Research Article

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Characterisation and classification of arecanut-growing soils of Karnataka, India

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Abstract

The present investigation was carried out to characterise the soils of areca based cropping systems considering soil type and agro-climatic variability. Ten typical soil profiles were studied representing five different agro-climatic zones (ACZs) of Karnataka, namely, Tumkur and Hesarghatta (Eastern Dry Zone), T. Narasipura and Maddur (Southern Dry Zone), H D Kote and Hassan (Southern Transition zone), Mudigere and Sirsi (Hilly Zone), and Belthangady and Kumata (Coastal Zone). These pedons were studied for their morphological characteristics, physical and chemical properties. The arecanut-growing soils of Karnataka are generally deep to very deep, non-gravelly and well-drained soils. Texture ranged from sandy clay loam to clay in sub-surface. Soils of coastal and hilly zones were strongly acidic and had high organic carbon. In contrast, other sites of the southern transition zone to southern and eastern dry zone soils were near neutral to moderately alkaline with medium to high organic carbon content. Cation exchange capacity (CEC) ranged from 2.5 to 32.6 cmol (p+) kg^{-1} and base saturation varied from 21.9 to 99.6 per cent. The major taxa of the soils identified at sub-group level of soil taxonomy were Rhodic Kanhaplustalfs, Typic Haplustalfs, Rhodic Paleustalfs, Typic Rhodustalfs, Vertic Haplustepts, Typic Haplustepts, Ustic Kanhaplohumults, Kanhaplic Haplustults and Typic Paleustults.

Keywords: Agro-climatic zone, Alfisols, arecanut, characterisation, classification, Inceptisols, Ultisols

Introduction

India is the major producer and consumer of arecanut. It is cultivated in about 4.51 lakh ha with a production of 7.47 lakh tonnes. Arecanut or betel nuts (*Areca catechu* L.) have contributed significantly for the sustainable livelihoods of millions of farmers in the country. Cultivation of palms in India also has a rich diversity and varied history and possesses its own distinct historical and economic context of development. The cultivation of arecanut can be traced back to Vedic periods and used in veterinary and ayurvedic medicines. India ranks first in arecanut production in the world. In India, the cultivation of arecanut is mostly confined to Karnataka, Kerala and Assam. The share of these states in terms of the total area under cultivation and production is around 83 per cent. Karnataka stands first both in terms of area and production followed by Kerala and Assam. Karnataka state alone contributes in terms of area and production is 2,35,770 ha, and 63.2 per cent share respectively. This crop is being cultivated in different agro-climatic regions in Karnataka (Singh *et al.,* 2013) from Eastern dry zone to Coastal zone.

Arecanut is capable of growing in a wide variety of soils. However, well-drained soils that have very good water holding capacity are the best suitable. It thrives in areas having a well-distributed annual rainfall of 750 mm to 4500 mm, and altitude up to 1000 meters above mean sea level (MSL). It is highly sensitive to moisture deficit and should be grown with assured irrigation facilities. A temperature range of 10 °C to 40 °C is best for its growth and yield. Arecanut, a major plantation crop

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of Karnataka, is occupied by hilly, coastal, southern transitional, eastern and southern dry zones. Sufficient information on the characterisation of arecanut-growing soils towards sustainability is lacking. Hence, the present study was carried out in the arecanut-growing areas of Karnataka to characterise and classify the arecanut-growing soils.

Materials and methods

Soil sampling

The soil profile samples were collected from arecanut plantations covering five different agro-climatic zones (ACZs), with varying rainfall, topography, soil type and climatic characteristics including cropping patterns. The profile samples were collected up to a depth of 150 cm or shallower depth limited by a rock or hard substratum. Two profiles from each five different ACZs of Karnataka were selected for the study based on the variability in site characteristics and productivity of arecanut. The location of profile samples collected from different ACZs and the details are shown in Table 1 and Figure 1. Soil samples were drawn for the laboratory analysis from all horizons layers to classify the physical and chemical properties. These soil samples were analysed for different parameters by following standard procedures (Table 2). Morphological properties of the soils were studied following the Soil Survey Manual (Soil Survey Staff, 2014).

Site description

The locations and site characteristics are given in Table 1. Eastern dry, Southern dry and Southern transitional zones experience hot moist semi-arid climate with average annual rainfall ranging from 750 mm to 950 mm and length of dry period >150 days. Hilly and Coastal zones have a hot, humid climate receiving an annual average rainfall between 1500 and 4500 mm with 90 days of dry period. The soil temperature regime is isohyperthermic for all the studied soils as they have a difference of less than 5°C between mean summer temperature and mean winter temperatures at a depth of 50 cm and a mean annual temperature of 22°C or higher.

Results and discussion

Morphological characteristics

The morphological characteristics of the arecanut soils are presented in Table 3. The soils were deep to very deep ranging from 112 cm to 157 cm. Soil profile P3 from T. Narasipur recorded lower depth (107 cm), and Hassan soil pedon (P6) was very deep (157 cm). The soils were reddish-brown to dark yellowish brown in colour with a hue of 2.5 YR to 10 YR, value ranging from 2 to 5 and chroma of 1 to 6. Soil colour of pedons other than southern

Table 1. Locations and site characteristics

Zone	Physiography	Serial no.	Location	Latitude	Longitude	Elevation (m above MSL)	Slope (%)	Rainfall (mm)
Eastern dry zone	The Deccan Plateau	Pedon 1	Kunigal	13°02'17.79"N	76°59'43.09"E	829	1-3	828
		Pedon 2	Hesargatta	13°08'29.24"N	77°29'08.42"E	950	1-3	963
Southern dry zone	The Deccan Plateau	Pedon 3	T. Narasipura	12°15'02.50"N	76°50'01.40"E	690	1-3	741
		Pedon 4	Maddur	12°35'16.85"N	76°01'56.86"E	649	1-3	812
Southern transitional zone	The Western Ghats and parts of the Plateau region	Pedon 5	H D Kote	12°05'45.28"N	76°19'03.51"E	783	0-1	819
		Pedon 6	Hassan	12°57'20.10"N	76°00'08.42"E	949	1-3	901
Hilly zone	Western Ghats	Pedon 7	Mudigere	13°06'24.83"N	75°36'26.99"E	934	1-3	2413
		Pedon 8	Sirsi	14°35'24.95"N	74°52'21.71"E	564	1-3	2507
Coastal zone	Coastal plain and uplands region	Pedon 9	Belthangady	13°03'50.40"N	75°12'17.96"E	120	1-3	4440
		Pedon 10	Kumata	14°35'24.91"N	74°52'21.39"E	64	1-3	3547

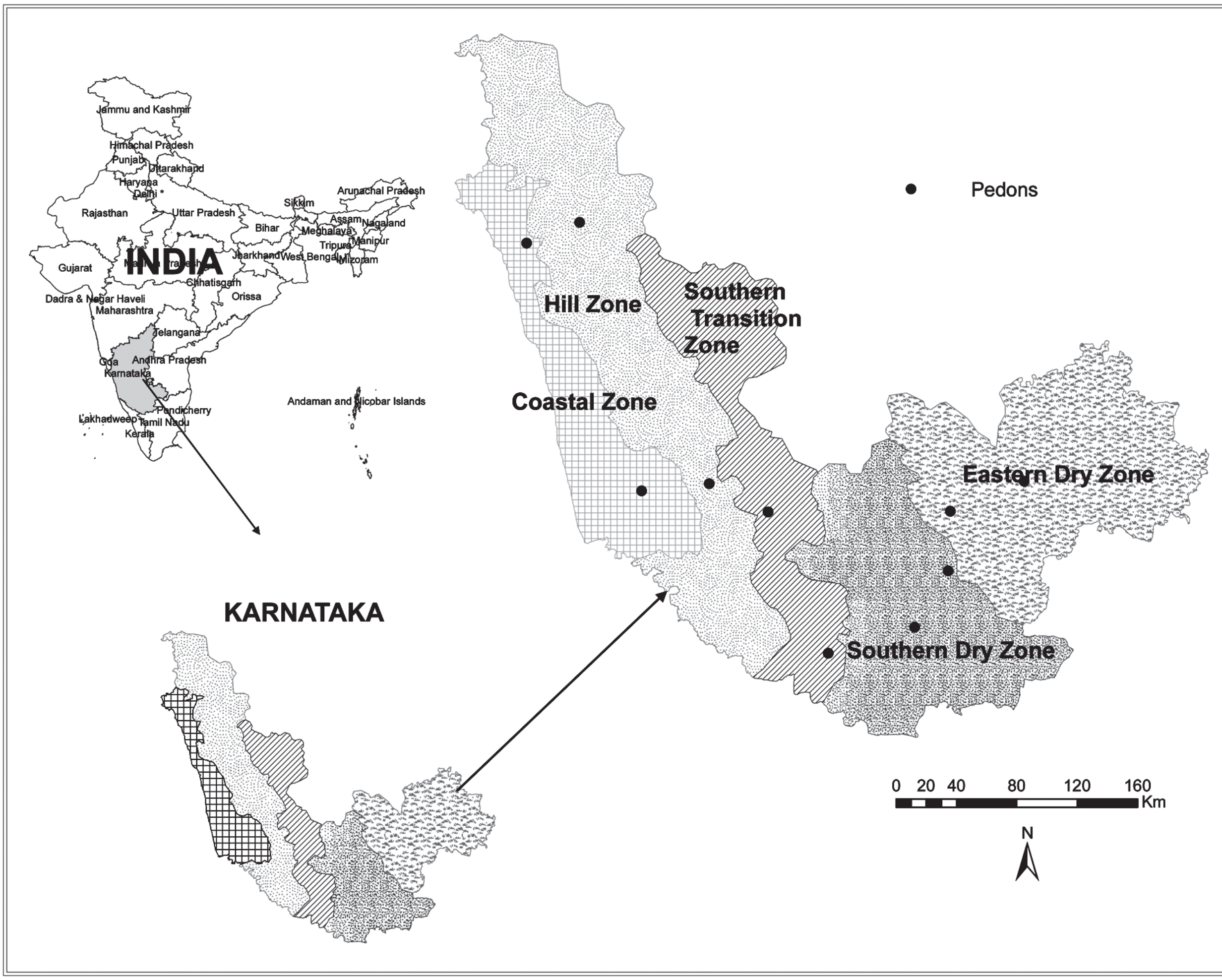

Fig. 1. Arecanut-growing soils of Karnataka, India and pedon locations

transitional zone (Pedons 5 and Pedons 6) varied from dark brown to reddish-brown in surface and brown to dark red in sub-surface horizons. Soil pedons 5 and 6 were dark yellowish-brown to dark brown in surface and dark yellowish-brown to very dark grey in sub-surface due to high transport of soil organic carbon. Soil structure varied from weak to moderate sub-angular blocky both in surface and sub-surface horizons. Gogoi *et al.* (2018) also observed sub-angular blocky structure for soils of Assam.

Texture varied from sandy clay loam to clay in sub-surface. Thus, wide textural variation was observed in arecanut-growing soils: sandy loam to

Table 2. Methods of soil analysis

Sl. No.	Parameter	Method and Reference
1.	Particle size analysis	International pipette method, Jackson (1973)
2.	Soil reaction	Potentiometry, Jackson (1973)
3.	Electrical conductivity	Conductometry, Jackson (1973)
4.	Organic carbon	Wet oxidation, Walkley and Black (1934)
5.	Cation exchange capacity	Sarma *et al*. (1987)
6.	Bulk density	Core method, Jackson (1973)

sandy clay in P1, sandy clay to clay in P2 and P6, sandy clay loam to clay in P3 and P4, clay loam to clay in P7, clay in P5 and P8, clay loam to sandy clay in P9, sandy loam to clay in P10. Generally, heavy texture in sub-surface horizon may be due to illuviation of clay from surface horizons to sub-surface horizons. High sand and low clay content in surface soils of ferruginous soils of the semi-arid tropics was reported by Chandran *et al*. (2009). Clay loam to clay in texture was found in the soils of

Table 3. Morphological characteristics of the pedons

Horizon	Depth (cm)	Colour (moist)		Structure	Texture
		P1: Kunigal (Eastern dry zone)			
Ap	0-28	Dark brown	7.5YR 3/4	1msbk	sl
Bt1	28-47	Reddish brown	5YR 4/4	1msbk	scl
Bt2	47-63	Reddish brown	5YR 4/4	2msbk	sc
Bt3	63-87	Dark red	2.5YR 3/6	2msbk	sc
Bt4	87-115	Dark red	2.5YR 3/6	2msbk	sc
Bt5	115-140	Dark red	2.5YR 3/6	2msbk	sc
		P2: Hesarghatta (Eastern dry zone)			
Ap	0-16	Reddish brown	5YR 4/4	2msbk	sc
Bt1	16-36	Reddish brown	5YR 4/6	2msbk	sc
Bt2	36-63	Reddish brown	5YR 4/6	2msbk	c
Bt3	63-102	Reddish brown	5YR 4/6	2msbk	c
Bt4	102-123	Reddish brown	5YR 4/6	2msbk	sc
		P3: T. Narasipura (Southern dry zone)			
Ap	0-16	Dark brown	7.5YR 3/2	2msbk	scl
Bt1	16-36	Dark reddish brown	5YR 3/4	1msbk	sc
Bt2	36-60	Dark reddish brown	5YR 3/4	1msbk	sc
Bt3	60-83	Dark reddish brown	2.5YR 3/4	2msbk	c
Bt4	83-112	Dark reddish brown	2.5YR 3/4	2msbk	c
BC	112-130	Dark reddish brown	2.5YR 3/4	2msbk	c
		P4: Maddur (Southern dry zone)			
Ap	0-13	Reddish brown	5YR 4/4	2msbk	sc
Bt1	13-28	Yellowish red	5YR 4/6	2msbk	sc
Bt2	28-47	Yellowish red	5YR 4/6	2msbk	sc
Bt3	47-72	Dark reddish brown	5YR 3/4	2msbk	scl
Bt4	72-105	Dark reddish brown	5YR 3/4	2msbk	c
BC	105-122	Dark reddish brown	5YR 3/4	2msbk	scl
		P5: H D Kote (Southern transitional zone)			
Ap	0-13	Dark yellowish brown	10YR 4/4	2msbk	c
Bw1	13-31	Dark yellowish brown	10YR 3/4	2msbk	c
Bw2	31-57	Dark yellowish brown	10YR 3/6	2msbk	c
Bw3	57-89	Dark yellowish brown	10YR 3/6	2msbk	c
Bw4	89-117	Dark yellowish brown	10YR 3/4	2msbk	c
Bw5	117-131	Dark yellowish brown	10YR 3/4	2msbk	c

P6: Hassan (Southern transitional zone)					
Ap	0-17	Dark brown	10YR 3/3	1msbk	sc
Bw1	17-36	Dark yellowish brown	10YR 3/4	2msbk	sc
Bw2	36-57	Dark yellowish brown	10YR 4/4	2msbk	sc
Bw3	57-81	Dark greyish brown	10YR 4/2	2msbk	sc
Bw4	81-102	Dark gray	10YR 4/1	2msbk	sc
Bw5	102-130	Very dark gray	10YR 3/1	2msbk	sc
Bw6	130-157	Black	10YR 2/1	2msbk	c
P7: Mudigere (Hilly zone)					
Ap	0-20	Reddish brown	5YR 4/3	2msbk	c
Bt1	20-54	Reddish brown	2.5YR 4/4	2msbk	c
Bt2	54-95	Reddish brown	2.5YR 4/4	2msbk	c
Bt3	95-135	Red	2.5YR 5/6	2msbk	cl
P8: Sirsi (Hilly zone)					
Ap	0-17	Brown	7.5YR 4/3	1msbk	c
Bt1	17-44	Brown	7.5YR 4/3	1msbk	c
Bt2	44-72	Brown	7.5YR 4/2	1msbk	c
Bt3	72-105	Brown	7.5YR 4/3	1msbk	c
Bt4	105-130	Brown	7.5YR 5/3	1msbk	c
P9: Belthangady (Coastal zone)					
Ap	0-16	Brown	7.5YR 4/4	1msbk	cl
Bt1	16-36	Strong brown	7.5YR 4/6	1msbk	scl
Bt2	36-65	Strong brown	7.5YR 4/6	1msbk	scl
Bt3	65-105	Strong brown	7.5YR 4/6	1msbk	c
Bt4	105-130	Yellowish red	5YR 4/6	1msbk	scl
Bt5	130-150	Yellowish red	5YR 4/6	1msbk	sc
P10: Kumata (Coastal zone)					
Ap	0-15	Reddish brown	5YR 4/3	1msbk	sl
Bt1	15-36	Reddish brown	5YR 4/4	1msbk	scl
Bt2	36-55	Dark reddish brown	5YR 3/4	1msbk	cl
Bt3	55-70	Reddish brown	5YR 4/4	1msbk	c
Bt4	70-85	Reddish brown	5YR 4/4	1msbk	c
Bt5	85-120	Reddish brown	5YR 4/4	1msbk	c

hilly zone soils. Prabhavati *et al.* (2017) reported that the soils of the hilly area generally have high clay content in sub-surface due to high degree of weathering as a result of higher precipitation, temperature and clay illuviation.

Physicochemical properties of soil

Data on particle size distribution (Table 4) showed that the sand content in eastern and southern dry zone soils (P1 to P4) ranged from 31.7 to 64.7 per cent within the profile. High sand content was seen at the surface horizon than the sub-surface horizon. It was due to the erosion of fine particles from higher slopes to lower under high rainfall situations. Similar findings were reported by Gogoi *et al.* (2018). Silt content in soil was distributed in uneven form, and it varied from 12.9 to 29.8

per cent. The per cent clay content varied from 12.0 to 53.0 and increased with depth (P1 to P4), whereas soil pedons P6, P8, P9 and P10 showed a declining trend. Higher content of sand at the surface soil (0-30 cm) in soil pedons (P1 to P5, P7) was observed. The soil BD in different ACZs of arecanut crop, varied from 1.20 to 1.64 Mg m^{-3}. In general, BD was lower in the surface layer and increased with depth, and these results are prominent in EDZ and SDZ profiles (Table 3). In STZ, HZ and CZ soil pedons, there was no regular trend in BD. Higher BD values were observed in SDZ, and EDZ soil pedons and least BD was noticed in HZ soil pedons.

The soil pH of EDZ, SDZ and STZ samples varied from neutral to strongly alkaline (7.21 to 8.59.) whereas in HZ and CZ strongly acid to slightly acid (4.99 to 5.65). High pH was observed in soil pedons P3 to P5 (Table 4). Moderate to strongly acidic soil reaction in HZ and CZ soils were mainly due to the heavy rainfall, which caused leaching of bases and thereby reducing the soil pH. Badrinath *et al*. (1995) reported that southern parts (CZ and HZ) of Karnataka were distributed with acidic soil, which affects crop yield. Slightly, moderately or strongly alkaline soil reaction in other areas was due to accumulation of basic salts from the weathered parent material. Electrical conductivity values indicated non-saline nature of soils of the study area.

The organic carbon content in the soils of arecanut crops ranged from 0.76 to 2.12 per cent in the surface layer. In arecanut crop, the P5 and P1 soil profiles showed higher and least organic carbon content, respectively. High organic carbon content in P5 might be due to clay mineralogy, clay fraction, and biochemical environment of the soil such as high pH favours higher production of biomass. It is very much evidenced (Table 4) that clay content of P5 soil pedons was high compared to other pedons. An overall depth-wise decreasing trend was observed for organic carbon in all zones profile (P1 to P10). The lowermost depth had the least organic carbon content compared to surface and sub-surface layers. Higher values of organic carbon were observed in surface soils. The higher build-up of soil organic carbon on surface layers under crops may be attributed to the higher accumulation of recyclable biomass. The concentration and turnover of SOC are usually highest in the surface soil (Conant *et al.*, 2001).

Lower CEC recorded in CZ indicates better soil development while higher CEC was observed in STZ soil pedons (Table 5). CEC of soil samples ranged from 6.51 to 26.0 cmol (p+) kg^{-1}. A high range in CEC was noticed in pedon 5 (9.32 to 26.0 cmol (p+) kg^{-1}) followed by SDZ (9.28 to 21.32 cmol (p+) kg^{-1}) and EDZ (10.71 to17.45 cmol (p+) kg^{-1}). Lower CEC was observed in HZ and CZ and ranged from 6.61 to 10.08 cmol (p+) $kg^{-1}$and 6.51 to 8. 7c mol (p+) kg^{-1}, respectively. Organic carbon and clay content play a major role in influencing the CEC (Table 4). Organic carbon content decreased with depth in all soils. Still, CEC showed increasing trend indicating the mineralogy of the soils, which probably had a larger role in regulating CEC in these soils than the organic matter. Saikh *et al.* (1998) observed a poor correlation between CEC and organic carbon in ferruginous soils under deciduous forest and attributed this change in CEC to mineralogy. Mineralogy of soils owes to the proximity of parent material influenced by the dominance of 1:1 type of clay minerals and sesquioxides.

The distribution of exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ in piedmont plain soil, ranged from 0.62 to 15.6, 0.22 to 13.35, 0.01 to 2.01 and 0.01 to 0.55 mg kg^{-1}, respectively. Irrespective of the agro-climatic zone, Ca^{2+} was the dominant exchangeable cation followed by Mg^{2+}, K^+ and Na^+. The dominance of exchangeable Ca^{2+} in the semi-arid (EDZ and SDZ pedons) soils were in agreement with the findings of earlier workers on soils of the semi-arid region (Vasundhara *et al.,* 2018). In general, the distribution of exchangeable Na^+ and K^+ declined with increasing depth. In high rainfall regions (HZ and CZ pedons) small amounts of exchangeable K^+ and Na^+ in these soil pedons may be due to preferential losses of monovalent cations over divalent cations in leaching along with percolating water (Jenny, 1931).

CEC/clay ratio varied from 0.06 to 0.69, which indicates the type of clay minerals in different profiles. The soil profiles P2, P3, and P6 pointed to semi-active clays, whereas profiles P1, P7, P9, and P10 had sub-activity clays. P5 pointed to super

Table 4. Physical and chemical properties

Horizon	Depth (cm)	Sand (%)	Clay (%)	Silt (%)	B.D (Mg m^{-3})	pH	EC (dS m^{-1})	O.C (%)
P1: Kunigal (Fine-loamy, mixed, sub active, isohyperthermic, Rhodic Kanhaplustalfs)								
Ap	0-28	81.3	12.0	6.7	1.32	7.64	0.17	0.76
Bt1	28-47	53.1	31.0	15.9	1.41	7.55	0.14	0.51
Bt2	47-63	57.1	35.4	7.5	1.52	7.63	0.14	0.36
Bt3	63-87	51.6	41.3	7.1	1.55	7.54	0.20	0.23
Bt4	87-115	52.0	40.5	7.5	1.55	7.42	0.24	0.19
Bt5	115-140	50.8	41.4	7.8	1.55	7.48	0.14	0.23
P2: Hesarghatta (Fine, mixed, semi-active, isohyperthermic, Typic Haplustalfs)								
Ap	0-16	52.1	35.4	12.5	1.62	7.48	0.37	1.03
Bt1	16-36	46.9	42.8	10.3	1.19	7.68	0.31	0.56
Bt2	36-63	44.1	44.8	11.1	1.40	7.90	0.22	0.44
Bt3	63-102	41.7	45.7	12.6	1.50	7.99	0.18	0.44
Bt4	102-123	41.2	46.7	12.1	1.60	7.78	0.15	0.36
P3: T. Narasipura (Fine, mixed, semi-active isohyperthermic, Rhodic Paleustalfs)								
Ap	0-16	68.7	23.3	8.0	1.39	8.40	0.16	1.13
Bt1	16-36	61.1	35.8	3.1	1.49	8.53	0.13	0.36
Bt2	36-60	51.8	36.4	11.8	1.55	8.18	0.14	0.28
Bt3	60-83	47.3	46.9	5.8	1.47	8.24	0.16	0.24
Bt4	83-112	49.3	46.7	4.0	1.52	8.39	0.17	0.12
BC	112-130	48.2	45.0	6.8	1.49	8.59	0.28	0.08
P4: Maddur (Clayey, skeletal mixed active isohyperthermic, Typic Haplustalfs)								
Ap	0-13	53.3	37.0	9.7	1.34	7.89	0.46	1.78
Bt1	13-28	47.8	41.4	10.8	1.37	7.91	0.18	0.52
Bt2	28-47	45.1	43.6	11.3	1.44	7.82	0.13	0.44
Bt3	47-72	70.4	25.8	3.8	1.44	7.97	0.11	0.48
Bt4	72-105	38.5	45.1	16.4	1.32	7.85	0.10	0.30
BC	105-122	50.8	34.4	14.8	1.46	7.82	0.11	0.28
P5: H.D Kote (Fine, smectitic, super-active isohyperthermic, Vertic Haplustepts)								
Ap	0-13	31.7	53.0	15.3	1.21	8.17	0.16	2.12
Bw1	13-31	33.7	46.5	19.8	1.34	8.30	0.34	1.65
Bw2	31-57	34.5	51.4	14.1	1.21	8.36	0.30	1.13
Bw3	57-89	31.8	46.9	21.3	1.33	8.32	0.22	0.81
Bw4	89-117	44.9	45.5	9.6	1.66	8.44	0.15	0.57
Bw5	117-131	49.1	38.0	12.9	1.64	8.10	0.18	0.53
P6: Hassan (Fine, mixed, semi-active, isohyperthermic, Typic Haplustepts)								
Ap	0-17	62.8	35.3	1.9	1.44	7.32	0.19	1.12
Bw1	17-36	62.1	36.0	1.9	1.60	7.43	0.20	0.40
Bw2	36-57	61.2	35.9	2.9	1.36	7.45	0.12	0.28
Bw3	57-81	64.5	35.0	0.5	1.44	7.26	0.05	0.32
Bw4	81-102	56.8	42.6	0.6	1.43	7.23	0.05	0.24
Bw5	102-130	45.8	44.9	9.3	1.59	7.21	0.04	0.53
Bw6	130-157	45.6	43.9	10.5	1.34	7.22	0.04	0.68

P7: Mudigere (Fine kaolinitic, sub-active, isohyperthermic, Typic Rhodustalfs)								
Ap	0-20	40.7	43.4	15.9	1.34	5.0	0.00	1.45
Bt1	20-54	35.0	40.9	24.1	1.39	5.1	0.00	0.33
Bt2	54-95	36.6	39.8	23.6	1.32	5.6	0.00	0.24
Bt3	95-135	29.1	38.4	32.5	1.36	5.7	0.00	0.16
P8: Sirsi (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaplohumults)								
Ap	0-17	37.8	44.9	17.3	1.50	5.6	0.10	1.45
Bt1	17-44	32.5	49.0	18.5	1.41	4.4	0.50	1.16
Bt2	44-72	37.9	43.9	18.2	1.19	4.4	0.00	0.76
Bt3	72-105	46.4	40.0	13.6	1.50	5.2	0.00	0.68
Bt4	105-130	44.9	40.2	14.9	1.47	5.4	0.00	0.59
P9: Belthangady (Fine, kaolinitic, sub-active, isohyperthermic, Kanhaplic Haplustults)								
Ap	0-16	54.9	34.5	10.6	1.59	6.0	0.10	1.20
Bt1	16-36	48.8	36.0	15.2	1.66	5.9	0.00	0.84
Bt2	36-65	39.2	41.6	19.2	1.49	5.8	0.00	0.96
Bt3	65-105	46.5	41.2	12.3	1.69	5.8	0.00	0.64
Bt4	105-130	62.7	35.7	1.6	1.63	5.4	0.00	0.44
Bt5	130-150	75.8	18.0	6.2	1.62	6.0	0.00	0.50
P10: Kumata (Fine, mixed, sub-active, isohyperthermic, Typic Paleustults)								
Ap	0-15	50.2	27.8	22	1.30	5.8	0.00	1.10
Bt1	15-36	45.3	39.4	15.3	1.26	5.8	0.00	0.66
Bt2	36-55	42.3	43.9	13.8	1.25	5.6	0.00	0.49
Bt3	55-70	35.4	46.8	17.8	1.21	5.6	0.00	0.55
Bt4	70-85	31.1	42.8	26.1	1.08	5.6	0.00	0.41
Bt5	85-120	31.0	45.5	23.5	1.20	5.7	0.00	0.32

active clays, *i.e.*, smectitic type. The base saturation ranged from 33.4 to 99.6 per cent. Soils were highly base saturated except hilly and coastal soils as indicated by P7 to P10 due to high rainfall water takes bases along with it to down.

Classification of soils

The studied arecanut-growing soils were classified, which is presented in Table 6 as per USDA taxonomy.

Soil pedons from the eastern and southern dry zones (P1 to P4) of arecanut-growing soils were classified as Alfisols because of the presence of argillic horizon with base saturation of >35 per cent and sub-order of Ustalfs owing to the ustic moisture regimes, and this is keyed out as Rhodic Kanhaplustalfs (pedon 1), Typic Haplustalfs (pedon 2) and Rhodic Paleustalfs (pedon 3) at the great group level. Kanhaplustalfs (pedon 1) as they have a CEC of 16 cmol (+) kg^{-1} clay or less (by NH_4OAc pH 7) in 50 per cent and its upper 100 cm is of the argillic horizon.

However, Pedon 2 and 4 in the argillic horizon did not display a hue of 2.5 YR. Hence, these pedons were logically classified as Haplustalfs at the great group level. Finally, the pedons were classified into Typic Haplustalfs at sub-group level due to the absence of lithic or paralithic contact, cracks, pumice like fragments and also due to the presence of argillic horizon with >75 percentage base saturation. Typic Haplustalfs have deep red soils and belong to Haplustalfs great group. At sub-group level, these two soils had been keyed out as Typic Haplustalfs. At the family level, the particle size class is fine (>35 % clay) with mixed mineralogy (pedon 2). And at sub-soil horizons the presence of

Table 5. Chemical properties of arecanut-growing pedons

Pedon no.	Depth cm	Exchangeable cations (cmol (p^+) kg^{-1}) Ca^{2+}	Mg^{2+}	K^+	Na^+	sum	CEC cmol (p^+) kg^{-1}	B S %	CEC/ clay
Kunigal	0-28	3.95	1.12	0.22	0.12	5.41	8.32	65.0	0.69
	28-47	4.73	1.61	0.33	0.14	6.81	7.78	87.5	0.25
	47-63	4.58	1.81	0.24	0.21	6.84	9.94	68.8	0.28
	63-87	4.76	2.02	0.28	0.22	7.28	9.40	77.5	0.23
	87-115	4.36	1.92	0.24	0.23	6.75	8.53	79.2	0.21
	115-140	4.38	1.93	0.24	0.17	6.72	8.53	78.8	0.21
Hesargatta	0-16	9.29	4.5	0.82	0.11	14.72	15.44	95.3	0.44
	16-36	4.61	3.91	0.26	0.22	9.00	10.8	83.3	0.25
	36-63	6.66	5.65	0.14	0.36	12.81	15.34	83.5	0.34
	63-102	12.10	6.36	0.15	0.42	19.03	20.30	93.7	0.44
	102-123	6.43	4.29	0.13	0.29	11.14	12.31	90.5	0.26
T. Narasipura	0-16	4.10	7.44	0.4	0.21	12.15	12.2	99.6	0.50
	16-36	4.00	7.19	0.15	0.21	11.55	12.2	94.7	0.34
	36-60	3.70	6.65	0.14	0.31	10.80	12.74	84.8	0.34
	60-83	5.37	9.78	0.05	0.42	15.62	20.09	77.8	0.46
	83-112	5.44	9.71	0.19	0.37	15.71	17.50	89.8	0.37
	112-130	6.61	11.68	0.23	0.47	11.14	20.95	90.6	0.45
Maddur	0-13	8.98	5.46	0.81	0.31	15.56	15.88	98.0	0.43
	13-28	6.53	3.97	0.33	0.48	11.31	12.31	91.9	0.29
	28-47	8.29	3.68	0.31	0.42	12.70	13.18	96.4	0.31
	47-72	12.08	5.30	0.38	0.51	18.27	18.47	98.9	0.72
	72-105	12.38	5.57	0.45	0.53	18.93	19.22	98.5	0.42
	105-122	13.74	5.17	0.41	0.55	19.87	20.09	98.9	0.57
H D Kote	0-13	15.60	13.35	2.03	0.42	31.40	32.6	96.3	0.62
	13-31	14.46	12.42	1.35	0.37	28.60	29.2	98.1	0.63
	31-57	11.83	10.42	0.64	0.32	23.21	29.5	78.7	0.57
	57-89	9.96	8.13	0.46	0.25	18.8	24.3	77.3	0.52
	89-117	4.96	9.15	0.28	0.21	14.60	15.6	93.9	0.34
	117-131	7.80	8.13	0.21	0.18	16.32	22.0	74.1	0.52
Hassan	0-17	6.31	3.708	0.191	0.46	10.66	11.6	92.0	0.34
	17-36	6.08	3.35	0.06	0.50	9.99	10.8	92.0	0.30
	36-57	6.01	3.58	0.06	0.30	9.95	10.9	91.0	0.30
	57-81	5.66	3.77	0.14	0.16	9.73	10.4	94.0	0.30
	81-102	5.99	3.76	0.16	0.14	10.05	11.3	89.0	0.27
	102-130	9.90	5.15	0.18	0.24	15.47	17.9	87.0	0.39
	130-157	11.48	5.45	0.16	0.29	17.37	20.6	84.0	0.46
Mudigere	0-20	2.76	0.81	0.17	0.07	3.81	9.83	38.8	0.22
	20-54	3.70	0.78	0.04	0.02	4.54	8.32	54.6	0.20
	54-95	3.48	0.99	0.04	0.09	4.60	8.10	56.8	0.19
	95-135	2.65	0.77	0.04	0.07	3.53	7.13	49.5	0.19

Sirsi	0-17	4.23	2.86	0.47	0.01	7.57	7.57	67.0	0.15
	17-44	1.33	1.38	0.36	0.01	3.08	3.08	34.0	0.06
	44-72	1.22	1.12	0.18	0.01	2.53	2.53	22.0	0.06
	72-105	1.91	1.523	0.10	0.04	3.57	3.57	52.0	0.09
	105-130	2.05	1.57	0.07	0.02	3.71	3.71	57.0	0.08
Belthangady	0-16	2.63	0.86	0.23	0.03	3.75	6.48	57.9	0.19
	16-36	1.43	0.58	0.12	0.04	2.17	6.48	33.4	0.18
	36-65	1.70	0.67	0.10	0.02	2.49	7.24	34.4	0.17
	65-105	1.49	0.73	0.10	0.03	2.35	6.8	34.5	0.16
	105-130	0.72	0.29	0.05	0.01	1.07	3.89	27.6	0.11
	130-150	0.60	0.22	0.05	00.1	0.88	2.59	34.1	0.15
Kumata	0-15	2.61	1.391	0.063	0.049	4.11	10.08	41.0	0.36
	15-36	2.95	1.774	0.079	0.121	4.92	9.66	51.0	0.24
	36-55	3.22	1.934	0.109	0.042	5.3	9.14	58.0	0.21
	55-70	3.27	2.305	0.132	0.04	5.75	10.5	55.0	0.23
	70-85	3.25	2.416	0.12	0.047	5.83	12.08	48.0	0.28
	85-120	3.48	2.457	0.12	0.034	6.09	12.08	50.0	0.27

coarse fragments >35 per cent grouped as clayey-skeletal particle size class (pedon 4).

Rhodic Paleustalfs (Pedon 3) have argillic horizon that has a clayey particle size class throughout one or more sub-horizons in its upper part. At its upper boundary, a clay increase either 20 per cent or more within a vertical distance of 7.5 cm or 15 per cent or more within a vertical distance of 2.5 cm is assigned to great group Paleustalfs and a hue of 2.5 YR or redder colour and value, moist, 3 or at least half of the argillic horizon lead to Rhodic (Table 4).

The pedons (Pedon 5 and 6) of the arecanut-growing soils were classified as Inceptisols because of the presence of cambic horizon (Table 4). The temperature regime was isohyperthermic, and soil moisture regime was ustic. So these soils were classified as Ustepts at sub-order level and Haplustepts at the great group level. The pedon 5 and pedon 6 soils were qualified for Vertic and Typic

Table 6. Classification of the soils

Agroclimatic zone	Serial no.	Location	Soil Classification
Eastern dry zone	Pedon 1	Kunigal	Fine-loamy, mixed, isohyperthermic, Rhodic Kanhaplustalfs
	Pedon 2	Hesargatta	Fine, mixed, semi-active, isohyperthermic, Typic Haplustalfs
Southern dry zone	Pedon 3	T. Narasipura	Fine, mixed, semi-active isohyperthermic, Rhodic Paleustalfs
	Pedon 4	Maddur	Clayey, skeletal, mixed, active isohyperthermic, Typic Haplustalfs
Southern transitional zone	Pedon 5	H D Kote	Fine, smectitic, super active isohyperthermic, Vertic Haplustepts
	Pedon 6	Hassan	Fine, mixed, semi-active, isohyperthermic, Typic Haplustepts
Hilly zone	Pedon 7	Mudigere	Fine, kaolinitic, sub-active, isohyperthermic, Typic Rhodustalfs
	Pedon 8	Sirsi	Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaplohumults
Coastal zone	Pedon 9	Belthangady	Fine, kaolinitic, sub-active, isohyperthermic, Kanhaplic Haplustults
	Pedon 10	Kumata	Fine, mixed, sub-active, isohyperthermic, Typic Paleustults

sub-group, respectively. Vertic Haplustepts have cracks within 125 cm of the mineral soil surface that are 5 mm or more wide through a thickness of 30 cm or more for some time in normal years, and slickensides or wedge-shaped aggregates in a layer 15 cm or more thick that has its upper boundary within 125 cm of the mineral soil surface. However, pedon 6 did not display any intergradations with other taxa or an extra shift from the central concept. This soil represented the central concept of sub-group. Hence, this pedon was logically grouped under Typic Haplustepts.

Families are differentiated with particle size, mineralogy, reaction, soil temperature and a few others. The particle size class of pedon 5 and 6 were fine having 35 to 60 per cent or more (by volume) clay. The mineralogy classes were based on the less than 0.002 mm fraction, which is smectitic for the black soils (Pedon 5) and mixed for pedons 6 and 7 are the Typic Rhodustalfs that do not have a lithic contact within 50 cm of the soil surface and have a CEC of 24 or more cmol (+) kg^{-1} clay (by 1N NH_4OAc, pH 7) in the major part of the argillic horizon or the major part of the upper 100 cm of the argillic horizon if the argillic horizon is thicker than 100 cm.

Among the arecanut-growing soils studied from the hilly and coastal zones, 3 soil profiles (Pedons 8, 9 and 10) belong to Ultisols owing to less than 35 per cent base saturation (Table 6). Pedon 8 grouped under Humults sub-order due to very high levels of soil organic carbon in the top 50 cm (>0.9 %) and pedon 9 and 10 keyed out as Ustults at sub-order level that have an ustic moisture regime. Pedon 8 showed CEC clay ratio of <0.16 and low ECEC by clay ratio of <0.12, has kandic horizon and classified as Kanhaplohumults. Pedon 9 having Ustic sub-order that have CEC of less than 24 cmol(+) kg^{-1} clay in 50 per cent or more of the argillic horizon as less than 100 cm thickness belongs to Kanhaplic Haplustults. Pedon 10 classified as Typic Paleustults that do not have a lithic, paralithic, or petroferric contact within 150 cm of the mineral soil surface and have 5 per cent or more skeletons on faces of peds in the layer that has showed no reduction of 20 per cent clay content. Low CEC, low bases and high clay content indicate the soils belong to hot, humid tropical origin and have a dominance of low activity clays in tropics noted by many researchers like Nair *et al*. (2018) and Patil and Anil Kumar (2014).

Conclusion

The arecanut-growing soils developed from different parent materials, climate and physiography, which made significant variations in morphological, physical and chemical properties. Higher organic carbon content at the surface horizon and declined with depth. Light soil texture in the surface, becomes heavy in sub-surface. They are deep to very deep. Very strongly acid to strongly alkaline in soil reaction with high organic carbon content belonging to Alfisols, Inceptisols and Ultisols. The CEC ranged from low to medium and exchange complex was dominated by Ca^{2+} followed by Mg^{2+}, K^+ and Na^+ ions. The major taxa of soils identified at sub-group level of Soil Taxonomy are Rhodic Kanhaplustalfs, Typic Haplustalfs, Rhodic Paleustalfs for Eastern and Southern dry zone soils, Vertic and Typic Haplustepts for Southern transitional zones of arecanut-growings soils. Kanhaplohumults, Kanhaplic Haplustults and Typic Paleustults for hilly and Coastal zone soil.

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