125-136 (2019)
DOI: 10.5958/0974-0228.2019.00014.8

Characterization, Classification and Evaluation of Soils in Semi-arid Region of Mahanandi Mandal in Kurnool District of Andhra Pradesh

K. Supriya, M.V.S. Naidu[1]*, P. Kavitha[2] and M. Srinivasa Reddy[2]
Department of Soil Science and Agricultural Chemistry, S.V. Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati, 517502, Andhra Pradesh

Ten representative pedons from surroundings of Mahanandi mandal in Kurnool district, Andhra Pradesh were studied for their morphological and physicochemical properties, and nutrient status. These soils were deep to very deep, neutral to moderately alkaline (pH 7.3-8.3), non-saline (0.19-1.00 dS m^{-1}), low to medium in organic carbon (0.2-7.5 g kg^{-1}) and low to high in CEC [4.31-52.11 cmol(p^+)kg^{-1} soil]. Soils were low to medium in available nitrogen (62.7-545.7 kg ha^{-1}), low to high in available phosphorus (2.7-65.7 kg ha^{-1}), high in available potassium (149-1125 kg ha^{-1}) and deficient to sufficient in available sulphur (1.3-79.2 mg kg^{-1}). The DTPA extractable Zn (0.02-4.97 mg kg^{-1}), Fe (0.46-22.56 mg kg^{-1}), Cu (0.02-0.55 mg kg^{-1}) and Mn (0.27-30.80 mg kg^{-1}) were deficient to sufficient. Pedon 2 having argillic (Bt) horizon was classified as Typic Haplustalfs and other pedons with cambic horizon (Bw) were classified as Fluventic Haplustepts (pedons 1, 4 ,6, 8, 9 and 10), Aridic Ustorthents (Pedon 5), Typic Haplustepts (Pedon 3) and Vertic Calciustepts (Pedons 7).

Key words: Soil classification, cambic horizon, argillic horizon, Inceptisols, Alfisols

Soil is the most important basic natural resource that determines ultimate sustainability of any agricultural system. Information on soil characteristics and its quality is prerequisite for sustainable management of soil resources. In view of the present global crises on food, rising food prices in the international market, progressive conversion of arable lands to grow bio-fuel crops and/or other non-agricultural uses, special economic zone (SEZ) challenge, demand for urbanization and industrialization *etc*., technologies in agro-ecological regions are of utmost importance towards ensuring productivity, profitability and national food security (Sarkar 2011). Achieving sustainable management of soil resources in agro-ecological regions necessitates timely monitoring of important soil physical, chemical and biological properties and their responses to changes in land management. It is also necessary to recommend crop-specific agricultural technologies considering soil-site characteristics for effective soil fertility management and enhancing crop productivity (Wakene and Heluf 2003). Suitable land management practices are urgently needed all over the world to preserve the production potential of agricultural lands while safeguarding environmental quality (FAO 1993). A wide variety of crops such as maize, rice, bengal gram, red gram and banana are grown on these soils in Mahanandi mandal with varied production. However, no information is available regarding characterization, classification and evaluation of soils in Kurnool district in general, and Mahanandi mandal in particular. Moreover, a necessity is always felt for mandal-wise database to take-up various agricultural developmental programmes in Andhra Pradesh. Keeping the above facts in view the present investigation was undertaken.

Materials and Methods

Mahanandi mandal lies between 15°22′ and 15°34′ N latitudes and 78°27′ and 78°43′ E longitudes at an elevation ranging from 192-237 m (msl) (Table 1). The area experiences semi-arid monsoonic climate with distinct summer, winter and rainy seasons with an annual rainfall of 1204 mm. The mean annual

*Corresponding author (Email: mvsnaidu66@gmail.com)
Present address
[1]ICAR-Saline Water Scheme, ANGRAU, Bapatla, 522 101
[2]Agricultural college, ANGRAU, Mahanandi, 518502

Table 1. Landscape characteristics of pedons in Mahanandi mandal, Kurnool district, Andhra Pradesh

Pedons / Villages	Location	Elevation above mean sea level (m)	Landform	Slope (%)	Drainage	Parent material
P1 Thimmapuram	15°29′02.1″ N 78°34′15.4″ E	192	Plain	0 – 1	Moderately well drained	Weathered gneiss with lime nodules
P2 Abbipuram	15°29′36.5″ N 78°34′10.8″ E	220	Upland	1 – 3	Moderately well drained	Weathered gneiss mixed with gravel
P3 Allinagaram	15°28′10.6″ N 78°35′00.8″ E	231	Upland	1 – 3	Well drained	Limestone
P4 Srinagaram	15°27′57.0″ N 78°36′21.7″ E	237	Plain	0 – 1	Well drained	Limestone
P5 Gajulapalle	15°24′00.3″ N 78°37′39.1″ E	224	Upland	1 – 3	well drained	Limestone
P6 Gopavaram	15°25′40.9″ N 78°35′31.1″ E	219	Plain	0 – 1	Well drained	Weathered gneiss
P7 AGCF 1	15°27′12.5″ N 78°35′31.9″ E	230	Upland	1 – 3	Well drained	Weathered gneiss with lime nodules
P8 AGCF 2	15°27′11.4″ N 78°35′35.2″ E	231	Upland	1 – 3	Moderately well drained	Weathered gneiss with lime nodules
P9 AGCF 3	15°27′26.1″ N 78°35′56.9″ E	232	Plain	0 – 1	Well drained	Weathered gneiss with lime nodules
P10 AGCF4	15°27′21.9″ N 78°35′39.7″ E	220	Plain	0 – 1	Well drained	Weathered gneiss with lime nodules

AGCF means Agricultural college farm

temperature is 28.3 °C with mean summer and mean winter temperatures of 33.0 °C and 27.2 °C, respectively. The maximum temperature recorded for last 10 years was 40.4 °C and the minimum temperature was 16.1 °C. Hence, the area qualifies for iso-hyperthermic soil temperature regime. The soil moisture is dry more than 90 cumulative days or 45 consecutive days in four months following summer solstice. So it qualifies for ustic soil moisture regime. The natural vegetation of the area comprises of Tridax daisy (*Tridax procumbens*), Carrot grass (*Parthenium hysterophorus*), Mesquite (*Prosopis juliflora*), Rubber bush (*Calotropis gigantia*), Papuan wattle (*Acacia auriculiformis*), Day flower (*Commilina benghalensis*), Star grass (*Cynodon dactylon*), Purple nutsedg (*Cyprus rotundus*), Karaj (*Pongamia pinneta*), Neem (*Azadirachta indica*) *etc*.

Soil survey was conducted in Mahanandi mandal located in semi-arid agro-ecological region as per procedure outlined by AIS&LUS (1970) and ten representative pedons were selected. The morphological characteristics of the pedons were studied in the field for as per procedure outlined in Soil Survey Manual (Soil Survey Division Staff 2015). Horizon-wise samples were collected, air-dried and processed and fine fraction (<2 mm) was used for analysis of physical and physicochemical properties and available nutrient status using standard procedures (Jackson 1973). The soils were classified as per Keys to Soil Taxonomy (Soil Survey Staff 2014).

Results and Discussion

Soil morphology

Morphological characteristics of the soils are presented in table 2. The soils were deep to very deep with moderately well to well-drained. In pedons 1, 3, 4, 6, 7, 8, 9 and 10 the colour (moist) varied from 10YR 2/1 (very dark brown) to 10YR 5/8 (yellowish brown) whereas in pedon 2, the colour ranged from 10YR 3/2 (dark grayish brown) to 10YR 4/4 (dark yellowish brown). The soils of pedon 5 exhibited 7.5YR 4/6 (strong brown). 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). The soils of Mahanandi mandal showed wide textural variations (sand to clay loam). The wide textural variation might be due to variation in parent material (granite-gneiss to limestone), topography, *in-situ* weathering and translocation of clay.

The dominant structure of the soils was sub-angular blocky and angular blocky. The blocky structures *i.e.* angular and sub-angular blocky were

Table 2. Morphological characteristics of the soils

Pedon No. and Horizon	Depth (m)	Colour Dry	Colour Moist	Texture	Structure S	Structure G	Structure T	Consistency Dry	Consistency Moist	Consistency Wet	Effervescence	Boundary D	Boundary T	Cutans T	Cutans TH	Cutans Q	Pores S	Pores Q	Roots S	Roots Q	Other features
Pedon 1 Fluventic Haplustepts																					
Ap	0.00-0.25	10 YR 3/2	10 YR 3/2	scl	m	2	sbk	sh	fi	ss sp	-	c	s	-	-	-	-	-	f	f	-
2Bw1	0.25-0.52	10 YR 3/4	10 YR 2/2	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
2Bw2	0.52-0.67	10 YR 3/4	10 YR 3/2	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
2Bw3	0.67-1.00	10 YR 3/3	10 YR 3/2	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
Cr	Weathered gneiss with lime nodules																				
Pedon 2 Typic Haplustalfs																					
Ap	0.00-0.22	7.5 YR 5/4	7.5 YR 4/2	sl	f	1	sbk	sh	fr	ss sp	-	c	s	-	-	-	-	-	f	f	-
2Bt1	0.22-0.42	7.5 YR 4/3	7.5 YR 4/3	cl	c	3	sbk	h	vfi	ss sp	-	d	w	-	-	-	-	-	-	-	-
2Bt2	0.42-0.80	7.5 YR 4/4	7.5 YR 4/3	cl	c	3	sbk	h	vfi	ss sp	-	d	w	-	-	-	-	-	-	-	-
2Bt3	0.80-1.10	7.5 YR 4/4	7.5 YR 4/4	cl	c	3	sbk	h	vfi	ss sp	-	d	w	-	-	-	-	-	-	-	-
Cr	Weathered gneiss mixed with gravel																				
Pedon 3 Typic Haplustepts																					
Ap	0.00-0.20	10 YR 4/4	10 YR 3/2	ls		sg	s	fr	so po	-	c	s	-	-	-	-	-	f	f	-	
AB	0.20-0.44	10 YR 3/2	10 YR 4/2	ls		sg	s	fr	so po	-	c	s	-	-	-	-	-	-	-	-	
Bw	0.44-0.69	10 YR 3/3	10 YR 4/3	sl	f	1	sbk	sh	fr	ss sp	-	d	w	-	-	-	-	-	-	-	-
R	Limestone																				
Pedon 4 Fluventic Haplustepts																					
Ap	0.00-0.17	10 YR 3/2	10 YR 3/1	l	m	1	sbk	sh	fr	ss sp	-	c	s	-	-	-	-	-	f	f	-
Bw1	0.17-0.50	10 YR 3/1	10 YR 4/1	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	f	f	conca
Bw2	0.50-0.79	10 YR 2/1	10 YR 4/1	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	conca
Bw3	7.90-1.04	10 YR 2/1	10 YR 4/1	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	conca
Bw4	1.04-1.25	10 YR 2/1	10 YR 5/1	cl	c	3	abk	vh	vfi	vs vp	-	c	s	-	-	-	-	-	-	-	conca
R	Limestone																				
Pedon 5 Aridic Ustorthents																					
Ap	0.00-0.24	7.5 YR 5/6	7.5 YR 4/4	sil	f	1	sbk	s	fr	so po	-	c	s	-	-	-	-	-	f	f	-
A2k	0.24-0.58	7.5 YR 4/6	7.5 YR 4/6	sl	f	1	sbk	sh	fr	so po	-	d	w	-	-	-	-	-	-	-	-
C1	0.58-1.02	7.5 YR 4/3	7.5 YR 4/4	sicl	m	2	sbk	sh	fr	ss ps	-	d	w	-	-	-	-	-	-	-	-
2C2k	1.02-1.32	7.5 YR 4/6	7.5 YR 4/6	s		sg	s	fr	so po	-	c	s	-	-	-	-	-	-	-	-	
2C3	1.32-1.55	7.5 YR 5/6	7.5 YR 4/4	sicl	m	2	abk	sh	fi	ss ps	-	c	s	-	-	-	-	-	-	-	-
R	Limestone																				
Pedon 6 Fluventic Haplustepts																					
Ap	0.00-0.16	10 YR 4/4	10 YR 4/4	sl	f	1	sbk	sh	fr	ss ps	-	c	s	-	-	-	-	-	f	f	-
2Bw1	0.16-0.41	10 YR 4/4	10 YR 4/4	l	f	1	sbk	h	fr	ss ps	-	d	w	-	-	-	-	-	-	-	-
3Bw2	0.41-0.74	10 YR 4/6	10 YR 4/6	sl	f	1	sbk	h	fr	ss ps	es	c	s	-	-	-	-	-	-	-	-
4Bw3	0.74-1.14	10 YR 5/6	10 YR 5/6	sicl	c	2	sbk	h	fi	ss ps	-	d	w	-	-	-	-	-	-	-	Fe and Mn mottles
5Bw4	1.14-1.62	10 YR 4/6	10 YR 4/4	cl	c	3	sbk	h	vfi	ss ps	es	d	w	-	-	-	-	-	-	-	Fe and Mn mottles
5Bw5	1.62-2.00	10 YR 5/8	10 YR 5/8	l	f	1	sbk	sh	fr	ss ps	-	d	w	-	-	-	-	-	-	-	Fe and Mn mottles
Cr	Weathered gneiss																				

Contd...

Pedon 7 Vertic Calciustepts																					
Ap	0.00-0.22	10 YR 3/3	10 YR 4/2	sl	f	1	sbk	sh	fr	ss ps	-	c	s	-	-	-	-	-	f	f	-
Bw1	0.22-0.62	10 YR 3/2	10 YR 4/2	sicl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
Bw2	0.62-0.98	10 YR 3/2	10 YR 3/2	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
Bk1	0.98-1.28	10 YR 3/1	10 YR 3/2	cl	c	3	abk	vh	vfi	vs vp	es	d	w	-	-	-	-	-	-	-	2-3 cm wide crack, conca
Bk2	1.28-1.70	10 YR 4/3	10 YR 4/2	cl	c	3	abk	vh	vfi	vs vp	es	d	w	-	-	-	-	-	-	-	2-3 cm wide crack, conca
Bk3	1.70-2.00	10 YR 4/4	10 YR 3/4	cl	c	3	abk	vh	vfi	vs vp	es	d	w	-	-	-	-	-	-	-	conca
Cr	Weathered gneiss with lime nodules																				
Pedon 8Fluventic Haplustepts																					
Ap	0.00-0.16	10 YR 4/4	10 YR 4/3	scl	m	2	sbk	h	fi	ss ps	-	c	s	-	-	-	-	-	f	f	-
AB	0.16-0.45	10 YR 4/4	10 YR 4/3	scl	m	2	sbk	h	fi	ss ps	-	d	w	-	-	-	-	-	-	-	-
2Bw1	0.45-0.86	10 YR 3/2	10 YR 3/2	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
2Bw2	0.86-1.29	10 YR 3/3	10 YR 3/4	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
2Bw3	1.29-1.59	10 YR 4/6	10 YR 4/4	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	conca
2Bw4	1.59-2.00	10 YR 4/3	10 YR 4/4	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	conca
Cr	Weathered gneiss with lime nodules																				
Pedon 9 Fluventic Haplustepts																					
Ap	0.00-0.20	10 YR 4/6	10 YR 3/4	sl	f	1	sbk	sh	fr	ss ps	-	c	s	-	-	-	-	-	f	f	-
Bw1	0.20-0.50	10 YR 4/4	10 YR 4/3	scl	m	2	sbk	h	fi	ss ps	-	d	w	-	-	-	-	-	-	-	-
Bw2	0.50-0.79	10 YR 4/3	10 YR 4/4	scl	m	2	sbk	h	fi	ss ps	-	d	w	-	-	-	-	-	-	-	-
Bw3	0.79-1.09	10 YR 4/3	10 YR 3/4	scl	m	2	sbk	h	fi	ss ps	es	d	w	-	-	-	-	-	-	-	conca
Bw4	1.09-1.33	10 YR 4/3	10 YR 3/4	scl	m	2	sbk	h	fi	ss ps	es	d	w	-	-	-	-	-	-	-	conca
Bw5	1.33-1.60	10 YR 4/3	10 YR 3/4	scl	m	2	sbk	h	fi	ss ps	es	c	s	-	-	-	-	-	-	-	conca
Cr	Weathered gneiss with lime nodules																				
Pedon 10 Fluventic Haplustepts																					
Ap	0.00-0.20	10 YR 3/2	10 YR 3/3	sl	f	2	sbk	h	fr	ss ps	-	c	s	-	-	-	-	-	f	f	-
BA	0.20-0.50	10 YR 3/4	10 YR 3/4	scl	c	2	sbk	h	fi	ss ps	-	d	w	-	-	-	-	-	-	-	-
2Bw1	0.50-0.80	10 YR 3/2	10 YR 3/2	cl	c	3	abk	vh	vfi	vs vp	-	d	w	-	-	-	-	-	-	-	-
2Bw2	0.80-1.12	10 YR 3/3	10 YR 3/3	cl	c	3	abk	vh	vfi	vs vp	es	d	w	-	-	-	-	-	-	-	conca
2Bw3	1.12-1.41	10 YR 3/3	10 YR 3/4	cl	c	3	abk	vh	vfi	vs vp	es	d	w	-	-	-	-	-	-	-	conca
2Bw4	1.41-2.00	10 YR 4/4	10 YR 5/3	cl	c	3	abk	vh	vfi	vs vp	es	d	w	-	-	-	-	-	-	-	conca
Cr	Weathered gneiss with lime nodules																				

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

attributed to the presence of higher quantities of clay fraction (Devi *et al.* 2015). Single grain structure found in pedon 3 might be due to initial stage of soil development. The consistency varied from soft to very hard, friable to very firm and non-sticky and non-plastic to very sticky and very plastic in dry, moist and wet conditions, respectively. However, very sticky and very plastic consistency may be due to high clay content of the soil (Sarkar *et al.* 2001) and friable and non-sticky and non-plastic consistency might be due to negligible or very small amount of expanding clay minerals (Sireesha and Naidu 2013). Pedons 1, 3, 4, 6, 7, 8, 9 and 10 exhibited cambic (Bw) sub-surface diagnostic horizons whereas pedon 2 had argillic horizon. Strong to violent effervescence with dilute HCl was observed in pedons 6, 7, 9 and 10. The horizon boundaries are clear to diffuse in distinctness and smooth to wavy in topography.

Soil characteristics

Physical characteristics

Particle size analysis data (Table 3) showed that the clay content varied from 3.9 to 36.7%. The increase in clay content in Bw horizon of pedons 1, 3 4, 6, 7, 8, 9 and 10 was primarily due to *in-situ* weathering of parent material. Pedons 2 exhibited an increasing trend with soil depth; this might be due to more intensive weathering at deeper layers and illuviation of clay particles. Higher clay content in the sub-surface horizons of pedon 5 might be due to lithological discontinuity. The silt content in general exhibited an irregular trend with soil depth and this irregular distribution of silt might be due to variation in the degree of weathering of parent material or *in-situ* formation (Kumar and Naidu 2012). Sand constitutes the bulk of mechanical fractions (except pedons 3 and 5), which could be attributed to the siliceous nature of granite-gneiss parent material.

The bulk density of different pedons varied from 1.11-1.75 Mg m^{-3} and high bulk density in the sub-surface horizon of pedon 5 may be due to coarse texture and low organic matter content (Basavaraju *et al.* 2005). Sub-surface horizons exhibited almost higher bulk density values as compared to surface horizons and this high bulk density in the sub-surface could be ascribed to decreased organic matter and secondary accumulation of illuviated clays in pore space (Reddy and Naidu 2016). Water holding capacity of the soils varied from 26.8-55.5%. Water

Table 3. Physical characteristics of the soils

Pedon No. and 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 Fluventic Haplustepts (Plain)							
Ap	0.00-0.25	66.0	8.0	26.0	1.48	2.60	44.7
2Bw1	0.25-0.52	41.4	30.0	28.6	1.23	2.49	45.7
2Bw2	0.52-0.67	39.5	26.3	34.2	1.19	2.42	47.7
2Bw3	0.67-1.00	31.1	36.5	32.4	1.11	2.29	51.8
Cr	1.00+Weathered gneiss with lime nodules						
Pedon 2 Typic Haplustalfs (Upland)							
Ap	0.00-0.22	74.6	10.2	15.3	1.33	2.64	40.9
2Bt1	0.22-0.42	38.7	28.0	33.3	1.33	2.59	42.2
2Bt2	0.42-0.80	33.8	31.2	35.1	1.21	2.55	55.5
2Bt3	0.80-1.10	37.2	26.9	35.9	1.23	2.49	50.5
Cr	1.10+Weathered gneissmixed with gravel						
Pedon 3 Typic Haplustepts (Upland)							
Ap	0.00-0.20	83.3	9.3	7.4	1.56	2.64	35.0
AB	0.20-0.44	81.1	13.2	5.7	1.42	2.53	32.8
Bw	0.44-0.69	77.2	10.5	12.3	1.40	2.67	27.0
R	0.69	Limestone					
Pedon 4 Fluventic Haplustepts (Plain)							
Ap	0.00-0.17	34.3	40.3	25.4	1.27	2.55	50.8
Bw1	0.17-0.50	38.6	32.9	28.6	1.28	2.50	44.2
Bw2	0.50-0.79	33.3	36.1	30.6	1.25	2.68	41.8
Bw3	7.90-1.04	34.7	32.0	33.3	1.20	2.47	48.6
Bw4	1.04-1.25	29.1	34.2	36.7	1.27	2.49	53.7
R	1.25+	Limestone					

Contd...

Pedon 5 Aridic Ustorthents (Upland)							
Ap	0.00-0.24	14.1	64.1	21.9	1.43	2.33	37.7
A2k	0.24-0.58	70.7	13.9	15.4	1.40	2.66	37.9
C1	0.58-1.02	10.1	62.4	27.5	1.38	2.58	39.5
2C2k	1.02-1.32	94.2	1.9	3.9	1.75	2.59	26.8
2C3	1.32-1.55	6.8	60.8	32.4	1.43	2.55	42.0
R	1.55+	Limestone					
Pedon 6 Fluventic Haplustepts (Plain)							
Ap	0.00-0.16	73.8	14.1	12.1	1.32	2.61	34.9
2Bw1	0.16-0.41	41.8	32.8	25.4	1.38	2.62	35.3
3Bw2	0.41-0.74	75.0	14.3	10.7	1.40	2.60	37.6
4Bw3	0.74-1.14	20.0	51.4	28.6	1.28	2.48	45.9
5Bw4	1.14-1.62	37.3	31.8	30.9	1.27	2.47	41.8
5Bw5	1.62-2.00	45.3	32.8	21.9	1.32	2.49	40.6
Cr	2.00+	Weathered gneiss					
Pedon 7 Vertic Calciustepts (Upland)							
Ap	0.00-0.22	74.1	12.1	13.8	1.36	2.65	44.3
Bw1	0.22-0.62	18.7	48.0	33.3	1.32	2.55	39.5
Bw2	0.62-0.98	42.3	28.2	29.6	1.32	2.60	38.6
Bk1	0.98-1.28	41.9	27.9	30.2	1.31	2.56	40.7
Bk2	1.28-1.70	27.7	38.1	34.4	1.33	2.62	39.9
Bk3	1.70-2.00	39.1	28.3	32.7	1.28	2.43	40.9
Cr	2.00+Weathered gneiss with lime nodules						
Pedon 8 Fluventic Haplustepts (Upland)							
Ap	0.00-0.16	64.2	10.5	25.4	1.47	2.82	35.9
A	0.16-0.45	60.9	11.6	27.5	1.45	2.28	42.6
2Bw1	0.45-0.86	40.2	24.7	35.2	1.32	2.53	43.1
2Bw2	0.86-1.29	39.2	30.8	30.0	1.26	2.44	40.3
2Bw3	1.29-1.59	27.7	38.2	34.2	1.26	2.45	41.9
2Bw4	1.59-2.00	36.1	33.3	30.6	1.28	2.40	34.0
Cr	2.00+Weathered gneiss with lime nodules						
Pedon 9 Fluventic Haplustepts (Plain)							
Ap	0.00-0.20	70.0	13.3	16.7	1.34	2.66	36.2
Bw1	0.20-0.50	67.7	5.9	26.5	1.47	2.44	39.6
Bw2	0.50-0.79	62.3	10.1	27.6	1.40	2.45	40.3
Bw3	0.79-1.09	62.5	12.0	25.6	1.50	2.66	43.0
Bw4	1.09-1.33	65.2	10.6	24.2	1.48	2.40	43.3
Bw5	1.33-1.60	64.1	14.1	21.9	1.42	2.41	42.5
Cr	1.60+Weathered gneiss with lime nodules						
Pedon 10 Fluventic Haplustepts (Plain)							
Ap	0.00-0.20	73.7	14.0	12.3	1.39	2.64	47.2
A	0.20-0.50	60.8	11.6	27.6	1.48	2.43	46.7
2Bw1	0.50-0.80	35.9	30.6	33.5	1.28	2.45	42.8
2Bw2	0.80-1.12	34.4	31.7	34.0	1.24	2.40	50.4
2Bw3	1.12-1.41	33.7	36.5	29.9	1.25	2.53	52.2
2Bw4	1.41-2.00	31.9	37.5	30.7	1.19	2.32	48.4
Cr	2.00+Weathered gneiss with lime nodules						

holding capacity was very less in sandy soils due to high sand and less clay content as evident from negative correlation (r = -0.35*) between water holding capacity and sand content (Devi *et al*. 2015).

Physicochemical characteristics

All the pedons were neutral to moderately alkaline in soil reaction and this may be attributed to the nature of the parent material, leaching, presence of calcium carbonate and exchangeable sodium. The difference between the pH_{KCl} and pH_{H_2O} values ($\Delta pH = pH_{KCl} - pH_{H_2O}$) with large negative value (>-0.5) indicated a high negative surface charge density in these soils. Similar results with regard to charge density were reported by Reddy and Naidu (2016) in soils of Chennur mandal of Kadapa district in Andhra Pradesh. Electrical conductivity shows that (Table 4) these soils were non-saline nature with values ranging

Table 4. Physicochemical properties of soils

Pedon No. & Horizon	Depth (m)	pH 1:2.5 H_2O	pH 1:2.5 1 *N* KCl	EC (dS m^{-1})	Organic carbon (g kg^{-1})	$CaCO_3$ (%)	CEC [cmol(p^+) kg^1]	Exchangeable bases [cmol(p^+)kg^{-1}] Ca^{2+}	Mg^{2+}	Na^+	K^+	Base saturation (%)
Pedon 1 Fluventic Haplustepts (Plain)												
Ap	0.00-0.25	8.3	7.2	0.83	7.0	2.00	28.23	19.86	0.25	0.63	1.28	78.0
2Bw1	0.25-0.52	7.7	7.1	0.85	4.5	1.00	41.63	29.33	2.50	1.41	0.48	81.0
2Bw2	0.52-0.67	7.7	6.8	0.90	6.0	2.50	49.29	34.79	8.50	1.98	0.44	92.7
2Bw3	0.67-1.00	7.7	6.6	1.00	5.6	1.50	45.12	33.12	5.00	1.82	0.44	89.5
Cr	1.00+Weathered gneiss with lime nodules											
Pedon 2 Typic Haplusalfs (Upland)												
Ap	0.00-0.22	7.6	7.1	0.80	7.2	1.50	17.92	10.23	0.14	0.92	1.29	70.2
2Bt1	0.22-0.42	7.7	7.0	0.80	5.6	3.00	47.33	34.00	6.59	1.28	1.28	91.2
2Bt2	0.42-0.80	8.0	6.8	0.52	6.0	4.00	50.16	35.02	10.23	0.99	1.28	94.7
2Bt3	0.80-1.10	7.8	6.9	0.77	5.3	3.00	51.25	36.59	10.00	2.11	1.27	97.5
Cr	1.10+Weathered gneiss mixed with gravel											
Pedon 3 Typic Haplustepts (Upland)												
Ap	0.00-0.20	8.0	6.8	0.30	7.1	9.50	8.21	5.14	0.18	0.16	0.15	68.6
AB	0.20-0.44	7.8	7.3	0.27	4.7	10.50	6.79	4.06	0.14	0.15	0.14	66.1
Bw	0.44-0.69	7.9	7.1	0.50	3.6	12.50	11.89	7.74	0.30	0.19	0.18	70.7
R	0.69+ Limestone											
Pedon 4 Fluventic Haplustepts (Plain)												
Ap	0.00-0.17	7.8	7.0	0.54	6.2	5.50	24.36	18.06	0.22	0.19	0.45	77.7
Bw1	0.17-0.50	7.8	6.8	0.47	4.5	5.50	42.01	28.56	4.01	0.38	1.26	81.4
Bw2	0.50-0.79	7.8	6.9	0.46	5.1	8.00	43.58	32.51	4.21	0.39	1.26	88.0
Bw3	7.90-1.04	7.8	7.1	0.50	4.5	11.00	44.03	34.52	4.62	0.36	1.26	92.6
Bw4	1.04-1.25	7.5	7.3	0.53	2.3	10.00	52.11	38.75	10.80	0.55	1.26	98.6
R	1.25+ Limestone											
Pedon 5 Aridic Ustorthents (Upland)												
Ap	0.00-0.24	7.4	6.9	0.66	2.3	1.00	21.64	15.00	0.67	0.16	0.24	74.3
A2k	0.24-0.58	7.4	6.7	0.75	1.5	2.00	18.67	12.58	0.18	0.36	0.25	71.6
C1	0.58-1.02	7.6	6.6	0.59	0.5	1.00	31.16	21.25	3.20	0.16	0.17	79.5
2C2k	1.02-1.32	7.7	6.4	0.45	0.5	2.00	4.31	2.05	0.11	0.11	0.13	55.7
2C3	1.32-1.55	7.7	6.4	0.46	0.3	1.50	40.74	33.29	2.29	0.41	0.55	89.7
R	1.55+ Limestone											
Pedon 6 Fluventic Haplustepts (Plain)												
Ap	0.00-0.16	7.9	6.8	0.30	7.1	1.00	11.13	7.21	0.20	0.23	0.11	69.6
2Bw1	0.16-0.41	8.1	7.1	0.29	2.0	2.00	25.93	18.35	0.25	0.93	0.27	76.4
3Bw2	0.41-0.74	8.3	7.2	0.32	0.3	15.00	10.11	6.48	0.22	0.14	0.14	69.0
4Bw3	0.74-1.14	8.3	7.1	0.32	0.2	5.00	32.09	25.03	0.32	0.39	0.12	80.6
5Bw4	1.14-1.62	8.2	7.3	0.39	3.0	16.00	43.98	33.00	5.11	0.80	0.37	89.3
5Bw5	1.62-2.00	8.2	6.3	0.43	0.3	7.00	20.51	14.59	0.28	0.19	0.15	74.2
Cr	2.00+Weathered gneiss											
Pedon 7 Vertic Calciustepts (Upland)												
Ap	0.00-0.22	7.7	6.3	0.19	4.5	1.50	13.93	8.55	0.16	0.22	1.01	71.4
2Bw1	0.22-0.62	7.8	5.7	0.22	2.7	1.00	41.21	33.65	2.69	0.37	0.65	90.7
2Bw2	0.62-0.98	7.7	6.3	0.21	2.6	1.00	42.83	29.45	5.22	0.34	0.92	83.9
Bk1	0.98-1.28	7.8	6.6	0.24	1.8	9.50	43.26	31.02	5.30	0.45	1.25	87.9
Bk2	1.28-1.70	8.1	7.0	0.27	1.2	16.50	49.88	34.99	10.01	0.59	1.26	93.9
Bk3	1.70-2.00	8.3	6.5	0.28	0.3	19.00	46.21	33.59	6.52	0.27	1.22	90.0
Cr	2.00+Weathered gneiss with lime nodules											
Pedon 8 Fluventic Haplustept s (Upland)												
Ap	0.00-0.16	7.5	5.7	0.54	7.5	4.00	27.16	18.32	0.78	0.36	0.91	75.0
A	0.16-0.45	7.5	6.0	0.46	4.5	3.00	29.22	21.29	0.52	0.44	0.92	79.3
2Bw1	0.45-0.86	7.5	6.4	0.47	6.6	3.00	50.79	36.50	10.23	0.52	1.26	95.5
2Bw2	0.86-1.29	7.6	6.9	0.49	5.4	3.50	43.06	30.03	4.33	1.04	1.26	85.1
2Bw3	1.29-1.59	8.0	7.2	0.52	3.0	3.00	48.91	34.81	7.58	1.97	1.28	93.3
2Bw4	1.59-2.00	8.2	5.9	0.57	0.8	5.00	43.46	32.87	4.35	0.18	1.07	88.5
Cr	2.00+Weathered gneiss with lime nodules											

Contd...

Pedon 9 Fluventic Haplustepts (Plain)												
Ap	0.00-0.20	7.4	5.6	0.45	6.5	1.50	19.27	12.98	0.14	0.16	0.65	72.3
Bw1	0.20-0.50	7.4	5.7	0.46	4.5	2.00	28.66	20.88	0.64	0.17	0.70	78.1
Bw2	0.50-0.79	7.3	6.3	0.47	3.8	1.00	30.12	22.01	1.19	0.18	0.70	80.0
Bw3	0.79-1.09	7.5	6.7	0.47	4.5	9.00	27.72	18.59	1.90	0.29	0.83	78.0
Bw4	1.09-1.33	7.8	6.9	0.49	3.8	14.00	26.37	16.61	1.74	0.38	0.98	74.7
Bw5	1.33-1.60	7.6	6.5	0.51	0.8	14.50	25.01	14.95	1.58	0.40	1.21	72.5
Cr	1.60+Weathered gneiss with lime nodules											
Pedon 10 Fluventic Haplustepts (Plain)												
Ap	0.00-0.20	7.7	6.3	0.58	7.5	5.00	12.26	7.89	0.10	0.15	0.58	71.1
A	0.20-0.50	7.6	6.3	0.43	5.7	2.00	30.23	22.03	0.32	0.45	1.26	79.6
2Bw1	0.50-0.80	7.7	6.5	0.49	4.2	2.50	47.90	33.88	8.55	0.58	1.16	92.2
2Bw2	0.80-1.12	7.7	6.7	0.44	3.0	11.00	48.68	34.42	8.80	0.61	1.26	92.6
2Bw3	1.12-1.41	7.8	6.9	0.43	3.8	10.00	42.99	29.87	4.69	0.49	1.27	84.5
2Bw4	1.41-2.00	7.9	7.0	0.50	3.3	12.00	43.71	32.88	4.30	0.43	1.26	88.9
Cr	2.00+	Weathered gneiss with lime nodules										

from 0.19-1.00 dS m^{-1}. The low electrical conductivity may be due to free drainage which favored the removal of released bases by percolating and drainage water.

Organic carbon content in these soils was found to be low to medium and ranging from 0.2-7.5 g kg^{-1} (Table 4). Soil organic carbon in pedons 3, 5 and 7 exhibited a decreasing trend with soil depth. This is attributed to the addition of plant residues to surface horizons. The low organic matter 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 (Sireesha and Naidu 2013). The CEC of the soils varied from 4.31-52.11 cmol(p^+)kg^{-1} soil which was related to clay content as evident from significant positive correlation of CEC with clay (r = 0.56**).

The free $CaCO_3$ ranged from 1.00-19.00% and the highest $CaCO_3$ content was noticed in the lower horizons of pedon 6. This might be due to high clay content which led to impeded leaching, consequently accumulation of $CaCO_3$ in the lower horizon. The $CaCO_3$ content of the pedon 3 increased with depth which might be due to downward movement of calcium and its subsequent precipitation as carbonate and / or decomposition of calcium carbonate (Reddy and Naidu 2016).

Exchangeable bases in all pedons were in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ on the exchange complex except in pedons 4, 7, 8, 9 and 10, where exchangeable K was higher than exchangeable Na in some sub-surface horizons. The higher exchangeable Ca in the surface soil may be due to redistribution of calcium by tree species (Patil and Prasad 2004). The ratio between Ca and Mg ranged from 3.42-92.71 and narrower Ca^{2+}/Mg^{2+} ratio was due to suppression of Ca solubility, substitution of Mg^{2+} or Ca^{2+} by plants and recycling of unusual amount of Mg^{2+} (Raghuwanshi *et al.* 2011). The decrease in Ca^{2+}/Mg^{2+} ratio in sub-surface horizons indicates more development of these soils (Gangopadhyay *et al.* 2016).

Soil classification

Based on morphological characteristics and soil properties, the pedons were classified up to subgroup level (Soil Survey Staff 2014). Pedon 2 exhibited argillic (Bt) horizon and were classified under Alfisols whereas remaining pedons (except pedon 5) showed cambic horizon (Bw) and were classified as Inceptisols. The soils of pedon 5 exhibited lithological discontinuity and did not show any soil development trend. So these soils were classified under Entisols.

Pedons 1, 3, 4, 6, 7, 8, 9 and 10 were grouped under Ustepts at sub-order level due to ustic soil moisture regime and except pedon 7, the remaining pedons are classified under Haplustepts at great group level as these pedons did not show 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. However, pedon 7 was classified as Calciustepts at sub-group level and Vertic Calciustepts at great group level as it showed vertic features like cracks of 2 to 3 cm wide and slickenside in sub-surface horizons. Pedons 1, 4, 6, 8, 9 and 10 are classified as Fluventic Haplustepts at sub-group level due to irregular decrease in organic carbon with depth and lithological discontinuity (sand/silt ratio). The soils of pedon 5 belonged to Entisols and regular decrease in soil organic carbon. So these soils were classified as Ustorthents at sub-group level and Aridic Ustorthents at great group level.

Soils of pedon 2 were classified as Ustalfs at sub-order level due to ustic soil moisture regime, high base saturation and lithic contact. These soils were classified as Haplustalfs at sub-group level and Typic Haplustafs at great group level as it did not exhibit any inter-gradation or extra-gradation with other taxa.

Macronutrients

The available nitrogen (N) varied from 62.7-545.7 kg ha^{-1} (Table 5) throughout the depth indicating low to medium in status. Pedons 4, 8 and 9 showed a decreasing trend with soil depth, whereas remaining pedons exhibited an irregular trend in available N. The available N was significantly and positively correlated (r = 0.532**) with organic carbon. The low available N in these soils may be due to semi-arid condition of the area that have favoured rapid oxidation and lesser accumulation of organic matter, releasing more NO_3^--N which could have been lost by leaching (Leelavathi *et al*. 2009).

The available phosphorus (P) status of the soil varied from 2.7-65.7 kg ha^{-1} indicating low to high status of available P. None of the pedons showed any particular trend with depth. The lower amount of available P in soils could be attributed to the fixation of released P by clay minerals and removal by rice-maize cropping system. Higher available P in the surface horizons, as compared to sub-surface horizons, might possibly due to the confinement of crop cultivation to the rhizosphere and supplementing of depleted P through external sources *i.e.* fertilizers (Thangasamy *et al.* 2005).

Available potassium (K) in soils ranged from 148.0-1125.4 kg ha^{-1} and these soils were high in available K. Pedon 9 showed an increasing trend of available K with soil depth whereas pedons 1 and 6 exhibited a decreasing trend with up to 2Bw2 and 2Bw1 hoizons, respectively. Pedon 8 showed an increasing trend up to a depth of 3Bw3 horizon and later on decreased. However, remaining pedons did not show any particular trend with soil depth. Amount and type of clay, organic carbon, and CEC significantly affected the K availability. This is evident from positive and significant correlation of available K with organic carbon (r = 0.339*). Very high amount of available K in these soils is attributed to more intensive weathering of K bearing minerals, release of labile K from organic residues and

Table 5. Available nutrient status of the soils

Pedon No. & horizon	Depth (m)	Available macronutients				Available micronutrients			
		N	P	K	S	Cu	Fe	Mn	Zn
		(kg ha^{-1})			(mg kg^{-1})	(mg kg^{-1})			
Pedon 1 Fluventic Haplustept(Plain)									
Ap	0.00-0.25	338.7	12.8	1116	22.1	0.49	9.08	0.41	0.02
2Bw1	0.25-0.52	188.2	17.3	415	6.0	0.04	0.46	0.69	0.16
2Bw2	0.52-0.67	138.0	12.8	383	75.1	0.01	2.67	3.57	0.44
2Bw3	0.67-1.00	175.6	21.6	386	14.8	0.01	1.85	0.94	0.30
Cr	1.00+Weathered gneiss with lime nodules								
Pedon 2 Typic Haplustalfs (Plain)									
Ap	0.00-0.22	257.2	25.2	1125	1.3	0.40	4.00	15.59	0.78
2Bt1	0.22-0.42	200.7	40.5	1121	79.2	0.01	4.22	0.27	0.26
2Bt2	0.42-0.80	257.2	17.6	1117	29.5	0.20	3.89	13.62	0.48
2Bt3	0.80-1.10	213.3	34.0	1113	34.9	0.31	4.39	10.59	0.29
Cr	1.10+Weathered gneiss mixed with gravel								
Pedon 3 Typic Haplustepts (Upland)									
Ap	0.00-0.20	376.3	35.8	1112	36.2	0.01	6.27	4.45	0.55
BA	0.20-0.44	181.9	65.7	1110	22.8	0.62	11.85	13.26	4.63
Bw	0.44-0.69	282.2	37.8	1125	39.6	0.57	9.08	10.59	3.73
R	0.69+	Limestone							
Pedon 4 Fluventic Haplustepts (Uplant)									
Ap	0.00-0.17	545.7	27.0	1116	29.5	0.90	6.76	1.77	1.60
Bw1	0.17-0.50	332.4	52.4	1097	18.1	0.46	6.87	6.70	0.73
Bw2	0.50-0.79	213.3	26.1	1099	16.8	0.42	6.38	5.97	1.60
Bw3	7.90-1.04	200.7	18.2	1103	51.0	0.19	3.12	6.15	1.80
Bw4	1.04-1.25	131.7	22.5	256	22.8	0.44	9.30	7.35	1.78
R	1.25+	Limestone							

Contd...

Pedon 5 Aridic Ustorthents (Upland)									
Ap	0.00-0.24	432.8	54.7	206	22.8	0.15	9.80	26.80	4.97
A2k	0.24-0.58	131.7	18.2	214	45.6	0.01	8.14	30.04	2.19
C1	0.58-1.02	94.1	41.0	149	6.7	0.01	6.32	24.60	1.70
2C2k	1.02-1.32	62.72	45.2	189	6.7	0.01	14.06	22.58	1.80
2C3	1.32-1.55	112.9	26.1	480	24.8	0.04	8.42	27.54	2.08
R	1.55+	Limestone							
Pedon 6 Fluventic Haplustepts (Plain)									
Ap	0.00-0.16	188.2	37.4	296	26.2	0.36	14.06	30.80	2.09
2Bw1	0.16-0.41	169.3	31.5	233	17.4	0.14	7.59	24.80	1.79
3Bw2	0.41-0.74	94.1	16.9	288	32.9	0.01	4.44	16.03	1.65
4Bw3	0.74-1.14	163.1	25.9	317	4.7	0.01	3.39	12.78	1.69
5Bw4	1.14-1.62	94.1	6.54	325	15.4	0.01	3.78	10.46	1.73
5Bw5	1.62-2.00	131.7	19.8	1103	16.8	0.01	3.34	9.53	1.41
Cr	2.00+	Weathered gneiss							
Pedon 7 Vertic Calciustepts (Upland)									
Ap	0.00-0.22	250.9	25.2	884	10.1	0.34	15.99	28.46	1.91
Bw1	0.22-0.62	439.0	51.8	571	14.8	0.38	15.66	25.90	1.65
Bw2	0.62-0.98	200.7	26.1	800	14.1	0.35	12.51	22.40	1.71
Bk1	0.98-1.28	200.7	15.5	1089	4.0	0.94	2.97	3.75	0.20
Bk2	1.28-1.70	194.4	45.2	1102	21.5	0.37	9.91	17.85	1.72
Bk3	1.70-2.00	194.4	41.0	1065	14.1	0.14	5.99	13.93	1.70
Cr	2.00+Weathered gneiss with nodules								
Pedon 8 Fluventic Haplustepts (Upland)									
Ap	0.00-0.16	370.1	51.5	797	22.1	0.03	5.10	10.97	1.79
A	0.16-0.45	319.9	21.8	801	20.8	0.01	4.33	11.89	1.44
3Bw1	0.45-0.86	225.8	18.2	1101	26.2	0.01	3.39	7.08	1.46
2Bw2	0.86-1.29	175.6	21.8	1105	10.1	0.01	1.68	3.29	1.41
2Bw3	1.29-1.59	169.3	18.2	1116	8.1	0.01	1.02	3.11	1.43
2Bw4	1.59-2.00	169.3	36.9	938	32.2	0.01	0.57	2.61	1.41
Cr	2.00+Weathered gneiss with nodules								
Pedon 9 Fluventic Haplustepts (Plain)									
Ap	0.00-0.20	414.0	18.9	569	4.7	0.01	7.54	18.42	1.50
Bw1	0.20-0.50	326.1	38.0	611	11.4	0.01	5.55	6.84	1.46
Bw2	0.50-0.79	232.1	29.9	613	16.1	0.03	3.34	8.26	1.44
Bw3	0.79-1.09	232.1	22.5	723	26.8	0.01	2.23	4.45	1.42
Bw4	1.09-1.33	150.5	26.1	857	24.2	0.01	1.57	3.88	1.41
Bw5	1.33-1.60	175.6	14.2	1058	25.5	0.01	1.51	4.02	1.44
Cr	1.60+Weathered gneiss with nodules								
Pedon 10 Fluventic Haplustepts (Plain)									
Ap	0.00-0.20	370.1	19.8	1091	22.8	0.26	22.5	14.84	1.62
A1	0.20-0.50	482.9	3.4	1099	12.1	0.01	2.23	6.39	1.36
Bw1	0.50-0.80	175.6	11.7	1014	12.1	0.01	3.01	4.58	1.36
Bw2	0.80-1.12	175.6	2.7	1098	38.2	0.01	3.23	3.26	1.36
Bw3	1.12-1.41	150.5	21.8	1108	13.4	0.01	2.56	2.69	1.39
Bw4	1.41-2.00	188.2	11.5	1103	25.5	0.01	0.69	2.84	1.42
Cr	2.00+Weathered gneiss with nodules								

application of K fertilizers and upward translocation of K from lower depths along with capillary rise of ground water (Reddy and Naidu 2016).

The available sulphur (S) in soils varied from 1.3-79.1 mg kg^{-1} and these soils were deficient to sufficient. All the pedons did not show any particular trend with soil depth. Higher amount of S in surface horizons as compared to sub-surface horizons was due to higher amount of organic matter in the surface horizons (Devi *et al.* 2015).

Micronutrients

The DTPA extractable zinc (Zn) ranged from 0.02-4.97 mg kg^{-1} soil. All the pedons showed no particular trend of distribution with depth. Considering 0.6 mg kg^{-1} as critical level (Lindsay and Norvell 1978) these soils were deficient to sufficient in available Zn. The low available Zn was possibly due to high soil pH values which might be resulted in the formation of insoluble compounds of Zn or insoluble calcium zincate (Thangasamy *et al*. 2005).

The available copper (Cu) content varied from 0.01-0.94 mg kg^{-1} soil. Pedons 1, 6, 8 and 10 indicated a decreasing trend and remaining pedons did not show any definite depth distribution. The soils were found to be deficient to sufficient in available Cu, as per critical limit of 0.2 mg kg^{-1} soil as suggested by Lindsay and Norvell (1978). Available Cu was positively correlated with organic carbon (r = 0.15). The higher amount of Cu in the surface horizon might be due to higher biological activity and the chelating of Cu with organic compounds.

The available iron (Fe) content ranged from 0.46-22.56 mg kg^{-1} soil. The soils were deficient to sufficient in available Fe content as per critical limit (4.5 mg kg^{-1} soil) of Lindsay and Norvell (1978). The distribution of available Fe showed a decreasing trend in pedons 6, 8 and 9, whereas remaining pedons did not show any depth trend of distribution, which 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 Fe by chelation effect might have protected the iron from oxidation and precipitation, which consequently increased the availability of Fe in the surface horizons.

The available manganese (Mn) content varied between 0.27 and 30.80 mg kg^{-1} soil. Pedons 6 and 8 showed a decreasing trend with soil depth and the remaining pedons did not show any definite trend of depth distribution. As per the critical limit of 1.0 mg kg^{-1} of Lindsay and Norvell (1978), the soils were deficient to sufficient in available Mn.

Conclusions

The soils of Mahanandi mandal were neutral to moderately alkaline, non-saline, low to medium in organic carbon and exchange complex was dominated by Ca^{2+}. The soils were low to medium in available N and low to high in available P, high in available K and deficient to sufficient in available S. The soils were deficient to sufficient in available Zn, Fe, Cu and Mn. Hence, judicious use of organic manures in combination with inorganics will not only pave the way of achieving sustainable yields of crops but also sustain the soil health.

Acknowledgment

The senior author is highly grateful to the Acharya N.G. Ranga Agricultural University, Lam Farm, Guntur, Andhra Pradesh for providing financial assistance in the form of stipend during the course of this investigation.

References

AIS&LUS (1970) *Soil Survey Manual*. All India Soil and Land Use Survey Organisation, IARI, New Delhi, pp. 1-63.

Basavaraju, D., Naidu, M.V.S., Ramavatharam, N., Venkaiah, K., Rama Rao, G. and Reddy, K.S. (2005) Characterisation, classification and evaluation of soils in Chandragiri mandal of Chittoor district, Andhra Pradesh. *Agropedology* **15**, 55-62.

Devi, P.A.V., Naidu, M.V.S and Rama Krishna Rao, A. (2015) Characterization and classification of sugarcane growing soils in southern agro-climatic zone: A Case study in eastern mandals of Chittoor District in Andhra Pradesh. *Journal of the Indian Society of Soil Science* **63**, 245-258.

FAO (1993) *World Soil Resources*, Report No.73, FAO Rome.

Gangopadhyay, S.K., Nayak, D.C. and Singh, S.K. (2016) Characterstics of tea growing soils in relation to soil acidity in upper Brahmaputra valley of Assam. *Journal of the Indian Society of Soil Science* **64**, 41-350.

Jackson, M.L. (1973) *Soil Chemical Analysis.* Prentice Hall of India (Pvt.) Ltd., New Delhi.

Kumar, Y.S. and Naidu, M.V.S. (2012) Characteristics and classification of soils representing major landforms in Vadamalapeta mandal of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science* **60**, 63-67.

Leelavathi, G.P., Naidu, M.V.S., Ramavatharam, N. and Karuna Sagar, G. (2009) Studies on genesis, classification and evaluation of soils for sustainable land use planning in Yerpedu mandal of Chittoor district, Andhra Pradesh. *Journal of the Indian Society of Soil Science* **57**, 109-120.

Lindsay, W.L. and Norvell, W.A. (1978) Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**, 421-428.

Patil, R.B and Prasad, J. (2004) Characteristics and classification of some *Sal* (*Shorea robusta*) supporting soils in Dindori district of Madhya Pradesh. *Journal of the Indian Society of Soil Science* **52**, 119-124.

Raghuwanshi, S.R.S., Tiwari, S.C., Prabha, S., Raghuwanshi, O.P.S., Sasode, D.S. and Umat, R. (2011) Characterization of salt-affected soils of Bhind district of Madhya Pradesh. *Journal of the Indian Society of Soil Science* **59**, 388-391.

Reddy, S.K. and Naidu, M.V.S. (2016) Characterization and classification of soils in semi-arid region of Chennur mandal in Kadapa district, Andhra Pradesh. *Journal of the Indian Society of Soil Science* **64**, 207-217.

Sarkar, D. (2011) Geo-informatics for appraisal and management of land resources towards optimizing agricultural production in the country-issues and strategies. *Journal of the Indian Society of Soil Science* **59** (supplement), S35-S48.

Sarkar, D., Gangopadhyay, S.K. and Velayutham, M. (2001) Soil toposequence relationship and classification in lower outlier of Chhotanagpur plateau. *Agropedology* **11**, 29-36.

Sireesha, P.V.G. and Naidu, M.V.S. (2013) Studies on genesis, characterization and classification of soils in semi-arid agro-ecological region: A case study in Banaganapalle mandal of Kurnool district in Andhra Pradesh. *Journal of the Indian Society of Soil Science* **61**, 167-178.

Soil Survey Division Staff (2015) *Soil Survey Manual* (Indian Print), USDA Handbook 18, US Govt. Printing Office, Washington.

Soil Survey Staff (2014) *Keys to Soil Taxonomy,* 12th edition, USDA, Natural Resource Conservation Service, Washington, DC.

Thangasamy, A., Naidu, M.V.S., Ramavatharam, N. and Reddy, C.R. (2005) Characterization, classification and evaluation of soil resources in Sivagiri micro-watershed of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science* **53**, 11-21.

Wakene, N. and Heluf, G. (2003) Forms of phosphorus and status of available nutrients under different land use systems of Alfisols in Bako area, Ethiopia. *Ethiopian Journal of Natural Resources* **5**, 17-37.

Walia, C.S. and Rao, Y.S. (1997) Characteristics and classification of some soils of Trans-Yamuna plains. *Journal of the Indian Society of Soil Science* **45**, 156-162.

Received 19 October 2017; Accepted 8 February 2019