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Characterization and Classification of Oil Palm Growing Soils of Khammam and Bhadradri Kothagudem Districts of Telangana

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ABSTRACT: Five distinctive soil profiles (pedons) from the oil palm (*Elaeis guineensis* Jacq.) cultivation areas in Khammam and Bhadradri Kothagudem districts of Telangana were analyzed and categorized. The findings revealed that these soils ranged from sandy loam to sandy clay in texture and had moderate permeability. They were slightly acidic to neutral in pH, non-saline, with medium to high organic carbon content, a mixture of mineral types, moderately deep to very deep, and moderately to well-drained. Bulk density increased with depth, ranging from 1.39 to 1.63 Mg m^{-3}. Cation exchange capacity and soil pH did not exhibit a consistent pattern with depth. The levels of nitrogen (N), phosphorus (P), and potassium (K) were rated as low to medium for N, medium to high for P, and medium for K, respectively. The available N, P, and K decreased with increasing soil depth. Based on these soil characteristics, the soils can be classified at the order level as Alfisols and Inceptisols, and at the subgroup level as Kanhaplic Rhodustalfs, Typic Haplustalfs, Typic Haplustepts, and Vertic Haplustepts.

Keywords: Characterization, Classification, Oil palm-growing soils.

INTRODUCTION

Oil palm cultivation covers an area of 19,000 hectares in Telangana, producing approximately 1.4 lakh metric tons of fresh fruit bunches (FFB) per hectare. In India, the total crude palm oil production is around 2.8lakh metric tons per hectare, with Telangana contributing approximately 39,000 metric tons per hectare (INDIASTAT 2020-2021). Oil palm is grown in Telangana across various soil types and resource conditions, primarily under irrigated conditions in flat to gently sloping upland areas. The soils in the region vary and include red, lateritic, black, alluvial, and colluvial soils, each with differing nutrient-supplying capabilities.

Due to the consistent variation and heterogeneity in soil and land resources within Telangana, there is a need for a systematic study of soil characteristics (Gogoi *et al.*, 2022). The existing knowledge about these soils does not fully meet the requirements of oil palm cultivation. To enhance oil palm yields, it is crucial to develop site-specific technologies based on soil types, which necessitates a thorough soil characterization. Therefore, the current study was undertaken to characterize and classify the soils used for oil palm cultivation in the Khammam and Bhadradri Kothagudem districts of Telangana.

MATERIALS AND METHODS

The study area, depicted in Fig. 1, is located between North Latitude 17°29'31.1" and East Longitude 81°07'28.8" and encompasses the central Telangana zone, specifically focusing on the oil palm growing soils in the Badradri Kothagudam and Khammam districts. This region experiences a semi-arid monsoon climate characterized by distinct rainy, winter, and summer seasons. The average annual precipitation is 1191 mm, with approximately 74 percent of this rainfall occurring during the peak southwest monsoon period, which extends from mid-June to mid-September. Temperature extremes in the research area range from as high as 39.3°C to as low as 18.3°C, with an annual average air temperature of 28°C. Relative humidity in the region averages around 64 percent.

In this study, five representative soil profiles (referred to as pedons P1 to P5) were examined from locations in Aswaraopeta, Apparaopeta, Guttagudem, Buggapadu, and Chandrugonda, where all soil horizons were observable. Each pedon was subjected to morphological analysis, and soil samples were collected from every horizon for the analysis of various soil properties. These properties included particle-size distribution using the hydrometer method, bulk density determined by the core method, pH measured in a 1:2.5 soil water solution, organic carbon content assessed using the methods of Walkley and Black (1934) ; Jackson (1973), and cation exchange capacity (CEC) determined with neutral normal ammonium acetate (Ashwini *et al.*, 2016). Soil classification was conducted in accordance with soil taxonomy guidelines (Soil Survey Staff, 2014; Soil Survey Staff, 1998; Soil Survey Staff, 2006).

RESULTS AND DISCUSSION

A. Morphology

The soil colors in this study were observed to fall within the 10YR, 7.5YR and 2.5YR hues, ranging from dark brown (10YR 3/2) to dark yellowish-brown (10YR 4/4) and reddish-brown (2.5YR 4/4). These soils exhibited varying degrees of hardness, from slight hardness to hardness and they were very friable to friable when moist, becoming slightly sticky when wet. The plasticity of these soils ranged from non-plastic to moderately plastic. In terms of texture, they varied from sandy loam to sandy clay, with the surface horizons of P1 being sandy clay and P2, P3, and P5 being sandy clay loam.

The oil palm growing soils in this study typically displayed a subangular blocky structure across all horizons. The physiographic characteristics of the study area, including undulations and localized relief features, had a significant impact on the sub-surface horizons. In P3, P4, and P5 pedons, the horizon sequence was A-Bw-C, while the remaining pedons had the sequence of A-Bt-C (Table 1) (Supriya *et al.*, 2019; John *et al.*, 2019).

B. Physical characteristics

The silt content in these soils varied between 6.6 to 19.1 percent, while the clay content ranged from 18.2 to 39.2 percent. In most pedons, there was a gradual increase in clay content with depth, although this trend was not observed in P3 and P4. Among these pedons, the Chendrugonda pedons had the lowest clay percentage, ranging from 18.2 to 24.8 percent, while the Apparaopeta pedons had the highest clay content, ranging from 23.0 to 39.2 percent (Table 2). The increase in clay content indicates a process known as illuviation, which has been documented in previous studies (Pardeep Kumar and Verma 2005; Kumar *et al.*, 2018; Deng *et al.*, 2016). These soils exhibited poor aggregation in both surface and sub-surface horizons, which might be attributed to clay illuviation under continuous irrigation conditions, given their long history of oil palm cultivation (Dey and Sehgal 1997).

Bulk density increased with depth in all pedons, consistent with the findings of previous studies conducted by John *et al.*, (2019) and Kumar *et al.*, (2018). The gravel content ranged from 7.75 to 71.50 percent, with an average of 45.18 percent in P4 and 45.58 percent in P5, and there was a gradual increase in gravel content observed in these pedons.

C. Chemical properties

The soils exhibited a neutral to slightly alkaline pH, ranging from 6.4 to 7.8, and were non-saline with electrical conductivity (EC) values ranging from 0.05 to 0.22 dS/m (Table 3). Organic carbon content varied between 7.4 to 11.9 g kg^{-1} in surface horizons and 1.9 to 9.1 g kg^{-1} in sub-surface horizons (Table 4), with a decrease in organic carbon content as depth increased. The relatively high temperatures experienced throughout most of the year in the region likely contributed to a higher rate of decomposition and comparatively higher organic carbon values in surface horizons compared to sub-surface horizons.

Cation exchange capacity (CEC) values ranged from 13.88 to 25.3 cmol(p+) kg^{-1} in surface horizons and from 16.26 to 26.3 cmol(p+) kg^{-1} in sub-surface horizons, which showed a positive correlation with clay content. Similar findings were reported by Dhanorkar *et al.* (2010). On the exchange complex, exchangeable bases were found in the order of $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$, with exchangeable calcium being the dominant cation, ranging from 5.7 to 16.56 cmol(p+) kg^{-1} soil. The highest value of 16.56 cmol(p+) kg^{-1} soil was observed in the Apparaopetapedon. Exchangeable magnesium, the second most dominant cation after calcium, varied from 2.8 to 6.8 cmol (p+) kg^{-1} soil, with the Bw1 horizon of P5 having the highest value of 6.8 cmol(p+) kg^{-1}. Exchangeable sodium on the exchange complex ranged from 0.28 to 1.1 cmol(p+) kg^{-1} soil, while exchangeable potassium values were among the lowest, ranging from 0.18 to 0.44 cmol(p+) kg^{-1} soil. The percent base saturation on the exchange complex ranged from 65.99% to 85.77%, with the highest value (85.77%) observed in the BC horizon of P2 and the lowest value recorded in the Ap horizon of P4. These findings align with previous research by John *et al.* (2019); Deepika *et al.* (2021); Satish *et al.*, (2018).

D. Soil Fertility

The available nitrogen (N) content in the surface horizons ranged from 194.4 to 28.8 kg ha^{-1}, while in the sub-surface horizons, it varied between 128.7 to 25.2 kg ha^{-1}. Based on the classification of less than 280 kg ha^{-1} N as low, 280-560 kg ha^{-1} N as medium, and more than 560 kg ha^{-1} N as high (Muhr *et al.*, 1965), most of the soils were categorized as having low to medium available nitrogen. For available phosphorus (P), the values ranged from 41.0 to 95.1 kg ha^{-1} in surface horizons and 7.2 to 68.6 kg ha^{-1} in sub-surface horizons. According to critical values, where less than 10 kg ha^{-1} is low, 10-25 kg ha^{-1} is medium, and more than 25 kg ha^{-1} is high (Muhr *et al.*, 1965), the majority of the soils were classified as having high available phosphorus.

Available potassium (K) content ranged from 177.8 to 323.0 kg ha^{-1} in surface horizons and 115.1 to 281.5 kg ha^{-1} in sub-surface horizons. Using the criteria of less than 118 kg ha^{-1} as low, 118-280 kg ha^{-1} as medium, and more than 280 kg ha-1 as high (Muhr *et al.*, 1965), the soils were generally categorized as having medium to high available potassium content.

Regarding available sulfur (S), it varied from 8.1 to 94.7 mg kg^{-1} in different pedons. The highest values were observed in P4, ranging from 16.5 to 94.7 mg kg^{-1}, while the lowest values were in P3, ranging from 8.1 to 62.3 mg kg^{-1}. There was a general trend of decreasing available sulfur with depth in most pedons, except for some exceptions. The subsurface to surface horizons were classified as having medium to very high sulfur content, but the lower horizons had comparatively lower sulfur content in comparison to the upper horizons. Sulfur content was found to be negatively correlated with electrical conductivity (EC) and pH, and positively correlated with organic carbon (OC), nitrogen (N), phosphorus (P), zinc (Zn), copper (Cu), and manganese (Mn). Similar findings were reported in previous studies by Behera *et al.* (2020); Behera *et al.* (2019a and 2019b); Ahukaemere (2018); Hima Bindu *et al.* (2022); Behera *et al.* (2015).

E. Soil classification

Based on a comprehensive analysis of the soil's morphological, physical, and physico-chemical characteristics, as well as climate data, the soils were classified according to the Keys to Soil Taxonomy (Soil Survey Staff, 2014). Pedons 1 and 2 were categorized as Alfisols due to the presence of an argillic (Bt) sub-surface diagnostic horizon. Pedons 3, 4, and 5 were classified as Inceptisols because they lacked any other diagnostic horizon except for the cambic (Bw) horizon. Considering the Ustic moisture regime, Pedons 1 and 2 were further classified as Ustalfs, while Pedons 3, 4, and 5 were classified as Ustepts at the suborder level. Pedon 1 was designated as "Rhodustalfs" at the great group level because of the presence of an argillic horizon with a hue of 2.5YR or redder and a moist value of three or less. It was further classified as Kanhaplic Rhodustalfs at the subgroup level, considering a cation exchange capacity (CEC) of less than 24 cmol(+) per kg clay in 50 percent or more of the argillic horizon within the upper 100 cm of the soil and the absence of lithic contact within 50 cm from the soil surface.

Pedon 2 was classified as "Haplustalfs" at the great group level because, apart from the argillic horizon, these soils did not exhibit any horizons such as natric horizon, petrocalcic horizon, duripan, or plinthite horizons. Additionally, Pedon 2 did not display any vertic properties or lithic contact within 50 cm from the soil surface. Hence, it was classified as Typic Haplustalfs at the subgroup level (Vasundhara *et al.*, 2020; Srinivasan *et al.*, 2021).

Pedons 3, 4, and 5 were categorized as "Haplustepts" at the great group level because these pedons lacked both duripan and calcic horizons, and their base saturation exceeded 60 percent at a depth between 0.2 to 0.7 m from the soil surface. Pedons 3 and 4 were further classified as Typic Haplustepts at the subgroup level due to the absence of vertic properties and lithic contact within 50 cm from the soil surface. Pedon 5 had lithic contact, albeit shallower, and was consequently classified as VerticHaplustepts at the subgroup level. Pedons 4 and 5, with gravel percentages greater than 45 percent, were categorized as Loamy-skeletal, mixed, iso-hyperthermic Typic Haplustepts and Loamy-skeletal, mixed, iso-hyperthermic Vertic Haplustepts, respectively. These findings are consistent with observations reported in previous studies by Ram Prasad and Govardhan (2011); Ram Prasad *et al*. (2013); Vasu *et al.* (2022); Karthika *et al.* (2022); John *et al.* (2019); Sekhar *et al.* (2019); Satish *et al.* (2018).

Table 1: Morphological properties of the pedons of the study area.

Pedon No. and location (1)	**Horizon (2)**	**Depth (cm) (3)**	**Colour (4)**	**Texture (5)**	**Structure (6)**			**Consistency (7)**		
			Moist		C	G	T	Dry	Moist	Wet
Pedon 1. Fine- loamy, mixed, isohyperthermic, Kanhaplic Rhodustalfs										
P1: Aswaraopeta	Ap	0-15	7.5 YR 3/4	SL	m	1	sbk	sh	vfr	sspo
	Bt1	15-39	2.5YR 3/6	SCL	m	2	sbk	h	fr	sssp
	Bt2	39-68	2.5 YR 3/6	SC	m	2	sbk	h	fr	msmp
	BC	68-115+	2.5YR 3/6	SC	m	2	sbk	h	fi	msmp
Pedon 2. Fine- loamy, mixed, isohyperthermic, TypicHaplustalfs										
P2: Apparaopeta	Ap	0-13	7.5YR 3/3	SCL	m	1	sbk	sh	vfr	sssp
	Bt1	13-29	2.5YR 4/4	SCL	m	2	sbk	sh	fr	sssp
	Bt2	29 -50	2.5YR 4/4	SCL	m	2	sbk	h	fr	sssp
	Bt3	50-68	2.5YR 4/4	SC	m	3	sbk	h	fr	msmp
	BC	68-105+	2.5YR 4/4	SCL	m	2	sbk	h	fr	sssp
Pedon 3. Fine- loamy, mixed, isohyperthermic, TypicHaplustepts										
P3: Guttagudem	Ap	0-24	10YR 3/2	SCL	m	2	sbk	-	fr	so sp
	Bw1	24-44	10YR 3/2	SCL	m	2	sbk	-	fr	sssp
	Bw2	44-77	10YR 4/3	SCL	m	2	sbk	-	fr	sssp
	Bw3	77-100	10YR 4/4	SCL	m	2	sbk	-	fr	sssp
	BC	100+	10YR 4/4	SL	m	2	sbk	-	vfr	msmp
Pedon 4. Loamy- skeletal, mixed, isohyperthermic, TypicHaplustepts										
P4: Buggapadu	Ap	0-15	10YR 3/4	SC	m	1	sbk	-	fr	sssp
	Bw1	15-30	7.5YR 2/3	SCL	m	2	sbk	-	fr	sssp
	Bw2	30-58	5YR 4/6	SCL	m	2	sbk	-	fr	msmp
	Bw3	58-82	5YR 4/6	SL	m	2	sbk	-	fr	msmp
Pedon 5. Loamy- skeletal, mixed, isohyperthermic, VerticHaplustepts										
P5:Chandrugonda	Ap	0-26	7.5YR 3/2	SCL	m	1	sbk	-	vfr	sssp
	Bw1	26-44	10YR 3/4	SCL	m	2	sbk	-	fr	msmp
	Bw2	44-70	10YR 5/6	SCL	m	2	sbk	-	fr	msmp
	BC	70-95	10YR5/6	SL	m	2	sbk	-	vfr	so po

Table 2: Physical properties of the pedons of the study area.

P.No. and location	Horizon	Mechanical composition (%)			Texture	Gravel %	B.D (Mg m^{-3})	Sand/Silt ratio
		Sand	Silt	Clay				
P1:.Aswaraopeta	Ap	72.6	8.0	19.4	SL	-	1.44	9.08
	Bt1	67.2	9.3	23.5	SCL	-	1.51	7.23
	Bt2	55.4	7.4	37.2	SC	-	1.58	7.78
	BC	56.2	7.7	36.1	SC	-	1.60	6.94
P2: Apparaopeta	Ap	65.4	11.6	23.0	SCL	-	1.43	5.64
	Bt1	62.3	8.0	29.7	SCL	-	1.52	7.79
	Bt2	59.2	8.2	32.6	SCL	-	1.55	7.22
	Bt3	52.1	8.7	39.2	SC	-	1.64	5.99
	BC	61.2	12.2	26.6	SCL	-	1.43	5.02
P3: Guttagudem	Ap	64.8	11.3	23.9	SCL	-	1.38	4.62
	Bw1	56.4	18.3	25.3	SCL	-	1.49	3.08
	Bw2	62.2	17.7	22.1	SCL	-	1.57	3.51
	Bw3	57.7	19.1	23.2	SCL	-	1.57	3.02
	BC	65.0	16.3	18.7	SL	-	1.59	3.66
P4: Buggapadu	Ap	56.2	6.6	37.2	SC	29.60	1.39	6.58
	Bw1	61.7	10.2	28.1	SCL	45.70	1.48	6.05
	Bw2	60.5	11.6	27.9	SCL	54.12	1.54	5.22
	Bw3	68.6	12.5	18.9	SL	63.32	1.56	5.02
P5:Chandrugonda	Ap	64.6	11.5	23.9	SCL	7.75	1.38	5.62
	Bw1	61.9	13.3	24.8	SCL	49.30	1.51	4.65
	Bw2	63.3	13.6	23.1	SCL	53.78	1.62	4.65
	BC	69.4	12.4	18.2	SL	71.50	1.63	5.60

Table 3: Physico-chemical characteristics of the pedons of study area.

P.No. and location	Horizon	pH	EC (dS m^{-1})	CEC (c mol (p+) kg^{-1})	Exchangeable cations (c mol (p+) kg^{-1})				B.S (%)	$CaCO_3$ (%)
					Ca	Mg	Na	K		
P1:.Aswaraopeta	Ap	7.1	0.07	13.88	5.70	3.80	0.32	0.21	72.26	0.20
	Bt1	7.2	0.07	16.26	7.30	4.20	0.43	0.21	74.66	0.38
	Bt2	7.3	0.22	16.92	7.58	5.80	0.46	0.18	82.86	0.33
	BC	7.8	0.19	16.89	8.20	5.08	0.34	0.21	81.88	0.56
P2: Apparaopeta	Ap	7.1	0.05	18.2	10.3	2.8	0.4	0.21	75.33	0.14
	Bt1	7.3	0.09	19.6	11.18	3.2	0.56	0.24	77.45	0.08
	Bt2	7.5	0.09	24.1	15.2	3.1	0.69	0.21	79.66	0.11
	Bt3	7.5	0.09	25.2	16.56	4.0	0.42	0.26	84.29	0.14
	BC	7.1	0.10	17.5	11.22	3.0	0.61	0.18	85.77	0.18
P3: Guttagudem	Ap	7.2	0.05	25.3	12.1	5.9	0.71	0.27	75.02	1.12
	Bw1	7.4	0.08	21.6	10.5	5.3	0.62	0.44	78.06	0.73
	Bw2	7.6	0.10	18.5	9.4	3.9	0.66	0.31	77.14	0.80
	Bw3	7.2	0.10	17.4	7.6	3.5	0.61	0.24	68.68	1.24
	BC	7.1	0.10	16.3	8.2	3.6	0.54	0.19	76.87	0.90
P4: Buggapadu	Ap	6.9	0.06	23.2	11.4	3.4	0.32	0.18	65.95	0.32
	Bw1	7.1	0.08	25.6	13.9	3.2	0.66	0.24	70.31	0.68
	Bw2	7.2	0.09	26.3	14.4	3.1	0.67	0.21	69.89	0.70
	Bw3	7.1	0.10	21.4	12.5	2.9	0.28	0.27	74.53	1.10
P5:Chandrugonda	Ap	6.4	0.07	24.2	9.6	5.7	0.81	0.18	67.31	1.04
	Bw1	6.9	0.08	25.6	11.1	6.8	0.92	0.24	74.45	1.30
	Bw2	7.5	0.09	23.4	10.8	4.6	1.1	0.18	71.28	1.80
	BC	7.2	0.20	18.2	8.4	3.9	0.8	0.16	72.86	2.10

Table 4: OC (g kg^{-1}), available N (kg ha^{-1}) and S content (mg kg^{-1}) of pedons of the study area.

P.No. and location	Horizon	Depth	OC	N	P_2O_5	K_2O	S
			(g kg^{-1})	(kg ha^{-1})			(mg kg^{-1})
1. Aswaraopeta	Ap	0-15	11.9	225.4	64.8	284.3	48.2
	Bt1	15-39	9.1	236.5	52.8	251.9	24.6
	Bt2	39-68	7.2	156.4	35.0	211.6	12.4
	BC	68-115+	3.6	135.1	24.8	194.5	10.3
2. Apparaopeta	Ap	0-13	10.6	234.2	79.6	321.5	44.4
	Bt1	13-29	8.8	223.0	65.2	266.9	26.2
	Bt2	29 -50	6.3	217.3	25.1	265.8	13.0
	Bt3	50-68	4.2	156.4	25.9	281.5	13.3
	BC	68-105+	3.1	151.1	8.2	239.3	8.1
3. Guttagudem	Ap	0-24	11.1	278.4	95.1	234.1	62.3
	Bw1	24-44	7.8	203.1	68.6	172.5	38.8
	Bw2	44-77	4.1	188.7	37.3	153.8	21.4
	Bw3	77-100	3.6	187.4	15.7	260.4	15.6
	BC	100+	2.9	185.2	14.4	254.8	8.7
4. Buggapadu	Ap	0-15	9.6	280.8	31.2	177.8	94.7
	Bw1	15-30	6.0	250.2	15.9	164.3	57.1
	Bw2	30-58	3.5	153.1	13.6	185.6	37.3
	Bw3	58-82	2.1	146.4	7.2	116.2	16.5
5. Chandrugonda	Ap	0-26	7.4	194.4	41.0	323.0	54.4
	Bw1	26-44	5.2	170.3	40.5	222.8	38.0
	Bw2	44-75	3.4	121.1	28.5	216.4	26.6
	BC	75-95	1.9	128.7	11.6	115.1	14.4

CONCLUSIONS

In summary, the study findings indicate that the soils used for oil palm cultivation in the Khammam and Bhadradri Kothagudem districts of Telangana exhibit a texture ranging from sandy loam to sandy clay, with moderate permeability. These soils tend to be slightly acidic to neutral in pH, non-saline, and have a medium to high organic carbon content. They also display a mixed mineral composition, are moderately deep to very deep, and show moderate to well-drained properties. The bulk density of these soils increases with depth, ranging from 1.39 to 1.63 Mg m^{-3}. In terms of nutrient content, nitrogen (N) levels are generally low to medium, phosphorus (P) levels are medium to high, and potassium (K) levels are medium. Additionally, the availability of N, P, and K decreases with increasing soil depth. Based on these soil characteristics, the soils have been classified up to the subgroup level.

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Conflicts of Interest. None.

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