International Journal of Applied Chemical and Biological Sciences (2021), 2(4), 12-29
ISSN 2582-788X

RESEARCH PAPER

Characterization and classification of normal soils of Kapurthala district, Punjab, India

Jaihoon Rafie *, Raj Kumar

School of Agriculture, Department of Soil Science and Agriculture Chemistry, Lovely Professional University, India

* For correspondence: jaihoonrafie@gmail.com

ABSTRACT

The study was carried out in the Kapurthala district of Punjab, North-West of India. The aim of the study was to evaluate the macro morphological, physical and chemical characteristics normal soils in Kapurthala district, five profile samples were collected from five villages, the macro morphological characteristics of samples were studied in the field, location of all the samples were recorded with help of GPS, and horizon wise samples were collected for further study in laboratory, the pH of these soils in epipedon ranged from 7.5 to 9.5, The electrical conductivity (EC) of these soils was below 1 dS m-1. Organic carbon of these soils in epipedon ranged from 0.2 per cent to 0.93 per cent, where in subsurface horizons it ranged from 0.06 per cent to 0.52 per cent. The available nitrogen, phosphorus and potassium of these soils ranged from 231.2 kg/ha to 627.2 kg/ha, 84.0 kg/ha to 107.9 kg/ha, and 263.2 kg/ha to 392.0 kg/ha respectively in the epipedon. CEC in these soils ranged from 3.72 comlc/kg to 11.60 comlc/kg. Accordingly exchangeable cations (Ca, Mg, Na and K) were evaluated in comlc/kg of soil. Exchangeable sodium percentage of these soils was ranged between 5.5 and 40.8. Saturation percentage of these soils ranged from 30.90 to 44.40 in epipedon. Accordingly, normal soils of Kapurthala district were extracted with the help of vacuum pump and the composition of soil saturation paste such as pHs, ECe, Ca++,Mg++, Na+, K+, HCO3-, CO3--, Cl- and SO4-- were examined. Soil texture of these soils was clay loam, sandy clay loam, sandy loam and loam, loamy sand, and sand respectively. Moreover, normal soils of Kapurthala district classified as per Soil Taxonomy (2015) up to family level. These soils qualified under Inceptisols and Entisols suborders.

Key word: Soil survey, soil characterization, soil classification, normal soils

1. INTRODUCTION

Agricultural growth is crucial for the survival of mankind, as the provision of food, shelter and clothing is closely associated with it. Food in particular is necessary for physical growth, energy production for good health and normal development of an individual. All living things depend on their environment for survival, thrive and reproduce their kinds. As it is known, nearly all green plants depend on soils which provide a favourable environment and supply all the

essential materials that they need for their growth. Since animals, in turn, depend on plants, it becomes obvious that all agricultural activities directly or indirectly depend on the soil. It is from the soil that plants obtain their nutrients and water. It also contains air needed for respiration of the roots [1].

Soils are formed by the interaction of different soil-forming factors and process. In India about four hundred soil series have been recognized and many more are being introduced as soil survey and mapping is extended to other state [2]. Characterization of soils is fundamental to all soil studies, as it is an important tool for soil classification, which is done based on its properties. It also provides information for understanding the physical, chemical, mineralogical and microbiological properties [3]. Soil classification, on the other hand, helps to organize our knowledge, facilitates the transferring of experience and technology from one place to another and helps to compare soil properties. A soil characterization study therefore is a major building block for understanding the soil, classifying it and getting the best understanding of the environment [4].

The soils of Punjab developed largely on alluvium, very widely and exhibit differences in their nature, properties and profile development as dictated by differential climatic and topographic conditions [5]. The Kapurthala district is occupied by Indo-Gangetic alluvium; the major portion of this region lies in the river tract falling between the Beas and Black Bein and is called “Bet” [6]. The Kapurthala district comprises two units, namely Kapurthala and Phagwara which are separated by a part of the Jalandhar district. The Kapurthala unit occupies a major part of the district. There are three tehsils, vis. Kapurthala, Sultanpur Lodhi and Phagwara [7].

The present study was conducted to characterize and classify the normal soils from Kapurthala district. It was highest importance as these soils were studied in the field, characterized in the laboratory and classified as per Soil Taxonomy (2015) [8]. This study will help to understand major soil type and its fertility. Based on the research result it is possible to classify the total area of lands under normal soils in the Kapurthala district into their suitability classes for the appropriate agricultural practices possible to do on the land.

2. METHODS AND MATERIALS

2.1. Study area

The Kapurthala district is situated in Punjab a state in India which lies between 31.0730° N and 75.4355°, and forms a sort of the Bist Doab in central Punjab. Soil profile observations have been taken from the five village of Kapurthala district, which Dhoda, Ucha, Bhanra, Kanjili and Fatehpur areas.

2.2. Soil sampling

The study was carried out by the standard soil survey procedure as described in the Soil Survey Manual [9]. Five profile samples were collected using Garmin GPS. The macro morphological characteristics of the soils were studied in the field. The soil was characterized by horizon, depth, colour, structure, consistency, reaction which HCl and boundary parameters. Soil

Table 1. Location of the profiles

Profiles	Location
Dhoda	About 600 m near north east of Jagjitpur village outside of Phagwara-Hoshiarpur road, Phagwara tehsil, Kapurthala district
Ucha	Near to Ucha Pind, in the village of Ucha, Kapurthala district
Bahanra	About 100 m north east of the village Fatehjalal, about 500 m from Kapurthala district
Kanjili	About 200 m near to Kanjili bridge and boat club, Kanjili village
Fatehpur	Muradpur Dona village opposite of Rampur village, Sultanpur Lodhi tehsil, Kapurthala district

samples collected from each horizon of the profiles were dried. The air-dried samples were passed through 2 mm sieve to separate the coarse fragments (>2 mm). The fine earth samples were stored in separate containers and used for various analyses.

2.3. Soil analysis

Five profile samples were collected using Garmin GPS. The macro morphological characteristics of the soils were studied in the field, and the physical and chemical characteristics of the soils were studied in laboratory.

The soil samples were analyzed for various parameters which are stated below

2.3.1. *Soil pH in water*:

The pH of the soil was analyzed according to Jackson (1967) with little modifications [10]. The air dried soil (<2 mm) and double deionized water was mixed in the ration of 1:2 and kept for an hour. The electrode was immersed into the clear supernatant and pH was recorded.

2.3.2. *Organic carbon:*

The organic carbon of the soil sample was determined by wet digestion method of Walkley and Black (1965) [11]. This method involved oxidation of organic matter by potassium

Table 2. Site characteristics of the studied soil pedons

No	Series	Depth (cm)	GPS Reading		Elevation (M)	Erosion	Vegetation	Slop %	Drainage
			Longitude	Latitude					
1	Dhoda	139	31°19'19.392"	75° 49' 8.982"	220	ei	wheat, Paddy	1-2	MWD
2	Ucha	142	31°10.592"	075° 42 .132'	129	ei	Wheat, Paddy	1-2	WD
3	Bahanra	140	31°24.075'	075° 29 .212'	180	ei	Wheat, Maize	1-2	ED
4	Kanjili	137	31°24.831'	075° 22 .717'	209	ei	Wheat, Maize , Trees	1-2	MWD
5	Fatehpur	145	31°15.196'	075° 27 .423'	227	ei	Wheat, Maize	1-2	MWD

Table 3. Macro-morphological characteristics of Dhoda series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-24	10YR 5/4	cl	2m sbk	dh	mfi	ws,wp	ev	ds
AB	24-45	10YR 6/4	cl	2m sbk	dsh	mfi	ws,wp	ev	gs
B1	45-65	10YR 5/6	scl	2c sbk	dh	mfi	ws,wp	es	gs
B21	65-87	10YR 5/4	cl	2c sbk	dh	mfi	ws,wp	ev	gs
B22	87-113	10YR 5/3	cl	2c sbk	-	mfi	ws,wp	es	gs
BC	113-139	10YR 4/6	cl	massive	-	mfi	ws,wp	es	gs

Table 4. Macro-morphological characteristics of Ucha series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-22	10YR 4/2	sl	1m sbk	dsh	mfr	wss,wsp	es	cs
AB	22-45	10YR 5/6	sl	2m sbk	-	mfr	wss,wsp	es	gs
B1	45-73	10YR 5/4	sl	2m sbk	-	mfr	wss,wsp	e	gs
B2	73-108	10YR 4/6	sl	2c sbk	-	mfr	wss,wsp	e	ds
B3	108-142	10YR 4/6	l	2c sbk	-	mfr	wss,wsp	e	-

m-medium, c- course, sbk- sub angular blocky, dsh-soft, dh- hard, mfr- Friable, mfi- loose, ws- sticky, wp- plastic, wso- non sticky, wpo- non plastic

dichromate (K2Cr2O7) with sulfuric acid (H2SO4) to heat the dilution(as the classical procedure) and titration.

2.3.3. Calcium carbonate:

The calcium carbonate of the soil sample was determined by Puri (1930) [12] with little modification. The samples were exposed to rapid titration method and result was observed.

2.3.4. *Nitrogen, phosphorous and potassium:*

The nitrogen of soil samples was estimated by Subbiah and Asija, (1965) [13]. The alkaline permanganate method was used to estimate the available nitrogen. The available phosphorus was determined by Olsen *et al.,* (1954) using the extracting procedure of the sample with 0.05 M sodium bicarbonate [14]. The available potassium of soil samples was estimated by Merwin *et al.,* (1950) method by extracted 1N ammonium acetate [15].

2.4. Cation exchange capacity:

CEC of soil samples was determined by using the method described by Jackson, (1967) [10], where soil was saturated with sodium by equilibrating with 1N sodium acetate. The exchangeable cations were determined as per procedure described in practical soil science and agriculture chemistry manual Tolanur, (2018) [16] and particle size distribution was analyzed as per Singh *et al*., (2013) manual [17].

2.5. Other parameters:

Saturation paste was prepared according to the procedure outlined by the Rhoades, (1982) [18]. Na+, K+ were determined by using flame photometer, calcium and magnesium were analyzed on flame photometer. CO^{3-} -, HCO_3^-, Cl^-

Table 5. Macro-morphological characteristics of Bahanra series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-24	10YR 5/4	cl	2m sbk	dh	mfi	ws,wp	ev	ds
AB	24-45	10YR 6/4	cl	2m sbk	dsh	mfi	ws,wp	ev	gs
B1	45-65	10YR 5/6	scl	2c sbk	dh	mfi	ws,wp	es	gs
B21	65-87	10YR 5/4	cl	2c sbk	dh	mfi	ws,wp	ev	gs
B22	87-113	10YR 5/3	cl	2c sbk	-	mfi	ws,wp	es	gs
BC	113-139	10YR 4/6	cl	massive	-	mfi	ws,wp	es	gs

Table 6. Macro-morphological characteristics of Kanjili series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-23	10YR 3/2	cl	2m sbk	dsh	mfr	ws,wp	ev	cs
B1	23-50	10YR 5/4	cl	2m sbk	-	mfr	ws,wp	es	ds
B21	50-78	10YR 4/4	scl	2c sbk	-	mfr	ws,wp	es	ds
B22	78-105	10YR 4/4	scl	2c sbk	-	mfr	ws,wp	e	gs
B23	105-137	10YR 4/6	scl	2c sbk	-	mfi	ws,wp	eo	gs

Table 7. Macro-morphological characteristics of Fatehpur series

Horizon	Depth (cm)	Color	Texture	Structure	Consistence			Reaction with HCl	Boundary
		Moist			dry	moist	wet		
Ap	0-24	10YR 4/3	sl	1m sbk	dsh	mfr	wss,wsp	0	cf
AB	24-55	10YR 6/4	ls	2m sbk	-	mfr	wss,wsp	0	ds
B1	55-78	10YR 5/6	sl	2m sbk	-	mfr	wss,wsp	0	gs
B21	78-120	10YR 6/4	s	2c sbk	-	mfr	wss,wsp	0	gs
B22	10-145	10YR 5/6	ls	2c sbk	-	mfi	wss,wsp	0	gs

m-medium, c- course, sbk- sub angular blocky, dsh-soft, dh- hard, mfr- Friable, mfi- loose, ws- sticky, wp- plastic, wso- non sticky, wpo- non plastic

and SO_4^{--} estimated as per the procedure outlined by the Jackson (1958) [19]. For the extraction of available zinc, iron, manganese and copper from the soil sample DTPA method was used as per the procedure described by Lindsay and Norvell (1978) [20].

3. RESULTS AND DISCUSSION

Five profile samples were collected from the five village of Kapurthala district in Punajb, NW-India for their macro morphological, physical and chemical characteristics. Location of all the pedons recorded with the help of GPS and normal soils of Kapurthala district were classified as per Soil Taxonomy (2015) manual. The results for the pedons are discussed and presented in tables bellow.

3.1. Macro morphological characteristics of pedons

Soil color is one of the important properties, which helps in identification of soil type and

Table 8. Physico-chemical characteristics of Dhoda series

Horizon	Depth (cm)	pH (1:2)	EC (1:2) (dS m $^{-1}$)	OC (%)	$CaCO_3$ (%)	Av. Nitrogen (kg/ha)	Av. Phosphorus (kg/ha)	Av. Potassium (kg/ha)
Ap	0-24	8.9	0.16	0.93	0.4	627.2	89.3	263.2
AB	24-45	9.1	0.07	0.52	0.2	489.2	77.2	240.8
B1	45-65	9.1	0.08	0.39	1.2	175.6	111.3	313.6
B21	65-87	9.2	0.10	0.42	1.1	426.4	33.82	313.6
B22	87-113	9.3	0.21	0.36	0.3	338.6	35.16	280.0
BC	113-139	9.0	0.16	0.4	0.4	200.7	35.61	313.6

Depth (cm)	CEC ($cmol_c$/kg)	Exchangeable cations ($cmol_c$/kg)				E.S.P	Particle size distribution (%)			Texture classes (USDA)
		Ca	Mg	Na	K		Sand	Silt	Clay	
0-24	7.91	6.2	0.6	0.60	0.51	7.5	26.2	41.6	32.4	cl
24-45	7.05	6.4	1.4	0.69	0.56	8.5	41.5	27.9	30.6	cl
45-65	7.24	4.8	1.0	0.78	0.66	10.7	47.8	18.3	33.9	scl
65-87	6.46	4.6	0.8	0.60	0.46	9.2	26.2	37.2	36.1	cl
87-113	6.81	4.0	1.8	0.60	0.41	8.8	31.4	33.8	34.6	cl
113-139	6.15	5.0	0.2	0.34	0.61	5.5	23.1	41.3	35.2	cl

Saturation paste and saturation extract analysis (me/l)										
Depth (cm)	Sat (%)	pH_s	EC_e	$Ca^{++}+Mg^{++}$	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-22	30.90	8.6	0.95	6.6	6.30	0.62	Nil	5.6	3.8	1.50
22-45	26.10	7.9	0.91	5.7	4.70	0.76	Nil	6.4	3.4	1.18
45-73	29.65	8.1	0.54	6.4	5.21	0.65	Nil	6.4	2.4	1.16
73-108	29.15	8.0	0.48	4.6	4.34	0.76	Nil	3.6	2.2	0.87
108-142	29.90	7.8	0.58	4.9	2.78	0.80	Nil	1.6	1.8	0.71

recognize the successions of soil horizons or layers in soil profiles. The process has been used for soil identification and qualitative measurements of soil properties as it is helpful field soil characterization [21]. Soil color (dry) in the epipedon horizons of normal soils from the Kapurthala district was recorded. The following variations were observed, gray colour in Dhoda (Table 3), grayish brown in Ucha, Bhanra, Kanjili and Fatehpur series (Table 4 to 7). According to Wakene (2001), color is a function of pH, redox reaction and organic matter [22]. Change in soil color from adjacent soil indicates difference in the origins of soil's, the developmental process, geologic origin and degree of weathering of the soil material, and leaching or accumulation of chemical compounds such as iron, which may greatly influence soil quality [23].

The soil collected from Kapurthala district had variation in grade, size and structure in each horizon of a pedon and among the pedon. The sub angular blocky structure was onserved in all the horizons of the pedons except BC horizon of Dhoda (Table 3). The structure in the epipedon and subsurface horizons of all the series varied from weak fine sub angular blocky structure to medium sub angular blocky

Table 9. Physico-chemical characteristics of Ucha series

Horizon	Depth (cm)	pH (1:2)	EC(1:2) (dS m $^{-1}$)	OC (%)	$CaCO_3$ (%)	Av. Nitrogen (kg/ha)	Av. Phosphorus (kg/ha)	Av. Potassium (kg/ha)
Ap	0-22	9.5	0.28	0.69	0.4	301.0	84.0	392.0
AB	22-45	9.4	0.31	0.39	0.2	50.1	77.9	336.0
B1	45-73	9.1	0.14	0.39	0.2	75.2	84.6	313.6
B2	73-108	9.5	0.16	0.43	0.2	213.2	78.6	268.8
B3	108-142	9.4	0.23	0.40	0.2	275.96	122.3	291.2

Depth (cm)	CEC ($cmol_c$/kg)	Exchangeable cations ($cmol_c$/kg)				E.S.P	Particle size distribution (%)			Texture classes (USDA)
		Ca	Mg	Na	K		Sand	Silt	Clay	
0-22	8.24	3.2	1.0	0.69	0.35	8.3	73.2	16.1	10.4	sl
22-45	6.39	4.0	1.2	0.78	0.41	12.2	66.1	19.6	14.3	sl
45-73	6.50	4.2	1.0	0.52	0.78	8.0	64.1	24.7	11.2	sl
73-108	6.21	3.8	1.4	0.60	0.41	9.6	62.6	22.3	15.1	sl
108-142	5.23	2.6	1.6	0.52	0.51	9.9	48.1	35.6	16.3	l

Saturation paste and saturation extract analysis (me/l)										
Depth (cm)	Sat (%)	pH_s	EC_e	$Ca^{++}+Mg^{++}$	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-22	30.90	8.6	0.95	6.6	6.30	0.62	Nil	5.6	3.8	1.50
22-45	26.10	7.9	0.91	5.7	4.70	0.76	Nil	6.4	3.4	1.18
45-73	29.65	8.1	0.54	6.4	5.21	0.65	Nil	6.4	2.4	1.16
73-108	29.15	8.0	0.48	4.6	4.34	0.76	Nil	3.6	2.2	0.87
108-142	29.90	7.8	0.58	4.9	2.78	0.80	Nil	1.6	1.8	0.71

structure. Soil structural property variations could be due to organic matter content and textural characteristics [24]. Soil structure is strongly affected by changes in climate, biological activities, soil management practices and physicochemical nature of the soil [25].

Soil consistence refers to the manifestations of the physical forces of cohesion and adhesion acting within the soil at a range of soil moisture contents [25]. Most of time, the consistence is described for three moisture levels; wet, moist, and dry [26]. The soil consistence of normal soils from Kapurthala district varied from hard to soft (dry), loos (moist), sticky and plastic (wet) in Dhoda (Table 3), soft (dry) friable (moist), slightly sticky and slightly plastic (wet) in Ucha and Fatehpur series (Table 4 and 7), soft (dry), friable (moist) except BC horizon, slightly sticky and non-plastic (wet) in Bahanra series (Table 5), and soft (dry), friable (moist) except B23 horizon (loose), sticky and plastic (wet) in Kanjili series respectively (Table 6). The results of macro morphology of the normal soils are presented below.

3.2. Physical and chemical characteristics of the pedons

Texture: The particle size analysis of soils showed that the texture classes of the normal soils in Kapurthala district observed as clay

Table 10. Physico-chemical characteristics of Bahanra series

Horizon	Depth (cm)	pH (1:2)	EC (1:2) (dS m $^{-1}$)	OC (%)	$CaCO_3$ (%)	Av. Nitrogen (kg/ha)	Av. Phosphorus (kg/ha)	Av. Potassium (kg/ha)
Ap	0-25	7.5	0.38	0.37	0.2	313.6	95.4	313.6
AB	25-55	8.3	0.17	0.27	nill	200.7	83.1	291.2
B11	55-79	8.5	0.28	0.17	0.1	238.3	80.1	291.2
B12	79-120	8.9	0.23	0.20	nill	100.3	68.5	246.4
BC	120-140	8.0	0.10	0.24	nill	125.4	86.4	263.2

Depth	CEC ($cmol_c$/kg)	Exchangeable cations ($cmol_c$/kg)				E.S.P	Particle size distribution (%)			Texture classes (USDA)
		Ca	Mg	Na	K		Sand	Silt	Clay	
0-25	3.72	2.2	0.4	0.52	0.60	13.9	86.9	7.3	6.0	ls
25-55	3.79	2.6	0.3	0.43	0.40	11.3	85.7	6.1	8.4	ls
55-79	3.95	2.4	0.8	0.34	0.41	8.6	79.3	9.9	10.8	ls
79-120	3.73	2.2	0.8	0.43	0.30	11.5	80.8	9.8	9.3	ls
120-140	3.17	1.8	0.6	0.52	0.25	16.4	84.8	8.1	7.1	ls

Saturation paste and saturation extract analysis (me/l)										
Depth (cm)	Sat (%)	pH_s	EC_e	$Ca^{++}+Mg^{++}$	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-25	34.65	7.2	0.48	5.2	1.40	0.70	Nil	4.3	0.8	0.84
25-55	27.15	7.2	0.41	4.7	1.17	0.39	Nil	3.4	0.6	0.72
55-79	26.55	7.3	0.70	4.3	1.13	0.36	Nil	3.2	1.0	0.62
79-120	25.00	7.3	0.20	2.1	0.95	0.33	Nil	2.4	1.0	0.43
120-140	23.15	7.4	0.45	1.5	0.82	0.30	Nil	1.3	0.8	0.51

loam in all the horizon of Dhoda series except B1 horizon which is sandy clay loam (Table 8), sandy loam and loam in Ucha (Table 9), loamy sand in Bhanra series (Table 10), clay loam and sandy clay loam in Kanjili series (Table 11), sandy loam, loamy sand and sand in Fatehpur series (Table 12) respectively.

Particle size distribution: The percentage of clay contents is low in Ucha and Bhanra series. In Fatehpur series percentage of clay contents was more in Ap horizon than bottom horizons. The clay contents in all the series did not follow regular pattern. The clay content of the normal soils of Kapurthala district in epipedon ranged from 6.0 per cent in Bahanra series (Table 10) to 33.4 per cent in Kanjili series (Table 11). The clay content in subsurface horizons ranged from 5.6 per cent to 36.1 per cent. The highest value of clay content 36.1 per cent was recorded in B21 horizon of Dhoda series and the lowest value of clay content 5.6 per cent was recorded in AB horizon of Fatehpur series. The low clay content is attributed to the fact that the parent material is alluvium which is rich in sand. Again, the soils seem to be receiving sediments on regular basis and elapsed time is not enough for the silt and fine sand to weather the clay. Low clay content could also be associated with young age of the soil as an index for measuring soil development [27]. The mean clay content of these soils was 19.1 per cent. The percentage of

Table 11. Physico-chemical characteristics of Kanjili series

Horizon	Depth (cm)	pH (1:2)	EC (1:2) (dS m $^{-1}$)	OC (%)	$CaCO_3$ (%)	Av. Nitrogen (kg/ha)	Av. Phosphorus (kg/ha)	Av. Potassium (kg/ha)
Ap	0-23	8.9	0.45	0.26	0.4	238.3	84.8	313.6
B1	23-50	9.6	0.48	0.11	0.3	672.7	87.3	313.6
B21	50-78	9.0	0.60	0.12	0.7	87.8	74.8	291.2
B22	78-105	9.6	0.56	0.08	0.3	37.6	78.6	291.2
B3	105-137	9.2	0.51	0.06	0.5	75.2	85.3	291.2

Depth (cm)	CEC ($cmol_c$/kg)	Exchangeable cations ($cmol_c$/kg)			E.S.P	Particle size distribution (%)				Texture classes (USDA)
		Ca	Mg	Na	K		Sand	Silt	Clay	
0-23	11.60	7.6	2.2	1.3	0.51	11.2	43.9	22.7	33.4	cl
23-50	12.60	7.2	2.4	2.26	0.30	17.9	43.9	24.7	31.4	cl
50-78	10.77	6.8	1.6	2.17	0.20	20.4	45.7	19.8	34.5	scl
78-105	11.45	5.4	1.8	3.82	0.43	33.3	46.1	23.0	31.0	scl
105-137	13.16	6.0	1.4	5.56	0.20	40.8	50.6	17.1	22.3	scl

Saturation paste and saturation extract analysis (me/l)										
Depth (cm)	Sat (%)	pH_s	EC_e	$Ca^{++}+Mg^{++}$	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-23	44.40	8.0	0.61	6.4	1.38	0.54	Nil	4.8	1.6	2.87
23-50	46.95	8.2	0.28	5.6	1.15	0.46	Nil	4.4	4.4	1.46
50-78	44.45	8.3	0.31	5.1	0.86	0.33	Nil	3.2	4.6	1.37
78-105	37.80	8.0	0.59	4.4	0.98	0.18	Nil	1.6	3.8	1.18
105-137	32.25	7.8	0.56	8.6	0.78	0.36	Nil	1.2	3.4	0.87

silt content in normal soil in Kapurthala district ranged from 7.3 per cent in Bahanra and Fatehpur series to 41.6 per cent in Dhoda series. The percentage of silt content in the subsurface horizons of these soils ranged from 3.8 per cent in B21 horizon of Fatehpur series to 41.3 per cent in BC horizon of Dhoda series. The mean silt content of normal soil in Kapurthala district was 19.5 per cent. The sand content of these soils in the epipedon ranged from 26.2 per cent in Dhoda series to 86.9 per cent in Bhanra series. The sand content in the surface horizon was ranged from 23.1 per cent in BC horizon of Dhoda series to 90.3 per cent B21 horizon of Fatehpur series. According to particle size distribution rating, the sand content of normal soils of Kapurthala district were characterized by moderate to very high except BC horizon of Dhoda series which was low [28]. The sand content of Dhoda series except BC horizon, Kanjili and Fatehpur series increased in subsurface horizons with depth. The mean of sand content for these soils was 60.5 per cent.

3.3. Soil reaction, EC, OC, $CaCO_3$:

According to Tekalign, (1991) rating, the pH of normal soils of Kapurthala district characterized under strongly alkaline pH except epipedon of Bhanra series (Table 10) which was 7.5 moderately alkaline pH [29]. The pH value of these soils in the epipedon ranged from 7.5 in Bhanra series to 9.5 in Ucha series. The pH value

Table 12. Physico-chemical characteristics of Fatehpur series

Horizon	Depth (cm)	pH (1:2)	EC (1:2) (dS m $^{-1}$)	OC (%)	$CaCO_3$ (%)	Av. Nitrogen (kg/ha)	Av. Phosphorus (kg/ha)	Av. Potassium (kg/ha)
Ap	0-24	8.4	0.53	0.36	0.4	213.2	107.9	364.0
AB	24-55	8.9	0.56	0.35	0.2	188.1	99.4	291.2
B1	55-78	8.7	0.61	0.25	0.2	250.8	92.9	336.0
B21	78-120	8.8	0.66	0.19	0.1	150.5	92.5	313.6
B22	120-145	9.0	0.70	0.16	0.1	100.3	92.2	212.8

Depth (cm)	CEC ($cmol_c$/kg)	Exchangeable cations ($cmol_c$/kg)				E.S.P	Particle size distribution (%)			Texture classes (USDA)
		Ca	Mg	Na	K		Sand	Silt	Clay	
0-24	4.89	2.8	0.8	0.78	0.51	15.9	78.8	7.3	13.9	sl
24-55	4.90	3.2	0.6	0.69	0.41	14.0	81.7	12.7	5.6	ls
55-78	5.35	3.6	0.8	0.60	0.35	11.2	80.3	9.3	10.4	sl
78-120	5.13	3.4	1.0	0.43	0.30	8.3	90.3	3.8	5.9	s
120-145	5.06	3.0	1.0	0.60	0.46	11.8	84.6	8.0	7.1	ls

Saturation paste and saturation extract analysis (me/l)										
Depth (cm)	Sat (%)	pH_s	EC_e	$Ca^{++}+Mg^{++}$	Na^+	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
0-24	33.65	9.8	9.8	0.4	5.80	1.30	nil	5.6	5.5	0.53
24-55	26.60	9.3	0.66	6.3	1.46	0.52	nil	4.0	5.2	0.43
55-78	26.95	8.9	0.53	5.6	1.36	0.52	nil	3.2	4.8	0.54
78-120	29.25	9.0	0.55	7.8	1.26	0.55	nil	4.8	4.6	0.67
120-145	28.85	9.0	1.01	6.9	1.50	0.48	nil	3.6	3.6	0.34

of subsurface horizons ranged from 8.0 in BC horizon of Bhanra series to 9.6 in B1 and B22 horizons of Kanjili series. The mean pH of these soils was 8.9. The pH value in all soil series increased with depth. pH was high in all the horizons of normal soils from Kapurthala district, this might be due to their calcareous nature and accumulation bases in the solum as soils were poorly leached [30]. Furthermore, the alkalinity of these soils may be due to over liming, also alkaline irrigation water may be the cause. The electrical conductivity of normal soils from Kapurthala district was below 1dS m^{-1}. The electrical conductivity of these soils in the epipedon ranged from 0.16 dS m^{-1} in Dhoda series (Table 8) to 0.53 dS m^{-1} in Fatehpur series (Table 12). While in the subsurface horizons ranged from 0.07 dS m^{-1} in AB horizon of Dhoda series to 0.70 dS m^{-1} in B22 horizon of Fatehpur series. The electrical conductivity value in Bahanra and Dhoda series except B22 horizon decreased with soil depth while in Kanjili series increased with depth but not followed the regular pattern. The mean of electrical conductivity in all these series was 0.36 dS m^{-1}. According to Havlin *et al.*, (1999) this range is categorized as very low and implies that the soils are not salt affected [31].

The organic carbon content of normal soil of the epipedon ranged from 0.2 per cent in Kanjili series to 0.93 per cent in Dhoda series, while in

Table 13. Available micronutrients content of normal soils in Kapurthala district

Horizon	Zinc (mg/kg soil)	Iron (mg/kg soil)	Manganese (mg/kg soil)	Copper (mg/kg soil)
Dhoda series				
0-24	0.48	4.80	6.88	1.02
65-87	0.28	3.38	1.78	0.36
113-139	0.24	2.16	0.88	0.20
Ucha series				
0-22	0.50	17.78	7.48	0.82
22-45	0.16	6.60	8.70	0.36
108-142	0.14	6.52	10.18	0.36
Bahanra series				
0-25	0.62	31.94	8.76	1.08
55-79	0.08	8.26	8.00	0.36
120-140	0.04	5.54	7.64	0.26
Kanjili series				
0-23	0.66	18.22	10.22	2.36
50-78	0.06	10.36	7.06	1.46
105-137	0.06	2.92	5.38	0.40
Fatehpur series				
0-24	1.70	27.78	9.88	1.62
55-78	0.18	8.74	6.28	0.72
120-145	0.04	5.26	9.16	0.38

the subsurface horizon it ranged from 0.06 per cent in B3 horizon of Kanjili series to 0.52 per cent in AB horizon of Dhoda series. The organic carbon content of normal soils of Kapurthala district was in range from low too high in the epipedon and low to medium in the subsurface horizons. The organic carbon content in the most of subsurface horizons was recorded low. Low organic matter content in the area could also be attributed to the return of little or no agricultural residue, high rate of transformation and translocation of organic matter in the tropical soils [32]. Most of the series has high organic carbon content in the surface horizon then subsurface horizon and decrease with soil depth which was similar to the observation made by Ojanuga (1971) [32]. The mean organic carbon of all the series was 0.32 per cent. Calcium carbonate content of normal soils of Kapurthala district in the epipedon ranged 0.2 in Bahanra series to 0.4 in Dhoda, Ucha, Kanjili and Fatehpur series respectively, while in the subsurface horizon it ranged from nil in AB, B12 and BC horizons of Bahanra series to1.2 per cent in B1 horizon of Dhoda series. According to FAO (1998), soils having more than 2 per cent calcium carbonate content in their subsurface horizons show the presence of calcareous soil material.

3.4. Available nitrogen, phosphorus and potassium

The available nitrogen content in the epipedon of normal soil of Kapurthala district ranged from 231.2 kg/ha in Fatehpur series to 627.2 kg/ha in Dhoda series while in the subsurface horizon ranged from 37.6 kg/ha in B22 horizon of Kanjili series to 672.7 kg/ha in B1 horizon of Kanjili series. The mean available nitrogen was 237.07 kg/ha. Available nitrogen in the epipedon of all the series of normal soils in Kapurthala district ranged from low to high. Dhoda series had higher available nitrogen in the surface horizon, Kanjili and Fatehpur series had low level of available nitrogen content and the rest series were had medium content of available nitrogen

Table 14. Soil Classifications

Series	Order	Suborder	Great group	Subgroup	Family
Dhoda	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Fine loamy, mixed hyperthermic
Ucha	Inceptisols	Ustepts	Haplustepts	Fluventic Haplustepts	Coarse loamy, mixed hyperthermic
Bahanra	Entisols	Psamment	Ustipsamment	Typic Ustipsamment	Sandy mixed, hyperthermic
Kanjili	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Fine loamy, mixed hyperthermic
Fatehpur	Inceptisols	Ustepts	Haplustepts	Typic Haplustepts	Coarse loamy, mixed hyperthermic

in the surface horizon. Accordingly B1 horizon of Kanjili series also had high level of available nitrogen. It could be due to the use of nitrogen fertilizers or could be attributed to the addition of plant residues and farmyard manure to epipedon horizons than in the lower horizons [33]. The available phosphorus in the epipedon of normal soils in Kapurthala district ranged from 84.0 kg/ha in Ucha series (Table 9) to 107.9 kg/ha in Fatehpur series (Table 12), while in subsurface horizon ranged from 33.8 kg/ha in B21 horizon of Dhoda series (Table 8) to 122.3 kg/ha in B3 horizon of Ucha series (Table 9). The available phosphorus contents were high in surface horizons of all the series except Ucha series. The available phosphorus content in all the horizons of all the pedons in normal soils of Kapurthala recorded high to very high. This was in agreement with the finding of Awdenegest *et al.*, (2013) who reported that the higher available phosphorus in the top soil layer of farmland may be related to the application of animal manure, compost, household wastes like ashes and DAP fertilizer for soil fertility management [34]. Girma and Endalkachew (2013) also support this finding by indicating that the high phosphorus in top soil might be attributed to external phosphorus supply, and phosphorus carry over from fertilization [35]. The mean available phosphorus of all the series was 69.13 kg/ha. The available potassium in the epipedon of normal soil ranged from 263.2 kg/ha in Dhoda series to 392.0 kg/ha in Ucha series, while in the subsurface horizons ranged from 212.6 kg/ha in B22 horizon of Fatehpur series to 336.0 kg/ha in AB horizon of Ucha and B1 horizon of Fatehpur series respectively. It may be due to soil pH and soil type. The available potassium content in all the series except Dhoda series were high in the epipedon horizons and it decreased with depth and not follow regular pattern. This could be attributed to more intense weathering, release of potassium from organic residues, application of potassium fertilizers and upward translocation of potassium from lower depth along with capillary raise of ground [36]. The similar results were reported in cotton based cropping system in Karnataka [37].

3.5. CEC, exchangeable cations, and ESP

The cation exchange capacity of normal soils in Kapurthala district ranged from 3.72 cmolc/kg in Bahanra series to 11.60 cmolc/kg in Kanjili series. In the subsurface horizon the CEC ranged from 3.17 cmolc/kg to 13.16 cmolc/kg. The highest value of CEC was recorded in B3 horizon of Kanjili series and the lowest CEC was recorded in BC horizon Bahanra series. CEC of these soils consistently decreased with soil

depth in Dhoda and Ucha series while it did not follow any consistent trend in other soil series. The result could strongly associat with the nature and amount of clay in the soils. Decrease in CEC with soil depth could be due the strong association between organic carbon and CEC. According Hazelton and Murphy (2007) the CEC values are rated < 6 cmolc/kg as very low, 6 - 12 cmolc/kg as low; 12 – 25 cmolc/kg as medium, 25 – 40 cmolc/kg as high and > 40 cmolc/kg as very high [28]. Accordingly, the CEC of the soils in the study areas ranged from very low to low except B1 and B3 horizons in Kanjili series which are medium, 12.06 cmolc/kg and 13.16 cmolc/kg respectively.

The exchangeable calcium in the epipedon of normal soil pedons in Kapurthala district ranged from 2.2 cmolc/kg in Bahanra series to 7.6 cmolc/kg in Kanjili series, while in subsurface horizons it ranged from 1.8 cmolc/kg in BC horizon Bahanra series to 7.2 cmolc/kg in AB horizon of Kanjili series. Exchangeable calcium increased with soil depth in Ucha series which might be due to the effect of washing away by soil erosion from the upper areas and adjacent slopes [38]. The exchangeable manganese in epipedon soils ranged from 0.4 cmolc/kg in Bahanra series to 2.2 cmolc/kg in Kanjili series, while in the subsurface horizon it ranged from 0.2 cmolc/kg in Dhoda series to 2.4 cmolc/kg in Kanjili series. Exchangeable sodium percentage in the study area ranged from 0.52 cmolc/kg in Bahanra series to 1.30 cmolc/kg in Kanjili series in the epipedon. In the subsurface horizons ranged from 0.34 cmolc/kg in BC horizon of Dhoda series and B11 horizon of Bhanra series respectively to 5.56 cmolc/kg in B3 horizon of Kanjili series. Accordingly, the exchangeable potassium content in the epipedon horizons of pedons were ranged from 0.35 cmolc/kg in Ucha series to 0.60 cmolc/kg in Bahanra series. In the subsurface ranged from 0.2 cmolc/kg in B21 and B3 horizons of Kanjili series to 0.78 cmolc/kg in B2 horizons of Ucha series. According to FAO (2006) rating exchangeable manganese content were very low to medium, exchangeable sodium contents were medium to very high [39]. The exchangeable potassium content were medium to high except BC horizon of Bhanra and B21 and B3 horizon of Kanjili which were recorded low (0.1-0.3 cmolc/kg).

The exchangeable sodium percentage was ranged to measure the exchangeable sodium content of the studied area. The ESP content in the epipedon horizons of all the pedons ranged from 7.5 per cent in Dhoda series to 15.9 per cent in Fatehpur series and in the subsurface ranged from 5.5 in the BC horizon of Dhoda series to 40.8 per cent in B3 horizon of Kanjili series. The ESP of all the series in normal soils of Kapurthala except subsurface horizons of Kanjili series is less the 15 per cent. This indicates that there is no sodicity problem in these soils. According to Brady and Weil, (2002), ESP of 15% is considered as critical for most crops [40].

3.6. Saturation past and saturation extract

Saturation percentage of normal soils in Kapurthala district ranged from 30.90 per cent in Ucha series (Table 9) to 44.40 per cent in Kanjili series (Table 11) in the epipedon. In subsurface horizons ranged from 23.15 per cent in BC horizon of Bahanra series to 46.95 per cent in B1 horizon of Kanjili series. The mean

saturation percentage of all normal soil series was 30.98 per cent.

Accordingly, the composition of soils saturation paste and saturation extract such as pHs, ECe, Ca^{++},Mg^{++}, Na^{+}, K^{+}, CO^{3--}, HCO_3^{-}, Cl^{-}, and SO_4^{--} were determined in laboratory (*Table 8 to 12*). The pHs of saturation paste of normal soils in the epipedon ranged from 7.2 in Bahanra series to 9.8 in Fatehpur series while in subsurface horizon it ranged from 7.2 in AB horizon of Bahanra series to 9.3 in AB horizon of Bahanra series. All the normal soils of Kapurthala district had an ECe of less than 4 me/l except epipedon of Fatehpur series which indicate no salinity [41]. It ranged from 0.20 me/l in B12 horizon of Bahanra series to 9.8 me/l in the epipedon of Fatehpur.

3.7. Micronutrients

Similar to the variations observed in other soil properties, the extractable micronutrients also exhibited some degree of spatial variability within a pedon with soil depth and among all the pedons in normal soils of Kapurthala district (Table 13). Extractable zinc in the epipedon horizons of the study area ranged from 0.48 mg/kg of soil in Dhoda series to 1.70 mg/kg of soil in Fatehpur series, while in subsurface ranged from 0.04 mg/kg of soil in BC horizon of Bhanra, and B22 horizon of Fatehpur series respectively to 0.28 mg/kg of soil in AB horizon of Dhoda series. Available zinc content was low in the epipedon of Dhoda, Ucha, and all the subsurface horizons of all the series in normal soils of Kapurthala district. Considering 0.6 mg/kg of soil as critical level for available zinc, these soils were classified as deficient in all the horizons of the series except epipedon horizons of Bhanra, Kanjili and Fatehpur series [20, 42].

The DTPA-Fe content ranged from of 2.16 in BC horizon of Dhoda series to 31.94 mg/kg of soil in the epipedon horizon of Bhanra series. Considering 4.5 mg/kg of soil as the critical limit for DTPA- extractable iron for normal plant growth [20]. It may be inferred that the soils of the study area were sufficient in available iron in the epipedon horizons and subsurface horizon except B21 and BC horizon of Dhoda series, and B3 horizon of Kanjili series respectively. This could be attributed to the parent material and pH condition of the soils [38].

The DTPA- extractable Cu in the epipedon horizons of normal soils in Kapurthala district ranged from 0.82 mg/kg of soil in Ucha series to 2.36 mg/kg of soil in Kanjili series, while in subsurface horizon ranged from 0.2 mg/kg in BC horizon of Dhoda series to 1.46 mg/kg of soil in B21 horizon of Kanjili series. Considering 0.2 mg/kg of as the critical limit of DTPA-extractable copper for normal plant growth, it may be inferred that all the soils contain adequate amount of available copper.

The available manganese content of these soils ranged from 6.88 mg/kg of soil in Dhoda to 10.22 mg/kg of soil in Kanjili series in the epipedon. In the subsurface horizon it ranged from 0.88 mg/kg of soil in BC horizon of Dhoda series to 10.18 mg/kg of soil in Ucha series. The available manganese content was sufficient to high in all the horizons of series except B21 and BC horizons of Dhoda series, considering 3.5 mg/kg of soil as critical limit of manganese content [20].

3.8. Soil classification

Filed investigation and laboratory analysis of physical and chemical characteristics of the soils were used to identify the dominant soil type of normal soils in Kapurthala district based on Soil Taxonomy (2015) [9]. These soils are classified up to family level. The morphological, physical and chemical characteristics of these soils indicated that normal soils of Kapurthala district are Entisols and Inceptisols (Table 14).

4. CONCLUSION

A study was under taken to characterize and classify the normal soils of Kapurthala district in Punjab. Profile samples were collected from five villages of Kapurthala district such as Dhoda, Ucha, Bhanra, Kanjili and Fatehpur respectively. The particle size analysis of soils showed that the texture classes of the normal soils of Kapurthala district were clay loam, sandy clay loam, sandy loam and loam, loamy sand, and sand in Fatehpur series respectively. These soils have a pH of alkaline, electrical conductivity of these soils were below 1 dS m-1. The most limiting factor of these soils is low organic matter in some of the places, loose or unsuitable structure, moderate drainage and sandy layers in some of the places. Accordingly these soils required appropriate management such as drainage, proper irrigation, improvement of texture and structure of the soils along with application of fertilizers and amendments. Furthermore, application of manure, compost mulching and crop rotation are required in these soils for better agriculture growth.

5. ACKNOWLEDGEMENT

NA

6. CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

7. SOURCE/S OF FUNDING

No source of funding

8. REFERENCES

1. Akinrinde E.A (2004) Soils: Nature, Fertility Conservation and Management, Agronomy Department, University of Ibadan, Ibadan, Nigeria AMS Publishing, Inc.
2. Das D.K (1996) introductory soil Science, published by Mrs Usha Raj Kumar, Kalani publishere, New Delhi, India, 110 0002
3. Ogunkunle A.O (2005) Soil Survey and Sustainable Land Management, Invited paper at the 29th annual conf, of SSSN held at University of Nigeria, Abeokuta, from 6th to 10th Dec. 2004
4. Esu, I. E. (2005). Characterization classification and management problems of the major soil order in Nigeria. The 26 th Inaugural Lecture of the University of Calabar, Nigeria, 66.
5. Sehgal j, M.S Bajwa, P.K sharma (1992) Soil of Punjab, research Bulletin, NBSS Publ, 31. Nagpur, India
6. Krishan, G., Lapworth, D. J., Rao, M. S., Kumar, C. P., Smilovic, M., & Semwal, P. (2014). Natural (baseline) groundwater quality in the Bist-Doab catchment, Punjab, India: a pilot study comparing shallow and deep aquifers. Int J Earth Sci Eng, 7, 16-26.

7. Sharma P.K, Charanjit Singh, jawahar L. Sehgal, & H.S Kanwal (1982) The soil of Kapurthala District for Land use Planning, Department of soil conservation and Eng, Punjab and Dept. of Soils, Punjab Agriculture University, Ludhiana
8. Soil Taxonomy (2015) Illustrated Guide to Soil Taxonomy, version 2, U.S Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska
9. Soil Survey Manual (USDA, 2017), soil science division staff. Retrieved from: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/ref/?cid=nrcs142p2_054262
10. Jackson M.L (1967) Soil Chemical Analysis, Asia publ. House, Delhi Pp.3856
11. Walkley, A., & Black, C. A. (1965). Organic carbon. Methods of soil analysis. *American Society of Agronomy*, 1372-1375.
12. Puri, A.N. 1930. A new method of estimating total carbonates in soils. Imp. Agric. Res. Pusa. Bulletin. 206-207 pp.
13. Subbiah BV and Asija GL. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* **25**:259–260
14. Olsen, S.R., C.Y. Cole, F.S. Watanabe and Dean (1954). Estimation of phosphorus by extraction with sodium bicarbonate, U.S.D.A. *Circular* 939-19
15. Merwin, H., & Peach, W. M. (1950). Exchangeability of sand, silt and clay fractions as influenced by the nature of complementary exchangeable cation. *Soil Scl. Soc. Amer. Proc.* **15**: 125, 128.
16. Tolanur Shivanand (2018). Second edition practical soil science and agriculture chemistry. CbS publishers and distributors Pvt. Ltd. New Delhi, India
17. Singh, K., J.S. Manchanda and U.S. Sadana (2013). Experiential Learning on Evaluating Soil Health and Irrigation Water. Kuwait Printers. Sant Nagar. Opp. Govt. College for Boys. Civil Lines, Ludhiana
18. Rhoades J.D (1982) Soluble salts, method of soil analysis- part II (ed) A.L Page, D.E Baker, R.E.Jr., D.R. Keeneym R.H Miller and J.D Rhades (ed.) Agronomy-Madisonn-Wise, USA
19. Jackson, M.L (1958) Soil Chemical Analysis, Asia Publ. House, Delhi
20. 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*, **43**, 421-428
21. Noshadi E, A Hossein, and S. Alavipanah (2013) Prediction of surface soil color using ETM+satellite images and artificial neural network approach, *International Journal of Agriculture*, **3 *(1)***: 87-95
22. Wakene Negassa (2001) Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bako area, Western Ethiopia, MSc Thesis, Alemaya University, Alemaya, Ethiopia Pp. 93
23. Fisher R.F, and D. Binkley (2000) Ecology and management of forest soils, 3rd Ed. John Wiley and Sons, Inc, New York, Pp. 489
24. Mohammed Assen, Leroux P.A.L, Barker C.H, and Heluf Gebrekidan (2005) Soils of Jelo micro-catchment in the Chercher highlands of eastern Ethiopia: I, Morphological and physiochemical

properties, *Ethiopian Journal of Natural Resources*, **7*(1)***: 55-81

25. Lal R, and M.K Shukla (2004) Principles of soil physics, Marcel Dekker, Inc. New York, USA, Pp. 699.
26. Buol S.W, R.J Southard, R.C Graham and P.A McDaniel (2003) Soil Genesis and Classification, 5th ed. Iowa state University Press. Ames, USA
27. Collins M.E, and Fenton T.E (1982) Characteristics of color soil series in the North Central Region, *Journal of Agropedology*, 11: 95-102
28. Hazelton, P., & Murphy, B. (2016). Interpreting soil test results: What do all the numbers mean?. CSIRO publishing.
29. Tekalign Tadese (1991) Soil, plant, water, fertilizer, animal manure and compost analysis, Working Document No. 13, International Livestock Research Center for Africa, Addis Ababa, Ethiopia
30. Satyanarayana T, and Biswas T.D (1970) Chemical and mineralogical studies of associated black and red soils, Mysore *Journal of Agric, Sc.*, **8**: 253-264
31. Havlin J.L, Beaton J.D, Tisdale S.L, and Nelson W.L (1999) Soil fertility and fertilizers. Prentice Hall, New Jersely. Pp. 345-355
32. Ojanuga, A.G (1971) A study of Soils and Soil genesis in South western upland of Nigeria, PhD Thesis, University of Wisconsin Madison, WI, USA
33. Adhanom D, and Toshome T (2016) Characterization and Classification of Soils of Soils of Aba-Midan Sub Watershed in Bambasi Wereda, West Ethiopia, *International Journal of Scientific and Research Publications*, **6*(6)***: 390–399.
34. Awdenegest M, Melku D, and Fantaw Y (2013) Land use effects on soil quality indicators: A case study of Abo-Wonsho Southern Ethiopia, Applied and Environmental Soil Science, Hindawi Publishing Corporation
35. Girma A, and Endalkachew W.M (2013) Soil properties and soil organic carbon stocks of tropical Andosol under different land uses, *Open Journal of Soil Science*, **3**: Pp 153-162
36. Raju D.B, Naidu M.V, Ramavatharam N, Venkaiah, & Reedy K (2005) Characterization, classification and evaluation of soils in Chandragiri mandai ofChittoor district, Andhra Pradesh. *Agropedology*, **15*(1)***: 55–62
37. Hirekurabar P.M, Satyanarayana T, Sarangmati P.A, and Manjunatham H.M (2000) Forms of potassium and their distribution in soils under cotton - based cropping system in Karnataka, *Journal of the Indian Society of Soil Science*, **48**: 604-608
38. Hailu, Alem Hagos (2014) Characterization and Classification of soils and land sitability evaluation of Kabe Subwatershed in SOUTH Wollo Zone, Northeastern Ethiopia, Department of Soil Science, Haramaya University, Msc thesis
39. FAO(Food and Agriculture Organization) (2006) Guidelines for soil description, FAO, Rome, Italy. 109p
40. Brady N.C and Weil R.R (2002) The Nature and Properties of Soil, 13th Ed. Preason Education, Asia
41. Balpande S.S, Deshpande S.B, and Pal D.K (1996) Factors and processes of soil degradation in vertisols of the Purna Valley,

Maharashira, India. *Land Degradation & Development*, **7*(4)***: 313–324

42. Venkatesu T, Venkaiah K, and Naidu M.V.S (2002) Depth wise distribution of nutrients in groundnut growing soils of Nellore district in Andhra Pradesh, *Journal of Oilseeds Research*, **19:** 185-189